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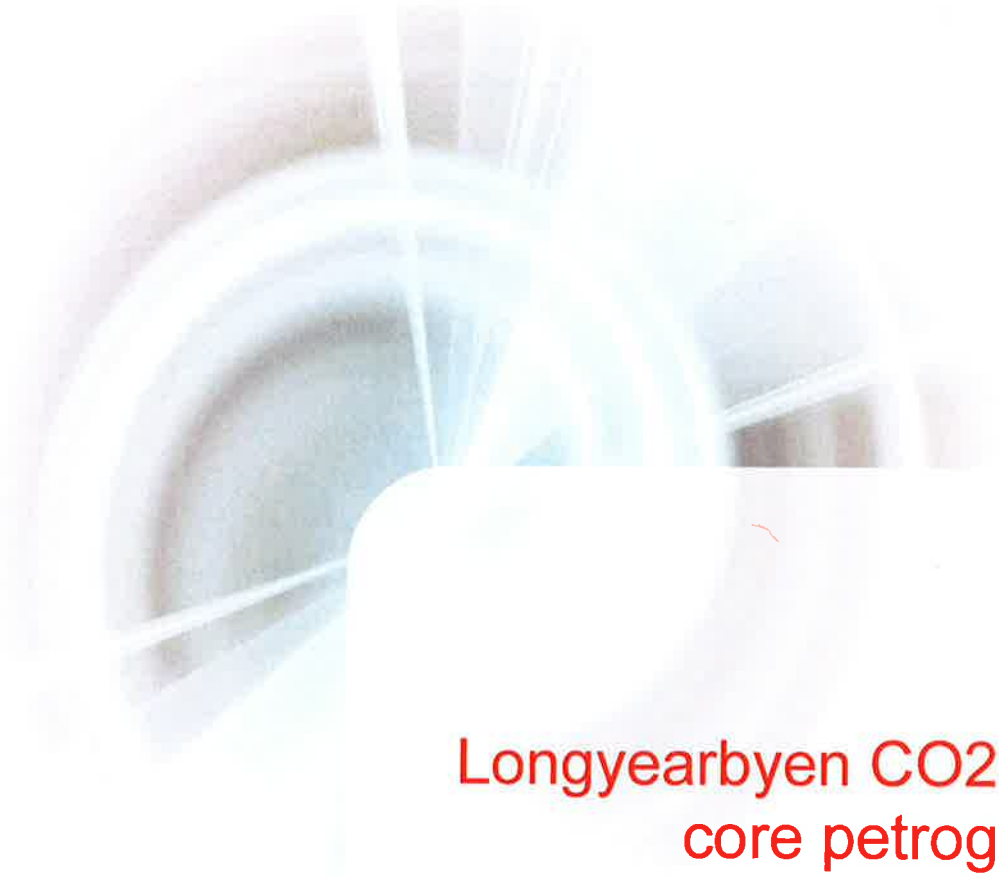

Longyearbyen CO2-lab – core petrography

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Report title

Longyearbyen CO2-lab –core petrography

Summary

This report includes detailed petrographic description of 58 core samples from Dh4, LYB CO2 lab in Adventdalen, sampled in 2010 and 2011. The work is part of the SUCCESS project related to the work packages WP3 -Sealing Properties and WP6- Operations (Inject).

The sequences above Agardfjellet Fm (Carolinefjellet Fm, Helvetiafjellet Fm and Rurikfjellet Fm) are only briefly considered, the main focus is the shaly overburden sequence of Agardfjellet Fm, as well as the reservoir section represented by Wilhelmøya Subgroup and De Geerdalen Fm, including Isfjorden member. A review of clay mineral characterization of selected samples are included, as well as some conclusions based on Sr isotope analysis of residual salts (RSA), related to compartment identification. Also briefly mentioned are the significance of the isotopic results of carbonates and pyrites.

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Contents

1 Summary of results

1.1 Cretaceous of Dh4

This part is only briefly described.

Carolinefjell Fm (one sample 105.11m): this is medium sandstone with moderate porosity (10%), local carbonate cement. The texture indicates low permeability..

Helvetiafjell Fm: (2 samples 125.22 and 165.35m): sandstone and inhomogenous pebbly siltstone. Compaction texture, glauconite and phosphogene grains, stylolitic lamina of organic debris. Kaolinite seen in pores. Oil inclusions within altered plagioclase. Some oversized pores, variable porosity. Local carbonate cement (calcite, siderite).

Rurikfjell Fm: Dominated by shale, the one sample analysed (185.34m) is an inhomogenous sandstone.In general low porosity but local larger pores, partly well cemented with quartz overgrowths. Local carbonate cement. Fracture zone with crushed and strained grains (in thin section scale). Clay rims on grains; glauconite occurs.

1.2 Jurassic overburden/caprock

The *Agardfjellet Fm* constitutes a sequence of about 260m above the reservoir units. A major damage zone characterized by shale fracturing between Agardfjellet and Rurikfjellet Fm was sampled for clay mineral characterisation, being potential zones of focused leakage. The dominant clay phase is illite with only subordinate amounts of a smectitic component. Chamositic (Fe-rich, 7Å) chlorite and kaolinite occur as well.

Agardfjellet Fm is a sequence of dark laminated shales, including local silty layers. The contents of organics in terms of TOC (total organic content) analysis show an increasing tendency from 350m to 611m (0.5 – 11.7%), followed by decrease to <2% in the lower part towards Knorringfjellet Fm in the upper part of the reservoir. The thermal maturity of the organics is not established, but should be considered concerning reactivity with CO_2.

Contents of framework grains (quartz+albite) varies between 44% and 75% (XRD quantification), highest in the lower parts of the formation. Albite constitutes 12-26%, thus contents are rather high. Clays are dominated by 10Å mica/illite with only subordinate contents of chlorite, and amounts to 48% in the middle part, varying from 22-48% in total. Characterisation of the 10Å phase reveals only minor amounts of smectite contents in an illite/smectite phase. This is important in terms of reactivity towards CO_2, as the general trend of I/S reaction with CO_2 is supposed to be illitisation of smectite (Kohler et al.2009; Credoz et al.2011). On the other hand experiments using clay rich caprock shale from Dh2 similar to our samples in Dh4 with CO_2-brine (T: 80-250^0) showed formation of smectite from the illite (Alemu et al.2011). Their experiments indicated dissolution of the Fe-chlorite as well.

Thin fractures are seen in the shale sequence, generally parallel lamination but also crosscutting. These fractures appear to be commonly open, only in one case is discontinuous mineralization observed. In this case tiny elongated crystals of $CaSO_4$ (anhydrite-gypsum) are seen to grow perpendicular to the fracture wall. Thus it appears that not all similar fractures are a result of decompaction during drilling, some has to be primary. On the other hand, obvious secondary fractures were observed during drilling shale sequences in Dh6 (2011) - both horizontal and dipping. Thus there are clear weaknesses inthe caprock shales, the issue is how they will respond to increasing pressure and fluid flow related to CO_2 injection.

Two caprock shales sampled by NGI were mineralogically characterized to reveal possible relation between geomechanical response and mineralogy. These were generally similar in terms of mineralogy, however differing in amounts and texture of framework grains. It was therefore considered that textural features are important parameters in evaluating caprock integrity, including por/perm, pore types, morphology and network in addition to mineral types and distribution. This is a topic reaching increased focus in general (Heath et al.2011 and others). SEM analysis has revealed apparent higher porosity than expected in the shales, however it can be difficult to distinguish between organics and porosity. A promising method of focused ion-beam (FIB) milling or Ar-ion-source milling (Ar-BIB) of the surface of shales has recently been applied by many workers, allowing for a qualitative and quantitative description of shale pore network (Loucks et al.2009, Heath et al.2011, Desbois et al.2011).

1.3 Reservoir sequence

1.3.1 Knorringfjellet Fm/Wilhelmøya Subgr.

The upper part of the reservoir includes the Knorringfjellet Fm (Wilhelmøya Subgr.) in the Kapp Toscana Gr. This formation is described as a condensed transgressive sequence of sandstones, shale, mudstones and conglomerate. According to the results in Farokhpoor et al. (2010), the highest por/perm values are seen within this formation. The inhomogeneity extends to the microscale. Typically the highest porosity occurs in the inhomogenous, pebbly (conglomeratic) zones, in the upper part (Brentskardhaugen Bed), and at depths 678.1, 687.3, 692.5 and 695.4m (Slottet Bed). The mineralogy is quite variable in these zones: Ca-phospate (often in oolitic pebbles, also in veins and as cement), chert, Fe-Mg carbonates and calcite in addition to framework grains of quartz and albite. The Fe-Mg carbonates are often zoned, with increasing Fe towards pores. Pyrite (framboidal) and Ti-oxides are minor constituents.

Framework grains (quartz+albite) vary between 43-77% within the formation, including both detrital and diagenetic grains. Carbonates vary between 4-14%, one sample has 14% Ca-phosphate (691.6) according to XRD. Clay contents are variable, from 8% to 32% in a silty shale at 687.5m. The XRD quantification identifies this clay as dominantly 10Å illitic, the clay mineral analysis of <2µm fraction shows both 10Å and 7Å chlorite, with no indications of smectite as an I/S phase. Illite and chlorite are verified in the SEM.

The texture within these samples show local extensive quartz cementation, clays in pores, often intimately mixed, and domains with compaction (grain packing). Thus the porosity appears rather poorly connected, although high in small domains. The diagenetic sequence appears to be quartz>phosphate>Fe-Mg carbonate>albite>clays. When present, pyrite cement is the earlier phase.

The horizon defining the boundary between Agardfjellet Fm and Knorringfjellet Fm (caprock-upper reservoir) is inhomogeneous in terms of both mineralogy and porosity. Siderite and pyrite occur as local cements.

1.3.2 De Geerdalen Fm/Isfjorden Member (695.8-727m)

The available samples are generally fine grained/silty sandstones with low porosity. In hand specimen the greenish colour is characteristic, and is due to high contents of chlorite. SEM point analyses confirm their Fe-rich nature as chamositic 7Å chlorites. Illite is also present but generally in lesser amounts. Framework grains (quartz and albite) varies between 43 to 77%, albite averages 20%. At 718.4m remnant oolitic textures occur, and a doleritic fragment is noted. The log description notifies HC smell, and oil inclusions are seen in one feldspar

grain. Carbonates occur in amounts 4-8%, dominantly calcite. Both pyrite and phosphate are seen in the XRD, however not noted in the SEM.

Tight pore fill of fibrous chlorite±illite are common, very local open pores occur as dissolution (secondary) pores. The identity of the dissolved mineral is not always obvious. However, dissolving Ti-oxide and precipitated authigenic Ti-oxides occur.

The lower part of this sequence (729-769m) are fine grained silty/shaly sandstone with low porosity.

1.3.3 De Geerdalen Fm (769.9-969.6m)

The reservoir unit is generally described as repeated upward coarsening successions with fine sandstone and shale as main lithologies.

The Sr residual salt analyses (RSA) indicate two main barriers, at about 828m and at about 875m (see Fig.4).The barrier at 828m is represented by a tight calcareous horizon, consisting of numerous shell fragments, slightly recrystallized and compacted with stylolitic textures. Organics/bitumen and pyrites are seen between the fragments. Similar fragments occur in the fine sandstones slightly below this horizon as well.

The barrier at 875m, close to the water injected zone, is less well defined in terms of mineralogy. Sample 875.7 is a fine sandstone with porosity about 11-15% (Farokhpoor et al.2010), however permeabilities are low. Framework grains amount to 70% (quartz, albite) and the quartz grains are fractured in a small transecting deformation zone. Clays (dominantly chlorite) amounts to 14%, and calcite cement to about 8%. The lower permeability is due to clays in pores, diagenetic cements as quartz, calcite, albite,Ti-oxide and scarce $CaSO_4$, and although dissolution of K-feldspar provides secondary porosity, the interconnection between pores are poor.

Two thin, very altered sill horizons occur, at 838.4 and 855.7m. Thicknesses are less than 30cm. Textures indicates rapid cooling with a fine, dense matrix with numerous thin plagioclase laths in addition to zoned plagioclase phenocrystals, albite chemistry all over. Alteration includes extensive chloritisation and possible serpentinisation, with no mafics left. These two sills indicate only possible minor barriers by the RSA data.

Sill horizons are further localised at about 802, 848 and 900m (NTNU report). The sill at 900m has a thin calcite cemented fracture, sampled in September 2011. RSA data do not indicate any major barriers defined by these thin sills in Dh4.

Minor barriers are further probably defined at shaly horizons at about 712m (Isfjorden Mb), 773m, and 798m (clays: ≈30%). Similarly a calcite cement horizon occurs at 787.6m as well.

A shale damage zone was noted at 754m (core store at UNIS) and sampled for clay mineral analysis. Results show illite and 7Å chlorite, with no or very subordinate indications of smectite.

K-feldspar is not seen in the upper parts of the reservoir section, but occurs in the sandstones below 775m, just below the Isfjorden Mb part of De Geerdalen Fm. According to XRD, contents are generally less than 3-4%, and albite is the dominant feldspar phase (22-32%). The K-feldspar shows more or less extensive dissolution features, leaving isolated, open secondary pores. Clays are illite (up to 7%) and chlorite (8-17%) in the siltstones/sandstones.

Calcite is the common carbonate in these horizons (3-8%), while dolomite amounts to about 2% and siderite less than 1% (XRD).

Pyrites are sampled at 770 and 776.5m for S-isotope analysis, occurring as local cemented domains or poorly defined concretions in siltstones. The values are consistent with early bacterial sulphate reduction with no indications of high T thermal sulphate reduction.

Three major sandstone sequences are pointed out in the core descriptions (Mørk et al.2010): 1) at 772-798m and 2) at 859-866m, above the water injection in the open section at about 870m in 2010, and 3) Below 970m to around 880m.

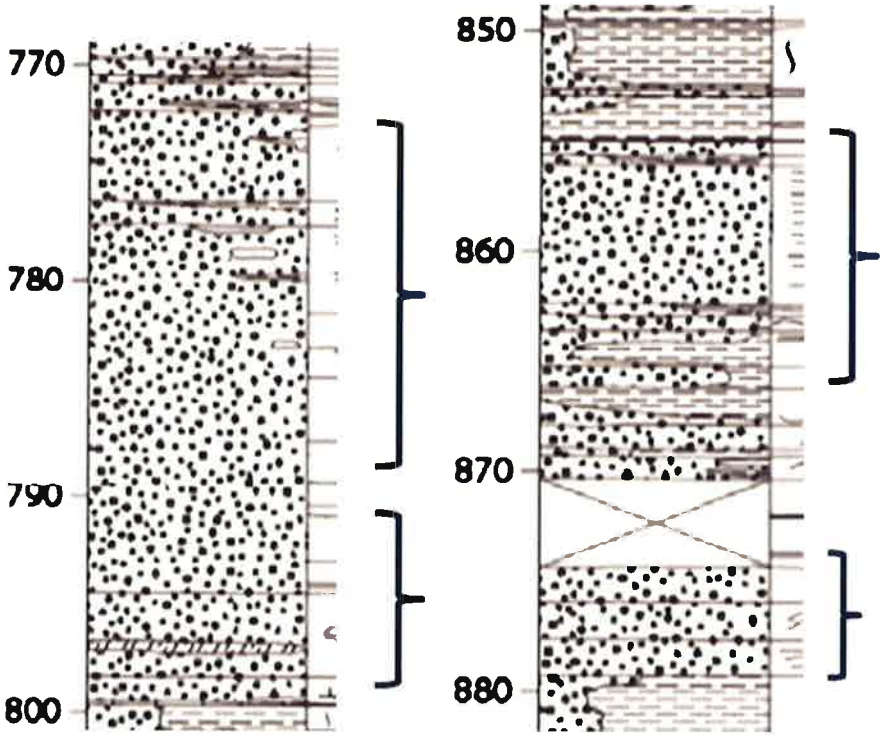

Figure 1 Potential CO_2 storage layers in Dh4.

1) 772-798m. This sequence is typically fine sandstones, porosities up to 15% but with low permeabilities (Farokhpoor et al. 2010). Rock fragments are hard to identify in these fine grained rocks as most of the framework grains are monomineralic and included in the quartz+feldspar quantifications (XRD). Polycrystalline quartz, microcrystalline quartz/chert, a few doleritic fragments and one possible spiculitic fragment (779.3m) are noted. Ductile grains now being dominantly clays (chlorite±illite) are presumably altered rock fragments (sediments?). Some grains show only remnant quartz, some clays and secondary porosity. Evidence of compaction, especially of the ductile grains is probably the more distinct feature. Fractured quartz-quartz grains are observed without pressure solution textures. Quartz cementation occurs, extent can be difficult to estimate due to compaction and disturbed grain boundaries. Feldspar overgrowths are noted as well. Other diagenetic cements are calcite, Ti-oxide, Ca-phosphate and albite. The sequence appears to be quartz>Ti-oxide>phosphate> calcite. Albite is predating calcite. Clays are late. No signs of kaolinite is seen (XRD, SEM).

2) 859-866m. Samples from this sequence appears more inhomogenous with some shaly laminaes, however with local higher porosity (estimated 15%). The general features are quite similar to the sequence above.

3) Below 870m (injection zone). As outlined above the RSA results indicates a main barrier at 875m (Fig.5), defined by the siltstone described above. The sample at 887.7m is a tighter silty shale (23% clays, chlorite dominates). The samples 897.4m and 901.5m is divided by a thin sill. They are fine sandstones, showing compaction features and high clay contents (around 22%). Porosity estimated to≤10% and pores are poorly connected. Diagenetic phases are quartz (overgrowths), calcite, Ca-phosphate, pyrite and albite. Baryte occurs in 901.5.

   Sample 969.6 is a tight shaly facies with thin open fractures.

1.4 Mineralogical overview

The mineralogy of the sediments from Dh4 has been quantified by XRD analysis (Fig.2). These features are notable: generally high contents of clays and albite. Albite dominance indicates that albitization of Ca-bearing plagioclase and/or K-feldspar has been an important diagenetic process.

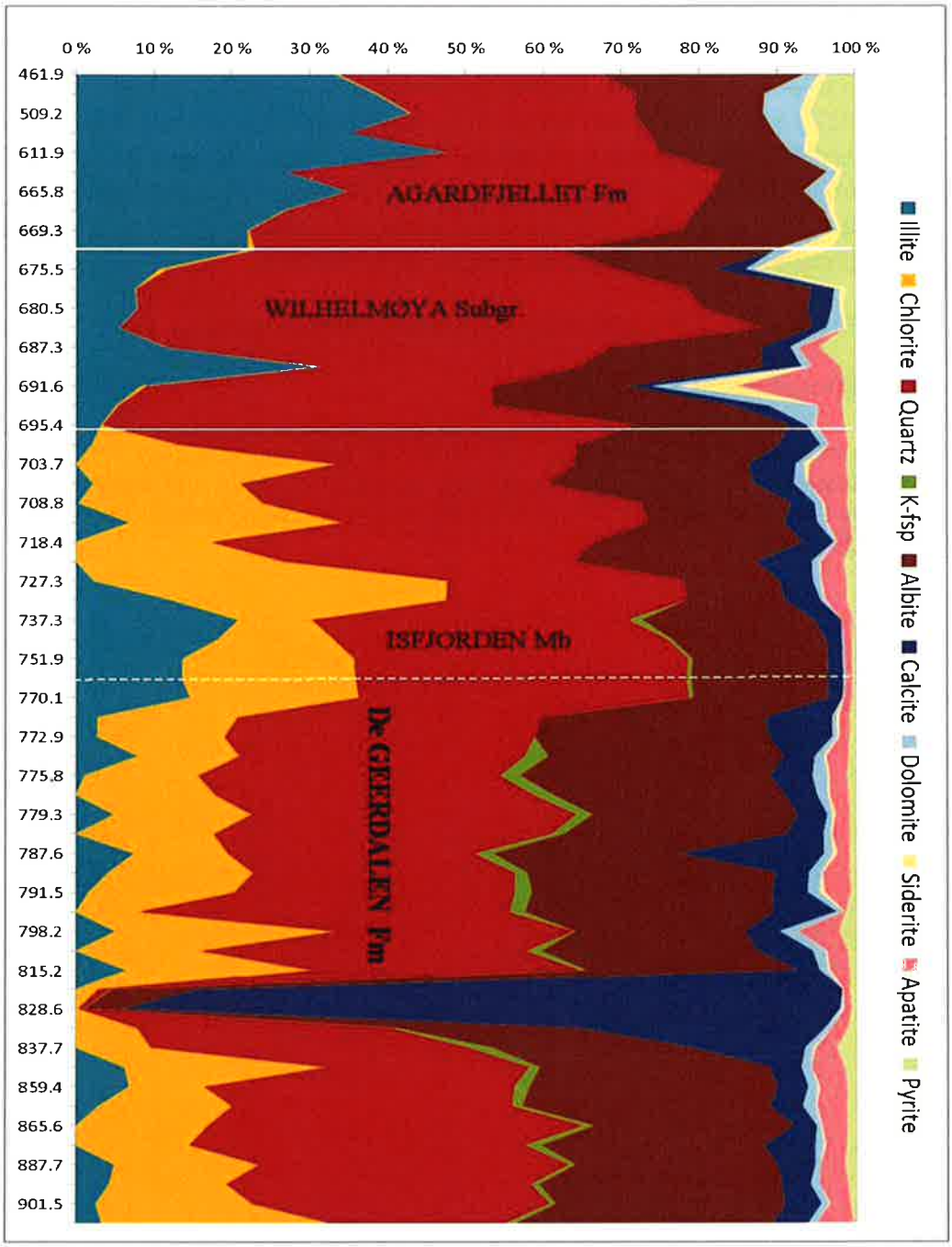

Figure 2 Semi-quantitative XRD mineralogy of caprock and reservoir whole rock samples in Dh4

The high clay/framework grain ratio is further illustrated by the simplified mineralogy plot in Fig.3.

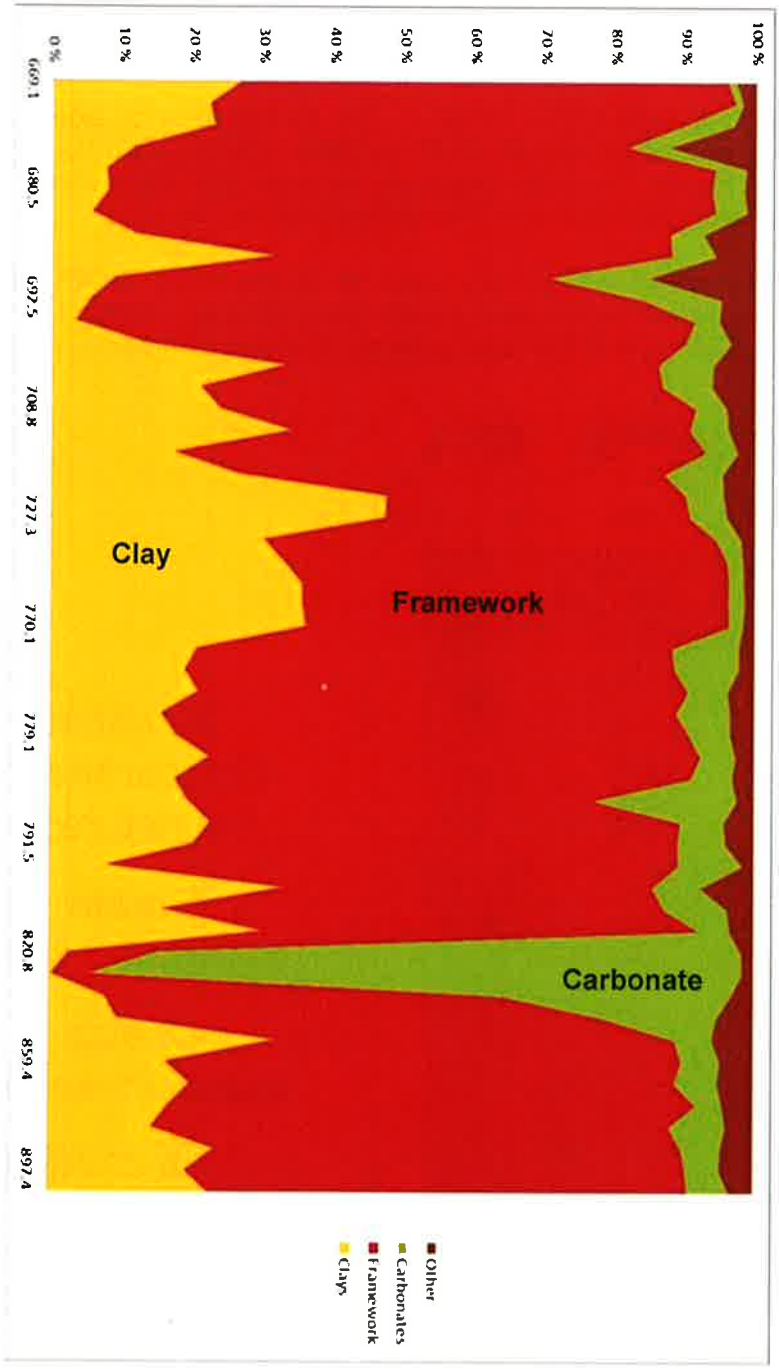

Figure 3 Simplified XRD mineralogy of the reservoir section in Dh4. Brown colour: other minerals (pyrite, apatite)

1.5 Summary of isotope work

Stable isotopes of carbonate cements (calcite, dolomite, ankerite): The very light $\delta^{18}O$ values (ranging from -11.7‰ to -18.6‰ VPDB, Table 1) indicate cementation temperatures well above 100°C and also that significant amounts of CO_2 has been available in the past. It is not possible to decide whether the high temperature is due to the intrusion of basic sills identified at depths 802, 838, 848, 855 and 900m or deep burial to 3-4km. Thermal maturation of

organic matter is the likely cause of the carbonate formation, because of the low values of both $\delta^{18}O$ and $\delta^{13}C$ (Table 2).

The pyrite isotope data ($\delta^{34}S$, Table 1) give no evidence of extensive thermal sulphate reduction, and the values indicate early bacterial sulphate reduction with sea water as the major sulphur source. Thus the carbonate cements and the pyrites appear to have been formed at different times and by different diagenetic mechanisms.

RSA Sr isotope depth profiles are used for compartment identification, and a tentative interpretation suggests presence of 4 main compartments, probably 13 subcompartments, 2 main barriers (828m and 875m) and probably 11 minor barriers (Fig.4)

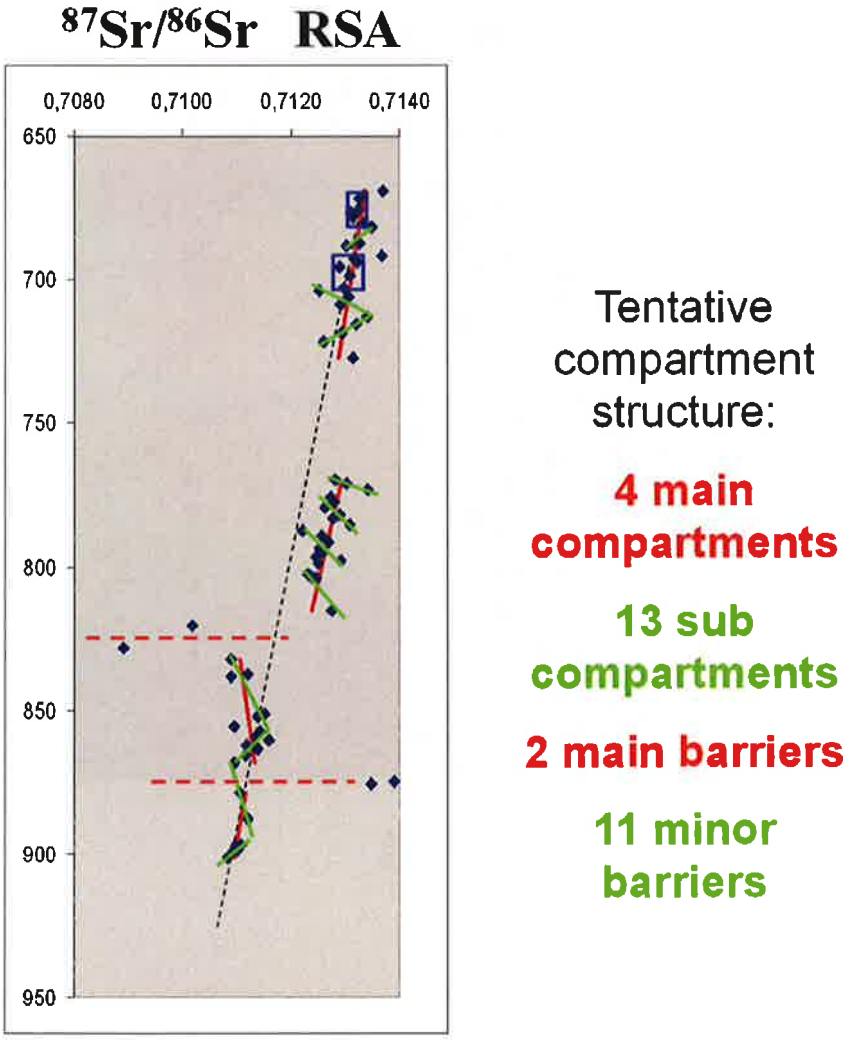

Figure 4 Possible compartment structure of Dh4 based on RSA sr isotope data, sub compartments in green.

A more detailed view of the RSA data related to specific samples and formations are shown in Fig.5.

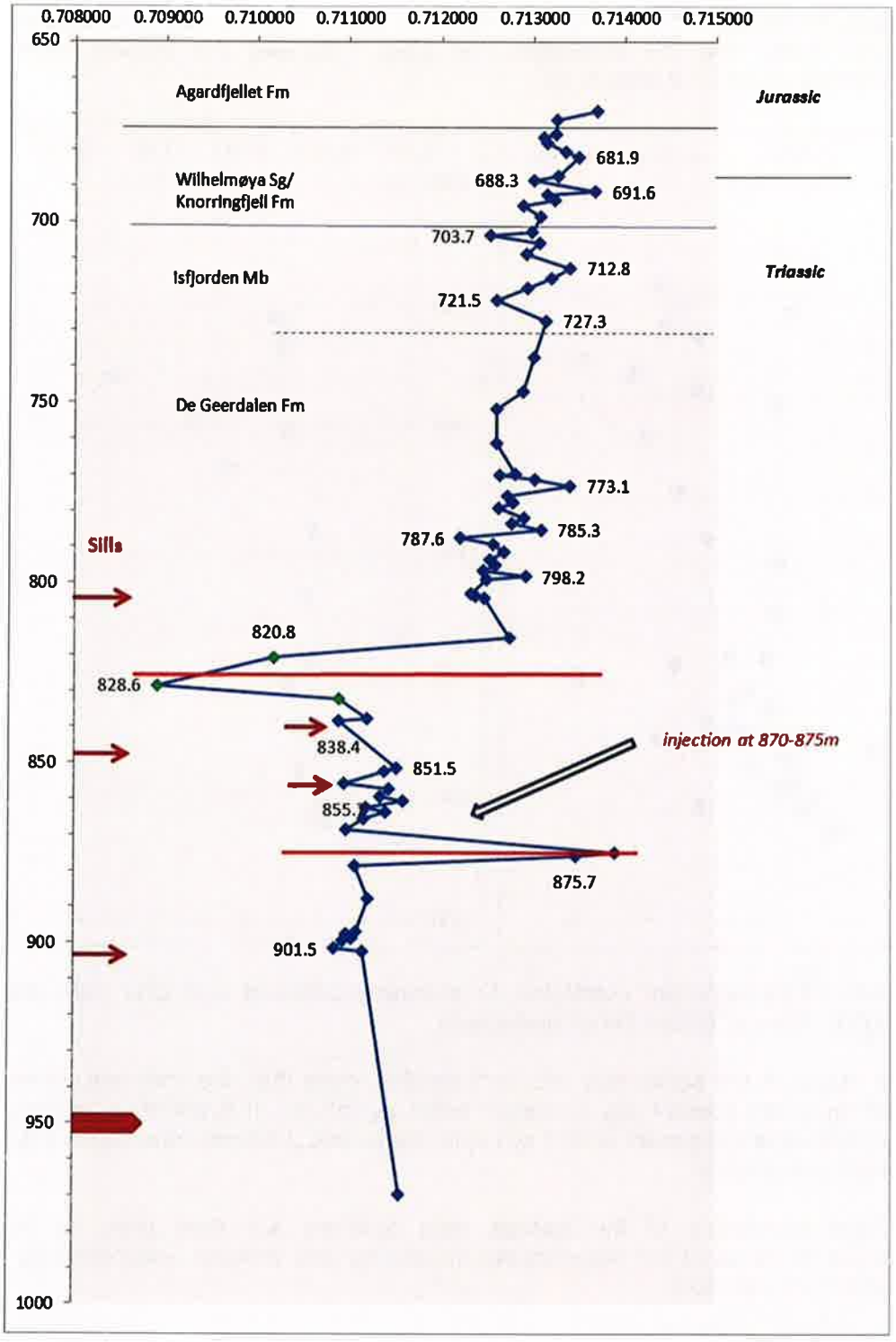

Figure 5 RSA data related to specific samples and formations. The two main barriers are outlined in red. Arrows show locations of sills. Water injection depth is pointed out.

Supplementary sampling of the reservoir sequence in Dh2 was done in 2011. The idea was to compare RSA Sr values in this well with corresponding values in Dh4, to evaluate the extensions of the observed compartments. The horizontal distance between the two wells is about 7km. The sequence in Dh2 corresponds tentatively to the Isfjorden Mb in Dh4, and as

seen in Fig.6, the profiles here are notably similar, including the absolute values as well. It is thus at least likely that the processes that have controlled the present pore water composition have acted on a large scale.

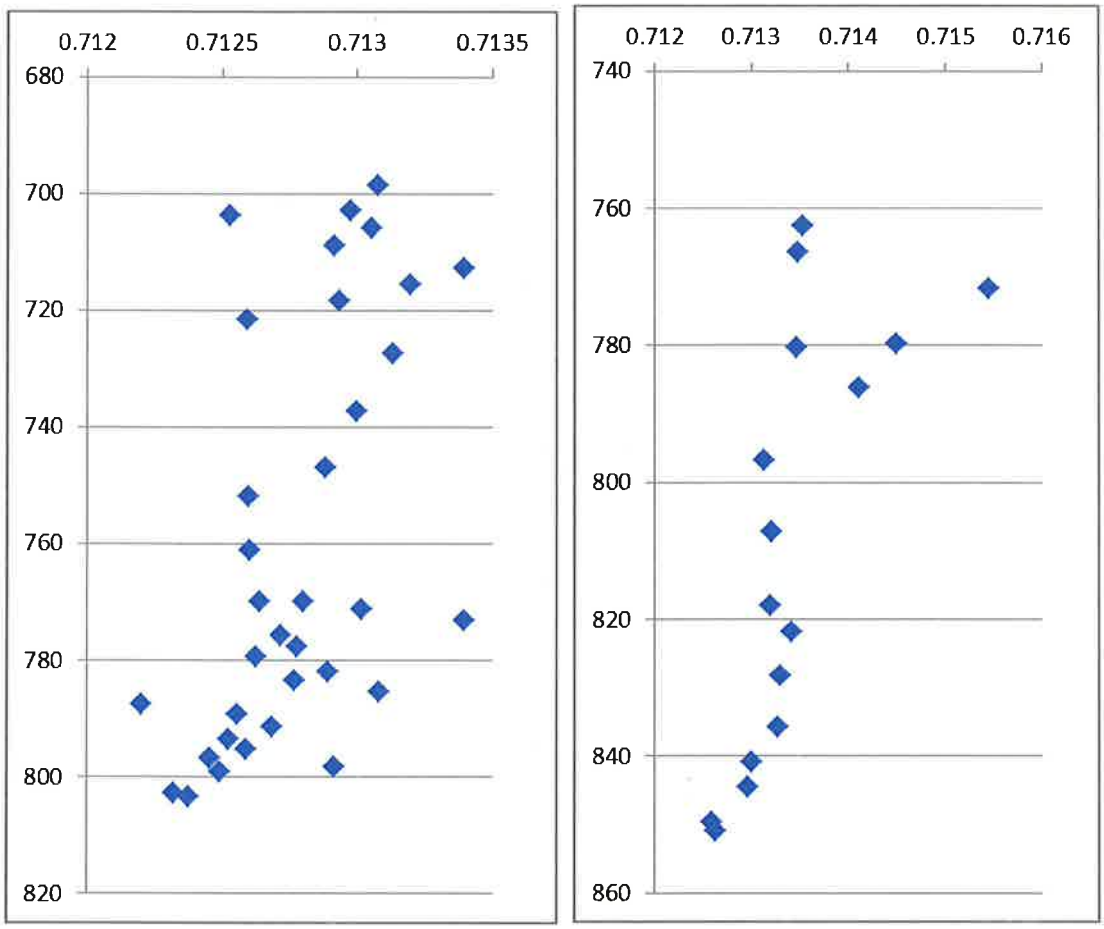

Figure 6 Stratigraphically correlated Sr isotope profiles of well Dh4 (left) and Dh2 (right), showing similar trends and values

Sr isotope values in the carbonates are considerably lower than the core leachates (RSA) values that represent present day formation water signatures. It is therefore indicated that significant pore water movement and/or syn uplift diagenetic reactions have taken place after the carbonate cementation.

An additional importance of the isotope data obtained are their utility as baseline documentation to be used for geochemical monitoring and process understanding in the planned future CO_2 injection.

1.6 Clay mineral characterization

1.6.1 Problem zone/fractured zone at about 400m

A fractured zone common to both Dh4 and Dh6 was sampled in September 2011, at depths 396.27m (Dh4) and 398.58 and 400.5m (Dh6) (Fig.7).

Figure 7 Core photo of the fractured zone in Dh4, 398-400m.

The dominant clay of the analysed samples are illitic clay (Fig.8). The 10Å peak indicates small amounts of an interlayered smectitic phase. The EG runs reveal no significant alteration in the 10Å peak, thus the smectite phase is subordinate. It appears that clay swelling properties is not the major reason for the drilling problems occurring in this zone.

A similar conclusion was achieved by Bøe and Mørk (2008) based on analysis of mudstone samples from Dh3 and Dh2.

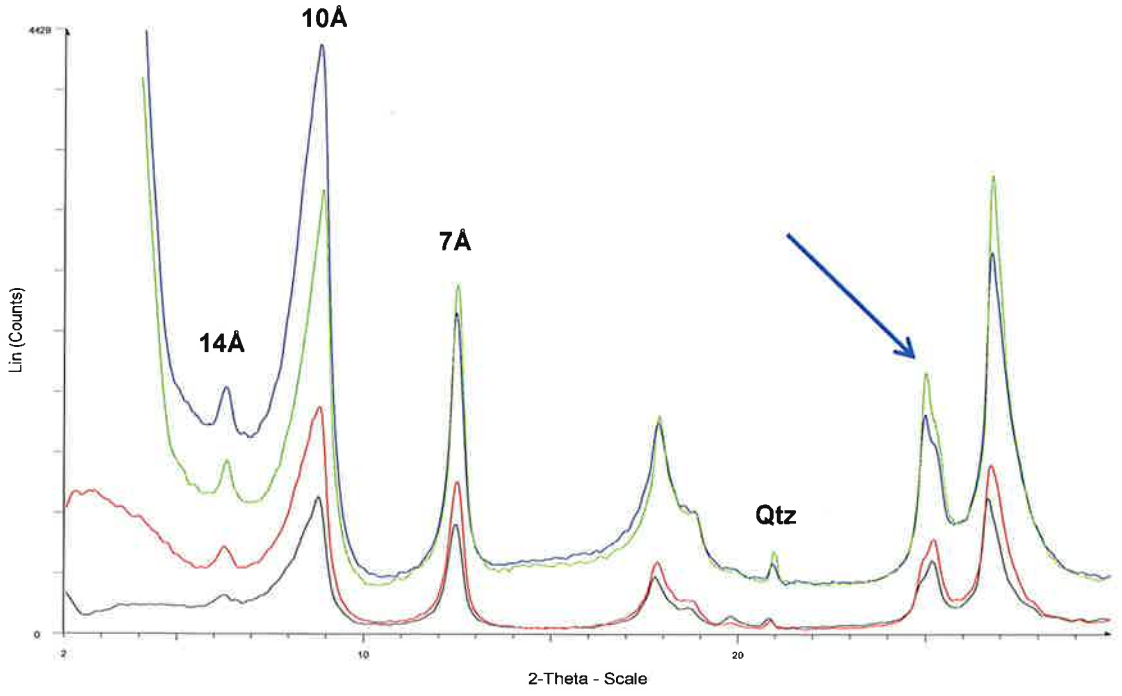

Figure 8 Oriented air dry (AD) runs of <2µm clay fractions from the fractured zone in Dh4 and Dh6, included is also sample 375.93 in Dh4 (Rurikfjellet Fm, red curve). Arrow points out the 3.5 peak, proving presence of both Fe rich chlorite (chamositic) and kaolinite. Green: Dh6 400.50m, Blue: Dh6, 398.58m, Black: Dh4, 396.27, Red: Dh4, 375.93m. Qtz: quartz peak

1.6.2 Dh6 shales

XRD runs of clay fractions of three samples in Dh6 are shown in in Fig.9. The samples range from 398.58m (fracture zone) to 433.85m. The deeper sample has no or very low amounts of kaolinite relative to chlorite compared to the samples at higher levels. The relative amounts of illite and 7Å clay varies; in general illite dominates.

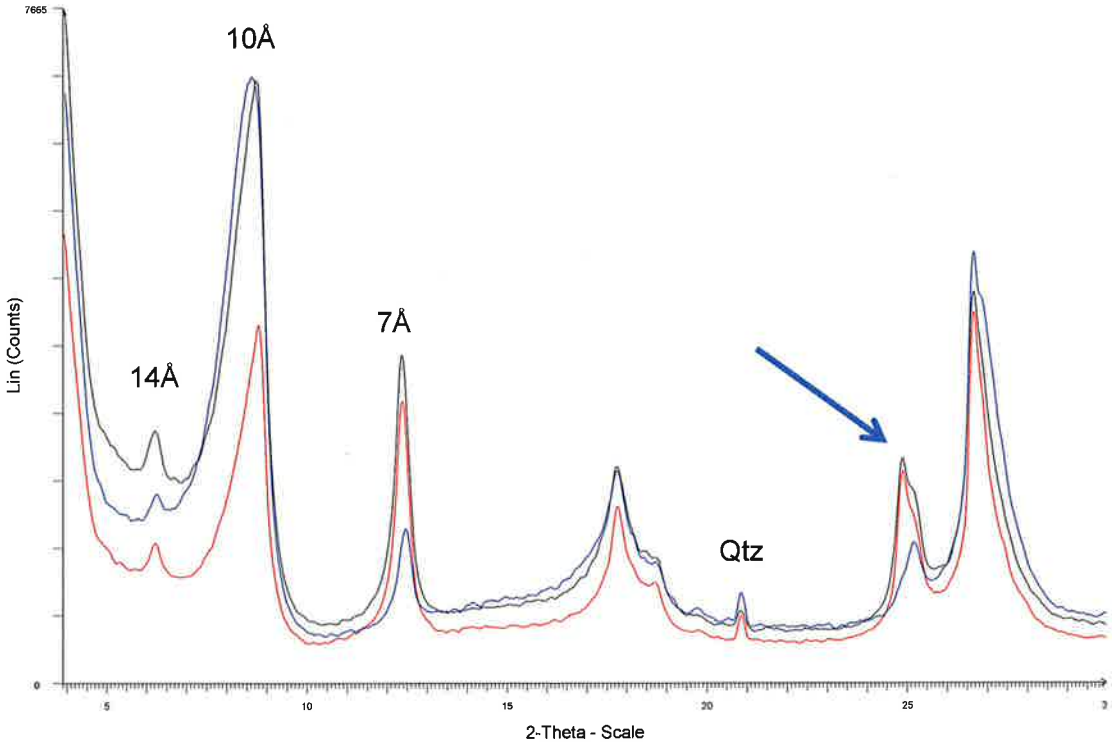

Figure 9 Oriented AD runs of Dh6 clay fractions, displaying the relative amounts of the illite, chlorite and kaolinite. Arrow points out the 3.5Å peak, including 3.52Å chlorite and 3.58 kaolinite peaks. Black: 398.58m, red: 400.50m and blue: 433.85m.

1.6.3 Overburden/caprock of Agardfjellet Fm, Dh4

The <2µm clay fractions of samples 499.5 to 665.3m are compared in Fig.10. The dominant clay is illitic with subordinate amounts of a smectite component as seen in EG runs. This also includes the sample 499.46m even if the AD 10Å peak is clearly asymmetric. Contents of chlorite appear to be low, and the 3.5 peak is poorly defined. Presence of fine quartz is evident. Calcite is present at 553.87m.

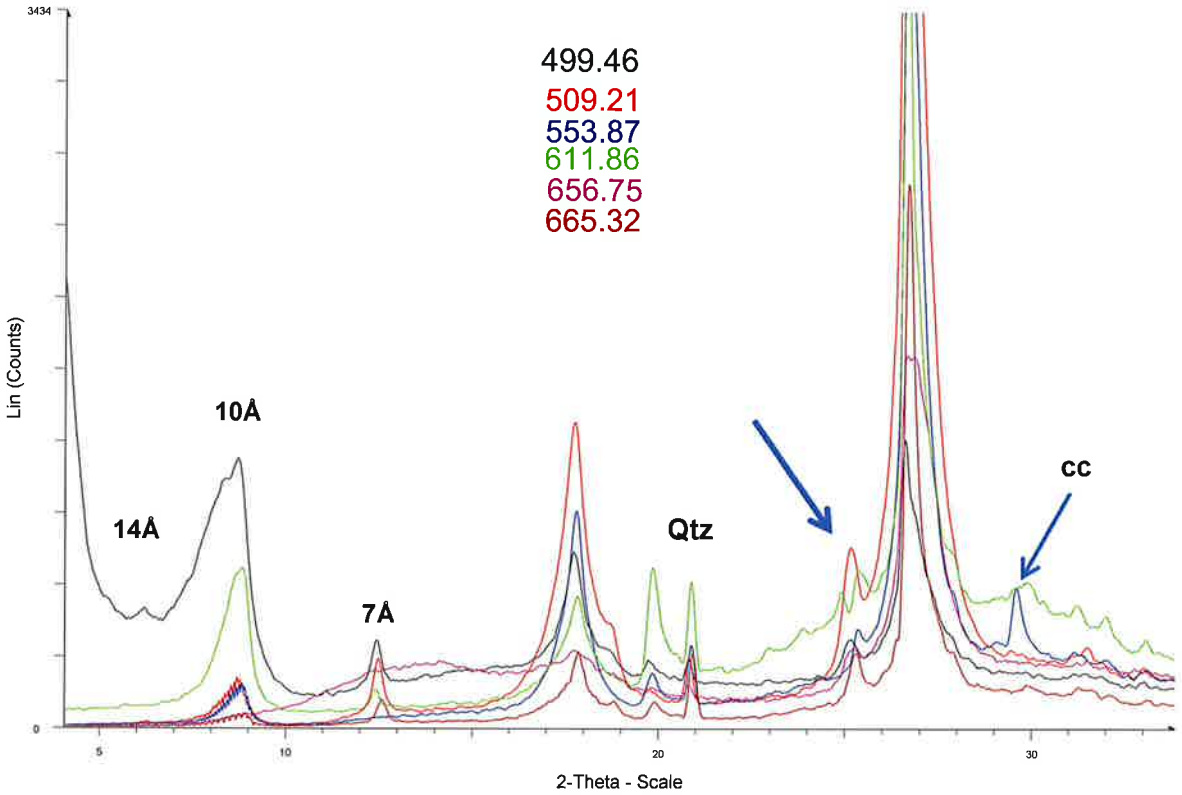

Figure 10 Compared XRD runs of clay fractions (oriented AD) within Agardfjellet Fm. Diagnostic clay peaks at 14Å, 10Å ,7Å and 3.5Å (illite and chlorite) are pointed out, as well as quartz and calcite peaks.

1.6.4 Reservoir sequence

The sample 687.5m represents the Isfjorden Mb (upper part of De Geerdalen Fm), and the clay fraction here includes similar amounts of illite and chlorite (chamositic, 7Å Fe-rich), shown in Fig.11.

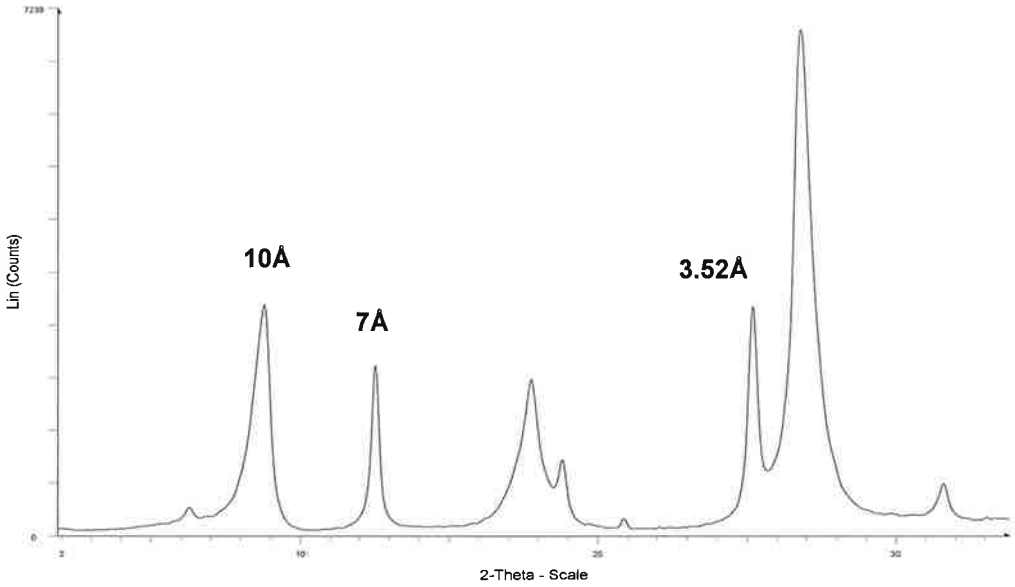

Figure 11 Fe-rich chlorite is identified by distinct peaks at 7Å and 3.52Å. The peak at 10Å displays insignificant amounts of smectite interlayering

A crushed zone at ≈753m in Dh4 (lower part of the Isfjorden Mb) was sampled in 2011 in the core store at UNIS, also included was a similar zone in Dh2 at 833.88m (Fig.12).

Figure 12 Crushed zones at ≈ 753m in Dh4(left), and 833.8m in Dh2 (right)

The Dh4 sample has similar amounts of illite and Fe-chlorite (chamositic), and no kaolinite or smectitic interlayers. The Dh2 sample is dominated by illite with no smectite and very low amounts of chlorite. Trace albite and quartz are present in the clay fraction.

Two samples from De Geerdalen Fm were further included in the clay mineral analysis (772.9m and 779.05m). The dominance of Fe-rich chlorite is obvious (Fig.13).

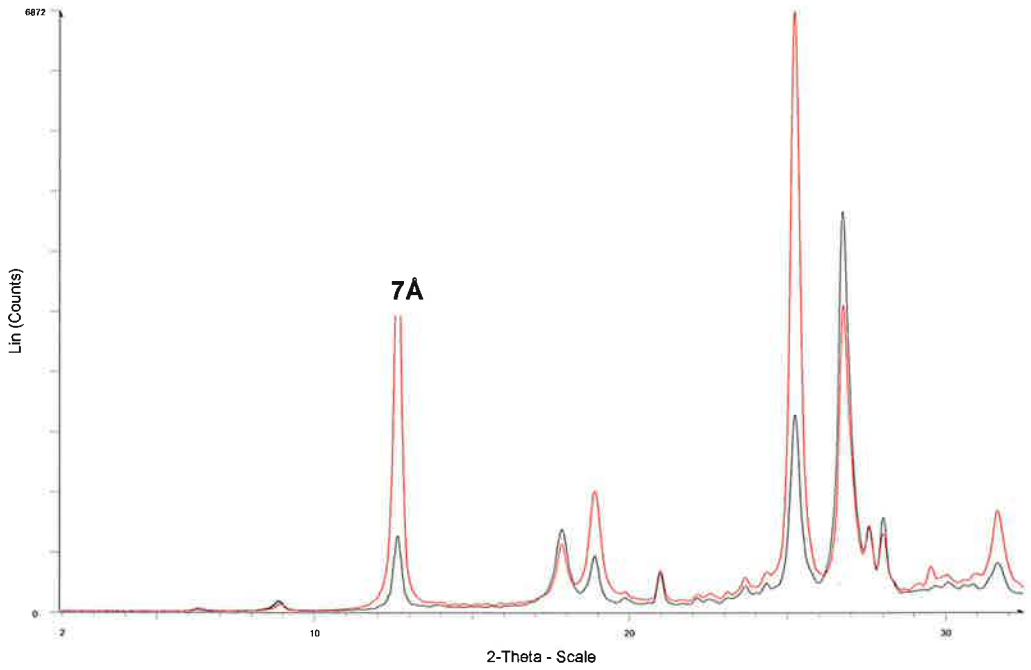

Figure 13 Comparison between the two samples within the reservoir. The main clay type is Fe-rich chlorite with dominant peaks of 7Å and 3.52Å. Quartz and trace calcite are present as well.

A compilation of EDS point analyses of the 7Å chlorites in terms of Mg-Al-Fe atomic%,are shown in Fig.14. Although such analyses are only semiquantitative, the similarity with diagenetic berthierine-chamosite chlorites are evident.

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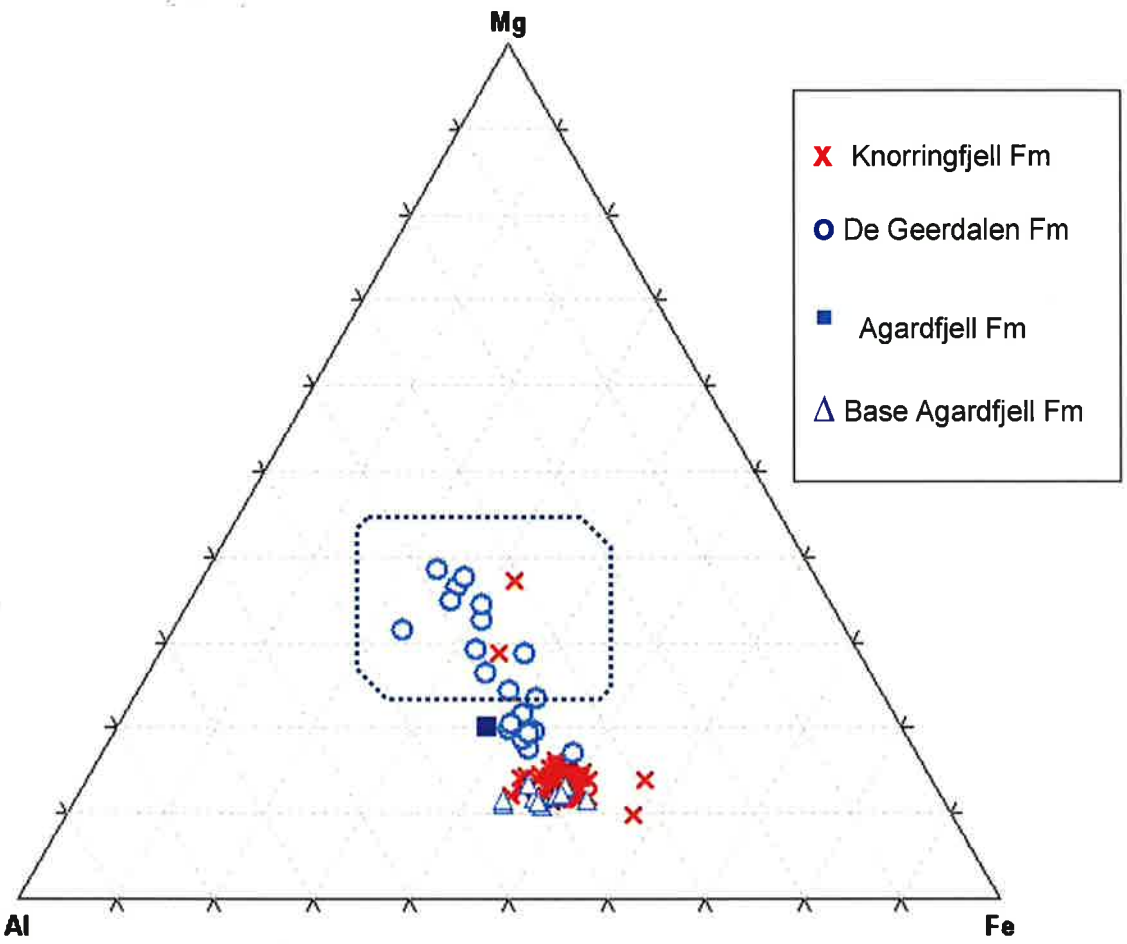

Figure 14 Composition of the 7Å chlorites (SEM EDS point analyses). Enclosed area: diagenetic berhierine-chamosite like chlorites (Ryan and Hilier 2002)

1.7 TOC data

The contents of organic carbon are given in Table 3. The highest amounts, with a maximum value of 11.7 weight%, are seen in Agardfjellet Fm in the depth interval 450m to 656m. The contents of inorganic carbon (carbonates) appear to be low in the analysed samples.

2 Tables

2.1 Sulphur isotopes

Table 1 Sulphur isotopes in pyrites in Dh4

Depth	Formation	$\delta^{34}S_{CDT}$
611.86	Agardfjell	-9.6
675.5	Wilhelmøya	-6.2
769.9	De Geerdalen	-6.7
770	De Geerdalen	-3.8
776.4	De Geerdalen	-3.8

2.2 Carbonate isotope data

Table 2 Stable isotopes and Sr isotope data of carbonates within Dh4

			Calsite/ankerite		Dolomite/Siderite					
Depth	**Carbonate**	**Formation**	$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VPDB}$	$\delta^{13}C_{VPDB}$	$\delta^{18}O_{VPDB}$	**87Sr/86Sr**	**2 sigma**	**Comments**	
671.6	**Siderite**, (ankerite)	Agardfjell	-9.21	-14.08	-8.8	-22.4	0.711783	0.000008	Extensive cement	
691.6	**Siderite**, (ankerite)	Knorringfjell	-11.84	-11.73	-14.3	-20.3	0.709648	0.000016	Extensive cement	
692.5	**Dolomite/ankerite**	Knorringfjell	-10.33	-15.21	-9.6	-14.3	0.710030	0.000012	Extensive cement	
721.5	Calcite	Isfj.Mb	-14.99	-18.63			0.710371	0.000014	Local cement	
771.3	Calcite	De Geerdalen	-10.10	-18.22			0.710396	0.000015	Local cement	
779.3	Calcite	De Geerdalen	-9.88	-17.57			0.711280	0.000012	Local cement	
787.6	Calcite	De Geerdalen	-10.90	-15.61			0.709585	0.000012	Only XRD data/extensive	
796.7	Calcite	De Geerdalen	-9.64	-16.99			0.711167	0.000012	Local cement	
803.5	Calcite	De Geerdalen	-9.56	-17.11			0.711160	0.000016	Local cement	sill ca 802
820.8	Calcite	De Geerdalen	-6.45	-13.64			0.708731	0.000012	cement+shell fragments	
828.6	Calcite	De Geerdalen	-3.40	-14.64	-5.1	-20.9	0.708297	0.000012	Shell dominate	
832.2	Calcite	De Geerdalen	-7.14	-16.25			0.709505	0.000010	Shell dominate	
837.7	Calcite	De Geerdalen	-7.42	-17.82			0.709912	0.000012	cement+shell fragments	sill 838.4
855.7	Calcite	De Geerdalen	-9.13	-17.01			0.710130	0.000011	Altered sill	sill 849.6
875.7	Calcite	De Geerdalen	-7.43	-16.42			0.710592	0.000010	Local cement	

2.3 TOC data

Table 3 Total organic carbon (TOC) and total carbon data (TC) of shaly samples in Dh4 and Dh6

Well	Depth (m)	TOC (%)	TC (%)	Formation
Dh4	375.93	1.09	1.29	Rurikfj/Agardfj
Dh4	396.27	0.62	0.68	Rurikfj/Agardfj
Dh4	449.46	1.59	2.28	Agardfjellet Fm
Dh4	461.87	4.00	4.29	Agardfjellet Fm
Dh4	509.21	3.36	3.84	Agardfjellet Fm
Dh4	553.86	4.45	4.91	Agardfjellet Fm
Dh4	611.86	11.70	11.50	Agardfjellet Fm
Dh4	656.75	1.45	1.68	Agardfjellet Fm
Dh4	665.32	0.59	0.61	Agardfjellet Fm
Dh4	669.1	0.54	0.47	Agardfjellet Fm
Dh4	671.6	1.21	1.94	Agardfjellet Fm
Dh4	687.3	0.58	0.51	Knorringfjell Fm
Dh4	712.8	0.30	0.22	Isfj.Mb/De Geerdalen Fm
Dh4	721.5	0.16	0.52	Isfj.Mb/De Geerdalen Fm
Dh4	727.3	0.18	0.12	Isfj.Mb/De Geerdalen Fm
Dh4	753.95	0.60	0.61	Isfj.Mb/De Geerdalen Fm
Dh4	851.5	0.81	0.81	De Geerdalen Fm
Dh4	887.7	0.59	0.69	De Geerdalen Fm
Dh6	398.6	0.46	0.55	Rurikfj/Agardfj
Dh6	400.5	0.46	0.51	Rurikfj/Agardfj
Dh6	433.9	1.49	1.84	Agardfjellet Fm

3 Sample locations

The detailed sample descriptions are given in Appendix. The majority of the samples are from Dh4, supplied by some from Dh2 and Dh6. These are however only briefly considered.

Fig.15 gives a simplified overview of the formations in the first four wells. The location of Dh6, drilled in 2011, is very close to Dh4.

Detailed locations of samples selected for RSA analysis and mineralogy (thin sections) related to the sediment log are seen in Figs.16. The sediment logs are available in the LYB CO2 home page.

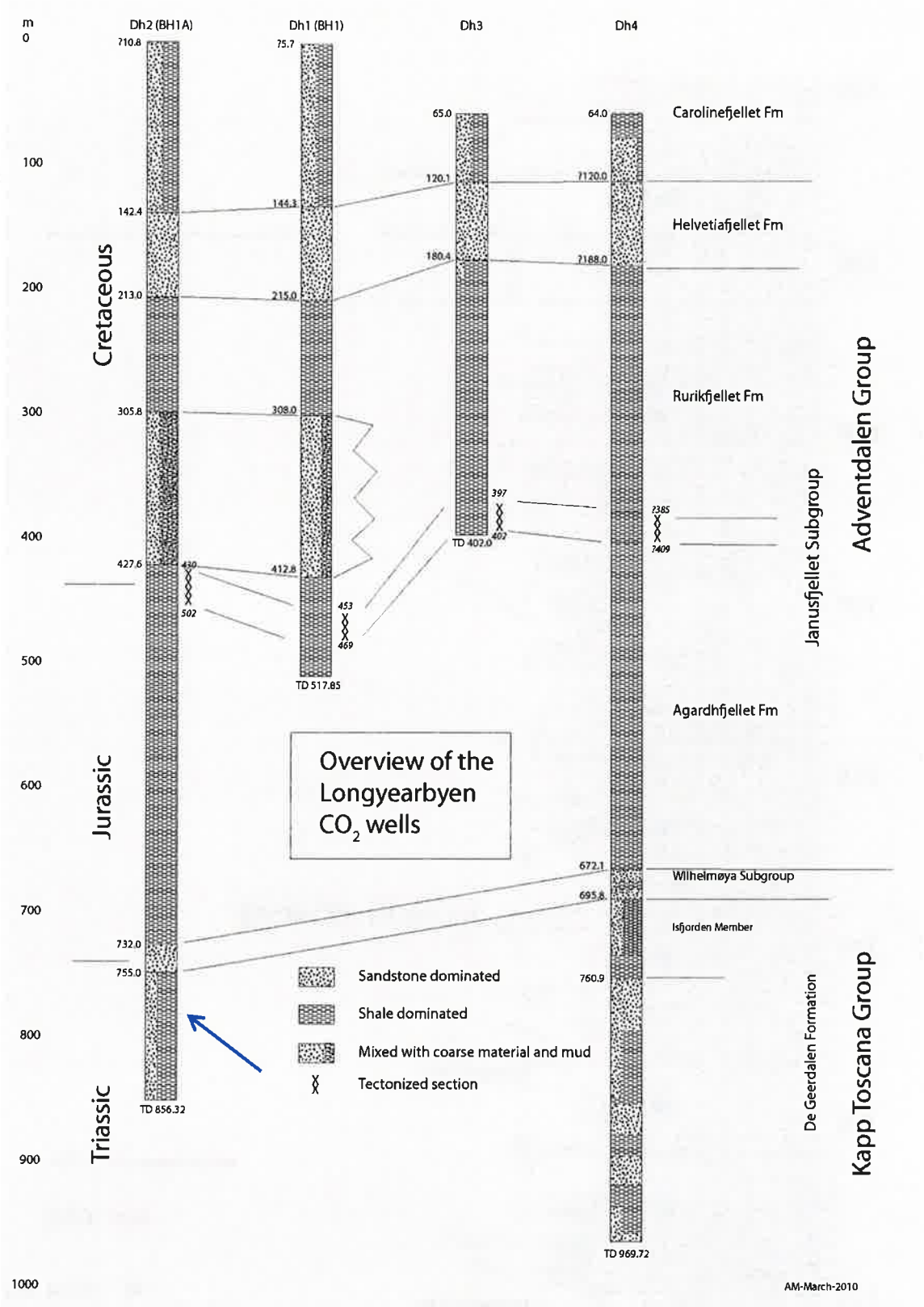

Figure 15 Simple overview of the wells Dh1-Dh4. Arrow points out the target of sampling in Dh2 (2011) for Sr RSA correlation with the Dh4 reservoir sequence

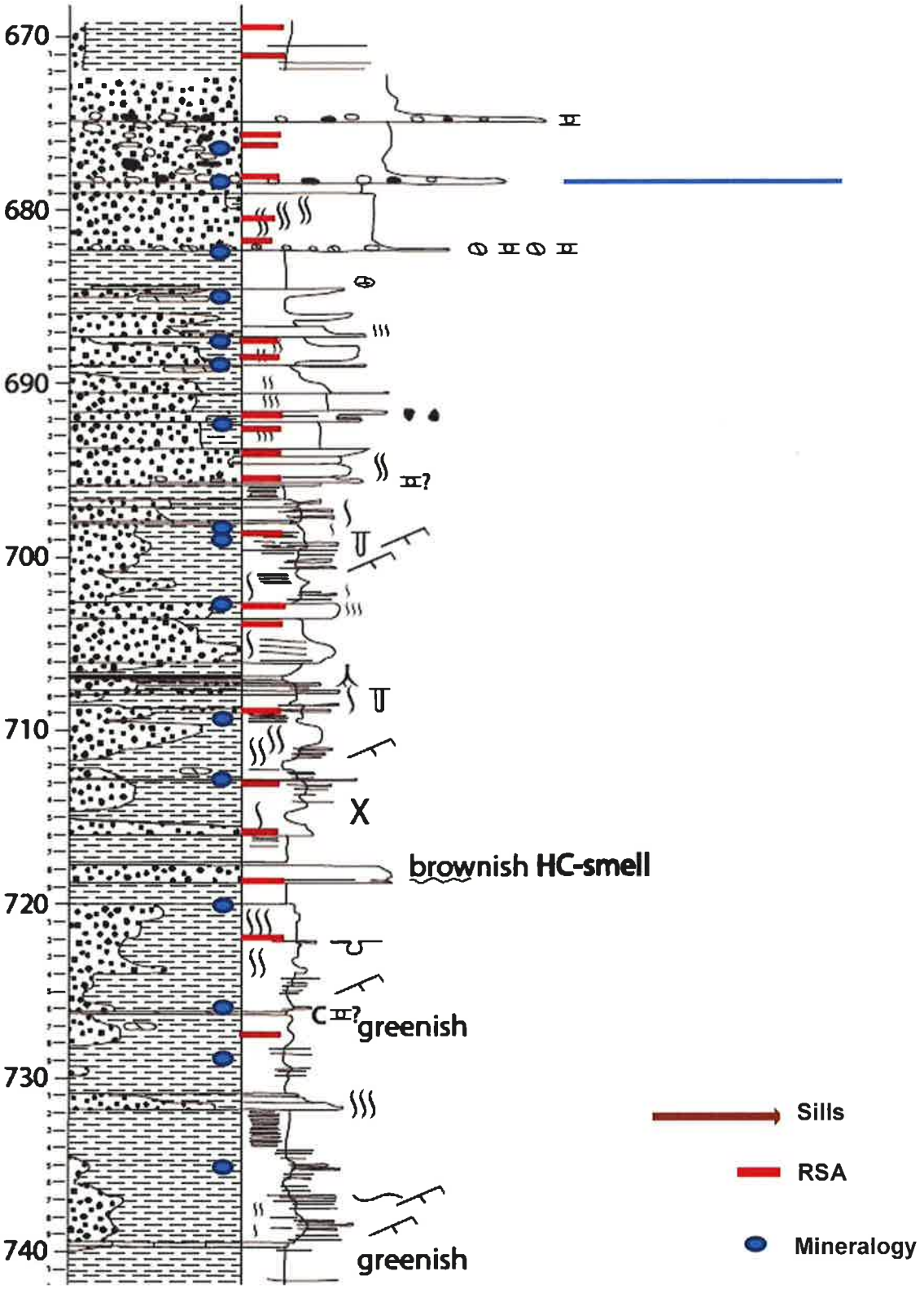

Figure 16 Detailed location of samples analysed for RSA Sr isotopes and samples for mineralogy, related to the sediment log (log from UNIS LYBCO2 lab homepage)).

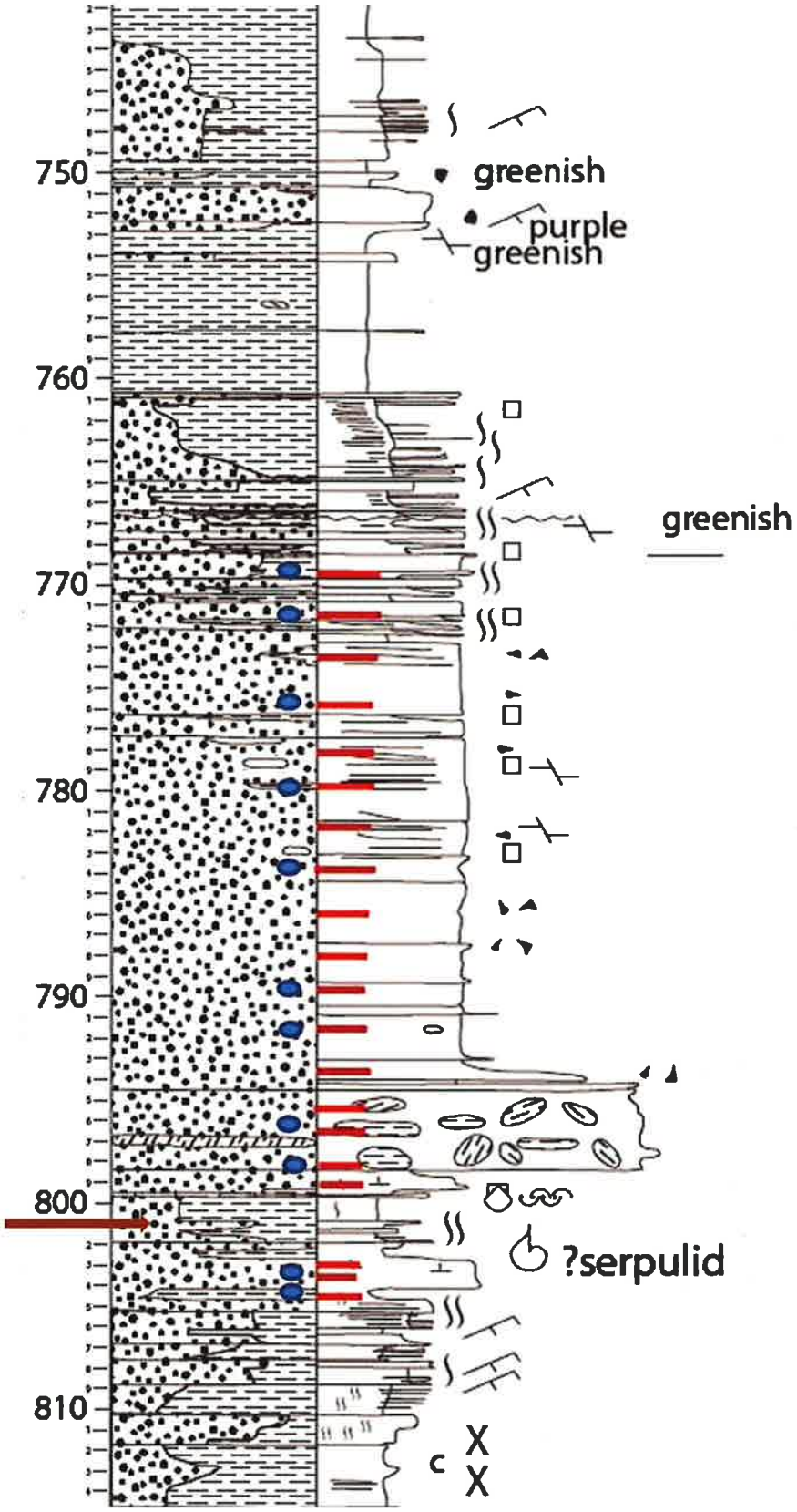

Figure 16 proceeded

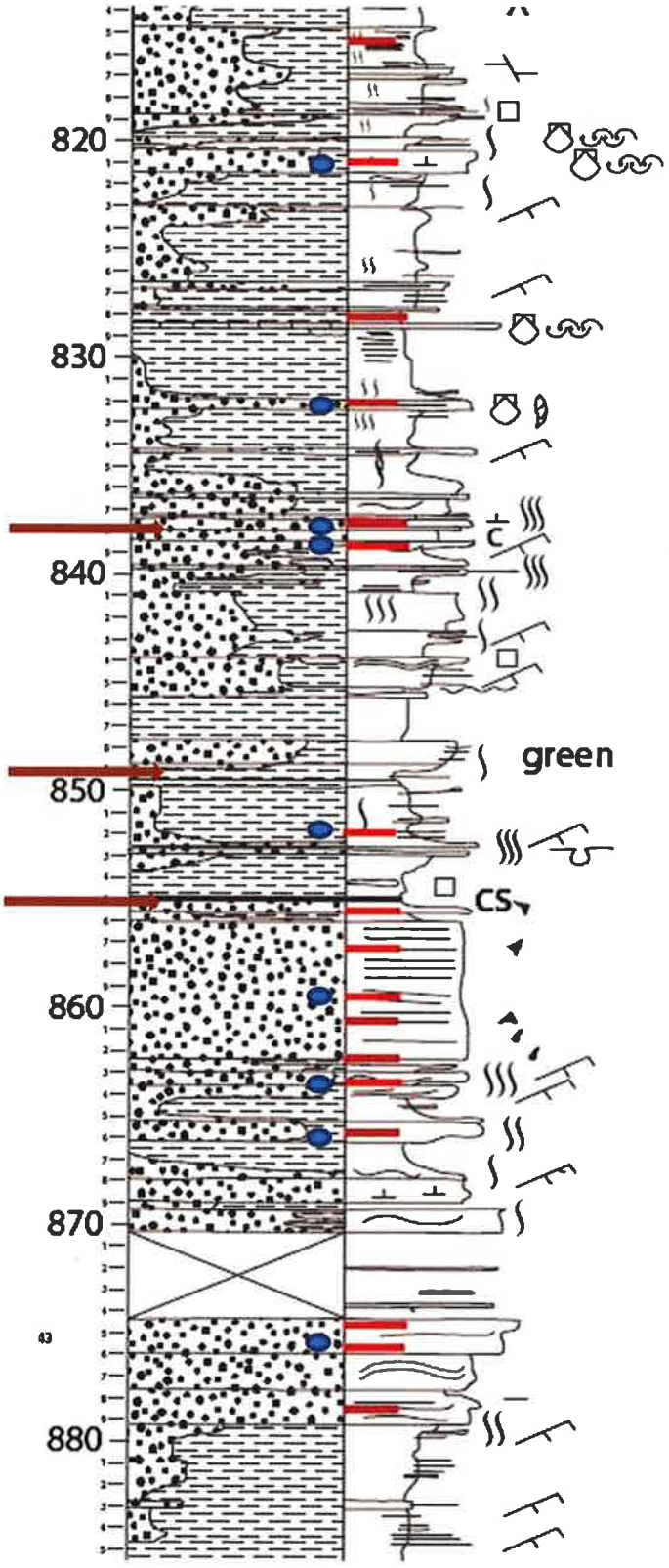

Figure 16 proceeded

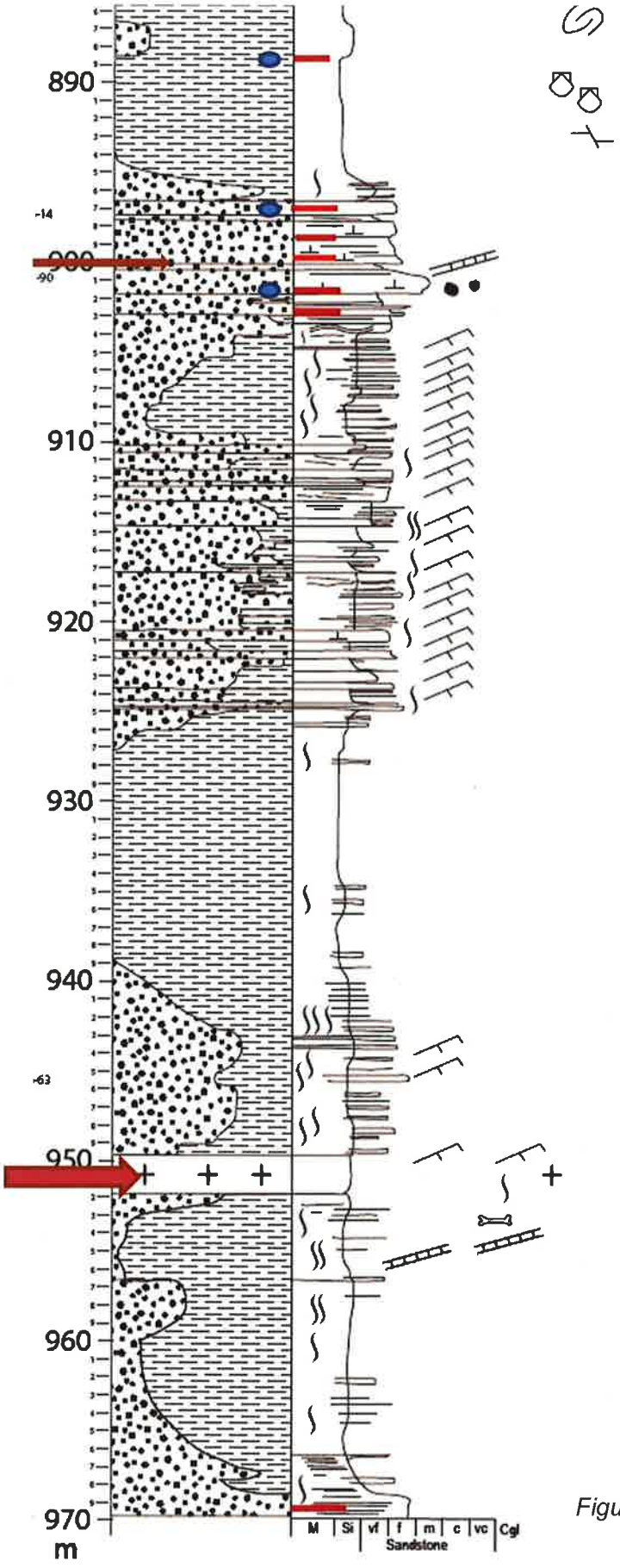

Figure 16 proceeded

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FULLPAT program for XRD mineral quantification: freeware with link
http://www.ccp14.ac.uk/ccp/web-mirrors/fullpat/

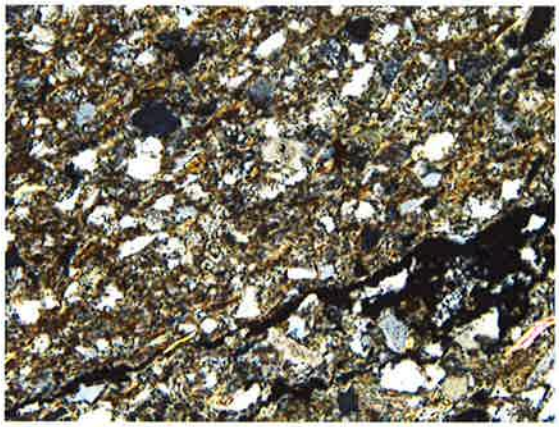
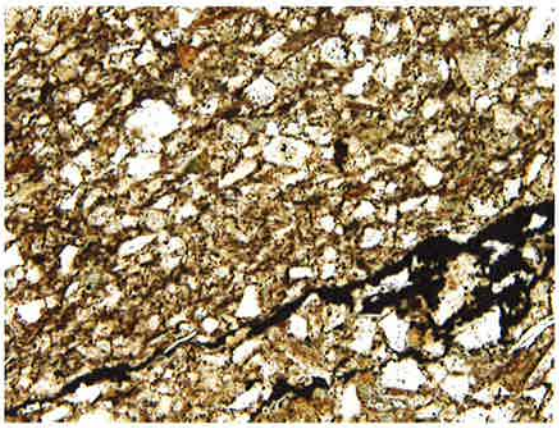
APPENDIX

Descriptions in terms of mineralogy and texture

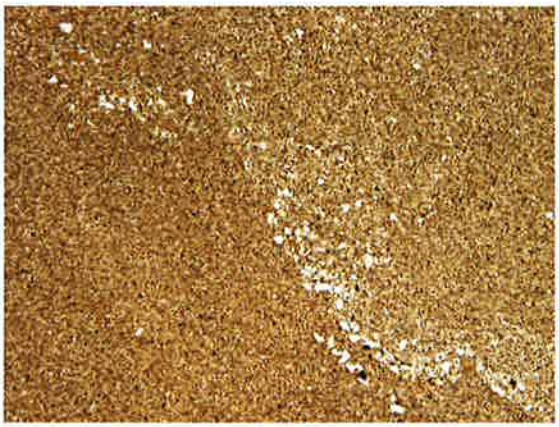
The following descriptions are based on optical microscopy of polished thin sections supplied with SEM analysis on selected samples. The FULLPAT software are used for the XRD mineral quantification. This software includes all mineral peaks compared to an internal library of various minerals.

The following abbreviations are used in the pictures:

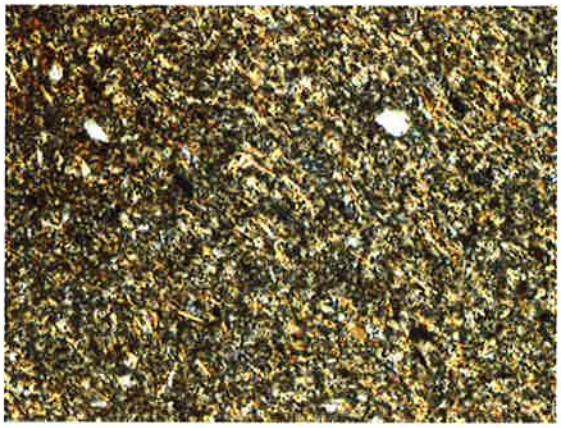
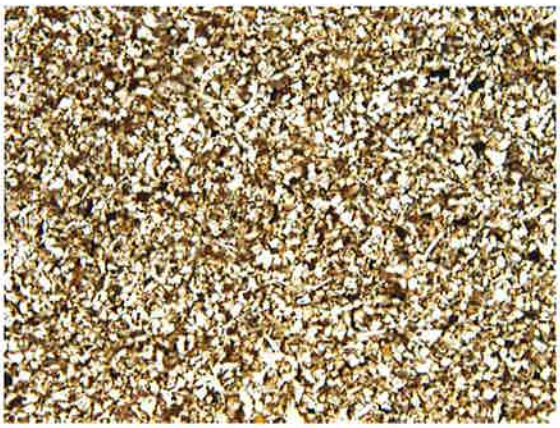
- xn: polarized light (crossed nicols)
- IIn: plain light (parallel nicols)
- UV: fluorescence light
- x4: long edge of the picture is 3.7mm
- x10: ling edge of the picture is 1.5mm
- x20: long edge of the picture is 0.75mm
- x40: long edge of the picture is 0.375mm

Dh2, 779.81m. Length of picture 1.5mm

Dh2, 786.20m. length of picture 3.7mm

Dh2, 786.20m. Length of picture 0.75mm

Well : Dh4 Depth, m:105.11 Type: Core / Carolinefjell Fm

Lithology	Sandstone
Sorting	Well
Grain size	Medium sand
Grain shape	Subangular-subrounded (compaction disturbed)
Porosity	Moderate low – estimate 5-10%

Detrital:

Fragments Microcrystalline quartz-chert, some ductile clayish grains, brown fibrous, polycrystalline quartz

Grains Quartz, plagioclase, microcline, low in mica, scattered oxides, zircon

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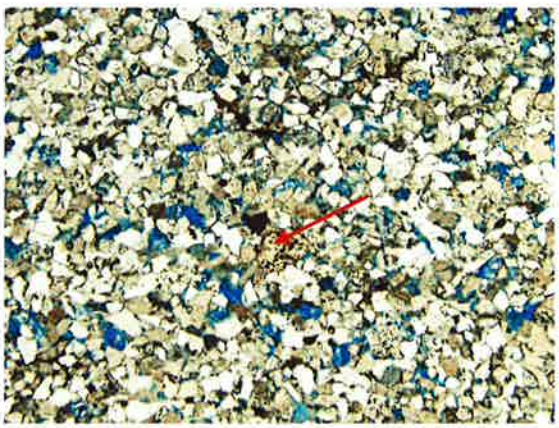
Authigenic:

Cement Local, very corroded carbonate, quartz overgrowths, trace siderite?

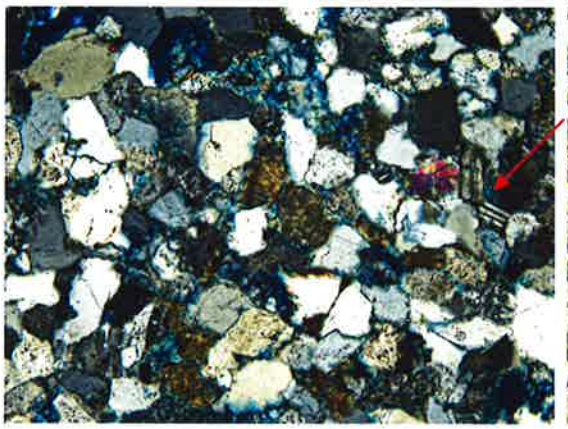
Clay Seen in pores, small amounts, probably chloritic, mostly from alteration?

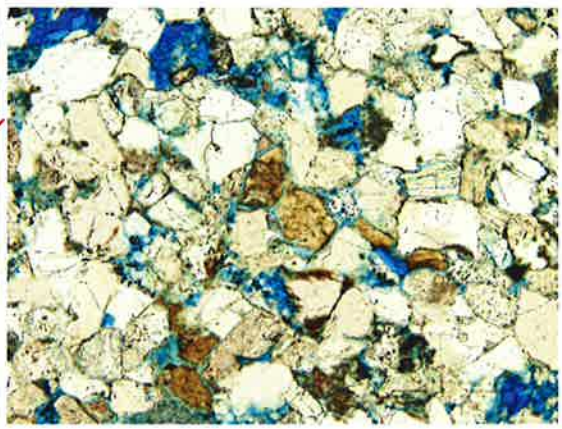
General: Poor polish? Feldspar dissolution and carbonation, oversized pores (grain dissolved), some feldspars are very altered-others quite unaltered . Brown grains related to apatite or glauconite or chert?? Cementation/compaction disurbing the texture, appears very rugged/dusty

Overview texture x4 xn

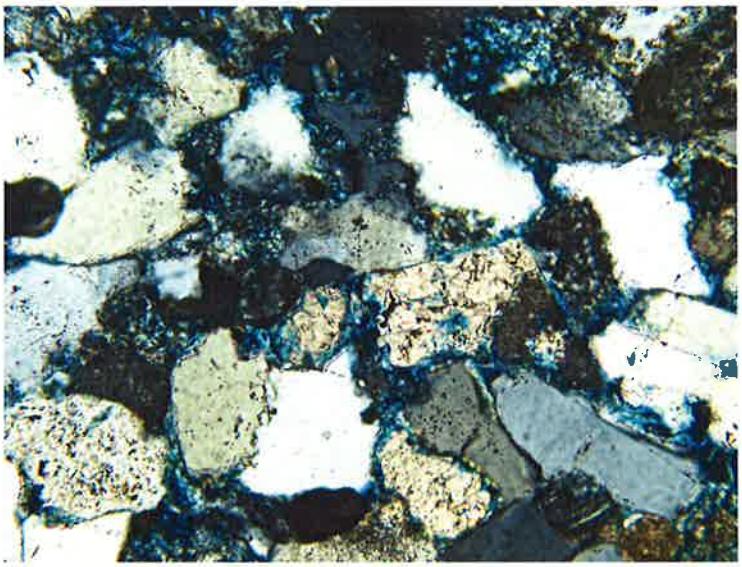


Blue: porosity. Chert in center (arrow) x4 lln

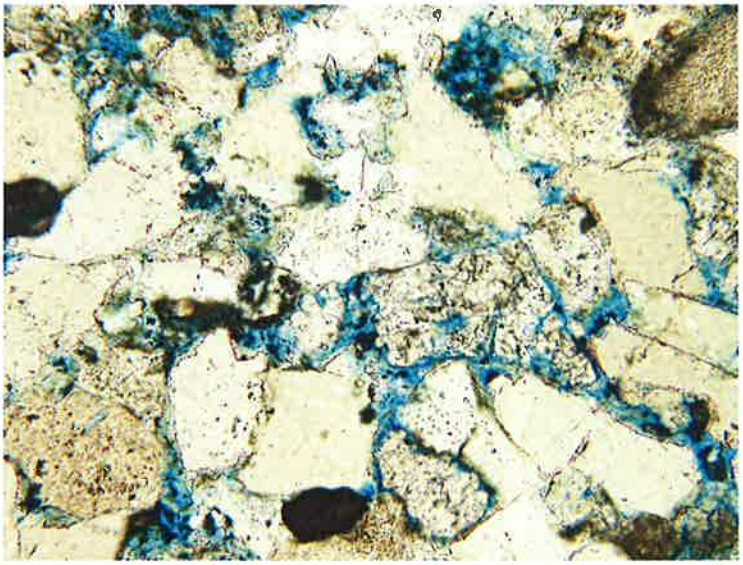




Closer view; quartz overgrowths, fine brown ductile grains, feldspar grains (microcline, plagioclase) (arrow) mica



x20 xn



x20 lln

Detail texture, dissolving carbonate cement in center

Well : Dh4 Depth, m: 125.22 Type: Core / Helvetiafjell Fm

Lithology	Sandstone
Sorting	Well
Grain size	Medium sand
Grain shape	Subrounded (Compaction disturbed)
Porosity	Moderate, estimate 10%, oversized pores

Detrital:

Fragments Microcrystalline quartz, chert, polycrystalline quartz, shaly (ductile) grains, organics – scattered or in discontinuous flasers. Possibly a very altered dolerite

Grains Quartz, plagioclase, pyrite (commonly related to organics)

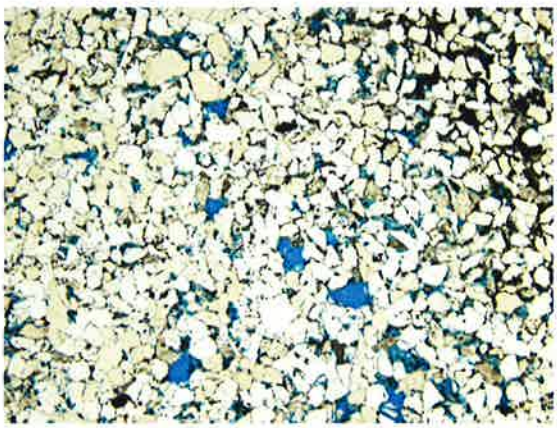
Authigenic:

Cement Tiny micritic siderite grains, scattered at grain boundaries and locally in clusters. Diffuse quartz overgrowths

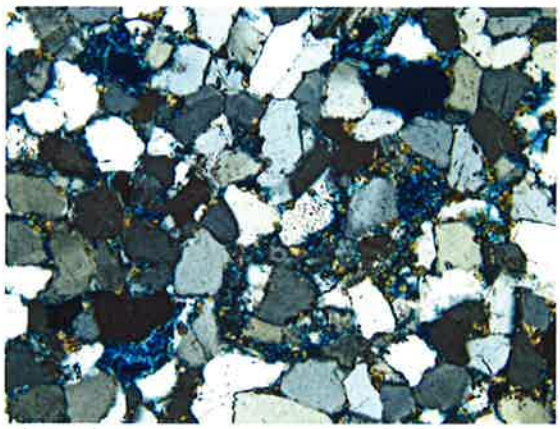
Clay Undefined (chloritic?) clay in pore and linings

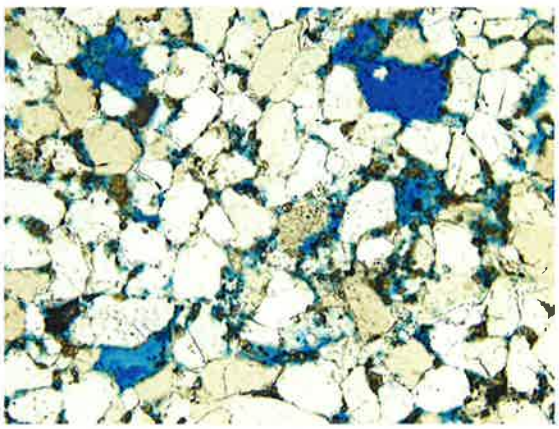
General: Scattered oil inclusions in altered plagioclase. Some compaction, blurred grain boundaries due to poor polish or corrosion by clays. Siderite is an early cement

Textural overview x4 xn



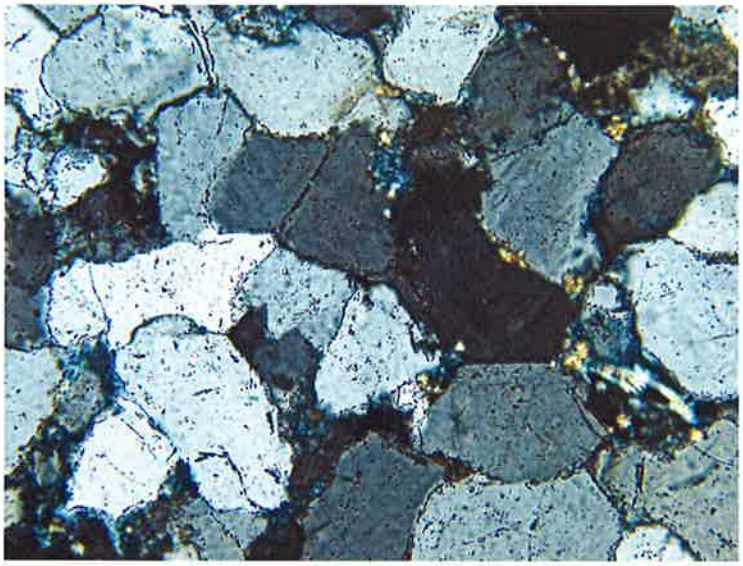
Blue: porosity x4 lln



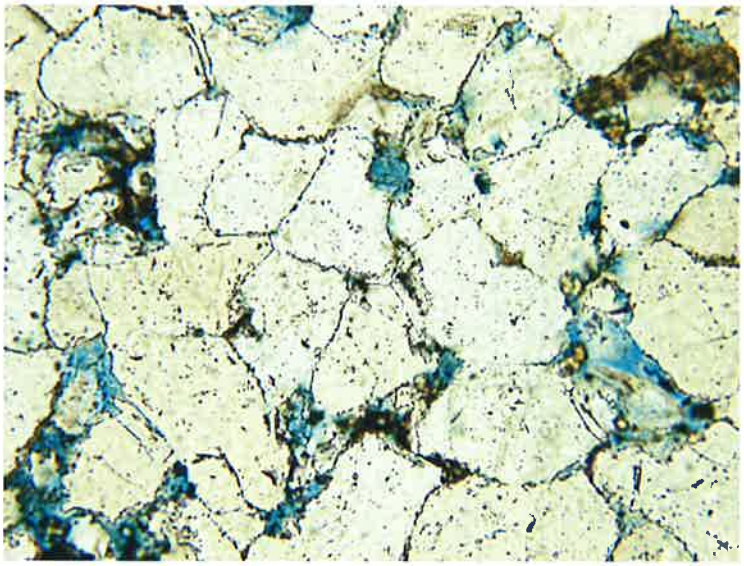


Closer view; scattered siderites, clay in pores, oversized pores (blue), quartz cement, compaction

x10 xn x10 lln



x20 xn



x20 lln

Detail of compaction grain texture; siderite grains on grain boundaries

Well : Dh4 Depth, m:165.35 Type: Core / Helvetiafjell Fm

Lithology	Pebbly siltstone, wavy, discontinuous lamina of organics
Sorting	Poor-moderate
Grain size	Silt-medium sand, pebbles up to about 1mm
Grain shape	Subangular, pebbles are more subrounded
Porosity	Low

Detrital:

Fragments Pebbles are commonly larger quartz grains, a few are fractured (artefact?), microcrystalline quartz, ductile clayish grains, chert, organics

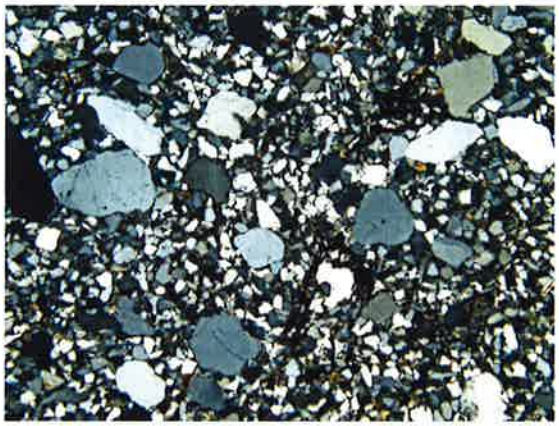
Grains Quartz, muscovite, altered ductile glauconites, few scattered oxides, zircon, plagioclase (low)

Authigenic:

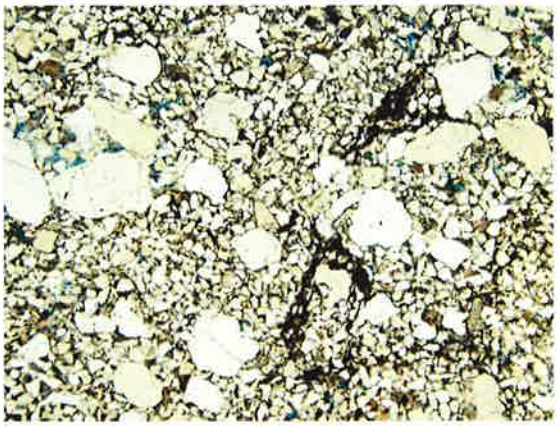
Cement Quartz overgrowths occur (compacted)

Clay Late kaolinite in pores, also undefined clay

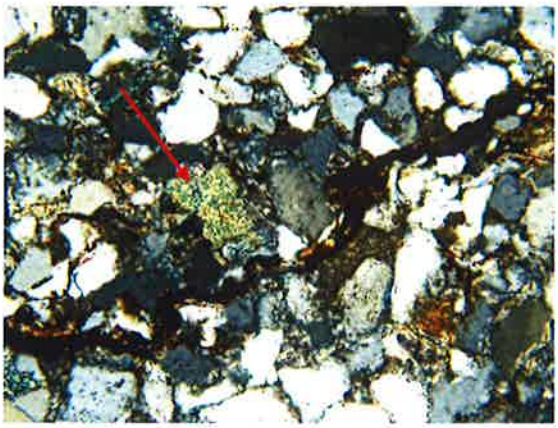
General: Compaction, blurred grain boundaries (poor polish?). Mica are seen to expand by alteration to coarse kaoline.

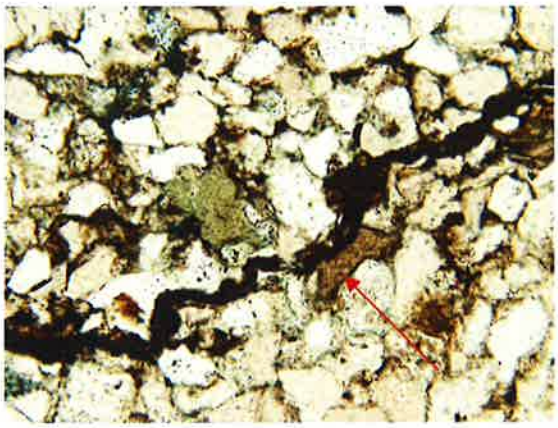


Textural overview, quartz pebbles x4 xn

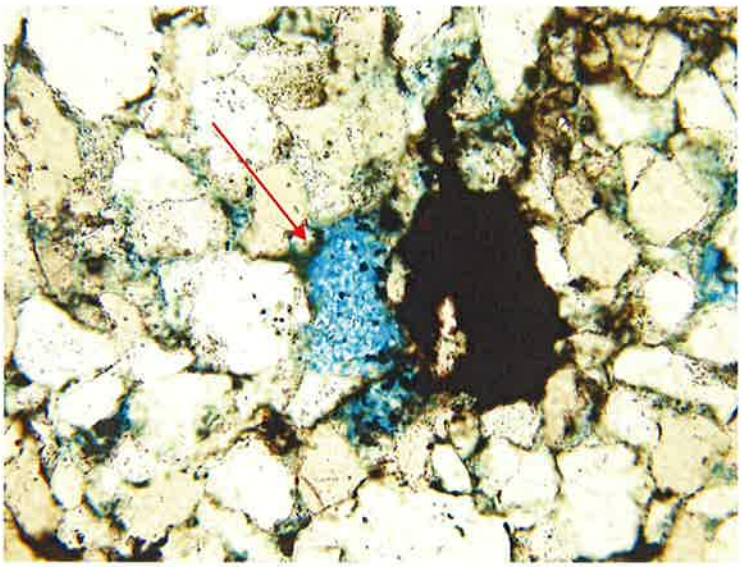


Wavy lamina of organics (dark brown) x4 lln





Close view of texture, ductile and altered glauconite (arrow), probable phosphogenic (brown) on left side of stylolitic organic layer x20 xn x20 ln



x20 lln

Kaolinite pore fill (center)

x20 UV

View of organic layer – terrestrial debris

Well : Dh4 Depth, m: 185.34 Type: Core / Rurikfjell Fm

Lithology	Sandstone
Sorting	Well within major layers (graded?)
Grain size	Medium – coarse sand, local pebbles
Grain shape	Cemented – appears subrounded
Porosity	Low, increasing in coarser layer

Detrital:

Fragments Few; chert, microcrystalline quartz, polycrystalline quartz, generally monocrystalline or two-three grain quartz. Locally some black organics

Grains Quartz, zircon, tiny Ti-oxides. Possible altered glauconite

---

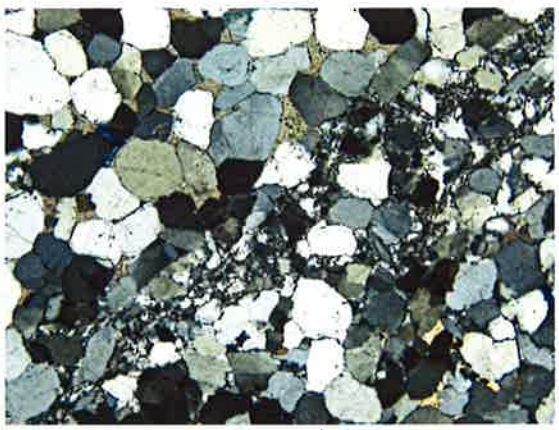
Authigenic:

Cement Quartz overgrowths, sparry carbonate - local corrosion

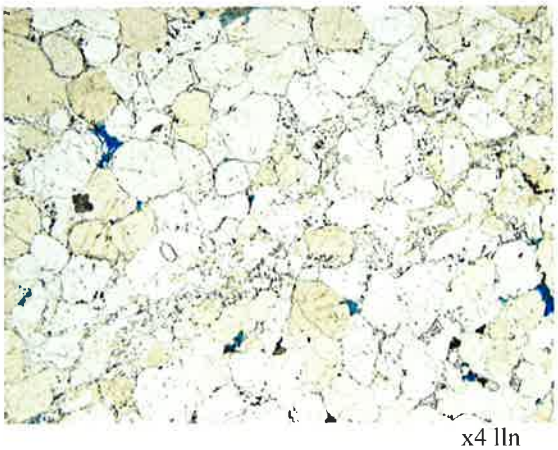
Clay Local clay in pores, also thin rims on grains, probably chloritic

---

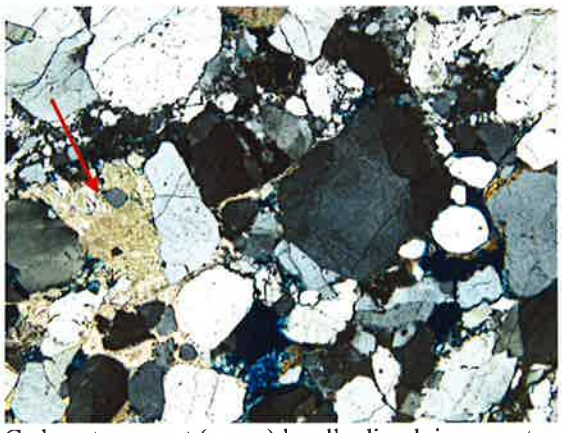
General: Thin fracture zones with crushed and strained grains. Partly well cemented sandstone, dominated by quartz. Carbonate cement postdates quartz cement. Remnant feldspar grain is seen (partly dissolved and replaced by carbonate). Some clay is due to alteration of grains. Some oversized open pores show grain dissolution, especially in coarser part. Carbonate appears to be later than the crush zones and is corroded by clay.

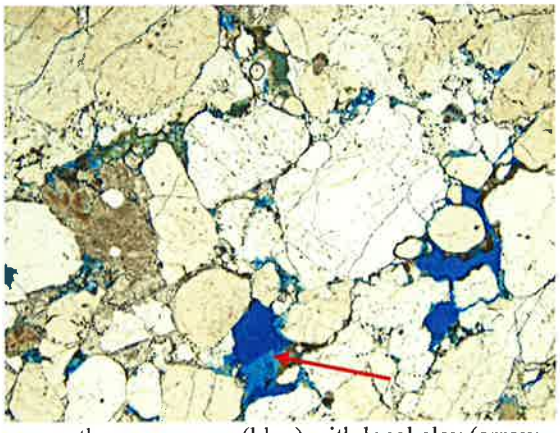


Cemented texture, crush zone in center x4 xn

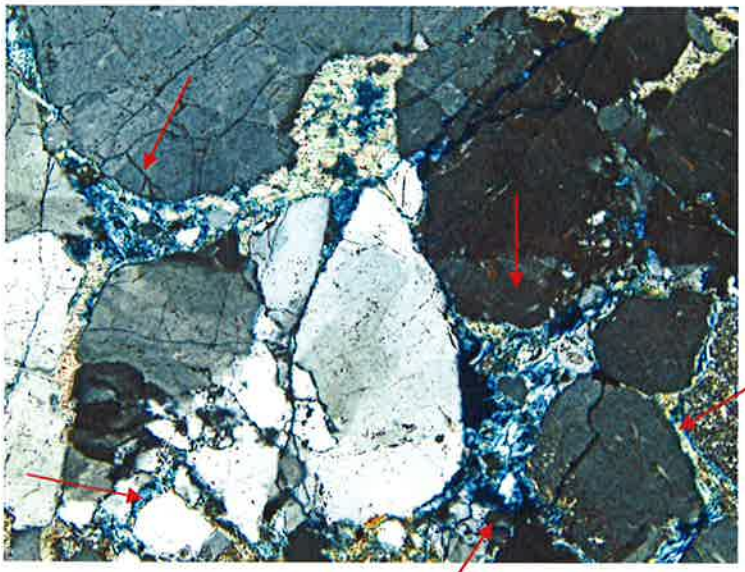


x4 lln

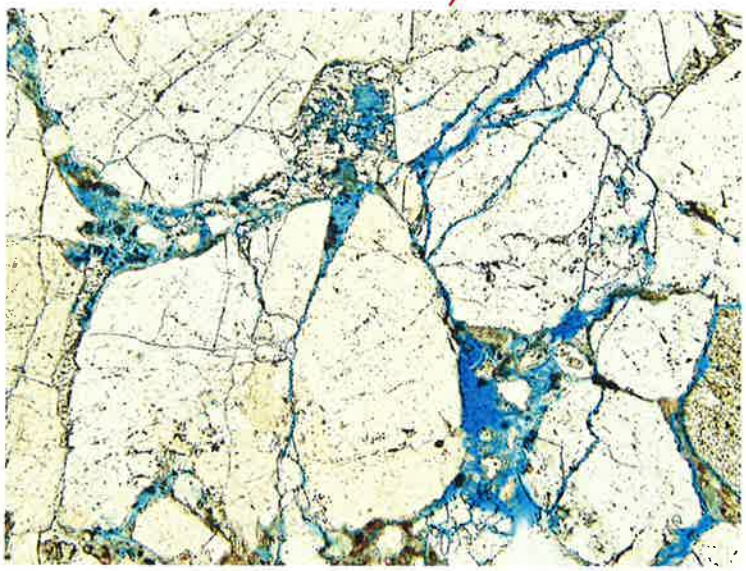




Carbonate cement (arrow) locally dissolving, quartz overgrowths, open pores (blue) with local clay (arrow right) x4 xn x4 lln



x10 xn



x10 lln

Closer view, fractured quartz grains, dissolving carbonate cement, occurrence of clay in pore and at grain boundaries (arrows)

Well : Dh4 Depth, m: 461.87 Type: Core / Agardfjellet Fm

Lithology Dark brown shale
Sorting
Grain size Clay + scattered fine sand/silt
Grain shape
Porosity Thin open fractures, parallel layering, occasionally crosscutting

---

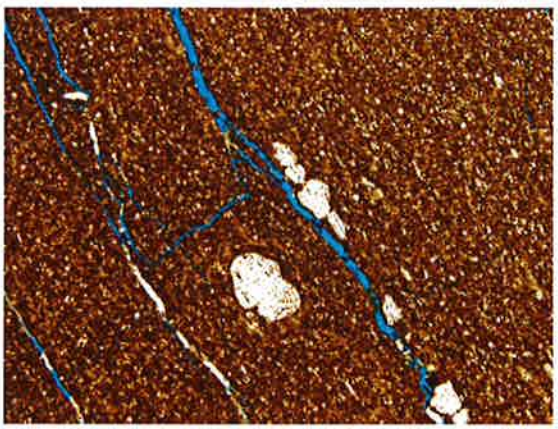
Detrital:
Fragments Black organic micro debris

Grains Appear to be quartz, thin mica (muscovite) laths also recognised
Some very fractured sand sized grains (up to 0.2mm) located along a fracture (causing breaking up?), a few carbonates observed. Numerous small framboidal pyrites are seen at high magnification

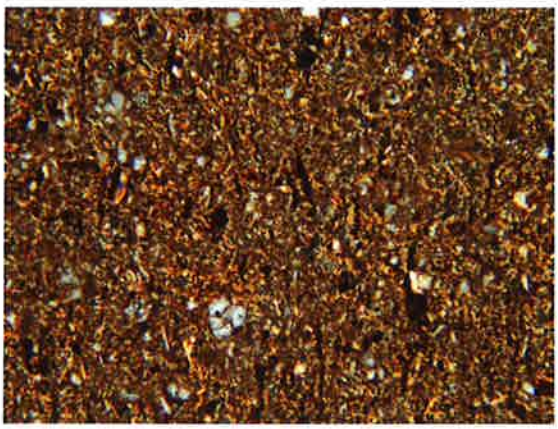
---

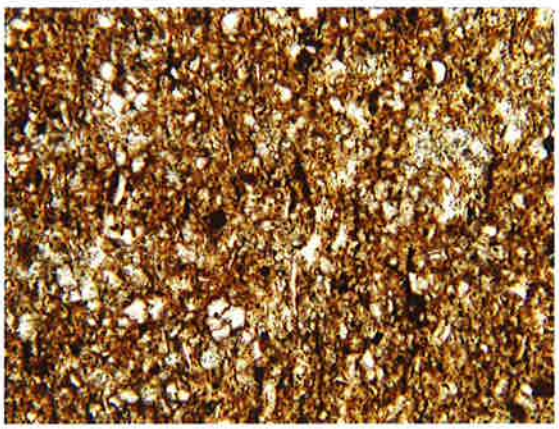
Matrix Brownish stained clay
Clay Type not identified in thin section.

General: The fractures are locally partly cemented, generally open and some can be due to preparation (fissile) and/or decompaction. The fracture cement appears perpendicular to the fracture wall: fibrous gypsum. May have been more extensive cementation, probably easily removed in preparation of thin section. Some reflectance is seen within matrix in reflected light, thus the organics appear to show a certain amount of maturation. Poor polish, difficult to focus.

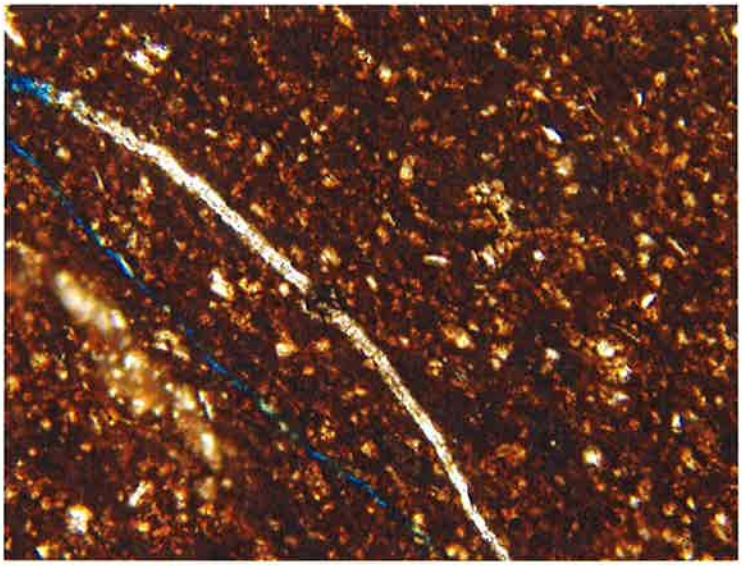


x4 lln
Overview, dark brown matrix, thin open fractures. Fractured rounded quartz grains at border



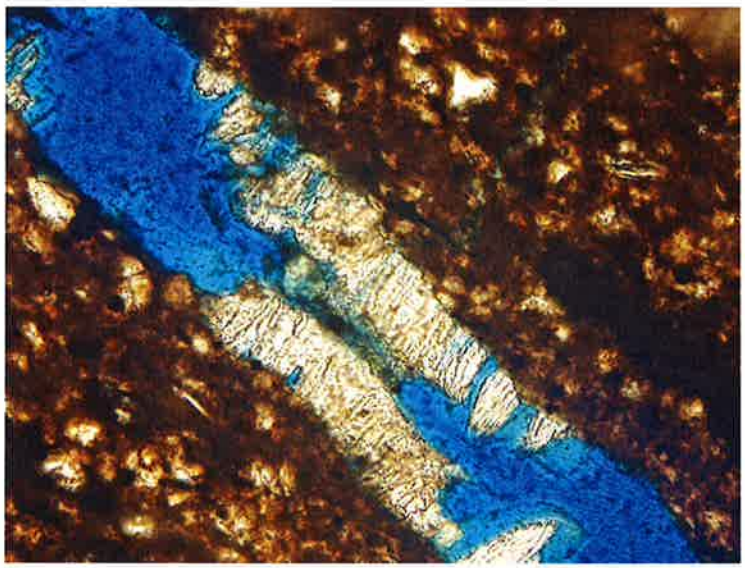


View of matrix; thin mica laths, quartz grains, carbonate (arrow), black organics and pyrite x20 lln
x20 xn



x20 lln

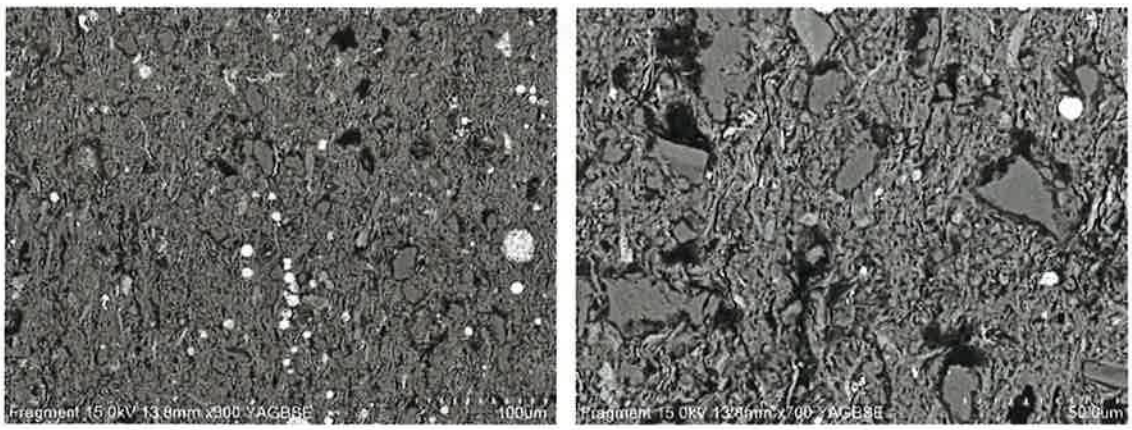
Thin cemented fracture, micro grains can be discerned in matrix



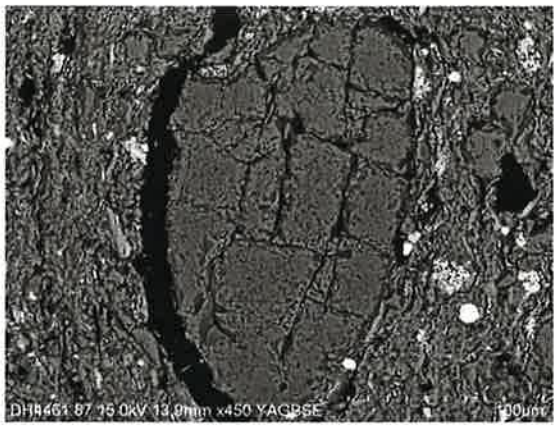
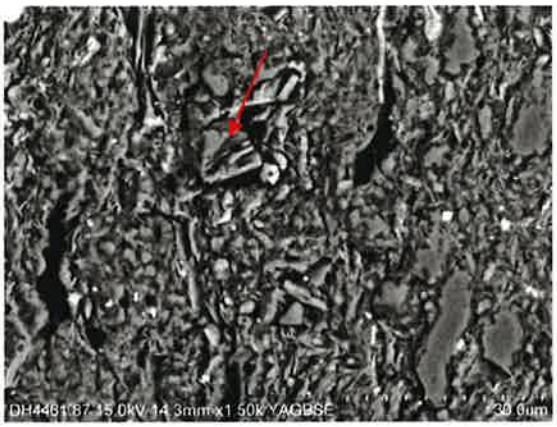
x40 lln

Closer view of partly cemented fracture, fibrous gypsum cement.

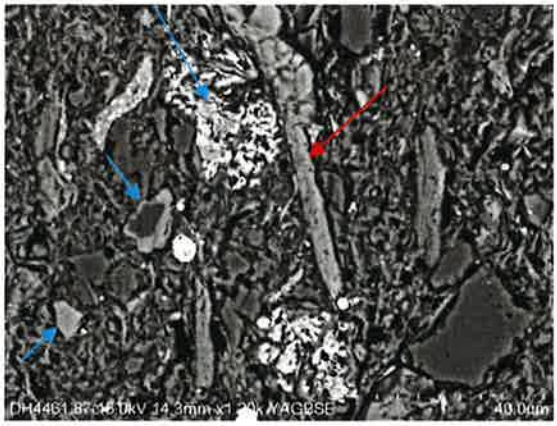
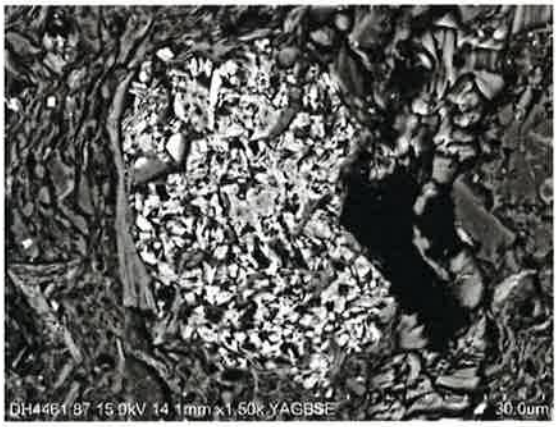
SEM analysis:



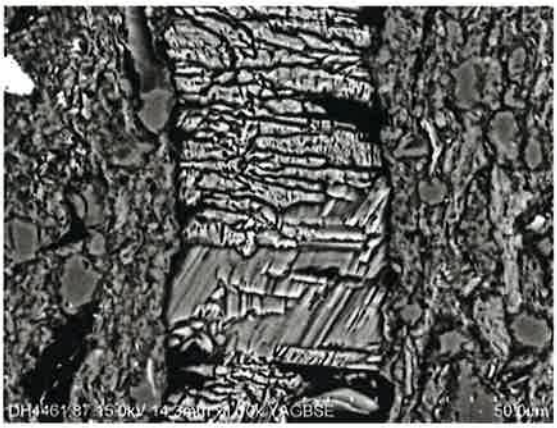
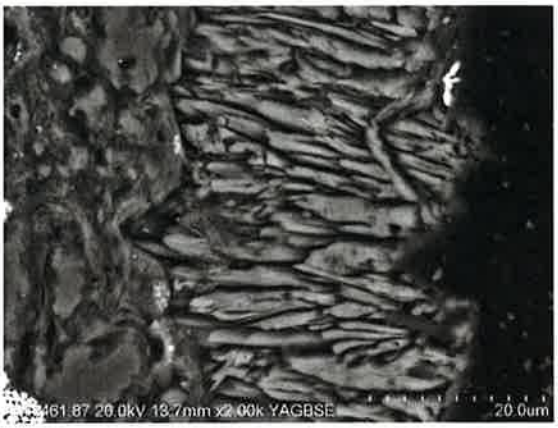
Textural overview, x300 (left), x700 (right). Quartz and albite in illitic clay matrix. Framboidal pyrites.

Fractured detrital quartz (left). Right: detail showing tiny quartz and albite grains (arrow) in clay matrix

Chlorite(arrow), complex carbonates compositions with dolomite and ankerite with variable contents of Ca, Mg and Fe (seen as variations in greyscales, blue arrows). Detail of similar dol/ank cluster to the right.

Thin cemented fracture with CaSO4 (gypsum or anhydrite). Left: detail, crystal orientation perpendicular to fracture wall.

XRD analysis:

Illite	Chlorite	Quartz	Albite	Dolomite	Siderite	Pyrite
33.4	0.4	33.6	26.2	1.9	0.8	3.7

TOC: 4.0 TC: 4.29

Well : Dh4 **Depth, m: 499.46** **Type: Core /Agardfjellet Fm**

Lithology Weakly layered silty shale

Grain size Silt/clay
Grain shape Subangular (silt)
Porosity None visible

Detrital:
Fragments A few microcrystalline quartz, organic debris

Grains Quartz, tiny mica laths, silty carbonate grains, plagioclase, tiny framboidal pyrites are common

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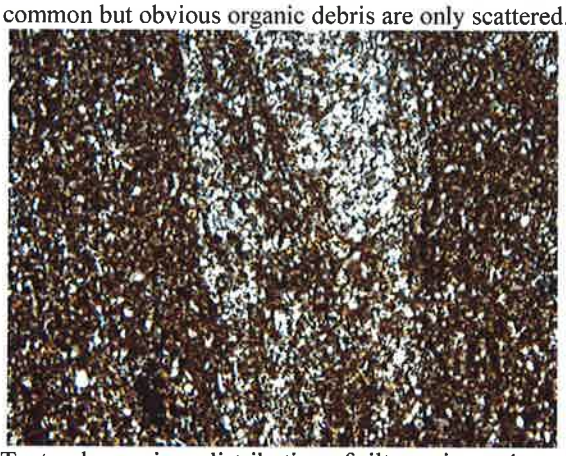
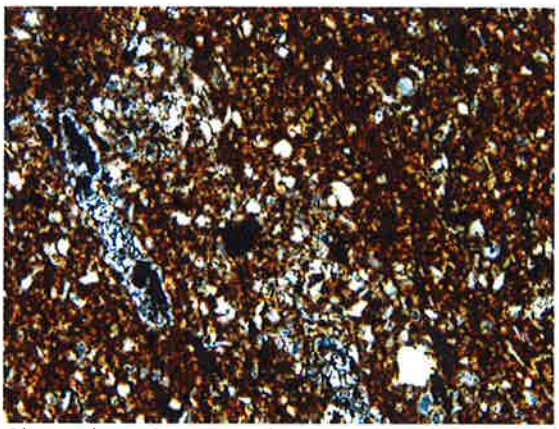
Matrix Matrix is dark brown, udefined clay, bitumen?

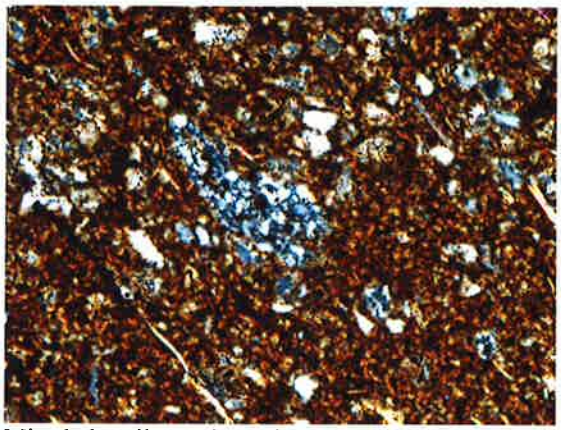
General: Dark shale, however silty grains are quite common, only weakly layered , pyrites are common but obvious organic debris are only scattered.



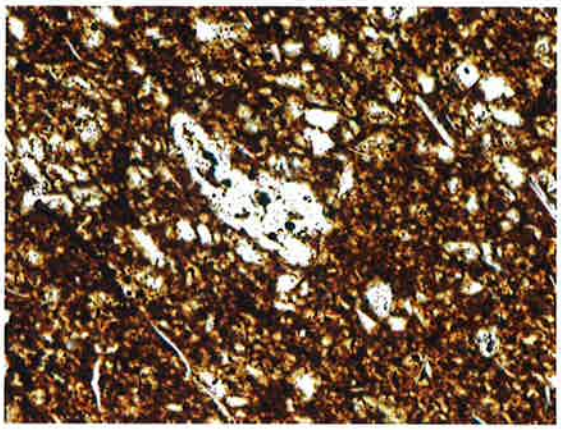
Textural overview, distribution of silty grains x4 xn



Closer view of texture, microcrystalline quartz and pyrite x10 xn

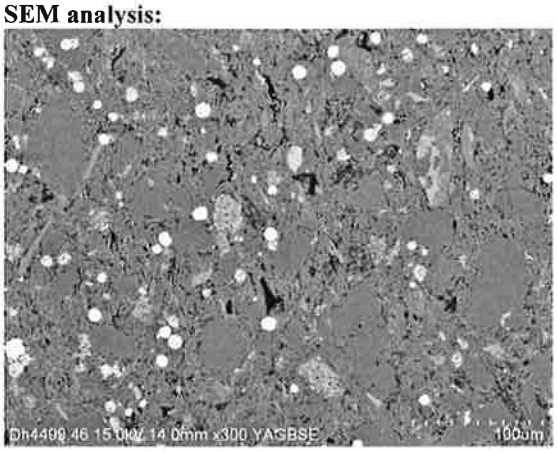


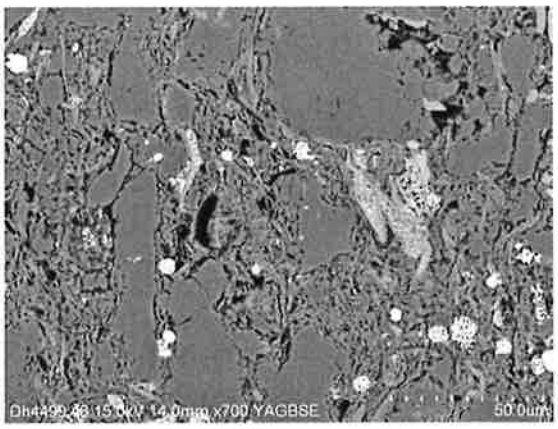
Mica laths, silty grains, microcrystalline quartz x20xn



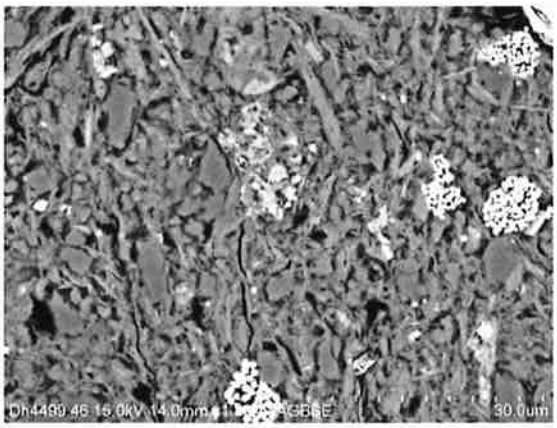
x20 lln

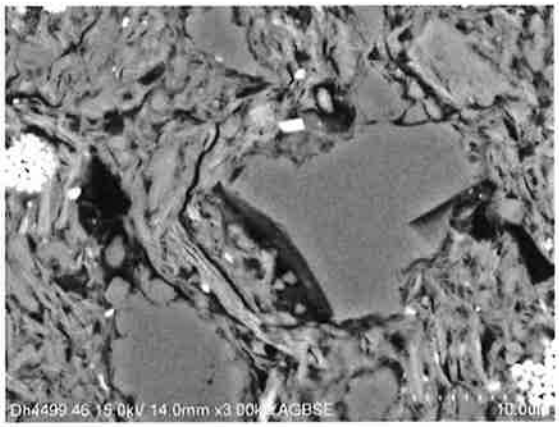
SEM analysis:





Textural overview x300 (left), x700 (right).Detrital quartz embayed in clay matrix, scattered framboidal pyrites, local carbonates and trace mica.





Closer views. clay matric mainly illitic,framboidal pyrites, tiny dol/ank grains. Right: Detail mica/illite around detrital quartz, a certain microporosity appears to be present.

XRD:

Depth	Illite	Chlorite	Quartz	Albite	Calcite	Dolomite	Siderite	Pyrite
499.5	38.6	0.3	33.1	16.5		5.5	1.2	4.9

Clay mineral analysis (<2µm): Illite (10Å) with small amounts of chlorite (7Å), trace quartz.

TOC: 1,45% TC: 2.28%

Well : Dh4 **Depth, m: 509.21** **Type: Core/Agardfjellet Fm**

Lithology Dark brown/black shale

Grain size Clay, silt, a few sand sized
Grain shape Silt: irregular
Porosity Low, a few thin open fractures

Detrital:
Fragments Very small mall black organic debris. Macro-polycrystalline quartz (a few grains)

Grains Scattered very small pyrites, often framboidal, oxides, carbonate, mica

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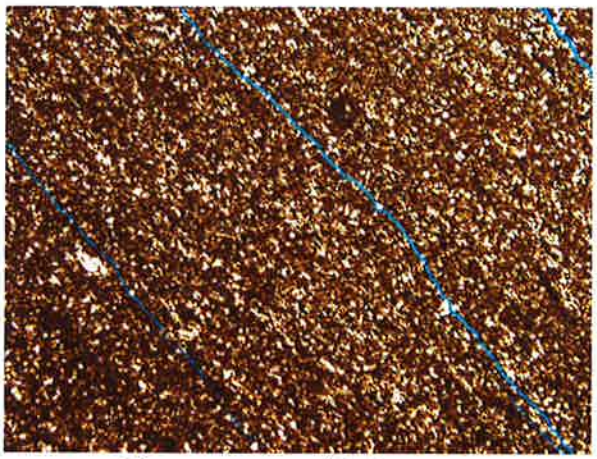
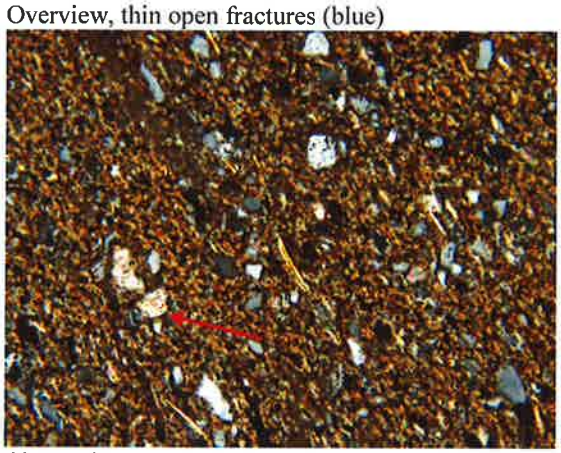
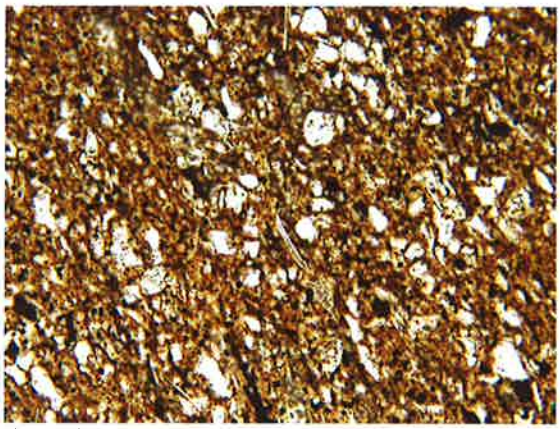
Clay Within matrix, undefined, detrital or authigenic?

General: Thin fractures are generally parallel layering, a few crosscutting. Some can be due to preparation (laminated, fissile). No cement is observed. A few of the organics appear to have some reflectance



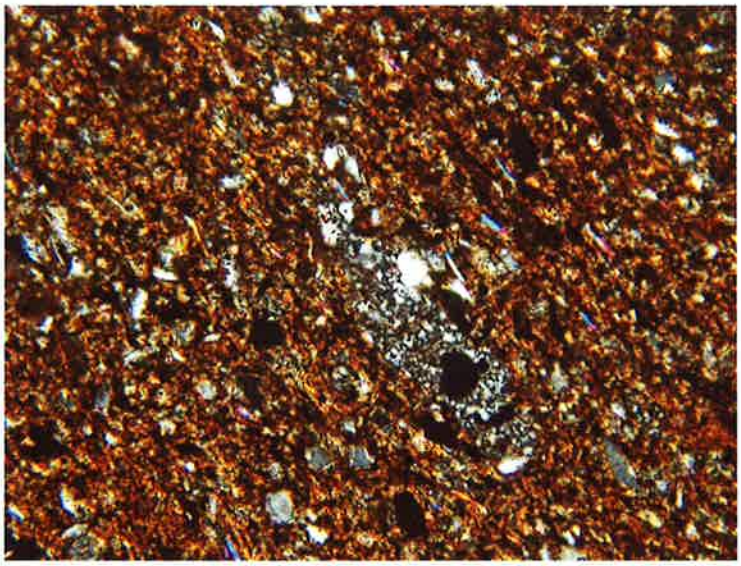
x4 lln
Overview, thin open fractures (blue)





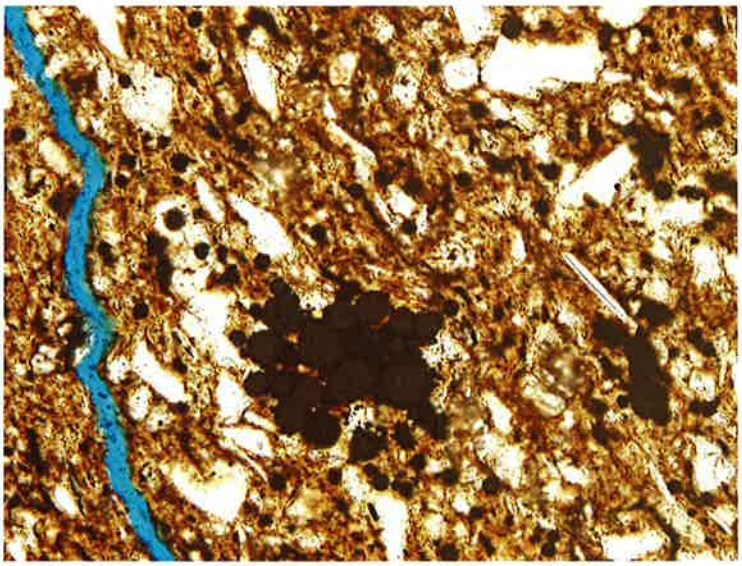
Closer view, quartz grains, mica laths, carbonate grains (arrow)
x20 xn

x20 lln



x20 xn

Microcrystalline quartz (center), including pyrite (black)



x40 lln

Cluster of framboidal pyrites

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
509.2	42.9	0.2	28.6		16.6		4.8	1.1		5.9

Clay mineral analysis (<2µm): Illite (10Å), chlorite (7Å), small amounts quartz

TOC: 3.36% TC: 3.84%

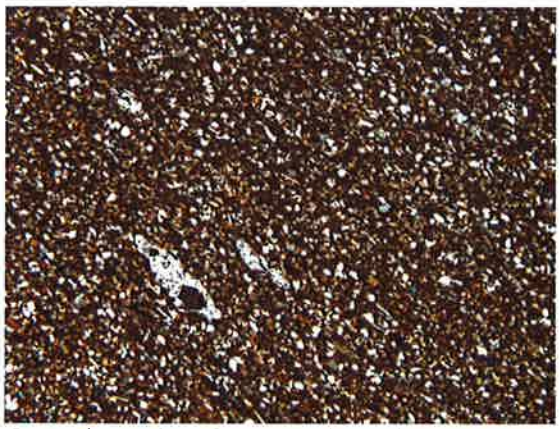
Well : Dh4 **Depth, m: 553.87** **Type: Core/ Agardfjellet Fm**

Lithology	Laminated silty shale, appear high in organics
Grain size	Clay, silt, fine sand
Grain shape	Angular/ subangular
Porosity	Low, except one thin, discontinuous open fracture

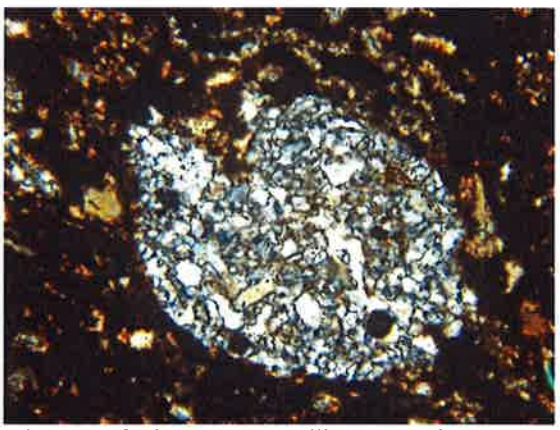
Detrital:	
Fragments	Altered felsic fragments? or sediment, chert? Organic debris (plant fragments?)
Grains	Quartz, plagioclase, muscovite, altered glauconites, carbonate (scattered grains), scattered tiny pyrites often framboidal, zircon

Matrix	Dark brown clay matrix (stained by organics – bitumen??) Local carbonate?
Clay	Undefined within matrix

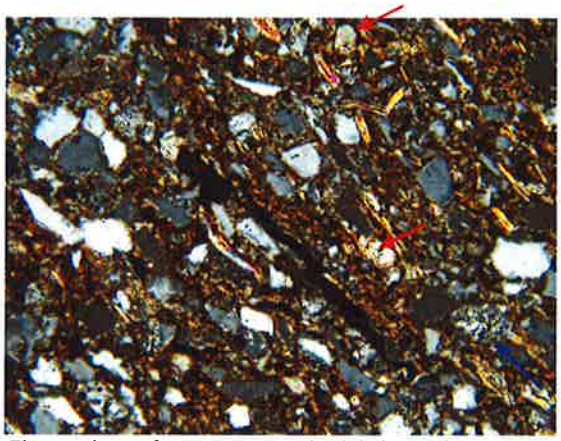
General: Poorly polished. The thin fracture is more or less parallel lamination, local crosscut. Discontinuous silty layers. Lamination is less obvious in microscale. The carbonate appear as tiny grains



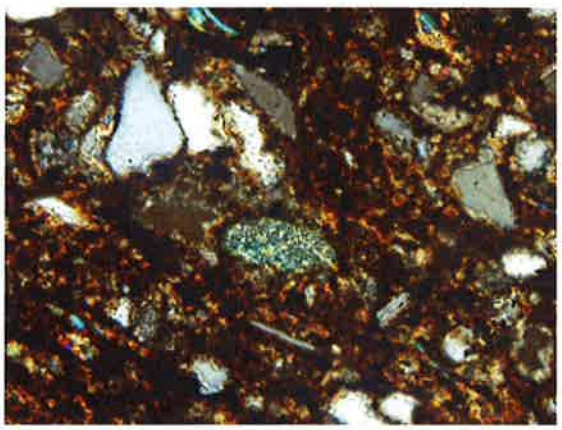
Textural overview, fragment with pyrite x4 xn



Close up of micro polycrystalline quartz fragment x20 xn

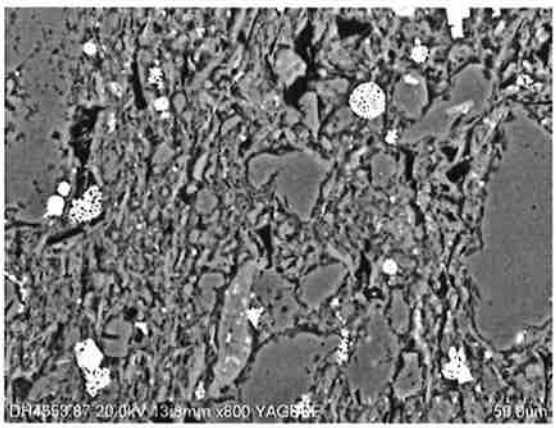
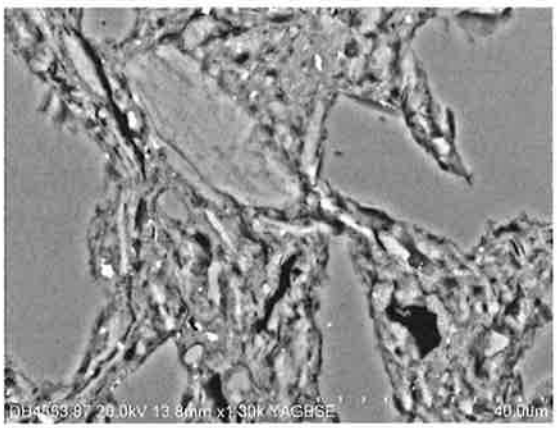


Closer view of texture, organic debris, grains Carbonates (red arrows), altered glauconite (blue Arrow) x20 xn

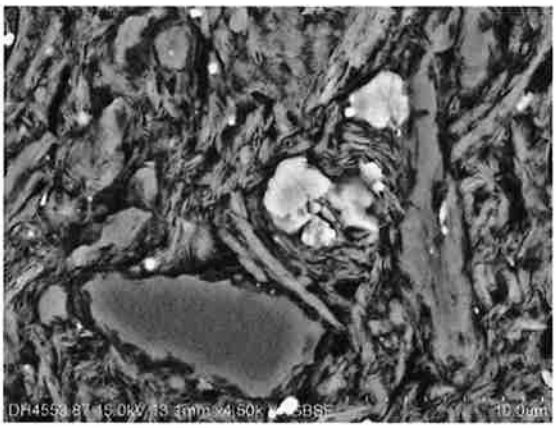
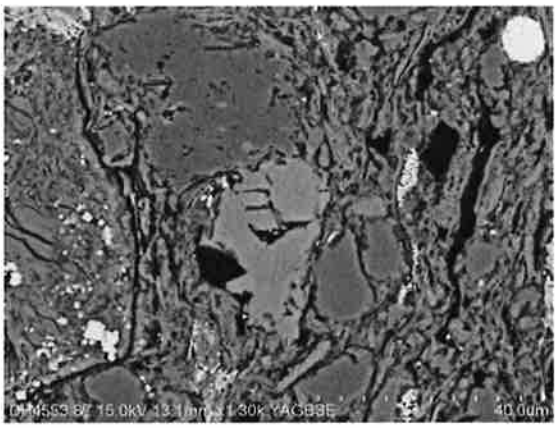


Altered glauconite (center) x40 xn

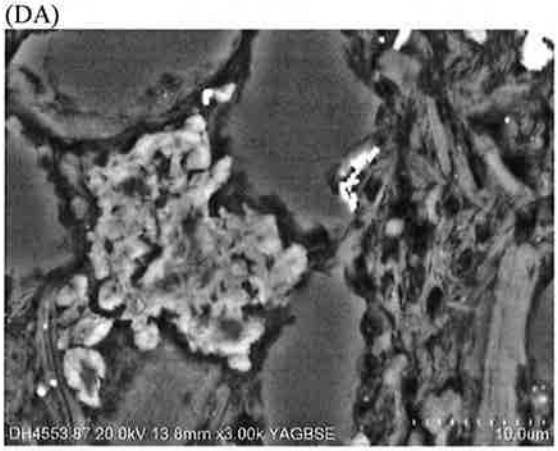
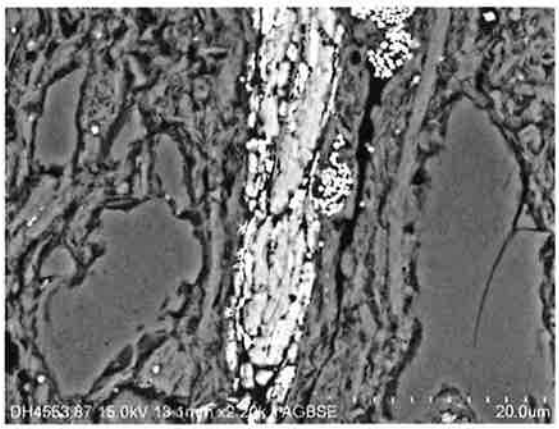
SEM analysis:

Left: texture, detrital quartz grains embayed in clay matrix, also very small quartz grains are discerned. Framboidal pyrites. Right: closer view, mica grain in center. Clay is dominantly illitic.

Left: Detail of clay matrix, quartz and ankeritic carbonate. Right: Carbonate grains: dolomite (D) and dol/ank (DA)

Dol/ank with variable contents of Fe

Ca-phosphate in center

XRD:

Depth	Illite	Chlorite	Quartz	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
553.9	35.4		38.2	16.2		4.1	1.5		4.7

Clay mineral analysis (<2µm): Illite (10Å), some quartz and Mg-calcite.

TOC: 4.45% TC: 4.91%

Well : Dh4 **Depth, m: 611.86** **Type: Core/ Agardfjellet Fm**

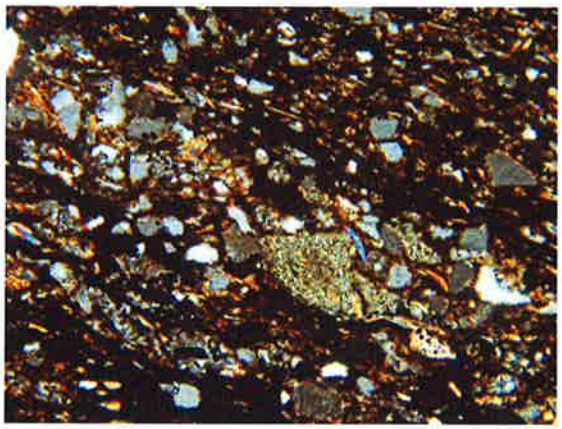
Lithology	Laminated shale, organic rich
Grain size	Silt, clay, a few sand size
Grain shape	Angular/ subangular
Porosity	None, except probably thin parallel, discontinuous open fractures

Detrital:

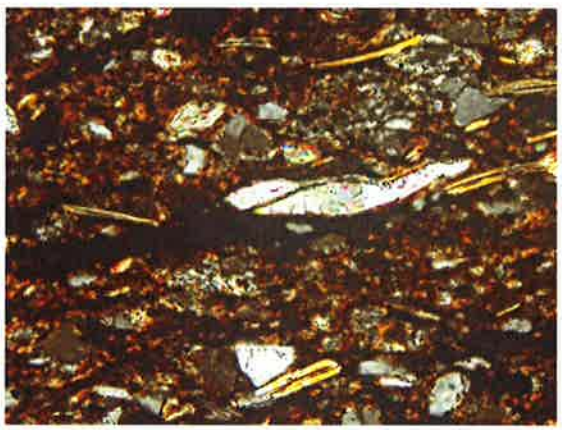
Fragments	A few elongated fine crystalline quartz clusters, organics (some reflectance), some cellular plant debris, probable altered carbonaceous
Grains	Quartz, muscovite, plagioclase identified, carbonate, scattered pyrites are commonly framboidal, oxides, altered glauconites
Clay	Unidentified, dark brown stained clay in matrix
General:	Finely laminated dark shale, well orientated and elongated thin mica laths,

Texture, pyrite grain (black) x4 xn

x4 lln

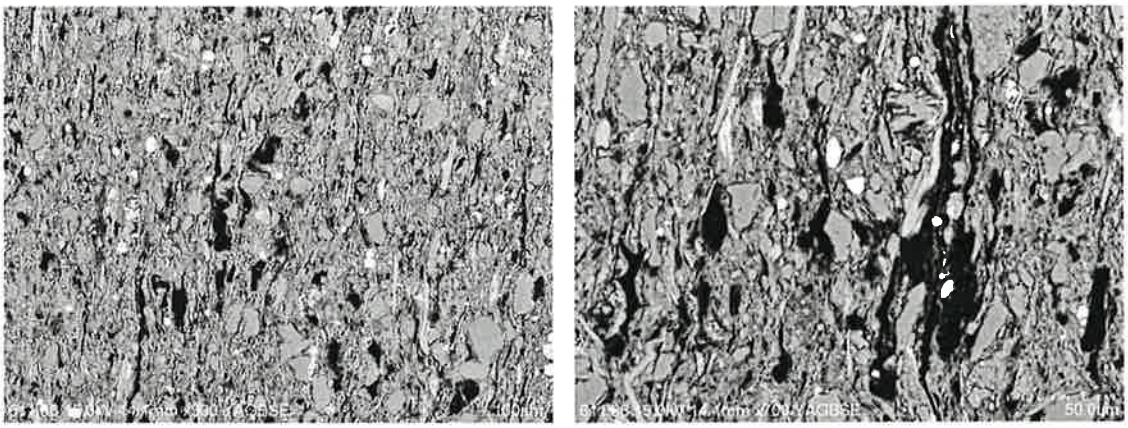


Altered glauconite (center). Mica laths. x20 xn

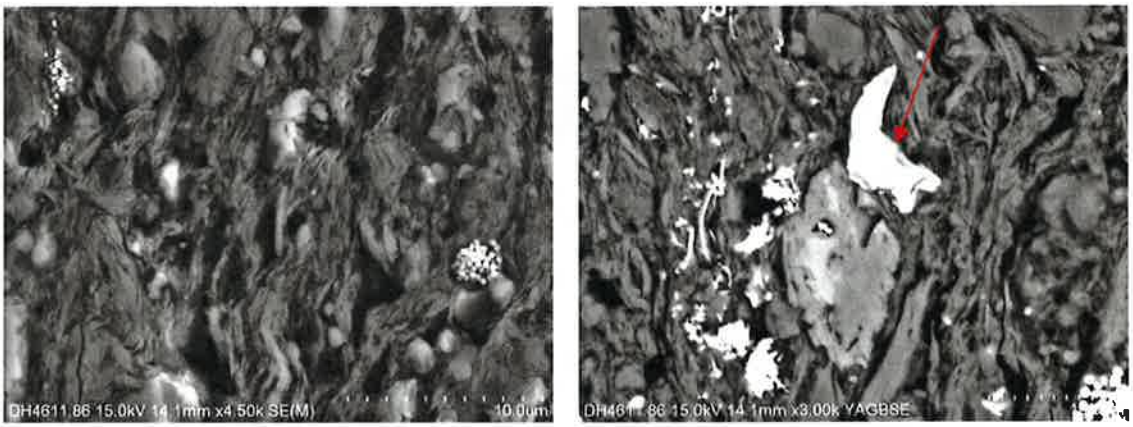


Carbonaceous fragment? (center), mica laths. x40 xn

SEM analysis:



Textural overview x300 (left), x700 (right).Small quartz grains in clay matrix. Black: organics and/or microporosity.



Left: close view of illitic clay matrix, tiny quartz grains, framboidal pyrite. Right: local dolomite/ankerite ± Ca-phosphate (center), Ti-oxide (arrow), pyrites (pale) and illitic clay.

XRD:

Depth	Illite	Chlorite	Quartz	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
611.9	47.5	0.1	27.3	16.7		1.8	1.2		5.3

Clay mineral analysis (<2µm): Illite (10Å), quartz and trace chlorite (7Å)

TOC:11.70% TC: 11.50

Well : Dh4 **Depth, m: 656.75** **Type: Core/ Agardfjellet Fm**

Lithology Silty shale

Grain size Silt/clay
Grain shape Subangular
Porosity Hardly visible

Detrital:
Fragments Only scattered organics, small

Grains Quartz, tiny mica laths, plagioclase, pyrite (low),

Clay Matrix is dark brown with undefined clay, appears to be low in carbonates

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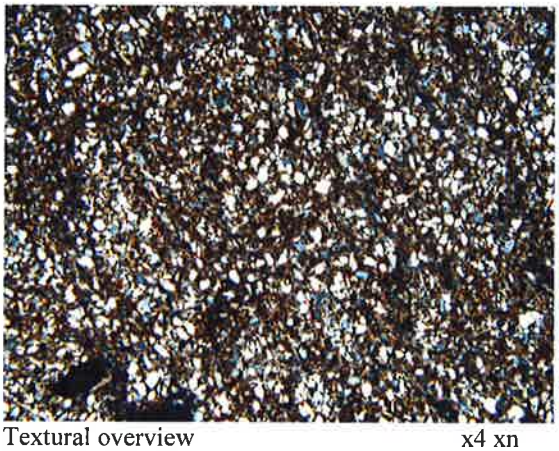
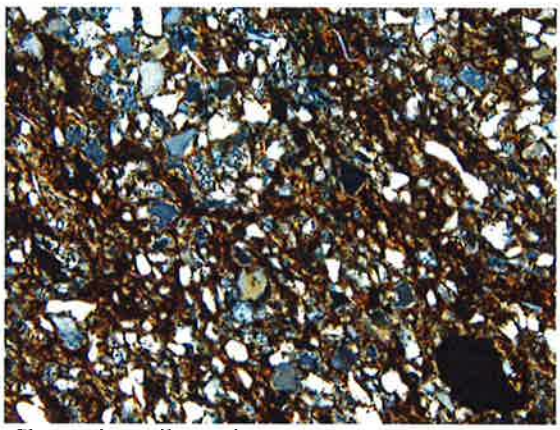
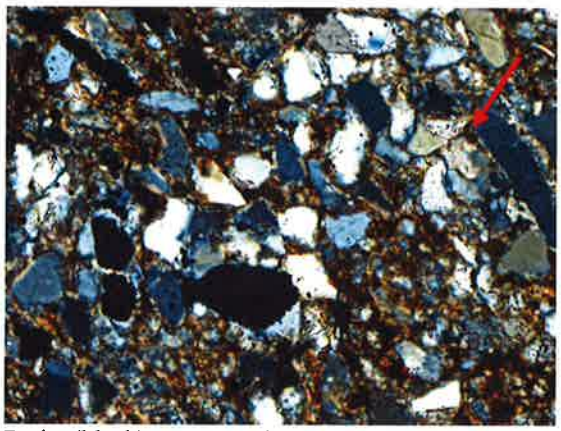
General: Dark silty shale, higher in silt than 499.46 (NGI sample)
Very thin discontinuous open fracture, probably artificial (due to coring, release)



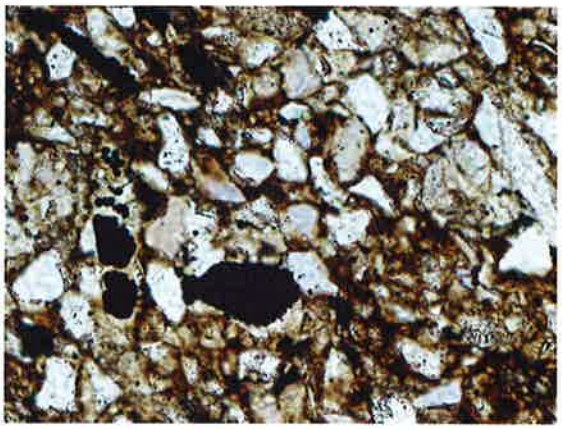
Textural overview x4 xn



Closer view, silty grains x10 xn

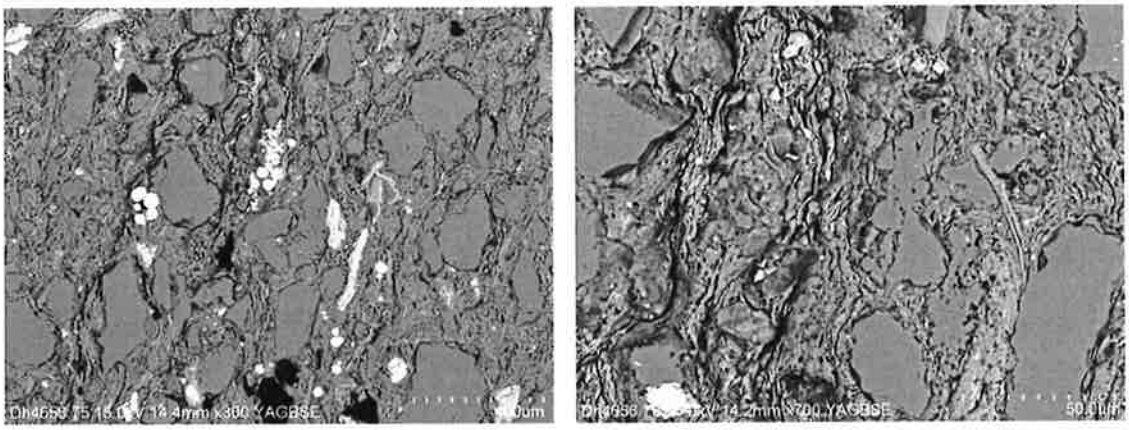


Pyrite (black), quartz grains, carbonate (arrow)
x20 xn

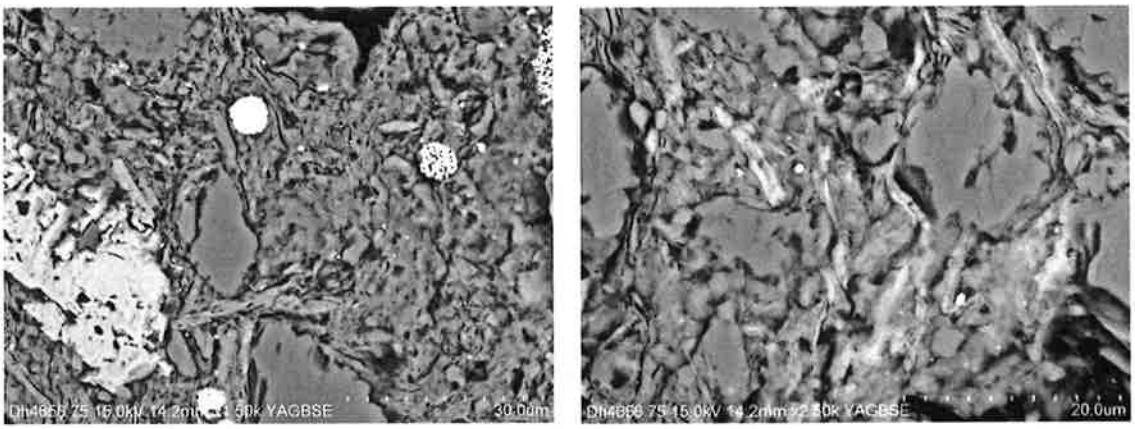


x20 lln

SEM analysis:



Texture; x300 (left), x700 (right). Silty quartz in mica/illitic clay matrix, framboidal pyrites are common,



Closer views: left side local Fe-Mg-oxide cement, pyrites and detrital grains in illitic clay. Right: higher magnification, mix of clay and mica remnants seen as tiny laths. Very local dolomite/ankerite is observed.

XRD:

Depth	Illite	Chlorite	Quartz	Albite	Calcite	Dolomite	Siderite	Pyrite
656.75	34.8	0.1	46.7	11.7		2.7	1.2	2.7

Clay mineral analysis (<2µm): Illite (10Å), chlorite and quartz close to detection limit.

TOC: 1.45% TC: 1.68%

Well : Dh4 **Depth, m: 665.32** **Type: Core**

Lithology	Flaser bedded siltstone
Sorting	Fairly well
Grain size	Silt/ fine sand
Grain shape	Angular/ subangular
Porosity	Low

Detrital:

Fragments Polycrystalline quartz (very few). Organic debris

Grains Quartz, plagioclase (few identified), muscovite, scattered oxides, tiny pyrites, often framboidal, associated with organics. Glauconite (one). Zircon.

Authigenic:

Cement Very local carbonate

Clay Unidentified clay matrix, probably detrital chloritic and illitic

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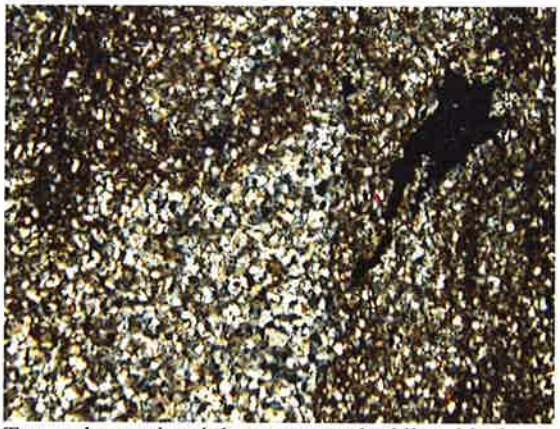
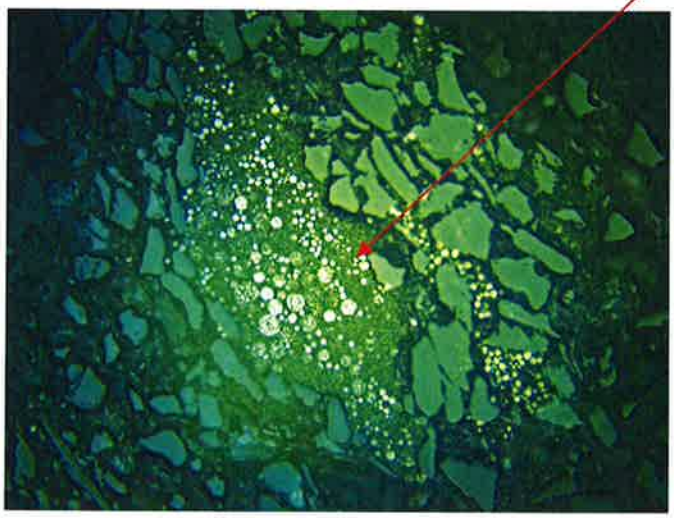
General: Poorly polished. Similar to 669.1 and 669.30, grains more or less floating in brown stained clay matrix.



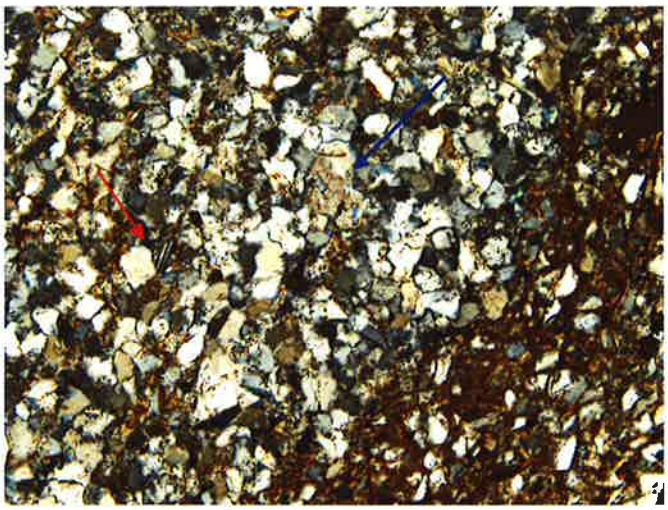
Textural overview,inhomogenous bedding, black organics with pyrite x4 lln

x4 xn

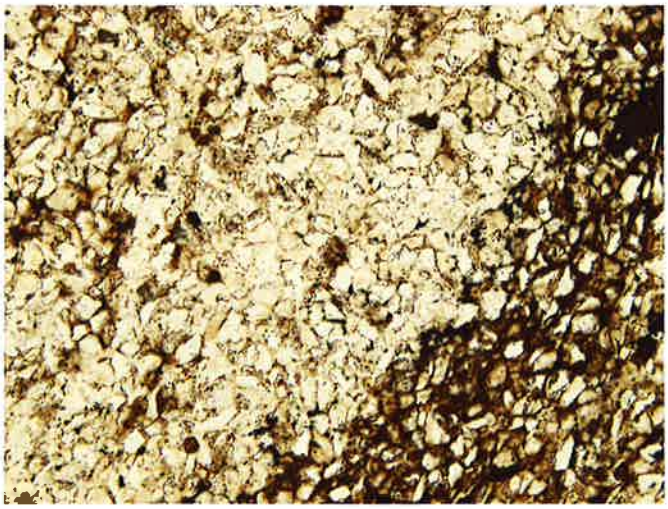


x20 reflected light

Close up pf organics with pyrite framboids



x10 xn



x10 lln

Detail of bedding, plagioclase is identified in silty part (red arrow), also carbonate cement (blue arrow)

XRD:

Depth	Illite	Chlorite	Quartz	Albite	Calcite	Dolomite	Siderite	Pyrite
665.3	27.1	0.1	55.8	13.4		1.4	0.5	1.7

Clay mineral analysis (<2µm): Illite (10Å), chlorite (7Å), quartz.

TOC: 0.59% TC: 0.61%

Well : Dh4 **Depth, m: 669.1** **Type: Core/Agardfjellet Fm**

Lithology	Flaser bedded siltstone
Sorting	Fairly well
Grain size	Silt/fine sand
Grain shape	Angular/ subangular
Porosity	Low

Detrital:

Fragments Organic debris

Grains Quartz, muscovite, scarce pyrite framboids with black organics, some oxides. Very altered glauconite? A few plagioclase grains are identified. A chert grain. Chlorite (alteration). Zircon

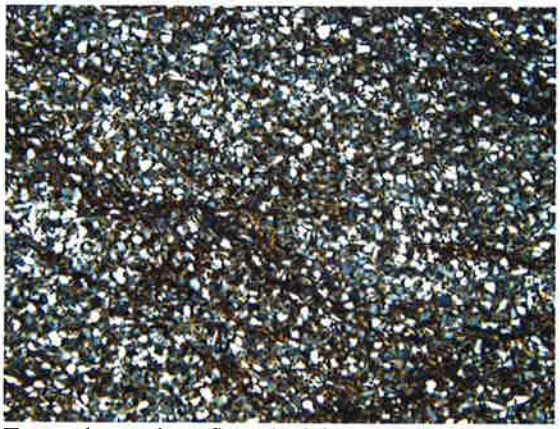
---

Authigenic:

Cement Very local carbonate

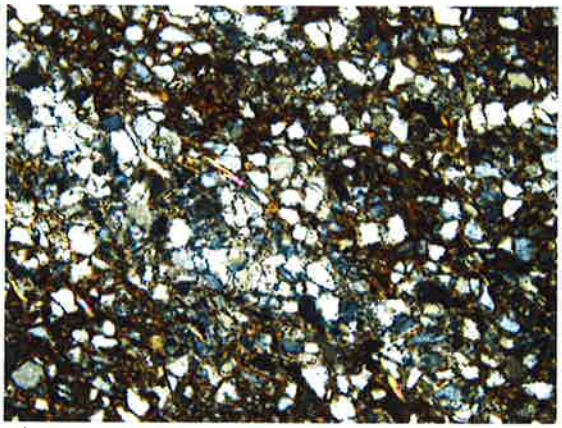
Clay Not obvious if clay matrix is detrital or authigenic. Unidentified, probably chloritic and illitic (kaoline not identified)

General: Poorly polished. Similar to 669.3. Blurred grain boundaries (corroded?). Some carbonates appear as grains. Grains are more or less floating in clay matrix

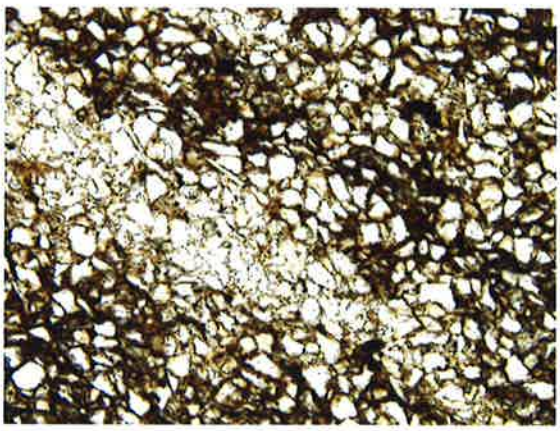


Textural overview, flaser bedding x4 xn

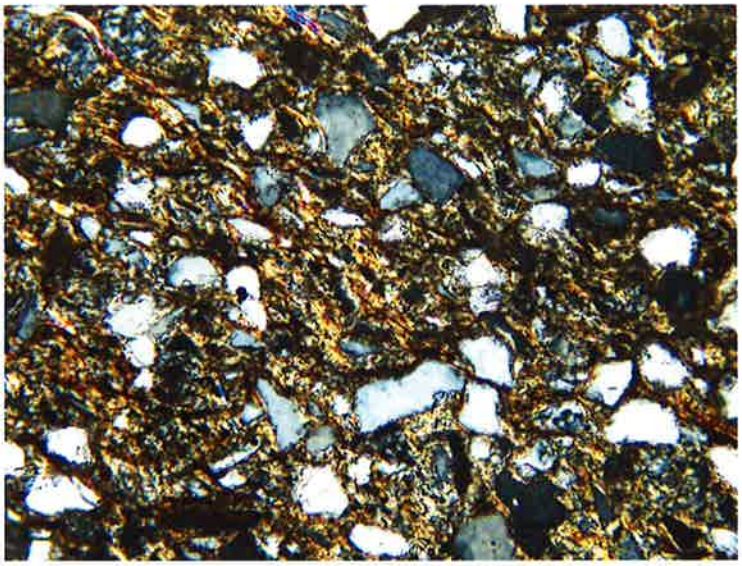
x4 lln



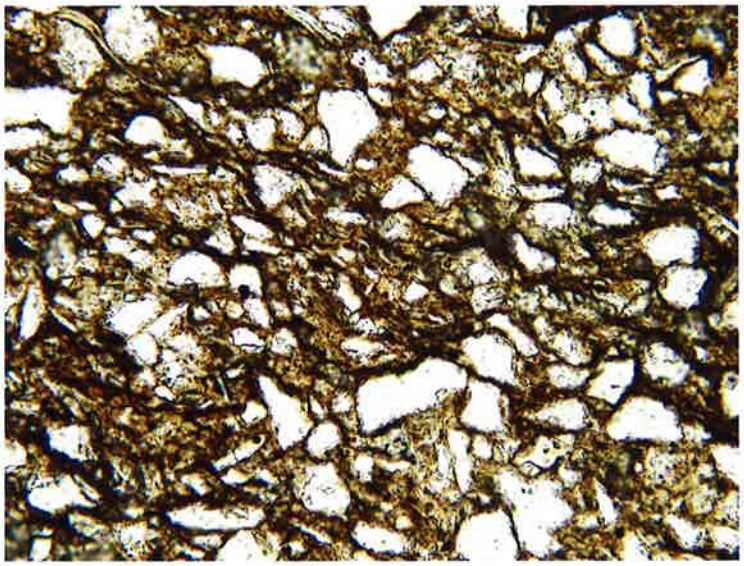
Closer view, grains surrounded by clay matrix x10 xn



x10 lln



x20 xn



x20 lln

Close up, brown stained clay matrix, thin muscovite laths

XRD:

Depth	Illite	Chlorite	Quartz	Albite	Calcite	Dolomite	Siderite	Pyrite
669.1	26.7	0.2	52.6	16.5		0.7	0.5	2.8

Clay mineral analysis (<2µm): Illite (10Å), chlorite (7Å), trace quartz.

TOC: 0.54 TC: 0.47

Well : Dh4 **Depth, m: 669.30** **Type: Core/Agardfjellet Fm**

Lithology	Unclean fine sandstone/siltstone
Sorting	Fairly well
Grain size	Fine sand/silt
Grain shape	Subangular
Porosity	Low

Detrital:

Fragments Probably organic mudclasts (or matrix), polycrystalline quartz (few). Organic debris.

Grains Quartz, muscovite, a few carbonates, few plagioclases identified. Scattered framboidal pyrites, some oxides, zircon, a few altered glauconites

---

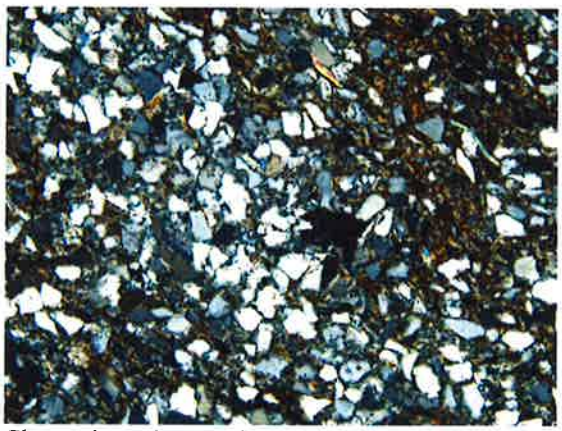
Authigenic:
Cement

Clay Unidentified clay matrix – probably illitic (chloritic?) Typical kaoline not identified.

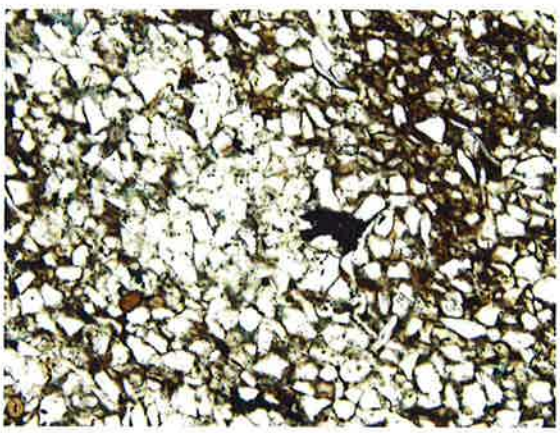
General: Difficult to polish properly. Generally grains floating in stained clay matrix, some flaser bedding , muscovite often strongly elongated, also crossing lamination. Irregular grain boundaries (appear corroded). The few carbonates appear as grains, not as cement.

Textural overview, flaser bedding x4 xn

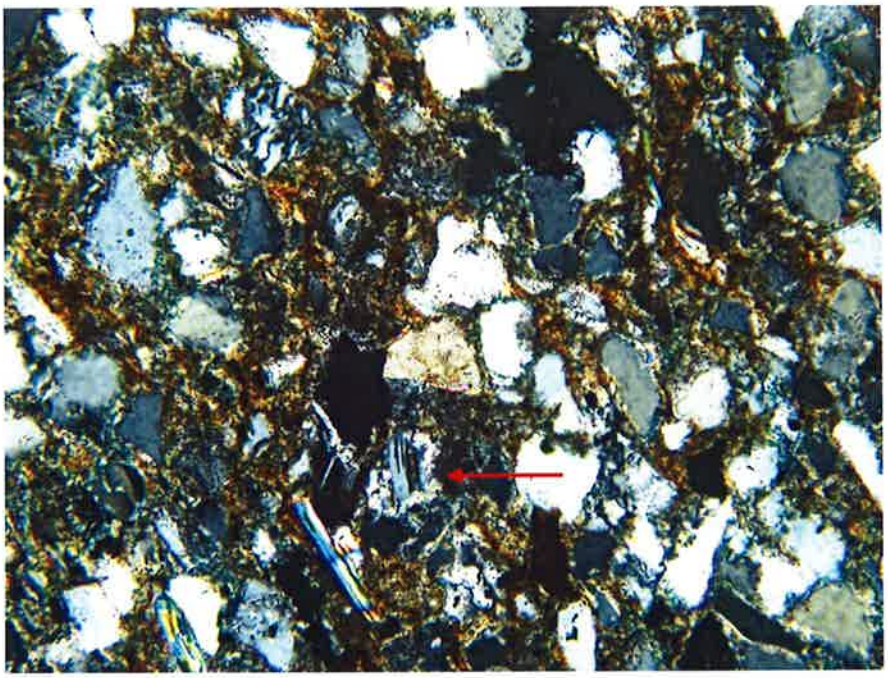
x4 lln



Closer view, clay matrix, muscovite laths x10 xn

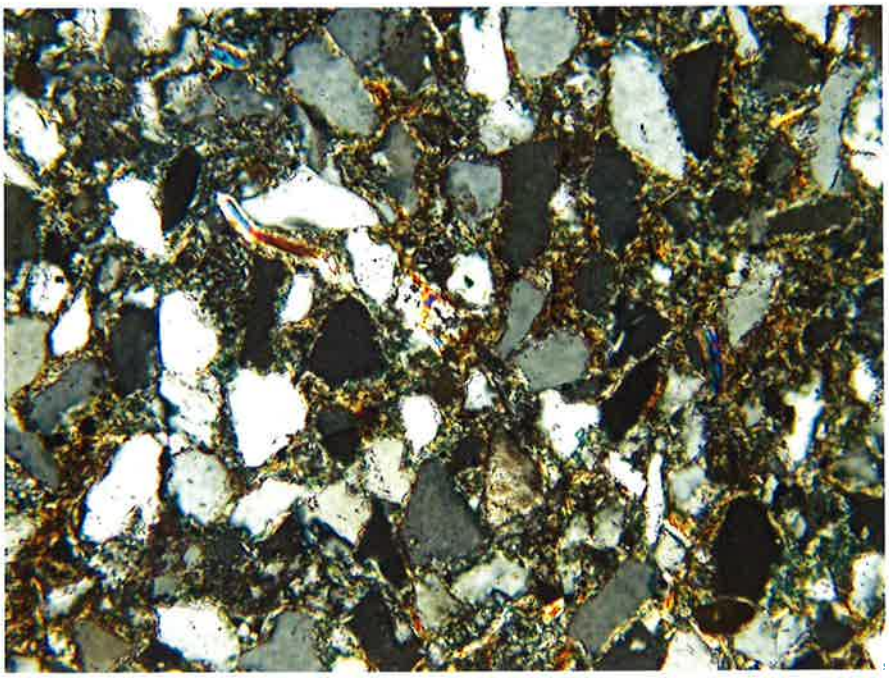


x10 lln



x20 xn

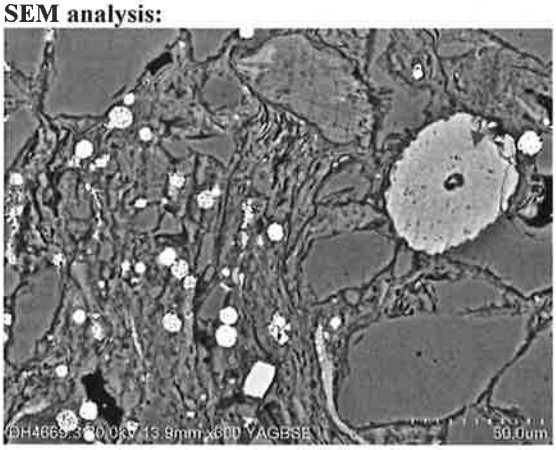
Detail grains and clay matrix.Carbonate grain (center), altered plagioclase grain (arrow)

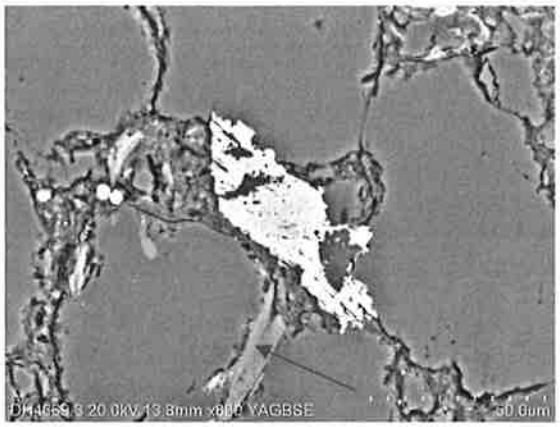


x20 xn

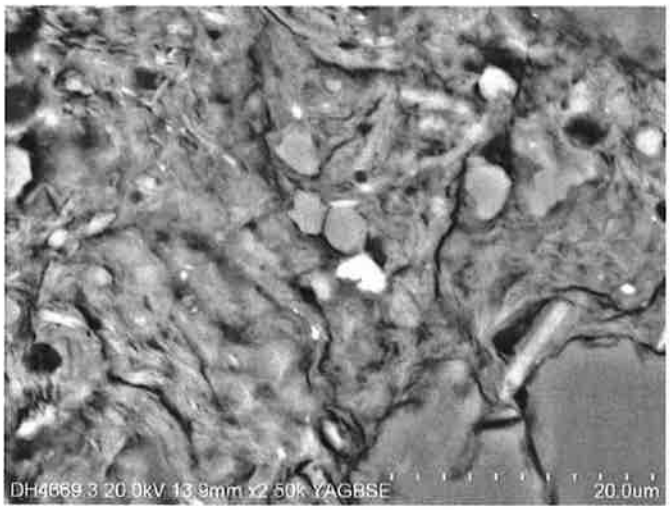
Clay matrix

SEM analysis:





Left: detrital grains, illite/mica clays, Ca-phosphate (arrow), tiny pyrite framboids and Ti-oxide (rectangular)
Right: closer view, local ankerite in center, mica lath (arrow)



Detail of clay matrix, including tiny quartz grains are seen. Clays are here illitic, but local chloritic is observed.

XRD:

Depth	Illite	Chlorite	Quartz	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
669.3	22.1	0.2	55.3	19.5		0.6	0.4		1.8

Well : Dh4 **Depth, m: 671.6** **Type: Core/bottom Agardfjellet Fm**

Lithology	Inhomogenous layered siltstone
Sorting	Well within layers, varies with scattered larger grains/fragments
Grain size	Grains: silty, larger grains up to coarse sand
Grain shape	Generally subangular, larger often subrounded
Porosity	Low; a thin fracture (artificial?)

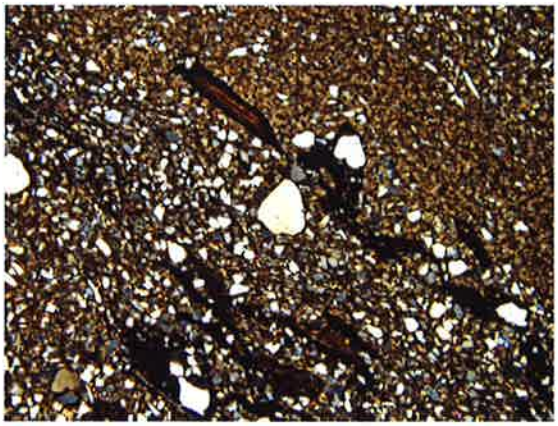
Detrital:

Fragments	Chert (fossil?aggregate), common monomin.quartz, polyqtz, glauconite (green, brownish), elongated organics, often concentric texture. A few sedimentary fragments (stained darker)
Grains	Quartz, appears low in feldspars, scattered small pale micas. Pyrite framboids and small grains, often concentrated within layers.

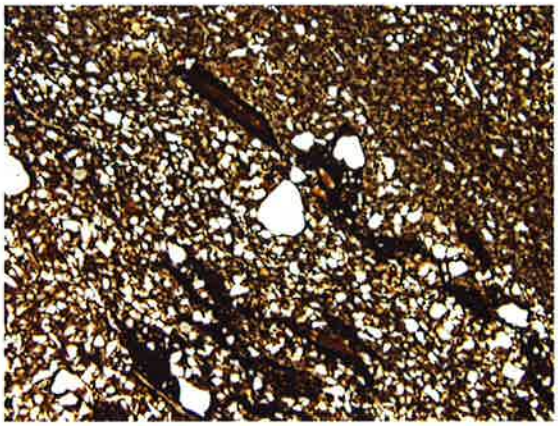
Authigenic:

Cement	Small siderite or dolomite rhombic grains concentrated in layers, brown stained
Clay	Brown stained clay matrix, undefined

General: Inhomogenous layered shale/siltstone, brown stain, organic debris?

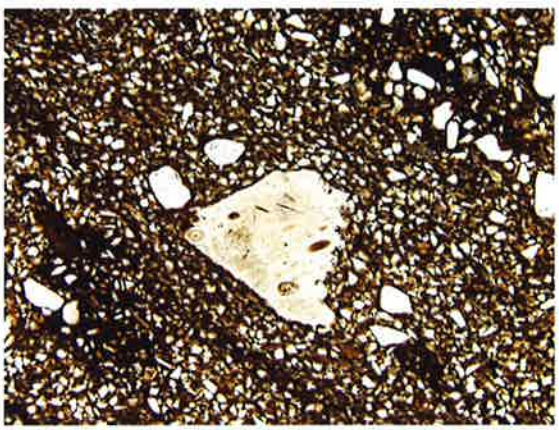


Texture. Carbonate layer to the right x4 xn

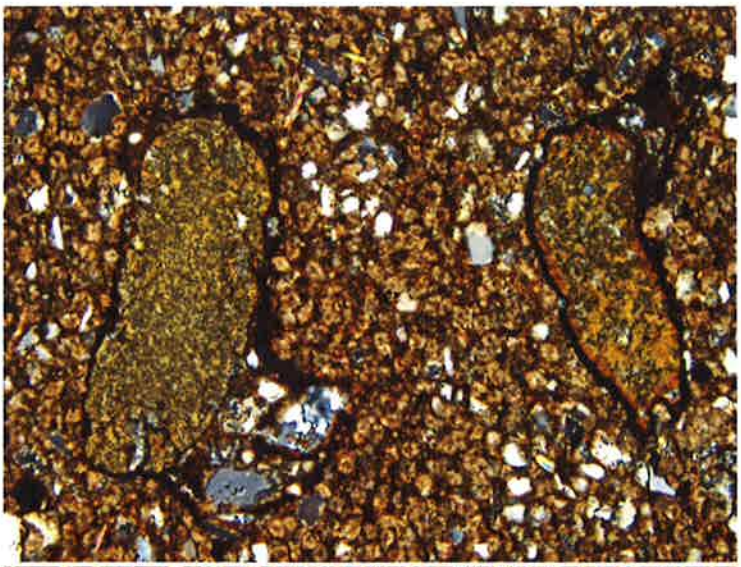


x4 lln

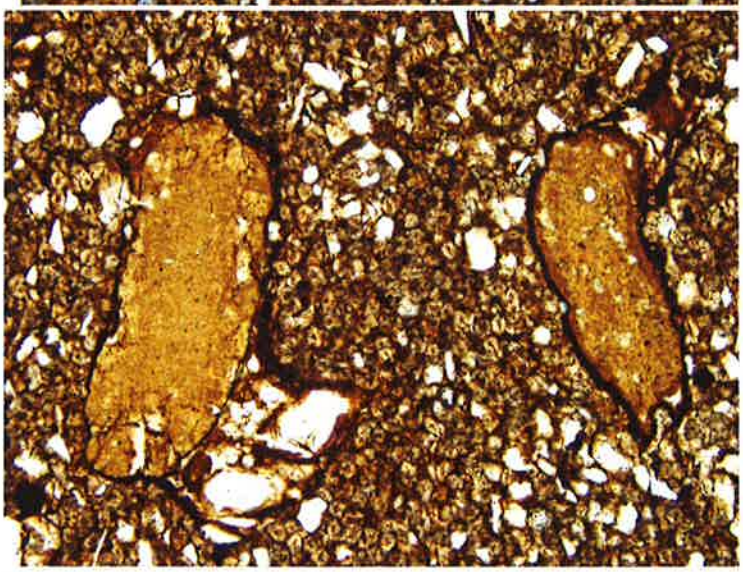
Chert fragment in center x4 xn



x4 lln



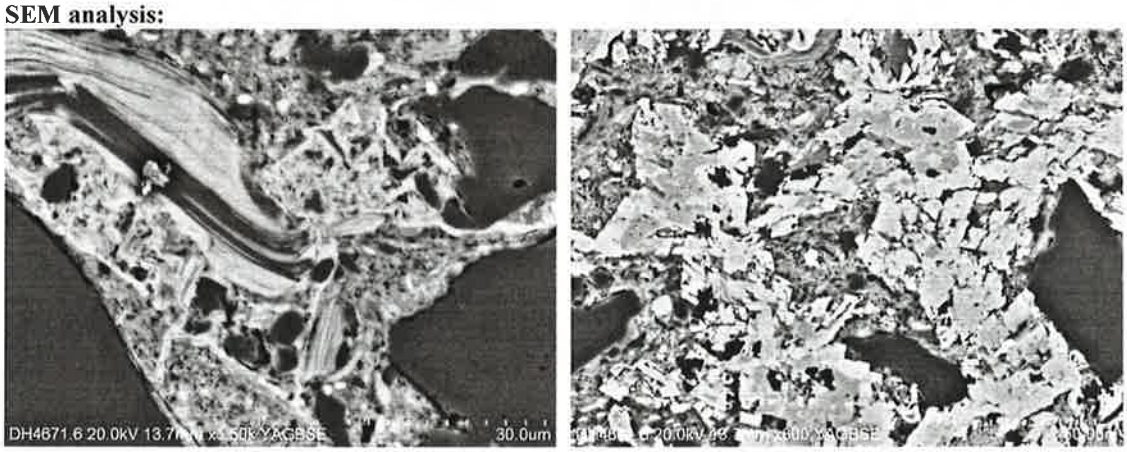
x10 xn



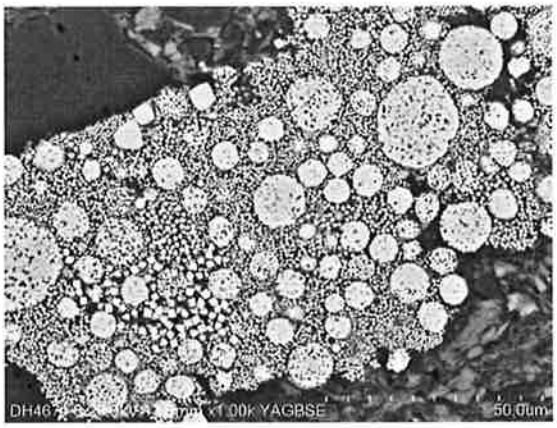
x10 lln

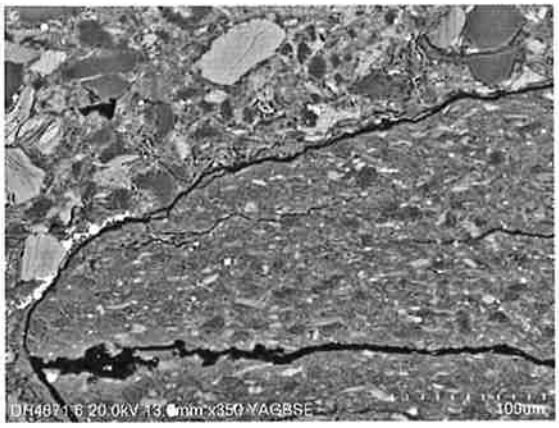
Closer view of carbonate layer, tiny rhombic grains. Two phosphogene? aggregates/grains (altered oolites?)

SEM analysis:



Left: Complex clay matrix, chlorite, illite, mica remnants (muscovite with trace kaolinite, chlorite), small quartz grains. Right: Detail of carbonate layer; dolomite/ankerite/siderite (various relative amounts of Fe, Mg and Ca)





Left: Pyrite layer, framboids. Right: The "aggregate" here consists of a mix of illite and Fe-chlorite with tiny quartz grains

XRD:

Depth	Illite	Chlorite	Quartz	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
671.6	22.1	1.0	39.3	27.5		2.5	4.6		3.1

Well : Dh4 **Depth, m: 678.1** **Type: Core/Knorringfjell Fm**

Lithology	Sandstone with a few larger pebbles (just above conglomerate zone)
Sorting	Fairly well except these fragments
Grain size	Medium sand
Grain shape	Generally subangular, pebbles are subrounded
Porosity	Estimated 15%, local variation

Detrital:

Fragments Quartz (large monocrystals), polyquartz, large white chert or microquartz fragments. One porous, circular fragment with preserved outlines (altered phosphogene nodule?)A few small quartzitic fragments

Grains Quartz, occasional feldspar (plag.), low in micas (pale green biotite), few tiny pyrites

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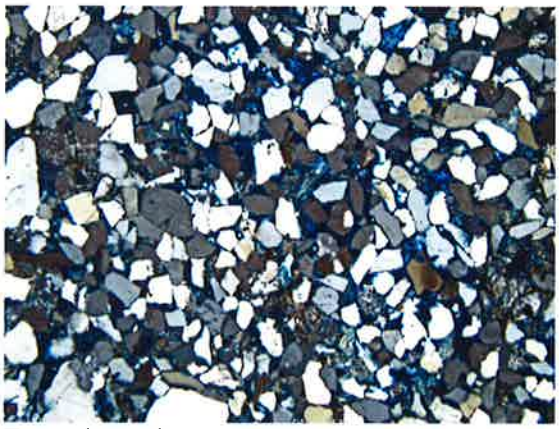
Authigenic:

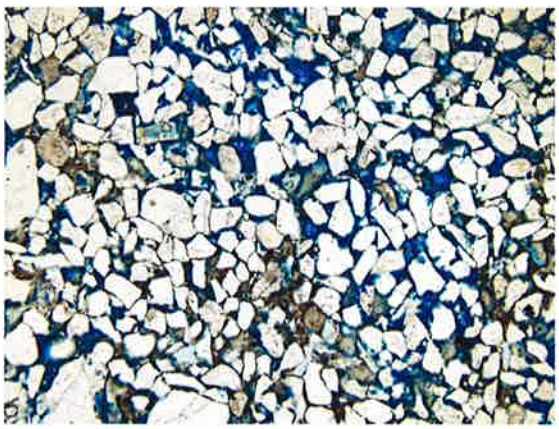
Cement Local carbonate

Clay Undefined clay, small amounts kaolin

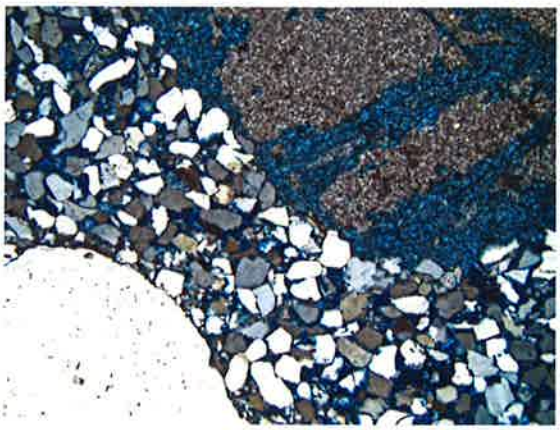
General: Appears to be dominated by quartz (see XRD). Moderate compaction, local grain dissolution (feldspars). Some oversized pores are probably artifacts. Fractures in the large microquartz fragments as channels of higher porosity.

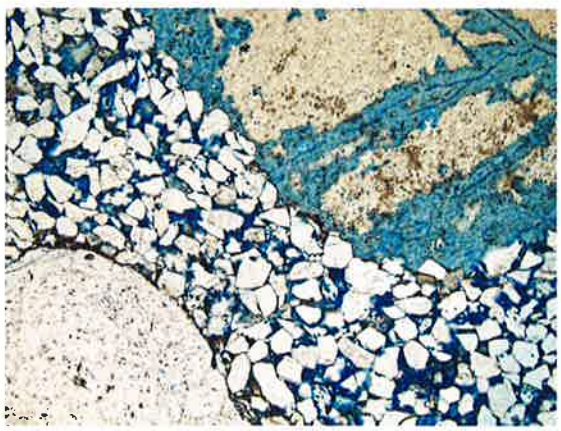


Textural overview x4 xn



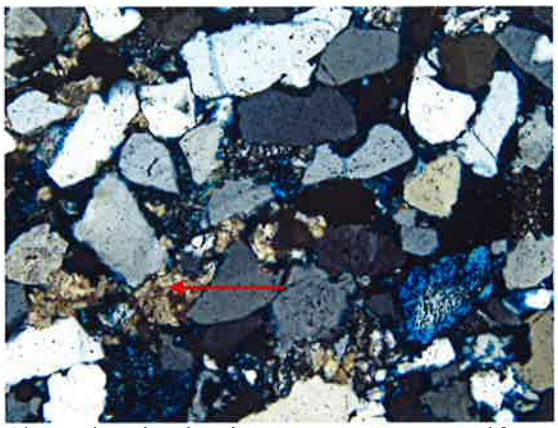
x4 lln



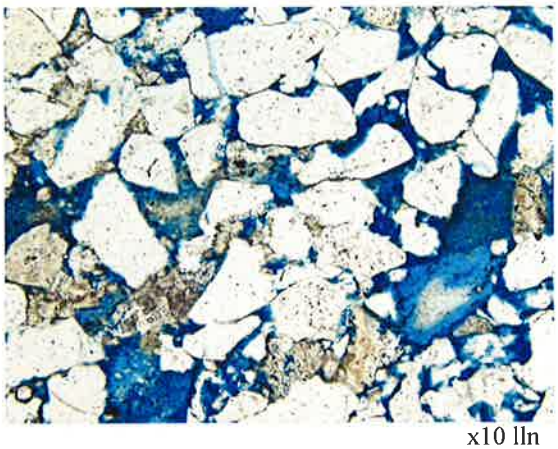


Large fragments: Quartz left, microcrystalline quartz upper right, microporosity along fractures

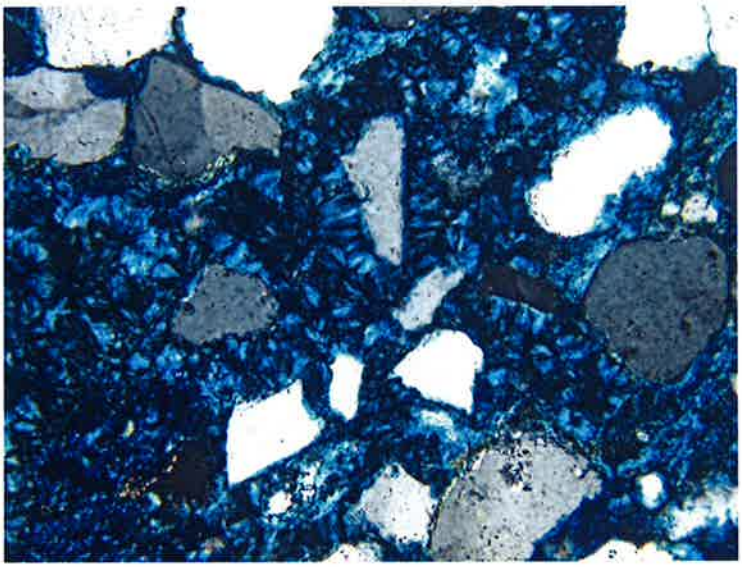
x4 xn x4 lln



Closer view, local carbonate cement x10 xn

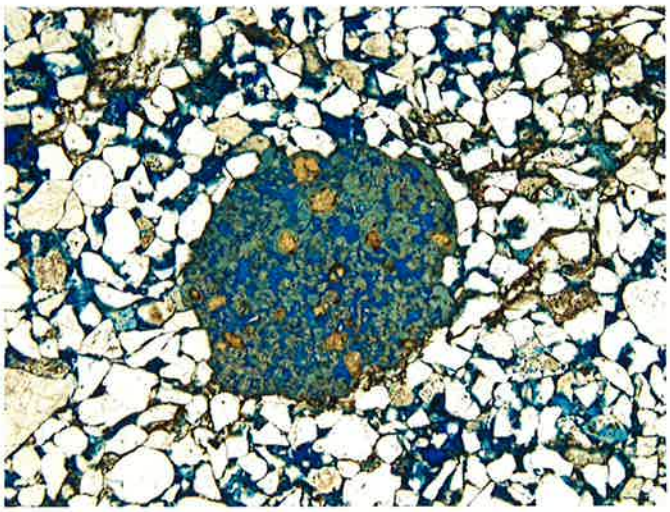


x10 lln



x10 xn

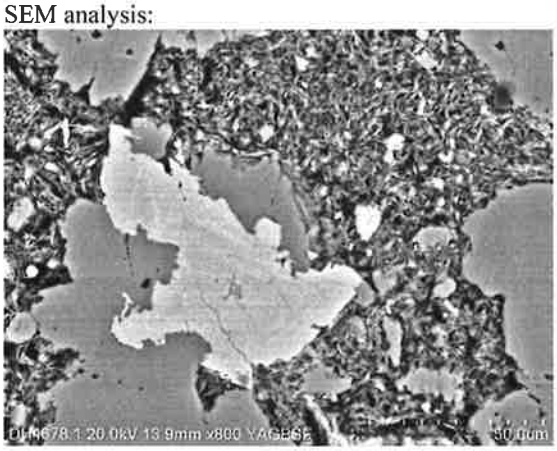
Local pore fill clay

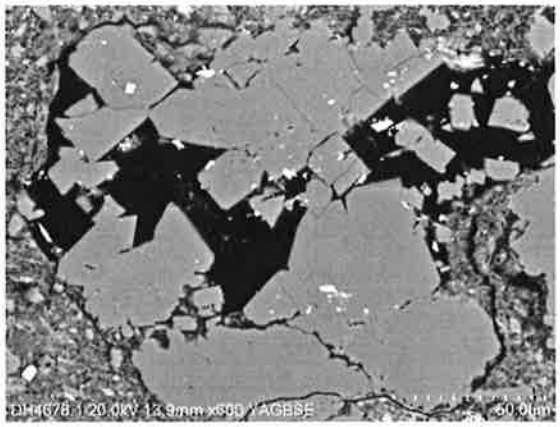


x4 lln

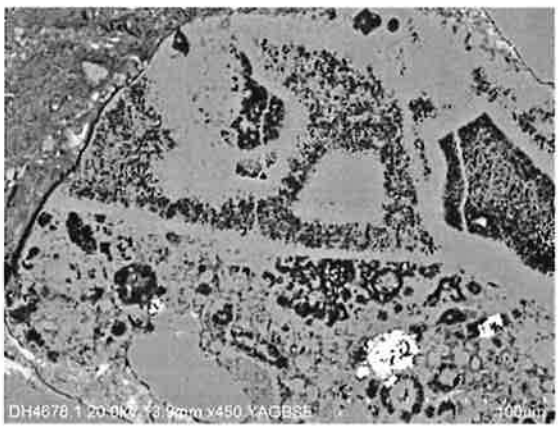
Altered phospogene nodule (?)

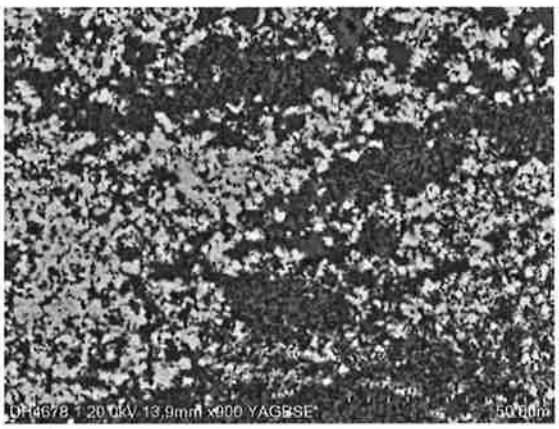
SEM analysis:





Left: Clay matrix with chlorite, quartz grains and zoned dolomite/ankerite cement. Right: Authigenic quartz in pore





Left: Nodule with Ca-phosphate and micro quartz altered nodule

Right: Intimate mix of micro quartz and apatite within

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
678.1	7.6	0.1	70.8		15.9	3.0	0.7	0.7		1.3

Well : Dh4 **Depth, m: 680.5** **Type: Core/Knorringfjell Fm**

Lithology Sandstone
Sorting Well
Grain size Fine sand/silt
Grain shape Subangular
Porosity Relatively low; 10% (some compaction)

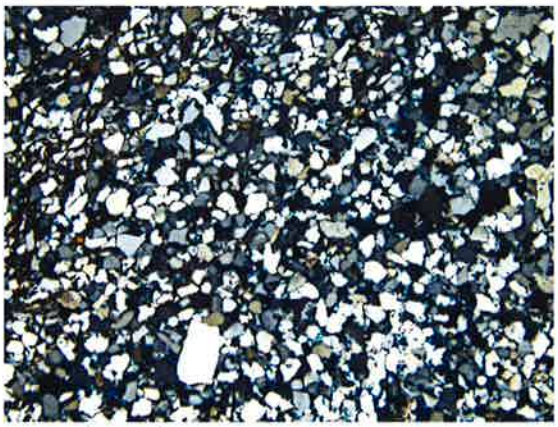
Detrital:
Fragments Very low in fragments. A few clay clasts. Macrocrystalline quartz.

Grains Dominantly quartz. Very few muscovite laths, scattered oxides and tiny pyrites, zircon, rutil (heavy min.)

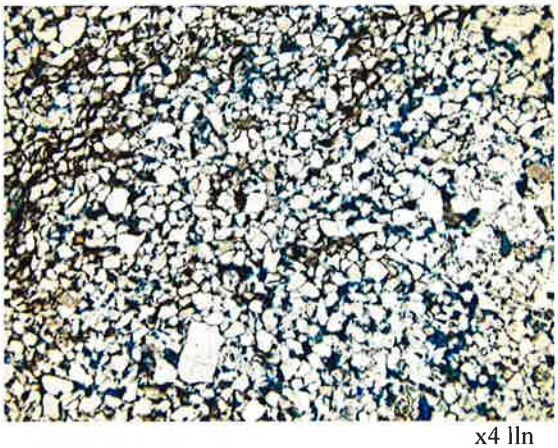
Authigenic:
Cement Very local corroded/irregular carbonate. Quartz cementation

Clay Undefined clay at grain boundaries (illitic?)

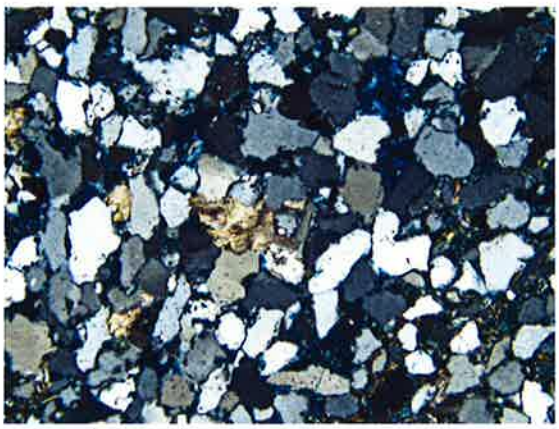
General: Sandstone/siltstone with low porosity due to compaction/mechanical influence and remnant overgrowths, Grain outlines are very irregular, often difficult to decide if overgrowths or compaction. Local dark organics in thin layers.



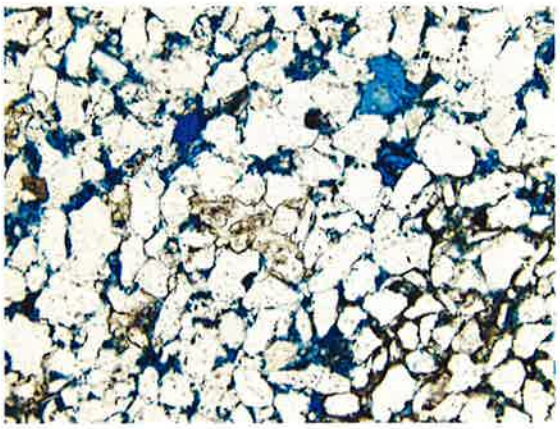
Textural overview x4 xn



x4 lln



Closer view. Carbonate cement (center), quartz texture X10 xn



x10 lln

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
680.5	7.9	0.1	72.4		13.5	3.2	1.1	0.3		1.6

Well : Dh4 **Depth, m: 681.9** **Type: Core/Knorringfjell Fm**

Lithology	Sandstone
Sorting	Well-moderately well
Grain size	Medium – coarse sand (0.4mm)
Grain shape	Subrounded-subangular
Porosity	Variable – locally high with oversized pores, other domains are tightly cemented with quartz

---

Detrital:

Fragments Polycrystalline quartz, fine sediment, microcrystalline quartz, chert,

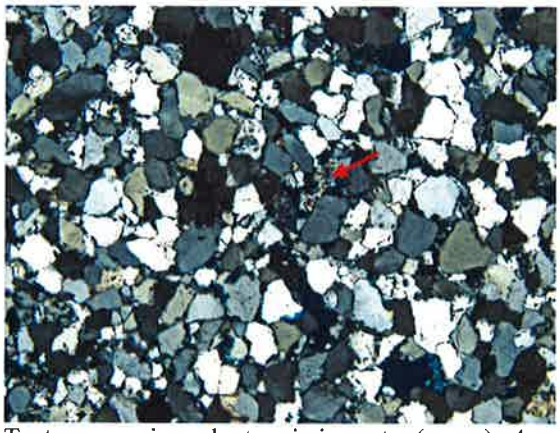
Grains Quartz, a few muscovite laths, zircon, very few feldspar grains identified (plagioclase)

Authigenic:

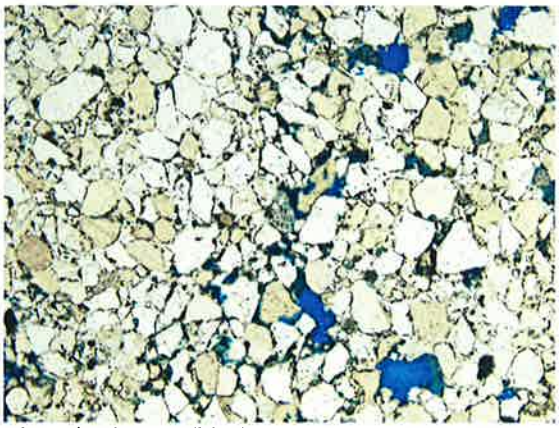
Cement Local carbonate (stressed-undulose extinction), extensive quartz overgrowths in domains

Clay Low in clays, some unidentified in pores (chlorite?)

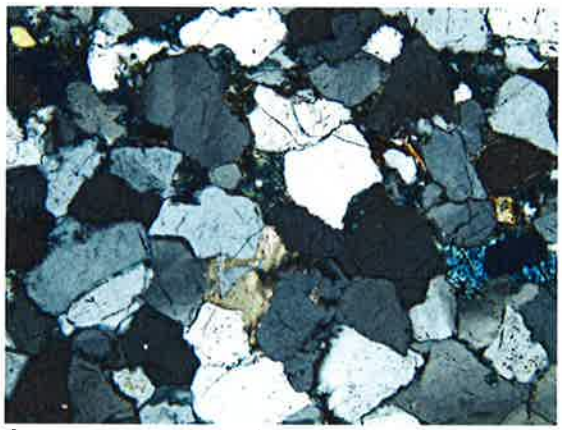
General: Some of the clays appear as clay clasts squeezed into pores, can be detrital. The oversized pores are presumably caused by grain dissolution – not obvious remnants indicating type of grain. Others are artificial? (due to preparation). Quartz grain boundaries are blurred, even for overgrowths. Cementation and compaction, also fractured grains. Carbonate predates quartz overgrowths? Carbonate also shows incipient dissolution



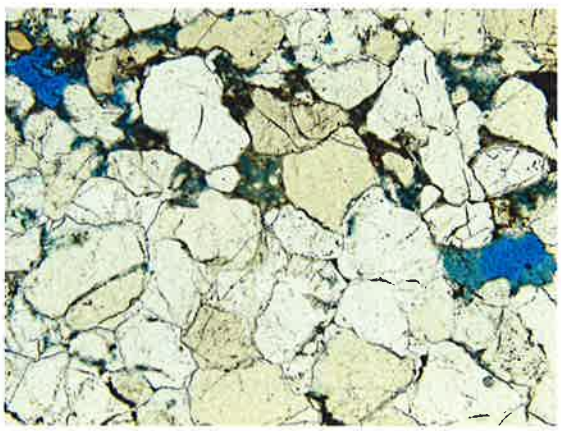
Texture overview, chert grain in center (arrow) x4 xn



Oversized pores (blue) x4 lln



Quartz overgrowths, carbonate cement in center x4 xn



x4 lln

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
681.9	5.5	0.1	82.4		6.2	2.0	2.2	0.3		1.2

Well : Dh4 **Depth, m: 687.3** **Type: Core/Knorringfjell Fm**

Lithology	Inhomogenous layered sandstone/ thin shaly layers
Sorting	Moderately well, patches with larger grains
Grain size	Medium sand/fine sand/silt
Grain shape	Subangular, larger grains subrounded
Porosity	Very low, probably in thin open fractures

Detrital:

Fragments Microcrystalline quartz, probable clay clasts, glauconite, felsic igneous, phosphogene (?)

Grains Quartz, few feldspars identified, scattered pyrite, very low in mica, zircon

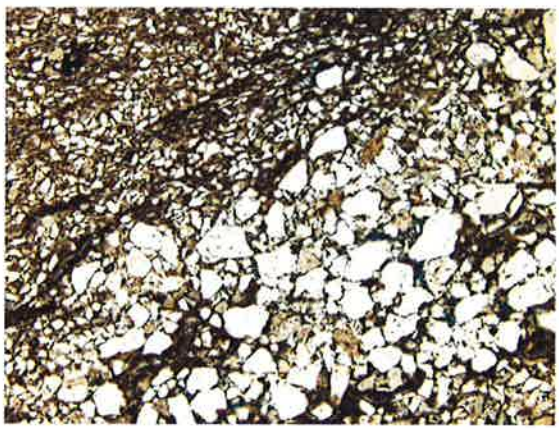
Authigenic:

Cement Local pyrite, remnant quartz overgrowths,

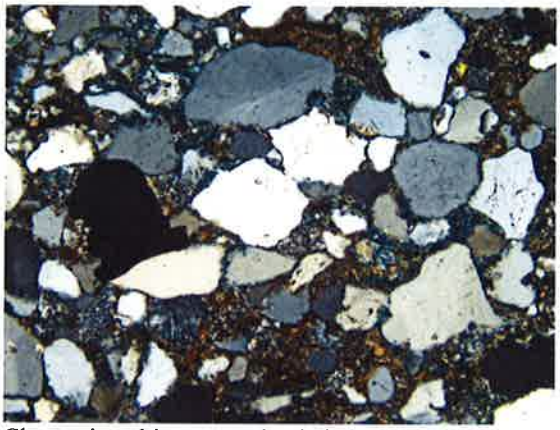
Clay Clay matrix/pore fill, variably brown stained

General: Fine grained, inhomogenous, irregular grain boundaries, in coarser grains overgrowths are seen. Difficult to decide if clay matrix or porefill, probably illitic or I/S type. Layers are wavy discontinuous

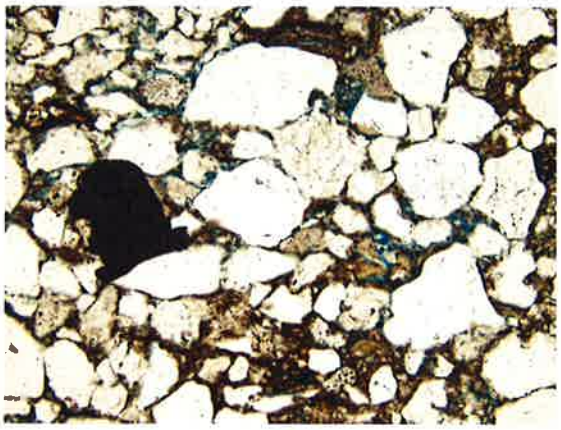
Overview inhomogenity x4 xn



x4 lln



Closer view, bitumen stained clay, pyrite cement x10 xn



x10 lln

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
687.3	11.6	0.2	56.4		19.3	3.8	0.9		2.9	4.5

TOC: 0.58 TC: 0.51

Well :Dh4 **Depth, m:691.6** **Type: Core/Knorringfjell Fm**

Lithology	Oolitic sandstone
Sorting	Moderately well
Grain size	Fine-medium sand, some coarse (0.4mm)
Grain shape	Subrounded – to angular
Porosity	Low, irregular distribution, estimate 5-7%, some oversized pores

Detrital:

Fragments Commonly monomin., a few polycrystalline quartz, microcrysttalline quartz, probable altered oolites, fine grained sediment, phosphogene grains, composite chert,

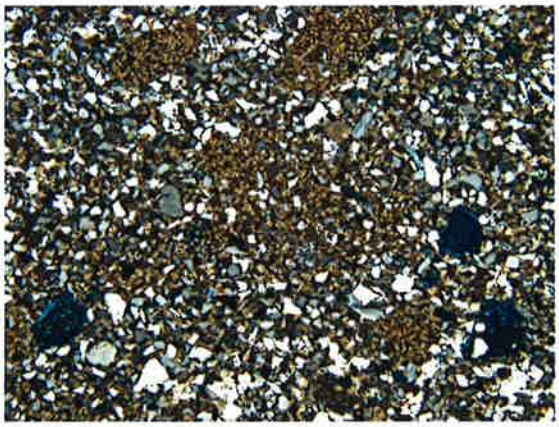
Grains Quartz, plagioclase, altered feldspar , few mica remnants, altered glauconites?, zircon,

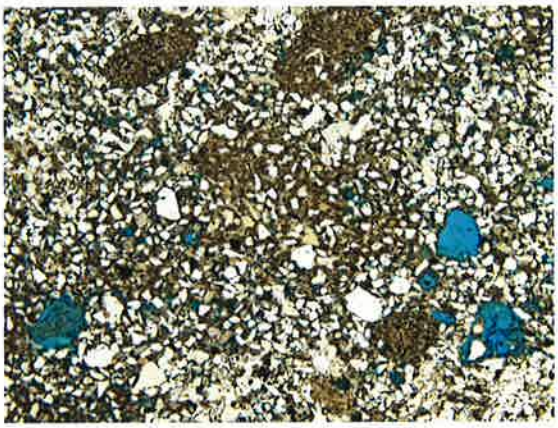
Authigenic

Cement Aggregates of tiny, zoned siderite grains (yellow fluorescens), some additional, younger carbonate, only trace quartz overgrowths

Clay Low, occurs in altered grains

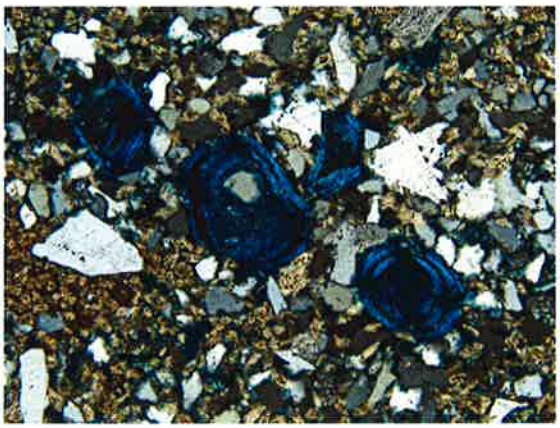
General: Siderite cement irregularly distributed, some tight domains, other more scattered. Very thin open fracture, not continuous, can be artificial

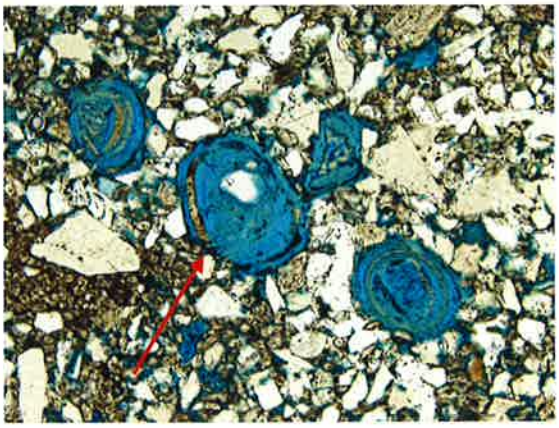




Textural overview, siderite cement (brown), oversized pore (blue)

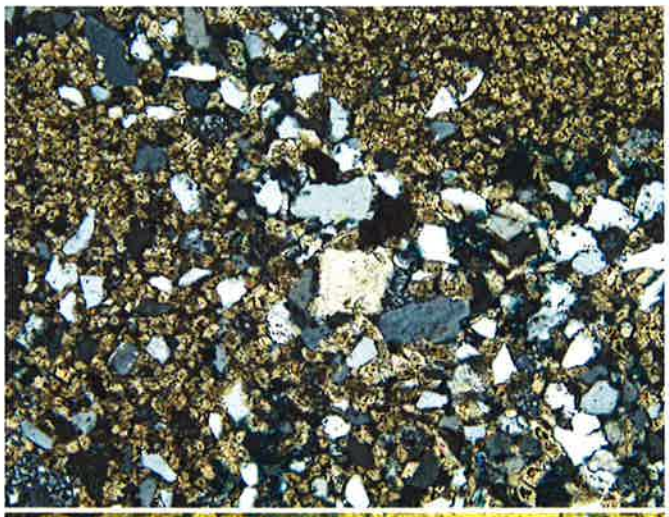
x4 xn x4 lln



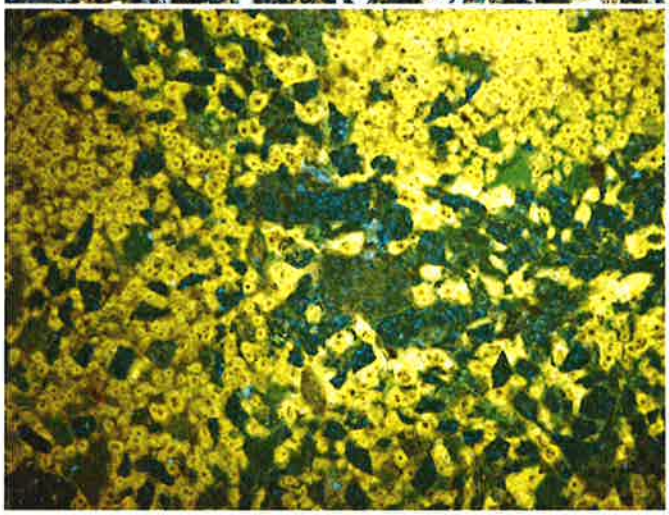


Oolitic remnants, thin phosphogene rim (arrow)

x10 xn x10 lln

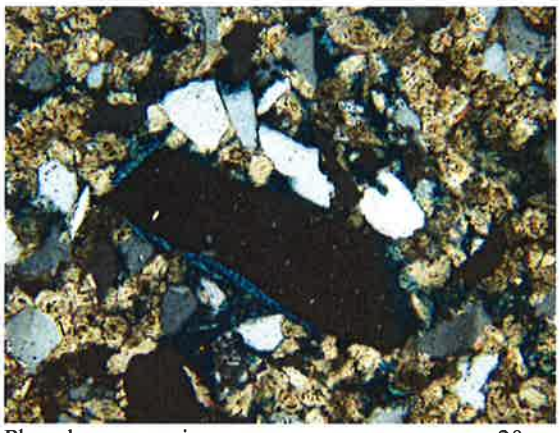


x10 xn

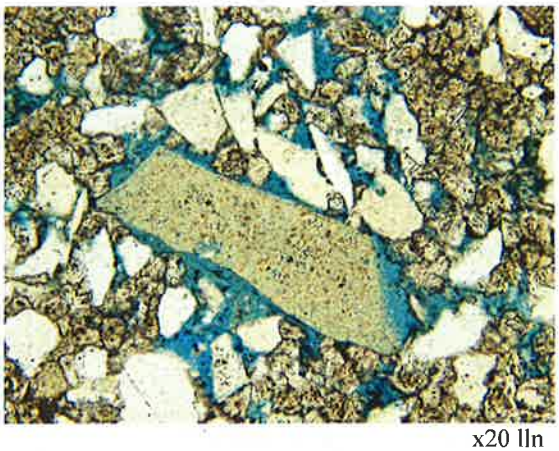


x10 UV

Detail of siderite cement, younger carbonate in center, zoned siderite grains are obvious in UV

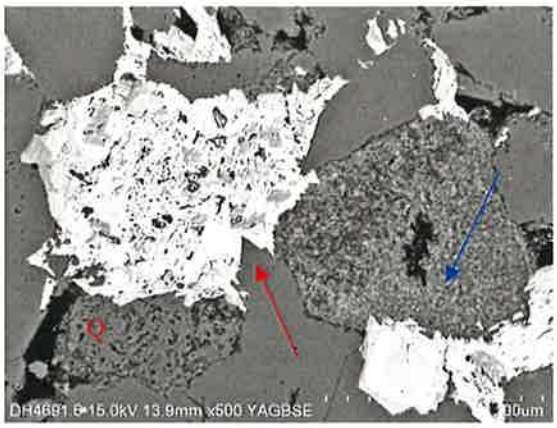


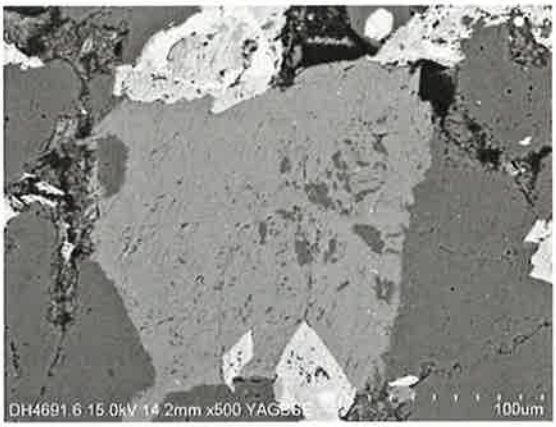
Phosphogene grain x20 xn



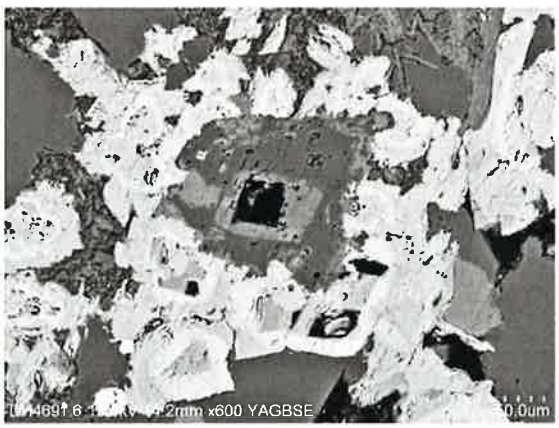
x20 lln

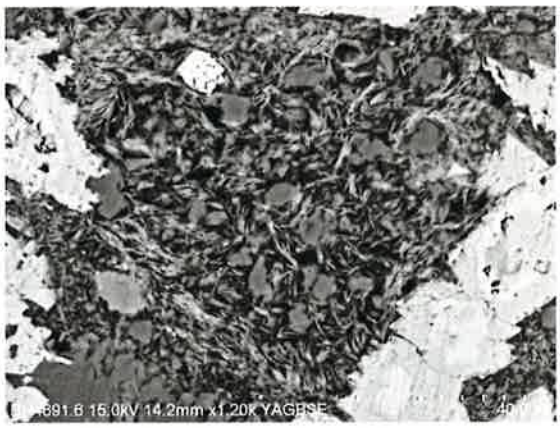
SEM analysis:



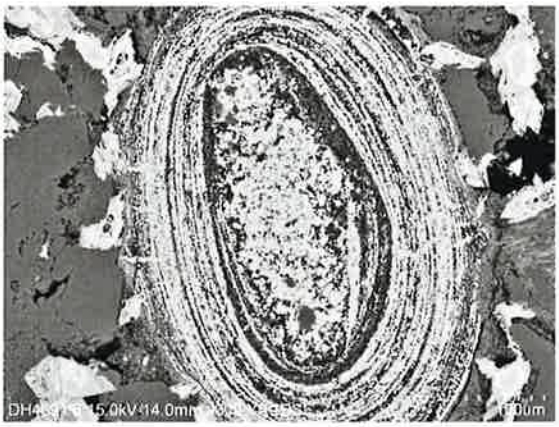


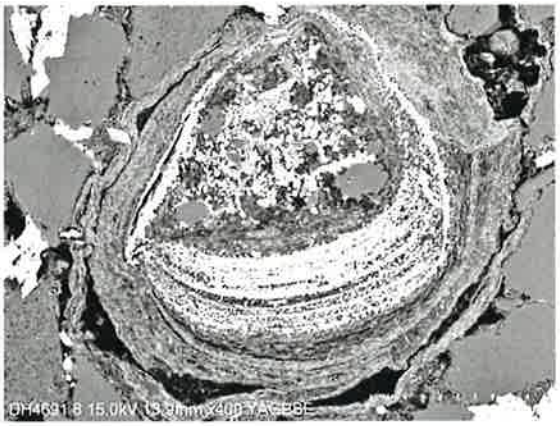
Left: Quartz overgrowth (red arrow) predates complex zoned Fe-Mg carbonate, again predating the the chloritic clay clast (blue arrow). Dissolving quartz (Q). Right: Dolomite in center predates the Fe-Mg carbonate cement (paler). Surrounding grains: albite and quartz





Left: Detail of complex Fe-Mg carbonate Right: Chloritic clay, quartz and Ti-oxide (small, pale grain) in pore, corroding carbonate cement.





Various oolite textures: circular orientation of pale Ca-phosphate and grey chlorite. Right: tiny quartz included in center.

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
691.6	8.3	0.7	44.4		17.2	3.3	3.6	7.2	13.9	1.3

Well : Dh4 **Depth, m: 692.5** **Type: Core/Knorringfjell Fm**

Lithology	Sandstone
Sorting	Fairly well, some larger grains
Grain size	Fine sand generally, larger grains up to 0.4mm
Grain shape	Subangular
Porosity	Vary, locally good but irregularly distributed

Detrital:

Fragments Very few, some carbonate aggregates, a few altered glauconites? Local clay clasts
Phosphogene grain

Grains Quartz, a few feldspar grains are identified, few micas (muscovite), zircon, rutile
Scattered tiny pyrites and oxides

Authigenic:

Cement Sparry carbonate (mainly non-fluoresc. but.fluoresc. occur) Local phosphogenic?

Clay Local clay in discontinuos layers/domains, brown stain. Local pore filling clay

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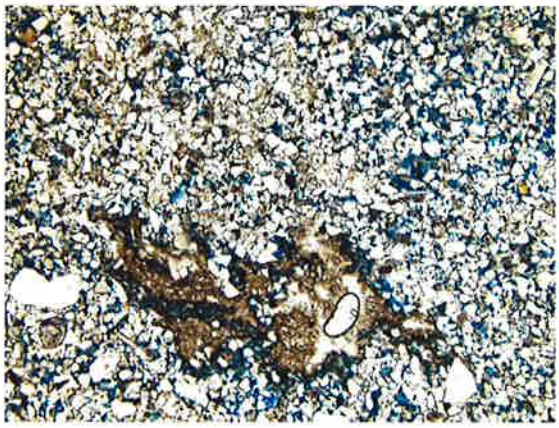
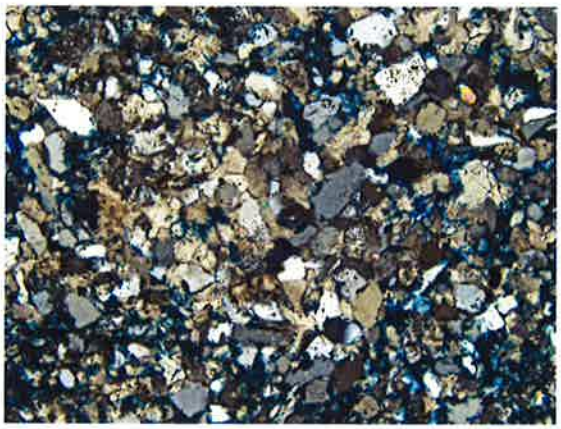
General: Fine sandstone, irregular flaserlike texture, inhomogen texture mainly due to cemented/porous domains, irregular staining especially of clays. Dissolving carbonate.

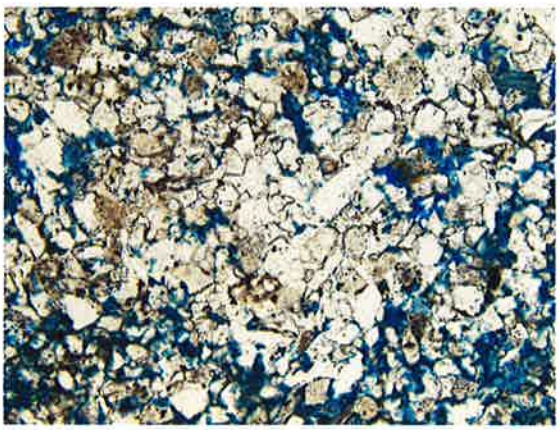
Textural overview, clay clast or altered phosphogene?
x4 xn



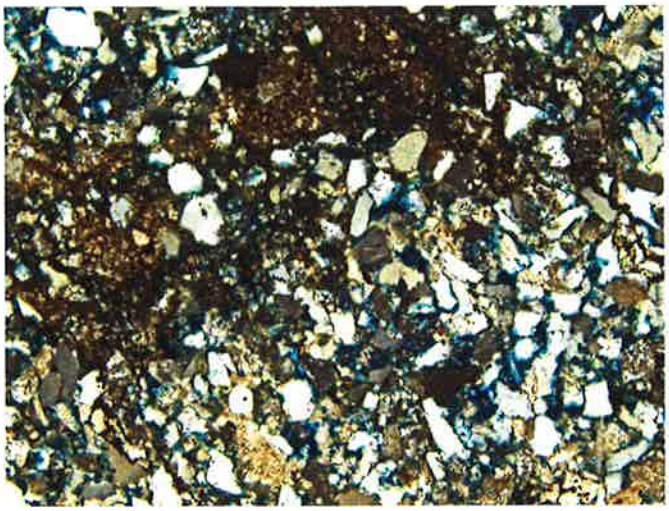
x4 lln



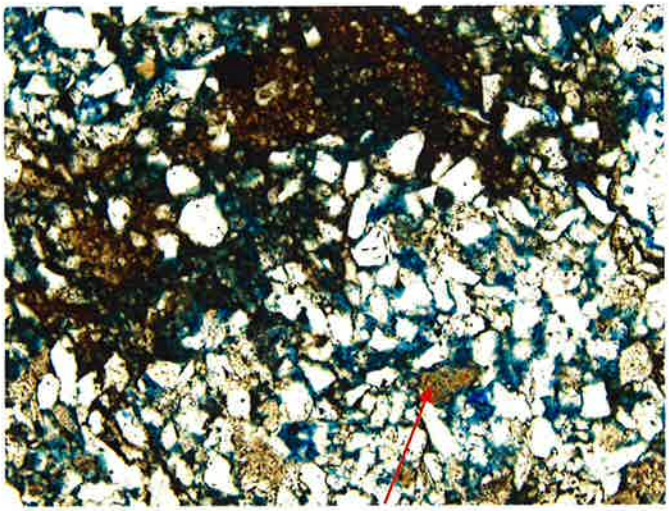
Carbonate cemented domain, variable porosity x10 xn



x10 lln



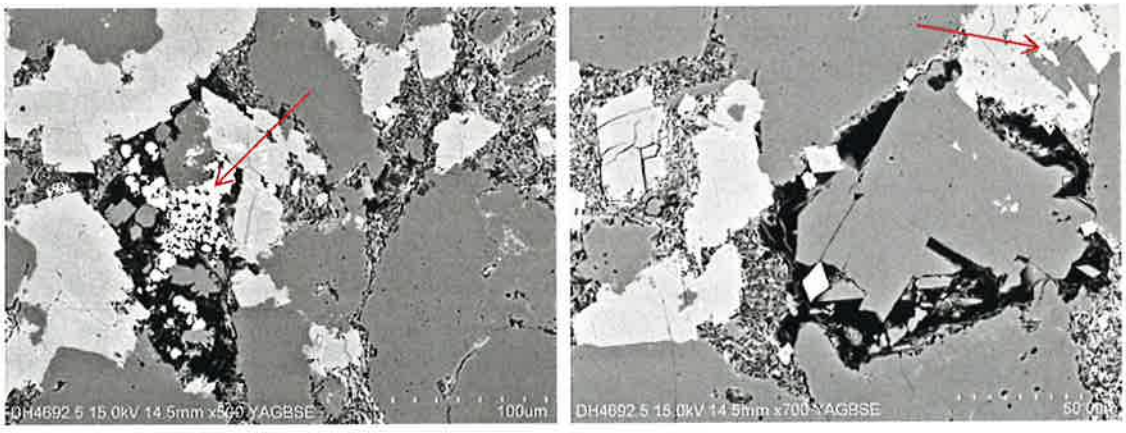
x10 xn



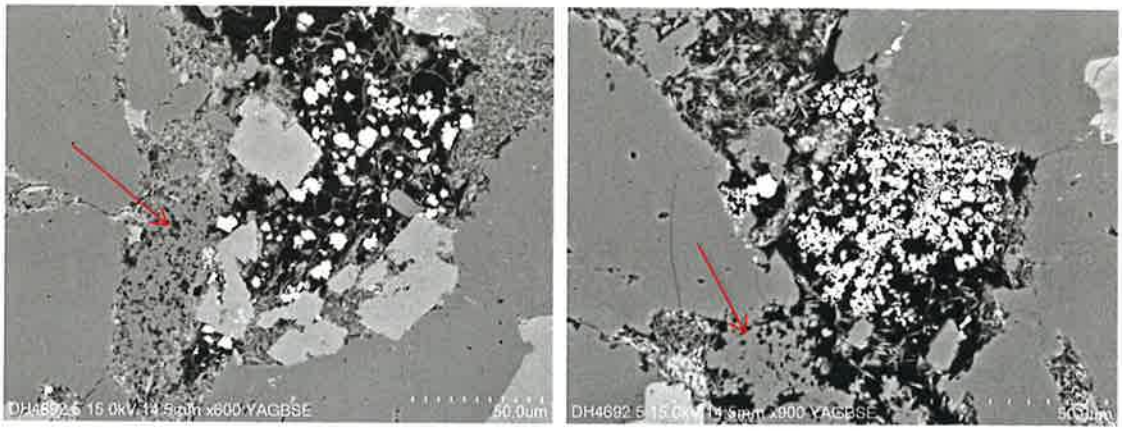
x10 lln

Closer view of texture and matrix (mix organics/phosphogenic?)
Phosphogene grain (arrow)

SEM analysis



Left: Dolomite/ankerite cement (pale), Ca-phosphate (arrow), chloritic clay in pores, authigenic quartz.
Right: Similar view, authigenic albite in center, albitisation of K-feldspar (arrow)
Tentative sequence: qtz>phosphate>dolomite>chlorite



Similar views, also showing dissolving quartz (arrows) and pore clay mix of illitic and chloritic type.

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
692.5	5.1	0.3	48.0		30.6	4.9	6.3		3.1	1.7

Well : Dh4 **Depth, m: 695.4** **Type: Core/Knorringfjell Fm**

Lithology	Sandstone
Sorting	Moderately well
Grain size	Fine to coarse sand
Grain shape	Subangular, larger grains can be subrounded
Porosity	Locally good but irregularly distributed

Detrital:

Fragments Larger grains are dominantly monomin.quartz, sometimes composite of few grains, few silty/shaly fragments, chert or crypocrystalline qtz, with chalcedony, clay clasts, some phosphogene (collophane) grains

Grains Quartz, plagioclase (appear low), altered feldspar grains, a few muscovite flakes, zircon, a few biogenic remnants (chert?),

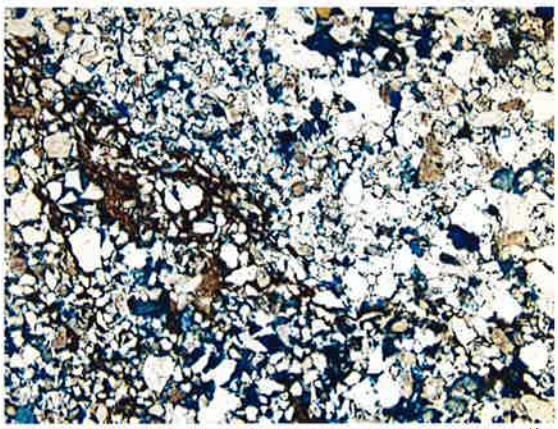
Authigenic:

Cement Scattered carbonates, apparent remnants of quartz overgrowths,

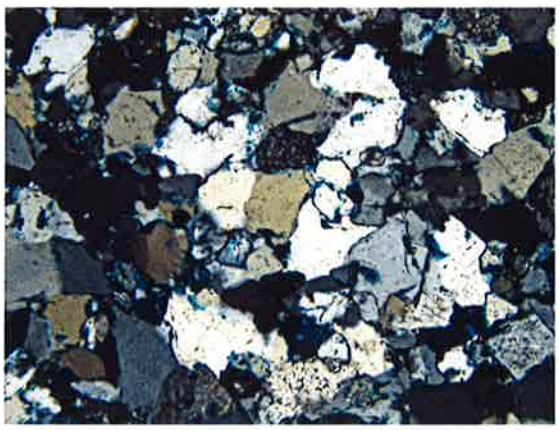
Clay Low in clays except within clasts, local small amounts in pores (undefined)

General: Irregular domains with variable (slumpy?) texture and porosity, grain boundaries often blurred and poorly defined - corroded, domains with apparent higher compaction. The clay clasts are possibly altered domains of phosphogene cement

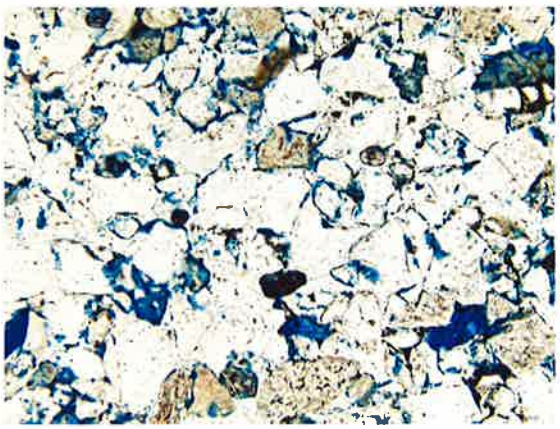
Textural overview, clay clasts, irregular porosity x4 xn



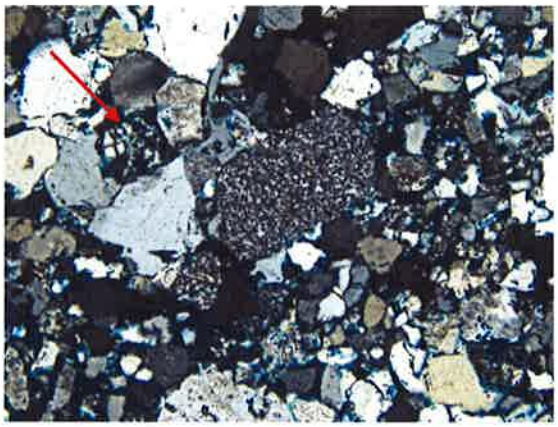
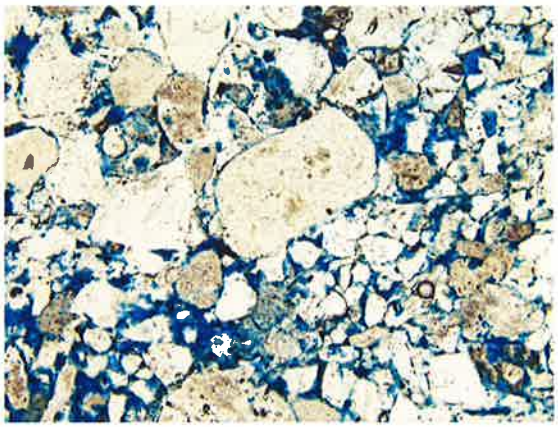
x4 lln



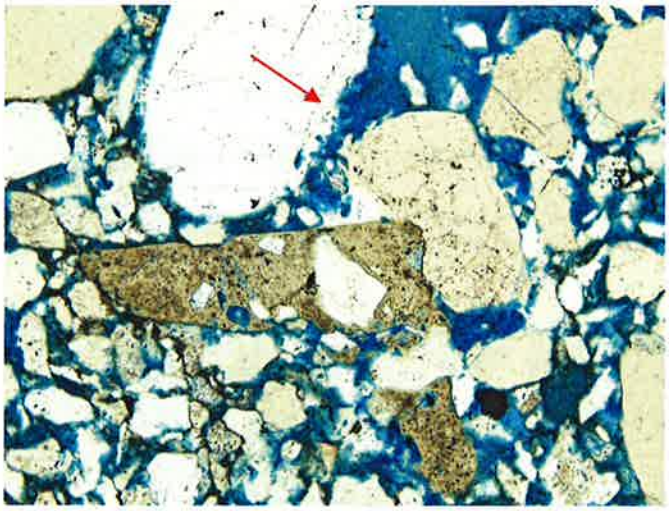
Closer view, quartz cementation x10 xn



x10 lln

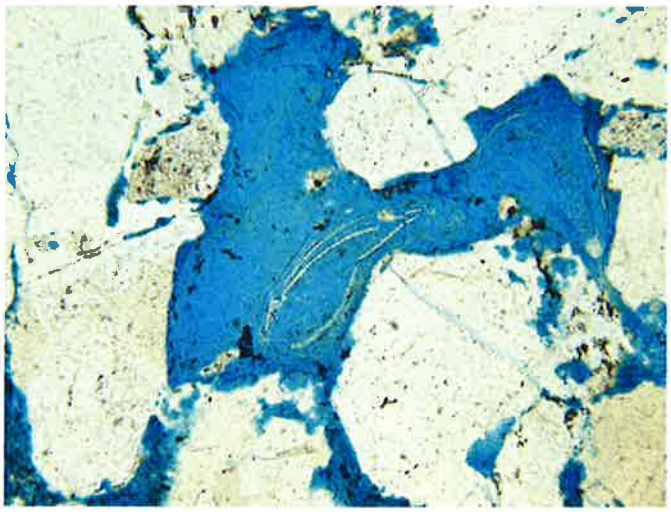



Cryptocrystalline quartz fragment (center), fragment with chalcedony (arrow) x10 lln x10 xn



x10 lln

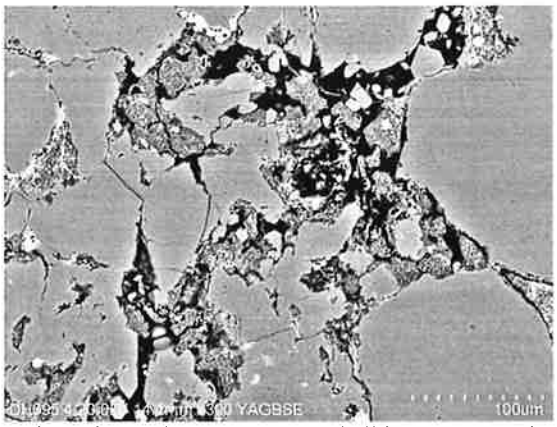
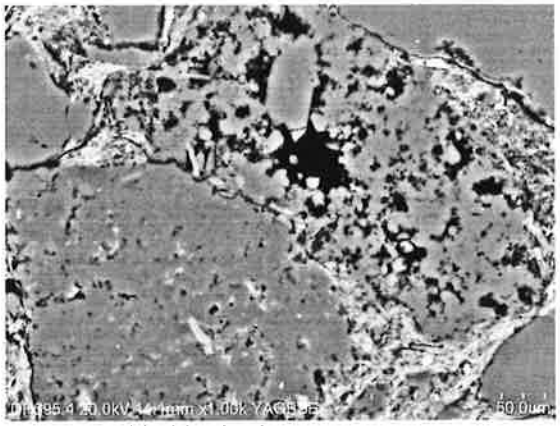
Phosphogene grain in center (brown). Also note corroded quartz overgrowths (arrow)



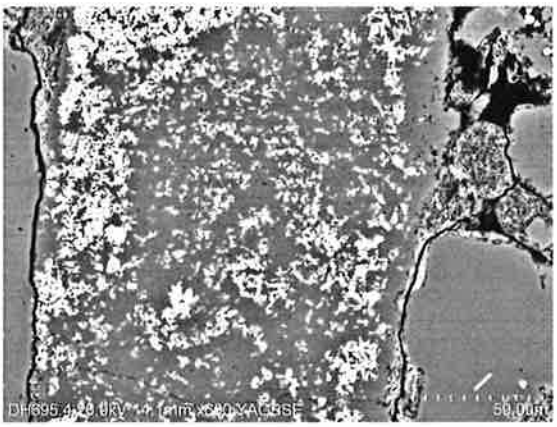
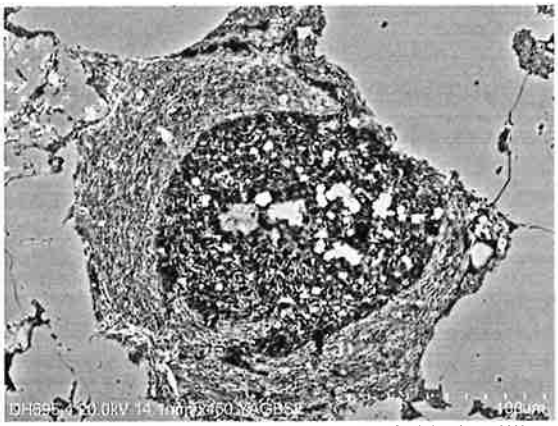
x20 lln

Trace remnant grain in pore, the pore is largely occupied with fibrous clayish material, hard to discern

SEM analysis

Left: Major grains are quartz and albite, overgrowths are evident. Chloritic clay in pores.
Right: Dissolving quartz and authigenic grains. Clays are mix of illitic and chloritic

Left: "Pebble" with Ca-phosphate (pale) and quartz Riht: Altered oolitic texture, outer rim of chlorite±illite, tiny grains of albite, Ca-phosphate and clays in center. Ca-phosphate also occurs locally as cement, in addition to dolomite/ankerite.

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
695.4	3.2	0.2	68.5		19.5	2.3	1.1	0.1	3.8	1.3

Well : Dh4 **Depth, m: 702.8** **Type: Core/De Geerdalen/Isfjorden Mb**

Lithology	Sandstone
Sorting	Well sorted
Grain size	Fine-medium sand
Grain shape	Subanglar (angular)
Porosity	Primary porosity very good, loose packing, but pores appear clogged with clays/matrix thus low permeability

---

Detrital:

Fragments	Micro/cryptocrystalline quartz, a few felsic fragments . low in clay clasts
Grains	Quartz, plagioclase, altered feldspars, a few muscovites, biotites, zircon, rutile,

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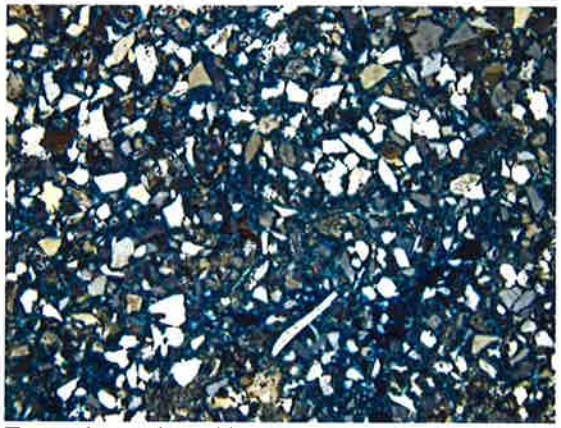
Authigenic:

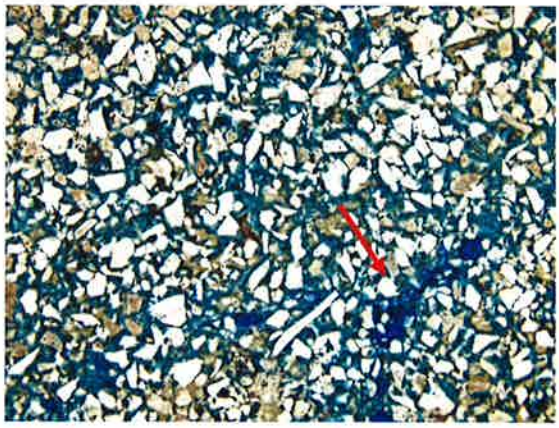
Cement	Local carbonate. Pale brown-yellow possibly phosphogene
Clay	Undefined clay in pores (illitic –chloritic?) difficult to identify

---

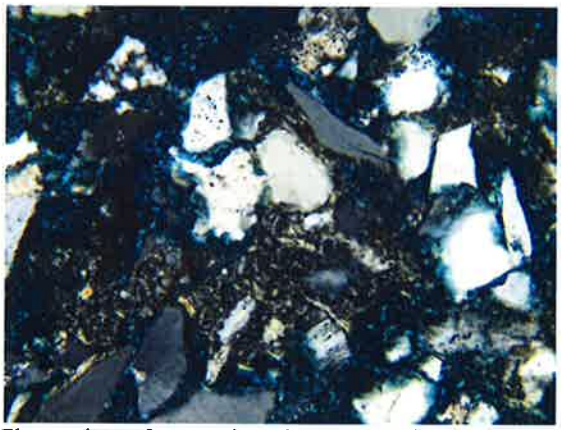
General: Pore clay probably not illitic (no fluorescence), occasionally looks greenish as chlorite. Grains are often angular but also blurred – corroded on one or more edge. Low compaction, floating grains. Dissolving feldspars (plagioclase, secondary porosity not prominent). Thin fracture with carbonate as well as discontinuous thin open fracture (major permeability path)

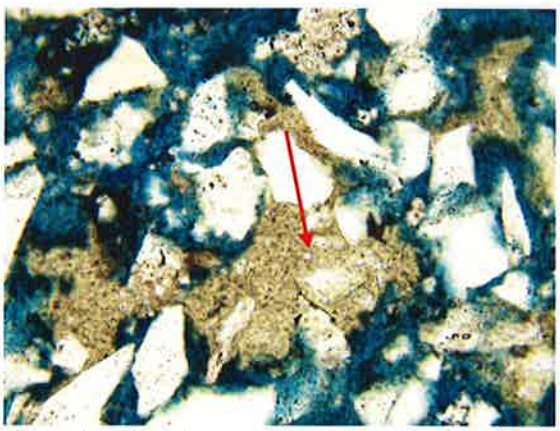


Textural overview, thin open fracture (arrow) x4 xn

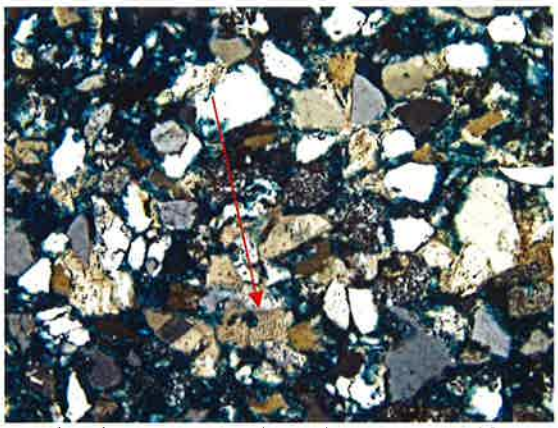


x4 lln

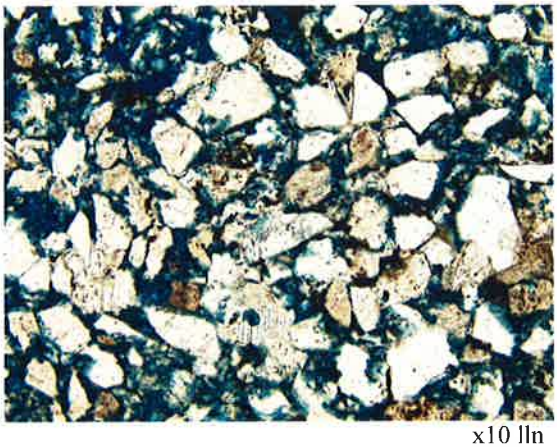




Closer view of cementing phases: greenish clay and pale brownish phosphogene? (arrow) x20 lln
Also notice the grain shapes x20 xn

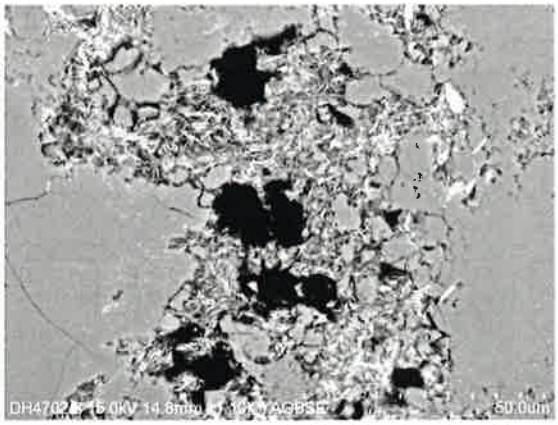


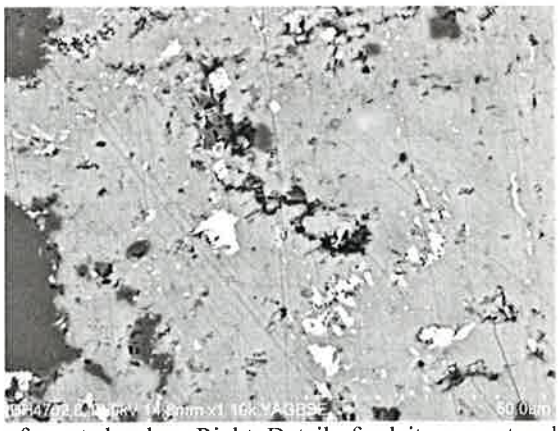
Local carbonate cement (arrow) x10 xn



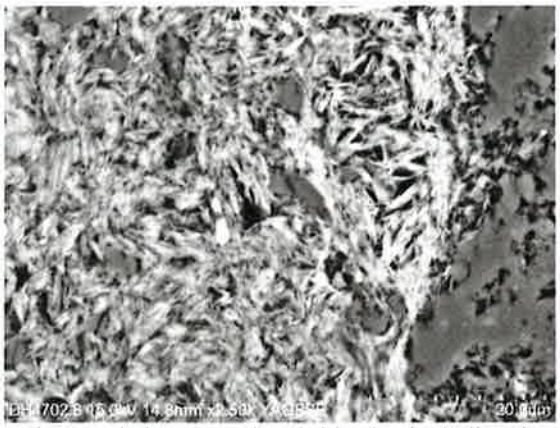
x10 lln

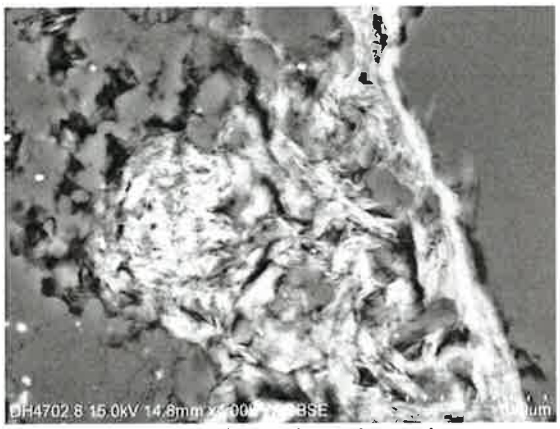
SEM analysis





Left: Texture of quartz and chloritic clay, breaking up of quartz borders. Right: Detail of calcite cement, pale spots are carbonate with some Fe





Left: Pore filling chloritic ± illitic clay including tiny quartz grains. Right: Closer view, also notice quartz texture

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
702.8	2.0	11.3	50.8		26.0	5.4	1.1		2.5	0.9

Well : Dh4 **Depth, m: 703.7** **Type: Core/De Geerdalen/Isfjorden Mb**

Lithology	Fine sandstone/siltstone
Sorting	Fairly well
Grain size	Silt – fine sand
Grain shape	Angular-subangular
Porosity	None visible

Detrital:

Fragments Microcrystalline quartz, polycrystalline quartz (few), scattered black organic debris

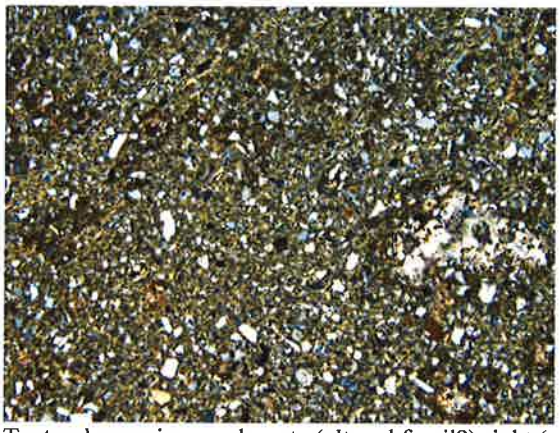
Grains Quartz, muscovite, plagioclase, pale biotite or chlorite?, a few scattered oxides

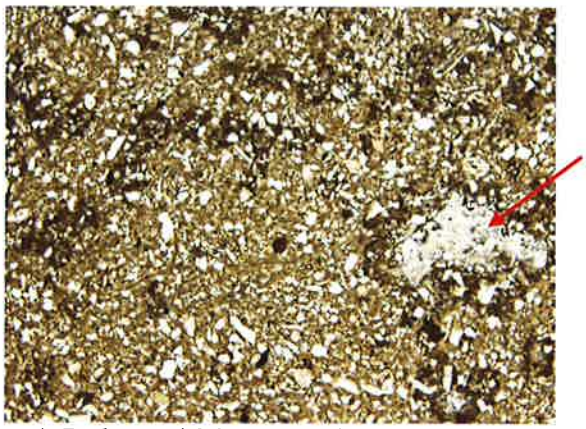
Authigenic:

Cement Local carbonate (can be very altered carbonaceous remnants)

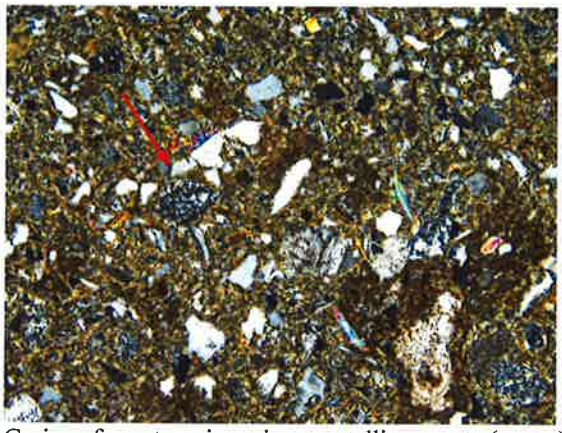
Clay Dark partly cloudy matrix, greenish in plain light, probably high in chlorite (see XRD)

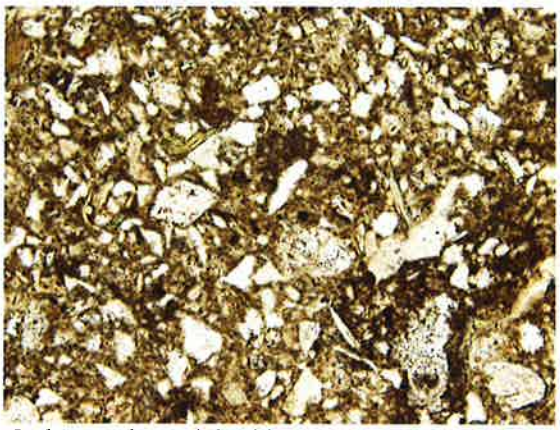
General: Some undefined grains can be very altered feldspars





Textural overview, carbonate (altered fossil?) right (arrow). Dark greenish brown matrix x4 lln x4 xn





Grains of quartz, mica,microcrystalline quartz (arrow). Carbonate down right side x10 lln x10 xn

x20 xn

x20 lln

Chlorite in center, alteration of biotite?

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
703.7		33.3	30.7		22.3	6.1	1.1	0.7	4.7	1.2

Well : Dh4 **Depth, m: 705.8** **Type: Core/De Geerdalen/Isfjorden**

Lithology	Sandstone/siltstone
Sorting	Well sorted
Grain size	Fine sand
Grain shape	Subangular, irregular boundaries
Porosity	Low

Detrital:

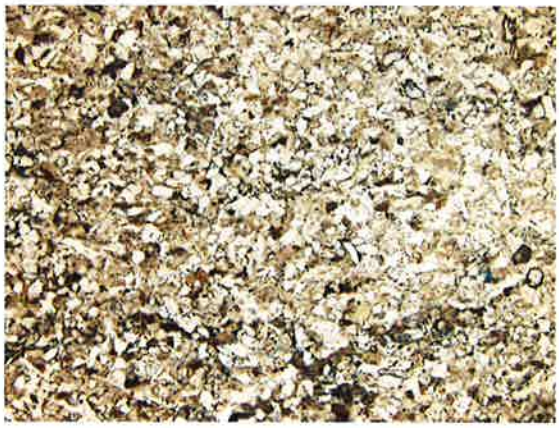
Fragments	Few fragments if any, schist?, microcrystalline quartz
Grains	Quartz, altered feldspars, biotite, muscovite, chlorite, plagioclase, scattered small oxides, opaques (probably organics without reflectance)

Authigenic:

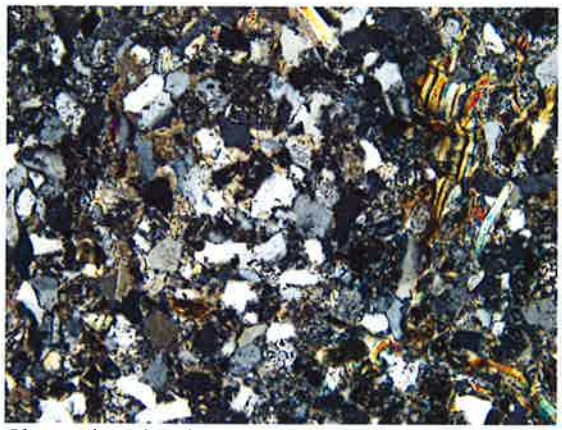
Cement	Local carbonate, very irregular
Clay	Undefined clay matrix or very altered grains

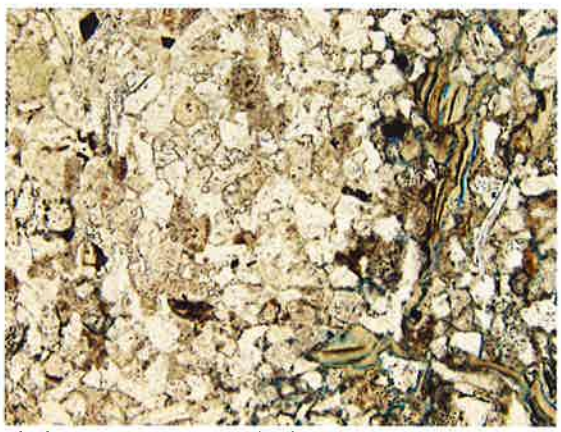
General: Weakly layered, not very obvious in thin section, mostly defined by micas. Very irregular texture (poorly polished?), diffuse grain boundaries. Weakly compacted with wavy micas, amounts of feldspars are probably relatively high, amount of clays difficult to estimate. Appear illitic in polarised light but no fluorescence, not typical chloritic. Kaoline not identified. Immature sediment.

Textural overview x10 xn



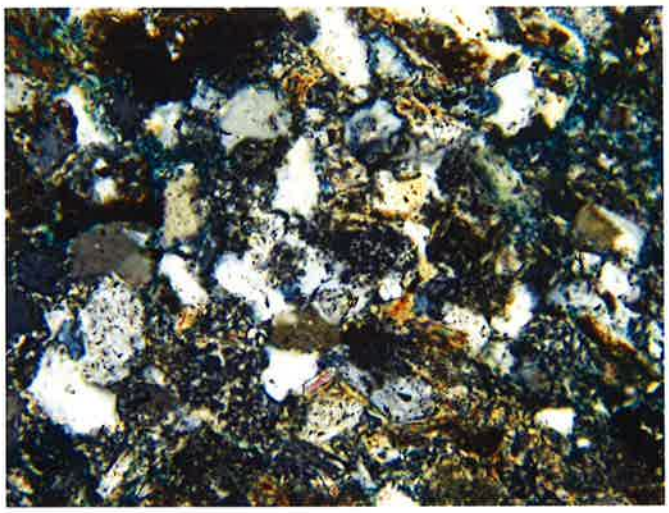
x10 lln



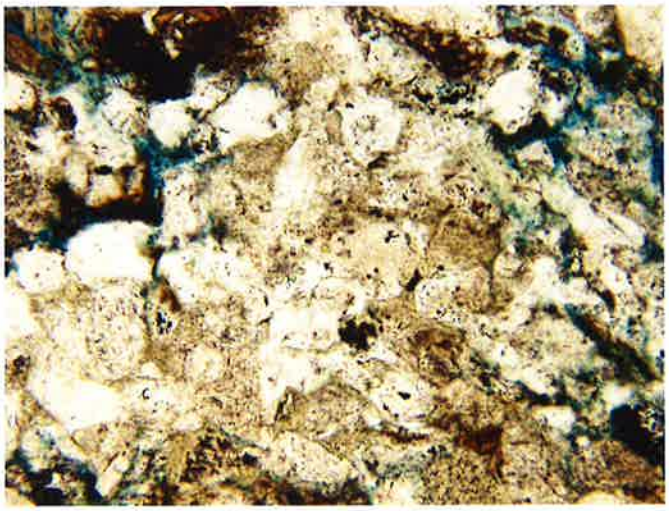


Closer view, local carbonate cement, blurred grain boundaries, wavy compacted mica

x10 xn x10 lln



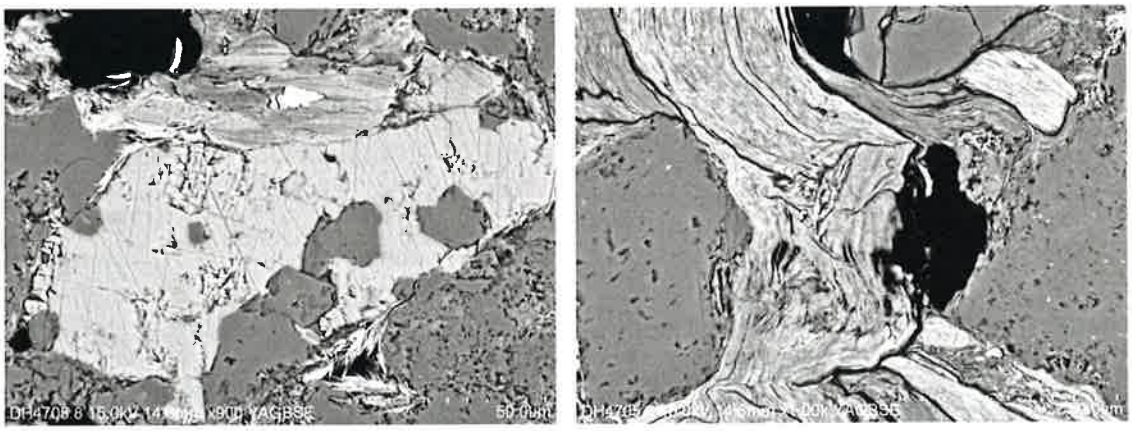
x20 xn



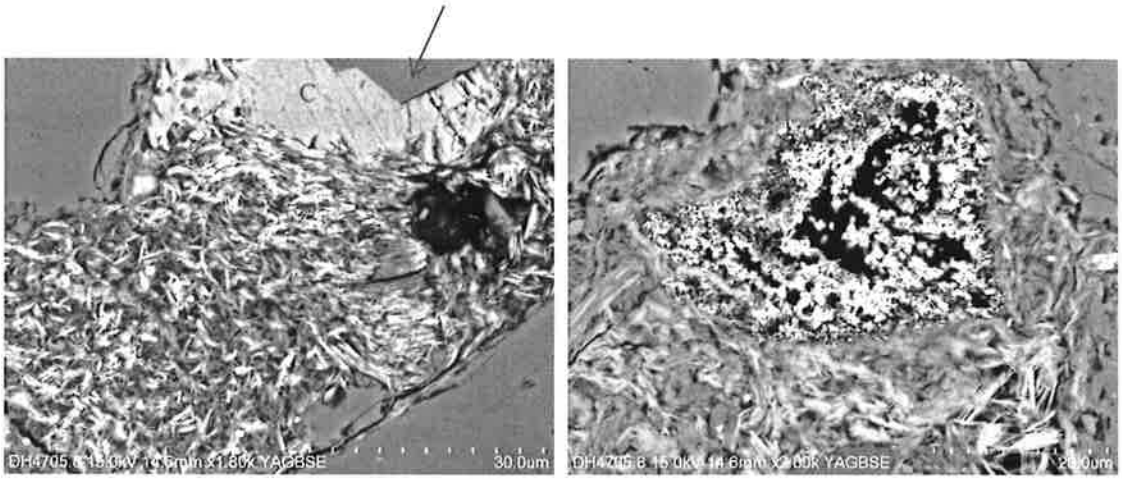
x20 lln

Closer view of texture, altered grains, opaque organics, clay matrix, blurred grain boundaries

SEM analysis



Left: Calcite cement, the clay cluster above is chlorite interlayered with illite. Right: Similar tight clays, apparently altered micas



Left: Quartz (arrow) >calcite (C)> clay mix (illite+chlorite) in pore. Right: Secondary porosity, Ti-oxide grains in center, similar clays.

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
705.8	2.2	19.2	39.5		26.8	5.3	1.8		5.3	0.9

Well : Dh4 **Depth, m: 708.8** **Type: Core/De Geerdalen/Isfjorden Mb**

Lithology	Siltstone, inhomogenous with different domains in microscope
Sorting	Fairly well
Grain size	Numerous scattered silt and fine sand
Grain shape	Angular- subangular
Porosity	Appears low

Detrital:

Fragments Black organic debris, microcrystalline quartz, phosphate fragment?

Grains Quartz, plagioclase, muscovite, local cluster of framboidal pyrite associated with organics

Authigenic:

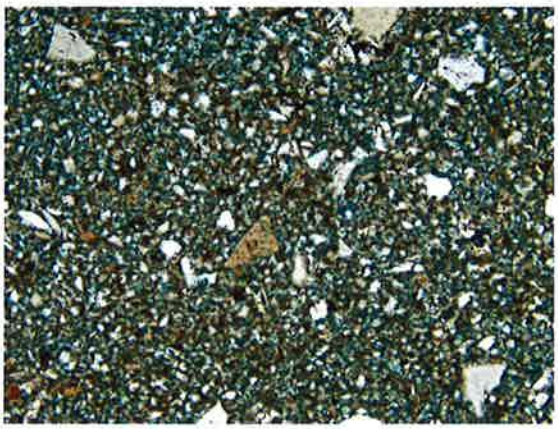
Cement One domain with very fine carbonate cement, siderite? (see XRD)

Clay Undefined in cloudy brownish domain, probably chloritic within green/blue domain?

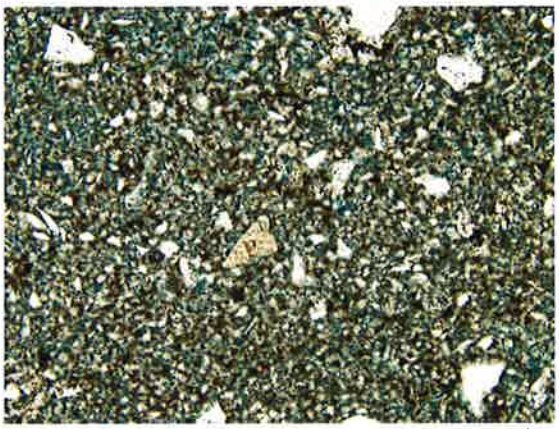
General: The brownish part appears similar to 703.7, nearly quite dark in polarised light (collophane?). The blue/green part appears higher in very irregular carbonate clusters.

Overview different domains, scattered grains. x4 xn

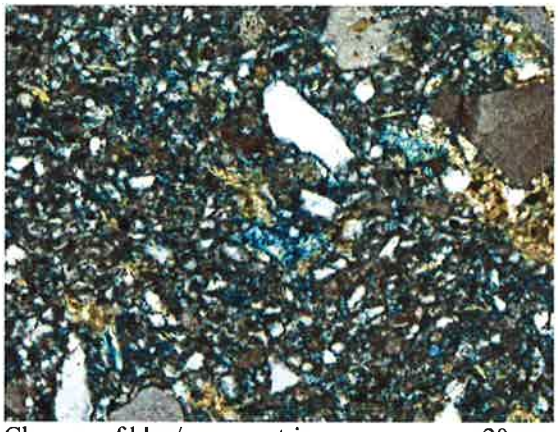
x4 ll n



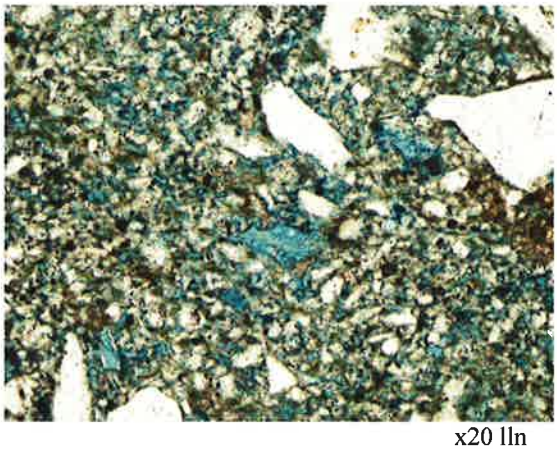
Closer view porous (bluish) part x10 xn



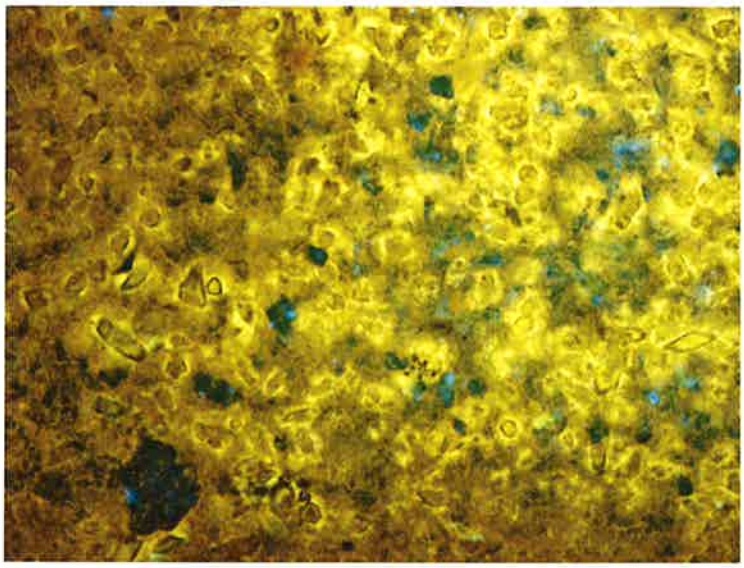
x10 lln



Close up of blue/green matrix x20 xn



x20 lln



x10 UV

Siderite? cemented domain

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
708.8	0.3	23.7	48.5		19.1	3.1	1.1	0.2	2.9	1.1

Well : Dh4 **Depth, m: 712.8** **Type: Core/De Geerdalen/Isfjorden Mb**

Lithology Weakly layered shale

Grain size Clay size, but sand – silt grains occur
Grain shape Visible grains often angular
Porosity None, except thin open, partly crosscutting fracture

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Detrital:
Fragments Polycrystalline quartz, chert

Grains Coarser grains: quartz, plagioclase, altered feldspar, muscovite-pale mica, zircon

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Cement A few carbonates observed

Clay Thin mica laths are recognised in the matrix, undefined . pale brown.clay

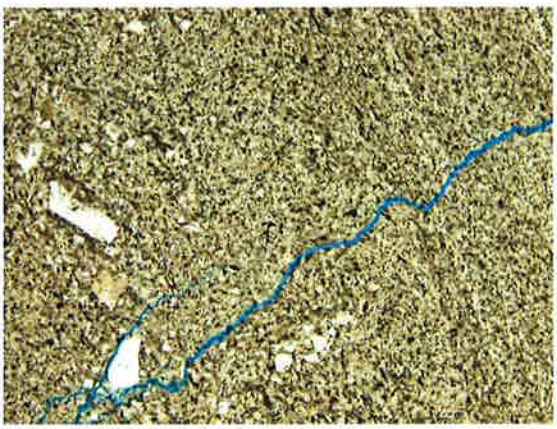
---

General: Variable layering, sediment structures (bioturbation- slumping). Layering commonly defined by more or less mica/clay. Scattered clay sized oxides, very scarce pyrite, organic debris also very scarce

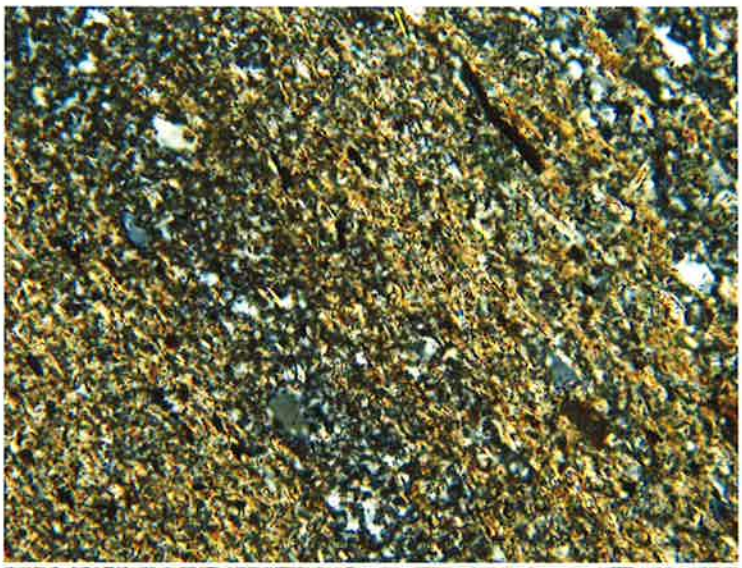
Inhomogenous shale x4 xn

x4 lln

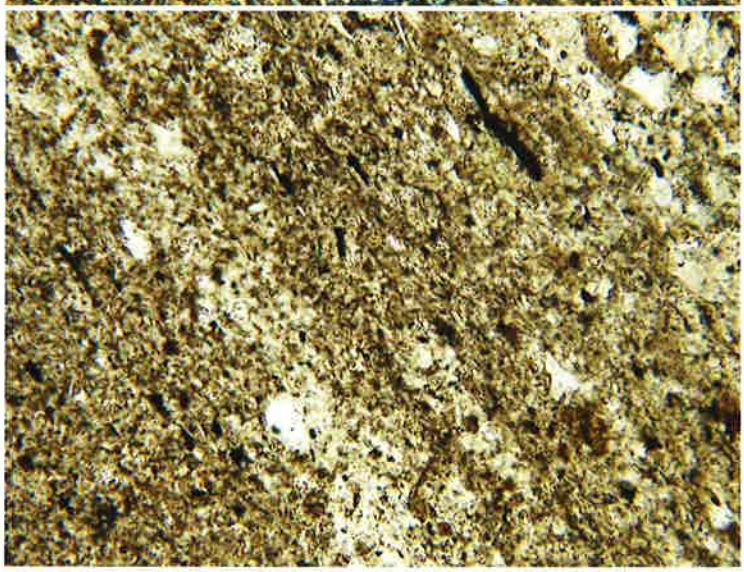
Thin open fracture x10 xn



x10 lln



x10 xn



x10 lln

Closer view of texture, thin mica laths can be discerned

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
712.8	6.9	27.3	39.1		17.4	4.4	1.1	0.1	3.1	0.6

Well : Dh4 **Depth, m:718.4** **Type: Core/De Geerdalen/Isfjorden Mb**

Lithology	Sandstone
Sorting	Appear well (disturbed by compaction)
Grain size	Medium sand
Grain shape	Subangular – irregular due to compaction
Porosity	Variable, not connected, partly tight, some oversized pores

Detrital:

Fragments Microcrystalline quartz-chert, polycrystalline quartz, plutonic or altered feldspar, altered diabas?, fine grained sediment, squeezed ductile grains (shale clast?), schist, phosphatic

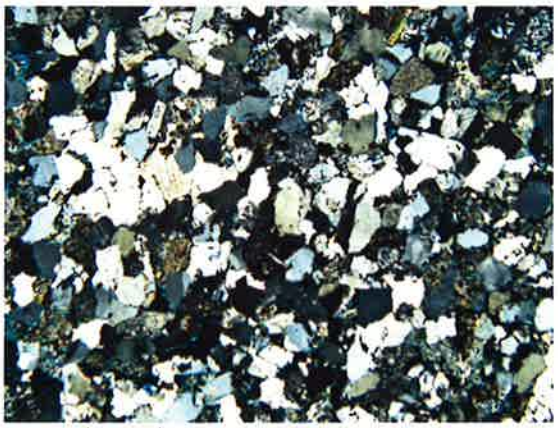
Grains Quartz, plagioclase, muscovite, zircon

Authigenic:

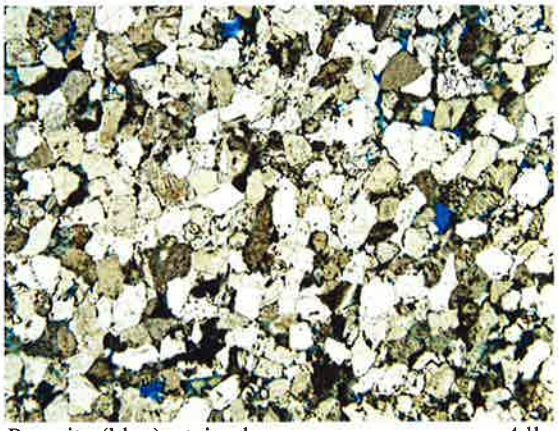
Cement Local carbonate, quartz overgrowths, feldspar overgrowths also observed. Local cluster of small siderite grains. Very local phosphatic

Clay Clay clasts mostly detrital altered grains?

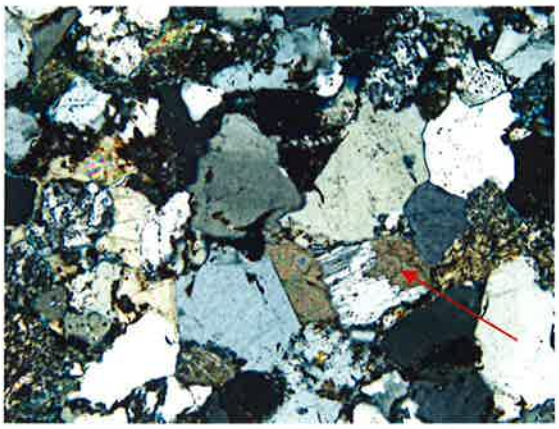
General: Complex composition with various fragments and grains. Black-dark brown organic appear more as bitumen or oil stain than debris material., reflectance not seen. Plagioclase grains variably altered, Plagioclase cement> quartz cement (appears as), carbonate is youngest. Irregular, fluorescent oil inclusions in altered plagioclase, following twin lamellaes

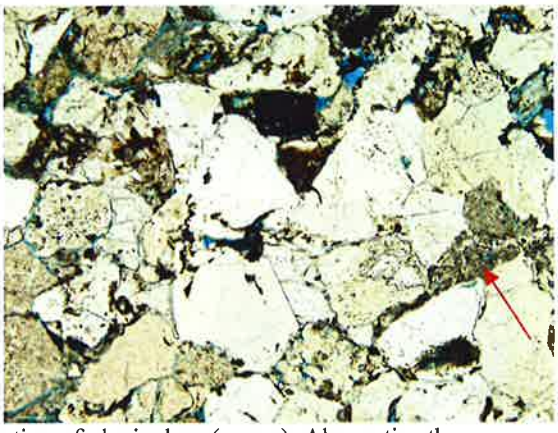


Textural overview x4 xn



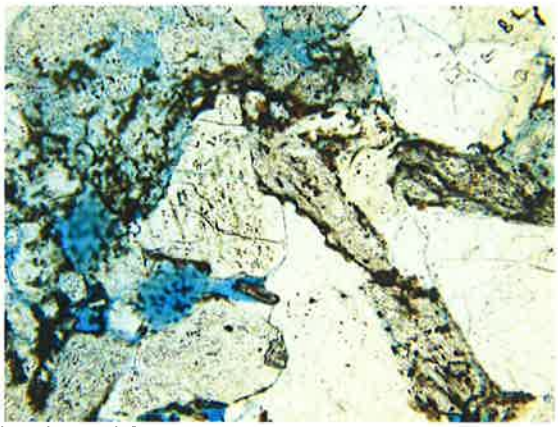
Porosity (blue), stained appearance x4 lln





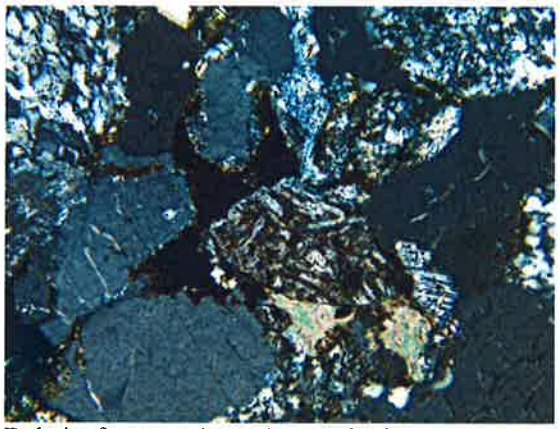
Quartz overgrowths, carbonate cement, carbonate alteration of plagioclase (arrow). Also notice the occurrence of organics. Local siderite (arrow right)

x10 xn x10 lln

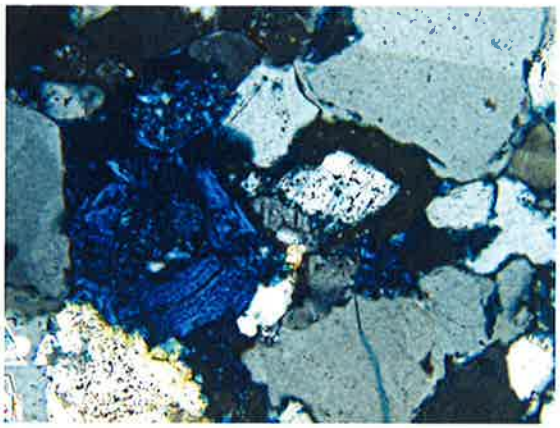
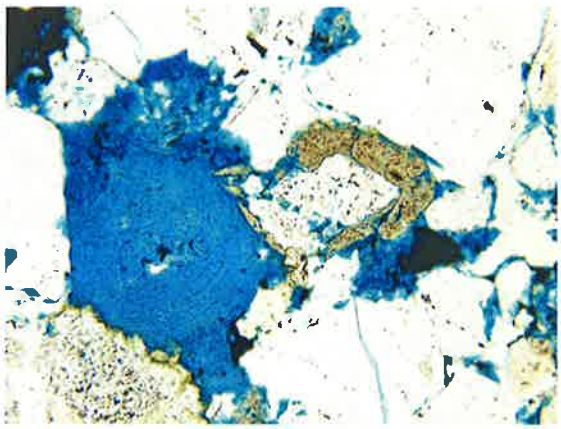
Feldspar overgrowth > quartz cement (arrow). Altered grains and fragments

x20 xn x20 lln



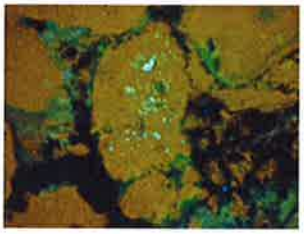

Dolerite fragment (center), organics in pore and at grain boundaries

x20 xn x20 lln

Local phospogene cement (brown), remnants of oolite now circular orientation of clay (arrow)

x20 xn x20 lln



x40 UV

Oil inclusions in plagioclase

Well : Dh4 **Depth, m:721.5** **Type: Core/Isfjorden Mb/De Geerdalen Fm**

Lithology	Inhomogenous, shale -ssiltstone, greenish
Sorting	Well – moderately well
Grain size	Clay-silt-fine sand
Grain shape	Angular, subangular
Porosity	None or very low

Detrital:

Fragments Schist, microcrystalline quartz, organic debris (small grains)

Grains Quartz, plagioclase, muscovite, Scattered oxides, very small framboidal pyrites, zircon,, chlorite laths, rutile, phosphogene grains

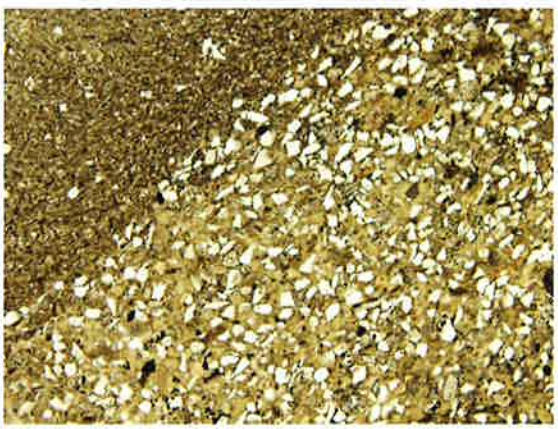
Authigenic:

Cement Partly carbonate cemented, corroded- dissolving, phosphogene?(apatite-collophane)

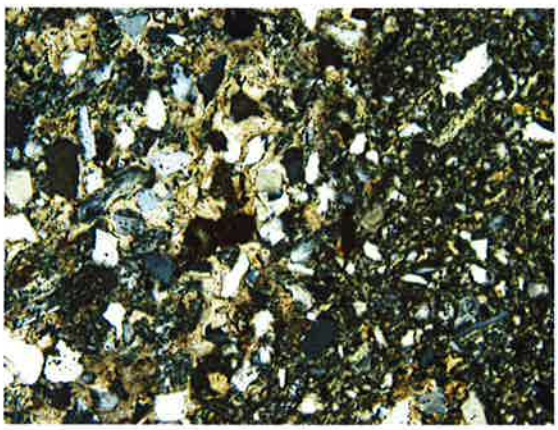
Clay 7Å chlorite-probably related to altered glauconite?

General: Fine sand-silt grains floating in greenish matrix of chloritic clay, altered glauconites? The chlorite has dark grey interference colours, appears dark in polarised light. Apatite/collophane probably present (needs verification by SEM)

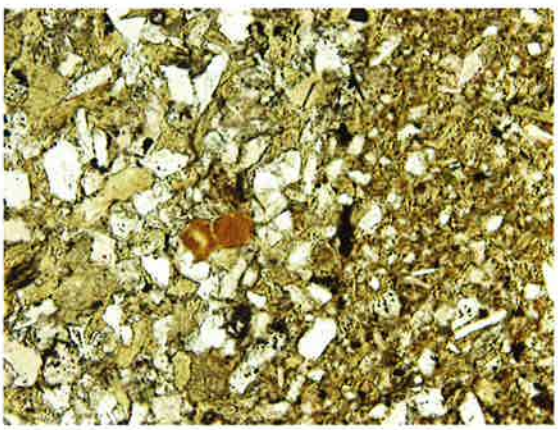
Shale-silt layer, mica laths can be discerned x4 xn



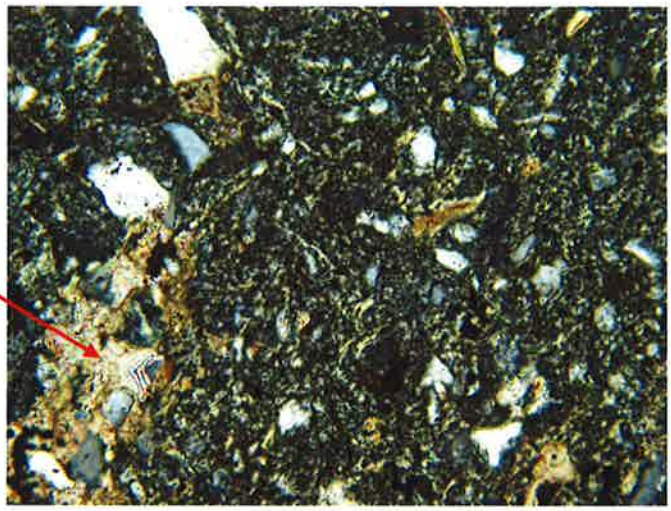
Greenish-brown clay matrix (phosphogene) 4 lln



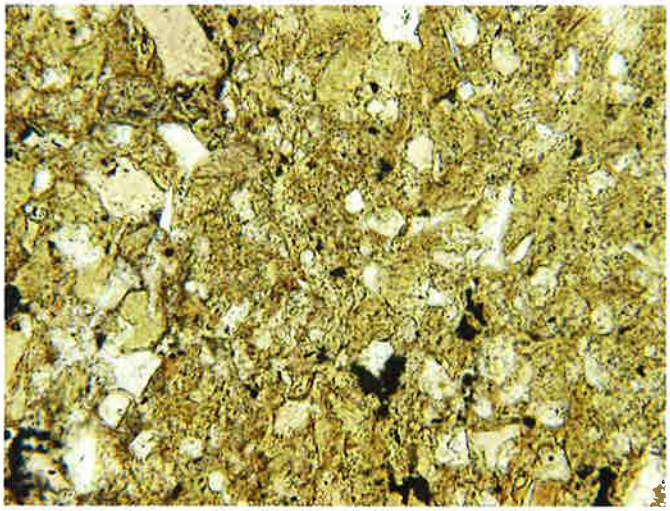
Closer view, dissolving carbonate cement x10 xn



Brown grain in center: possibly phosphogene x10 lln



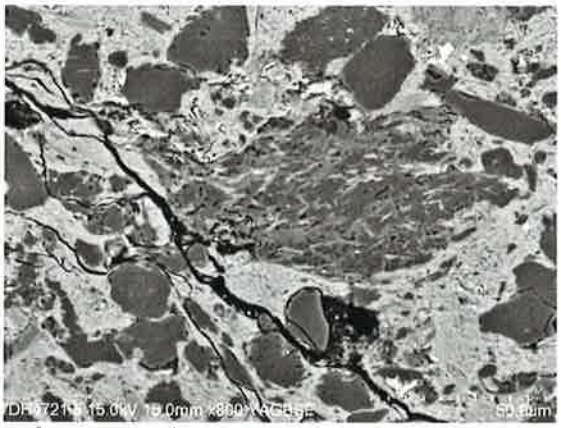
x20 xn

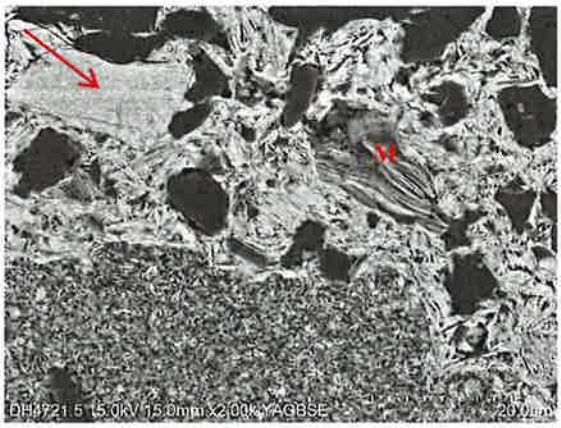


x20 lln

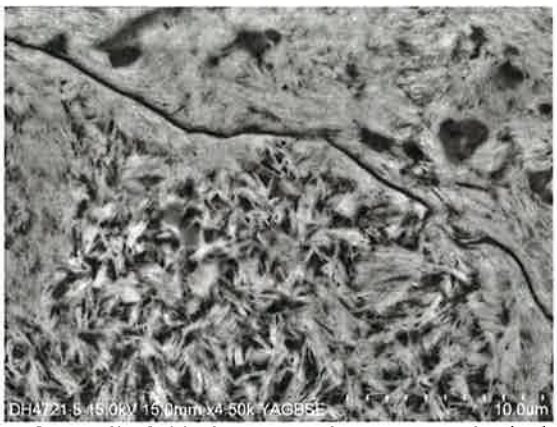
Closer view of the matrix, mica laths are discerned, otherwise nearly isotropic in polarised light. Dissolving carbonate on the left side (arrow)

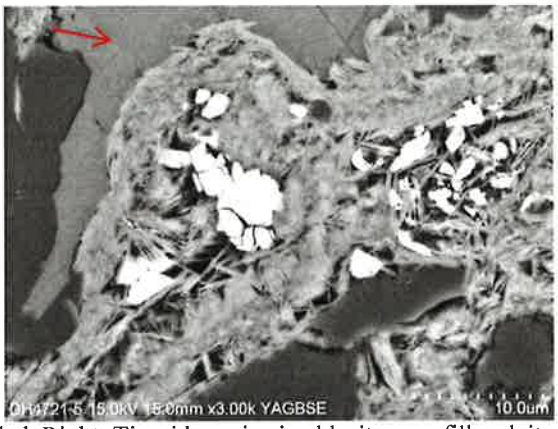
SEM analysis:



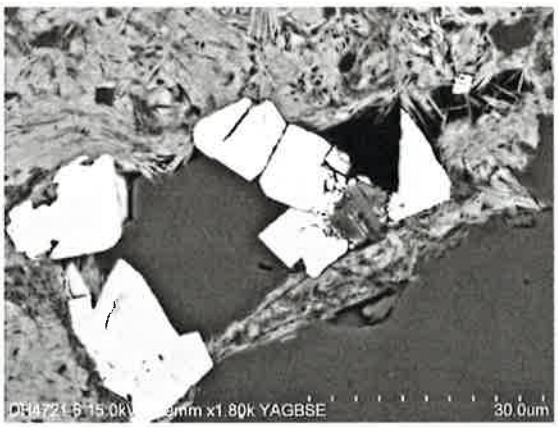


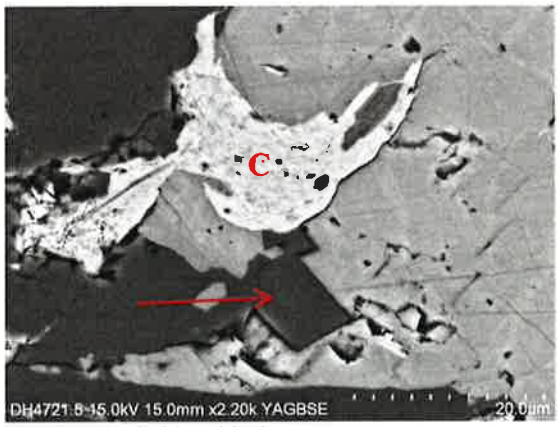
Left: Quartz grains floating in chloritic clay, in center a mix of quartz, chlorite and illite.
Right: Chlorite grain (arrow), mica/illite (M), clays are various morphology of chloritic type





Left: Detail of chlorite texture tiny quartz grains included. Right: Ti-oxide grains in chlorite pore fill, calcite cement (arrow) and quartz grains.





Left: Authigenic Ti-oxides predation authigenic quartz (Q) surrounded by chlorite.
Right: Authigenic albite (arrow) predating calcite cement, chlorite (C) is later.

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
721.5	0.0	26.4	36.7		23.1	7.2	1.0	0.1	3.0	1.5

Well : Dh4 **Depth, m:727.3** **Type: Core/Isfjorden Mb/De Geerdalen Fm**

Lithology	Inhomogenous siltstone with shaly irregular layers
Sorting	Moderately well within each layer
Grain size	Clay-silt, local fine sand
Grain shape	Angular-subangular
Porosity	None

Detrital:

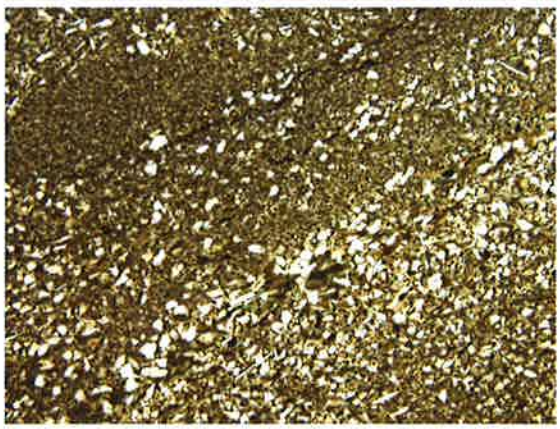
Fragments	Altered glauconite? (few). Scattered tiny organics. Mostly monomin.grains. Chert
Grains	Quartz, plagioclase, muscovite, apatite/collophane?, biotite/chlorite (few –pleocroic), a few tiny oxides

Authigenic:

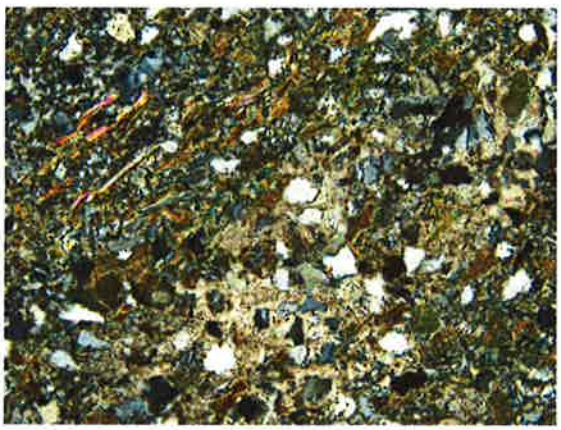
Cement	Very local dissolving/blurred carbonate
Clay	Clay matrix, probably detrital, brown (greenish) colour in plain light, appear nearly isotropic in polarised light (chloritic)

General: Bad polish, appear somewhat similar to 721.5.

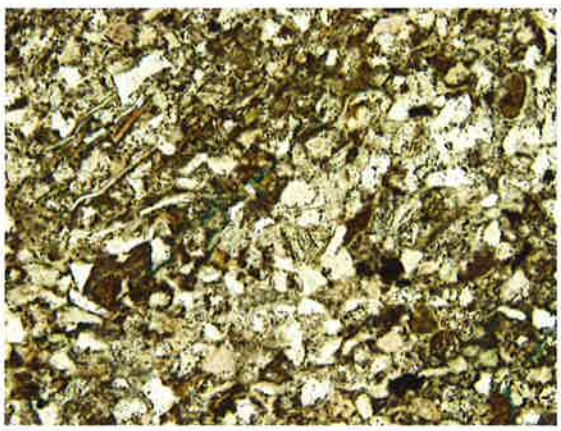
Alternating layers x4 xn



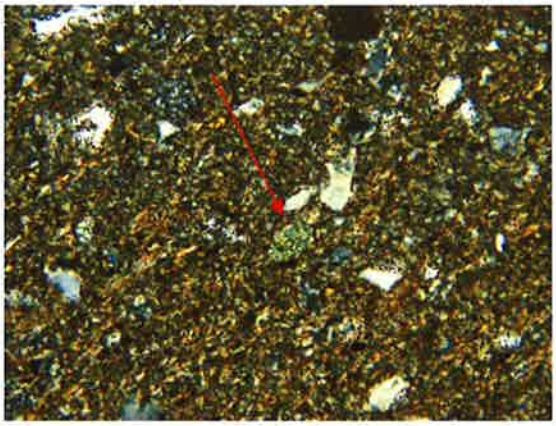
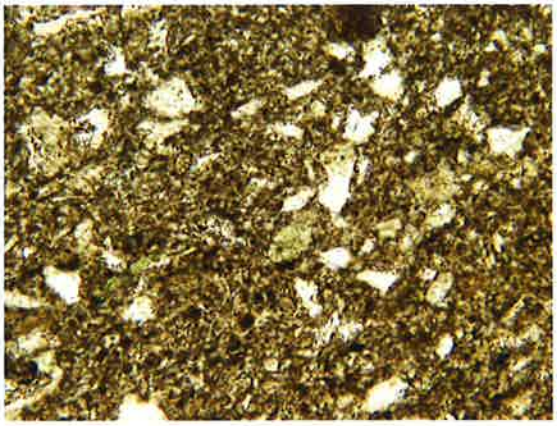
x4 lln



Closer view silty part, clay matrix, dissolving carbonate (center)
x10 xn

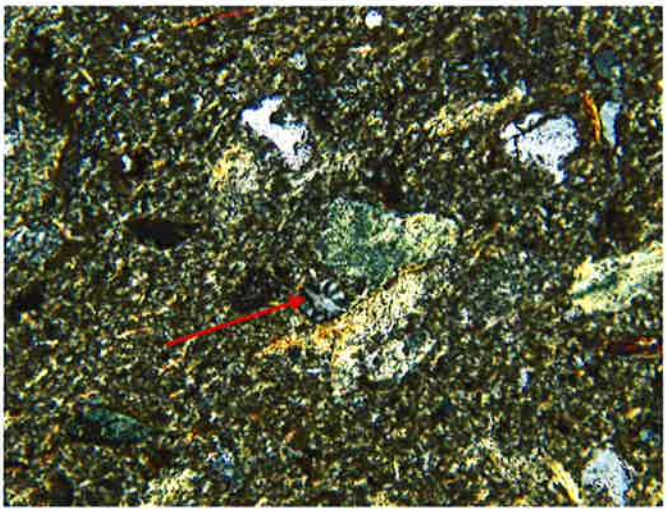


x10 lln

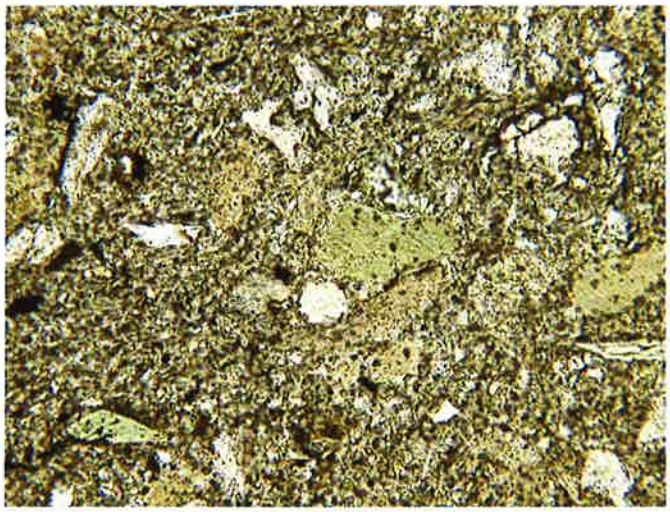



Close up of clay matrix, altered glauconite in center (arrow)

x20 xn x20 lln



x20 xn



x20 lln

Similar view, radial chert in center (arrow), close to altered glauconite, altered mica and clay matrix

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
727.3	2.3	45.3	30.3		12.2	4.3	1.0	0.1	3.3	1.1
727.3	12.5	35.0	30.8		12.5	4.7	0.5	0.1	2.8	1.1

Well : Dh4 Depth, m: 769.9 Type: Core/Isfjorden Mb/De Geerdalen Fm

Lithology	Pyrite cemented layer
Sorting	Well sorted
Grain size	Fine-medium
Grain shape	Angular? Enclosed in the pyrite cement
Porosity	None

Detrital:	
Fragments	Very low if any; microcrystalline quartz
Grains	Quartz, plagioclase, altered feldspars, muscovite, chlorite, zircon

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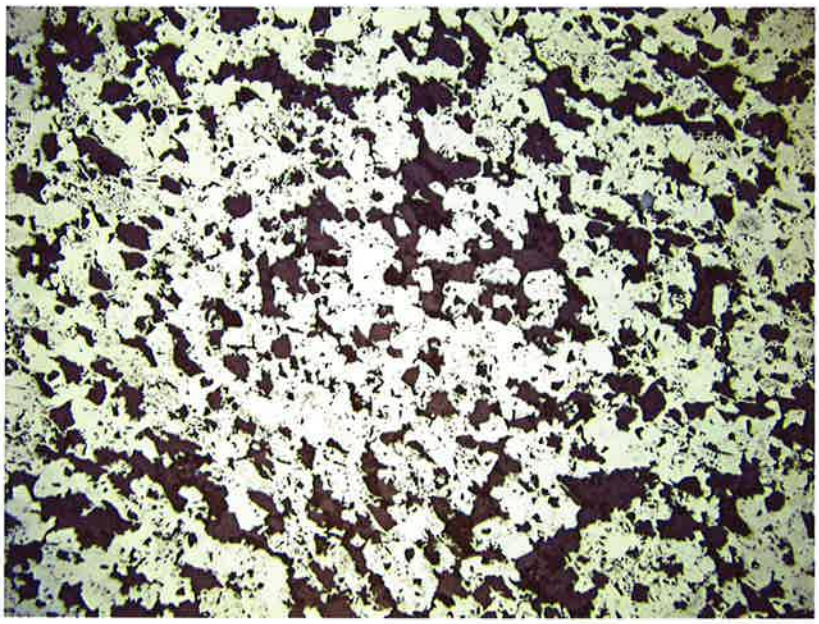
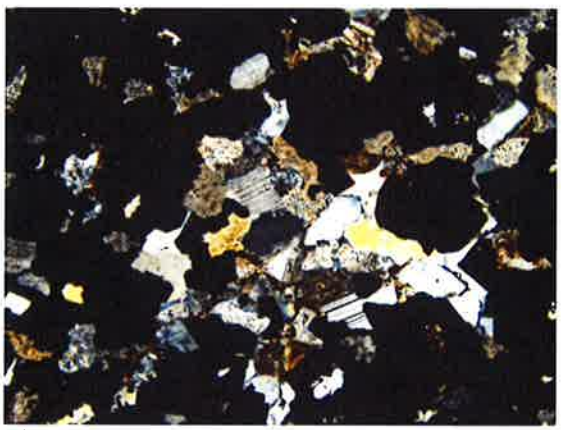
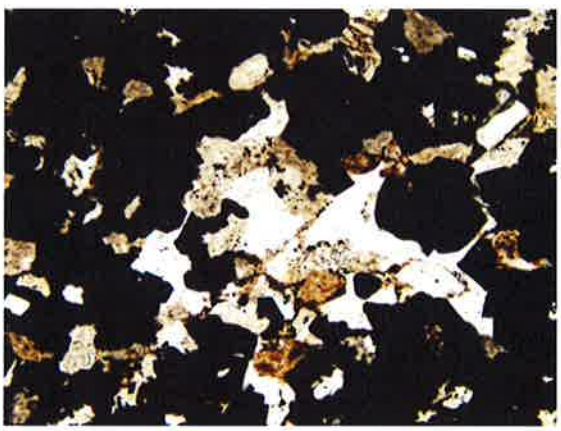
Authigenic:	
Cement	Pyrite
Clay	Alteration product (?), not obvious as cement

General: Heavily cemented by crystalline pyrite, also intruding fingers into grains



x4 reflected light
Texture, pyrite cement (pale)





Closer view, plagioclase grains (center), pyrite texture
x10 xn x10 ll

Well : Dh4 **Depth, m: 770.10** **Type: Core/De Geerdalen Fm**

Lithology	Dark layered sand/siltstone
Sorting	Fairly well within layers
Grain size	Fine sand/silt
Grain shape	Subangular/compacted
Porosity	Generally low, except thin fractures and small irregular domains

Detrital:

Fragments Not common, a few polycrystalline quartz and plutonic (quartz+feldspars), fine organic debris, unspecified ductile grains. microquartz (chert?)

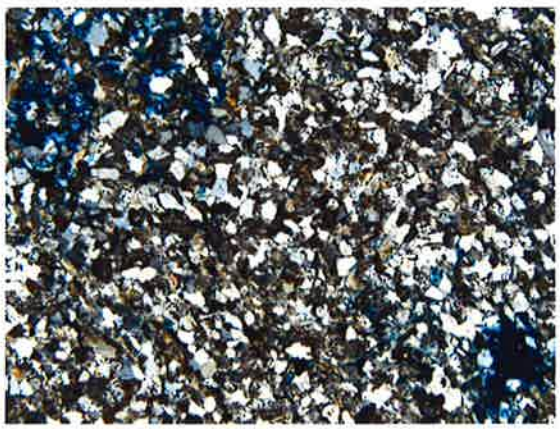
Grains Quartz, plagioclase, muscovite, chlorite, a few biotites, scattered oxides and pyrites, probably altered glauconites, scattered organics, zircon. Brown grains: phosphatic?

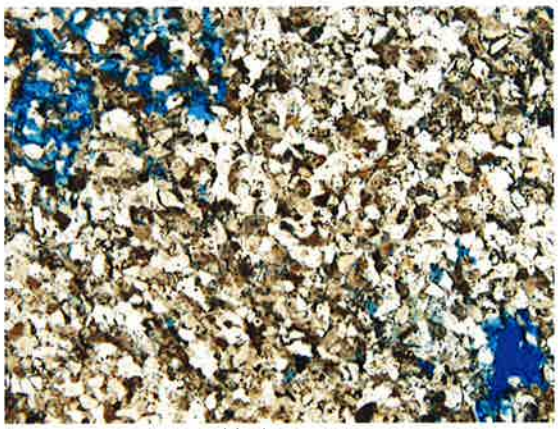
Authigenic:

Cement Small domain with carbonate cement , scattered sparry carbonate. Local quartz overgrowths (pre-compaction)

Clay Within clay clasts and disrupted shale layers, probably not diagenetic but altered ductile grains

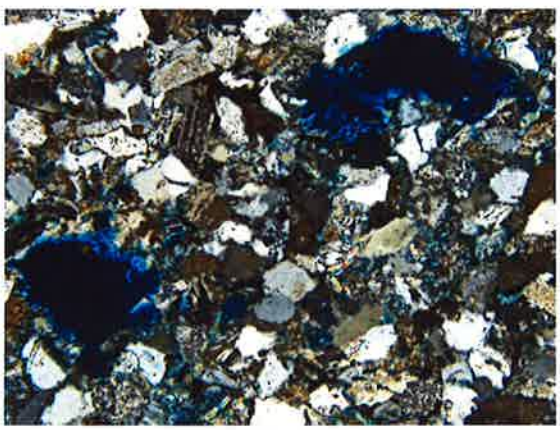
General: Sampled for fracture evaluation. Difficult to establish the reason for porosity domains- artificial or oversized (dissolution) pores? The sample appears compacted and ductile grains are squeezed – probably not much remnant microporosity available. Sealed hairline fracture type?

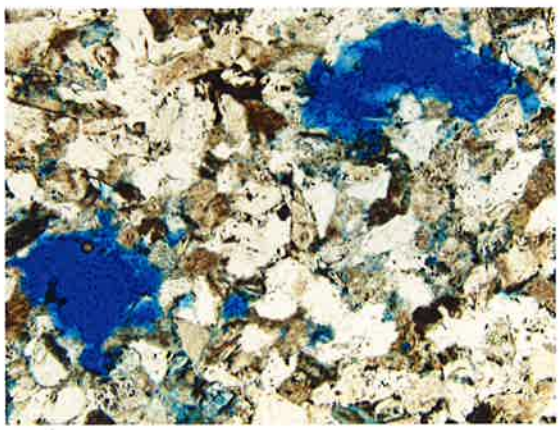




Overview. Porous domain and oversized pore (down right). Well compacted in between.

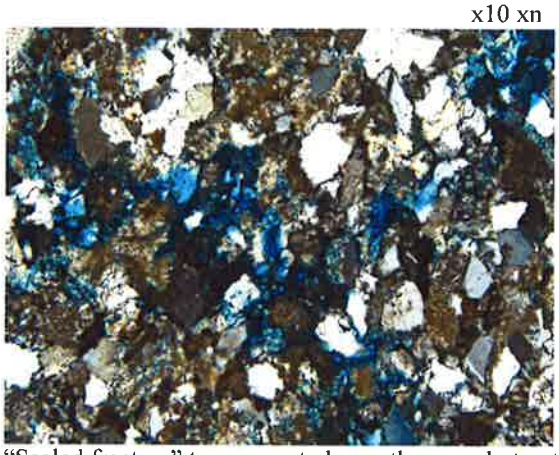
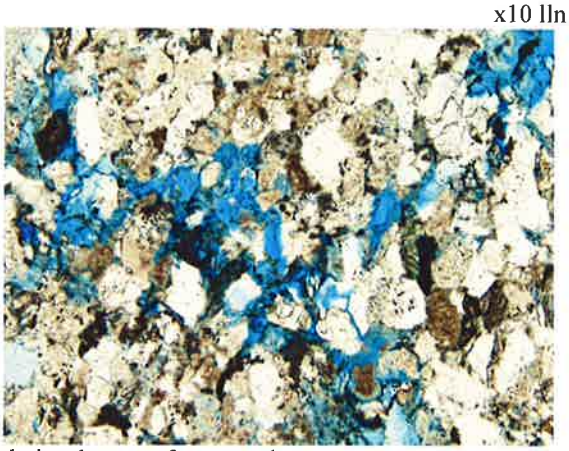
x4 xn x4 lln





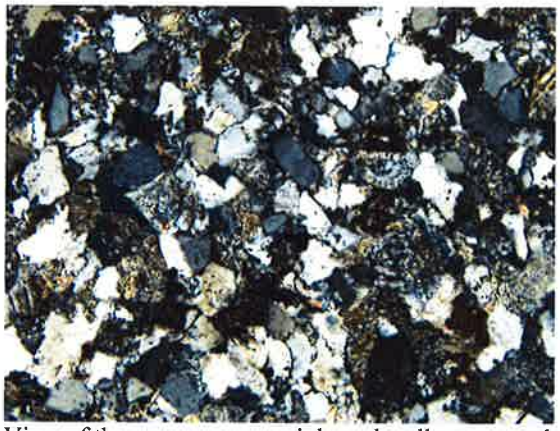
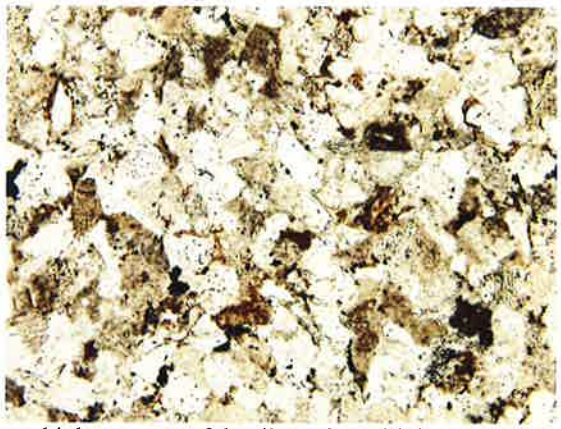
Closer view oversized pores without direct or poor connection

x10 xn x10 lln

"Sealed fracture" type, seen to be partly open, but not obviously part of a network.

x10 xn x10 lln

View of the more common tight and well compacted part, high contents of ductile grains with low microporosity

x10 xn x10 lln

Zoned zircon seen in UV mode- length of crystal : 0.1mm

Well : Dh4 Depth, m:771.3 Type: Core/Isfjorden Mb/De Geerdalen Fm

Lithology	Sandstone
Sorting	Fairly well
Grain size	Fine-medium sand
Grain shape	Subangular, ofter blurred/irregular grain boundaries
Porosity	Moderate, both primary and secondary

Detrital:

Fragments	Felsic plutonic (quartz±feldspars), microcrystalline quartz, scattered organics
Grains	Quartz, plagioclase, microcline, scattered micas (muscovite), chlorite, zircon, oxides, pyrites

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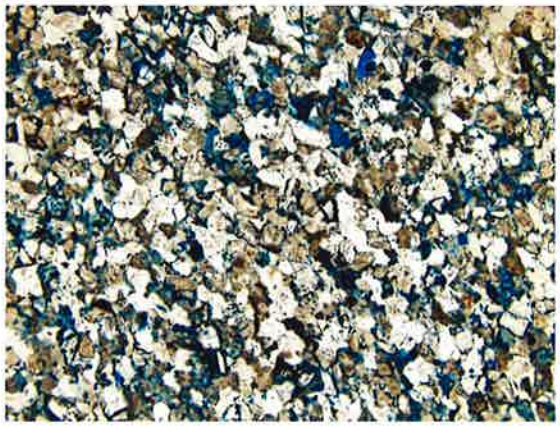
Authigenic:

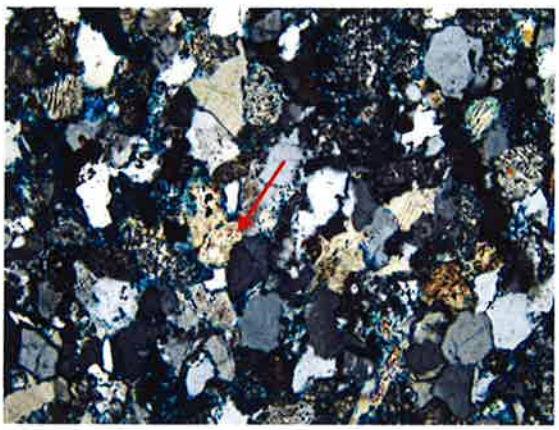
Cement	Local carbonate, also in local grain clusters, quartz overgrowths occur
Clay	Very altered feldspar grains appear similar to clay clasts , also authigenic clay in pores (undefined, probably I/S and/or chloritic, possibly traces of kaolin)

General: Irregular texture with blurred grain contacts, local compaction (or mechanically altered fragments), extensive alteration of feldspar but also unaltered grains, feldspar dissolution (secondary porosity)

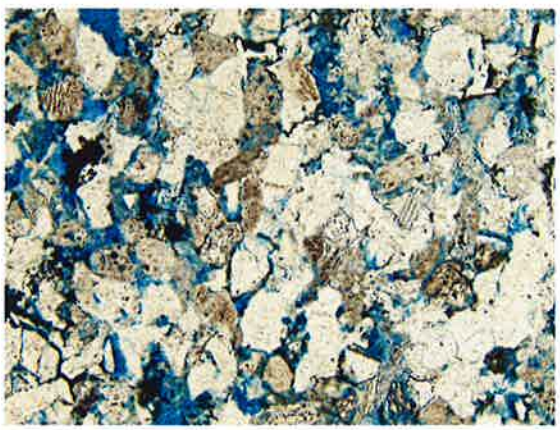
Textural overview x4 xn



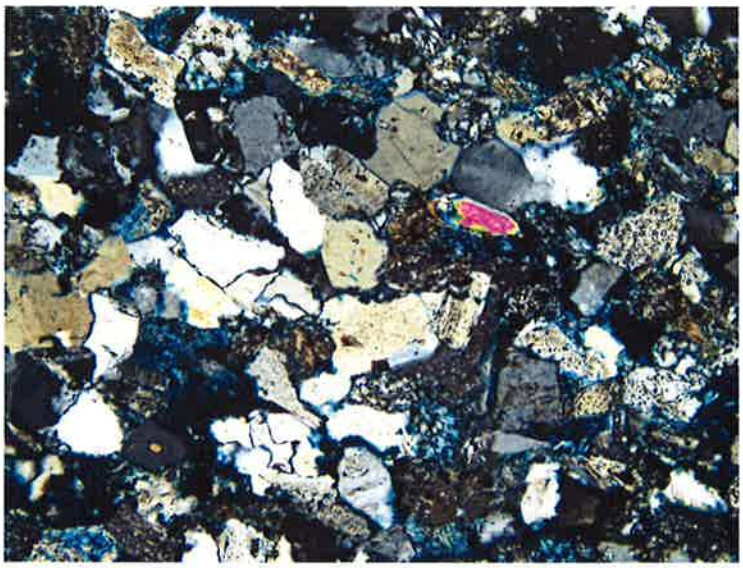
x4 lln



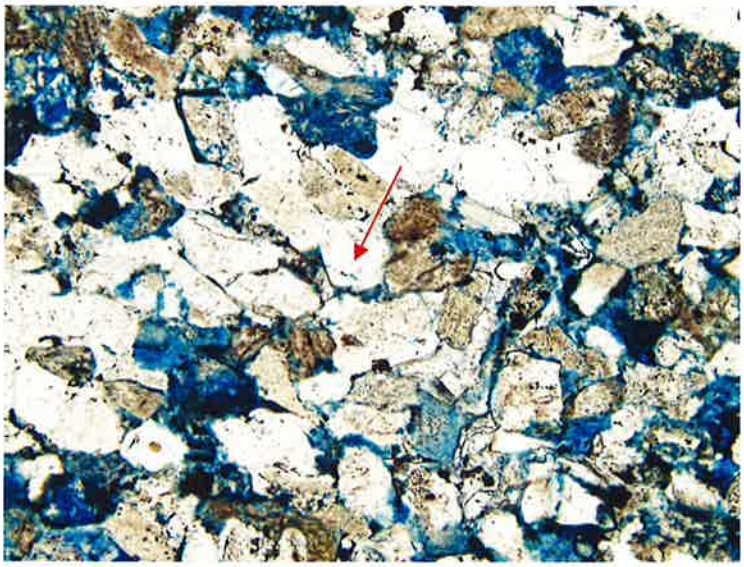
Cøoser view, carbonate cement (arrow) x10 xn



x10 lln



x10 xn



x10 lln

Local quartz cement (arrow), porosity, ductile grains, dissolving grains, scattered opaques.

XRD

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
771.3	2.8	18.0	38.8		28.6	8.6	0.6	0.3	1.4	0.8

Well : Dh4 **Depth, m: 772.9** **Type: Core/De Geerdalen Fm**

Lithology	Fine/medium sandstone
Sorting	Good
Grain size	Medium sand
Grain shape	Often irregular (some compaction)
Porosity	Moderately good, often secondary

Detrital:

Fragments Ductile grains may be altered mica rich fragments, polycrystalline quartz, metamorphic, plutonic?

Grains Quartz, plagioclase (often cloudy due to alteration), muscovite (often altered), microcline, perthitic feldspar, local irregular pyrite, chlorite laths, rutile,

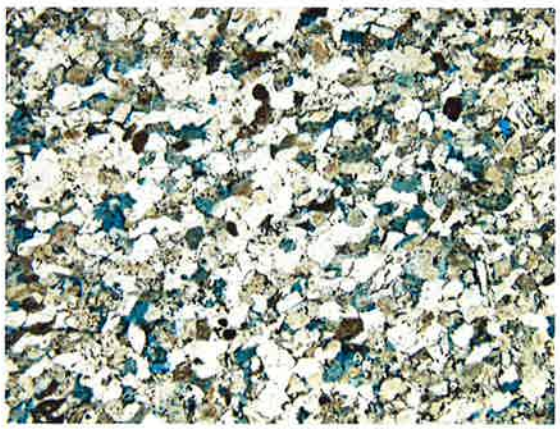
Authigenic:

Cement Quartz overgrowths, local sparry carbonate

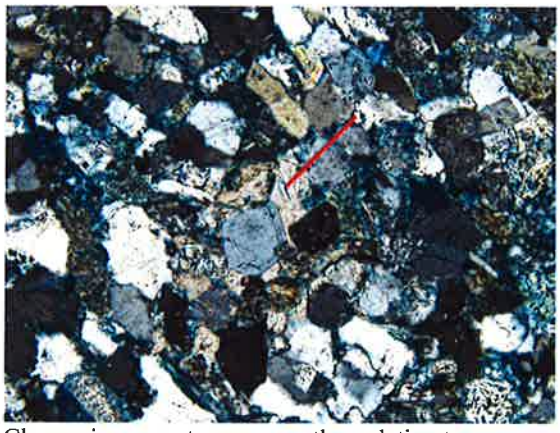
Clay Matrix: clay, probably illlitic + chloritic, probably mix of altered detrital grains and pore fill

General: Very irregular texture with blurred quartz/feldspar grain boundaries, partly due to compaction and interaction between detrital resistant grains and ductile grain/matrix. Overgrowths are obvious, seen to predate (at least) two generations carbonate cement. Although porosity appears moderately good, the permeability is estimated to be low (irregular texture, secondary pores, poor communication)

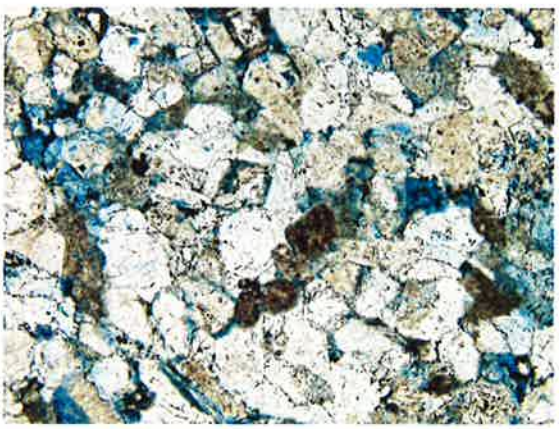
Overview texture x4 xn



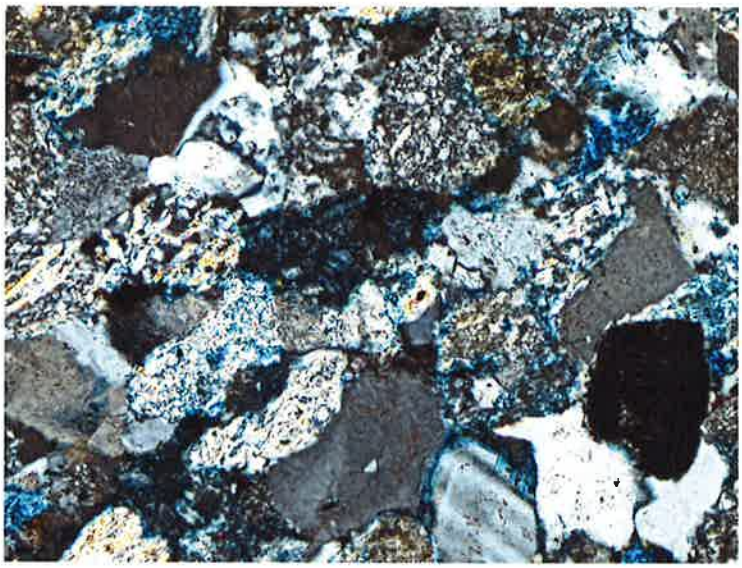
x4 lln



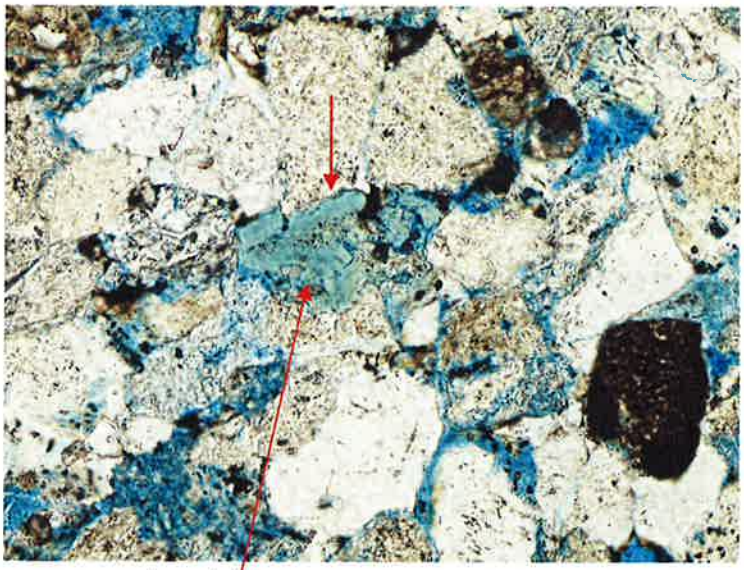
Closer view, quartz overgrowth predating two generations carbonate cement in center (arrow) x10 xn



x10 lln

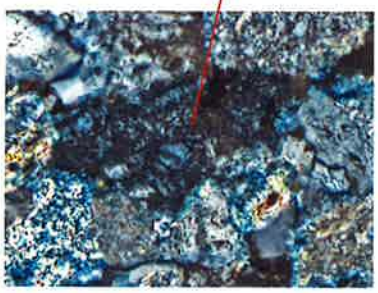


x20 xn



x20 lln

Detrital grain boundaries, ductile grains, altered grains. Authigenic greenish clay, probably chloritic (arrow)



XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
772.9	2.7	16.4	39.7		29.9	8.3	0.7	0.1	1.4	0.8

Well : Dh4 **Depth, m: 775.8** **Type: Core/De Geerdalen Fm**

Lithology	Sandstone
Sorting	Good
Grain size	Fine - medium
Grain shape	Appears subangular, (some compaction)
Porosity	Moderate

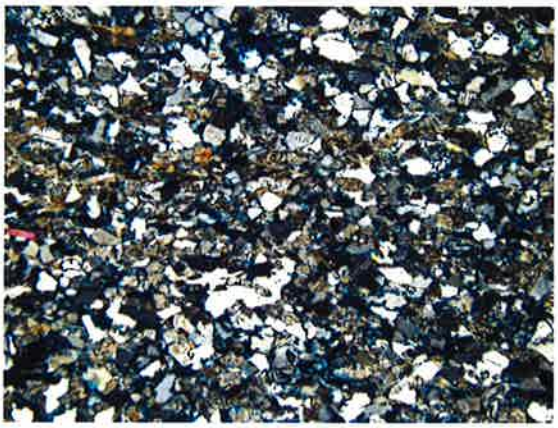
Detrital:

Fragments	Some mud clasts?, low in obvious rock fragments,
Grains	Quartz, plagioclase, microcline, muscovite, altered micas, myrmekite, rutile, chlorite, scattered opaques (oxides), probably low in organics, glauconite, tiny heavy minerals (zircons?)

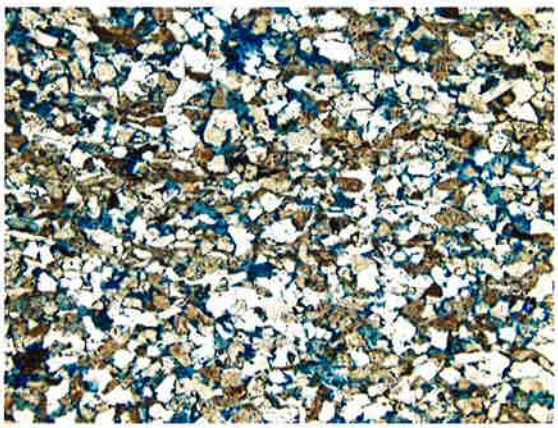
Authigenic:

Cement	Local carbonate, also located in clusters, quartz overgrowths occur
Clay	Undefined clay, as alteration product and/or diagenetic?

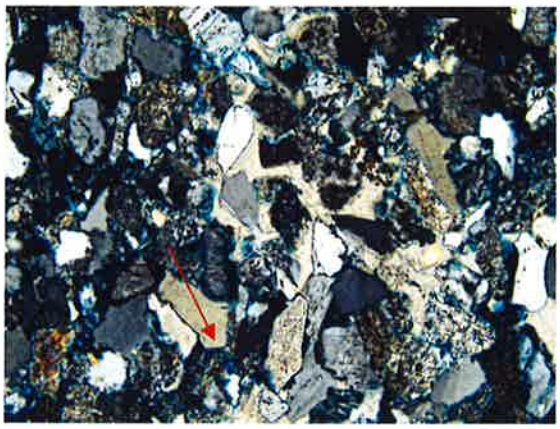
General: Appear similar to 771.3, fine homogenous sandstone, immature – common feldspars, textures appear influenced by contents of ductile grains, although quartz overgrowths are seen, as well as dissolving feldspars. Small brownish shale/mud clasts occur. Often difficult to decide whether clay it is clasts, altered mica or altered other grain



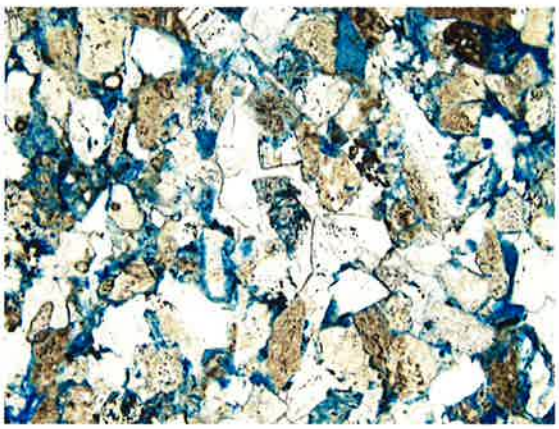
Textural overview x4 xn



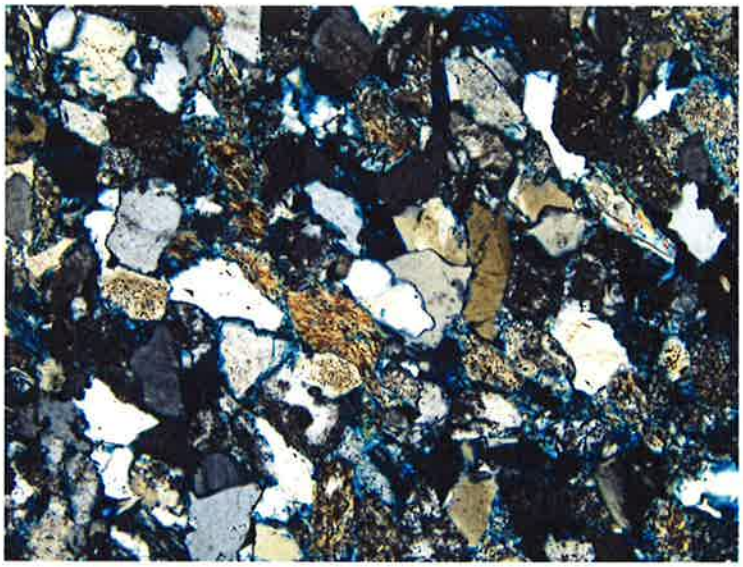
x4 lln



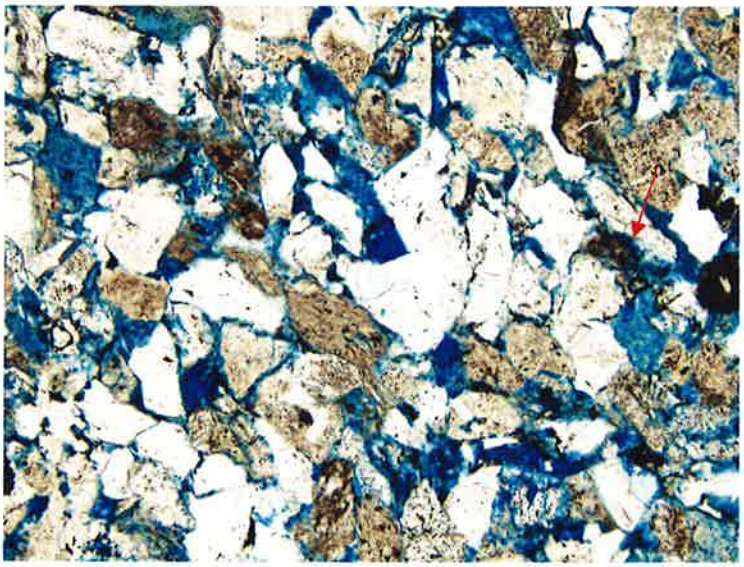
Local sparry carbonate cement in center, also quartz overgrowth (arrow) x10 xn



x10 lln



x10 xn



x10 lln

Shale/mud clast in center (brown), altered grains, cluster of tiny heavy minerals (arrow)

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
775.8	8.0	13.1	36.7	3.0	30.2	4.1	1.2	0.3	2.9	0.9
775.8	1.1	14.6	38.6	2.5	31.9	5.5	2.0	0.2	2.3	1.1

Well : Dh4 **Depth, m:776.5** **Type: Core /De Geerdalen Fm**

Lithology	Fine/medium sandstone, thinly laminated
Sorting	Fairly good
Grain size	Fine-medium sand
Grain shape	Subangular
Porosity	Low, in coarser domains slightly higher. Thin open fractures occur.

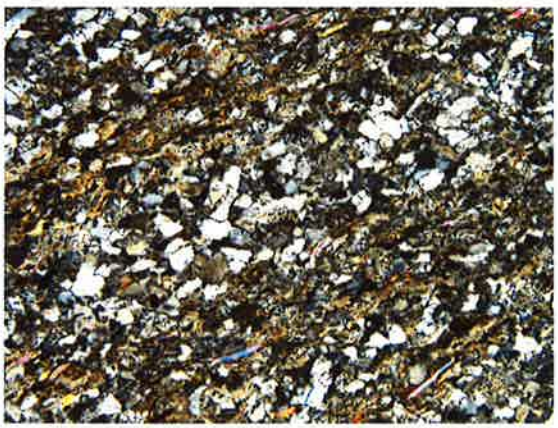
Detrital:

Fragments	Not common, probably some plutonic (coarser quartz-feldspar), ductile clay clasts, microcrystalline quartz (chert?), some organic debris, schist?, diabas?, a few very altered glauconites
Grains	Quartz, plagioclase, microcline, muscovite, chlorite, biotite remnants, zircon, scattered tiny oxides, rutile

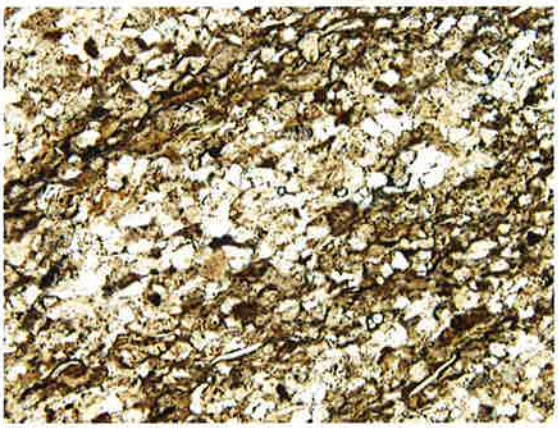
Authigenic:

Cement	Local sparry carbonate, corroded grain boundaries. Remnants of quartz overgrowths, occasionally also feldspar overgrowths
Clay	Probably detrital, in ductile clay clasts, often related to mica alteration

General: Appears quite tight, mostly due to the amount of clay clasts and altered mica, but also some compaction. Mica/illite is common, kaolinite is not identified in the microscope. The significance of the very thin fractures is not obvious, but a communication with the scarce porosity seems poor. Appear related to weak zones with sheet silicates.



Texture, thin lamina with sheet silicates x4 xn

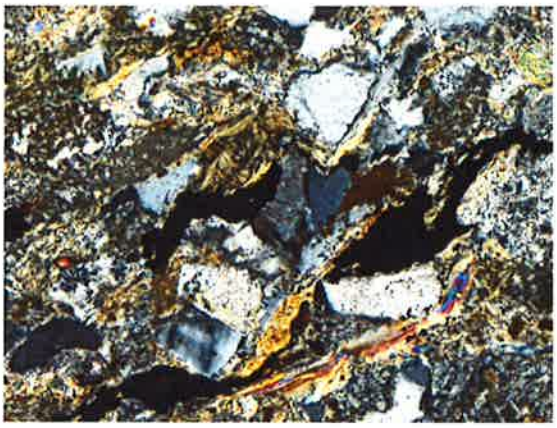


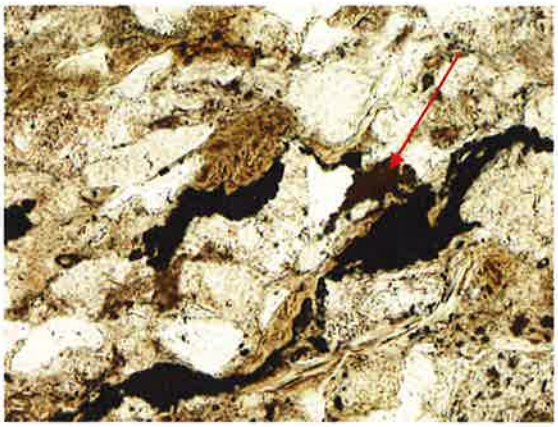
x4 lln

Closer view of "clay clasts", the relation to mica alteration is often obvious

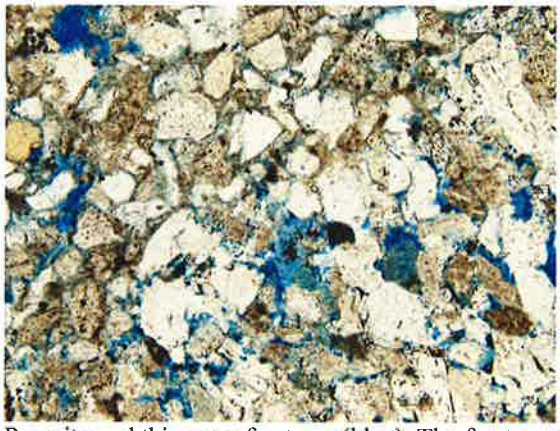
x10 xn

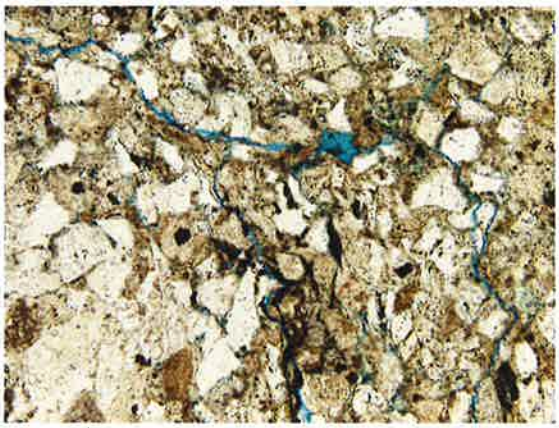
x10 lln



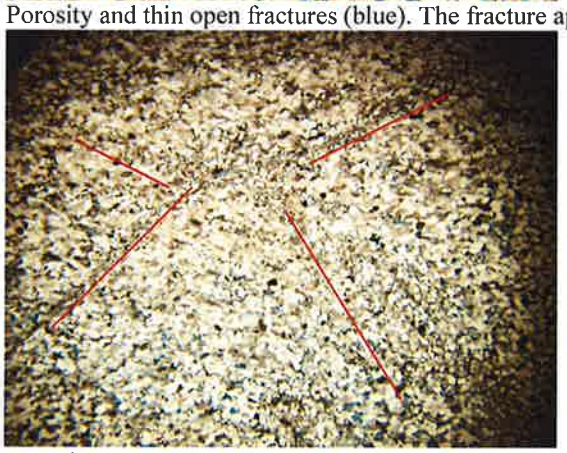


Detail mica/clay and opaques shown in polarised light (upper left), plain light (upper right) and reflected light (right). It is seen that some of the opaques are organics with some reflectance, as well as oxides, probably Ti-oxides (arrow). x10





Porosity and thin open fractures (blue). The fracture appears without clear relation to porosity. x10 lln



Overview showing outlined directions of possible fractures often very poorly defined, sometimes open and sometimes not. x1.5 lln

Well : Dh4 Depth, m: 779.30 Type: Core/De Geerdalen Fm

Lithology	Fine sandstone
Sorting	Fairly well
Grain size	Fine (up to 0.25 mm)
Grain shape	Disturbed by compaction
Porosity	Generally low, irregularly distributed, secondary, also a few oversized pores

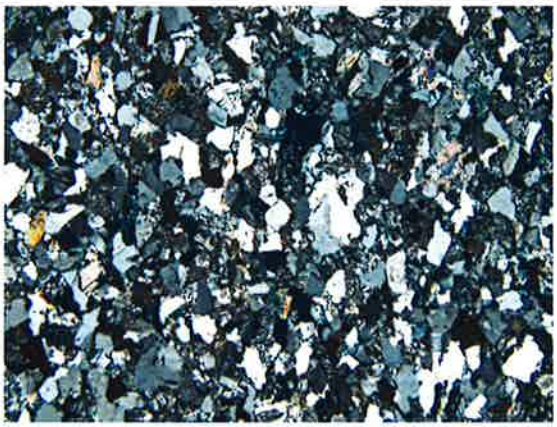
Detrital:

Fragments	Polycrystalline quartz, microcrystalline quartz, altered dolerite, spiculite?
Grains	Quartz, plagioclase, microcline, muscovite, altered ductile grains, biotite, zircon. rutile, chlorite

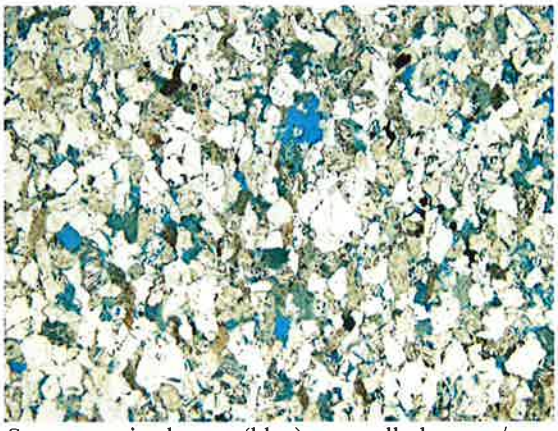
Authigenic:

Cement	Local sparry carbonate, quartz overgrowths, feldspar overgrowths
Clay	Undefined, probably chloritic, commonly related to altered grains

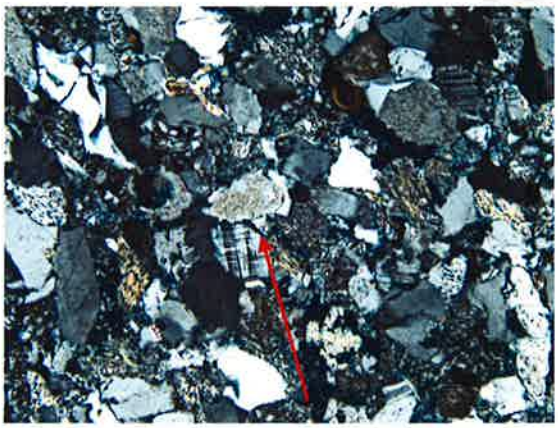
General: Feldspars are often highly altered but occur also rather fresh as well. Clay as pore fill appears to be very low. The carbonate cements are locally dissolving.



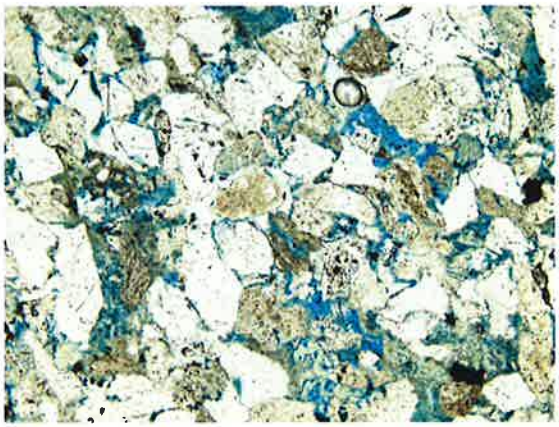
Textural overview, quartz cementation, compaction. x4 xn



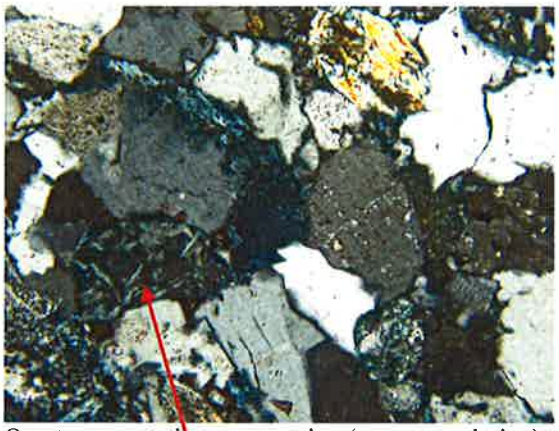
Some oversized pores (blue), generally low por/perm x4 lln



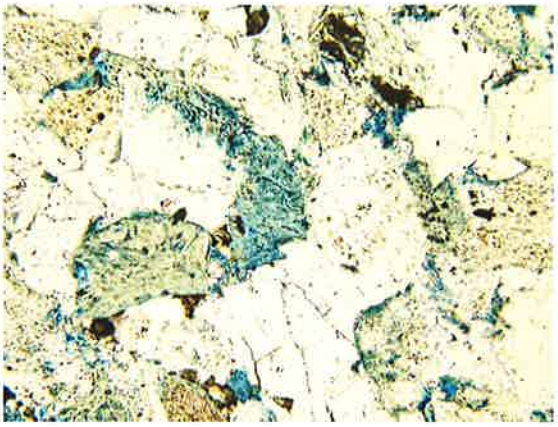
Closer view, microcline and feldspar overgrowths x10 xn



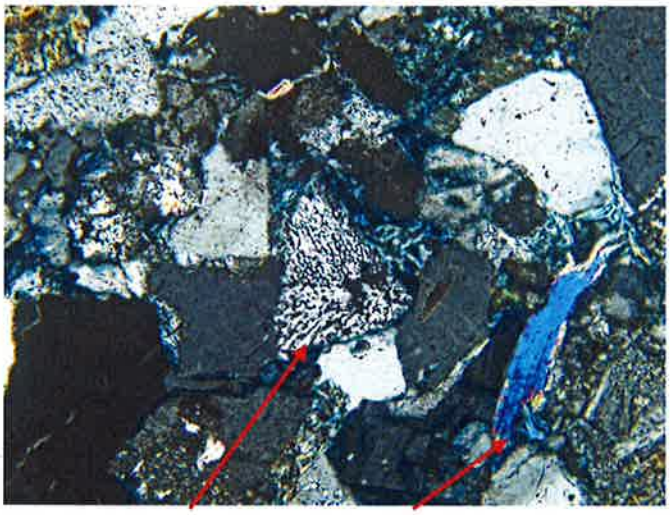
Secondary porosity due to grain dissolution (blue) x10 lln



Quartz cementation, compaction (pressure solution)
Altered grains (dolerite?) x20 xn

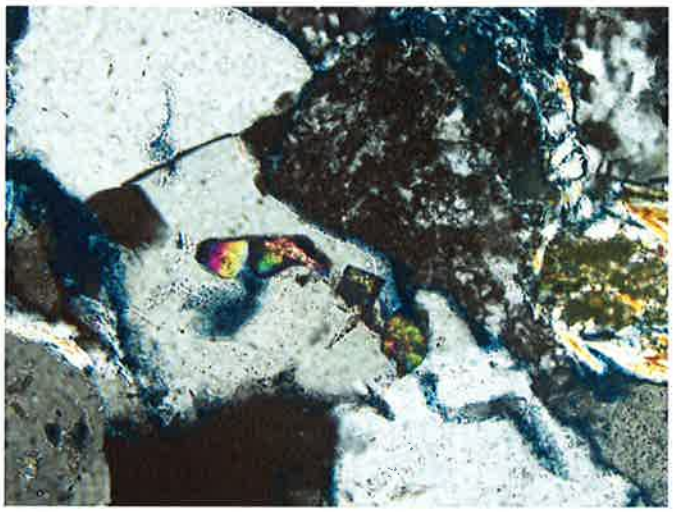


x20 lln



x20 xn

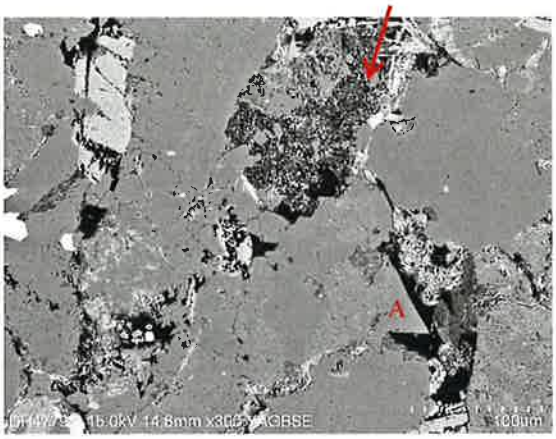
Spiculite (silica sponge)? Muscovite grain

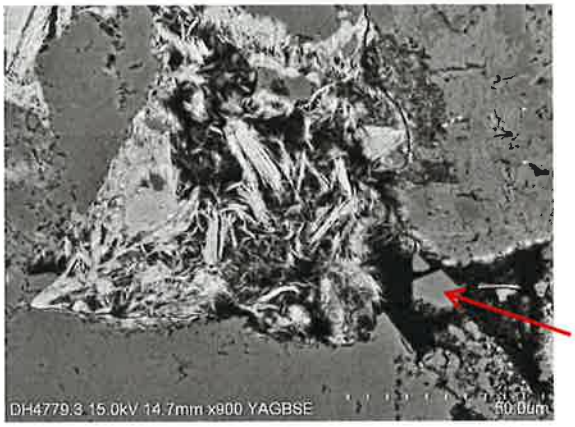


x40 xn

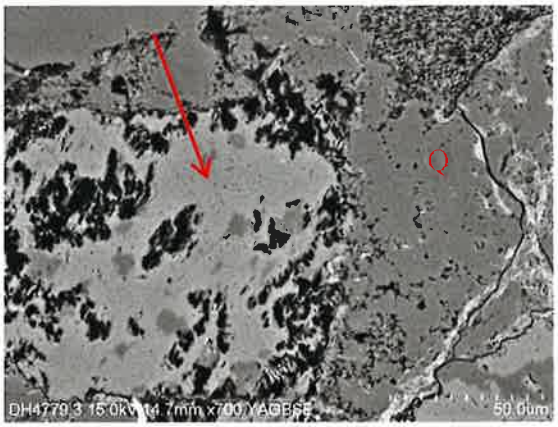
Rutile grains (anatase?) precipitated at border zone of quartz overgrowth

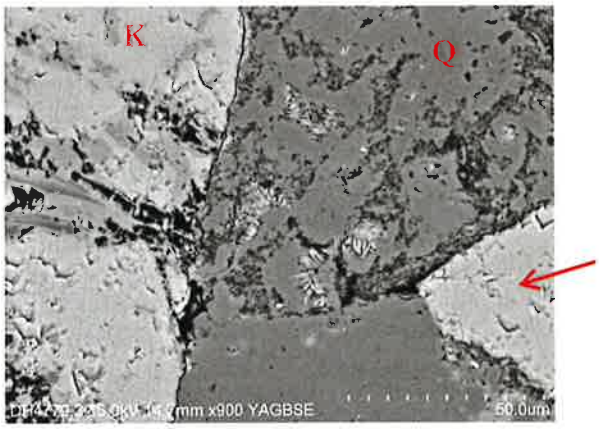
SEM:



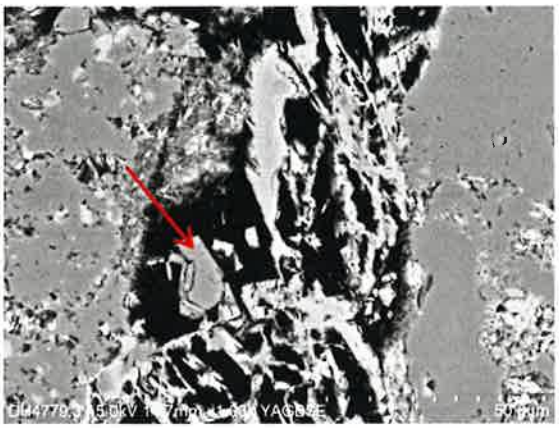


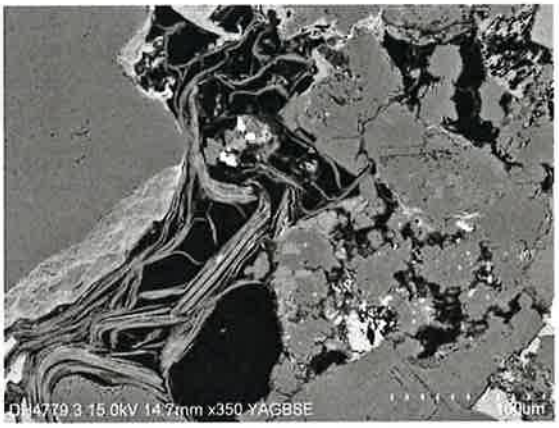
Left: Dissolution texture, ductile grain with illitic clay, albite, chlorite (arrow). Authigenic albite (A). Right: Pore filling chlorite±illite. Authigenic quartz (arrow), altered K-feldspar upper right.



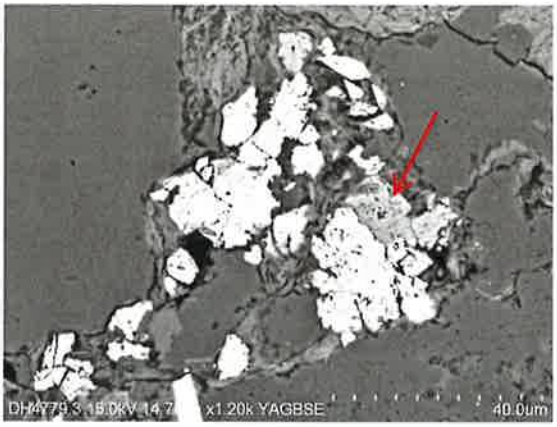


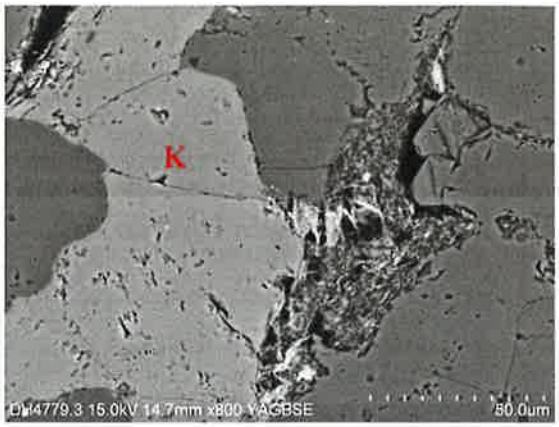
Left: dissolving K-feldspar (arrow), local albitisation. Qtz (Q) with dissolution texture. Right: similar dissolution/alteration texture in K-feldspar (K) and quartz (Q). Calcite down right (arrow)





Left: Secondary porosity in K-feldspar, albite precipitation(arrow). Qtz grains on both sides. Right: Muscovite remnants. Texture: secondary pores with poor communication.





Left: Local apatite cement (white) and Ti-oxide cement (arrow). Right: Unaltered K-feldspar grains (K). Chloritic clay in pore.

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
779.3	4.9	17.7	41.6	2.0	26.2	3.9	0.7	0.4	1.9	0.7

Well : Dh4 Depth, m: 783.5 Type: Core/De Geerdalen Fm

Lithology	Sandstone
Sorting	Good
Grain size	Fine – medium sand
Grain shape	Subangular (disturbed by compaction)
Porosity	Moderate – 10% (but low permeability)

Detrital:

Fragments A few possible shale/mud clasts, altered chert (microcrystalline quartz)?, generally monomineral grains

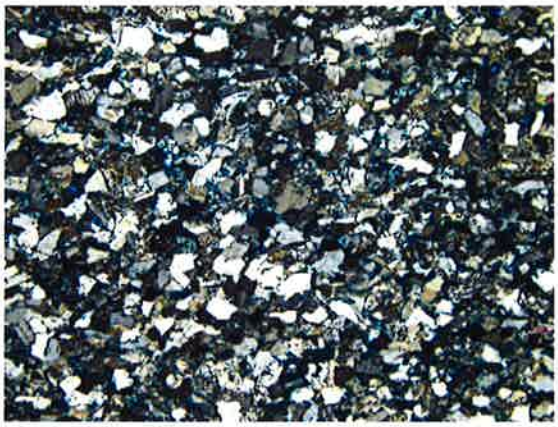
Grains Quartz, plagioclase, microcline, muscovite (few), rutile, chlorite (alteration of mica), glauconite, clusters of tiny zircons

Authigenic:

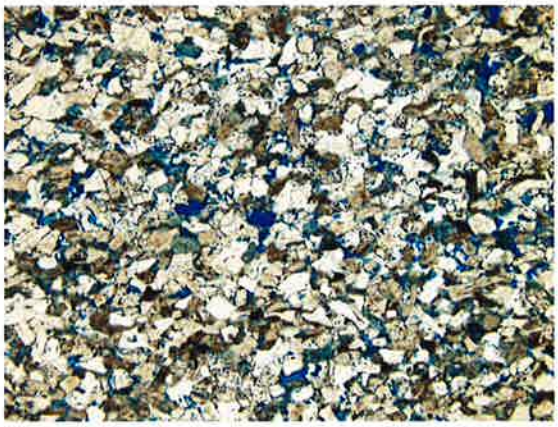
Cement Local sparry carbonate, quartz overgrowths occur

Clay Probably some undefined clay in pores, or due to alteration

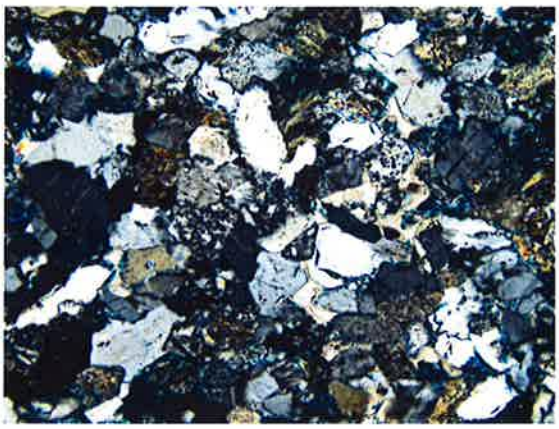
General: Irregular textures in thin section, probably mechanical more than diagenetic alteration in spite of local calcite and quartz overgrowths. Feldspar dissolution locally, also some oversized pores, also compaction texture

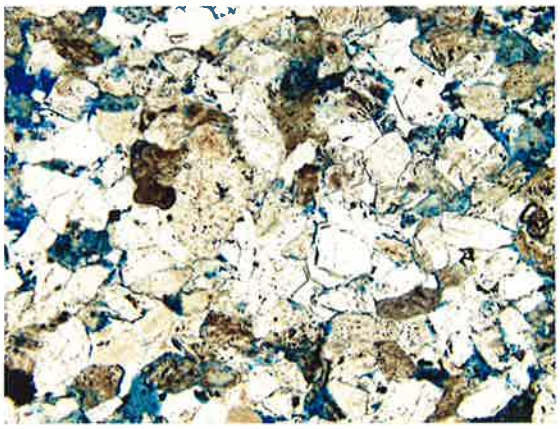


Textural overview x4xn



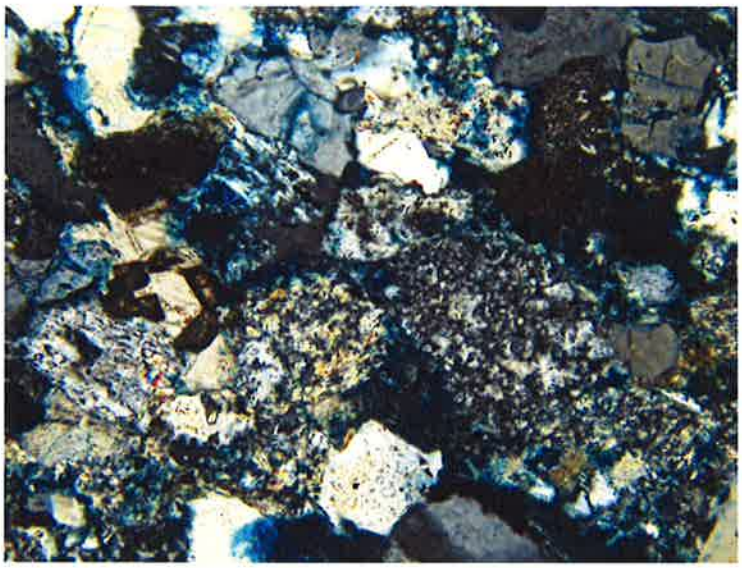
Some oversized pores in center (blue) x4 lln



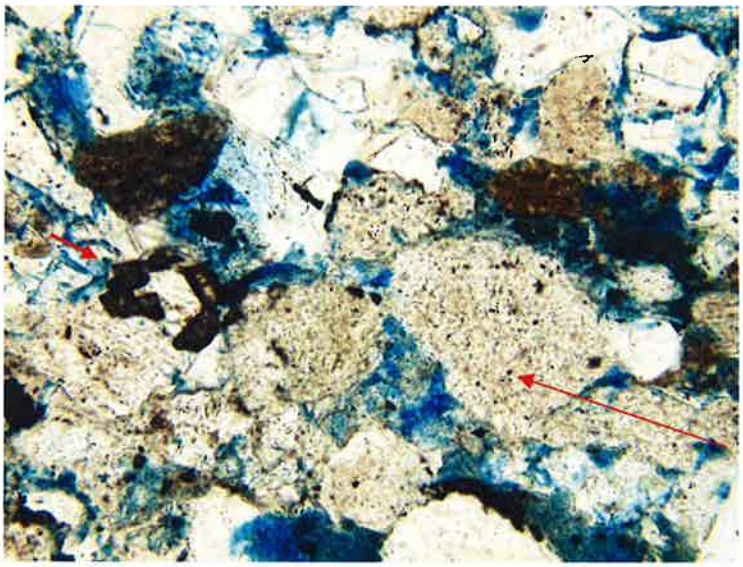


Closer view; carbonate cement and quartz overgrowth (center); small shale/mud clasts? (brown)

x10 xn x10 lln



x20 xn



x20 lln

Tiny zircons (arrow) and altered grains. Right arrow points out possible altered chert.

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
783.5	0.0	17.7	43.3	1.5	28.4	4.8	1.0	0.1	2.3	0.8

Well : Dh4 **Depth, m:789.3** **Type: Core/De Geerdalen Fm**

Lithology Sandstone
Sorting Good
Grain size Fine – medium sand
Grain shape Subangular
Porosity Relatively high – 15-20%

Detrital:
Fragments Probable sediments as silty shale (subrounded) and altered chert

Grains Quartz, plagioclase, microcline, muscovite (few), zircon, altered biotite, chlorite

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Authigenic:
Cement Not obvious, appears to be more depositional texture than diagenetic

Clay Probably some due to alteration (chloritic?), not obvious diagenetic clay

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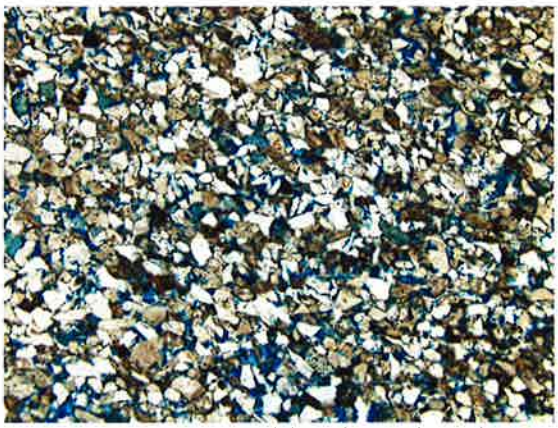
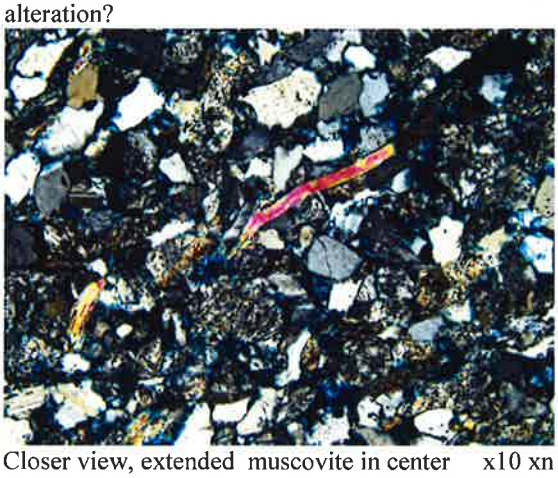
General: Although better porosity, the impression is of an immature sediment with fractured grains and irregular texture. Substantial amount of brownish altered grains which can be feldspars and/or altered fine grained sediments. Local grain dissolution, a few oversized pores.

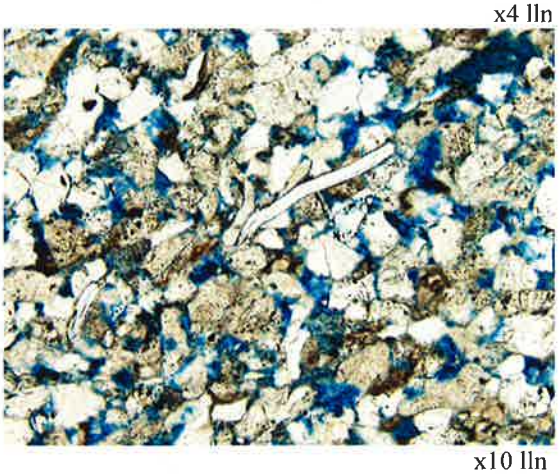
Textural overview x4 xn



Note the common brownish grains- stain or due to alteration? x4 lln



Closer view, extended muscovite in center x10 xn



x10 lln

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
789.3	4.1	18.7	33.5	1.6	31.7	4.3	1.7	0.1	3.5	0.8

Well : Dh4 **Depth, m:791.5** **Type: Core/De Geerdalen Fm**

Lithology	Sandstone
Sorting	Good
Grain size	Fine - medium
Grain shape	Subangular
Porosity	Medium – 10-12%

Detrital:

Fragments Clay/mud clasts, possible metamorphic, some altered glauconites, generally few fragments

Grains Quartz, plagioclase, microcline, muscovite, altered micas (muscovite, biotite), chlorite. oxides, organics (show some reflectance in reflected light), rutil, zircon

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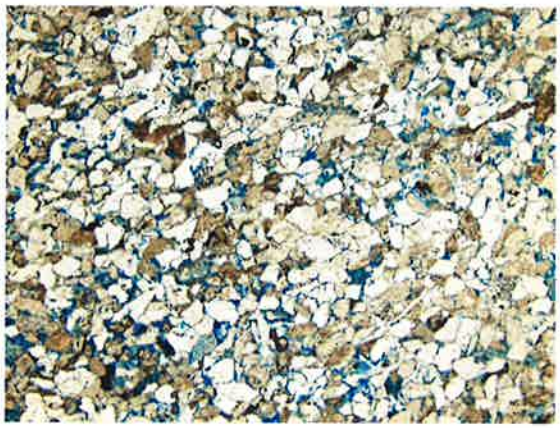
Authigenic:

Cement Local sparry carbonate, local quartz overgrowths

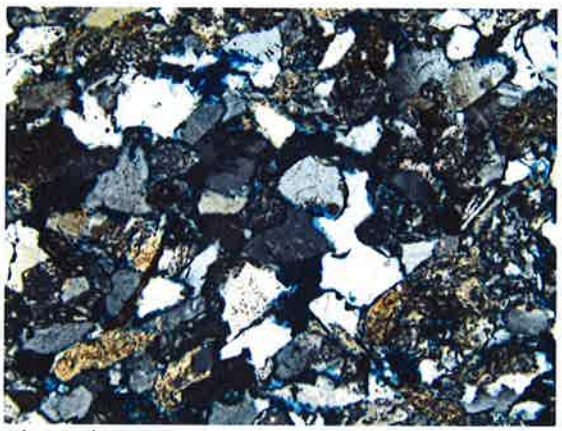
Clay Local chlorite

General: Irregular grain boundaries indicative of local dissolution, altered feldspar and mica grains (similar to clay clasts). Feldspar dissolution is observed, as well as carbonate replacement of feldspar. Also some compaction texture, mica squeezed between grains.

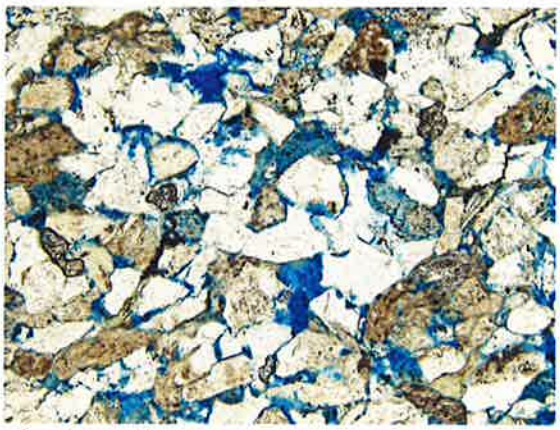
Textural overview x4 xn



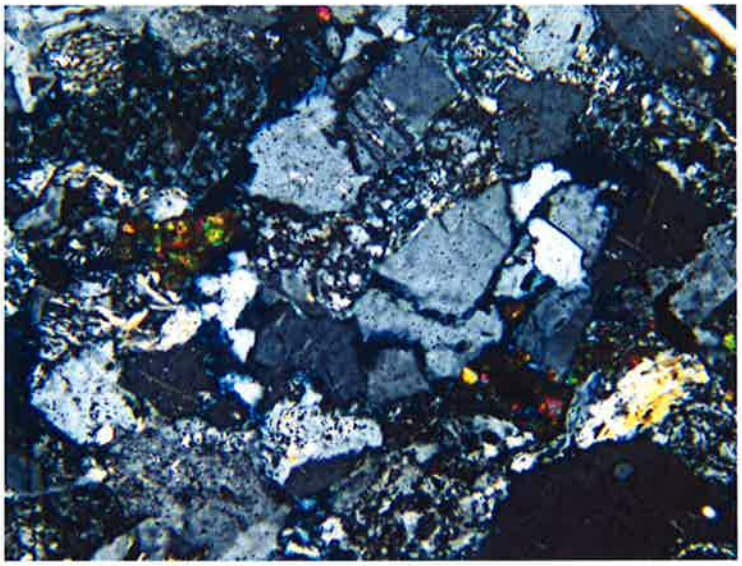
x4 lln



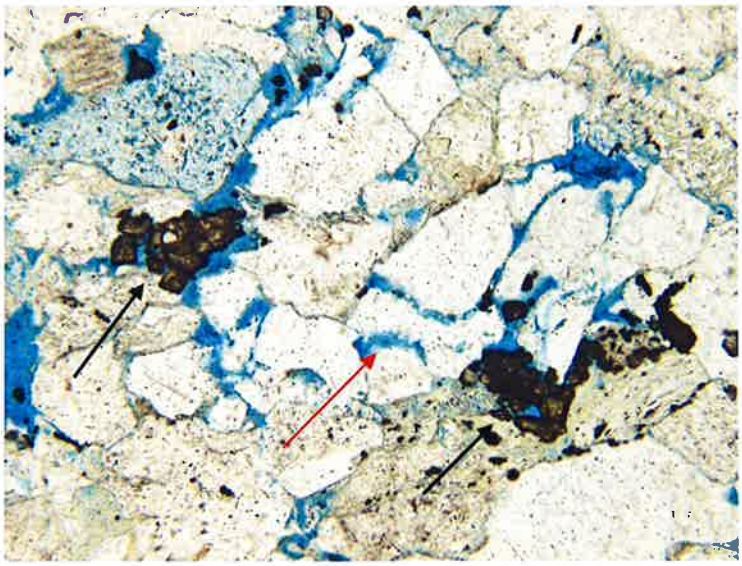
Closer view, irregular grain boundaries, brownish altered grains and/or clay/mud clasts x10 xn



x10 lln



x20 xn



x20 lln

Occurrence of tiny rutile grains (black arrows). Red arrow: dissolution textures

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
791.5	1.6	18.7	35.8	2.2	30.6	4.6	1.6	0.6	3.4	0.6

Well : Dh4 **Depth, m: 796.7** **Type: Core/De Geerdalen Fm**

Lithology	Sandstone
Sorting	Fairly good
Grain size	Medium
Grain shape	Due to compaction unclear, probably subangular
Porosity	Relatively low, estimated 5-7%

Detrital:

Fragments Glauconite, probable fine grained sediments/microcrystalline quartz, shaly fragments (or very altered micas), dolerite?, scattered organics (with some reflectance)

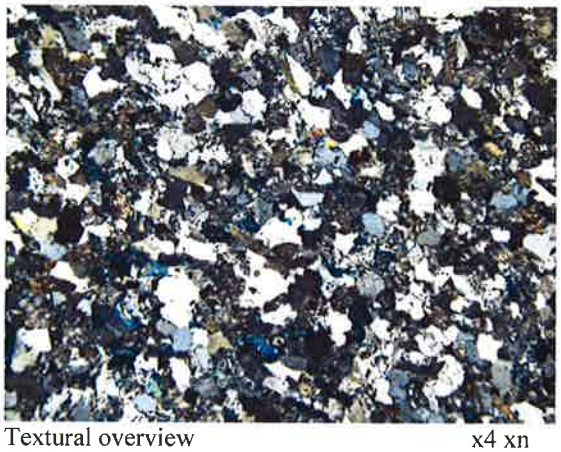
Grains Quartz, plagioclase, microcline, scattered muscovite, zircon, rutile, (titanite?), altered biotite, chlorite, tiny pyrites associated with organics

Authigenic:

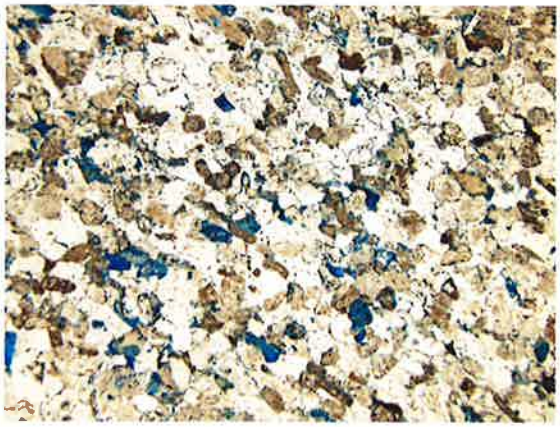
Cement Locally sparry carbonate, sometimes dissolving. Quartz overgrowths are relatively common

Clay Unspecified clay (chloritic?) can occur, however may be due to alteration , not obvious diagenetic

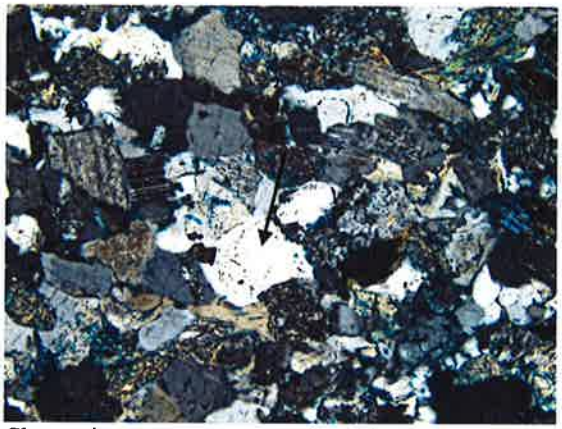
General: Oversized pores occur – dissolved grains. Generally compacted and cemented, but grain dissolution are seen as well. Heavy minerals more than usual amounts



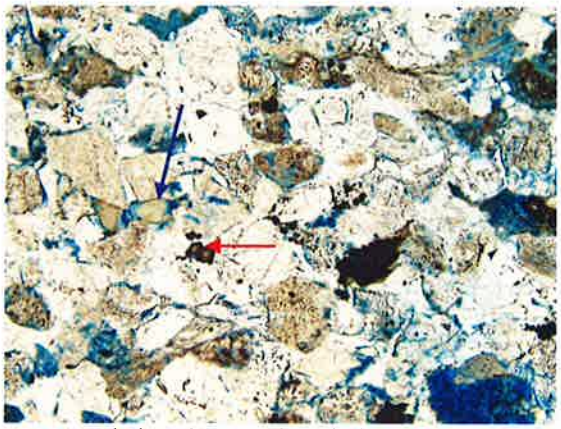
Textural overview x4 xn



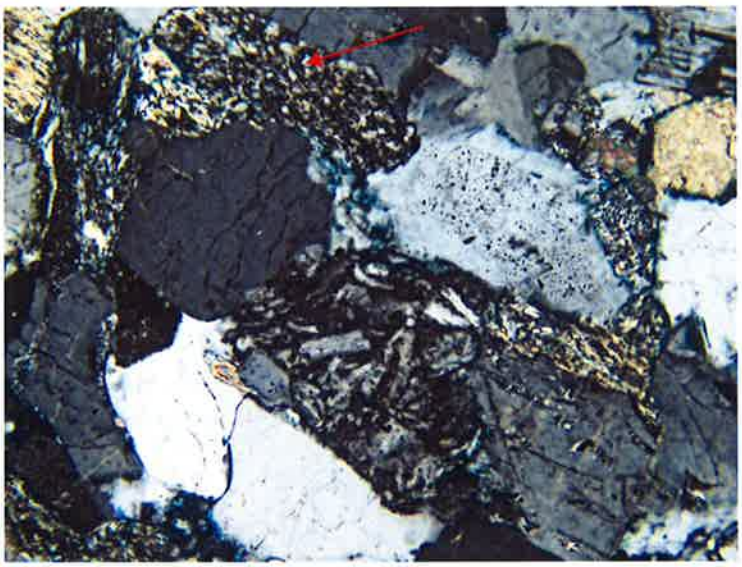
x4 lln



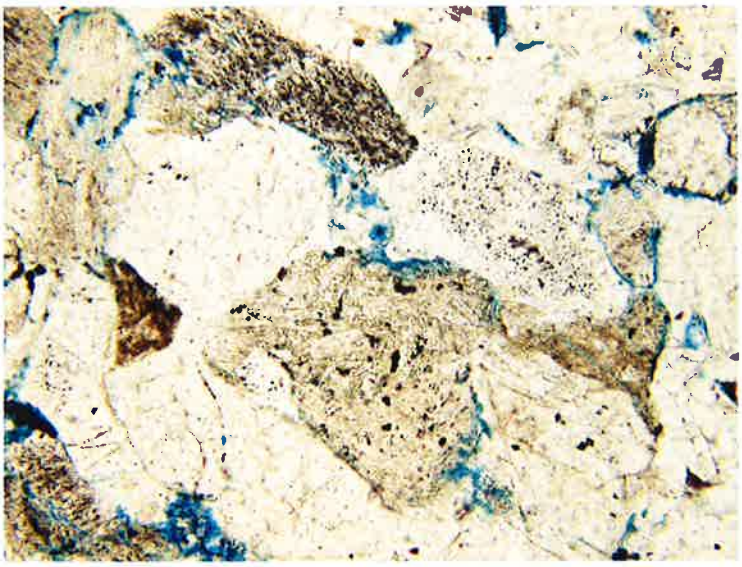
Closer view; quartz cementation (black arrow),carbonate cement below, heavy minerals (red arrow), altered glauconite (blue arrow) x10 xn



x10 lln



x10 xn



x10 lln

Dolerite fragment with plagioclase laths and chlorite (center). Quartz cements, ductile sediment fragment (arrow)

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
796.7	0.0	8.0	47.6	1.9	31.8	8.2	0.9	0.0	0.3	1.3

Well : Dh4 Depth, m: 798.2 Type: Core/De Geerdalen Fm

Lithology	Layered siltstone/shale
Sorting	Fairly well
Grain size	Silt
Grain shape	Subangular
Porosity	Low – none visible

Detrital:

Fragments Organics, more or less oriented

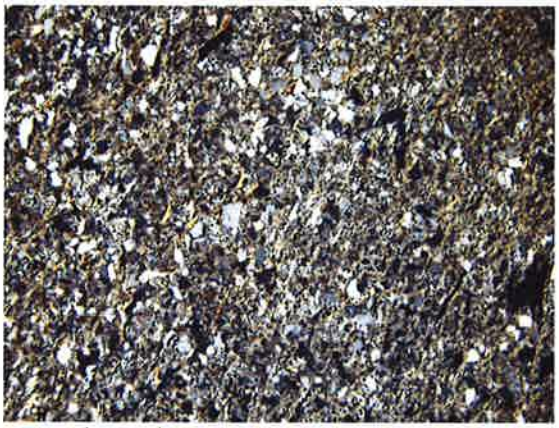
Grains Quartz, some plagioclases are identified, scattered muscovite variously altered, heavy min (rutile?), tiny pyrites associated with organics (often framboidal), chlorite (alteration of biotite), altered glauconite?

Authigenic:

Cement Scattered carbonate

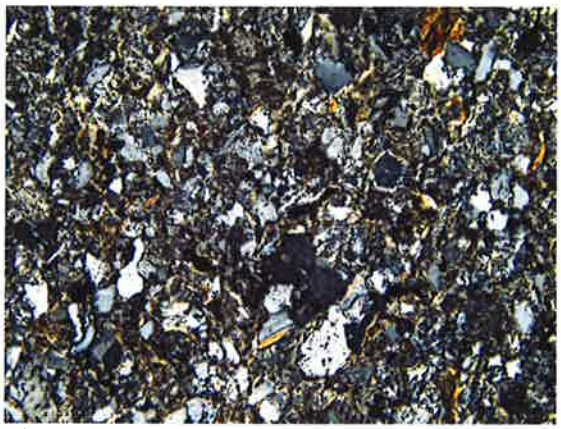
Clay Unidentified in matrix, probably illitic?

General: Laminated shaly siltstone. Clays appear to be common related to mica, difficult to decide if altered sediment fragments as well. Organics are probably plant debris?

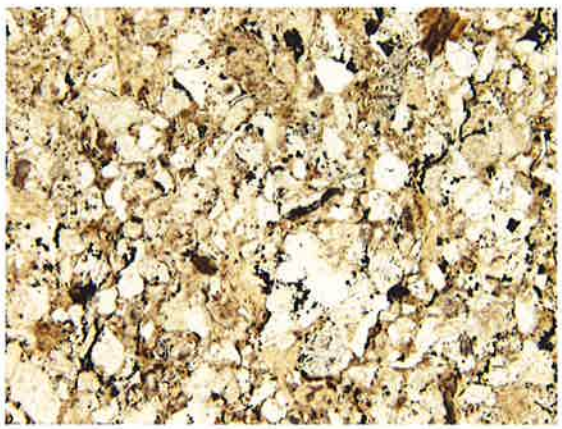


Textural overview x4 xn

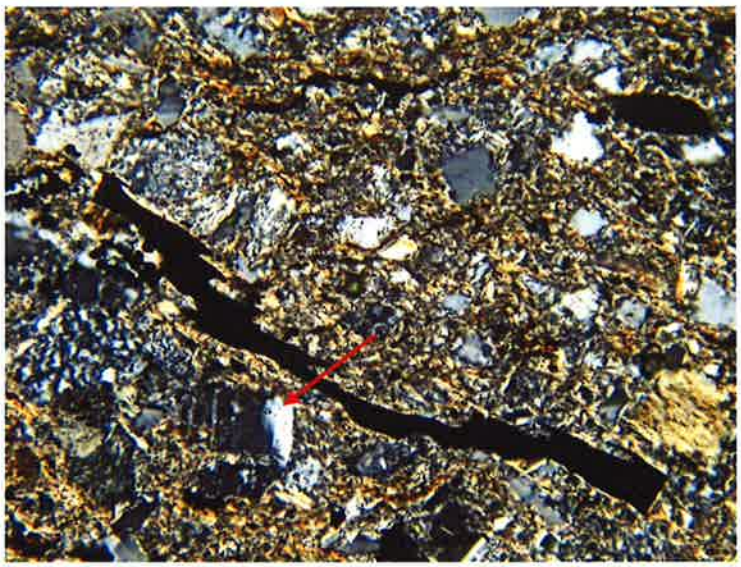
x4 lln



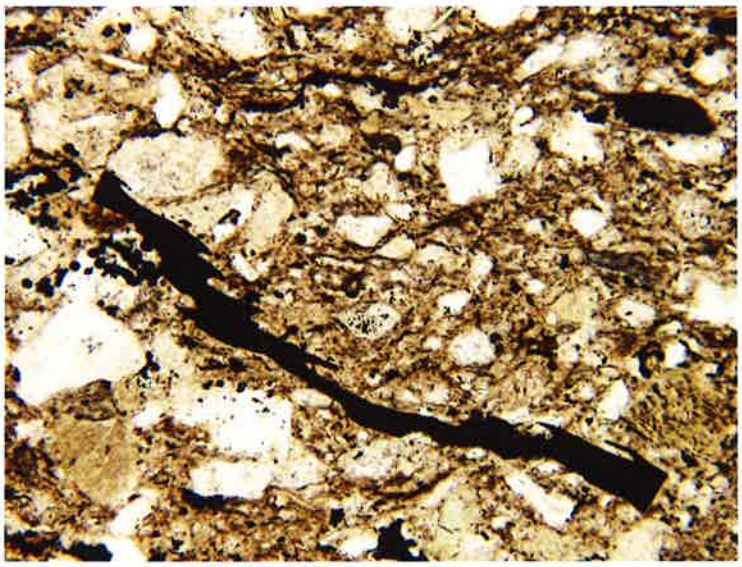
Closer view grains and clay matrix x10 xn



Black: organics and pyrites x10 lln



x20 xn



x20 lln

Plagioclase grain (arrow), terrestrial debris (black)

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
798.2	5.1	28.2	30.6	0.2	21.6	4.6	2.2	0.0	5.5	2.1

Well : Dh4 **Depth, m: 803.5** **Type: Core/De Geerdalen Fm**

Lithology	Sandstone
Sorting	Good
Grain size	Medium sand
Grain shape	Subangular, some compaction
Porosity	Moderate, <10%

Detrital:

Fragments Rounded fine grained sediments (chert?), doleritic fragments (plagioclase laths), polycrystalline quartz,

Grains Quartz, plagioclase, muscovite, altered biotite, microcline (low, probably K-fsp present Low in oxides. Rutile (?), zircon. A few altered glauconites. Chlorite

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Authigenic:

Cement Local quartz overgrowths, local sparry carbonate with corroded boundaries. Ti-oxides are noted.

Clay Appear related to fsp alteration, difficult to define in pores. Probably small amounts

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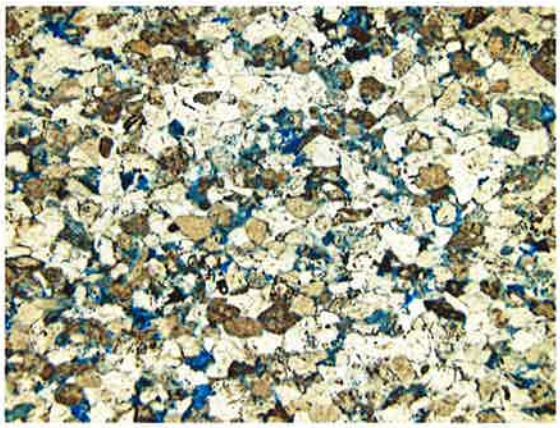
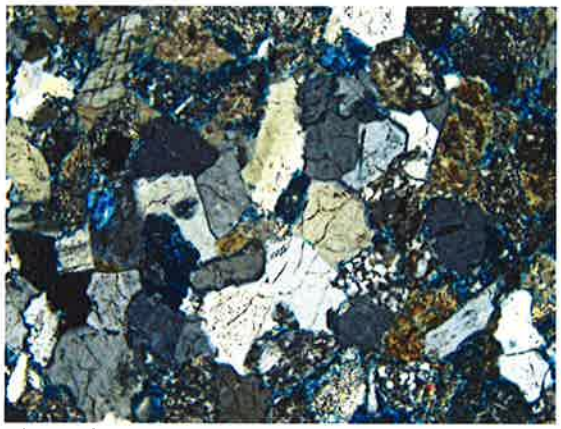
General: Compaction textures, fractured grains and grains squeezed into pore space,. Altered mica, some splays. Altered feldspar is common (sericite?). Impression of rel.extensive alteration, some grains are hard to recognise.

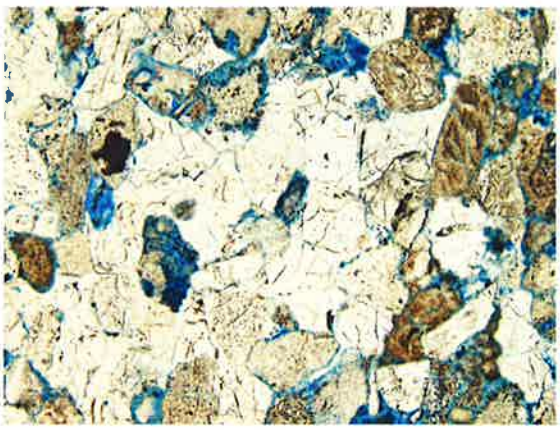
Textural overview x4 xn



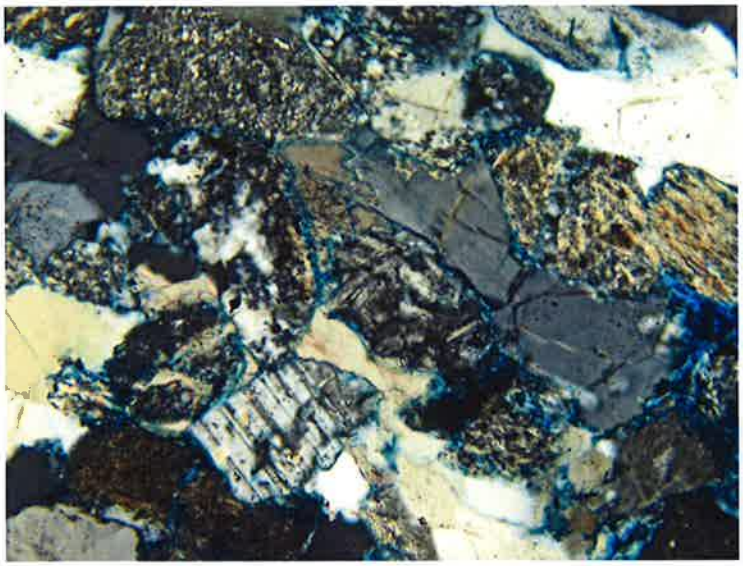
x4 lln



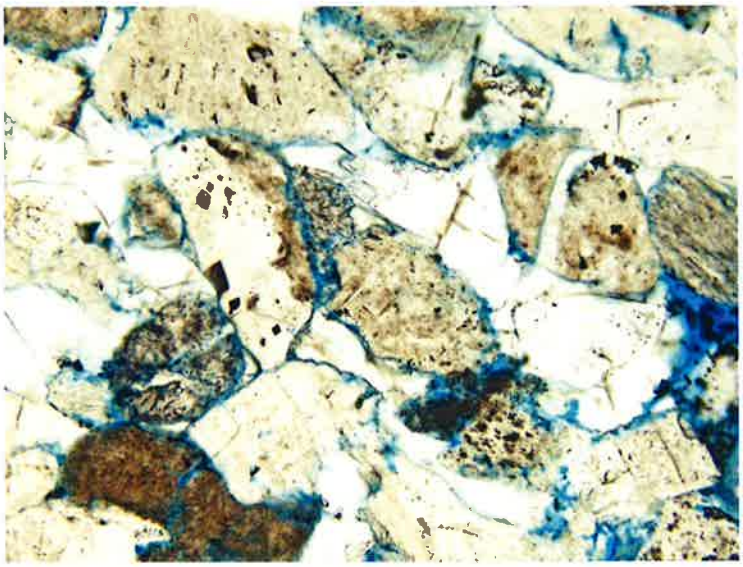
Closer view: quartz cementation, fractured grains, carbonate cement, altered grains
x10 xn



x10 lln



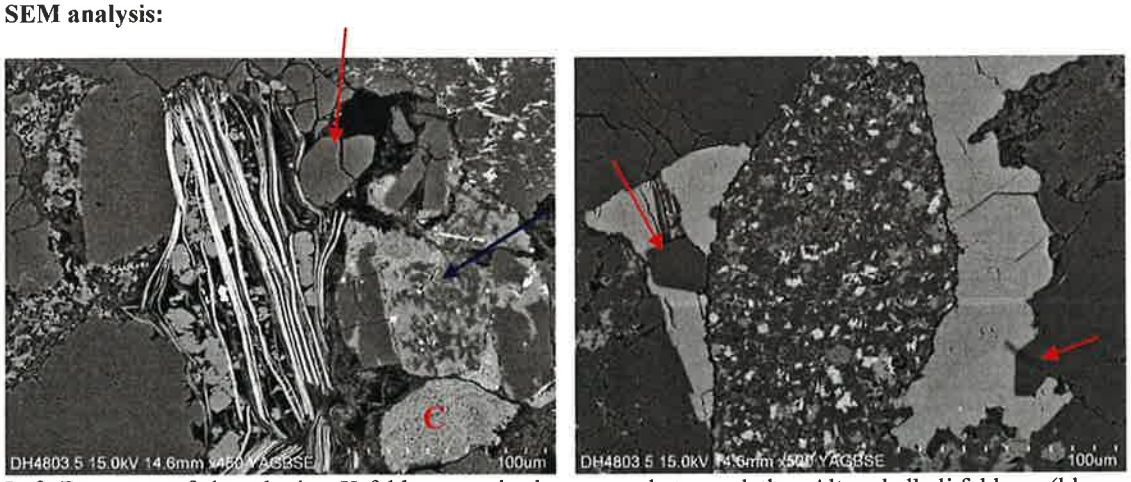
x20 xn



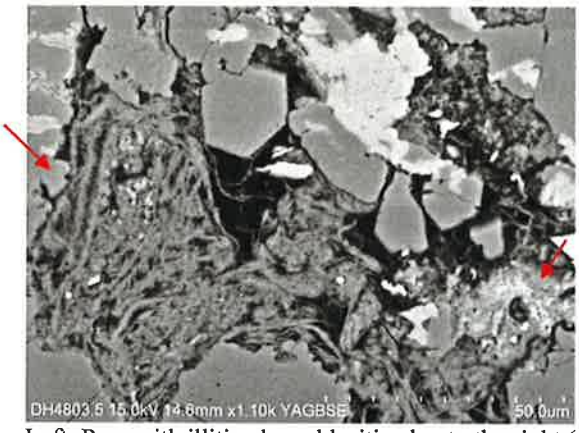
x20 lln

Doleritic grain in center. Quartz cementation, carbonate cement, altered grains, probable chert grain

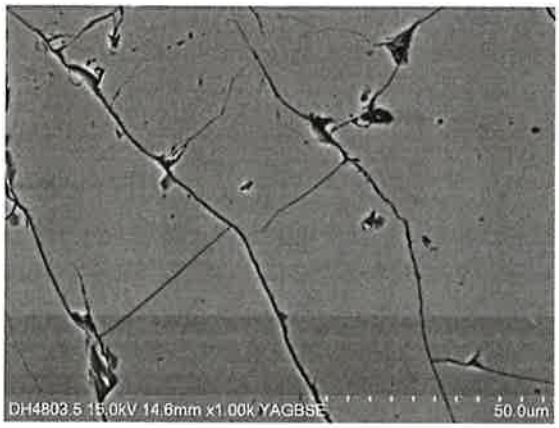
SEM analysis:

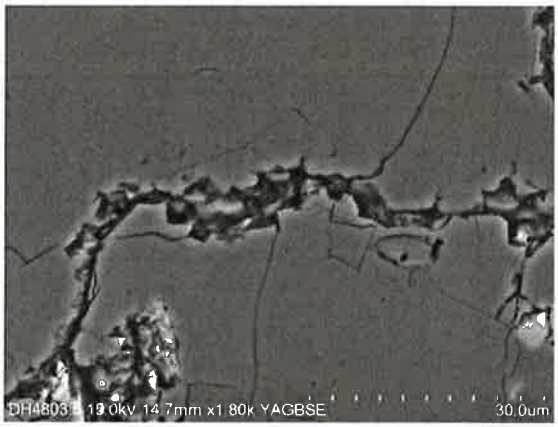


Left: Remnants of altered mica, K-feldspar grains has grown between laths. Altered alkali feldspar (blue arrow), pore fill on the left side is probably partly dissolved feldspar. Authigenic and fractured quartz (red arrow). Altered clast, now chloritic (C). Compaction textures. Right: The center grain is probably an altered fragment, now quartz, K-feldspar and chlorite, surrounded by calcite cement (pale grey). This cement is seen to postdate authigenic quartz (arrows). Compaction textures.



Left: Pore with illitic clay, chloritic clay to the right (arrow). Authigenic quartz in center, as well as authigenic albite on the left side (arrow). The upper pale grain is K-feldspar, partly dissolved.
Right: Dense illitic clay pore fill, fractured quartz (Q), K-feldspar seen to the right (pale). Fairly well compacted.





Quartz-quartz grain boundaries; appears compacted and partially fractured, without distinct pressure solution

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
803.5	0.0	16.0	41.8	1.9	27.7	7.1	1.7	0.1	2.8	1.0

Well : Dh4 Depth, m: 811.40 Type: Core/De Geerdalen Fm

Lithology	Siltstone, curved nonparallell layers, poorly defined fractures?
Sorting	Fairly well
Grain size	Clay-silt-fine sand
Grain shape	Subangular, diffuse
Porosity	Very low, probably a few thin open fractures (decompression?)

Detrital:

Fragments	A few microcrystalline quartz; organic debris
Grains	Quartz, plagioclase, muscovite, biotite, chlorite, altered glauconite, zircon, scattered tiny opaques(oxides)

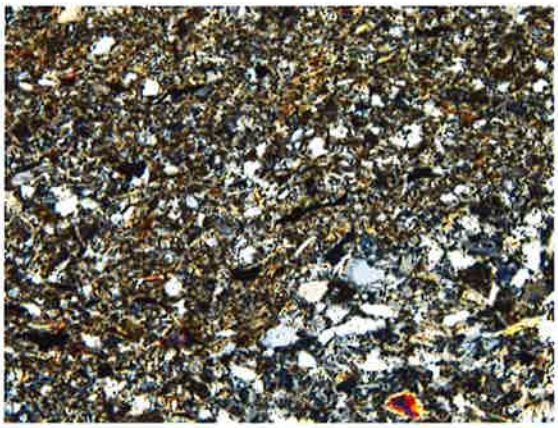
Authigenic:

Cement	Local carbonate (also probable irregular fracture cement)
Clay	Unspecified clay, weakly brown stain

General: The apparent hairline fractures are not easily discerned in the microscope. Appear more like sedimentary features. However, shaly, discontinuous lamina have local very thin, open hairy lines and may represent a local path/instability.

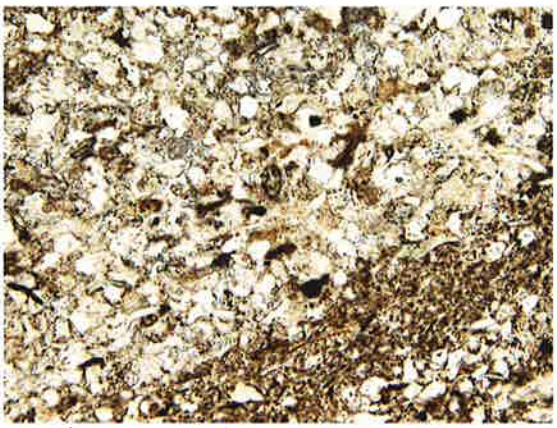
Hairy local fracture in shaly lamina (arrow); textural overview.

x4 xn x4 lln



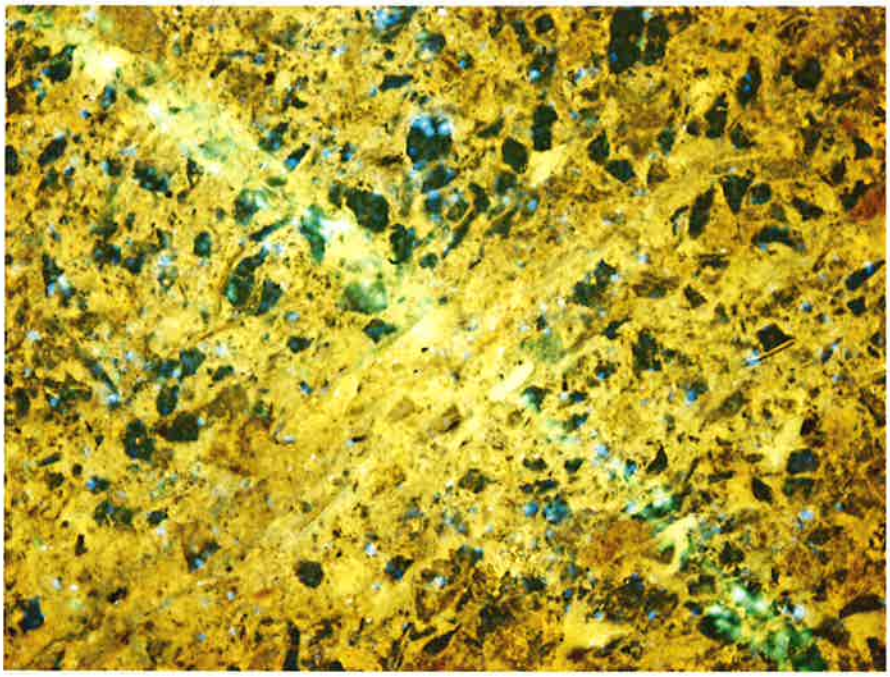
Closer view, sedimentary lamina variation, mica laths are discerned

x10 xn x10 lln



Similar view, local carbonate cementation (not appearing as fracture cement)

x10 xn x10 lln



Very local indication of fracturing? x10 UV

Well : Dh4 **Depth, m: 828.6** **Type: Core/De Geerdalen Fm**

Lithology Calcareous breccia
Sorting -
Grain size Up to mm size
Grain shape Stretched/bend/wavy ovale fossil grains
Porosity None visible

Detrital:
Fragments Carbonate shell fragments (?), often pale cloudy interior

Grains -

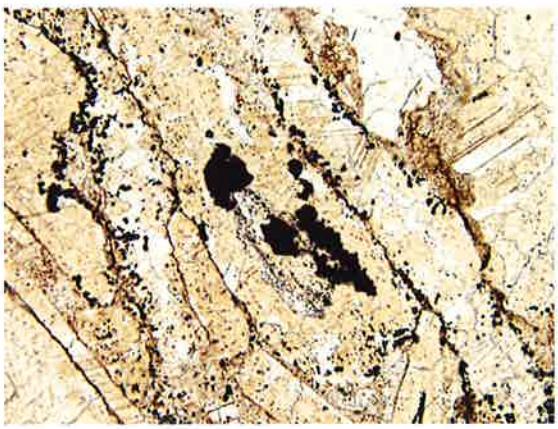
Authigenic:
Cement Carbonate, some recrystallisation. Organics/bitumen between carbonate grains
Small opaques, appear as oxides rather than pyrites (XRD: below detection))
Clay

General: Carbonate dominated, wavy texture where the fragments appear cemented with thin black bitumen(?). Some coarser carbonate grains without cloudy appearance are probably recrystallised and appear as local cement. Tiny opaques (pyrite or oxides) on grain boundaries. Stylolitic texture.

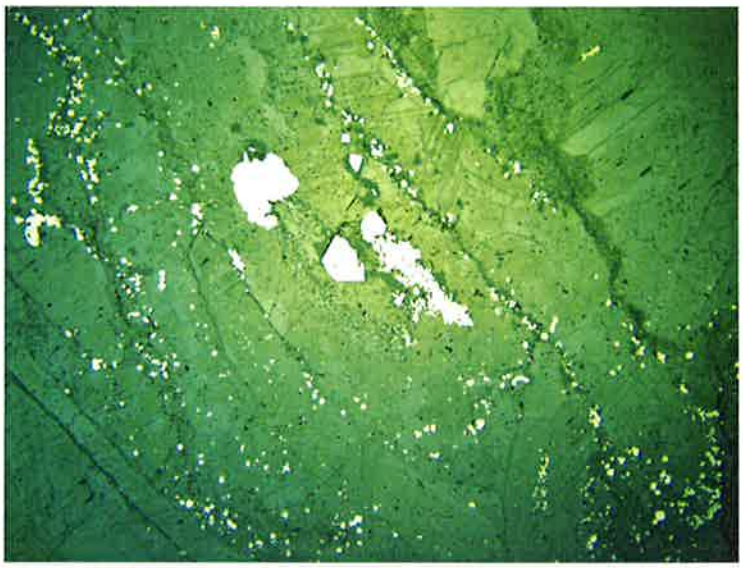
Textural overview, stylolitic texture x4 xn

x4 lln

Opaques, small grains located to grain boundaries
x10 xn



x10 lln



x10 reflected light

Pyrites or oxides on grain boundaries

x4 lln

Detail of stylolitic texture

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
828.6	0.0	0.3	0.7	0.1	4.7	92.0	0.4	0.1	1.1	0.5

Well : Dh4 **Depth, m: 832.2** **Type: Core/De Geerdalen Fm**

Lithology	Siltstone/fine sandstone
Sorting	Fairly well
Grain size	Fine sand-silt
Grain shape	Subangular
Porosity	Low

Detrital:

Fragments Bioclasts/shell fragments, microcrystalline polyquartz or chert possibly, local clay/shale clasts, otherwise hard to discern fragments

Grains Quartz, plagioclase, muscovite, K-feldspar, tiny scattered pyrites, also related to bioclasts, oxides, chlorite, zircon,

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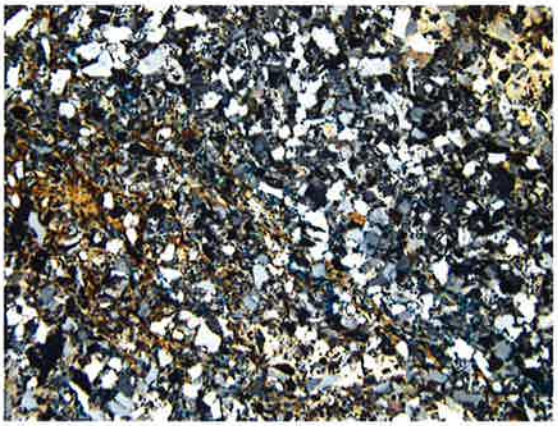
Authigenic:

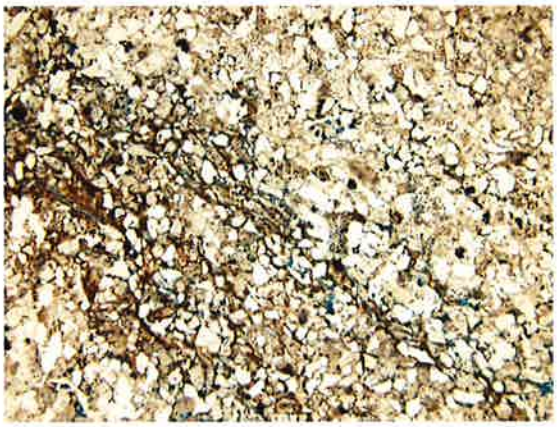
Cement Carbonate, locally sparry

Clay Difficult to identify, some may be present (breakdown of mica, feldspar)

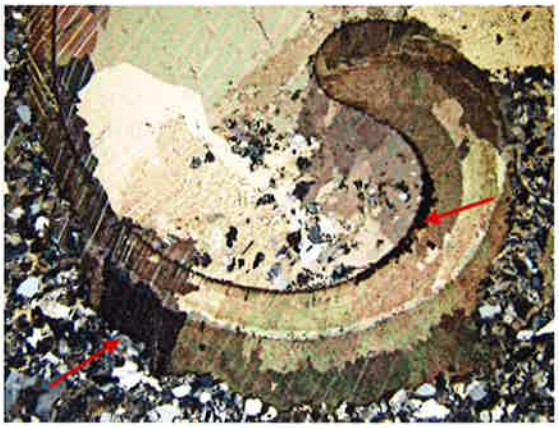
General: Tight, compacted texture, also carbonate cemented, blurred grain boundaries. Some carbonate appear corroded by chlorite (alteration of biotite?). Coarse recrystallised carbonate within circular bioclast



Textural overview, clay/shale clast to the left x4 xn



x4 lln



x4 xn

Calcite bioclast, pyrite (arrows), coarse calcite in center

x10 xn

x10 lln

Closer view of texture. Carbonate cement, plagioclase (albite) grains, fine polyquartz/chert grains, scattered small pyrites

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
832.2	0.0	7.9	32.6	0.8	23.1	31.6	0.8	0.0	2.2	1.0

Well : Dh4 **Depth, m:837.7** **Type: Core/De Geerdalen Fm**

Lithology	Sandstone
Sorting	Well
Grain size	Medium sand
Grain shape	Subrounded-subangular (cemented)
Porosity	Low, associated with dissolving grains (secondary)

Detrital:

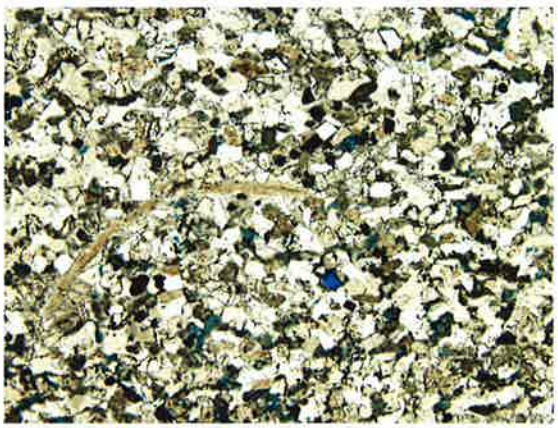
Fragments	Calcareous fossils, microcrystalline quartz, scattered organic debris
Grains	Quartz, plagioclase, microcline, chlorite, muscovite, pyrite xx, rutile, some ductile clayish grains, apatite (ordinary type), zircon

Authigenic:

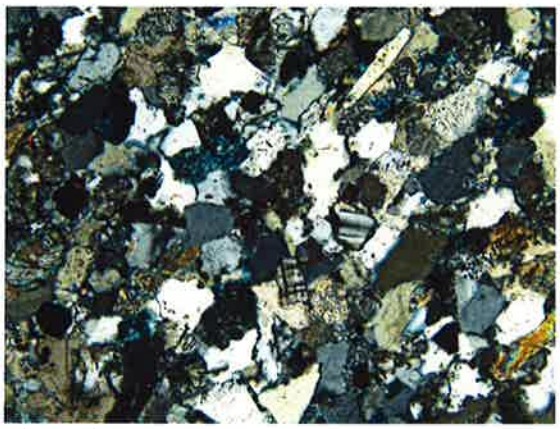
Cement	Partly carbonate cemented, quartz overgrowths occur
Clay	As alteration product, in ductile grains

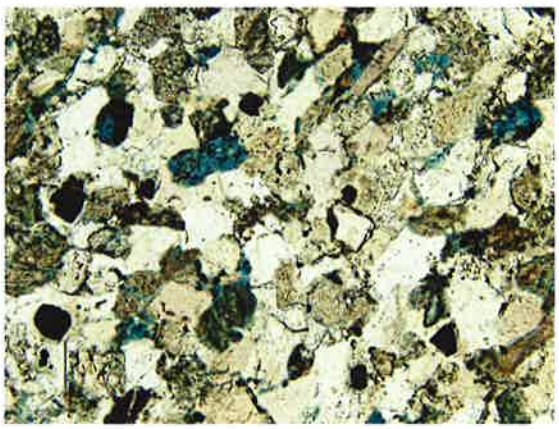
General: Above dolerite sill. Poor polish? Extensive compaction, blurred grain shapes and diagenetic sequence. Some carbonate cement appears linked to the fossil remnants (some recrystallisation?) Pyrite> quartz overgrowths> carbonate. No obvious signs of reactions due to the sill intrusion

Textural overview, carbonaceous fossil remnant x4 xn



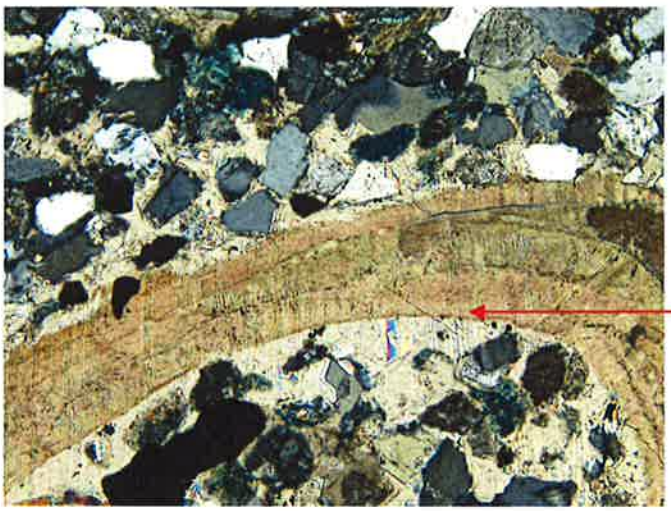
Low porosity (blue) x4 lln



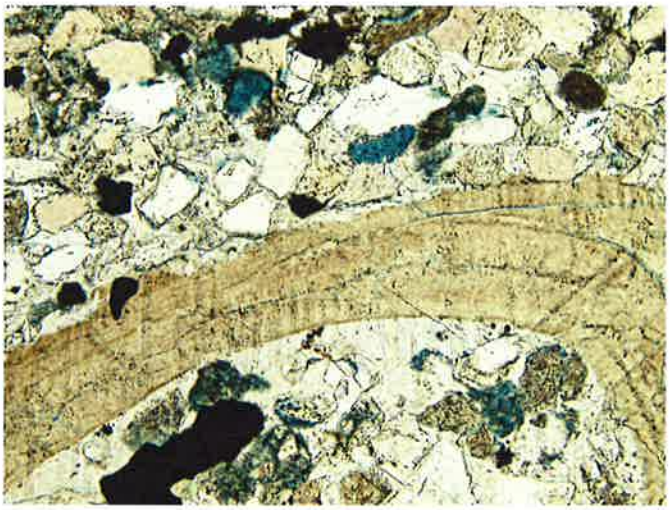


Closer view, plagioclase and microcline grains in center (arrows). Compacted and cemented texture, carbonate cement, quartz overgrowths. Black grains are pyrites

x10 xn x10 lln



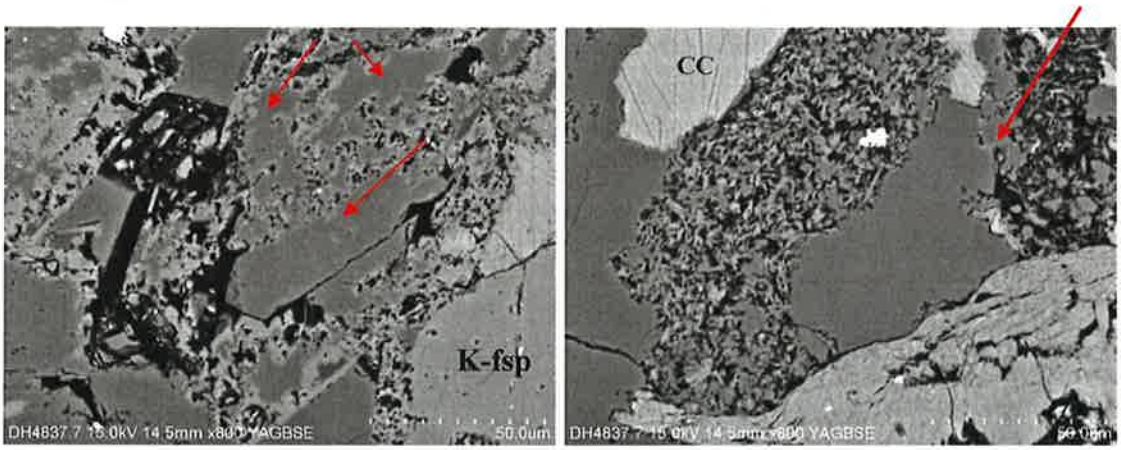
x10 xn



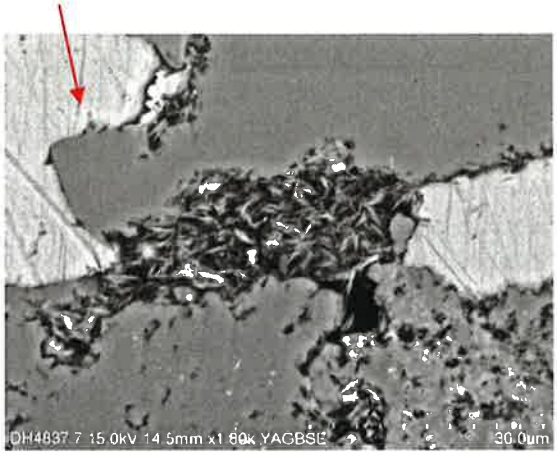
x10 lln

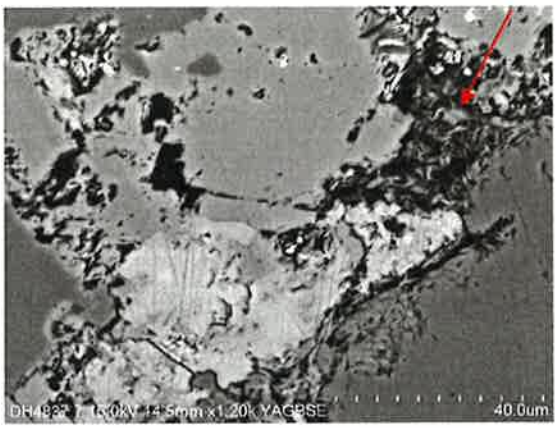
Closer view of bioclast remnant, the carbonate cement is in crystallographic continuation with the clast carbonate(arrow) Black: pyrite
))

SEM analysis:

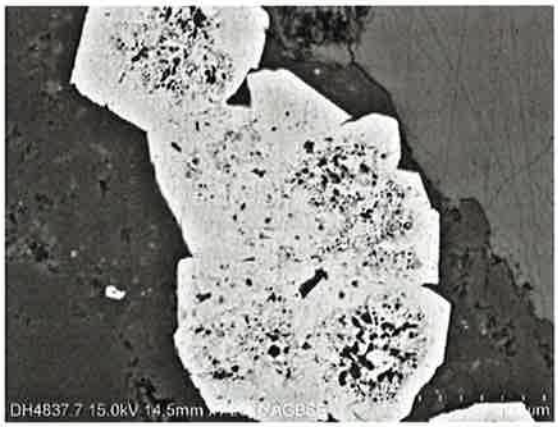
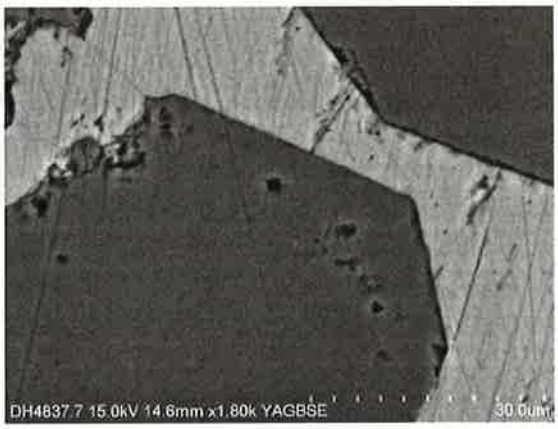


Left: Feldspar alteration: dissolution and albitisation of feldspar in center (arrows), quartz to the left. Right: Pore fill with chloritic/illitic clay and albite, probably altered fragment or feldspar. Dense chlorite down right. Calcite cement (CC) and quartz with overgrowths (arrow)





Left: Chloritic clay in pore, surrounded by dissolving K-feldspar (down right) and quartz (down left). Remnant quartz overgrowth predates the calcite cement (arrow)
Right: Dissolving K-feldspar, chloritic clay (arrow) and calcite (pale grey); some secondary porosity but low primary porosity.

Left: Pyrite cement.
Right: Quartz cement > calcite cement

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
887.7	5.0	18.5	39.6	0.8	25.7	4.9	0.7	0.0	3.2	1.4

Well : Dh4 **Depth, m: 838.4** **Type: Core/De Geerdalen Fm**

Lithology Dolerite sill

Minerals Crossing laths of plagioclase phenocrystals (2-3mm), groundmass with numerous plagioclase laths about 0.5mm, Some grains are zoned
Strongly altered possible olivine (or pyroxene) in rounded pseudomorphs
Dark matrix/groundmass with very tiny grains of pyrite/oxides

Alteration Carbonate alteration of plagioclase
Olivine remnants? Altered to chlorite/serpentine

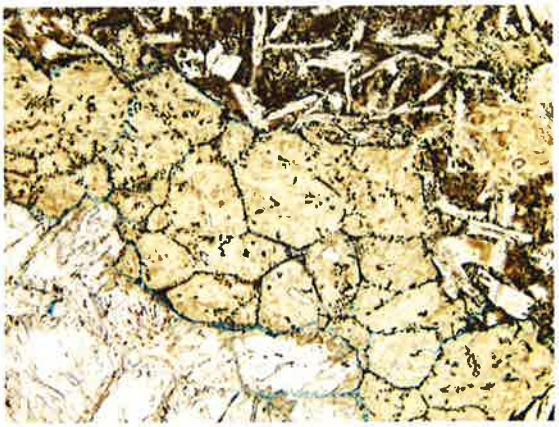
General: Strongly altered dolerite sill with typical dolerite textures.

Typical dolerite texture, plagioclase laths x4 xn

x4 lln

Zoned plagioclase phenocrysts.. Dark groundmass with tiny pyrites/oxides, numerous unoriented plagioclase laths.

x4 xn x4 lln



Altered olivine or ortopyroxene? Now serpentine mineral

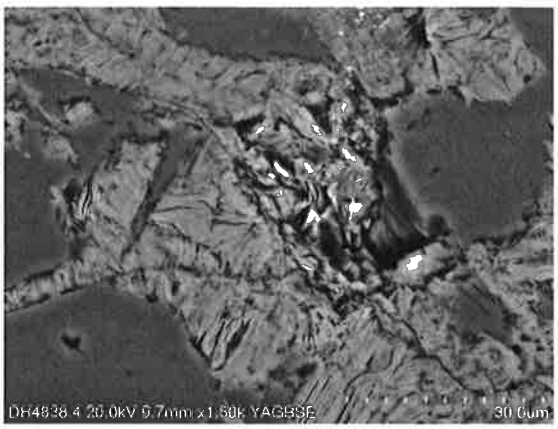
x10 xn x10 lln

x10 xn

Alteration of plagioclase phenocryst to calcite

SEM analysis:

Left: SE image of texture, remnant albite grain in center, numerous albite laths in fine groundmass.
Right: Similar view in BSE, white spots are pyrites. All this feldspar is now albite.



Left: Complex texture with calcite (arrow), albite (dark) and chlorite.
Right: Detail of chlorite and albite alteration

Well : Dh4 **Depth, m: 851.5** **Type: Core/De Geerdalen Fm**

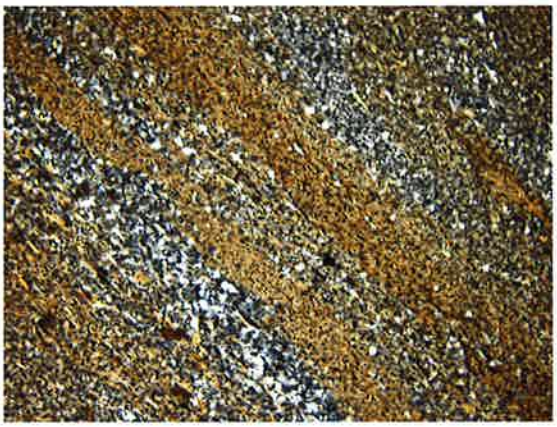
Lithology	Wavy layered silt/shale
Sorting	Good within layers
Grain size	Silt
Grain shape	Subangular
Porosity	Not visible

Detrital:

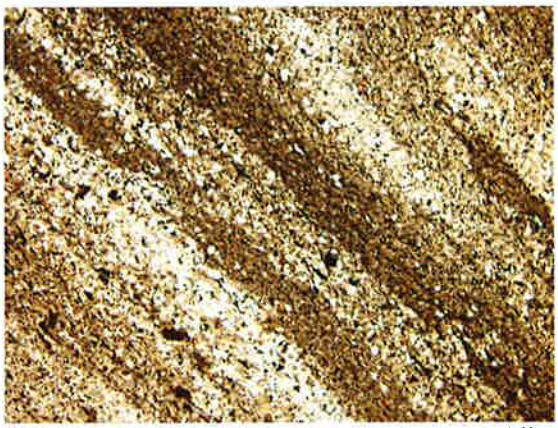
Fragments	Hardly identified, a few probably remnants of bioclasts
Grains	Quartz, plagioclase, common very small mica laths (both types), glauconite, scattered tiny pyrites/oxides, zircon, organic debris

Authigenic:

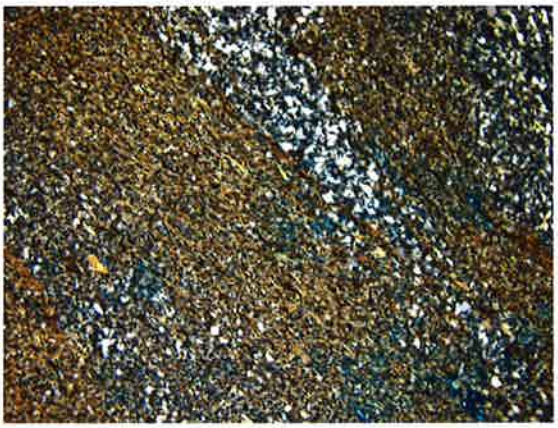
Cement	
Clay	Present but hard to identify (XRD: kaolinite, chlorite)
General:	Discontinuous irregular layers. Shaly layers are dark brown



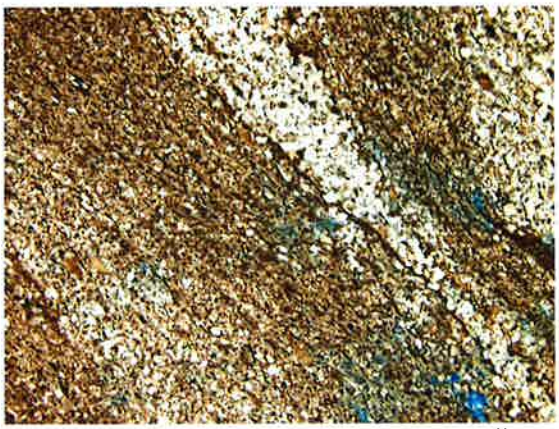
Textural overview alternating silty/shaly layers x4 xn



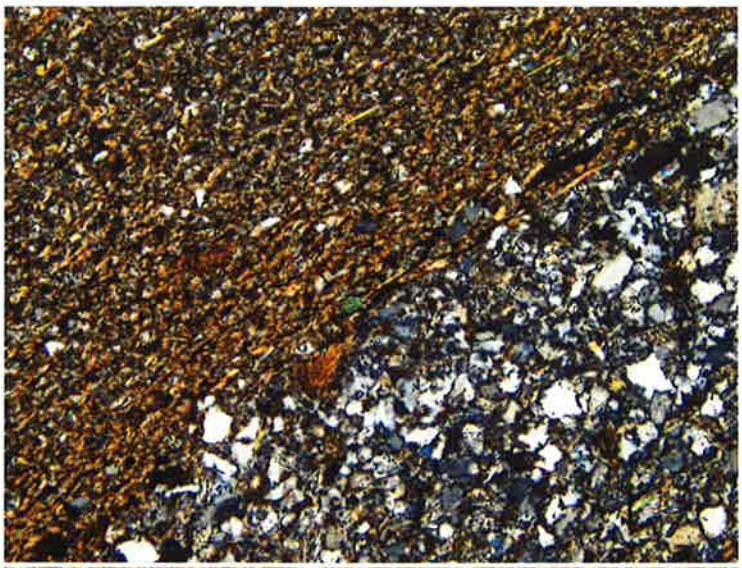
x4 lln



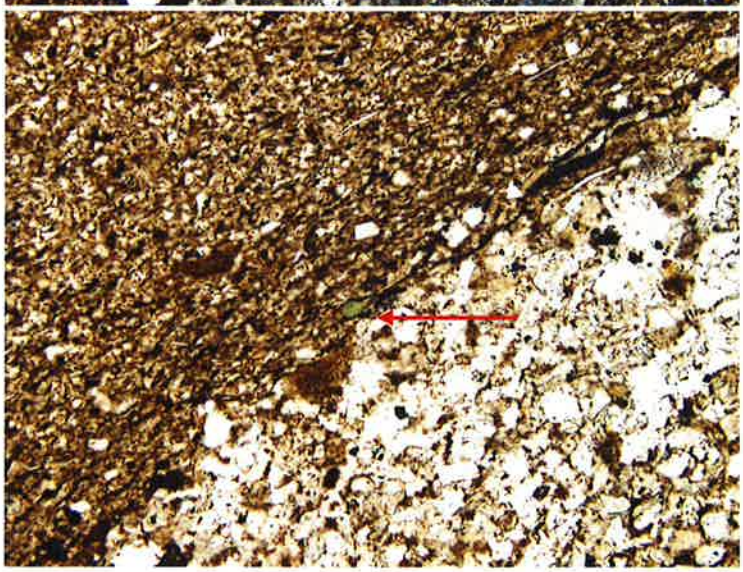
Local porosity (blue) x4 xn



x4 lln



x10 xn



x10 lln

Closer view of alternating layers, tiny glauconite (arrow)

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
851.5	6.2	25.7	25.8	1.3	29.1	4.1	1.2	0.0	4.4	1.4

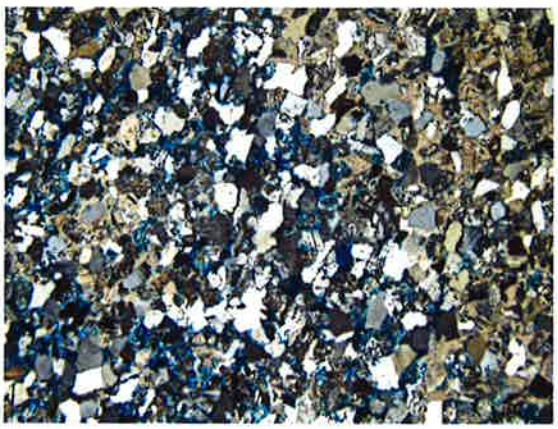
TOC: 0.81%

Well : Dh4 **Depth, m: 859.4** **Type: Core/De Geerdalen Fm**

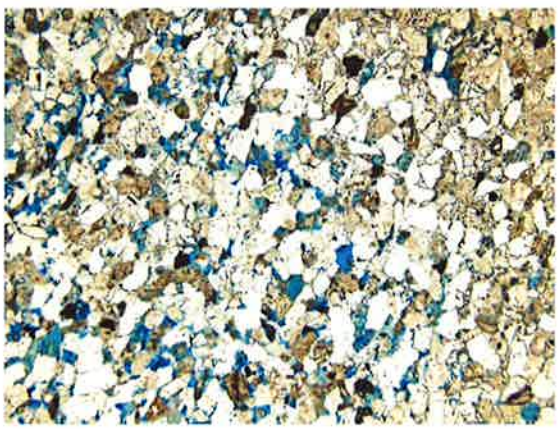
Lithology	Sandstone
Sorting	Fairly well
Grain size	Medium sand
Grain shape	Subangular
Porosity	Irregular but rel high (15%). Also some secondary (dissolving grains)

Detrital:	
Fragments	Shaly (brown), very fine polycrystallline quartz/chert. Common altered grains difficult to identify – can be fine grained sediment and/or altered feldspar, polycryst.quartz (a few), scattered organics, few coarser igneous/metamorphic, possibly a few doleritic
Grains	Quartz, plagioclase, microcline, myrmekite, scattered muscovite, chlorite, pyrite, oxides (rutile?), zircon,

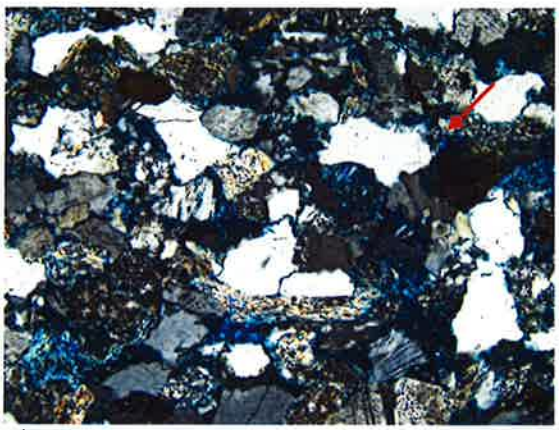
Authigenic:	
Cement	Local sparry carbonate, quartz overgrowths (remnants?)
Clay	Present clay (low) appear to be related to grain breakdown (muscovite, feldspar), probably illitic? Kaoline not identified
General:	Quartz overgrowths appear prior to compaction/pressure solution



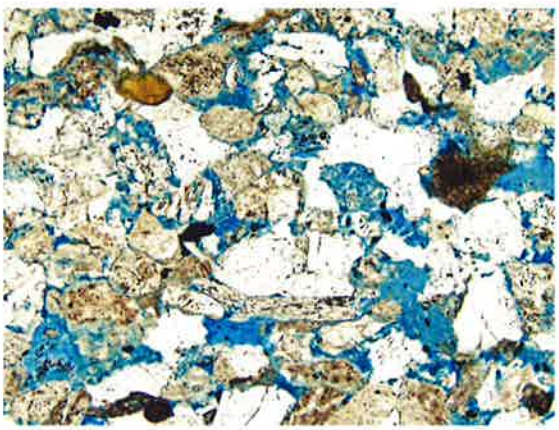
Textural overview, variable porosity x4 xn



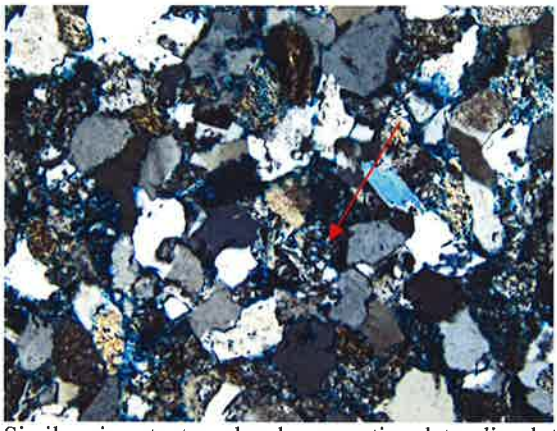
x4 lln

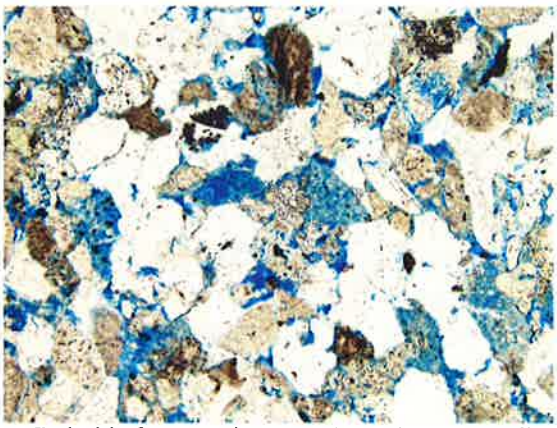


Closer view, grains, shaly fragments, quartz cement (arrow) x10 xn

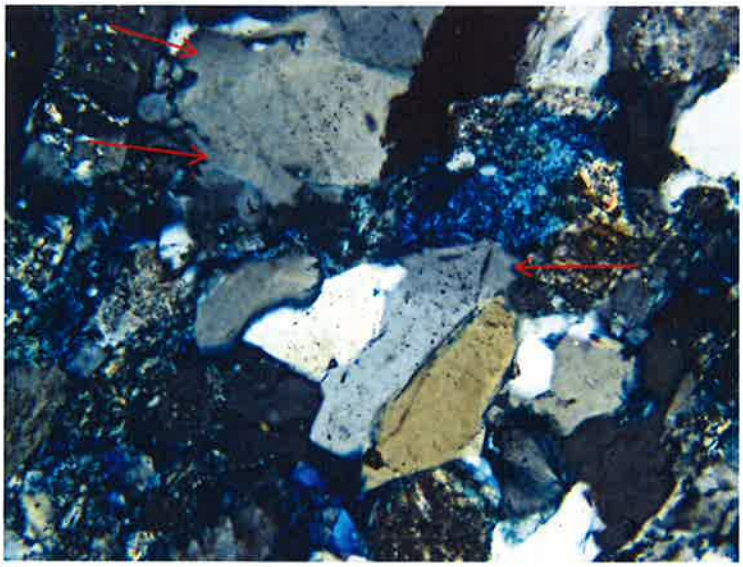


x10 lln

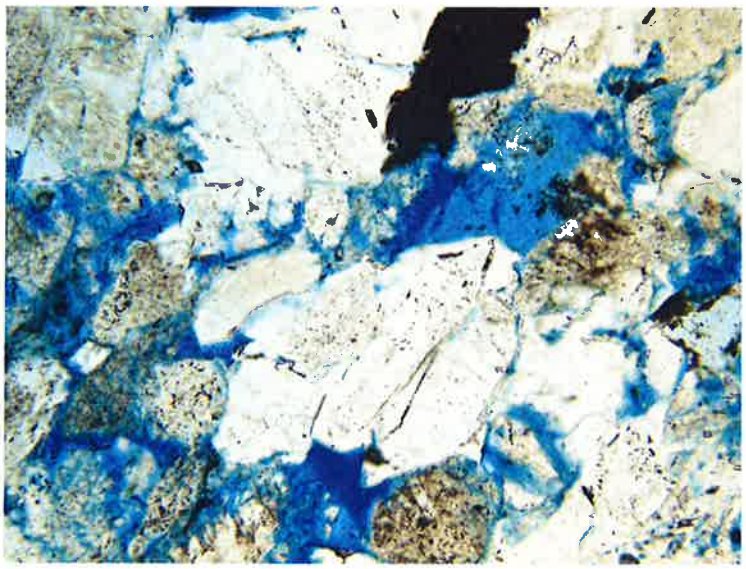




Similar view, texture, local compaction, later dissolution. Doleritic fragment in center (arrow) x10 ll
x10 xn



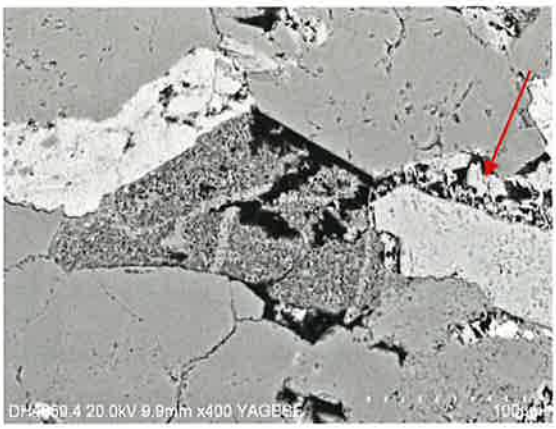
x20 xn



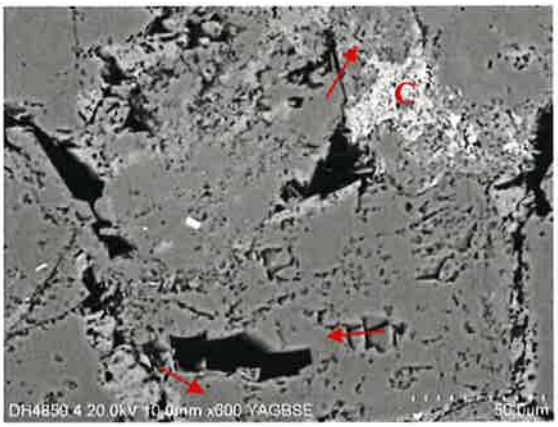
x20 lln

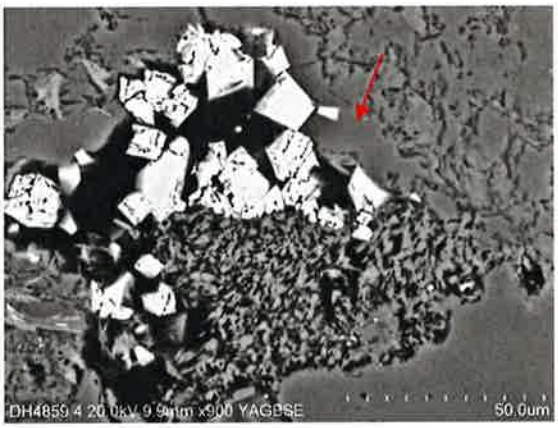
Detail of quartz texture: overgrowths (some pointed out by arrows), compaction, dissolution.

SEM analysis:



Left: In center microcrystalline quartz (chert) appearing as cement without obvious relation to surrounding quartz grains, the straight border of the quartz grain above suggests also authigenic growth. K-feldspar is partially dissolved (arrow), dense chlorite is seen upper left (detrital?)
Right. Common pore view; dissolving K-feldspar and alkali feldspar (right), altering micas with muscovite, chlorite and some kaoline, authigenic albite (center). Poorly connected pore volumes.





Left: Quartz texture, albite (arrows), chlorite (C).
Right: Illitic clay and authigenic Ti-oxide (pale grains). Albite (arrow)

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
859.4	6.9	9.7	39.6	2.0	31.7	4.0	1.3	0.2	3.6	1.1

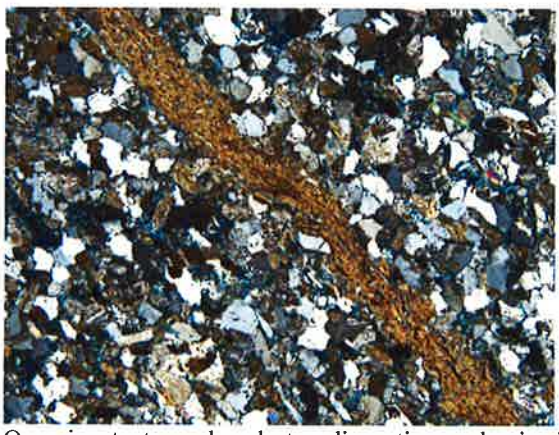
Well : Dh4 **Depth, m: 861.65** **Type: Core/De Geerdalen Fm**

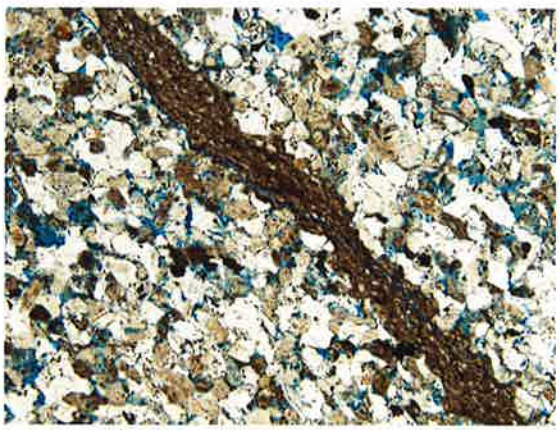
Lithology	Sandstone
Sorting	Well
Grain size	Medium sand
Grain shape	Subangular
Porosity	Moderate, estimated 10%

Detrital:	
Fragments	Polycrystalline quartz, probable plutonic, microcrystalline quartz/chert, altered doleritic, shale clasts, black organics in thin wavy layers (fracture like)
Grains	Quartz, plagioclase, muscovite, trace biotite, chlorite, opaques (pyrites, tiny oxides)

Authigenic:	
Cement	Quartz overgrowths, local carbonate, feldspar overgrowth
Clay	Unspecified, also within ductile detrital grains

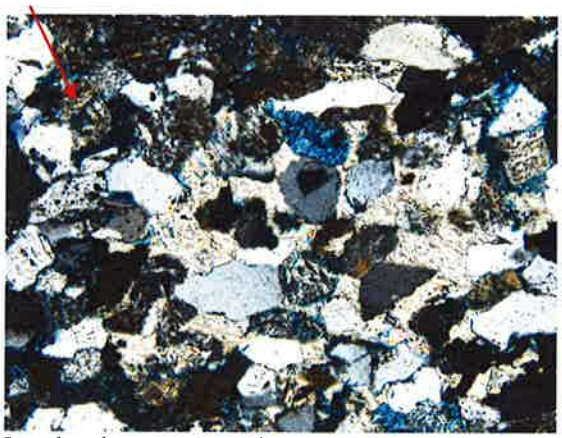
General: Irregular texture due to compaction, quartz overgrowths and clays/ductile grains. Although porosity is obvious, some is secondary and related to grain alteration. Feldspar dissolution, also overgrowths are seen. Compaction of ductile grains, clays in pores. It appears to be general poor connectivity between pores. Organics and extended and wavy mica laths define fracture like texture, organics show some reflectance.

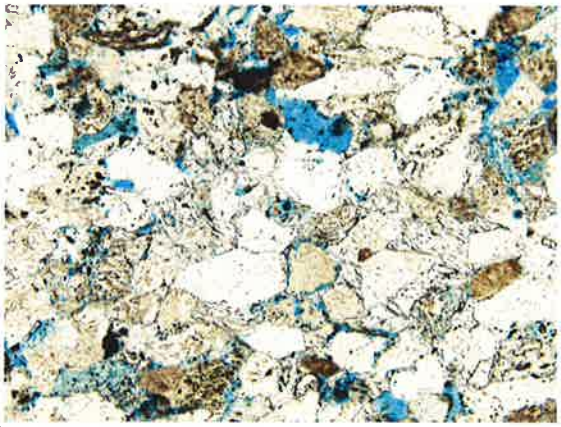




Overview texture, clay clast or discontinuous lamina in center. Microporosity, low communication.

x4 xn x4 lln

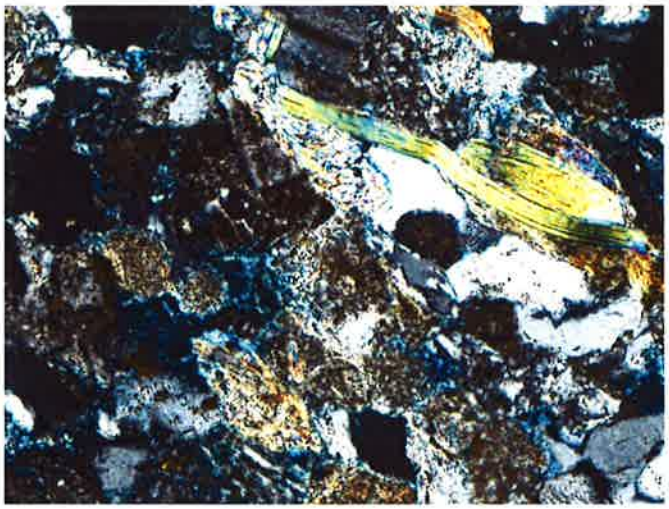




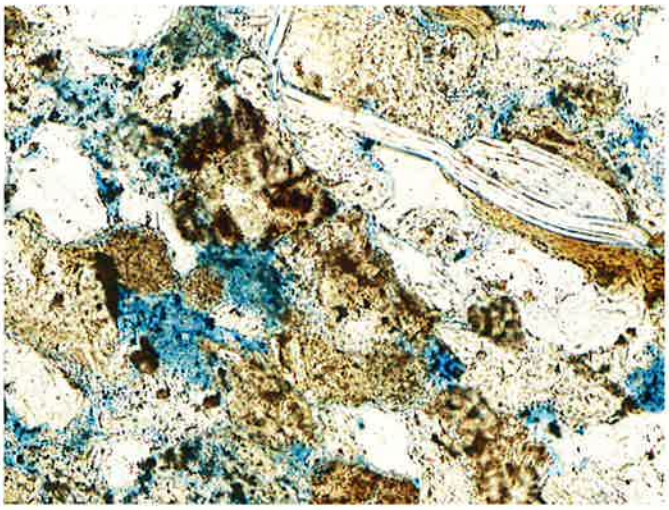
Local carbonate cement in center, ductile altered? grains, dolerite grain (arrow)

x10 xn

x10 lln



x20 xn



x20 lln

Closer view of microporosity, altering mica grain (no kaolinite), undefined ductile grains.

Well : Dh4 **Depth, m: 863.7** **Type: Core/De Geerdalen Fm**

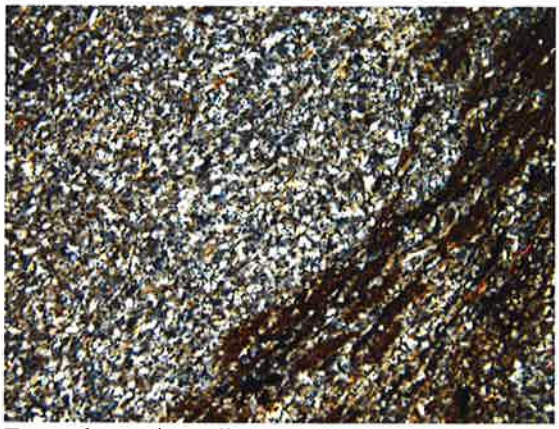
Lithology	Siltstone with shaly fragment (2.5cm). Inhomogenous
Sorting	Fairly well within each category
Grain size	Silt
Grain shape	Subangular
Porosity	Low, local variation within siltstone

Detrital:

Fragments	Hardly recognised. Organic debris (especially in shaly part)
Grains	Quartz, plagioclase, muscovite, chlorite, biotite. Common pyrite in shaly part (not seen in bulk XRD), possibly some altered glauconites

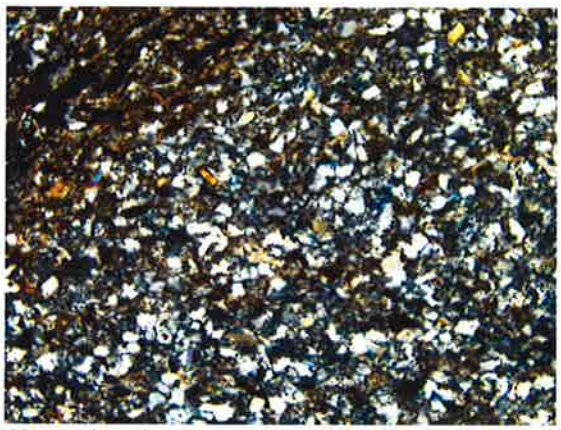
Authigenic:

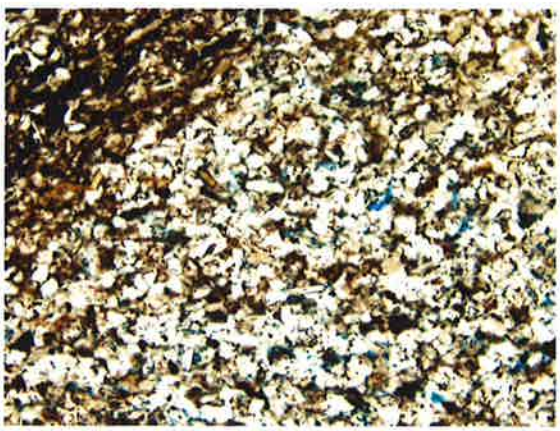
Cement	Scattered carbonate (scarce)
Clay	Appear to be altered mica, not clearly identified, no kaoline is recognised
General:	Inhomogenous siltstone with disrupted shaly layers



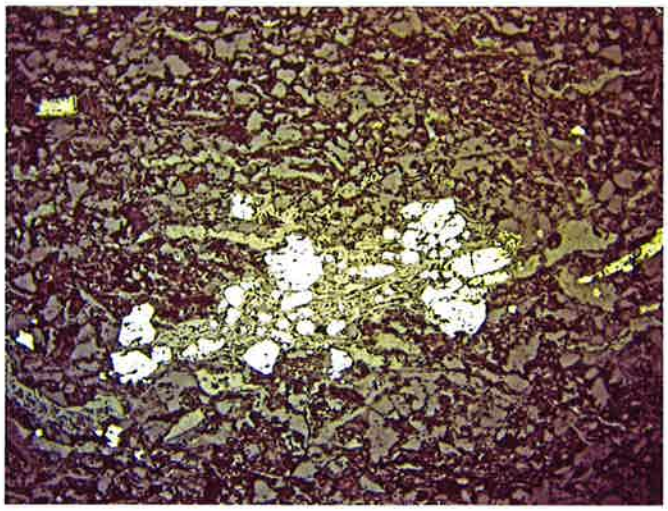
Textural overview; siltstone and shale x4 xn

x4 lln



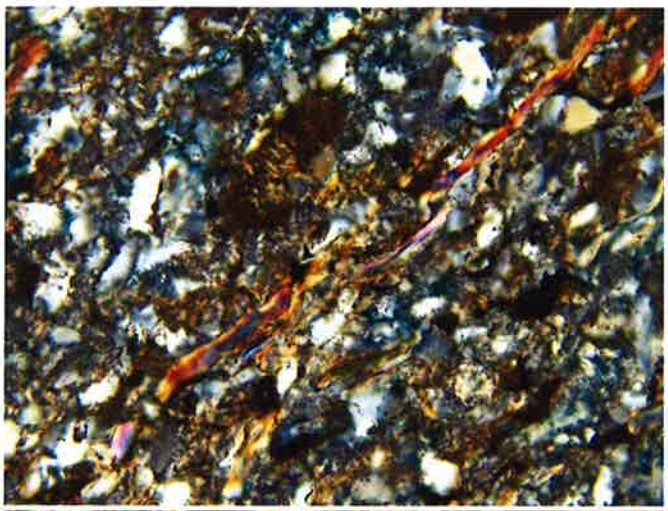


Closer view, low porosity(blue)



x10 reflected light

Pyrite associated with organics in shale layer. Some reflectance seen in organics



x20 xn

x20 lln

Close view, arrows show micas (biotite, muscovite, chlorite)

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
863.7	2.9	17.2	35.9	1.2	31.6	4.3	1.7	0.1	3.9	1.2

Well : Dh4 **Depth, m: 865.6** **Type: Core/De Geerdalen Fm**

Lithology	Flaser laminated fine sandstone
Sorting	Moderate well
Grain size	Fine – medium sand, some silty sizes
Grain shape	Subangular - subrounded
Porosity	Variable, locally fairly well (inhomogenous)

Detrital:

Fragments	Shale clasts, a few polycrystalline quartz, possibly some fine grained sediments (chert?), biogene carbonate grain, biogene silica grains, a few altered dolerites
Grains	Quartz, plagioclase, microcline, muscovite, biotite, zircon, rutile?, scattered small pyrites and oxides, chlorite

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Authigenic:

Cement	Quartz overgrowths in layers, very local carbonate
Clay	Some chloritic? Difficult to identify, probably alteration products

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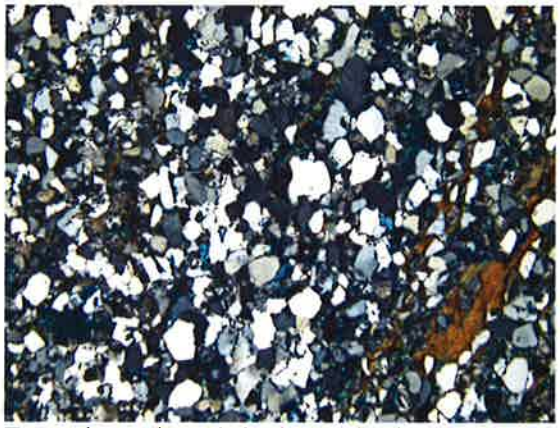
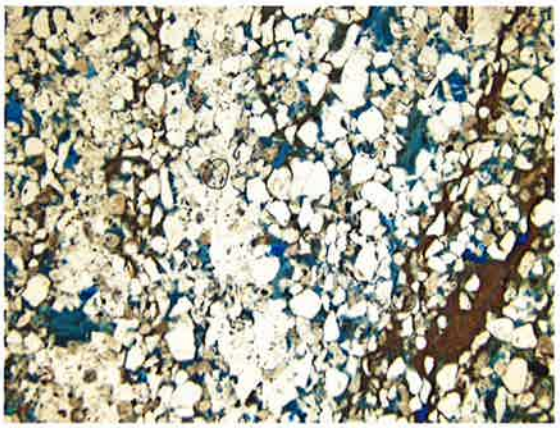
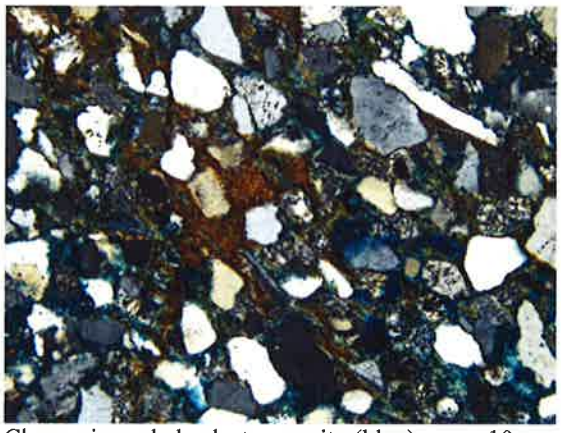
General: Very inhomogenous with quartz cemented thin layers, other layers have high porosity, oversized pores occur, irregular discontinuous shale clasts. Some porosity (fractures) probably artifacts from preparation (variably polished). Quartz cemented layers appear also compacted with irregular grain boundaries



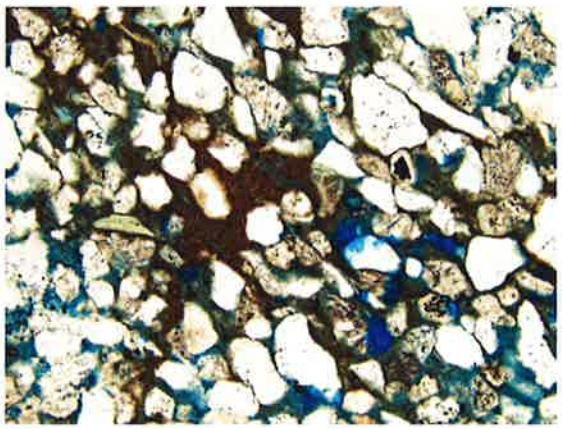
Textural overview, shale clast to the right x4 xn



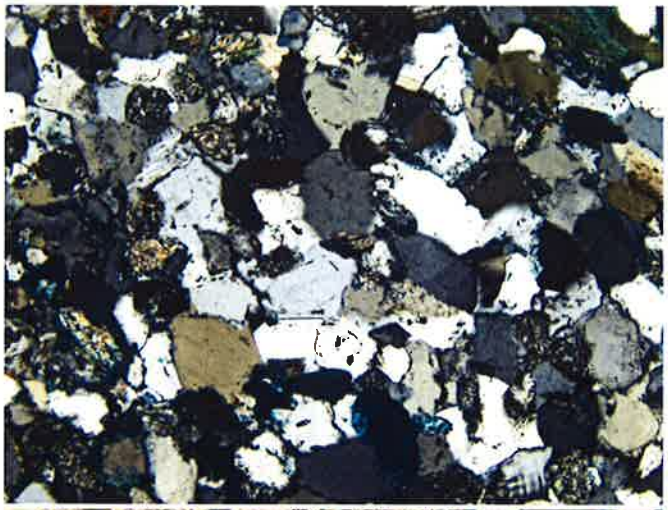
x4 lln



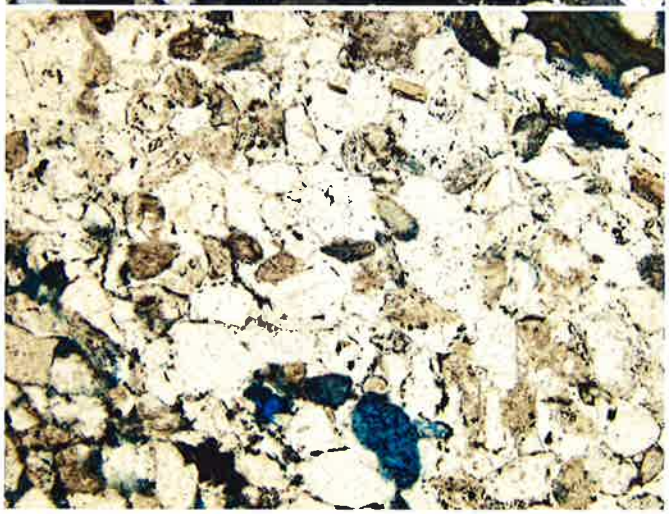
Closer view, shale clast, porosity (blue) x10 xn



x10 lln

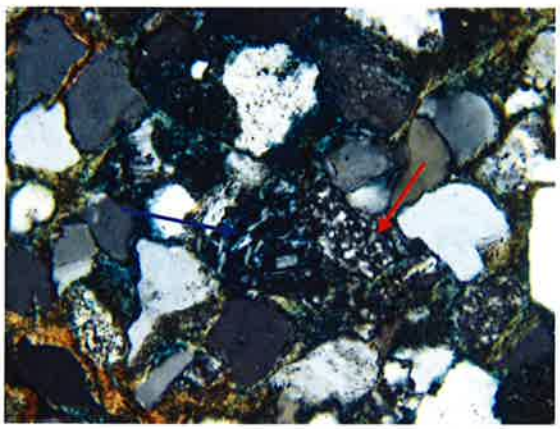


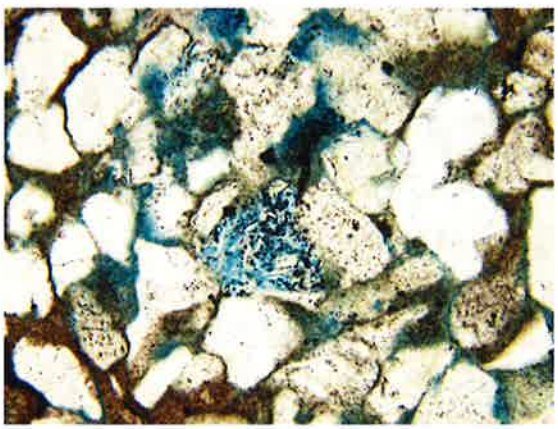
x10 xn



x10 lln

Quartz cemented, compacted layer





Texture and fragments: micro quartz/chert (red arrow), altered dolerite (blue arrow)

x20 xn x20 lln

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
865.6	0.1	16.9	48.0	1.3	25.5	3.0	0.6	0.1	3.3	1.1

Well : Dh4 **Depth, m: 875.7** **Type: Core/De Geerdalen Fm**

Lithology	Sandstone
Sorting	Fairly well
Grain size	Medium sand
Grain shape	Subangular; some are subrounded
Porosity	Irregularly distributed – estimate 12-15%. Also oversized pores and secondary porosity

Detrital:

Fragments Fine grained quartz (sediment), polycrystalline quartz, shale, dolerite, schist, gneiss, plutonic, possibly also a few carbonaceous

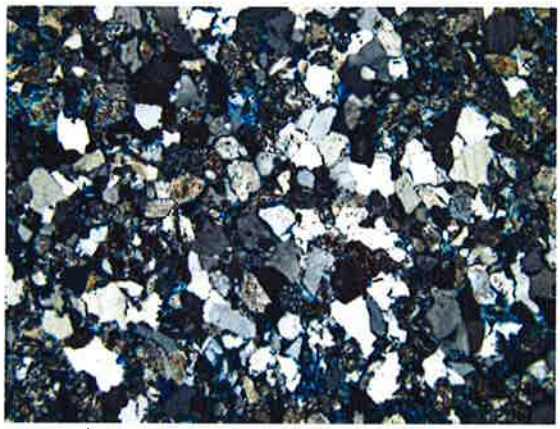
Grains Quartz, plagioclase, microcline, muscovite, scattered pyrite, tiny oxides, chlorite, zircon, rutile, anatase?

Authigenic:

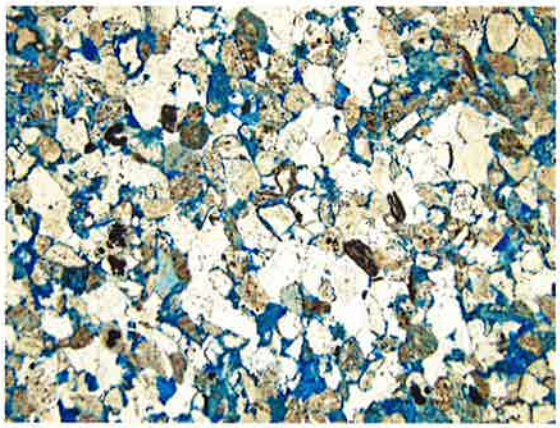
Cement Quartz overgrowths, plagioclase also occur, local sparry carbonate (often corroded borders)

Clay Appear to be present, generally as alteration product (chloritic?), typical kaolinitic or illlitic not obviously seen (see SEM results)

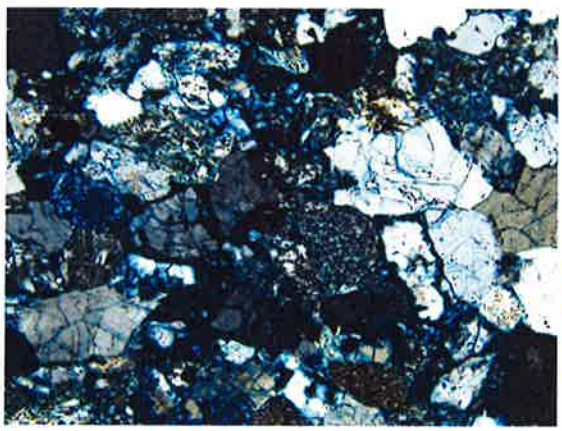
General: Small fractured zone (artificial?) with fractured grains (secondary porosity), dark spots in hand specimen are dark shale grains, cloudy (altered) feldspar grains or sulfides/oxides. Dissolving grains, local carbonation. Local compaction, and also local dissolution of quartz overgrowths. Very inhomogenous.



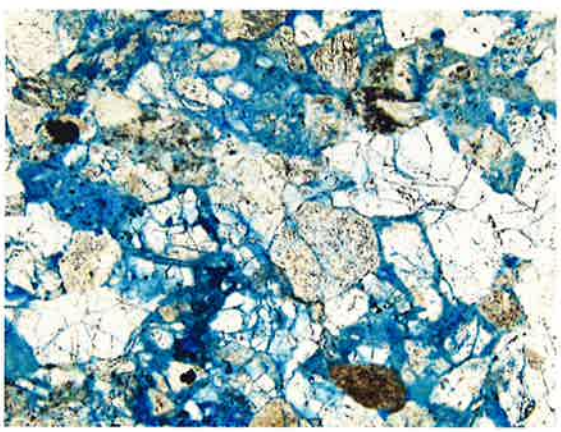
Textural overview, porosity distribution x4 xn



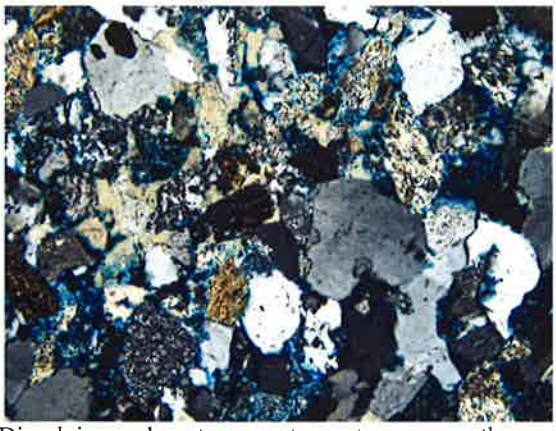
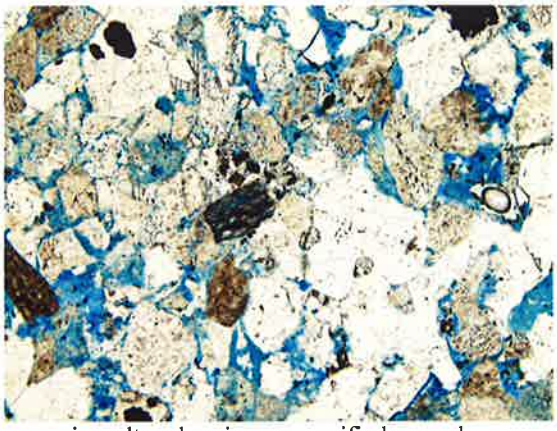
x4 lln



Fractured grains x10 xn

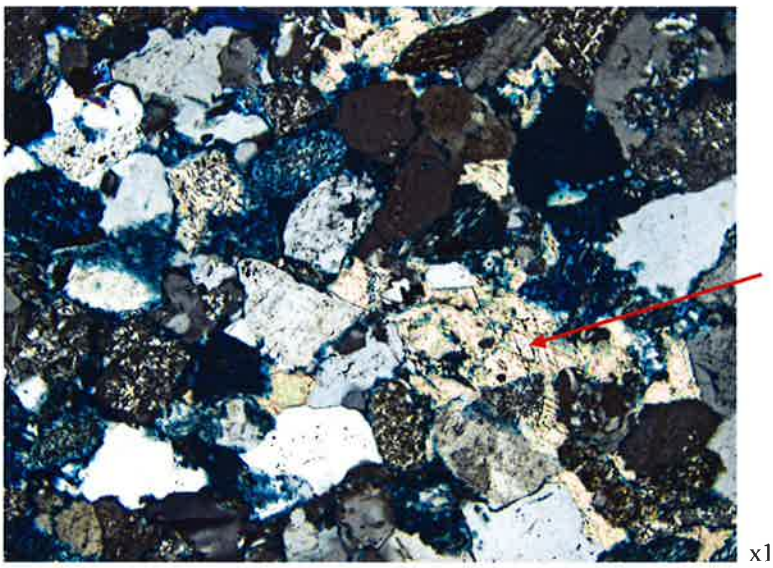


x10 lln

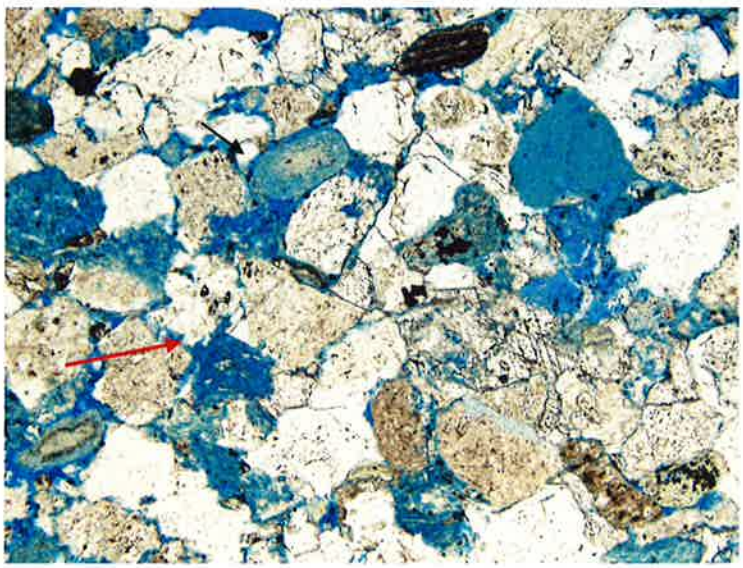



Dissolving carbonate cement, quartz overgrowths, various grains, altered grains, unspecified pore clays

x10 xn x10 lln



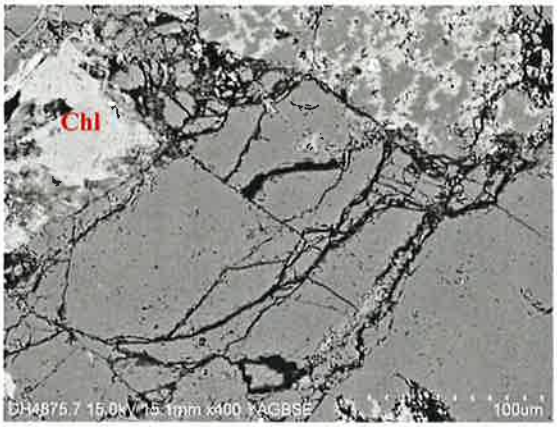
x10 xn

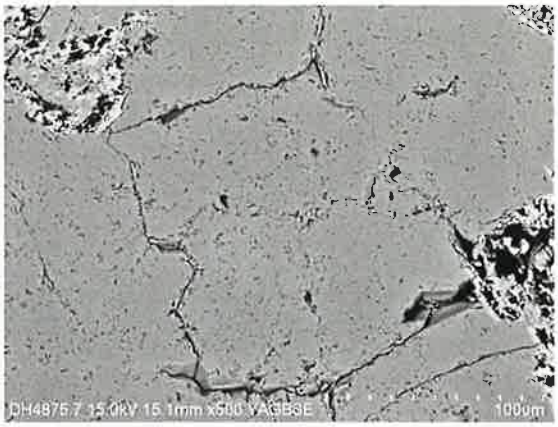


x10 lln

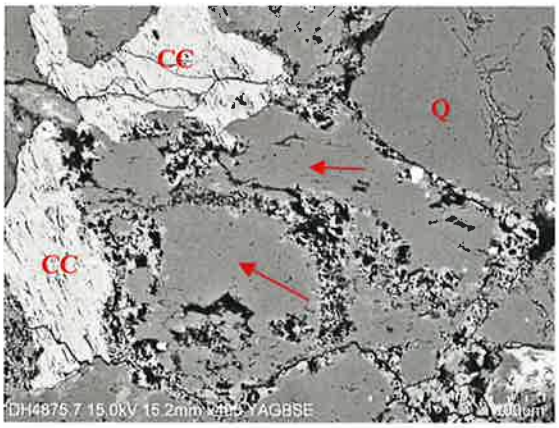
Similar view, plagioclase overgrowth (lower arrow), dissolving carbonate cement (upper arrow), altered glauconite (black arrow)

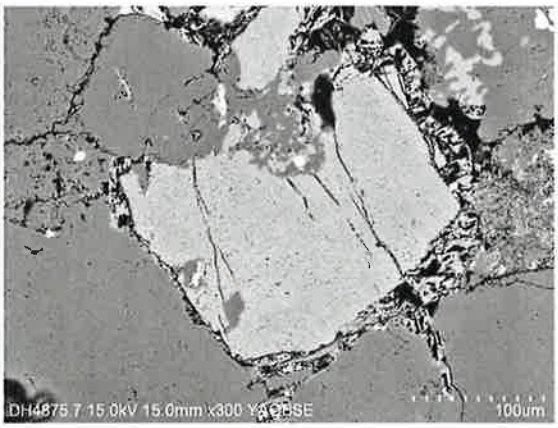
SEM:



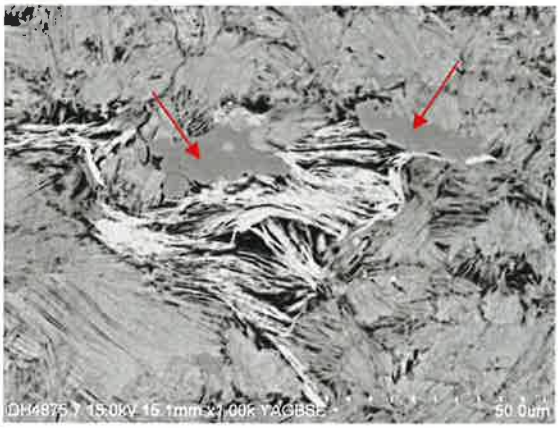


Left: Fractured quartz grains. Chlorite (Chl), alkalifeldspar above. Right: compaction

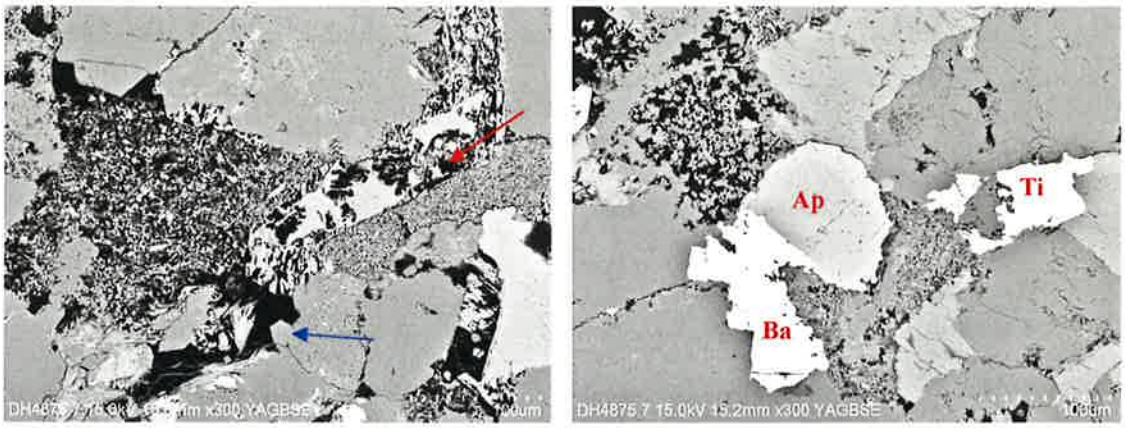




Left: Calcite cement (CC), albite indicated with arrows. Dissolution textures, dissolving K-feldspar down right. Q: quartz. Right: K-feldspar with dissolving margins in center; compaction texture.



Left: Clays/ductile clasts: Chlorite in center (pale), surrounded by mica/illite (grey), quartz (arrows)
Right:Pore fill with illite/mica, possibly including some kaoline.



Left: Complex pore texture: In center altered grain, now mix of quartz, K-feldspar and illite. Dissolving K-feldspar (arrow) bordering a ductile grain with similar chemistry. Albite is seen in the upper part, authigenic quartz below (blue arrow) Right: Various cements: Apatite (Ap), barite/gypsum (Ba), Ti-oxide (Ti). Compaction and dissolving grains.

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
875.7	0.0	14.6	42.9	2.0	28.3	6.7	1.2	0.2	2.7	1.2

Well : Dh4 **Depth, m: 887.7** **Type: Core/De Geerdalen Fm**

Lithology	Silty shale
Sorting	Well
Grain size	Clay-silt
Grain shape	Irregular, mica laths
Porosity	Non visible, except a small discontinuous fracture

Detrital:

Fragments	Not identified. Dark organic debris, more or less focused in layers
Grains	Quartz, muscovite, chlorite, scattered pyrites and/or oxides, few dark micas, possibly small altered glauconites, trace heavy minerals

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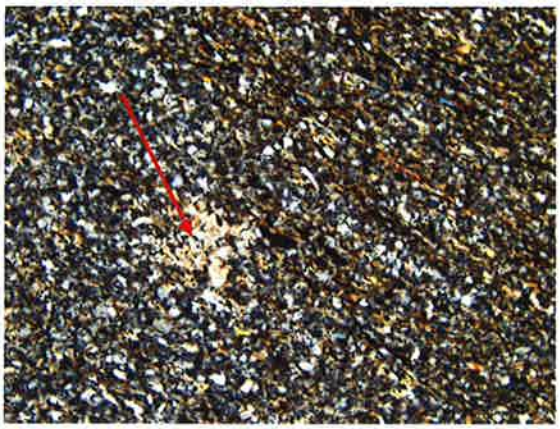
Authigenic:

Cement	Local carbonate, appears located to more silty layers
Clay	Difficult to identify

General: Local cross-lamination, some flaser bedding, thin fracture (or result of bioturbation?) defined by organics

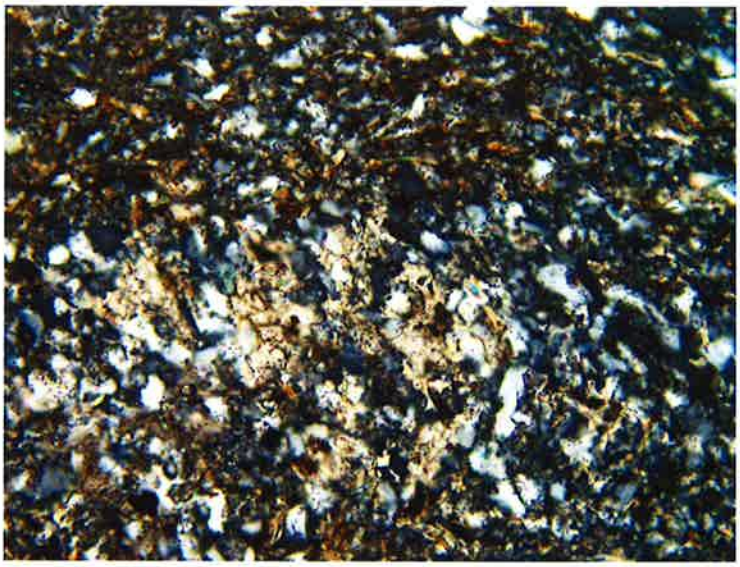
Textural overview, cross lamination x4 xn

x4 lln

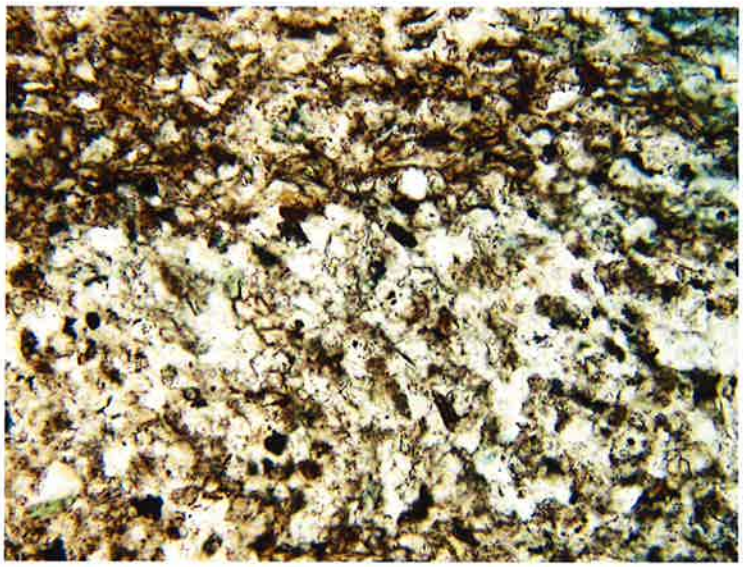


Closer view of texture, local carbonate cement (arrow), black organics, oriented mica laths

x10 xn x10 lln



x20 xn



x20 lln

Lamination, local carbonate cement (center)

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
887.7	5.0	18.5	39.6	0.8	25.7	4.9	0.7	0.0	3.2	1.4

Well : Bh4 **Depth, m: 897.4** **Type: Core/De Geerdalen Fm**

Lithology	Sandstone
Sorting	Fairly well
Grain size	Fine-medium sand
Grain shape	Subangular (some compaction)
Porosity	Appears low , estimated<10%, also secondary, a few oversized pores

Detrital:

Fragments Fine grained sediments (shaly), micro crystalline quartz fragments (chert?), a few plutonic (coarser quartz grains±feldspar) probably present but appears not to be common, one dolerite, organic debris

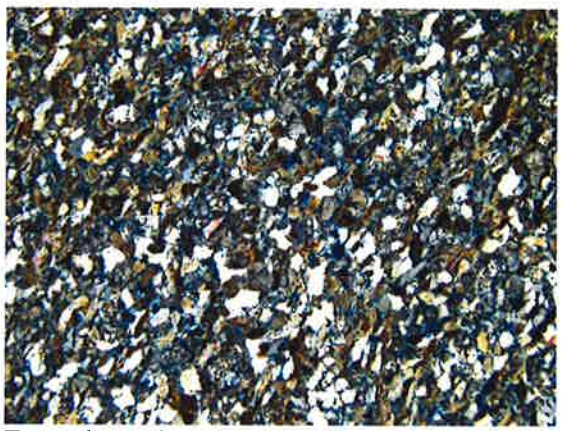
Grains Quartz, plagioclase, muscovite, altered biotite, chlorite, rutile?, scattered oxides-pyrites,

Authigenic:

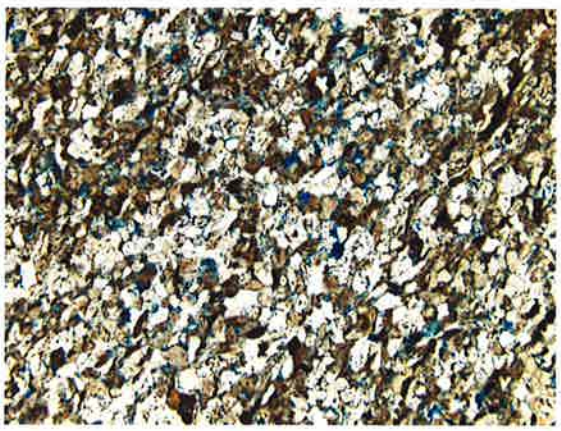
Cement Very local carbonate, quartz cement, probably also albite

Clay Clays appear to be generally alteration products (not typically pore fill), but pore fill occur (appears illitic)

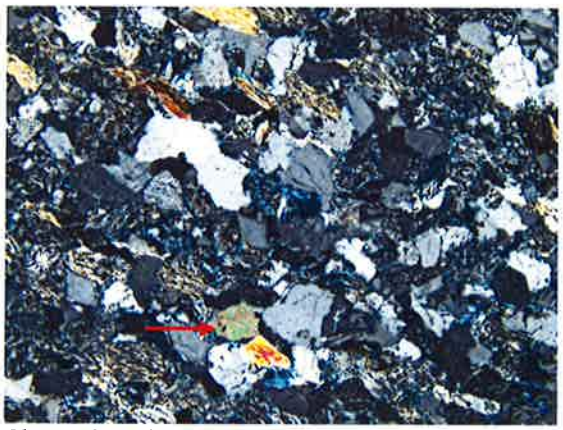
General: Clear evidence of dissolving grains, corroded grain boundaries, but also compaction features, elongated micas. Shaly fragments often dark brown. Fractured grains occur. Very indistinct grain boundaries, but remnant quartz overgrowths occur. Some plagioclase grains are very clear (authigenic) while others are altered/speckled and probably detrital

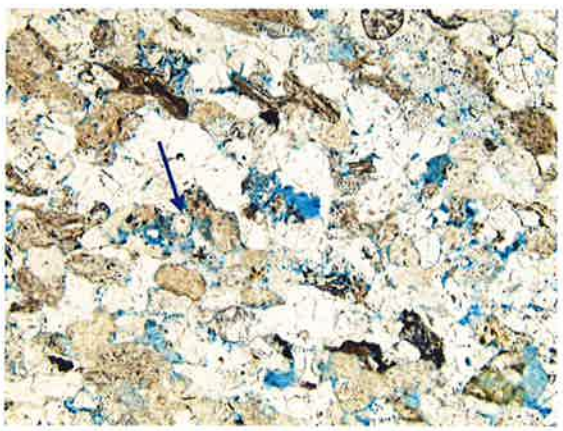


Textural overview x4 xn



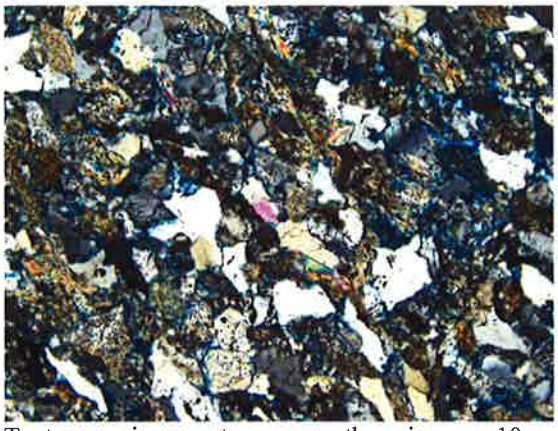
x4 lln



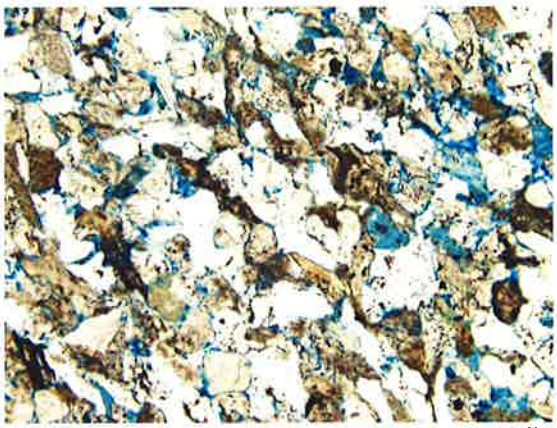


Closer view, fractured grains, local carbonate cement (red arrow), circular chert (blue arrow)

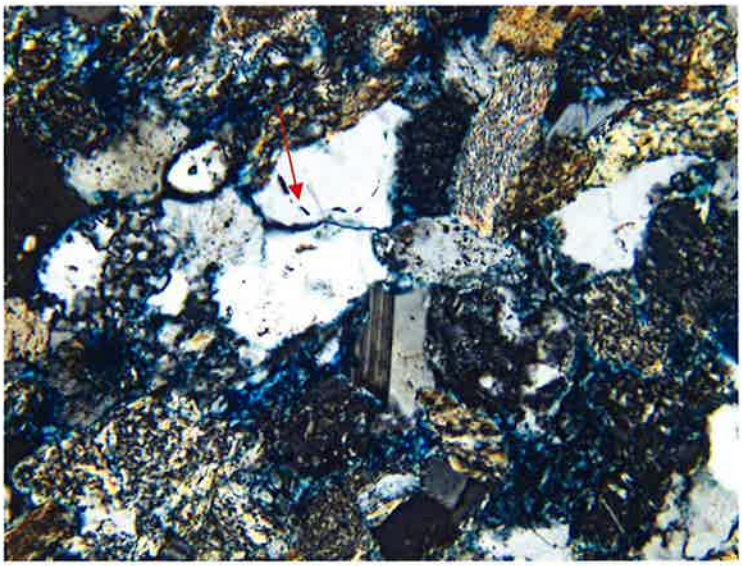
x10 xn x10 lln



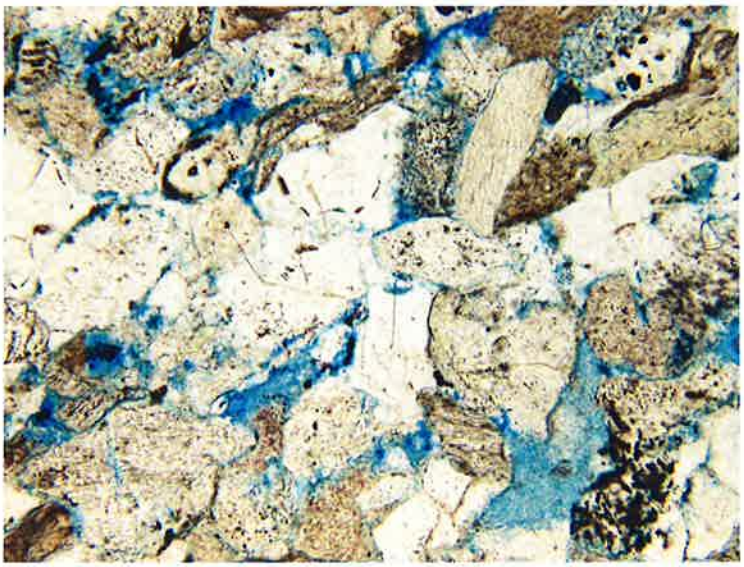
Texture; grains, quartz overgrowths, mica x10 xn



x10 lln



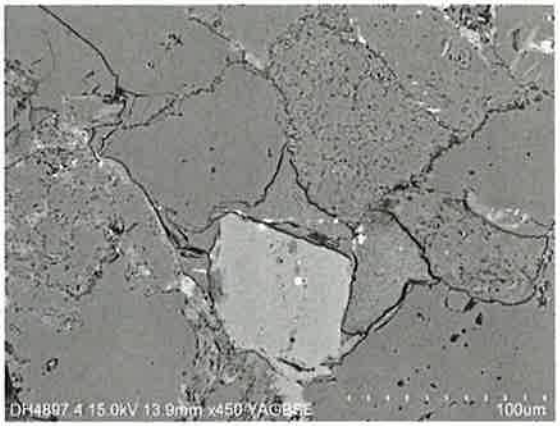
x20 xn



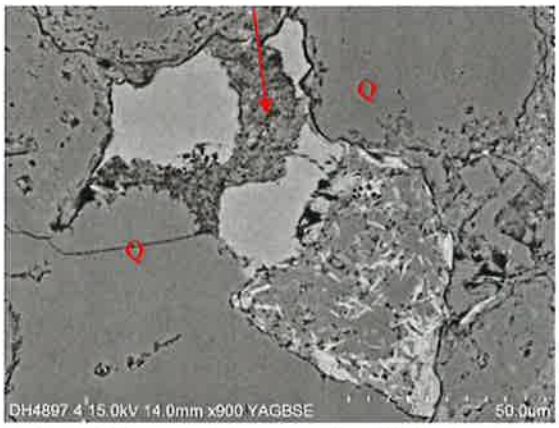
x20 lln

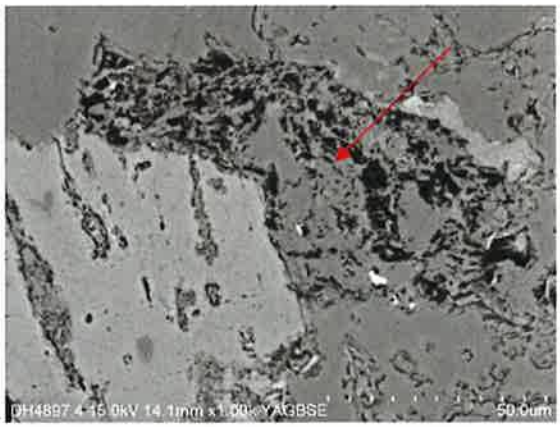
Closer view of quartz overgrowths (arrow), plagioclase (center) and ductile altered grains

SEM:

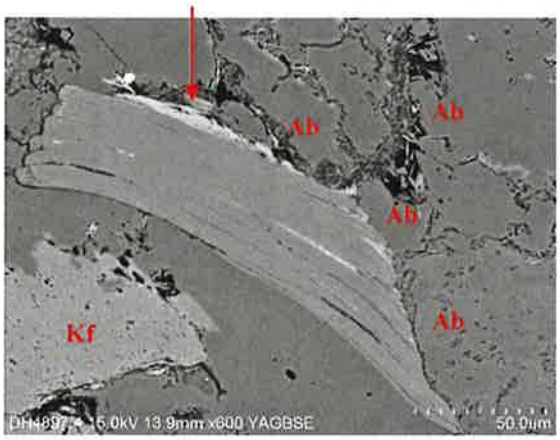


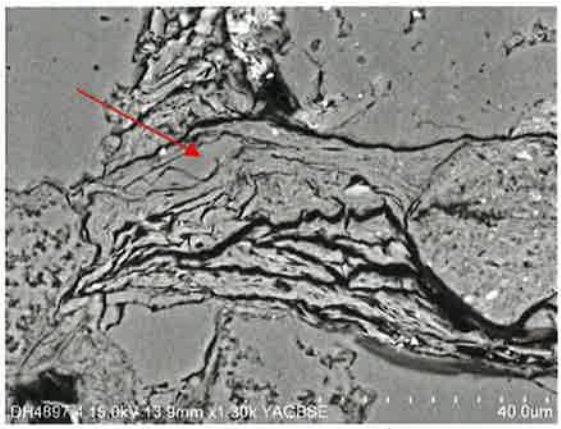
Left: Compacted texture, chlorite±illite in center. The altered circular grain down right shows a mix of K-feldspar and illite ± kaolinite. Right: Similar compacted texture, K-feldspar in center (pale).



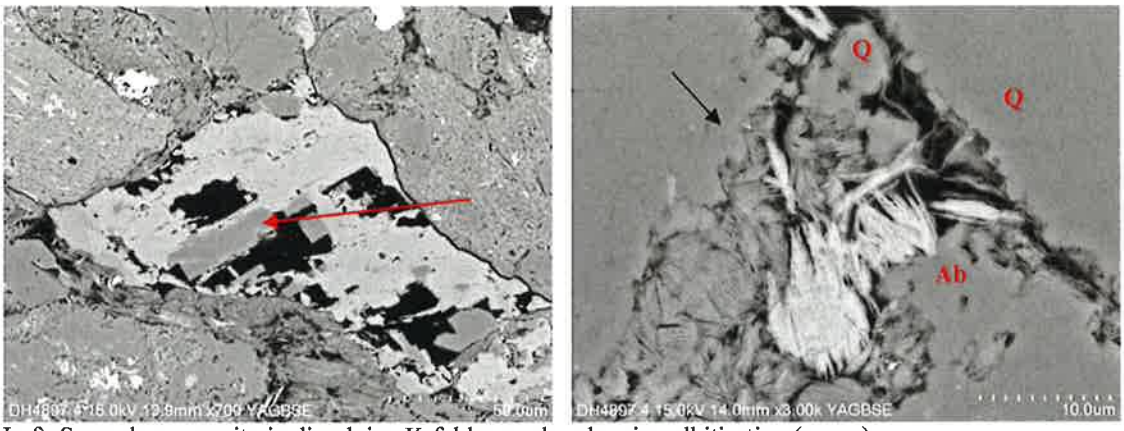


Left: K-feldspar (pale) surrounding illitic clay (arrow). Phases identified in the altered grain to the left are chlorite, albite and K-feldspar. Q: quartz Right: Dissolving quartz (arrow), incipient alteration of K-feldspar to the left.





Left: Unaltered muscovite grain with narrow rim of chlorite towards pore(arrow). Kf: K-feldspar, Ab: albite Right: Detail of ductile pore fill dominated by illitic. Quartz grain (arrow) included



Left: Secondary porosity in dissolving K-feldspar, also showing albitisation (arrow).
Right: Detail of clays in pore: pale chlorite + illite. Ab: albite, Q: quartz. Corroded quartz overgrowth (arrow).

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
897.4	4.3	15.1	38.9	1.0	31.0	3.7	1.1	0.0	3.8	1.0

Well : Dh4 Depth, m: 900.31 Type: Core / De Geerdalen Fm

Lithology Sill/dolerite

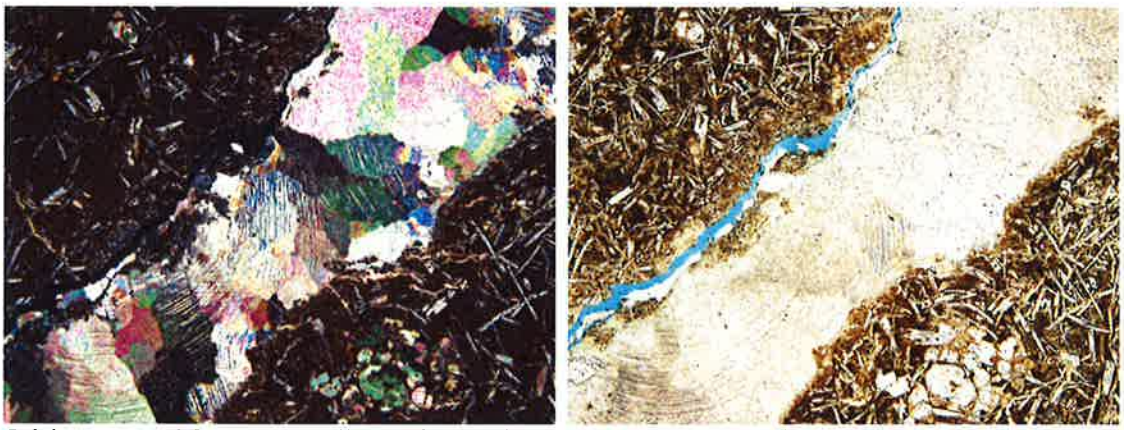
Porosity None visible, except along border of calcite fracture (artifact?)

Minerals Thin unoriented laths of plagioclase in dark groundmass, indicative of rapid cooling. Similar to 838.4 but generally smaller plagioclase crystals.except phenocrystals. Tiny opaques: probably Ti-oxides.

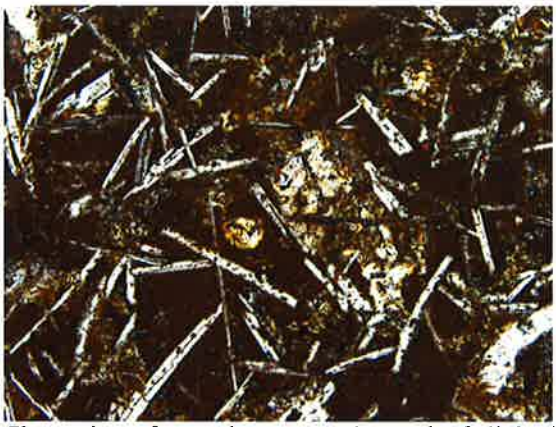
Alteration The larger plagioclases are altered to calcite
Pseudomorphs after olivine/pyroxene with chlorite/serpentine?, may also include carbonate.

General: Altered sill with dolerite texture. Crosscutting calcite fracture with coarse calcite grains, partly radial texture. A small open fracture follows the borders, may be due to preparation. Texture indicative of rapid cooling.

Dolerite texture, coarser plagioclase phenocrystals altering to calcite. Groundmass is dark with numerous unoriented plagioclase laths. x4 xn x4 lln

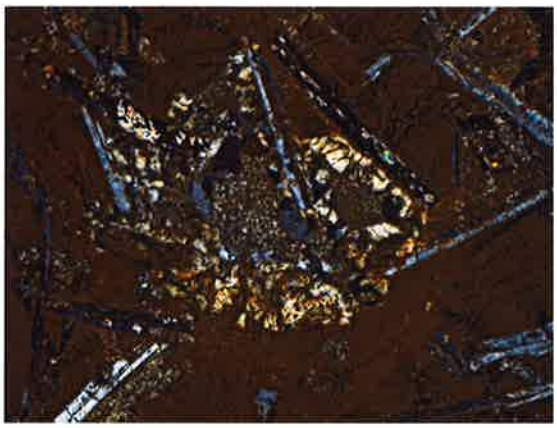


Calcite cemented fracture, smnall open fracture is probably due to preparation
x4 xn x4 lln




Closer view of groundmass, pseudomorph of olivine/pyroxene in center.

x10 xn x10 lln




Even closer view of similar pseudomorph in center

x20 xn x20 lln

Well : Dh4 **Depth, m: 901.5** **Type: Core/De Geerdalen Fm**

Lithology	Sandstone
Sorting	Fairly well
Grain size	Medium sand
Grain shape	Often irregular, not primary outlines, others subangular-subrounded
Porosity	Medium (10%), also secondary and oversized pores

Detrital:

Fragments Altered dolerite, brown shaly fragments, one large shale fragment (mm size), plutonic (coarser quartz/feldspar), polycrystalline quartz, microcrystalline quartz,.schist (metamorphic), organic debris, probable calcareous fragment, a few altered glauconites (?), small radial chert grain

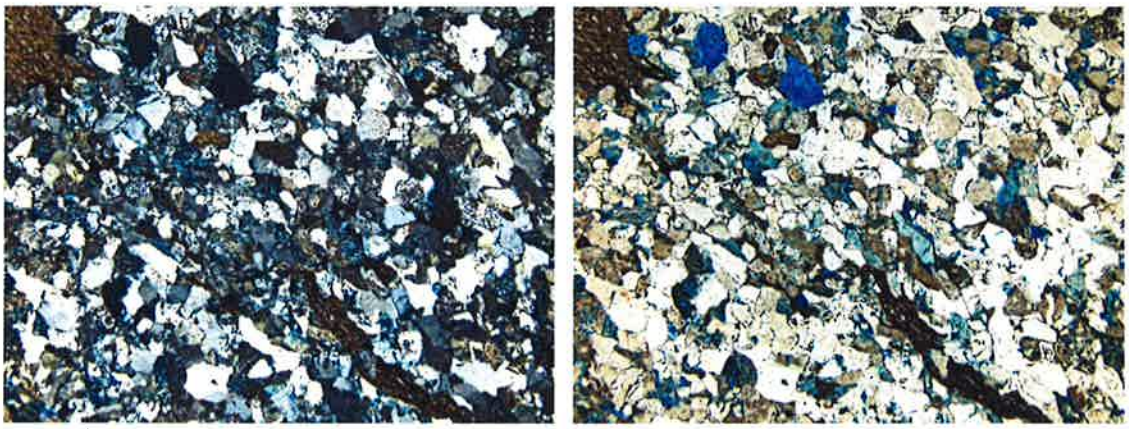
Grains Quartz, plagioclase, K-feldspar, muscovite (often altering), chlorite, scattered pyrites/oxides, rutile, zircon, altered biotite (few)

Authigenic:

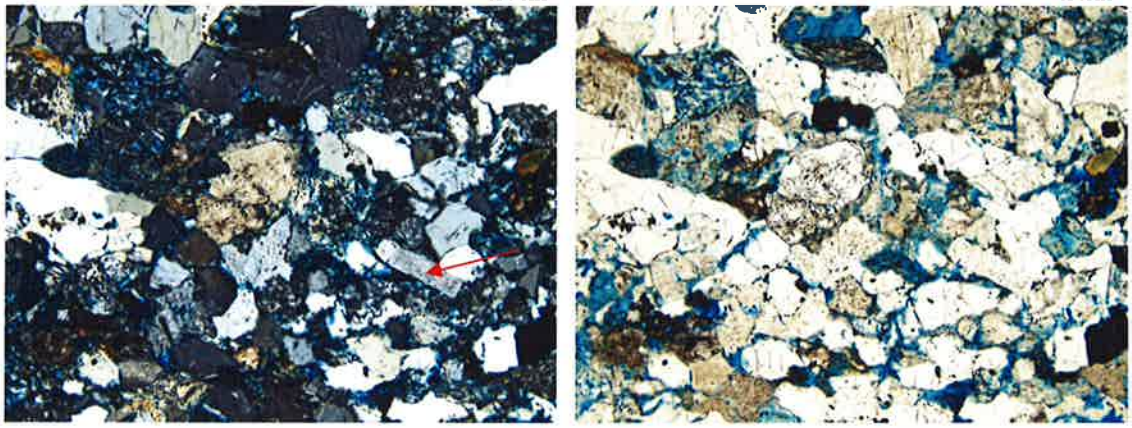
Cement Local sparry carbonate, often dissolving, quartz overgrowths, plagioclase overgrowth (few). Late carbonate. Quartz overgrowths are earlier, predating compaction and fracturing. Local feldspar overgrowths

Clay Unspecified; from alteration, locally in pores (no typical kaolinite)

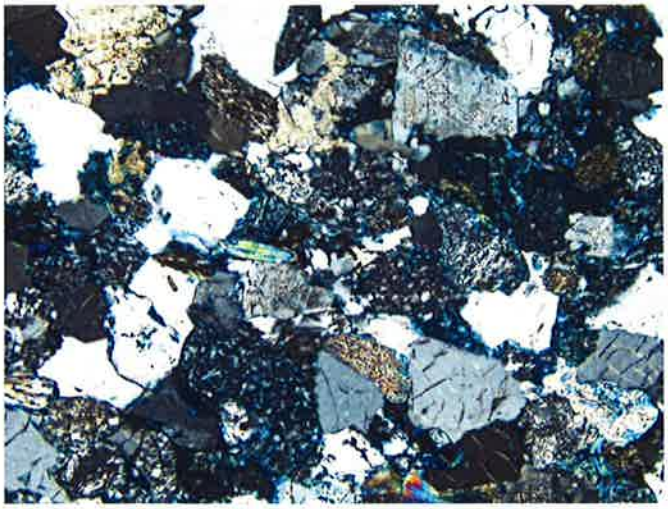
General: Irregular texture, quartz overgrowths are obvious but compaction is distorting grain boundaries. Shale fragments and altered feldspars often appear similar. Shale fragments are more or less ductile. Fractured quartz grains, but also well preserved feldspar grains. Carbonate seen replacing feldspar.



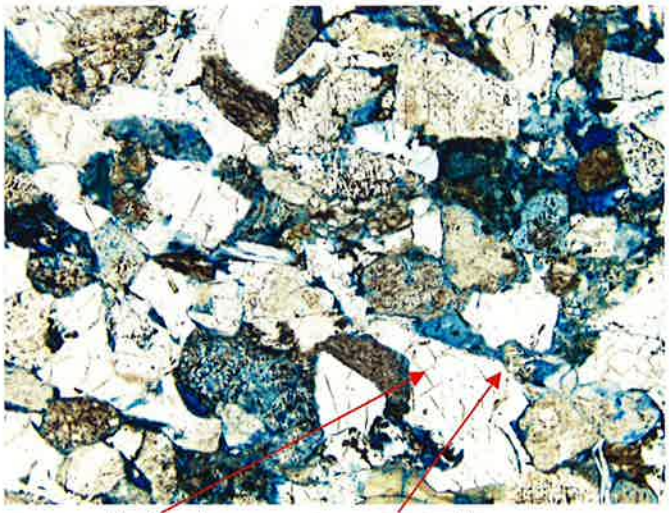
Textural overview, shale fragment upper left and lower right. Oversized pores (blue), upper part.
x4 xn x4lln



Complex texture; carbonate cement in center, altered grains, compaction, preserved feldspar (arrow)
Heavy minerals are common (dark brown) x10 xn x10 lln



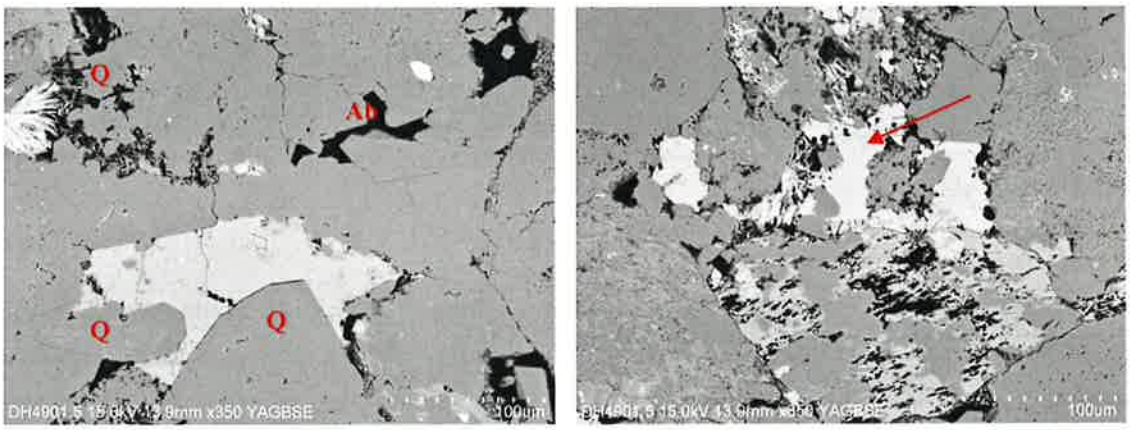
x10 xn



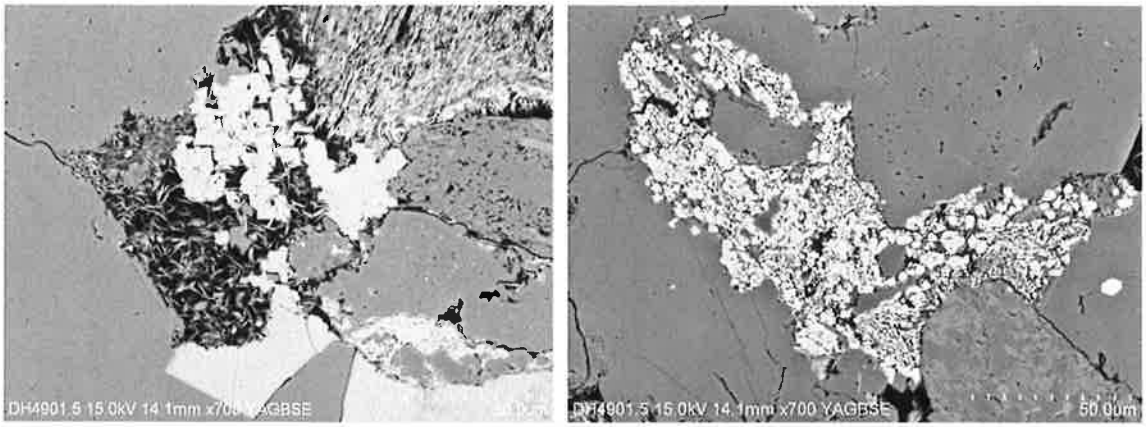
x10 lln

Texture – fractured quartz grains, overgrowths, compaction, isolated pores (blue)

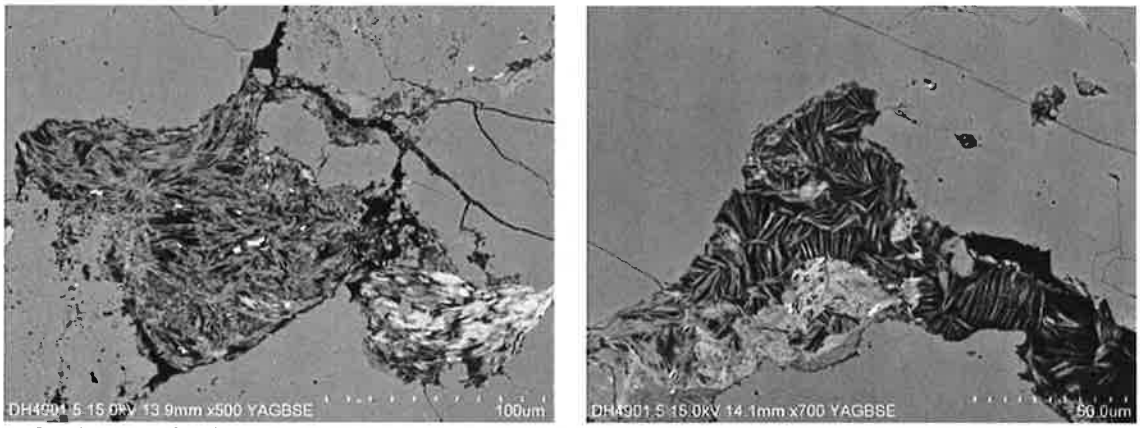
SEM:



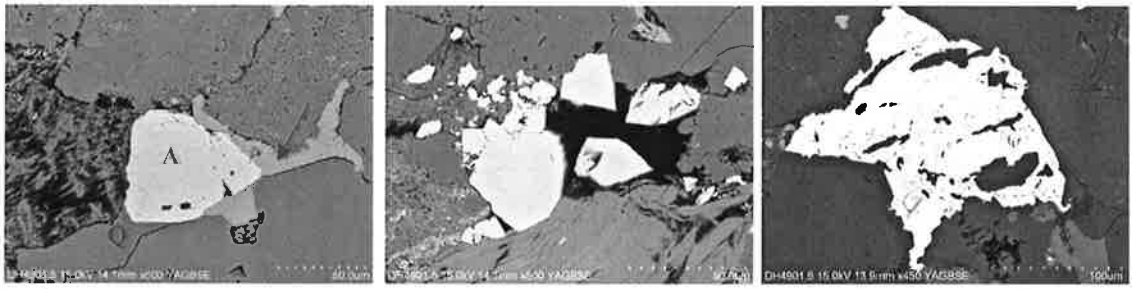
Left: Compact texture, small isolated primary pores. Calcite cement in center (pale), authigenic albite (Ab) and quartz (Q). Right: Dissolving feldspar (albite+K-feldspar) with secondary porosity, calcite cement (arrow)



Left: Calcite cement phases (pale), appear to be corroded by clays (chlorite ± illite). Upper altered grain is probably altered muscovite (illite/muscovite chemistry). Right: Another calcite morphology (pale grains), considered to be replacive.



Left: Clay pore fill: in center illitic clay, down right a mix of illite and chlorite (pale) Right: Clay mix of illite, chlorite and muscovite remnants



Various cements: Left : apatite (A), calcite (arrow) and quartz (Q). Center: Ti-oxide (pale). Right: Barite
Sequence: quartz>apatite>calcite

XRD:

Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
901.5	2.6	20.1	38.1	0.7	29.2	4.8	1.0	0.1	2.7	0.7

Well : Dh4 **Depth, m: 969.6** **Type: Core/De Geerdalen Fm**

Lithology Very fine tight shale, thin diffuse layers
Sorting -
Grain size -
Grain shape -
Porosity Thin, poorly defined fractures, partly open (no cement)

Detrital:
Fragments Probably microcrystalline quartz, fragments not revealed

Grains A few silty grains probably quartz, scattered oxides. Thin mica remnants can be discerned

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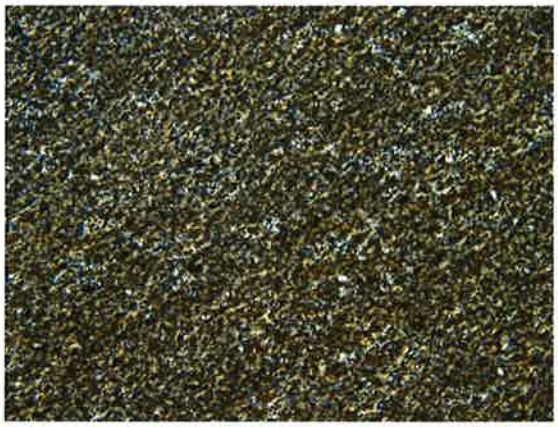
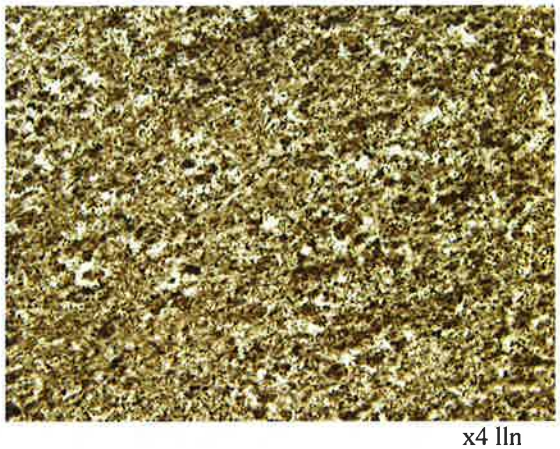
Authigenic:
Cement Carbonate observed

Clay Clay matrix, undefined

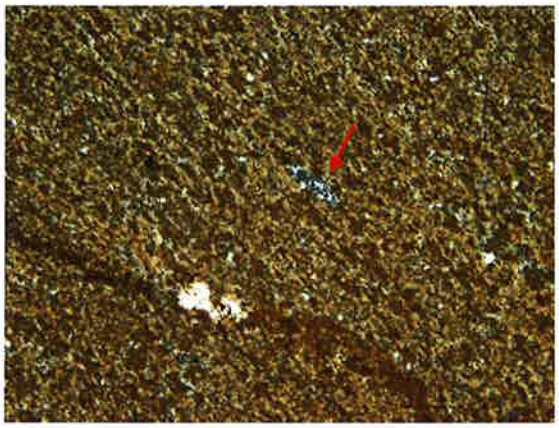
General: Very fine grained, but XRD shows: quartz, albite, 7Å chlorite, small amounts illite (10Å). The layering is less obvious in microscope scale



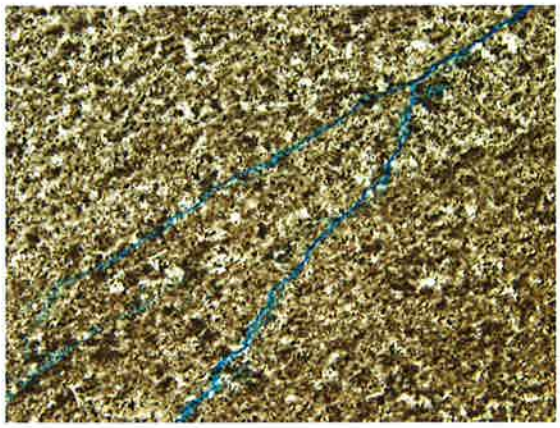
Overview, weak layering x4 xn



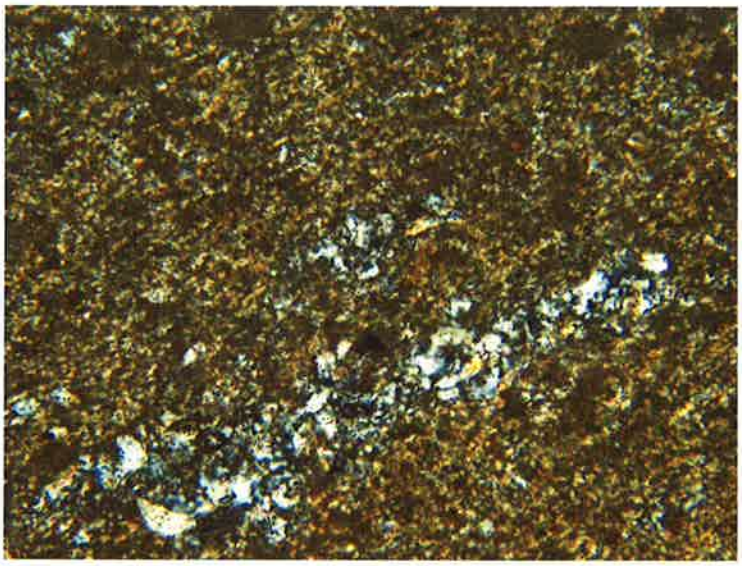
x4 lln



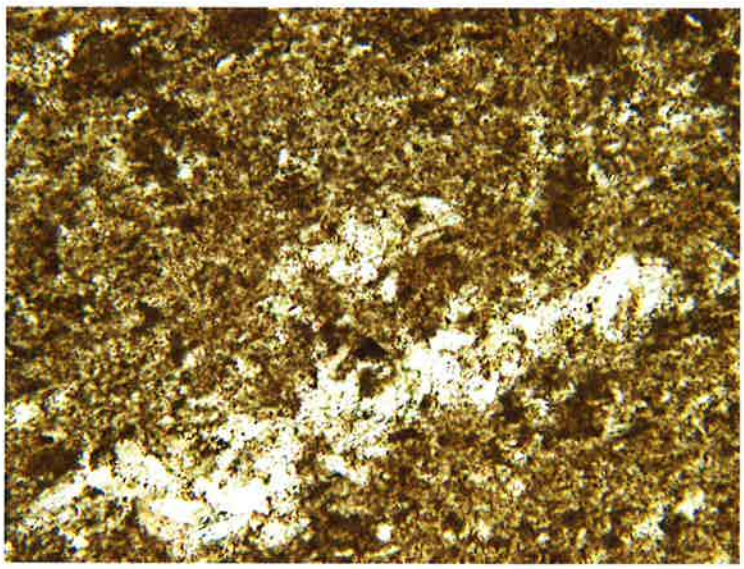
Carbonate cement (pale), microcrystalline quartz (arrow) x10 xn



Thin, open fractures, parallel and crosscutting layers x10 lln



x20 xn



x20 lln

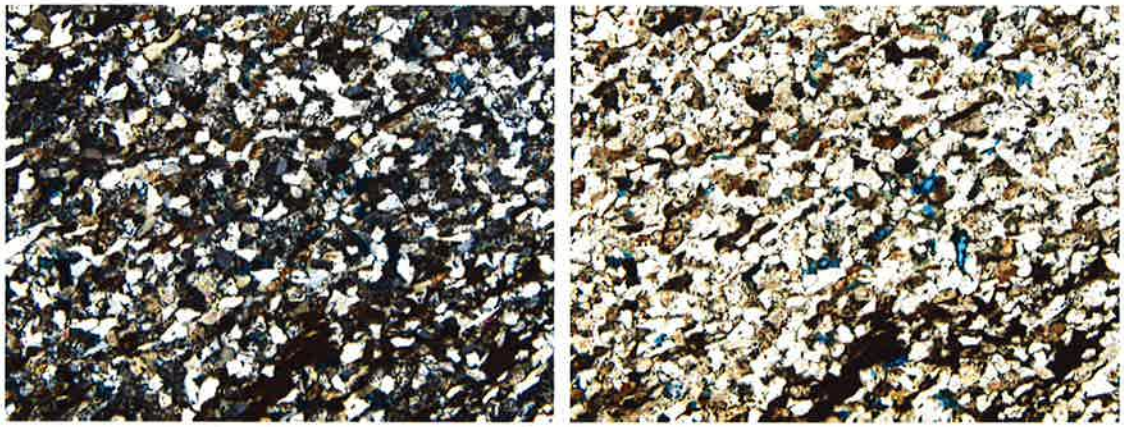
Close up of texture; clay matrix and local occurrence of silty grains

XRD:

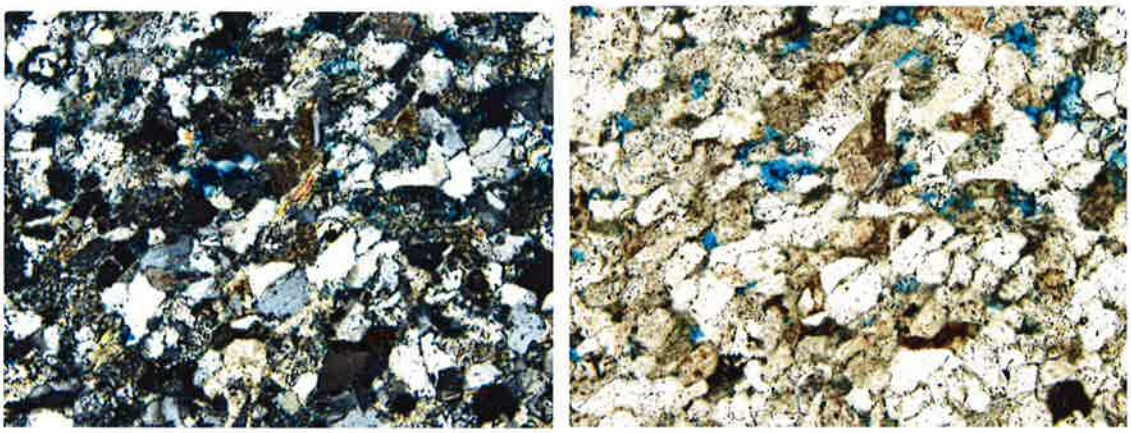
Depth	Illite	Chlorite	Quartz	K-fsp	Albite	Calcite	Dolomite	Siderite	Apatite	Pyrite
969.6	3.3	29.3	22.4	1.3	32.9	4.5	1.0	0.0	4.9	0.3

Dh2 documentation

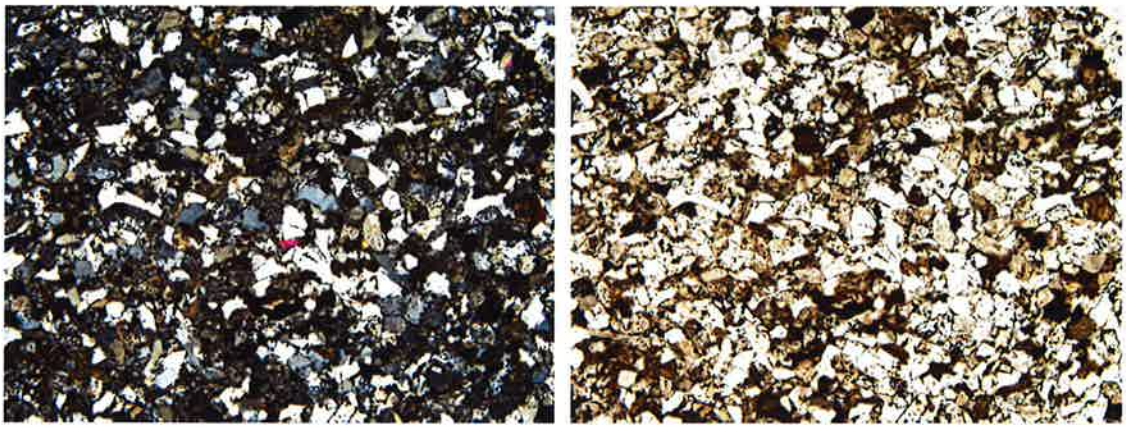
Left side: xn , right side: lln



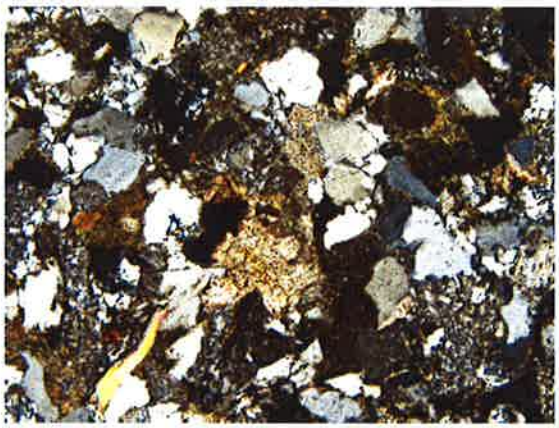
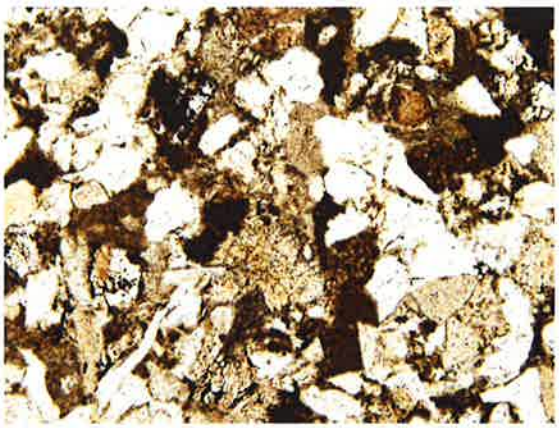
Dh2, 766.50m. Length of picture 3.7mm



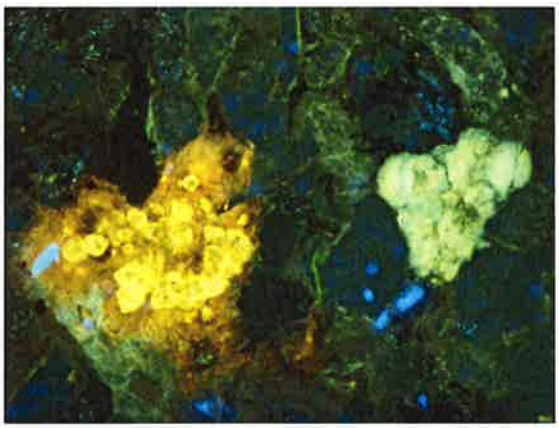
Dh2, 766.50m. Length of picture 1.5mm



Dh2, 771.77m. Length of picture 3.7mm

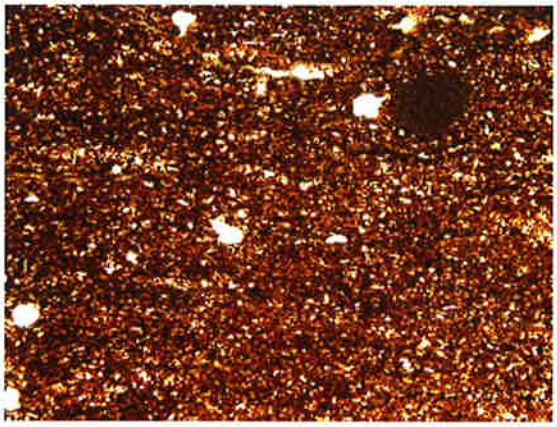
Dh2, 771.77m. Length of picture 1.5mm

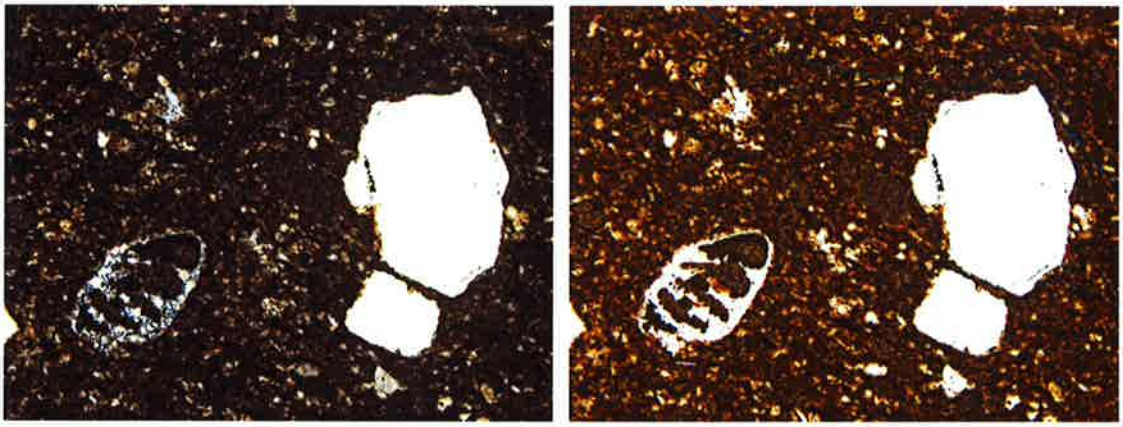
Dh2, 771.77m. Length of picture 1.5mm. UV light right side


Dh2, 779.81m. Length of picture 1.5mm

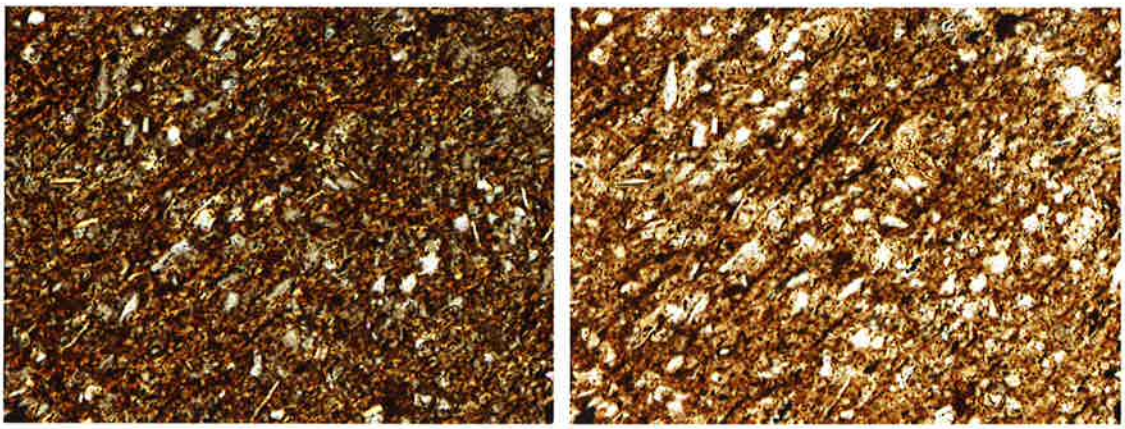
Documentation of Dh6



433.85m lln, length of picture 3.7mm



433.85m, length of picture 1.5mm. Left: xn, right: lln



433.85m, length of picture 0.75mm. Left: xn, right: lln

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