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Description of drill cores from the Rolla and Evenes areas, Troms and Nordland counties

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REPORT

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Title:

Description of drill cores from the Rolla and Evenes areas, Troms and Nordland counties.

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Summary:

A number of carbonate occurrences in the Evenes and Rolla areas, in Nordland and Troms County respectively, contain calcium carbonate with low content of crystal-bound iron and manganese. The calcite in such rocks has potentially high whiteness, and the rock might be suitable for production of high-purity calcite products (such as GCC). Short core boreholes have been drilled to provide continuous samples from four localities in the Evenes area and five localities at Rolla.

The purpose of this report is to provide detailed information about the character of Rolla and Evenes carbonate rocks based on studies of these boreholes, largely based on microphotographs, SEM-images and whole-rock analytical data.

In the Evenes area several tens of square kilometres are marbles with various compositions; some of these are characterised by low content of crystal-bound iron and manganese, and is therefore of potential interest as raw material for industrial production of high-purity calcium carbonate (GCC). However, the Evenes marbles are fairly dolomitic and mineralogically complex and exploitation would be challenging. Localities with low content of crystal-bound iron and manganese, preferentially less than 250 ppm; such as at Bjørnåsen, are of potential economic interest if an industrial-feasible mineral processing can be developed.

A characteristic geological feature at the island of Rolla is a flat lying marble and mica schist/gneiss succession that is several hundred meters thick with an area expansion of more than 10 km^2. Potentially high-quality calcite marble occurs at certain horizons in this succession, and in contrast to the Evenes area the dolomite content is low. Of particular interest is the Breivoll marble unit, potentially several square kilometers wide, fairly flat laying, at least 25 meters thick.

Keywords:	Industrial mineral	Carbonate
Calcium carbonate	Characterisation	Chemical analyses
Core drilling		

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1. INTRODUCTION

A number of carbonate deposits in the Evenes and Rolla areas, in Nordland and Troms Counties respectively, contain calcium carbonate with low content of crystal-bound iron and manganese. As crystal-bound iron and manganese may cause a discoloration in finely grounded calcium carbonate products, these low-Fe-Mn-calcium carbonate rocks may be suitable as raw materials for industrial refinement (processing).

The basic requirement is the presence of high-purity calcite (see below) within a calcite carbonate rock, and a number of deposits pointed out by Korneliussen et al. (2011 a, b) have favorable characteristics in this respect.

High-purity calcium carbonate is first of all characterized by its high whiteness, and is used in paper, paints etc. Iron and manganese within the carbonate crystal structure reduces whiteness, and only deposits with a low content of these elements are attractive for industrial production of GCC and PCC (see below). In general less than 250 ppm crystal-bound Fe+Mn identified by standard "acid soluble" analytical procedures is regarded as excellent in this perspective, and such deposits have been the focus of the Evenes and Rolla projects. GCC (Ground Calcite Carbonate) is high-purity calcium carbonate produced by mechanical-chemical processing of carbonate rocks from favorable deposits, with prices varying considerably depending of the quality of the product. PCC (Precipitated Calcium Carbonate) is another highly valuable product, but with a more complex production procedure (see Harben 2002 for additional information about GCC and PCC).

Another major issue is "processability", i.e. it must be industrial feasible to produce a valuable high-purity calcite carbonate product from the rock. The processing characteristics are largely dependent on the mineral characteristics of the rock, i.e. grain-size and amount of other minerals such as quartz, mica, graphite and dolomite, and how effectively calcite can be separated from these mineral impurities into a valuable product.

Since sufficient geological information was not available for an appropriate assessment of the mineral resource potential, two projects were carried out in 2010-11. One of the projects focused on calcium carbonate marbles at the island of Rolla in Ibestad municipality, organized as a collaboration project between NGU and Troms County (Korneliussen et al. 2011b). The other project focused on carbonates in the Evenes area geographically including parts of the municipalities Evenes, Tjeldsund, Skånland and Ballangen (Korneliussen et al. 2011a), in collaboration between NGU and Nordland County.

For both projects it was concluded that

- The "probable resource potential" of high-purity calcium carbonate is very large and most likely sufficient for industrial production, and further steps should be taken towards an industrial development.

Three issues were pointed out as crucial for the continued process towards industrialization:

- The local community, particularly the landowners, must be in favor of a mineral-based industrial development.
- It must be demonstrated by processing tests that high-quality products can be produced from the respective deposits.
- One or several competent industrial companies must be involved, and the continued development must be industrially driven.

The purpose of this report is to provide detailed mineral and mineral-chemical information of the character of the Rolla and Evenes carbonate rocks based on studies of drill cores. Furthermore, geochemical data will be provided.

The report is based on characterization studies carried out by student Astrid Schaller (University of Freiberg, Germany) during January-March 2011, as a combined training session to study carbonate rocks and to provide information to be used in the continued investigations of the deposits. The study includes core logging, optical microscopy and SEM, and is compiled in collaboration with NGU-geologists Agnes Raaness and Are Korneliussen (responsible). Astrid Schaller produced an earlier version of this report as a preliminary report in March 2011.

Some characteristic mineral relationships are shown in the main part of the report, while more extensive information is provided in two appendixes.

Additional information in the form of microphotographs, SEM-images and notes is available upon request.

2. GEOLOGIC SETTING

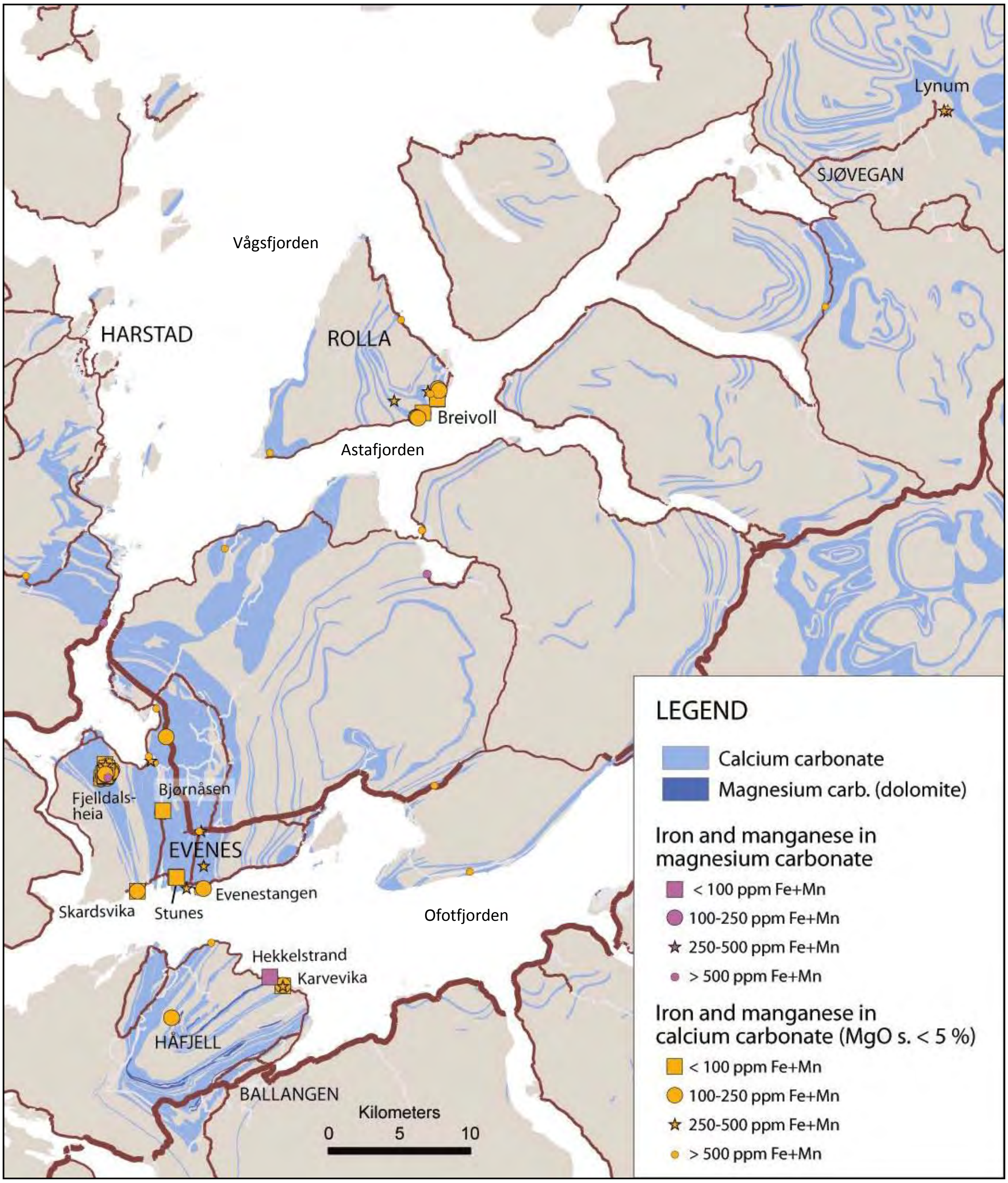

Figure 1: Carbonates (blue) in Ofoten (northern Nordland County) and southern Troms (Korneliussen et al. 2008).

2.1 Evenes area

The Evenes area carbonates occur within the western limb of the Ofoten Synform (Figure 1). The Ofoten Synform is an asymmetric syncline trending in the NNE-SSW direction and represents a geological sequence consisting of parautochthonous Precambrian basement followed by overlaying allochthonous Caledonian nappes (Melezhik et al. 2003). These nappes include the Narvik, Evenes, Bogen and Niingen Nappe Complexes, as indicated in Figure 2.

The carbonates of the Evenes Group, exposed in the study area, were deformed by high-grade Caledonian metamorphism. The complex contains a variety of calcite marbles commonly associated with dolomite marbles in alternate successions with mica schist. Melezhik et al. (2003) considered an age of the deposition of the Evenes Nappe Complex in the Vendian (Late Proterozic) to Early Cambrian and Early Silurian.

The Ofoten Synform is asymmetric, which is reflected in changes in structural thickness of the Evenes Group. The thickness decreases from more than 12 km in the western limb north of Ofotfjorden to 3 km south of Ofotfjorden. Melezhik et al. (2003) explained this phenomenon with tectonic thinning caused by orogenic deformation and metamorphism.

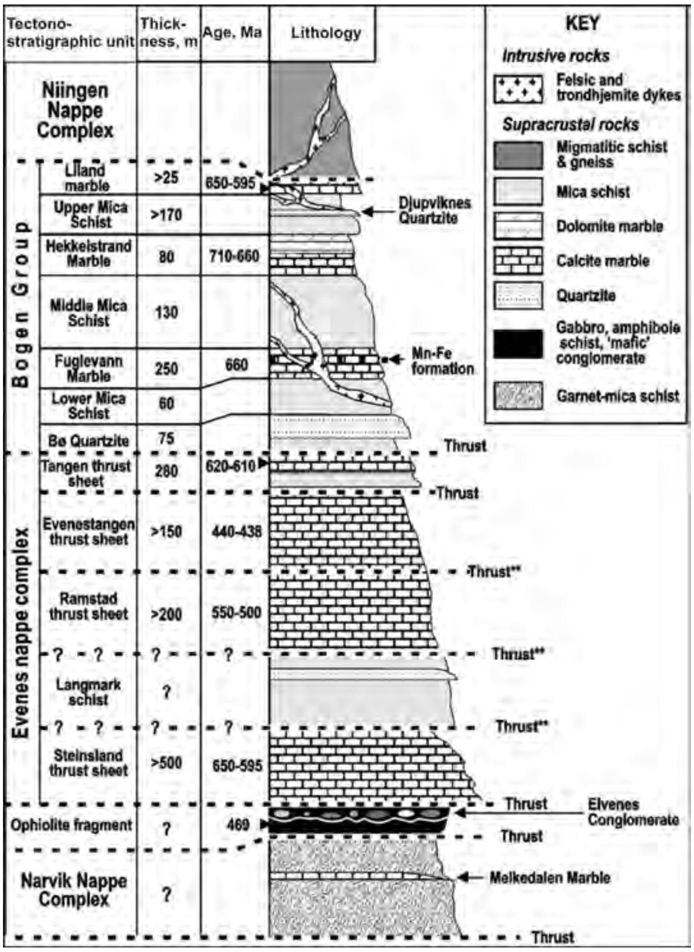

Figure 2: Stratigraphy of the Uppermost Allochthon in the Ofoten region (modified after Melezhik et al. 2003)

2.2 Rolla

The island Rolla has been less investigated than the Evenes area and the general geological information is based on information from Gustavson (1966 and 1974a-c) and El Saleh (1969). The main rock types, as mapped by El Saleh (1969, Figure 3), are quartz-mica-schists, calcite marbles, sedimentary iron ores and quartzites. These rocks are correlated with rocks in the Bogen group in the Evenes area (Figure 2).

There are two major areas of carbonates at Rolla with two different types of calcite marbles. The carbonates on the western shore are correlated with carbonates in the lower part of the Bogen Group in the Evenes area, and consist of banded, fine-grained impure marbles.

The carbonates in the eastern parts of Rolla, which are the focus of this investigation due to their high mineral purity, are correlated with the upper part of the Bogen Group. These carbonates are coarse-grained, white marbles. Strike and dip of the meta-sediments have been measured by El Saleh to range between 15 and 25° ESE with a NNE-SSW strike.

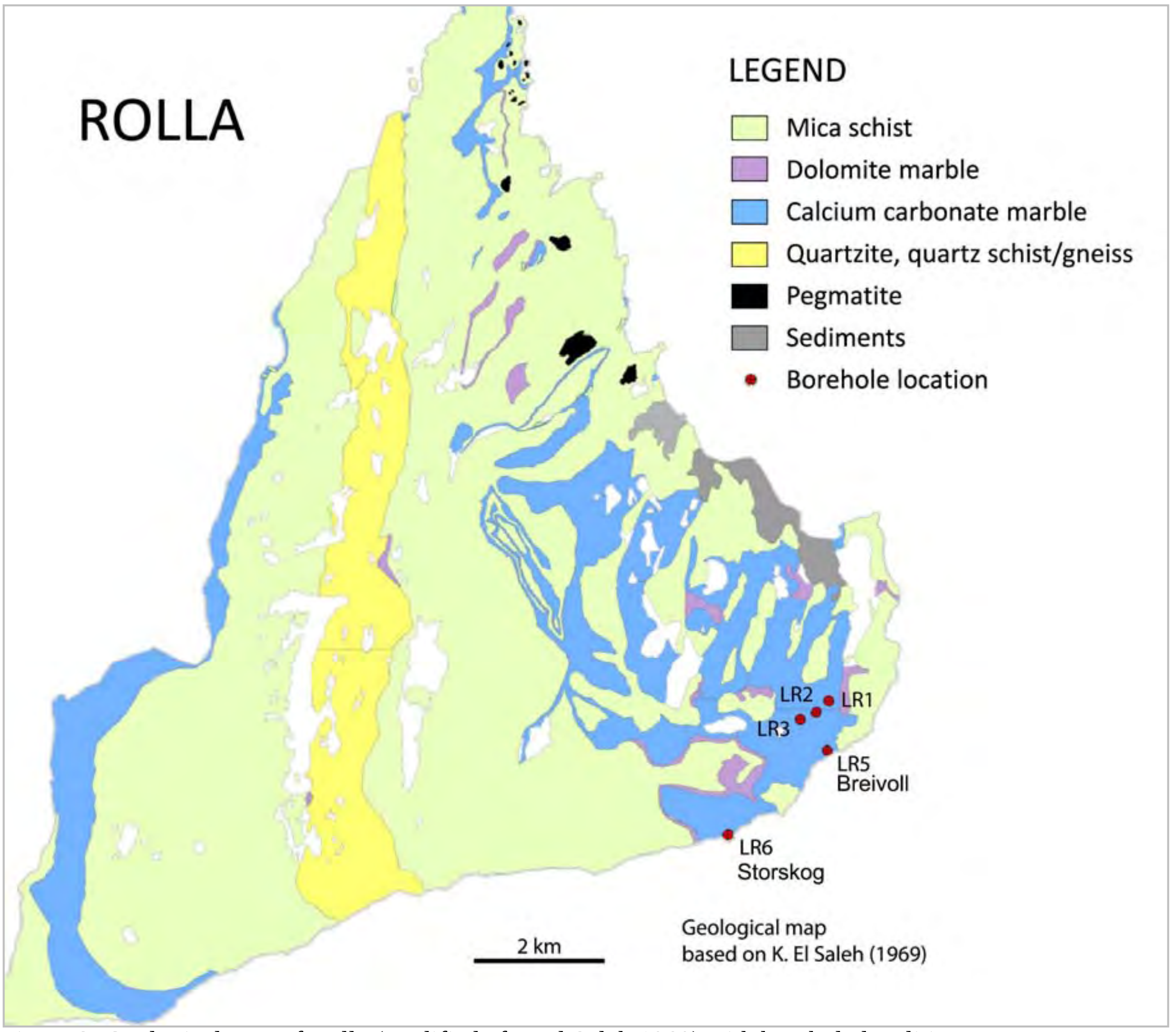

Figure 3: Geological map of Rolla (modified after El Saleh 1969) with borehole localities.

3. METHODOLOGY

Sampling and sample preparation

The drill cores, up to 25 m long, were drilled by a lorry-based drill machine. Four of the drill cores are from the Evenes area and five drill cores are from Rolla.

The drill cores were split, keeping one part for reference and the other part for analyses. The latter were grinded. Grinded materials for sections of 5 m were mixed and split to produce a sample for chemical analyses, resulting in 20 samples from the Evenes area drill cores and 23 samples from the Rolla drill cores.

Polished thin sections have been made from samples from the cores; 9 from the Evenes cores and 9 from the Rolla cores. These samples represent a variety of carbonate and adjacent rocks found within the cores.

Analytical techniques

X-RAY FLUORESCENCE (XRF): Major and trace elements were analysed on 5 m mixed samples from the drill cores by X-ray fluorescence spectrometry using a PANalytical AXIOS 4kW. In addition, XRF measurements have been carried out directly on the cores by using a portable XRF analyser; Thermo Scientific Niton XL3 Analyzer.

ICP-AES: Acid-soluble Fe, Ca, Mg, and Mn were analysed by ICP-AES (plasma-spectrometer Perkin Elmer 4300 Dual View). ICP-AES is the most essential analytical method in this project. Crystal-bound iron and manganese reduces the whiteness of carbonate minerals. A very high-whiteness carbonate product can only be made from a rock in which crystal-bound iron and manganese are low, i.e. roughly 250 ppm Fe+Mn and lower, the lower the better. In the ICP-AES analytical procedure the rock is dissolved in an acid (cold 1 N HCl) sufficiently strong to dissolve carbonate but not silicate minerals, and data for Fe and Mn give a good indication of the "whiteness potential".

TC, TS, TOC: Total carbon (TC), total organic carbon (TOC) and total sulphur (TS) was analysed by LECO SC-444. Detection area ranges from 0.005% to 100% carbon. Analytical uncertainty in regard to TC measurements for concentration with >0.5% carbon is ±15% rel. and for 0.07-0.5% carbon ±0.07% abs. For TOC determination the analytical uncertainty is ±25% rel. for 0.1-3% and ± 20% rel. for >3% carbon. Analytical uncertainty for TS is 30% for a concentration between 0.01-3% and 20% for >3% sulphur.

OPTICAL LIGHT MICROSCOPY AND SCANNING ELECTRON MICROSCOPY (SEM): The thin sections were investigated by using optical light microscope (ZEISS Axioplan 2) and a scanning electron microscope (LEO Model 1450VP) to determine the main mineralogical characteristics of the respective rocks. The tools used in the SEM were back-scattered electron (BSE) images and EDX (energy dispersive x-ray) analyses.

4. RESULTS EVENES AREA

4.1 Main characteristics

The high-grade metamorphic carbonates are strongly deformed crystalline marbles compressed in sub-horizontal folds (Melezhik et al. 2003). Recrystallisation and partial dolomitisation has affected the compositional structure of the carbonates.
The carbonate rocks range from white to pale grey and dark grey, banded or platy, sometimes fairly massive. The composition changes from calcite or dolomite marbles to mixed calcite-dolomite marbles. The carbonates sometimes include thin mica-schist layers, graphite and sulphide-rich layers.

Commonly tectonic deformation have overprinted all traces of primary sedimentary features and resulted in the development of the thin compositional banding (Melezhik et al. 2003)

The core samples for the Evenes project were taken in four different localities (Figure 4).

See Appendix 1 for detailed information about the character of carbonate rocks in the Evenes cores.

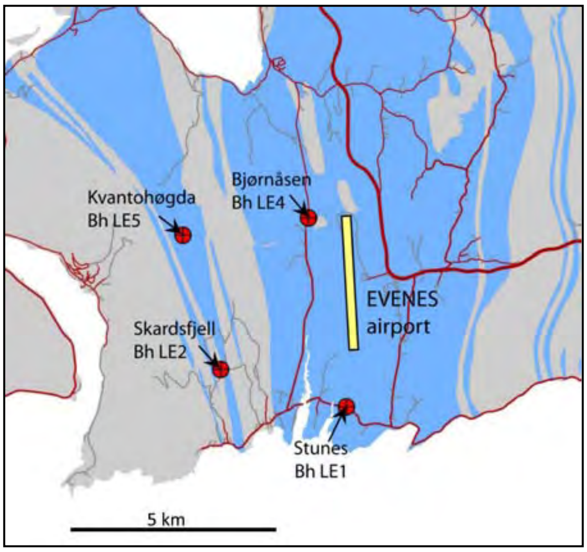

Figure 4: Overview map showing the distribution of carbonate rocks (blue) and borehole localities in the Evenes area.

Table 1: Borehole localities in the Evenes area

Locality	UTM coordinates (eds84)
Stunes (LE1)	N 7595440/E 568531, vertically
Skardsfjellet (LE2)	N 7596357/E 565457, direction 250^o, plunge 45^o
Bjørnåsen (LE4)	N 7600045 /E 567604, vertically
Kvantokollen/Kvantohøgda (LE5)	N 7599624/E 564535, direction. 260^o, plunge 30^o

Figure 5: Fairly flat lying pale to dark grey, banded carbonates at Rotneset (Evenes), with the Hekkelstrand dolomite mine on the other side of the fjord.

The main chemical characteristics of the cores are summarised in Table 3, based on analyses of 5m core sections giving average numbers for each 5m-section. Detailed variations in cm to dm scale are not observable in this data set. In contrast, the point analyses from the core surface by portable XRF (Table 4) are semi-quantitatively picking up small-scale chemical variations in SiO_2, CaO and Fe.

XRF-data give the total composition of the respective element. The $SiO_{2\ xrf}$-content is a good indication of the amount of silicate minerals present, in which the dominant silicate mineral is quartz. Silicate minerals tend to be irregularly distributed within the carbonate rock, frequently enriched in bands.

The LECO analyses give the sulphur content (S), total carbon (C), and total organic carbon (TOC = graphite). In general the S- and TOC contents are fairly low, although there are considerable variations.

The ICP analyses define the amount of acid soluble elements, i.e. elements included in the carbonate mineral crystals (crystal-bound elements). MgO_{icp} is an indication of dolomite ($MgCaCO_3$) content. Low MgO_{icp}-values indicates that only minor dolomite is present. In general the MgO_{icp} content in the Evenes cores is considerable and the carbonate rocks are therefore fairly dolomitic.

The content of crystal-bound iron and manganese as defined by Fe_{icp} and Mn_{icp} is crucial, since these elements reduce the whiteness of the carbonate products. High whiteness is essential for important industrial applications of calcite carbonate such as GCC (ground calcium carbonate).

For this reason the focus of the Evenes and Rolla projects has been to identify calcium carbonate with low content of crystal-bound iron and manganese, i.e. low Fe_{icp} and Mn_{icp}. Although there is no absolute higher limit for Fe_{icp} and Mn_{icp} (the lower the better); a practical target has been to identify calcium carbonate with less than 250 ppm Fe_{icp} + Mn_{icp}.

As already mentioned the cores have been analyzed (point analyses) by a portable XRF instrument (Niton XL3). Although these data are semi-quantitative they give a good indication of variations in SiO_2, CaO and Fe (Table 4).

The main mineral in the Evenes carbonates is calcite with grain-size ranging from fine (< 0.8 mm) to coarse grained (> 5 mm), dominated by the coarse-grained variety (Figure 6). Accessory graphite, sulphides, pyroxenes and other silicates have smaller grained sizes, usually between 0.1 and 0.3mm. Mixtures of dolomite and calcite are common such as shown in Figure 7 and Figure 8.

Table 2: Thin-sections, cores from the Evenes area.

Sample	Thin section	Borehole
73702	LE1-10.0	LE1 Stunes
73705	LE2-07.4	LE2 Skardsfjell
73707	LE2-21.9	LE2 Skardsfjell
73709	LE4-12.5	LE4 Bjørnåsen
73710	LE4-23.8	LE4 Bjørnåsen
73712	LE5-04.8	LE5 Kvantohøgda
73713	LE5-08.4	LE5 Kvantohøgda
73716	LE5-23.7	LE5 Kvantohøgda

Table 3: Summary analyses, cores from the Evenes area.

Sample	XRF (%)						LECO (%)			ICP (%)		ICP (ppm)				Calculated		
From-To (m)	SiO2	Al2O3	Fe2O3	MgO	CaO	K2O	S	C	TOC	MgO	CaO	Fe	Mn	Sr	P	Calcite	Dolom.	Other
Bh LE1																		
LE1-00-05	0,50	-0,02	0,02	0,44	55,90	-0,01	-0,01	11,36	-0,10	0,40	52,60	47	11	257	34	92,52	1,85	5,64
LE1-05-10	8,99	2,65	1,29	1,37	47,70	0,25	-0,01	9,92	-0,10	0,61	45,05	1490	80	228	142	78,58	2,77	18,64
LE1-10-15	0,63	0,05	0,02	0,57	55,40	0,02	-0,01	11,66	-0,10	0,54	52,46	101	12	269	30	91,93	2,46	5,60
LE1-15-20	1,48	0,27	0,12	1,38	53,60	0,09	-0,01	11,38	-0,10	1,20	50,78	458	88	324	152	87,31	5,48	7,21
LE1-20-25	2,03	0,35	0,17	1,71	53,00	0,14	-0,01	11,30	-0,10	1,50	51,20	527	124	312	215	87,30	6,88	5,82
Average:	2,73	0,66	0,32	1,09	53,12	0,10	-0,01	11,12	-0,10	0,85	50,42	525	63	278	115	87,53	3,89	8,58
Bh LE2																		
LE2-00-05	7,04	0,33	0,15	7,35	43,50	0,15	-0,01	11,23	0,18	6,85	40,85	311	68	451	302	55,62	31,38	13,00
LE2-05-10	4,84	0,19	0,09	4,43	48,60	0,08	-0,01	11,38	-0,10	3,98	45,75	148	59	757	323	71,45	18,24	10,32
LE2-10-15	2,86	0,10	0,04	4,69	49,20	0,04	-0,01	11,39	0,11	4,31	46,17	113	18	812	166	71,37	19,76	8,87
LE2-15-20	4,25	0,28	0,17	5,47	47,50	0,14	0,03	12,16	0,12	4,92	44,49	426	60	711	333	66,86	22,57	10,57
LE2-20-24.7	8,54	0,71	0,43	10,40	39,10	0,27	0,08	11,18	0,14	9,20	37,21	729	83	331	348	43,30	42,17	14,52
Average:	5,51	0,32	0,17	6,47	45,58	0,14	0,01	11,47	0,09	5,85	42,89	345	57	612	294	61,72	26,82	11,46
Bh LE4																		
LE4-00-05	4,02	0,10	0,08	3,31	50,10	0,03	0,01	11,84	0,12	2,92	47,71	115	34	337	636	77,56	13,37	9,06
LE4-05-10	8,97	0,41	0,18	6,00	43,90	0,13	0,01	10,89	0,18	5,22	41,27	221	50	348	587	60,40	23,94	15,67
LE4-10-15	11,60	0,59	0,21	8,10	40,30	0,25	0,05	11,11	0,23	6,75	37,21	290	43	390	551	49,40	30,93	19,68
LE4-15-20	11,80	0,59	0,26	8,08	40,10	0,16	0,03	10,92	0,12	6,83	37,07	202	61	440	453	48,94	31,31	19,75
LE4-20-25.2	5,04	0,30	0,18	5,72	46,60	0,12	0,03	12,13	0,19	4,97	43,09	307	52	435	399	64,25	22,80	12,95
Average:	8,29	0,40	0,18	6,24	44,20	0,14	0,03	11,38	0,17	5,34	41,27	227	48	390	525	60,11	24,47	15,42
Bh LE5																		
LE5-00-05	4,58	0,64	0,22	8,57	43,10	0,34	-0,01	11,68	-0,10	7,61	40,57	964	52	179	67	53,23	34,88	11,90
LE5-05-10	4,17	0,91	0,36	11,70	39,70	0,48	-0,01	11,79	-0,10	10,50	36,65	1730	81	169	92	39,10	48,10	12,80
LE5-10-15	3,86	0,59	0,25	9,68	42,10	0,35	0,01	11,67	-0,10	8,74	39,03	1210	58	166	60	47,69	40,04	12,27
LE5-15-20	9,91	1,67	0,63	6,24	42,30	0,93	0,01	10,18	-0,10	4,66	38,75	1740	78	311	136	57,32	21,35	21,33
LE5-20-25.3	4,85	0,78	0,30	5,65	46,30	0,49	0,02	11,59	-0,10	4,86	43,51	1210	72	240	86	65,28	22,26	12,45
Average:	5,47	0,92	0,35	8,37	42,70	0,52	0,01	11,38	-0,10	7,27	39,70	1371	68	213	88	52,52	33,33	14,15

Table 4: Core-analyses by portable XRF, Evenes area.

Bh LE1 Stunes			
Pos (m)	% SiO2	% CaO	ppm Fe
0,5	0,7	61,3	260
1,5	0,7	56,9	250
2,5	0,8	58,1	260
3,5	0,5	56,9	220
4,7	0,7	57,0	400
5,5	0,6	57,1	310
6,3	0,7	56,3	330
7,5	1,1	57,1	1620
8,5	0,7	56,2	930
9,5	1,1	56,0	440
10,5	0,6	56,1	330
11,6	0,9	55,4	330
12,5	0,7	57,1	390
13,5	0,9	56,6	370
14,5	1,4	56,3	390
15,5	1,6	54,8	800
16,5	1,0	56,7	440
17,5	2,0	55,8	640
18,5	2,4	54,1	1100
19,7	2,3	52,9	1220
20,5	2,0	54,8	1020
21,5	3,4	52,6	1310
22,6	1,9	55,7	790
23,5	4,2	51,3	1460
23,8	6,7	50,4	1850
24,5	1,6	56,0	1430
25,4	1,3	55,9	570

Bh LE2 Skardsfjell			
Pos (m)	% SiO2	% CaO	ppm Fe
0,8	4,4	50,7	510
1,6	6,3	48,4	830
2,6	3,6	53,5	600
3,6	11,7	40,2	440
4,5	7,6	49,7	500
5,5	4,9	53,0	620
6,5	1,7	46,4	340
7,6	1,0	54,4	290
8,7	3,2	53,0	540
9,3	1,6	50,9	500
10,6	1,7	53,9	280
11,5	2,2	51,2	660
12,5	1,8	51,1	390
13,5	7,1	50,4	590
14,5	1,9	46,1	350
15,5	2,7	48,1	680
16,5	7,4	42,3	340
17,5	4,9	49,2	1690
18,6	5,7	41,2	1650
19,7	11,3	34,4	2860
20,5	1,6	32,6	1730
21,6	2,1	53,4	420
22,6	2,4	48,9	420
23,3	1,2	32,6	1290
24,4	2,3	52,5	740

Bh LE4 Bjørnåsen			
Pos (m)	% SiO2	% CaO	ppm Fe
0,5	1,5	52,0	420
1,5	1,4	55,3	250
2,6	0,7	56,2	200
3,5	7,9	52,1	300
4,5	3,7	52,4	430
5,5	25,3	27,1	680
6,5	1,0	56,5	230
7,5	1,9	48,6	550
8,5	32,2	22,6	4190
9,5	0,6	56,2	320
10,5	13,5	37,4	870
11,5	30,1	21,5	1860
12,5	11,8	36,7	2100
13,5	13,8	35,8	1150
13,5	15,1	34,9	1120
14,5	1,4	52,3	310
15,5	17,0	24,8	2160
16,5	15,1	32,4	2290
17,4	4,7	53,6	350
18,5	12,6	42,5	960
19,5	3,0	46,7	580
20,5	1,6	48,4	670
21,5	7,6	51,3	1150
22,5	5,1	51,5	760
23,5	3,1	53,6	430
24,5	2,0	51,5	520

Bh LE5 Kvantohøgda			
Pos (m)	% SiO2	% CaO	ppm Fe
0,6	2,4	26,9	1810
1,3	23,8	43,2	430
1,7	4,5	29,7	2130
2,8	1,4	54,2	570
3,4	0,9	57,5	420
4,5	15,9	27,7	5780
5,3	1,6	41,1	2190
5,7	4,2	47,0	1580
5,7	4,2	47,2	1670
6,3	18,2	26,2	3830
6,6	6,8	31,2	3300
7,5	4,4	41,5	2330
8,3	4,7	31,8	2350
8,7	1,6	56,0	540
9,5	1,3	56,7	560
10,3	3,0	43,7	2100
10,6	4,4	34,3	2130
10,8	0,9	55,9	520
11,5	2,7	31,4	2070
12,5	6,6	34,7	3270
12,5	6,7	35,0	3400
13,4	6,1	29,5	4200
13,7	1,8	53,3	740
14,5	5,4	51,1	1150
15,3	1,7	54,6	660
15,5	1,2	56,6	450
15,8	20,0	36,2	7420
16,5	0,8	56,8	530
17,5	2,9	49,7	2850
17,8	23,6	31,3	6980
18,5	20,1	41,2	2330
19,3	13,8	35,0	6260
19,8	6,1	47,6	2070
20,3	10,8	37,9	4650
20,7	6,2	47,0	3430
21,3	1,2	55,4	940
21,6	1,7	56,5	870
22,3	3,7	53,1	1320
22,6	5,7	44,3	2170
22,8	6,4	41,8	2500
23,3	1,3	56,6	680
23,8	1,1	56,3	700
24,5	1,0	55,0	830

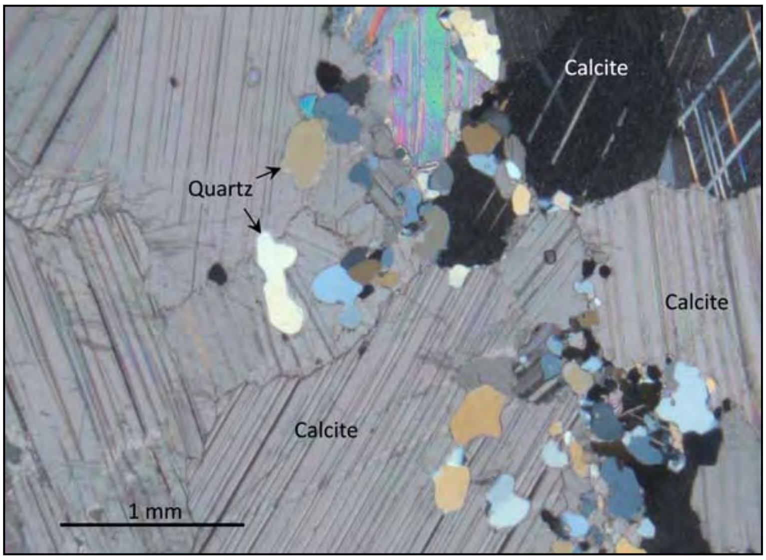

Figure 6: Photomicrograph of coarse-grained calcium carbonate with inclusions of silicate minerals (mainly quartz). Crossed polarisers, Bh LE1 at 10.0 m.

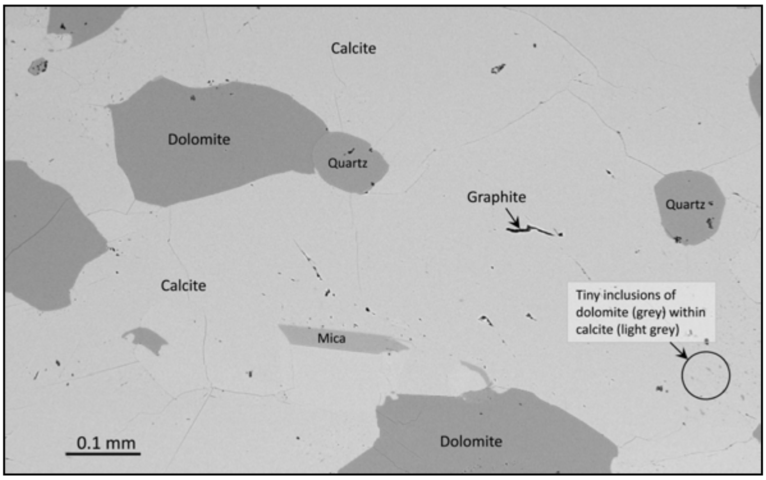

Figure 7: SEM back-scattered electron image showing inclusions of dolomite (two generations), quartz, mica and graphite in calcite. Bh LE4 at 12.5 m.

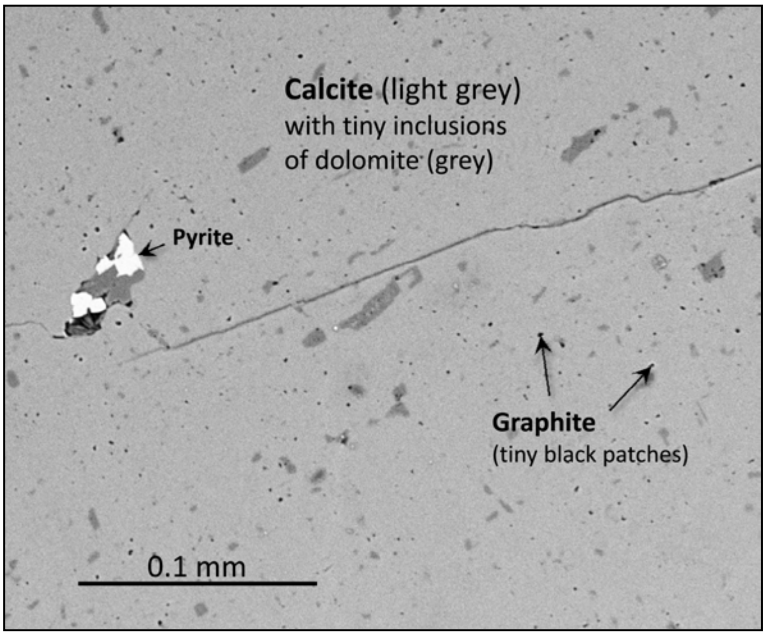

Figure 8: SEM back-scattered electron image showing calcite (light grey) packed with tiny inclusions of dolomite (grey). Bh LE4 at 23.8 m.

4.2 Borehole LE1 Stunes

The carbonates at Stunes are mainly massive, pale grey, coarsely crystalline calcite marbles with some thinly banded, graphite-bearing dark grey parts. The dark grey, fine-grained marbles preserve relict sedimentary bedding and reflect partly recrystallisation (Melezhik et al, 2003).

The core was drilled at this location because the outcropping carbonate marble had been observed to be of excellent quality in terms of low content of crystal-bound iron and manganese as well as low in silica. These characteristics were verified for the first 5m-core sample that contains 47 ppm Fe_{icp}, 11 ppm Mn_{icp} and 0,50 % $SiO_{2\ xrf}$ (Table 3).

Further along the core (downwards) these parameters vary considerably, and the average Fe_{icp} and Mn_{icp} for this 25 long borehole is 525 ppm and 63 ppm, respectively. The high-quality characteristics from the upper part are therefore not continuous.

This kind of variation from apparently good quality with less than 250 ppm Fe_{icp} + Mn_{icp} through various intermediate varieties (250 - 500 ppm Fe_{icp} + Mn_{icp}) to calcium carbonate with minor or no industrial interest (> 500 ppm Fe_{icp} + Mn_{icp}) is common among the white carbonates in the surrounding area, i.e. south of Evenes airport.

The MgO_{icp} content in the first parts of the core is distinctly less than 1 % MgO_{icp} which is excellent, but increases to more than 1 % MgO_{icp} downwards. However, all in all the dolomite content (indicated by MgO_{icp}) is relatively low.

Figure 6 and Figure 9 shows the coarse-grained character of the Stunes marble as well as enrichments of silicate minerals diagonal from the lower right corner of the image upwards; this enrichment is believed to represent a silica-rich layer in the rock.

The Stunes core is regarded as fairly representative for carbonates in this part of the Evenes area. All in all the resource potential for calcite marble resembling the Stunes core is very large, but due to the fairly high content of crystal-bound iron and manganese industrial production seems less feasible.

See additional characterisation information in Appendix 1.

Figure 9: White, coarse-grained calcite carbonate with dark bands from Stunes, borehole LE1 at 19.7m.

4.3 Borehole LE2 Skardsfjellet

The marbles at Skardsfjellet varies from light grey and grey to dark grey. Then are often thinly banded and partly dolomitic. Commonly small, recrystallised white calcite veins cut the sub-horizontal bedding.

Previous reconnaissance investigations had identified a zone (north trending and steeply dipping to the east) with low content of crystal-bound iron and manganese, outcropping in a road cut at Skardvik near the sea shore, and continuing several kilometers northwards (see Korneliussen et al. 2011b). The purpose of the LE2 Skardsfjellet borehole was to collect a continuous core section through parts of this zone.

The rock is calcite-dolomite mixed carbonate marble with an average calculated dolomite content of 26,82 % (Table 3). The corresponding MgO_{icp} content is 5,85 %. Mineralogically the rock is a mixture of calcite and dolomite as shown in Figure 11.

Average Fe_{icp} and Mn_{icp} are 345 ppm and 67 ppm respectively, which is fairly high, although there are considerable variations.

The mineral resource potential for marble with the characteristics of the rock in the Skardfjell core is probably considerable. The “ore-zone” is 20-30 m wide, steeply dipping to the east and stretching from the sea at Skardsvik northwards, may be as far as 4-5 kilometers. However, the high dolomite content presumably excludes this rock as a raw material for production of high-purity calcium carbonate in today’s market.

See mineral characterization information in Appendix 1.

Figure 10: Greyish, locally banded carbonate from Skardsfjell, borehole LE2 at 11.2 m.

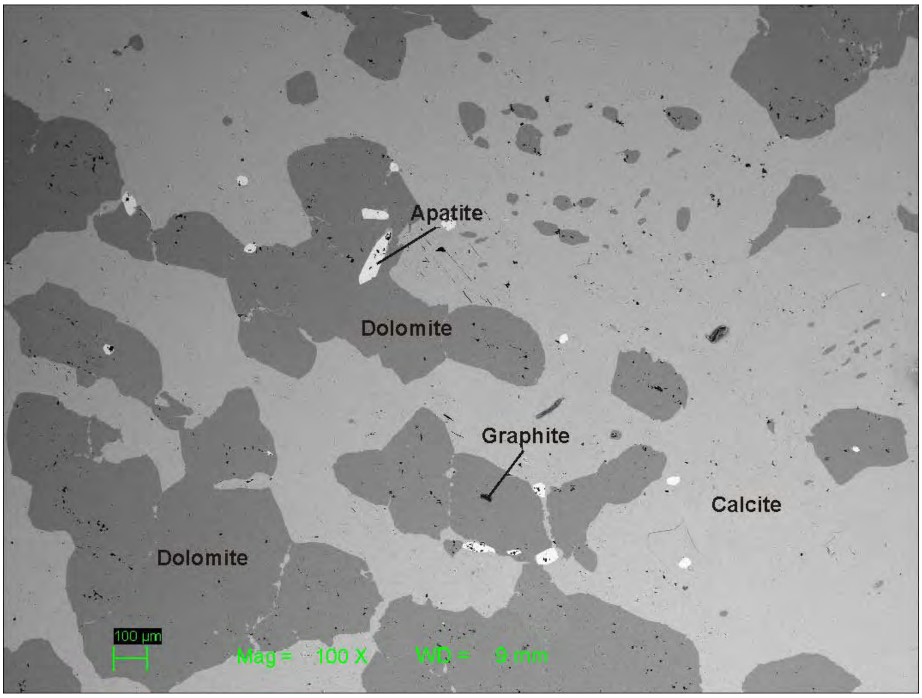

Figure 11: SEM back-scattered electron image of Skardsfjell marble from borehole LE2 at 7.4 m.

4.4 Borehole LE4 Bjørnåsen

One vertical 25 m long borehole was drilled in coarse-grained fairly white carbonate (road-cut) within a sequence of flat lying, variably banded marble of potential high quality. The core provides a continuous sample from the surface 25 m downwards in the carbonate sequence.

The upper part of the borehole transect "high class" carbonate in terms of low content of crystal-bound iron and manganese (115 and 34 ppm Fe_{icp} and Mn_{icp} respectively, see Table 3) consistent with previous observations at this locality.

Fe_{icp} and Mn_{icp} tend to increase along the core. Average values for the full 25m long core is 227 ppm Fe_{icp} and 48 ppm Mn_{icp}, which is the lowest of all boreholes in the Evenes area. The Bjørnåsen area may be the most favorable area for high-whiteness carbonate in the larger Evenes area (see discussion in Korneliussen et al. 2011b).

However, the dolomite content is very high with 24,47 % dolomite in average (equivalent to 5,34 % MgO_{icp}). Characteristic calcite-dolomite mineral relationships are shown Figure 13.

Figure 12 is fairly representative for this coarse-grained, slightly heterogeneous and variably banded marble. The coarse-grained, white and well-crystalline marble is a recrystallised variety, while the dark bands are believed to be remnants of an older generation of marble that have survived the recrystallisation process. Graphite is coarse-grained and irregularly distributed in the white marble variety, and more finely and regularly distributed in the dark variety.

From a high-potential-whiteness point of view, due to the fairly low content of crystal-bound iron and manganese, this deposit and its surrounding area should be of considerable interest. But in today's market situation the high MgO_{icp} content is likely to prevent further development, unless a suitable processing procedure is developed.

See Appendix 1 for additional information.

Figure 12: Photo of greyish, coarse-grained marble from Bjørnåsen, borehole LE4 at 8.8m.

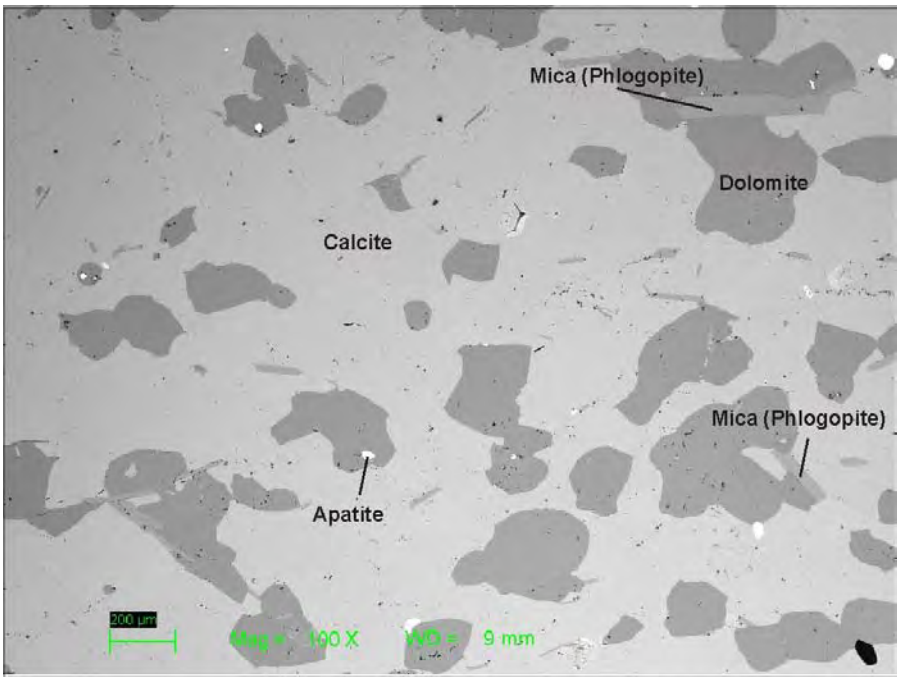

Figure 13: SEM back-scattered electron image of thin section LE4-12.9 (borehole LE4 at 12.9 m) showing calcite (light grey) and dolomite (dark grey) and interlocked mica and graphite (black).

4.5 Borehole LE5 Kvantokollen

The drill core from Kvantokollen consists of very heterogeneous, banded marble, and has been subdivided into several units (see Appendix 1, chapter 1.4).

Similar to the marble at boreholes LE2 and LE4 this marble is highly dolomitised (Table 3). In addition, the content of crystal-bound iron and manganese is high throughout the core. The potential whiteness is therefore low, and the carbonate in this deposit is not of interest for the production of high-whiteness products.

The core is highly heterogeneous. In general, the colour changes from the top of the core to the bottom. At first, the marble appear in a white, pale grey, pinkish colour and change into medium grey to dark grey colour. The same happens with the crystallinity, which changes from fine to very coarse-grained. The rock is a mixture of white, pinkish fine-grained dolomite marble and pale to medium grey, coarse-grained dolomite-calcite marble.

Thin mica-layers such as those in the left part of the core sample of Figure 14 are frequent, and the colour of the rock locally changes into brown-grey caused by the appearance of mica (phlogopite).

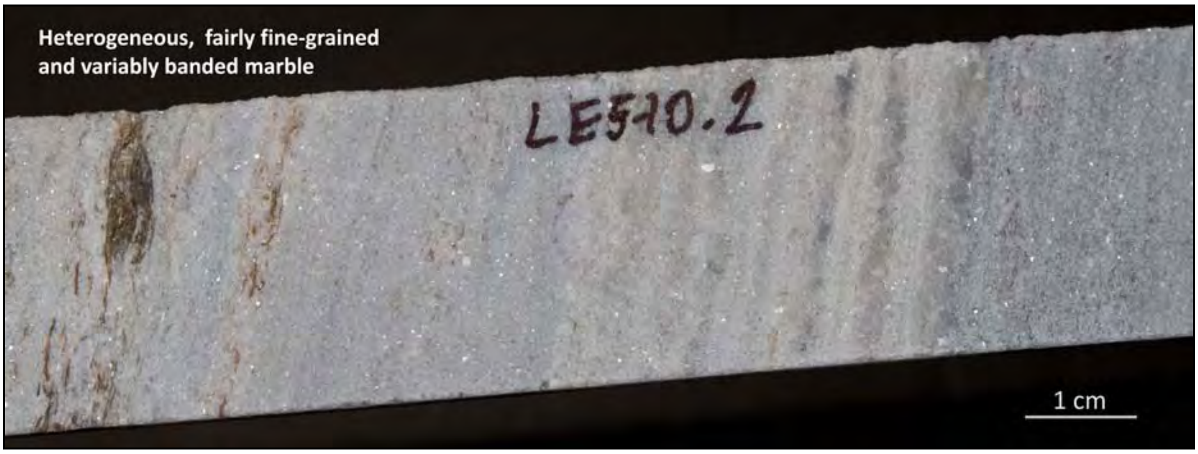

Figure 14: Photo of a heterogeneous and locally banded, greyish marble, borehole LE5 at 10.2m.

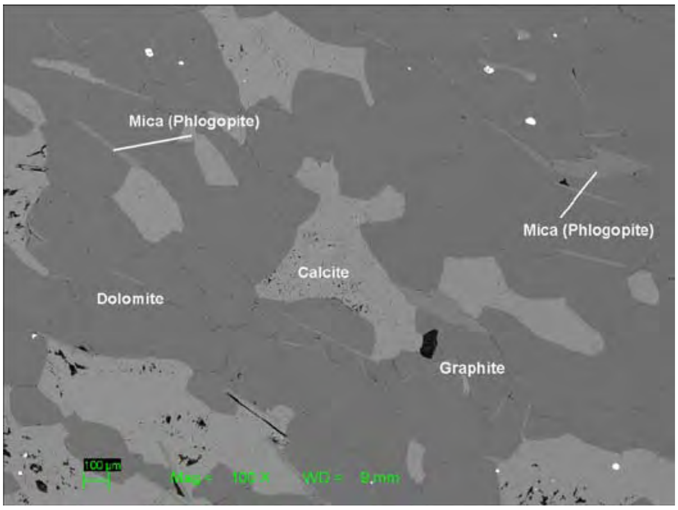

Figure 15: SEM back-scattered electron image with dolomite-rich part, borehole LE5, at 8.4m. The elongated mineral is mica.

5. RESULTS ROLLA

5.1 Main characteristics

Eastern parts of Rolla are characterised by a several hundred meter thick, fairly flat lying (generally dipping 10-15^o to the NNE) succession of alternating calcite marble and mica schist/gneiss (locally amphibolitic). This succession is excellently exposed in the eastern slopes of the mountain Sula (Figure 17) 2-3 km west of Breivoll.

The marble is dominantly coarse-grained and light grey to white. Certain units or layers contain white calcite marble with high-purity calcite, i.e. the content of crystal-bound (acid soluble) iron and manganese is below 250 ppm. These are the rocks of potential interest as raw material for high-purity calcite carbonate, and the focus of the present investigations; see further details by Korneliussen et al. 2011b.

The cores from Rolla have been drilled in the eastern part of Rolla. Boreholes LR1, LR2 and LR 3 are located in Breivollia, along the tractor road from Breivoll to Lake Ibestad at the slope of the mountain Drangen-Sula. A planned borehole LR4 was cancelled due to difficulties to access the planned drill-site. Borehole LR5 was drilled at a small industrial area near Breivoll and borehole LR6 was drilled at Storskog 2.5 km SW of Breivoll. These boreholes are cutting this succession at different levels in the stratigraphy, showing variations of calcite carbonate and mica schist/gneiss.

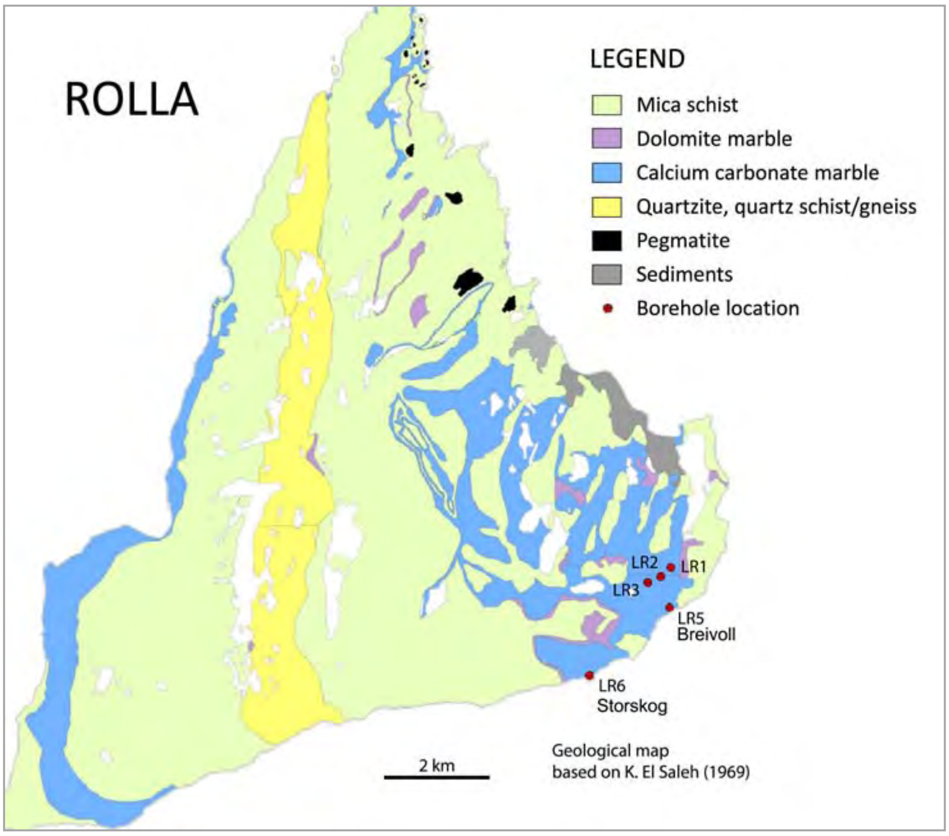

Figure 16: Geological map of Rolla (modified after El Saleh 1969) with borehole localities.

Table 5: Borehole localities, Rolla.

Locality	UTM coordinates (eds84)
Rolla (LR1) Breivollia; road from Breivoll towards lake Ibestadvatnet.	N 7629954/E 587054
Rolla (LR2) Breivollia; road from Breivoll towards lake Ibestadvatnet.	N 7629810/E 586985
Rolla (LR3) Breivollia; road from Breivoll towards lake Ibestadvatnet.	N 7629801/E 586862
Rolla (LR5) Breivoll; within industrial area at Breivoll.	N 7629197/E 587037
Rolla (LR6) Storskog; road cut.	N 7627906/E 585519

The main chemical characteristics of the cores are summarised in Table 7 based on analyses of 5m core sections giving average numbers for each 5m-section; consequently, detailed variations that are often in cm to dm scale are not observable in this data set. Semi-quantitative point analyses directly on the core surface by a portable XRF instrument (Table 8), are picking up small-scale chemical variations in SiO_2, CaO and Fe.

In general the MgO_{icp} content in the Rolla cores is low and in most cases below 1 %. MgO_{xrf} tend to be distinctly higher than MgO_{icp}, indicating a presence of magnesium bearing silicate minerals, mainly diopside.

As also pointed out in the description of the Evenes cores, within-carbonate crystal-bound iron and manganese as defined by Fe_{icp} and Mn_{icp} is crucial, since these elements reduce the whiteness of carbonate minerals. And, similar to the Evenes area, focus has been to identify calcium carbonate with less than 250 ppm Fe_{icp} + Mn_{icp}.

See Korneliussen et al. (2011b) for further information about similarities and differences between Rolla and Evenes carbonates.

Figure 17: Fairly flat laying series of alternating marbles (white) and mica schists/gneisses in the eastern slopes of the mountain Sula approx. 3 km west of Breivoll.

The marbles from the eastern part of Rolla are mainly medium to dark grey, coarsely grained, with many quartz-mica-schist layers and beds of amphibolites. In general, the Rolla cores are more homogeneous and massive compared with the Evenes carbonates, although there are large variations locally. Tiny braided calcite veins commonly cut through the massive marbles. Dark grey to black, horizontal and sub-horizontal layers represent relict sedimentary bedding, as also observed in the marbles of the Evenes area (Melezhik et al, 2003).

The results of the thin section inspection of the samples from Rolla are very similar to the previous presented results from the Evenes area, although the Rolla samples seem to be more homogenous.

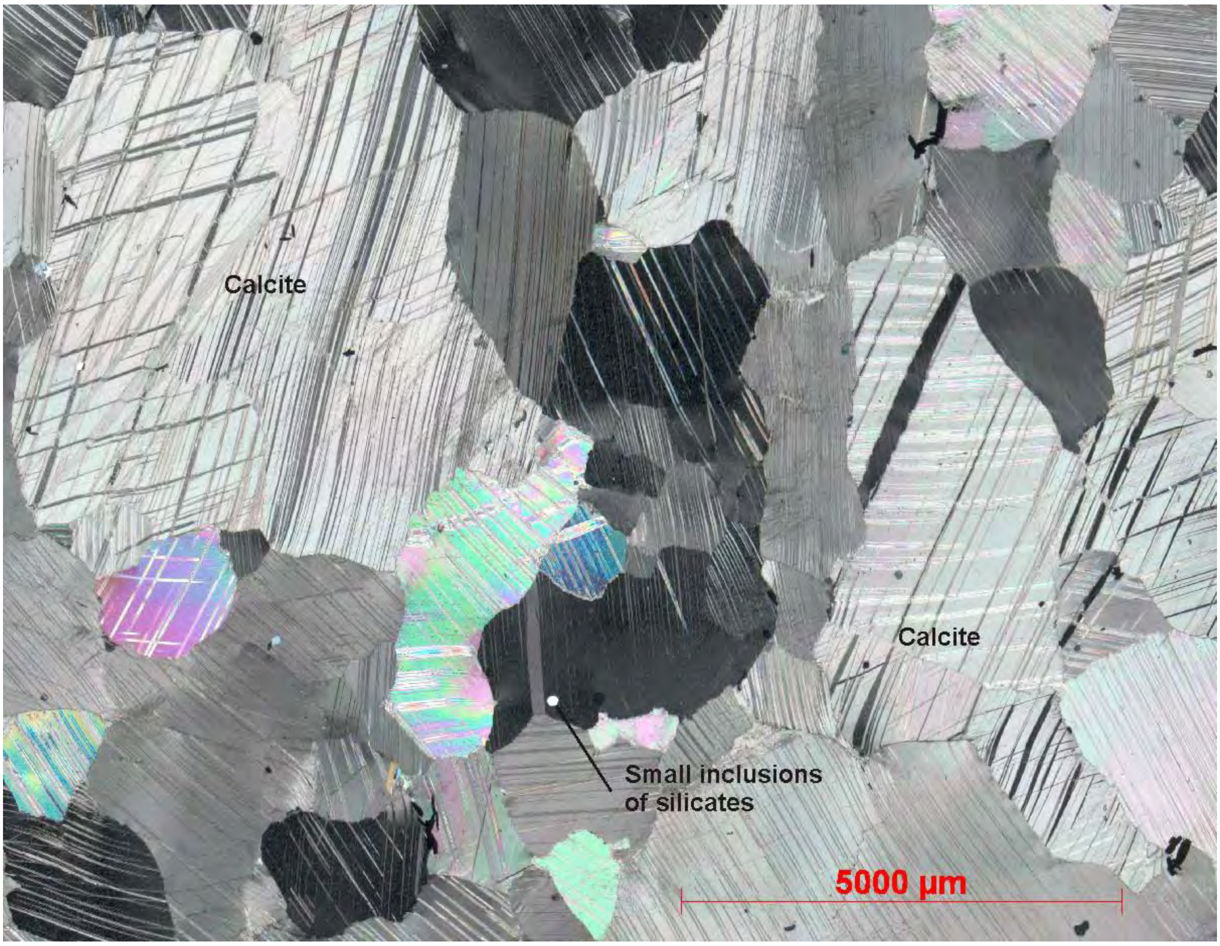

Figure 18: Microphotograph with crossed polarisers, showing coarse-grained calcite with tiny inclusions of silicate minerals. Borehole LR2 at 12.9 m, Breivollia.

The calcite crystals are mainly medium to coarse-grained in contrast to fine grained and poorly sorted silicates of diopside, augite/ titanaugite and epidote. In general, the amount of silicates is higher within transition zones where calcite marbles are mixed with mica-rich schists. Apatite and silicates are the common interlocked particles between the calcite crystals. Graphite is the most frequent accessory mineral. However, zircon and titanite were identified in one sample as well. The distinct recrystallisation rims are evidence for carbonate recrystallisation.

Most of the pure calcite domains are intercalated with mica-schist and amphibolite. The observed brown mica-schist and greenish amphibolitic schist tend to be altered (alteration minerals have not been described in detail, but talc and serpentine has been observed).

The microphotograph in Figure 19 illustrates the occurrence of silicate minerals, particularly quartz, in coarse-grained marble.

Graphite tends to occur as inclusions in the calcite crystals as distinct well-crystallised grains as shown by the large grain in Figure 20 and of the numerous predominantly flaky grains in Figure 21. This type of graphite is usually distinctly visible in the rock when viewed by the naked eye. Finely distributed graphite with particle size 2-3 microns or less (Figure 20) has been detected using SEM. The total amount of graphite present in the cores is indicated by the TOC-numbers in Table 7; for the marble of interest, i.e. samples with low Fe_{icp} and Mn_{icp} values, TOC (graphite) tend to be in the range 0.1 - 0.3 %.

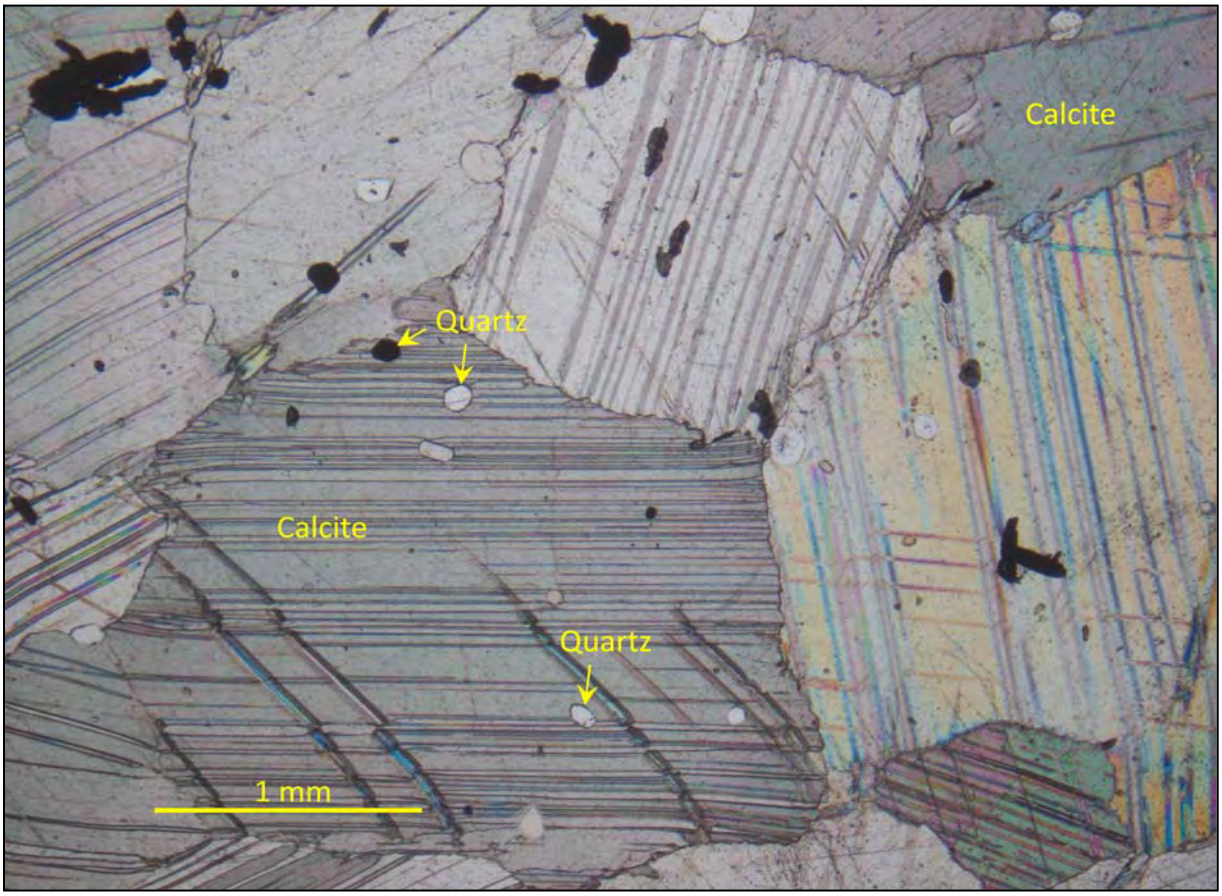

Figure 19: Microphotograph of coarse-grained calcite marble from borehole LR5 (Breivoll) at 9.0m, parallel polarisers.

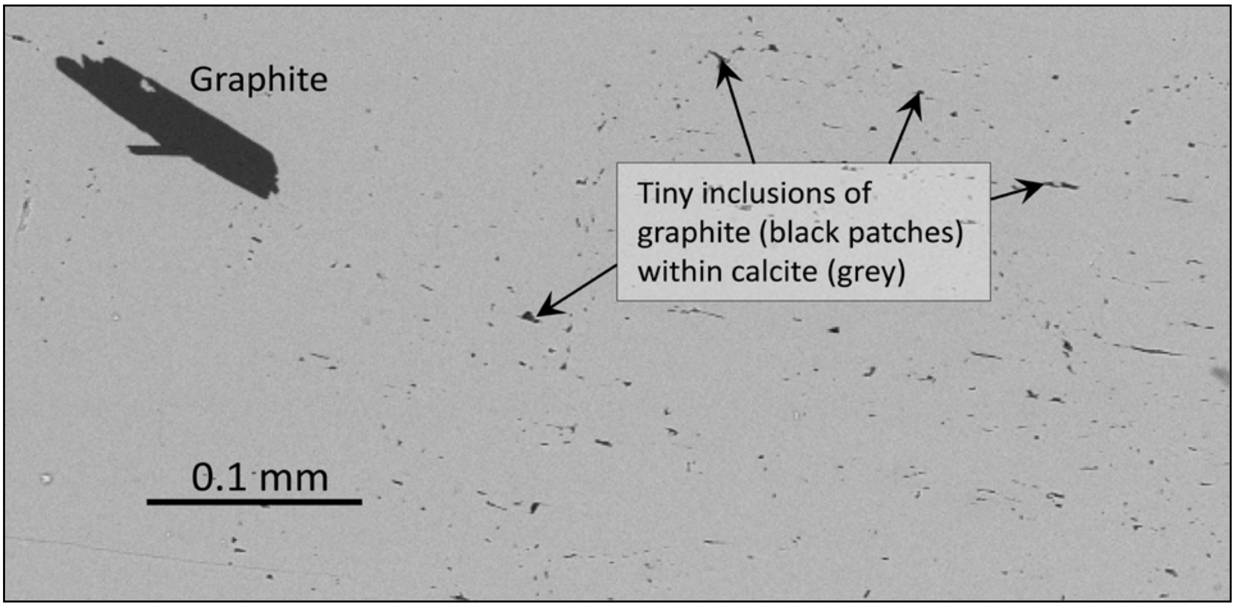

Figure 20: SEM back-scattered electron image showing two distinct occurrences of graphite in calcite; finely distributed graphite and well-crystallised larger grains. Borehole LR5 (Breivoll) at 23.9m.

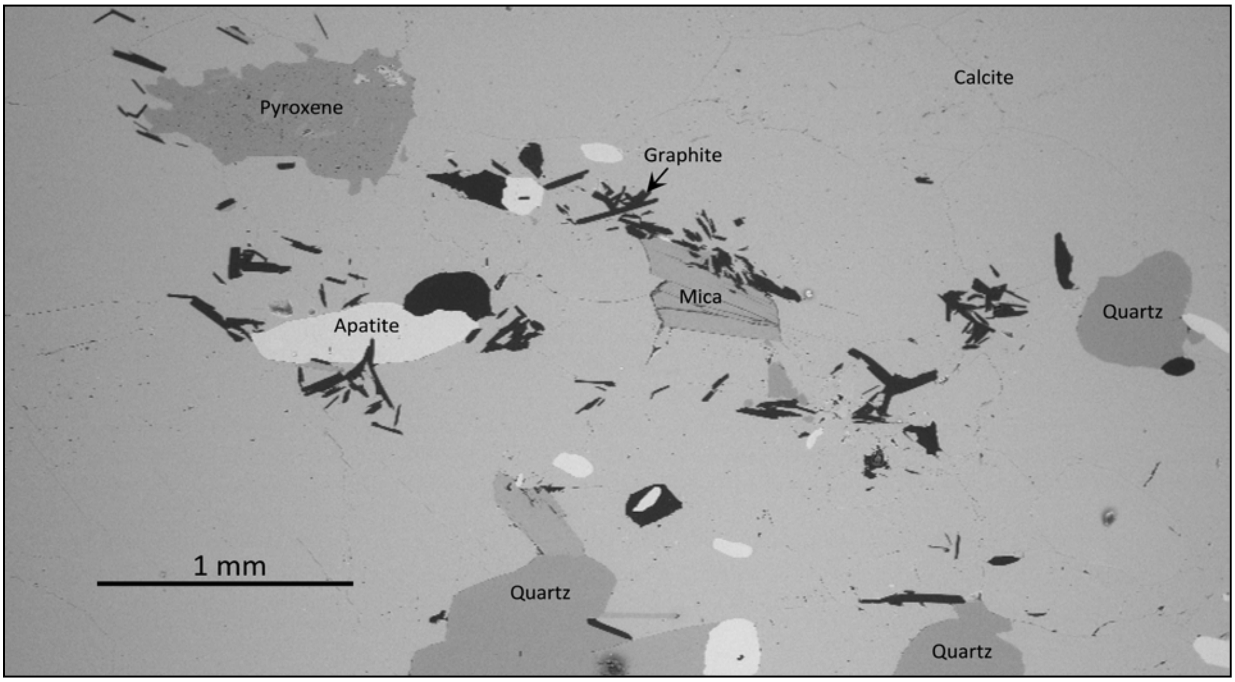

Figure 21: SEM back-scattered electron image of a silicate- and graphite-rich portion of the calcite marble in borehole LR6 at 2.1m, Storskog.

Table 6: Thin-sections, cores from Rolla.

Sample	Thin section	Borehole
73718	LR2-07.0	LR2 Breivollia
73720	LR2-12.9	LR2 Breivollia
73724	LR3-12.2	LR3 Breivollia
73726	LR3-21.9	LR3 Breivollia
73727	LR5-09.0	LR5 Breivoll
73729	LR5-23.9	LR5 Breivoll
73730	LR6-02.1	LR6 Storskog
73732	LR6-13.0	LR6 Storskog
73734	LR6-22.0	LR6 Storskog

Table 7: Summary analyses, Rolla cores.

Sample	XRF (%)						LECO (%)			ICP (%)		ICP (ppm)				Calculated		
From-To (m)	SiO2	Al2O3	Fe2O3	MgO	CaO	K2O	S	C	TOC	MgO	CaO	Fe	Mn	Sr	P	Calcite	Dolom.	Other
Bh LR1																		
LR1_00-05	19,80	4,09	2,78	2,31	39,40	0,84	0,12	8,31	0,13	0,73	34,84	1220	95	1410	467	60,12	3,34	36,54
LR1_05-10	60,40	10,70	11,40	4,17	7,44	2,45	0,21	0,16	-0,10	0,55	1,62	11500	89	48	2000	1,53	2,50	95,97
LR1_10-14.5	62,50	16,70	8,04	3,00	2,24	3,27	0,34	0,12	0,16	0,48	0,36	6090	44	11	540	-0,54	2,19	98,35
Average:	47,57	10,50	7,41	3,16	16,36	2,19	0,23	2,86	0,06	0,58	12,27	6270	76	490	1002	20,37	2,67	76,96
Bh LR2																		
LR2_00-05	18,70	2,50	0,82	4,22	41,50	0,40	0,04	9,59	0,45	0,38	35,95	505	92	2050	607	62,96	1,76	35,27
LR2_05-10	22,50	3,15	1,71	4,22	39,10	0,31	0,09	8,52	0,52	0,37	32,18	733	127	1720	729	56,28	1,70	42,02
LR2_10-15	5,03	1,89	0,70	0,92	51,30	0,08	-0,01	11,85	0,15	0,51	46,03	347	56	2110	371	80,55	2,36	17,09
LR2_15-20	11,30	2,53	1,10	1,25	46,10	0,52	0,06	10,37	0,16	0,65	41,97	446	162	1950	351	73,00	2,99	24,02
LR2_20-25.1	8,13	1,59	0,19	0,38	49,70	0,12	0,01	11,36	0,15	0,30	46,31	194	44	2410	351	81,57	1,38	17,04
Average:	13,13	2,33	0,91	2,20	45,54	0,28	0,04	10,34	0,29	0,44	40,49	445	96	2048	482	70,87	2,04	27,09
Bh LR3																		
LR3_00-05	23,00	2,64	2,03	5,36	38,00	0,24	0,10	8,27	0,72	0,49	31,90	1400	210	1640	937	55,49	2,25	42,26
LR3_05-10	18,40	1,84	1,32	4,11	42,10	0,22	0,07	9,58	0,72	0,61	36,37	1160	179	1780	833	63,15	2,79	34,06
LR3_10-15	0,74	0,13	0,06	0,70	52,90	0,01	-0,01	12,68	0,17	0,62	50,78	115	43	2290	316	88,75	2,83	8,42
LR3_15-20	19,00	4,25	1,84	1,16	40,60	0,93	0,13	8,92	0,12	0,51	36,23	2260	117	1920	459	63,14	2,36	34,50
LR3_20-26.7	14,10	2,93	0,91	2,88	42,80	0,69	0,05	9,77	0,23	1,71	39,31	1500	239	1110	407	65,65	7,83	26,53
Average:	15,05	2,36	1,23	2,84	43,28	0,42	0,07	9,84	0,39	0,79	38,92	1287	158	1748	590	67,24	3,61	29,15
Bh LR5																		
LR5_00-05	0,91	0,17	0,08	1,02	54,20	0,03	0,01	12,65	0,19	0,84	50,50	74	25	2220	321	87,69	3,86	8,45
LR5_05-10	5,64	1,29	0,84	0,73	50,80	0,22	0,10	11,39	0,25	0,42	46,73	272	123	2350	369	82,02	1,94	16,04
LR5_10-15	0,91	0,11	0,07	0,54	55,00	0,02	-0,01	12,72	0,12	0,47	50,78	71	24	2760	334	89,12	2,14	8,74
LR5_15-20	5,28	1,17	0,41	1,33	51,00	0,06	0,04	12,20	0,13	0,87	47,99	297	32	2050	309	83,16	3,97	12,87
LR5_20-25.4	4,30	0,90	0,37	1,14	51,70	0,16	0,04	12,33	0,23	0,67	47,99	170	38	2170	336	83,65	3,07	13,28
Average:	3,41	0,73	0,35	0,95	52,54	0,09	0,04	12,26	0,18	0,65	48,80	177	48	2310	334	85,13	3,00	11,88
Bh LR6																		
LR6_00-05	6,10	1,27	0,53	0,93	50,40	0,20	0,12	11,72	0,31	0,53	46,73	269	40	2020	338	81,75	2,43	15,82
LR6_05-10	3,55	0,49	0,20	2,13	51,50	0,08	0,03	12,17	-0,10	1,40	47,15	123	20	1370	297	80,33	6,43	13,24
LR6_10-15	4,46	0,95	0,48	1,05	51,60	0,14	0,07	11,95	0,24	0,68	48,27	326	51	1940	346	84,13	3,10	12,77
LR6_15-20	3,50	0,78	0,43	1,08	52,40	0,15	0,04	12,15	0,15	0,78	48,27	163	40	2110	347	83,86	3,59	12,55
LR6_20-25.3	16,90	2,39	1,77	3,53	43,20	0,16	0,04	9,23	0,44	0,38	35,25	1740	200	1610	622	61,73	1,75	36,52
Average:	6,90	1,17	0,68	1,74	49,82	0,15	0,06	11,44	0,21	0,75	45,13	524	70	1810	390	78,36	3,46	18,18

Table 8: Core-analyses by portable XRF, Evenes area.

Bh LR1 Breivollia

Pos (m)	% SiO2	% CaO	ppm Fe
0,50	4,5	54,6	980
1,50	1,2	49,1	780
1,90	1,8	55,5	390
2,60	20,7	42,4	2250
3,50	3,1	54,6	530
4,50	35,3	23,2	43480
5,50	58,0	4,9	181660
6,50	65,0	8,4	67940
7,60	69,8	5,0	38410
8,50	73,9	4,8	33590
9,30	72,5	3,2	42510
10,50	67,0	5,2	42840
11,50	64,1	1,7	50930
12,50	74,4	0,7	46950
13,40	79,6	0,8	36510

Bh LR2 Breivollia

Pos (m)	% SiO2	% CaO	ppm Fe
0,50	10,9	42,9	8710
0,50	10,9	42,9	8710
1,50	16,9	37,8	8050
2,60	19,2	36,5	3300
3,50	11,9	39,0	2290
3,90	61,0	3,3	570
4,20	55,5	2,4	2880
4,50	10,8	46,2	2880
5,20	12,6	42,5	2730
5,40	23,6	39,9	1320
5,50	21,7	40,5	1690
6,54	43,4	12,4	54330
6,70	11,7	48,7	3670
6,70	11,7	48,7	3670
7,20	6,9	50,7	3720
7,30	19,5	18,8	52210
7,50	15,3	45,0	8440
7,70	6,7	46,5	6160
7,80	11,4	44,4	6410
8,20	72,5	2,0	10140
8,40	6,4	37,4	14850
8,50	44,3	22,4	54180
8,60	25,3	35,5	21780
8,80	23,5	12,2	37590
8,90	2,2	54,4	1370
9,20	13,5	45,5	4100
9,50	18,0	41,2	12110
9,80	15,0	42,3	13000
10,20	2,0	55,7	610
10,50	2,4	56,1	240
10,70	1,6	55,5	790
10,80	18,8	41,0	14850
11,50	1,1	56,6	190
12,40	2,0	55,5	580
12,50	1,3	55,3	650
12,70	24,8	28,6	51120
12,80	1,6	50,5	450
13,30	43,1	13,8	14300
13,50	1,2	55,3	350
13,70	1,2	52,6	510
14,10	50,1	20,2	67330
14,30	1,4	53,4	380
14,50	1,2	56,6	240
15,20	1,5	55,6	560
15,60	0,9	54,8	410
15,80	3,5	55,2	400
15,94	44,8	16,0	33540
16,20	31,7	32,4	28980
16,40	21,8	44,1	1380
16,50	6,3	53,2	1610
16,70	1,7	49,9	1700
17,20	2,0	55,6	690
17,50	1,6	53,9	3410
17,80	1,8	55,3	1100
17,94	65,7	4,3	250
18,20	4,0	54,5	1470
18,50	2,2	56,3	290
19,50	1,1	53,6	290
19,70	83,3	1,8	410
19,92	56,6	6,9	8380
19,98	2,7	55,5	2190
20,20	3,0	49,6	35710
20,50	2,1	49,2	710
20,80	1,5	57,5	780
21,50	1,9	56,0	480
21,80	3,8	48,6	1220
22,20	3,0	56,0	930
22,30	2,4	55,1	950
22,60	62,5	4,3	300
22,60	62,5	4,3	300
22,80	78,7	2,7	5300
22,95	6,3	52,5	3830
23,20	3,9	55,0	1460
23,50	1,5	57,6	580
23,80	1,7	53,7	430
24,50	1,2	56,4	330

Bh LR3 Breivollia

Pos (m)	% SiO2	% CaO	ppm Fe
0,50	31,8	34,5	10310
1,50	19,5	40,6	4800
2,50	6,7	51,6	4720
2,80	11,9	44,1	6790
3,20	15,5	40,1	16700
3,50	22,6	33,8	29860
3,80	7,0	37,2	8060
4,20	11,2	29,6	24680
4,50	9,5	46,6	6190
5,50	12,1	42,5	11740
5,80	20,6	42,0	2700
6,30	28,3	38,0	2360
6,80	16,0	38,8	11280
7,30	13,7	46,1	7100
7,80	17,3	42,2	13420
8,30	20,4	40,0	10660
8,80	14,5	47,4	2860
9,30	2,1	54,0	380
9,60	1,1	58,0	430
10,30	1,9	57,0	260
11,50	1,2	56,7	350
12,30	1,1	54,5	320
12,80	1,3	56,2	450
13,50	1,1	54,7	260
14,50	1,1	56,9	370
15,10	1,8	56,1	350
15,50	12,5	49,1	4430
15,60	5,4	50,0	4190
15,80	61,1	4,2	27040
15,80	67,1	4,1	25590
16,30	62,3	3,0	39940
16,40	64,4	3,6	39730
16,60	2,1	50,4	4180
16,80	3,0	57,0	610
17,50	2,2	56,5	540
18,30	1,6	55,3	400
18,50	2,8	53,0	2060
18,60	36,6	4,0	32700
18,80	68,6	4,6	33660
18,95	63,5	5,4	33540
19,10	1,5	57,1	400
19,50	1,3	55,8	290
20,60	2,2	53,2	1040
21,50	1,3	33,3	2120
22,50	2,8	54,3	1310
22,50	1,4	56,1	720
22,80	32,8	25,1	18580
22,90	37,4	21,9	15250
23,30	63,4	4,0	18660
23,60	59,0	8,8	9530
23,90	1,7	55,5	1220
24,50	0,8	56,0	440
25,30	3,5	54,6	5070
25,80	66,8	4,0	340

Bh LR5 Breivoll

Pos (m)	% SiO2	% CaO	ppm Fe
0,50	1,0	55,2	340
1,50	1,1	56,1	310
2,50	1,1	55,8	220
3,50	1,0	55,3	250
4,50	1,2	56,5	380
5,50	10,0	50,4	340
5,60	2,7	53,7	1770
5,70	49,3	21,8	28170
5,90	15,5	43,5	15030
6,10	4,3	54,8	4350
6,40	1,2	56,7	1840
6,40	4,6	52,7	4270
6,50	20,4	31,2	15570
6,60	2,4	47,4	660
6,80	3,1	48,7	450
7,30	1,7	56,0	300
7,50	1,7	49,2	500
7,80	1,9	56,0	540
8,20	1,9	56,6	470
8,50	2,3	55,8	730
8,80	2,9	54,7	970
9,50	2,1	55,9	1810
10,20	2,6	54,9	450
10,50	3,2	54,3	1580
10,70	4,0	54,6	1280
11,20	1,4	52,9	390
11,50	1,1	57,6	200
11,80	2,1	55,3	1090
12,50	1,0	55,3	260
13,30	1,0	56,9	250
14,50	1,2	56,4	260
14,50	1,3	56,9	170
15,20	1,7	49,8	470
15,30	1,5	56,9	270
15,40	54,4	15,4	19620
15,70	2,2	54,5	840
15,95	49,0	23,1	26980
16,20	2,8	53,1	990
16,50	1,6	53,7	480
16,80	1,7	55,0	540
17,50	1,2	55,4	610
17,80	3,2	54,9	780
18,20	3,3	53,2	570
18,50	3,4	53,9	1300
18,80	5,3	50,6	570
19,50	2,6	55,4	530
20,50	3,4	55,0	650
21,20	3,1	53,3	1380
21,50	1,8	53,9	410
21,80	2,0	55,3	420
22,30	1,2	56,3	330
22,50	1,7	56,1	400
22,80	1,8	51,4	520
23,20	1,6	55,1	420
23,50	1,1	54,9	320
23,80	2,3	56,0	490
24,30	1,3	51,8	420
24,90	2,5	55,0	710

Bh LR6 Storskog

Pos (m)	% SiO2	% CaO	ppm Fe
0,20	1,6	57,1	680
0,50	1,9	55,7	560
0,80	5,6	53,6	810
1,30	15,9	43,6	6890
1,50	3,7	52,5	16340
2,30	6,4	51,7	2310
2,60	1,9	55,7	550
3,40	1,3	55,1	570
3,80	4,4	55,0	630
4,20	1,8	56,1	1460
4,50	6,5	52,3	2690
4,80	69,0	12,2	500
4,95	6,7	51,8	420
5,20	2,5	56,1	510
5,60	10,1	47,8	320
5,80	4,4	54,0	2420
6,20	2,8	56,7	970
6,60	1,1	54,6	410
7,50	1,0	53,8	260
8,50	1,5	52,1	250
9,20	3,2	55,0	700
9,40	18,4	42,7	1940
9,50	3,8	50,1	1370
9,80	3,6	54,7	1090
10,20	2,8	54,0	1860
10,50	3,2	54,5	820
11,50	6,6	51,7	1770
12,50	6,5	51,5	1900
12,88	38,7	27,2	9840
13,20	7,2	50,5	1630
13,50	8,2	50,5	440
14,20	1,7	55,6	550
14,50	4,7	52,0	2660
14,80	1,5	56,3	540
15,70	1,0	55,5	340
16,60	1,0	56,2	280
17,60	0,8	55,4	280
18,20	3,3	53,4	510
18,60	2,0	53,3	840
18,80	1,9	51,5	420
19,50	1,3	55,9	430
19,60	60,2	3,8	40460
19,70	4,8	54,7	1440
20,10	1,9	57,1	440
20,30	2,5	56,7	1290
20,50	10,7	46,4	14970
20,70	10,8	47,7	12900
20,90	29,2	32,3	16330
21,20	10,0	47,2	13200
21,50	12,0	47,7	10810
21,50	12,8	45,3	12170
21,80	20,6	40,4	16590
22,20	17,8	44,2	16520
22,40	19,5	42,4	10320
22,50	24,9	39,7	24640
22,70	16,4	44,3	17020
23,20	19,9	43,3	13400
23,50	16,4	43,7	9950
23,60	23,4	40,0	14190
24,30	10,9	47,5	3160
24,50	26,5	38,4	7060
24,60	12,0	48,2	6250
24,80	21,9	42,7	4120
25,70	13,7	47,8	4040

5.2 Borehole LR1 Breivollia

The LR1 core consists of two different lithologies: The first few meters of the core consist of pale to medium grey, coarsely grained, partly quartz-rich calcite marbles. At about 4,8 m there is a change into quartz-rich schist followed by banded sequences of amphibolite. The shift in quartz, CaO and Fe-content are distinct when plotted along the length of the core (see Appendix 2, figure 2.2).

The carbonate in this core has a high content of carbonate-bound iron and manganese, and is therefore of no interest from an economic point of view.

See Appendix 2 for more detailed information.

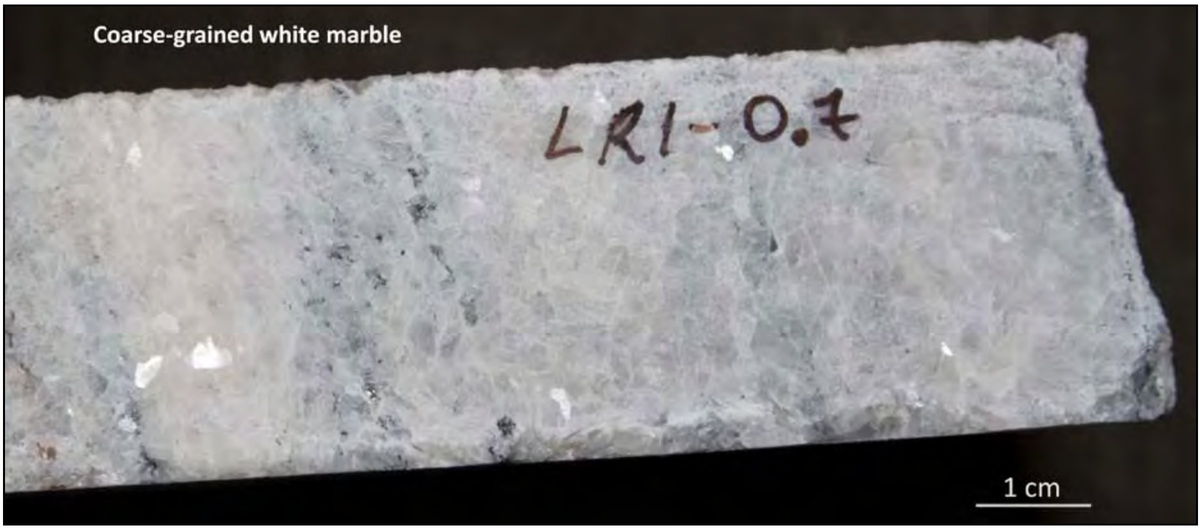

Figure 22: Fairly homogeneous white marble in borehole LR1 at 0.7 m, Breivollia.

5.3 Borehole LR2 Breivollia

The content of crystal-bound iron and manganese is generally high (Table 7); only the last analysed section contains homogeneous, white calcite marble (Figure 24) with “good values”, 195 ppm Fe_{icp} and 44 Mn_{icp}, respectively.

The lower part of the core is believed to be the upper part of the more than 25 meter thick white carbonate horizon, which is outcropping in the centre of Breivoll (see borehole LR5).

The marbles of the second borehole locality, LR2, are mainly characterised by medium to dark grey colour, medium grain size, thin layering and enrichment of quartz, diopside and epidote.

The core is very heterogeneous due to considerable amounts of quartz-rich schist, thin bands of amphibolite and banded quartz-mica-rich carbonate (Figure 23).

The occurrence of diopside and altered epidote is seen within dark grey, thinly layered calcite-rich schist or amphibolite.

Only the lowermost part of the borehole transects carbonate of potential interest with low contents of crystal-bound iron and manganese. At the same time the dolomite content is very low.

See Appendix 2 for additional information.

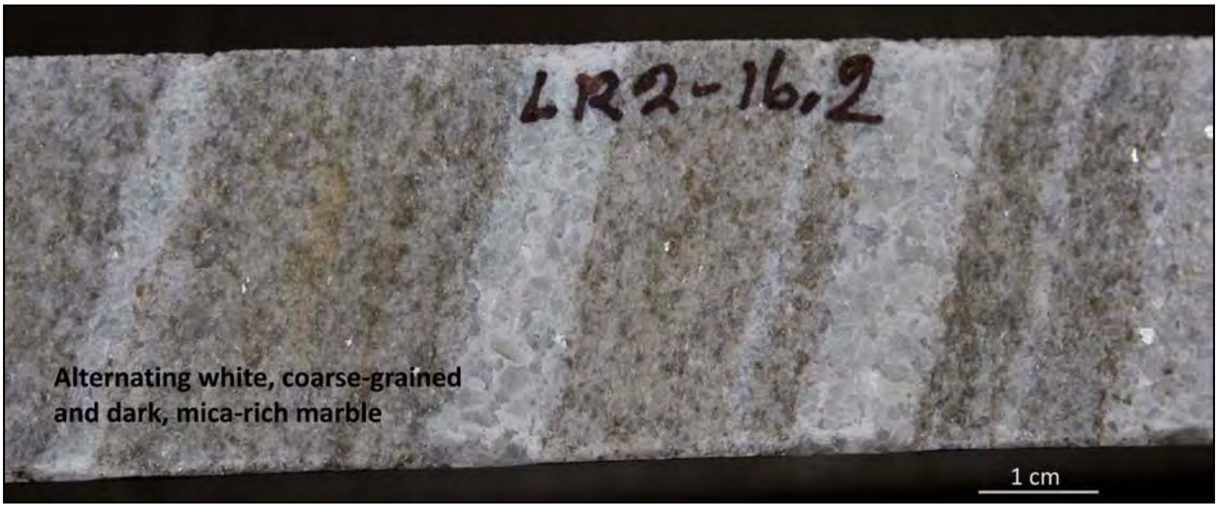

Figure 23: Banded marble with alternating coarse-grained white layers and dark layers rich in silicate minerals. Borehole LR2 at 16.2 m, Breivollia.

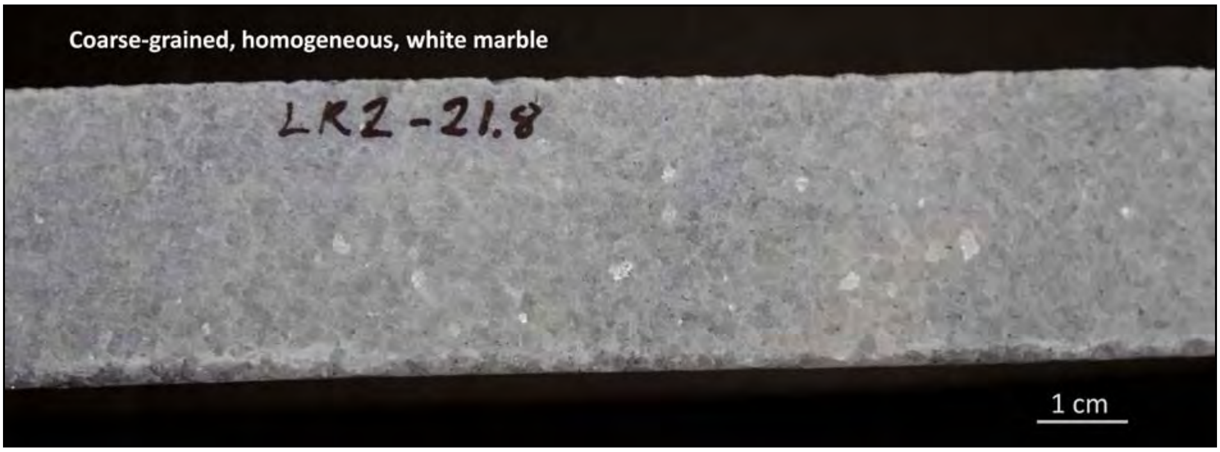

Figure 24: Homogeneous, coarse-grained white marble in the lowermost part of borehole LR2, Breivollia.

5.4 Borehole LR3 Breivollia

Borehole LR3 is the uppermost of the three boreholes in the marble - mica schist/gneiss succession in Breivollia, and is believed to transect a somewhat higher stratigraphic level.

Only the central portion of the core contains carbonate with low content of carbonate-bound iron and manganese; 115 and 43 ppm Fe_{icp} and Mn_{icp}, respectively.

The core sample shown in Figure 25 is representative for this carbonate, and presumably this high-quality unit is a parallel unit to the main Breivoll marble unit beneath.

The variations of white calcite marble are almost indistinguishable by the naked eye. The main chemical parameter that defines "good" from "bad" varieties is carbonate-bound iron (Fe_{icp}), but such data are only obtained by laboratory analyses. Total iron, i.e. the sum of carbonate-bound iron and iron from other minerals, can be analysed by portable XRF (Fe_{xrf}); such data are very useful in identifying low-Fe carbonate. In the case of the two core-photos (Figure 25 and Figure 26) sample LR3-13.3 is very low in Fe_{icp} while LR3-24.5 is not.

See Appendix 2 for additional information.

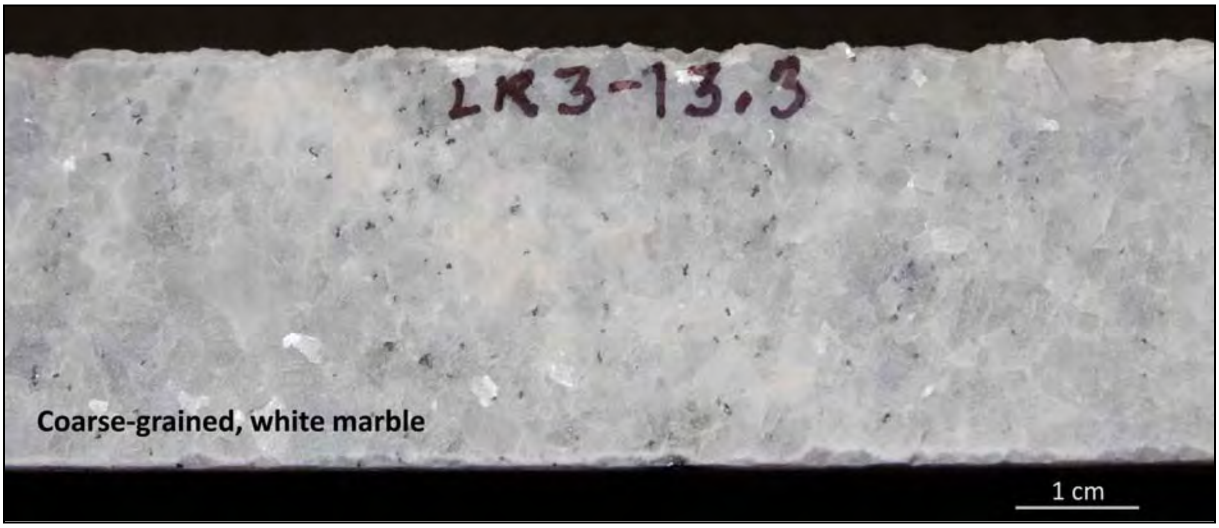

Figure 25: Coarse-grained, "high-quality" white marble with patches of graphite (black), Bh LR3 at13.3 m, Breivollia.

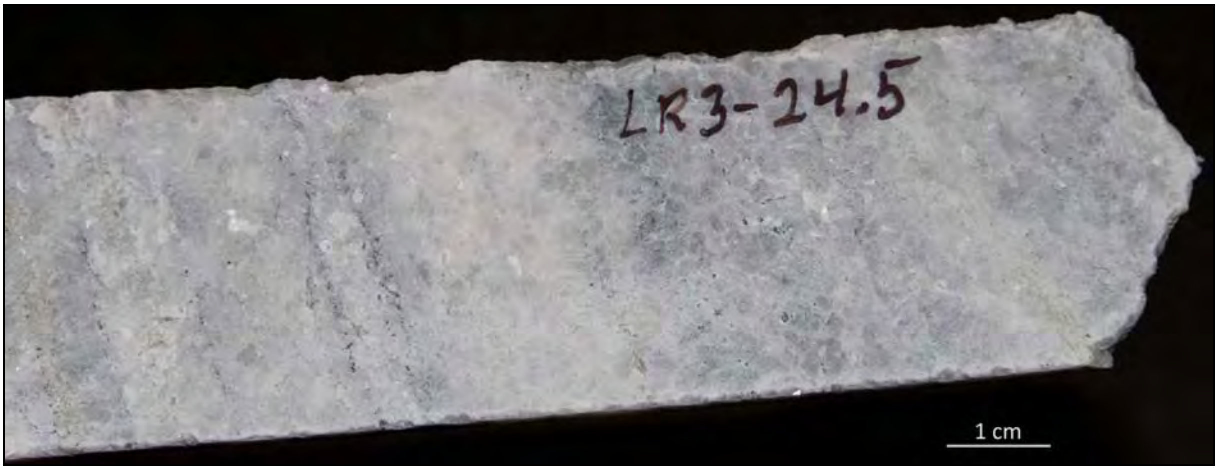

Figure 26: Coarse-grained, slightly banded white marble, Bh LR3 at 24.5 m, Breivollia.

5.5 Borehole LR5 Breivoll

Fairly flat-laying (dipping 10-15^o NNE) white calcite marble outcrops various places in between houses and along the sea at Breivoll. Based on field observations the thickness of this unit (or zone) is at least 25-30 meters, and it continuous westwards in Breivollia (see Korneliussen et al. 2011b), partly exposed and partly underlying zones of mica schist/gneiss and carbonate zones of lesser quality. This marble unit is believed to be identical with the marble in the lowermost part of borehole LR2.

The Breivoll marble unit potentially represent a very large mineral resource, and the purpose of borehole LR5 is to achieve a continuous transect through as much as possible of this rock.

The marble within borehole LR5 is mainly medium grey, coarse grained, and banded. Dark bands presumably represent relicts after sedimentary bedding in the protolith. (Melezhik et al, 2003)

See Appendix 2 for additional information.

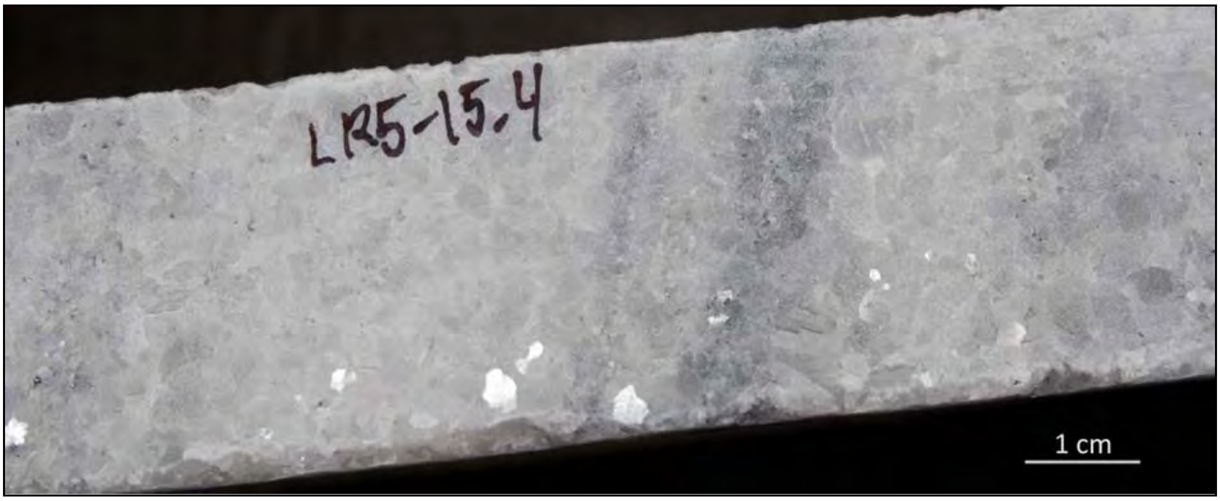

Figure 27: Coarse-grained, white marble. Borehole LR5 at 15.4 m, Breivoll.

5.6 Borehole LR6 Storskog

The white calcite marble at Storskog 2 km SW of Breivoll is a southern extension of the Breivoll marble zone, probably just slightly lower in the sequence.

The purpose of borehole LR6 was to achieve a continuous section of the carbonate downwards, starting vertically from a road-cut of “high quality”.

The quality based on low content of crystal-bound iron and manganese is “good” to “fairly good” except for the lowermost part that contains very silicate-rich marble and crystal-bound iron and manganese is very high.

See Appendix 2 for additional information.

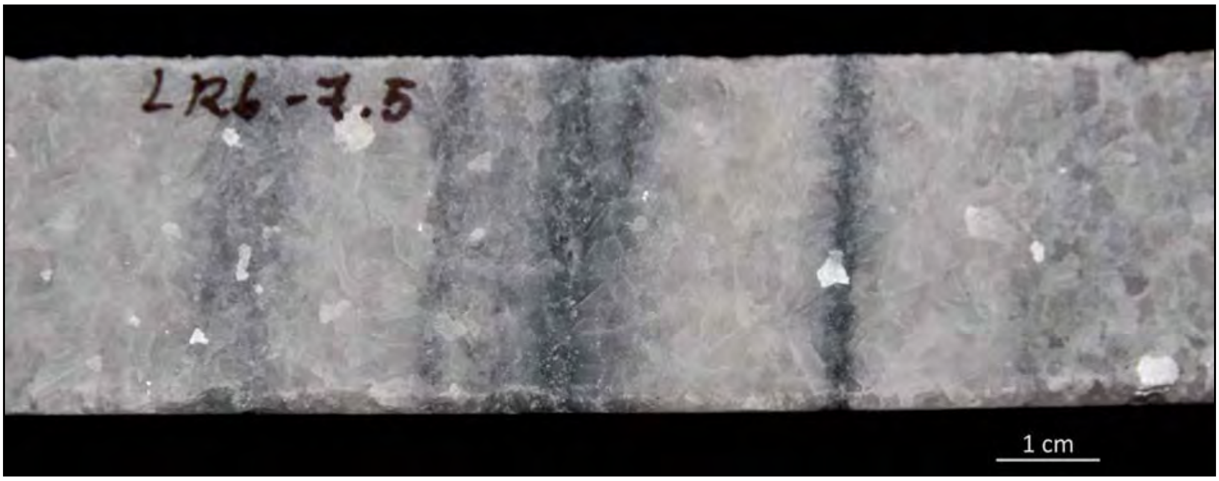

Figure 28: Coarse-grained, slightly banded marble. Borehole LR6 at 7.5 m, Storskog.

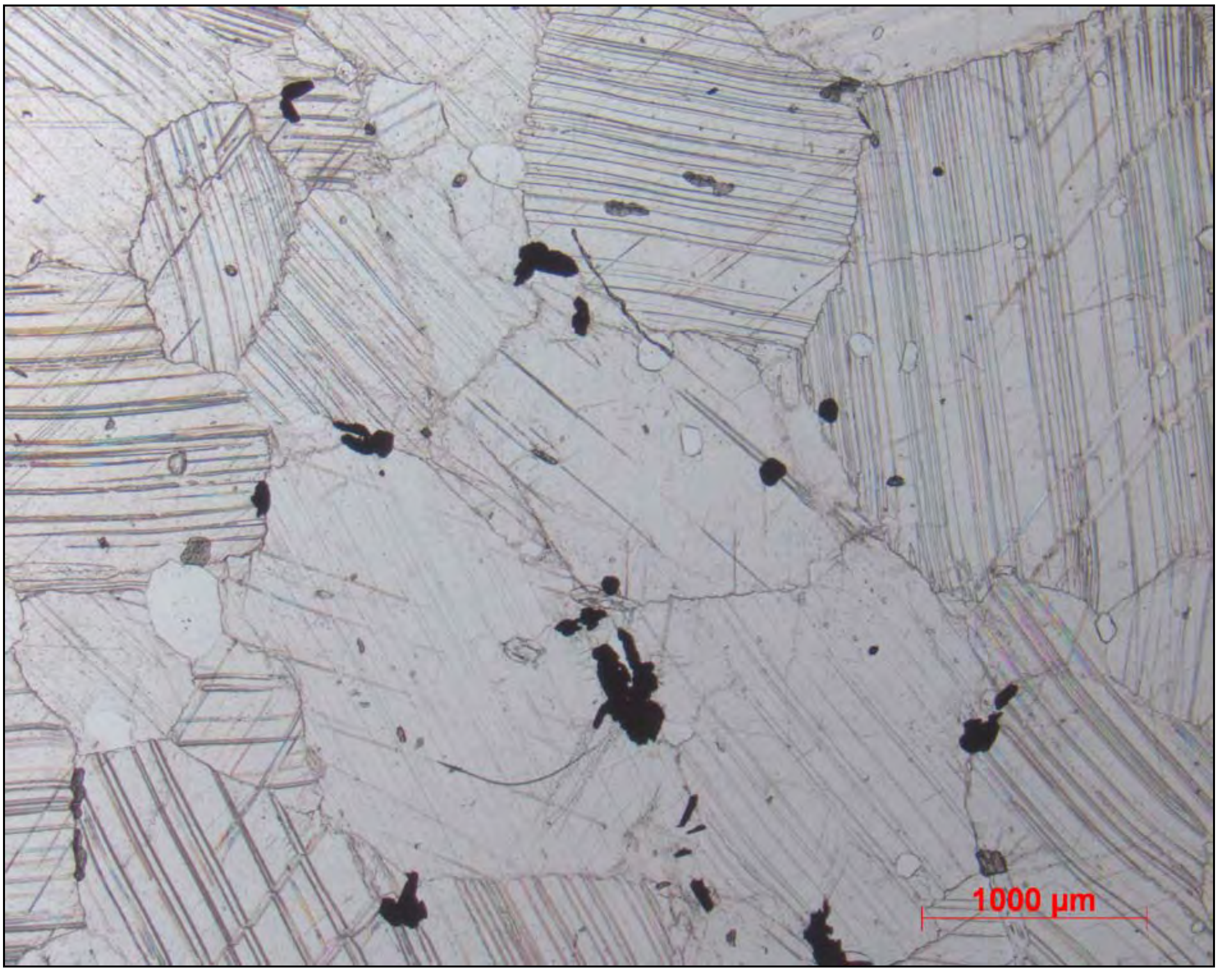

Figure 29: Microphotograph of coarse-grained calcite marble, borehole LR5 at 9.0 m, Breivoll.

6. SUMMARY

The two reports by Korneliussen et al. (2011 a, b) give an overview of the mineral resource situation for the Evenes area and Rolla, while this document provides additional information about the character of marbles within a number of short boreholes from these areas, as well as summarise some general geological characteristics.

The mineral-chemical character of the marbles is a consequence of the combination of primary depositional characteristics, deformation and metamorphism, and there is a huge complexity. At the present stage of knowledge the large geological complexity can to some extent be recognised, but is not fully understood. For practical reasons the reports developed so far are largely descriptive, including this document, which focuses on characterisation information that might be of significance for the continued mineral resource development.

In general, the carbonate rocks in the Evenes area range in age from late Precambrian to Silurian (Melezhik et al. 2003) with a considerable chemical variation in the depositional regime, which is reflected in the present whole-rock chemistry. Tectonostratigraphically the Evenes marbles belong to the Evenes Nappe Complex, and the Rolla marbles are believed to belong to the Late Precambrian Bogen Group, higher up in this stratigraphy. Marbles in the central Evenes area are mainly Silurian.

Effects of metamorphic recrystallisation are extensive. Presumably all white, coarse-grained marbles are recrystallised varieties, although with a large variation in mineral-chemical characteristics. Marble dykes described by Roberts & Zwaan (2007) from Rotneset in the Evenes area are examples of metamorphic mobilisation of calcite carbonate. Dark bands or layers within the white marbles, commonly observed in core samples, are believed to represent relics of a carbonate protolith.

The Karvevika marble (Korneliussen et al. 2011a) within the Bogen group in Ballangen on the southern side of the Ofotfjord, are chemically very similar to the Breivoll marble at Rolla and is probably it's southern equivalent. However, the Karvevika marble is not further discussed in this report since no borehole is available from this locality.

Mineral intergrowths of other minerals such as graphite, quartz and dolomite, with calcite, are extensive, particularly within marbles from the Evenes area. A large amount of microphotographs and SEM-images are available, showing considerable mineral variations; a selection of such images is shown in this report while others are available upon request. For deposits with extensive and complex intergrowths of other minerals in calcite, particularly those deposits with significant amounts of dolomite, industrial production of high-purity calcite might be particularly challenging.

In general, mineral intergrowths in the Rolla marbles are less extensive compared with marbles from the Evenes area, although there are large variations. The amount of dolomite in the Rolla carbonate is negligible, and for that reason Rolla deposits as well as Karvevika in Ballangen (see Korneliussen et al. 2011a) might be more attractive from a processing point of view. However, this report is providing only characterisation information; processing information is not available at this stage.

Table 9: Main borehole characteristics (see analytical data in Table 3 and 7):

	MgO_{icp}	$(Fe + Mn)_{icp}$	Other comments
EVENES AREA: In general the Evenes marbles are fairly dolomitic and mineralogically complex. Marbles with low content of crystal-bound iron and manganese, such as at Bjørnåsen, are of potential economic interest if an industrial-feasible mineral processing can be developed. Further investigations should focus on developing a mineral-processing setup suitable for deposits in the area, as suggested by Korneliussen et al. (2011a).			
LE1 Stunes	Low MgO_{icp} in the beginning of the borehole, increasing downwards. Average 0.85 % MgO_{icp}.	Large variations in crystal-bound iron and manganese; some good core sections with less than 250 ppm Fe_{icp} + Mn_{icp}.	There is a large resource potential in the area but further investigations are not recommended due to high crystal-bound iron and manganese.
LE2 Skardsfjell	Dolomitic, with high MgO_{icp} throughout the borehole; avg. 5.85 % MgO_{icp}.	Distinct variations; some good sections with less than 250 ppm Fe_{icp} + Mn_{icp} (avg. 402 ppm).	There is a large resource potential in the area but further investigations are not recommended due to high dolomite content.
LE4 Bjørnåsen	Dolomitic, with high MgO_{icp} throughout the hole; avg. 5.34 % MgO_{icp}.	Distinct variations, but generally fairly low Fe_{icp} + Mn_{icp} (avg. 275 ppm).	There is a considerable resource potential in the area for carbonate with fairly low content of crystal-bound iron and manganese. Further investigations are recommended only if a feasible mineral processing procedure can be developed.
LE5 Kvantohøgda	Dolomitic.	Very high content of Fe_{icp} and Mn_{icp}.	Due to the dolomitic character and very high content of crystal-bound iron and manganese, further investigations are not recommended.
ROLLA: The Rolla marble and mica schist/gneiss succession is several hundred meters thick, fairly flat lying. Some if the marble units are of potentially high industrial quality with low content of crystal-bound iron and manganese as well with low dolomite content. The potential areal distribution of the Breivoll marble unit is several square kilometers with a thickness of more than 25 meters, and the resource potential for high-quality calcite marble might be more than 100 Mt. Further investigations should focus on developing a feasible mineral-processing setup, as suggested by Korneliussen et al. (2011b). From an economical geological point of view lithological and structural geologic mapping hand-in-hand with additional core drilling (longer holes) and the establishment of a 3D geological model, is advisable.			
LR1 Breivollia	Low MgO_{icp}	Very high content of Fe_{icp} and Mn_{icp}.	This borehole is positioned fairly low in the marble and mica schist/gneiss succession, with good-quality marbles higher up in the stratigraphy (see below). Only the upper part of the core contains marble, the rest is mica schist/gneiss.
LR2 Breivollia	Low MgO_{icp}	Fairly high Fe_{icp} and Mn_{icp} in general, but with low values in the lowermost part of the hole.	The good marble in the lowermost part of the borehole is probably the upper part of the Breivoll marble zone (see LR5).
LR3 Breivollia	Low MgO_{icp}	High content of Fe_{icp} and Mn_{icp} except the section at 10-15 meters that is within a high-quality marble (115 Fe_{icp}, 43 ppm Mn_{icp}).	This borehole transects marbles stratigraphically above the previous boreholes as well as above the Breivoll marble zone (see below). The good marble unit in the middle of this borehole indicate that the marble and mica schist/gneiss succession contain several marble horizons of potentially high quality.
LR5 Breivoll	Low MgO_{icp}	Although variable, the overall content of Fe_{icp} and Mn_{icp} is low (avg. 225 ppm); some sections are excellent.	The entire borehole (25 m) transects good marble with fairly low content of crystal-bound iron and manganese, indicating a large resource potential since the areal distribution of this unit may be several square kilometers.
LR6 Storskog	Low MgO_{icp}	Although variable, the overall content of Fe_{icp} and Mn_{icp} is low to moderate in the upper and central parts of the core, but very high (1940 ppm) in the lowermost part	The upper 4/5 of the borehole are within marble with roughly similar characteristics as the Breivoll marble 2 km to the NE, and might represent a lower part of a fairly wide “Breivoll zone”. The lowermost part of the core is a very impure, silicate-rich marble with high level of crystal-bound iron and manganese.

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Appendix I:

Core descriptions, Evenes area

Chemical and mineralogical characteristics of carbonate rocks in drill cores from Rolla. Supplementary information to NGU-report 2011.041 "Forekomster av kalsiumkarbonat i Breivollområdet på Rolla" (Korneliussen, Raaness, Schaller & Gautneb 2011a).

CONTENTS

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TABLES

Boreholes in the Evenes area

1. Borehole LE1 Stunes

1.1 Core description LE1

Table 1: Comments on borehole LE1 Stunes.

Unit	Location [m]	Rock-description
1	0-5,60	Mainly pale grey, coarse-grained, recrystallised calcite marble. Darker grey parts are enriched in graphite. The marble mainly comprise of apparently pure calcite crystals and graphite particles.
2	5,60-6,60	White-yellowish, coarse-grained, recrystallised marble, partly banded where darker layers of graphitic carbonate marks the banding. Within the marble there are Fe-weathered veins with mica (phlogopite), and it is characterised by thin layers of amphibolite.
3	6,60-7,18	First part of the unit is characterised by a dark, fine-grained silicate-rich calcite marble; distinct silicate minerals are quartz, amphibole and mica (phlogopite). The second part has less calcite, with distinct sulphide (pyrite) content.
4	7,18-8,8	Pale grey to yellow-white, coarse-grained and massive calcite marble with a distinct content of pyrite and graphite. Mica (phlogopite) is enriched in thin layers. The pyrite is partly corroded and appears in shiny Cu-colours.
5	8,8-18,6	White to pale grey, coarse-grained calcite marbles with distinct graphite and sulphide grains. Dark bands presumably represent relics of a dark grey, banded calcite carbonate *Thin section *LE1_10.0*
6	18,6- 25	Pale grey to dark grey, distinctly banded calcite marble. The dark grey parts are fine-grained and thin layered and are believed to represent relics of a previous generation of the rock. The coarse-grained white marble is interpreted to have forms by metamorphic recrystallisation of the dark-grey carbonate; this process has been incomplete resulting in a mixture of the “primary” banded dark grey marble and the “secondary” white marble. The dark grey marble bands apparently have a higher content of graphite (visually estimated up to 5 % locally), mica and sulphides (pyrite). The light grey parts, similar to unit 5, are mainly coarse-grained and consist of pure calcite crystals. Calcite veins cut through the layered marble.

1.2 Chemical analyses LE1

Table 2: Summarized analyses, borehole LE1 Stunes

Locality		Stunes	Stunes	Stunes	Stunes	Stunes
Borehole		LE1	LE1	LE1	LE1	LE1
Sample		LE1-00-05	LE1-05-10	LE1-10-15	LE1-15-20	LE1-20-25
NGU identification no		101666	101667	101668	101669	101670
From-to (m)		0-5	5-10	10-15	15-20	20-25
SiO_2 XRF	%	0,50	8,99	0,63	1,48	2,03
Al_2O_3 XRF	%	-0,02	2,65	0,05	0,27	0,35
Fe_2O_3 XRF	%	0,02	1,29	0,02	0,12	0,17
TiO_2 XRF	%	-0,01	0,21	-0,01	0,02	0,02
MgO XRF	%	0,44	1,37	0,57	1,38	1,71
CaO XRF	%	55,90	47,70	55,40	53,60	53,00
Na_2O XRF	%	-0,10	0,35	-0,10	-0,10	-0,10
K_2O XRF	%	-0,01	0,25	0,02	0,09	0,14
MnO XRF	%	-0,01	0,02	-0,01	0,01	0,02
P_2O_5 XRF	%	-0,01	0,03	-0,01	0,04	0,05
LOI XRF	%	43,30	37,20	43,10	42,90	42,70
SUM XRF	%	99,99	100,06	99,65	99,81	100,10
Ca ICP	ppm	376000	322000	375000	363000	366000
CaO ICP	%	52,60	45,05	52,46	50,78	51,20
CaO ICP vs. CaO XRF	%	94	94	95	95	97
Mg ICP	ppm	2430	3650	3240	7210	9060
MgO ICP	%	0,40	0,61	0,54	1,20	1,50
MgO ICP vs. MgO XRF	%	92	44	94	87	88
Fe ICP	ppm	105	9017	140	818	1181
Fe ICP	ppm	47	1490	101	458	527
Mn ICP	ppm	nd	170	nd	108	132
Mn ICP	ppm	11	80	12	88	124
Fe+Mn XRF	ppm	105	9187	140	926	1313
Fe+Mn ICP	ppm	58	1570	113	546	651
Fe+Mn ICP vs. Fe+Mn XRF	%	55	17	81	59	50
P ICP	ppm	34	142	30	152	215
Ba ICP	ppm	3,4	9,3	2,7	5,7	2,4
Sr ICP	ppm	257	228	269	324	312
Dolomite Calculated	%	1,8	2,8	2,5	5,5	6,9
Calcite Calculated	%	92,5	78,6	91,9	87,3	87,3
Others Calculated	%	5,6	18,6	5,6	7,2	5,8
S LECO	%	< 0,01	< 0,01	< 0,01	< 0,01	< 0,01
TC LECO	%	11,36	9,92	11,66	11,38	11,30
TOC LECO (graphite)	%	< 0,1	< 0,1	< 0,1	< 0,1	< 0,1

Table 3: Semi-quantitative analyses by Niton portable XRF, borehole LE1.

Bh	Pos. (m)	% SiO2	% CaO	ppm Fe	Pos. (m)	% SiO2	% CaO	ppm Fe	Pos. (m)	% SiO2	% CaO	ppm Fe
LE1	0,5	0,7	61,25	260	10,5	0,6	56,14	330	20,5	2,0	54,80	1020
LE1	1,5	0,7	56,85	250	11,6	0,9	55,37	330	21,5	3,4	52,56	1310
LE1	2,5	0,8	58,09	260	12,5	0,7	57,11	390	22,6	1,9	55,66	790
LE1	3,5	0,5	56,93	220	13,5	0,9	56,58	370	23,5	4,2	51,26	1460
LE1	4,7	0,7	57,02	400	14,5	1,4	56,32	390	23,8	6,7	50,43	1850
LE1	5,5	0,6	57,07	310	15,5	1,6	54,77	800	24,5	1,6	56,01	1430
LE1	6,3	0,7	56,25	330	16,5	1,0	56,66	440	25,4	1,3	55,88	570
LE1	7,5	1,1	57,13	1620	17,5	2,0	55,78	640				
LE1	8,5	0,7	56,25	930	18,5	2,4	54,12	1100				
LE1	9,5	1,1	56,02	440	19,7	2,3	52,92	1220				

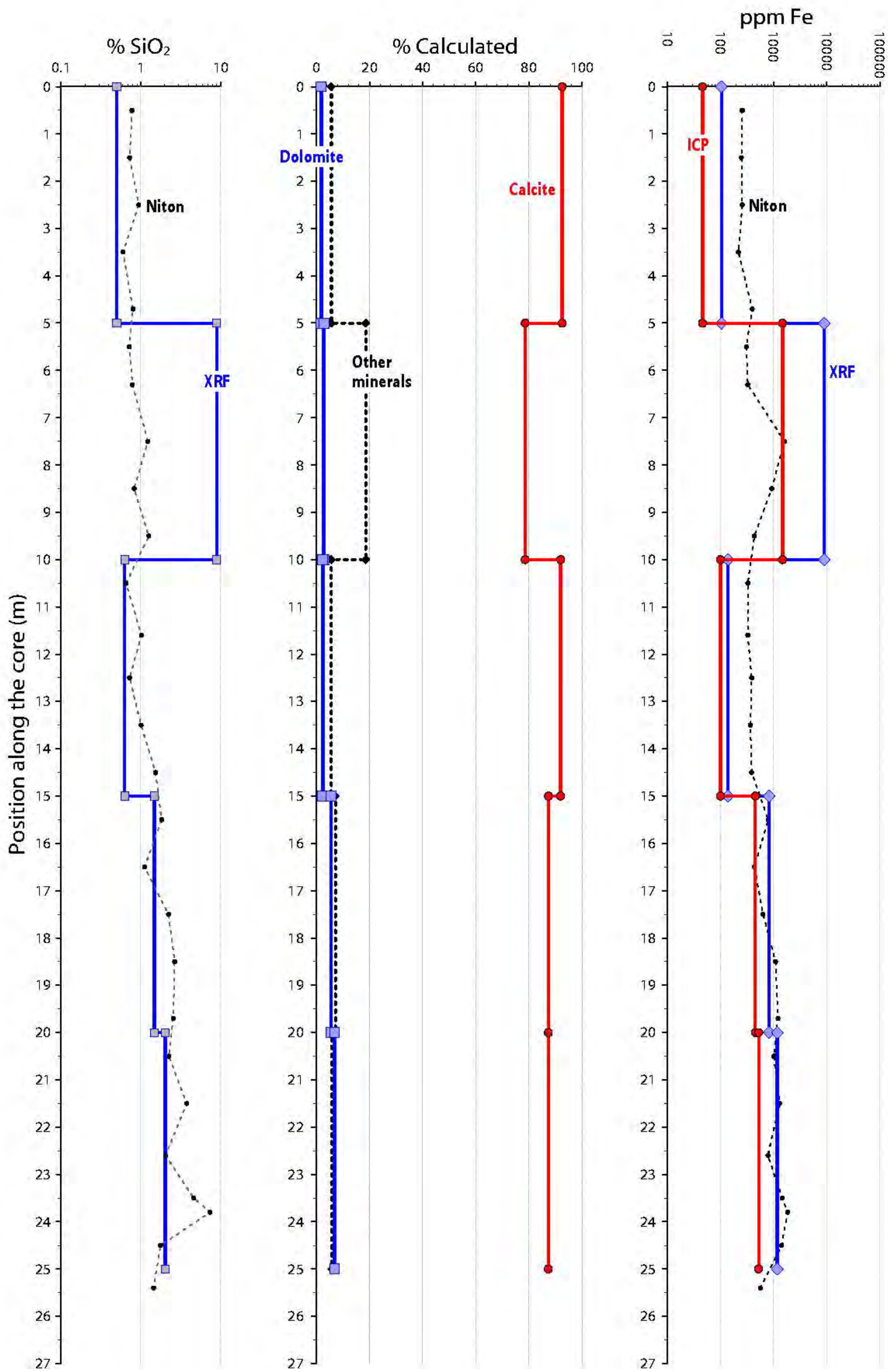


Figure 1: Variations in SiO_2, Fe and major minerals along borehole LE1.

1.3 Core photographs LE1

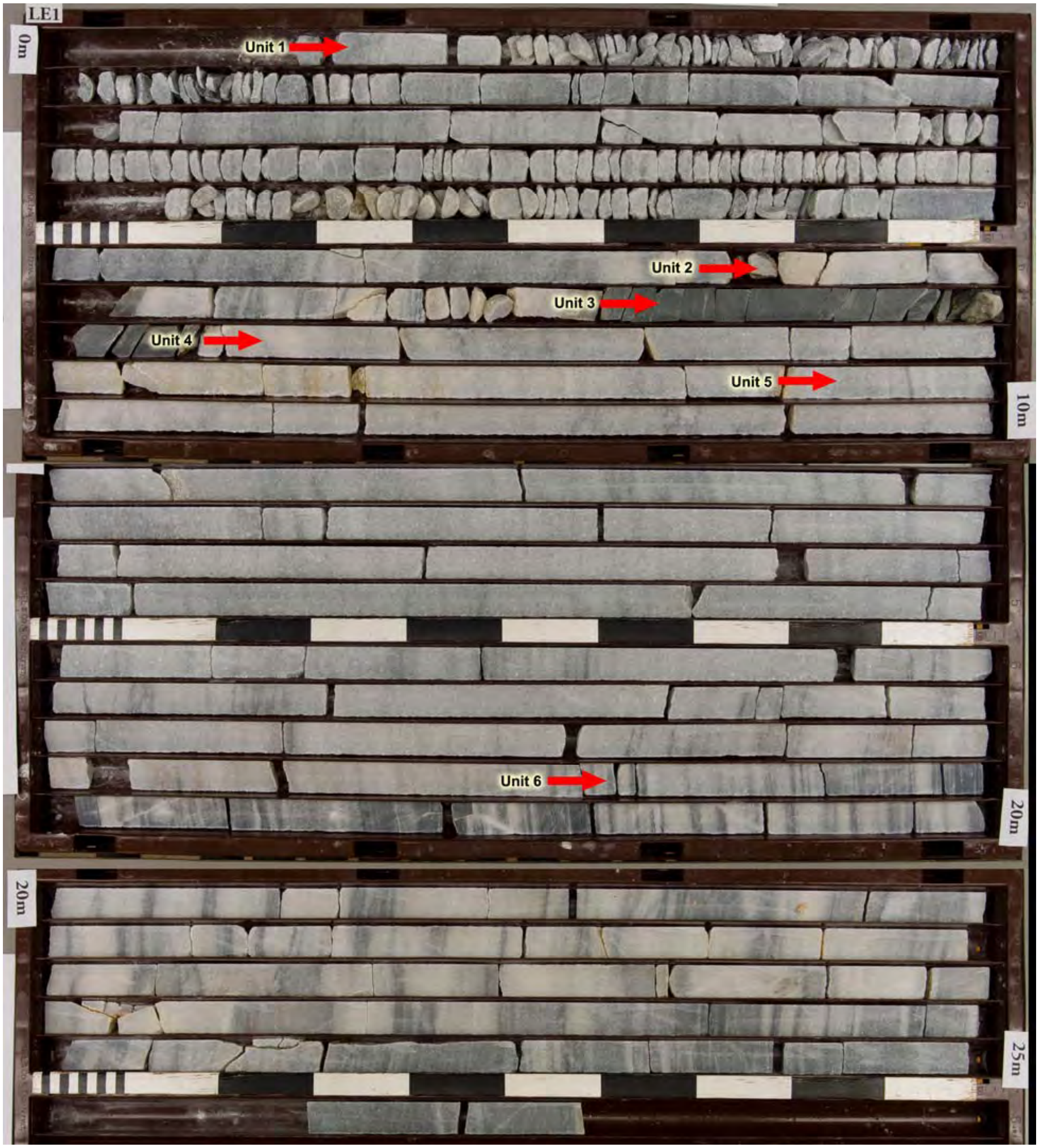


Figure 2: Overview photo of core LE1, Stunes.

Borehole LE 1 (Figure.3) is characterized by coarse grained pale grey marble with dark grey parts of graphite. The black layers are relics of preserved sedimentary bedding. The marbles were strongly recrystallized.

Figure 3: Photo of coarse-grained white calcite marble with relicts of sedimentary bedding (dark layeres); LE1 10-20 m.

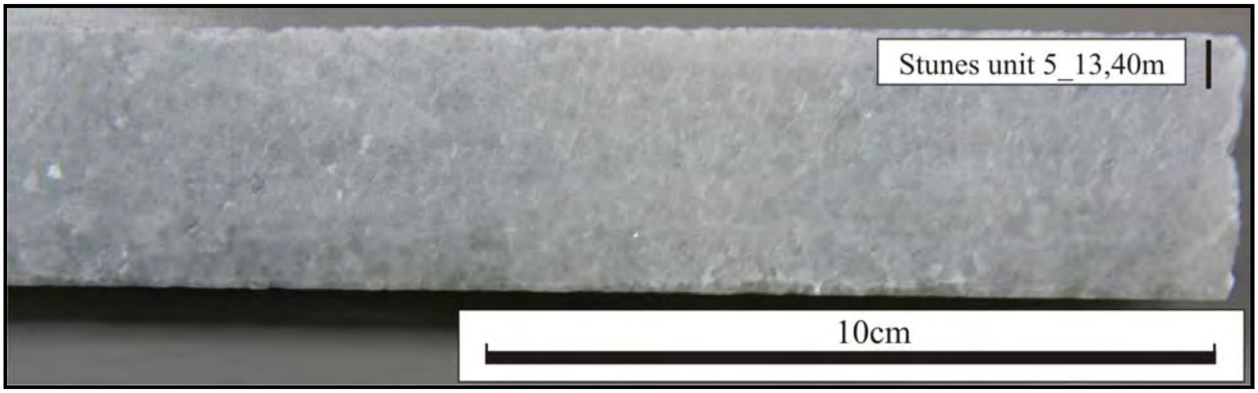


Figure 4: Close-up photo of white homogeneous calcite marble; LR5 at 13,4 m.

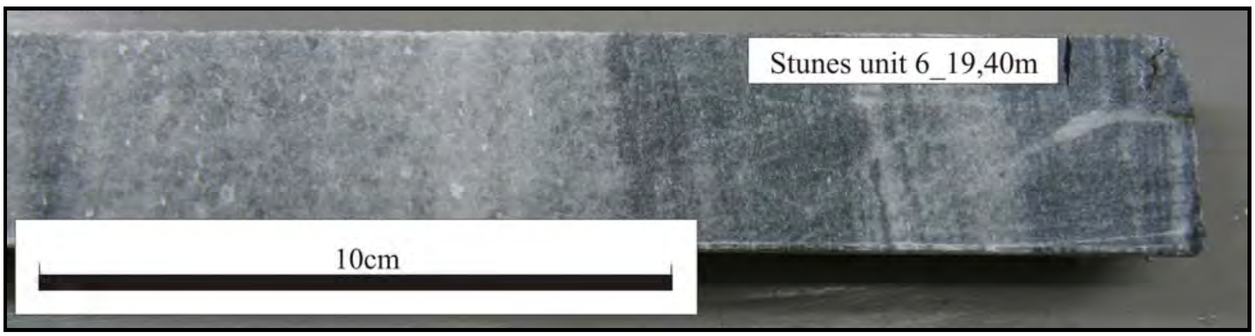


Figure 5: Close-up photo of alternating massive and banded calcite marble; LE1 at 19,4 m.

Figure 6: Close-up photo of alternating coarse-grained massive white to banded grey (fine-grained graphite-bearing) calcite marble; LE1 at 19,2-19,5 m.

Remobilized calciumcarbonate are also visible as white veins that are crossing the initial layering, as seen in Figure 5 and Figure 6.

1.4 Micrographs LE1

1.4.1 Thin section LE1-10.0 m

Calcite is dominating the LE1 10.0 thin section. Mica (phlogopite), quartz and accessorial minerals such as graphite and apatite are also present in calcite crystals.

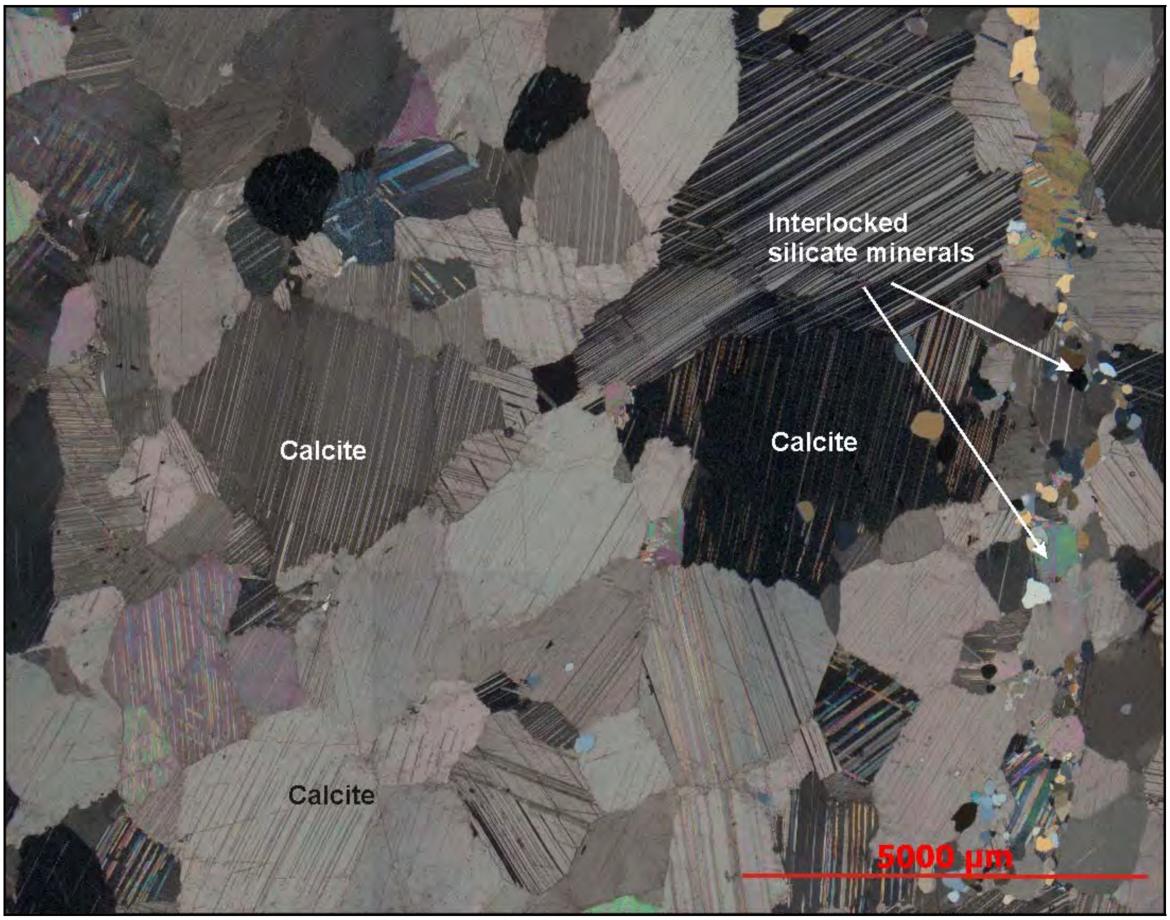


Figure 7: Mosaic microphotograph of coarse-grains marble with inclusions of silicate minerals, mainly quartz; thin section LE1-10.0m, crossed polarized light.

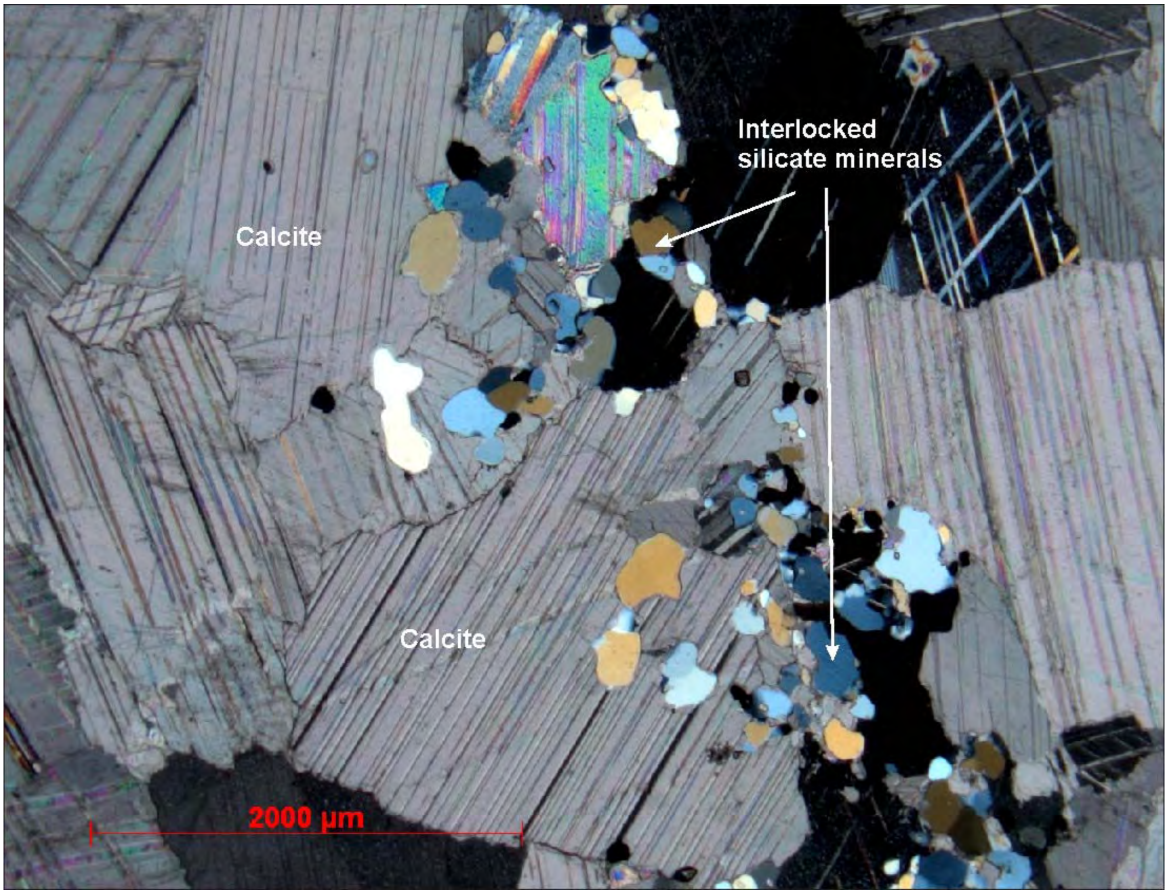


Figure 8: Close-up photograph of inclusions of other minerals, mainly quartz, in medium to coarse grained carbonate; thin section LE1-10.0 m, crossed polarized light.

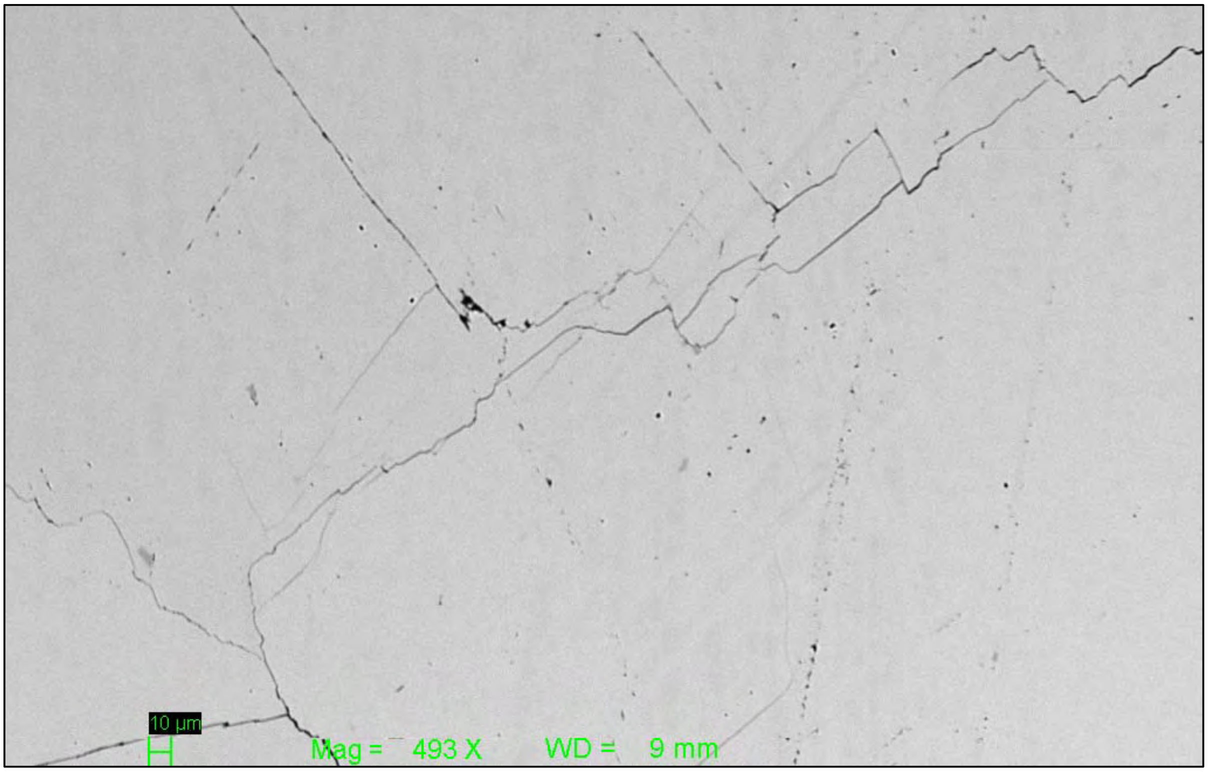


Figure 9: SEM back scattered electron (BSE)-image showing tiny inclusions of graphite (black patches) in calcite crystals. Thin section LE1-10.0 m.

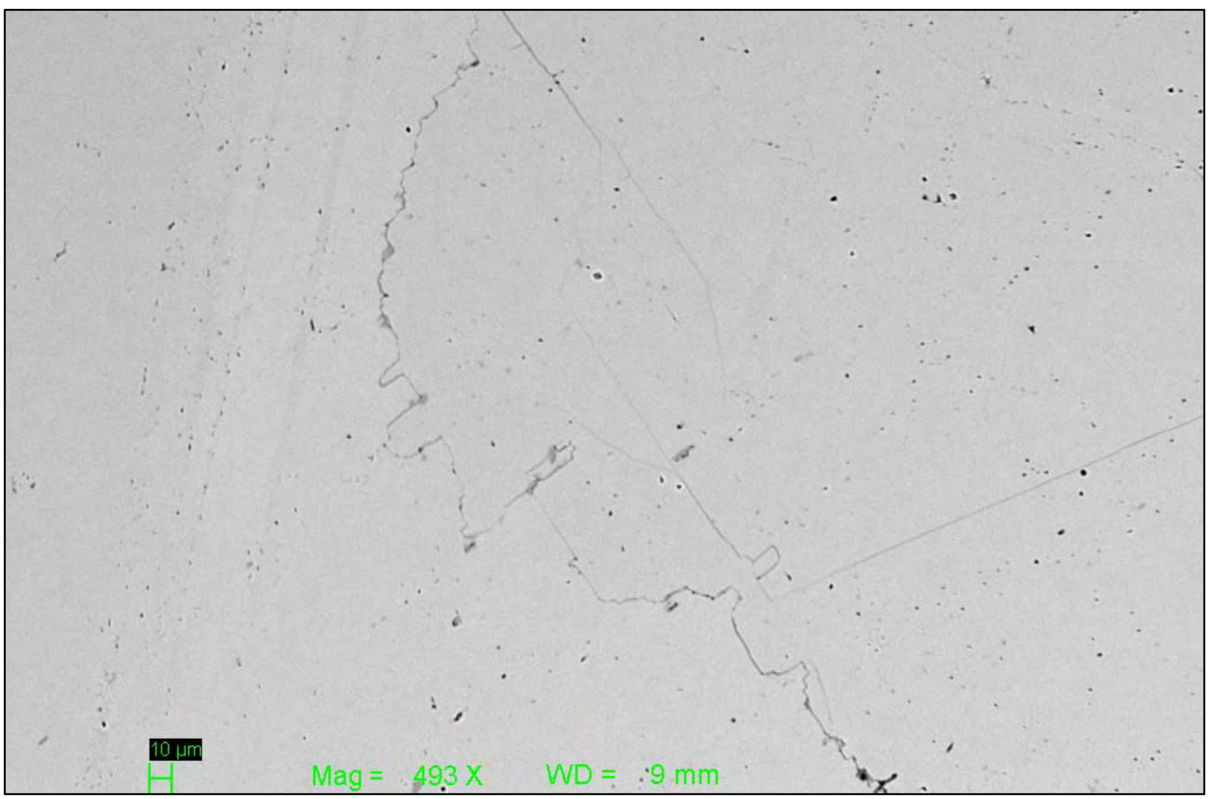


Figure 10: SEM BSE-image showing stylolitic effects on calcite grain boundaries; graphite occurs as tiny inclusions within calcite. Thin section LE1-10.0 m.

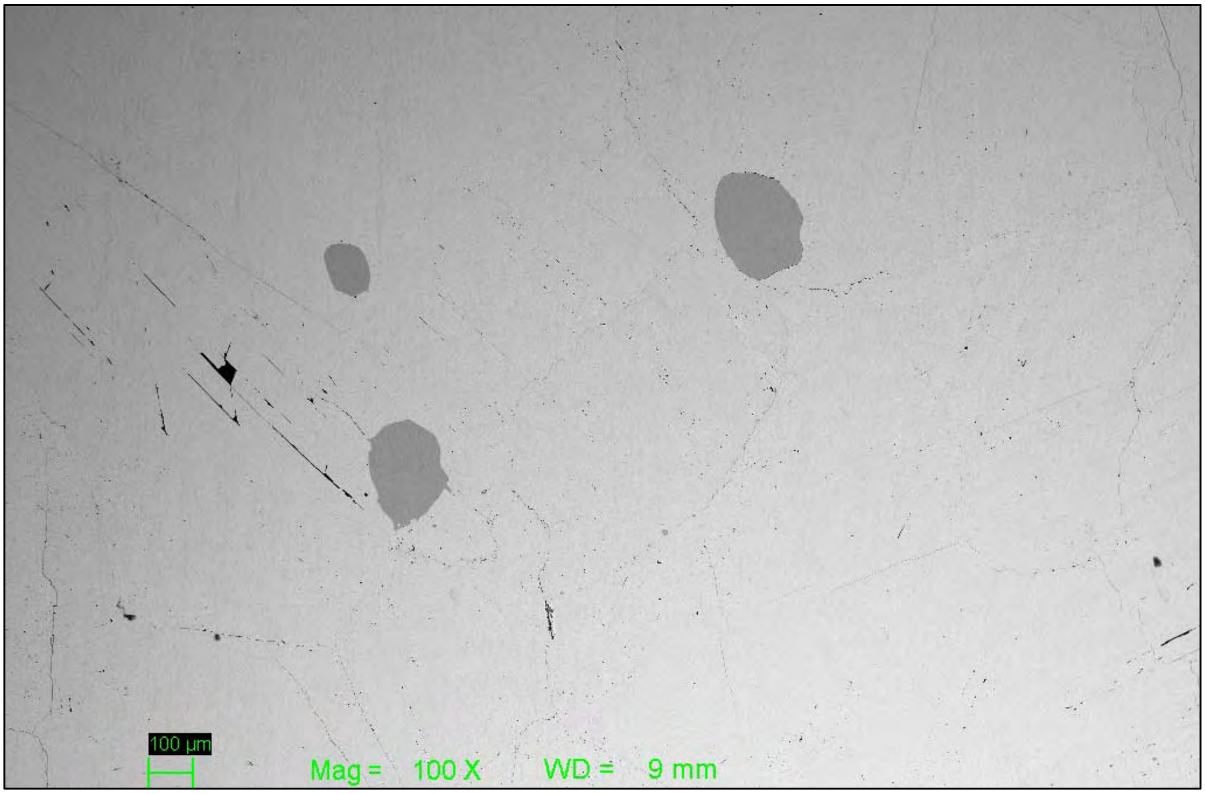


Figure 11: SEM BSE-image showing inclusions of quartz (dark grey) and graphite (black) in calcite. Thin section LE1-10.0 m.

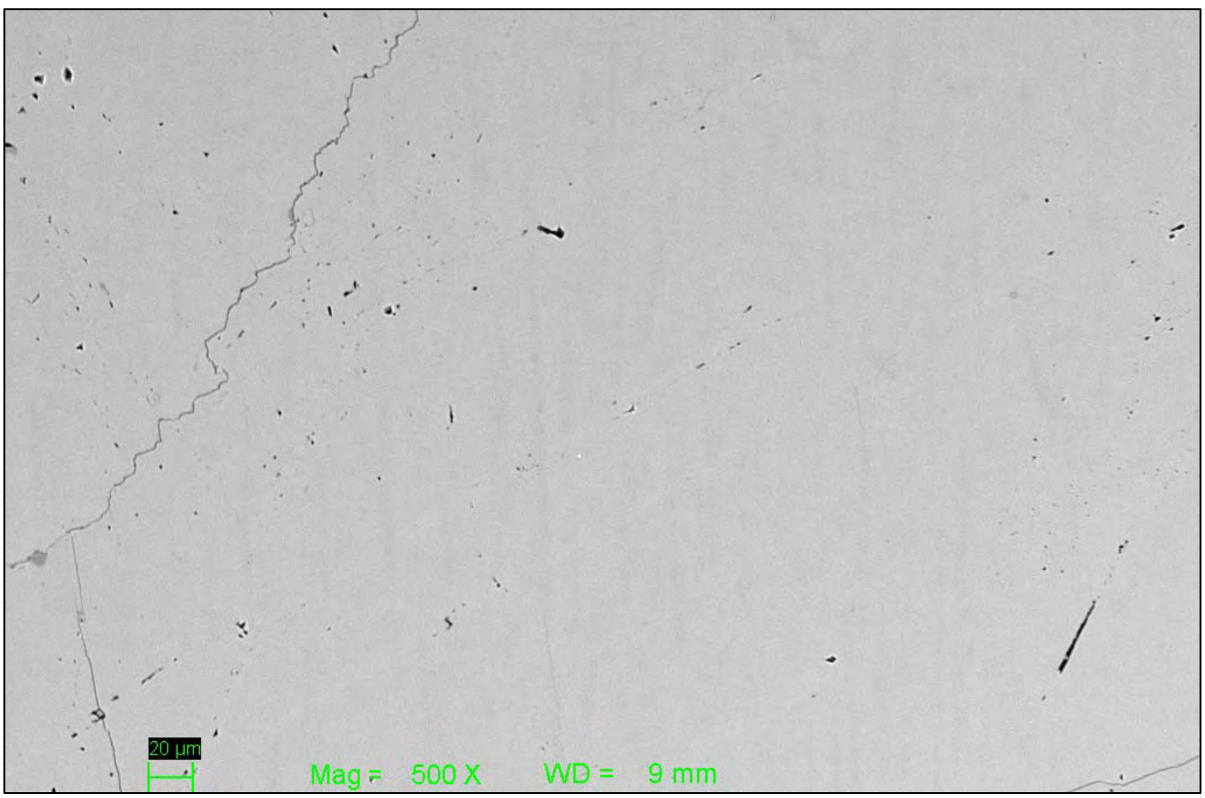


Figure 12: SEM BSE-image showing inclusions of graphite (black) in calcite. Thin section LE1-10.0 m.

2. Borehole LE2 Skardsfjell

2.1 Core description

Table 4: Comments on borehole LE2 Skardsfjell.

Unit	Location [m]	Rock-description
1	0-6,10	Variably banded, light to dark grey, heterogeneous calcite-dolomite marble. In the first few meters thin layers are enriched in quartz and mica (phlogopite), sulphide and graphite.
2	6,10-23	Variably banded, light to dark grey, heterogeneous calcite-dolomite marble. Calcite veins cut across the layering. The unit is enriched in pyrite. *Thin sections: LE2-07.4m and LE2-21.9m*
3	23-24,7	White-yellow, banded, pale grey to dark grey marbles that are thin layered. Calcite veins cut across the sub-horizontal bedding like in unit 2. Sulphides are present as well as quartz and mica (phlogopite), particularly concentrated in thin layers.
4	24,7-25	White-pale yellow, coarse-grained calcite marbles with comprising white mica (muscovite) schist layers.

2.2 Chemical analyses

Table 5: Semi-quantitative analyses by Niton portable XRF, borehole LE2.

Bh	Pos. (m)	% SiO2	% CaO	ppm Fe	Pos. (m)	% SiO2	% CaO	ppm Fe	Pos. (m)	% SiO2	% CaO	ppm Fe
LE2	0,8	4,4	50,7	510	10,6	1,7	53,9	280	20,5	1,6	32,6	1730
LE2	1,6	6,3	48,4	830	11,5	2,2	51,2	660	21,6	2,1	53,4	420
LE2	2,6	3,6	53,5	600	12,5	1,8	51,1	390	22,6	2,4	48,9	420
LE2	3,6	11,7	40,2	440	13,5	7,1	50,4	590	23,3	1,2	32,6	1290
LE2	4,5	7,6	49,7	500	14,5	1,9	46,1	350	24,4	2,3	52,5	740
LE2	5,5	4,9	53,0	620	15,5	2,7	48,1	680				
LE2	6,5	1,7	46,4	340	16,5	7,4	42,3	340				
LE2	7,6	1,0	54,4	290	17,5	4,9	49,2	1690				
LE2	8,7	3,2	53,0	540	18,6	5,7	41,2	1650				
LE2	9,3	1,6	50,9	500	19,7	11,3	34,4	2860				

Table 6: Summarized analyses, borehole LE2.

Locality		Skardsfjell	Skardsfjell	Skardsfjell	Skardsfjell	Skardsfjell
Borehole		LE2	LE2	LE2	LE2	LE2
Sample		LE2-00-05	LE2-05-10	LE2-10-15	LE2-15-20	LE2-20-24.7
NGU identification no		101671	101672	101673	101674	101675
From-to (m)		0-5	5-10	10-15	15-20	20-24.7
$SiO_{2\ XRF}$	%	7,04	4,84	2,86	4,25	8,54
$Al_2O_{3\ XRF}$	%	0,33	0,19	0,10	0,28	0,71
$Fe_2O_{3\ XRF}$	%	0,15	0,09	0,04	0,17	0,43
$TiO_{2\ XRF}$	%	0,01	-0,01	-0,01	-0,01	0,07
MgO_{XRF}	%	7,35	4,43	4,69	5,47	10,40
CaO_{XRF}	%	43,50	48,60	49,20	47,50	39,10
Na_2O_{XRF}	%	-0,10	-0,10	-0,10	-0,10	-0,10
K_2O_{XRF}	%	0,15	0,08	0,04	0,14	0,27
MnO_{XRF}	%	0,01	-0,01	-0,01	-0,01	0,01
$P_2O_{5\ XRF}$	%	0,08	0,08	0,04	0,09	0,09
LOI_{XRF}	%	41,20	41,80	42,70	42,30	40,20
SUM_{XRF}	%	99,73	99,98	99,56	100,07	99,72
Ca_{ICP}	ppm	292000	327000	330000	318000	266000
CaO_{ICP}	%	40,85	45,75	46,17	44,49	37,21
CaO_{ICP} vs. CaO_{XRF}	%	94	94	94	94	95
Mg_{ICP}	ppm	41300	24000	26000	29700	55500
MgO_{ICP}	%	6,85	3,98	4,31	4,92	9,20
MgO_{ICP} vs. MgO_{XRF}	%	93	90	92	90	88
Fe_{ICP}	ppm	1055	594	273	1174	3006
Fe_{ICP}	ppm	311	148	113	426	729
Mn_{ICP}	ppm	85	nd	nd	< 77	85
Mn_{ICP}	ppm	68	59	18	60	83
$Fe+Mn_{XRF}$	ppm	1141	594	273	1097	3091
$Fe+Mn_{ICP}$	ppm	379	207	131	486	812
$Fe+Mn_{ICP}$ vs. $Fe+Mn_{XRF}$	%	33	35	48	44	26
P_{ICP}	ppm	302	323	166	333	348
Ba_{ICP}	ppm	2,1	2,7	2,8	3,6	5,0
Sr_{ICP}	ppm	451	757	812	711	331
$Dolomite_{Calculated}$	%	31,4	18,2	19,8	22,6	42,2
$Calcite_{Calculated}$	%	55,6	71,4	71,4	66,9	43,3
$Others_{Calculated}$	%	13,0	10,3	8,9	10,6	14,5
S_{LECO}	%	< 0,01	< 0,01	< 0,01	0,026	0,079
TC_{LECO}	%	11,23	11,38	11,39	12,16	11,18
TOC_{LECO}	%	0,18	< 0,1	0,11	0,12	0,14

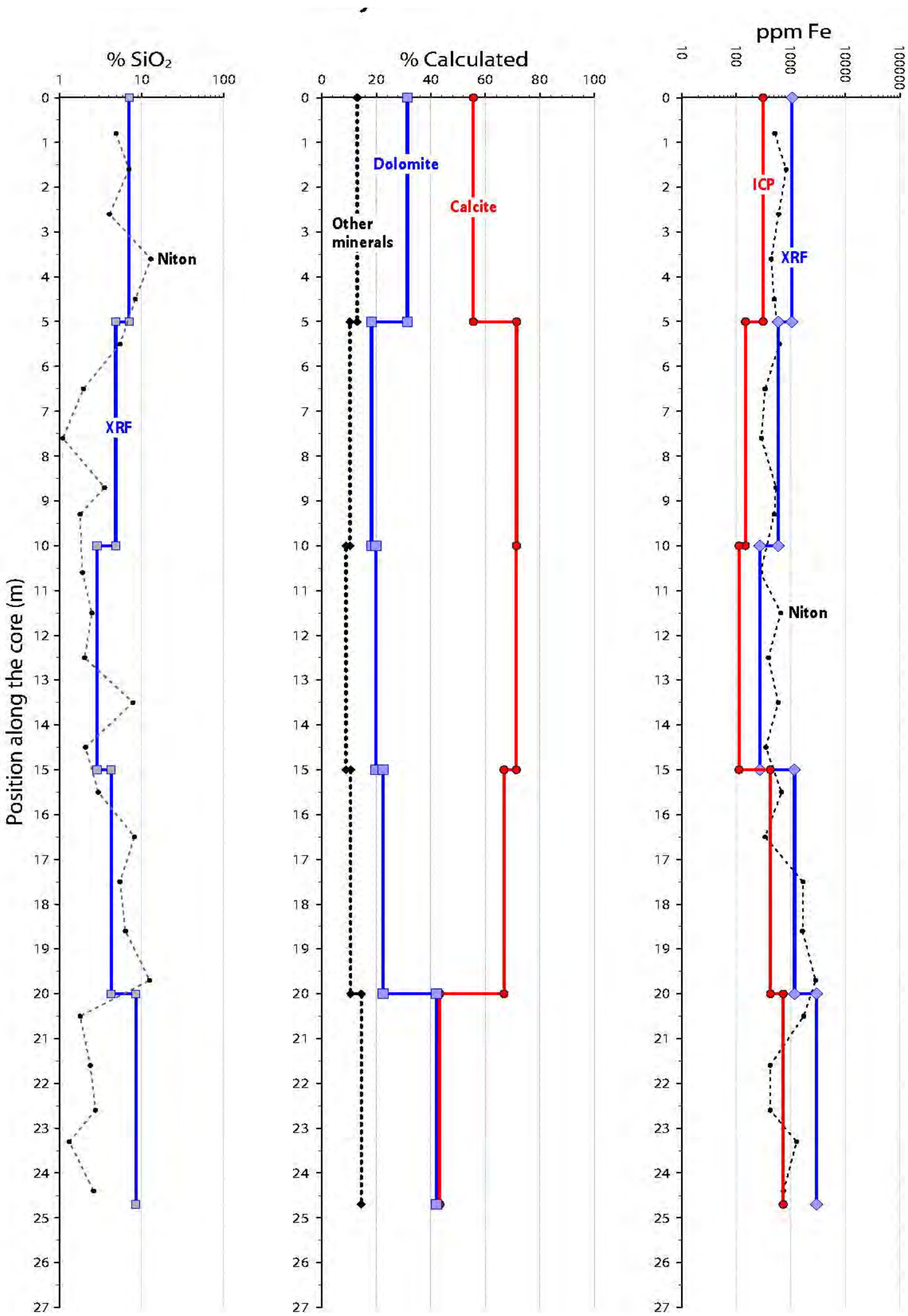


Figure 13: Variations in SiO_2, Fe and major minerals along borehole LE2.

2.3 Core photographs

Figure 14: Overview photo of core LE2, Skardsfjellet.

Figure 15: Photo of heterogeneous medium to dark grey, banded calcite-dolomite marble.

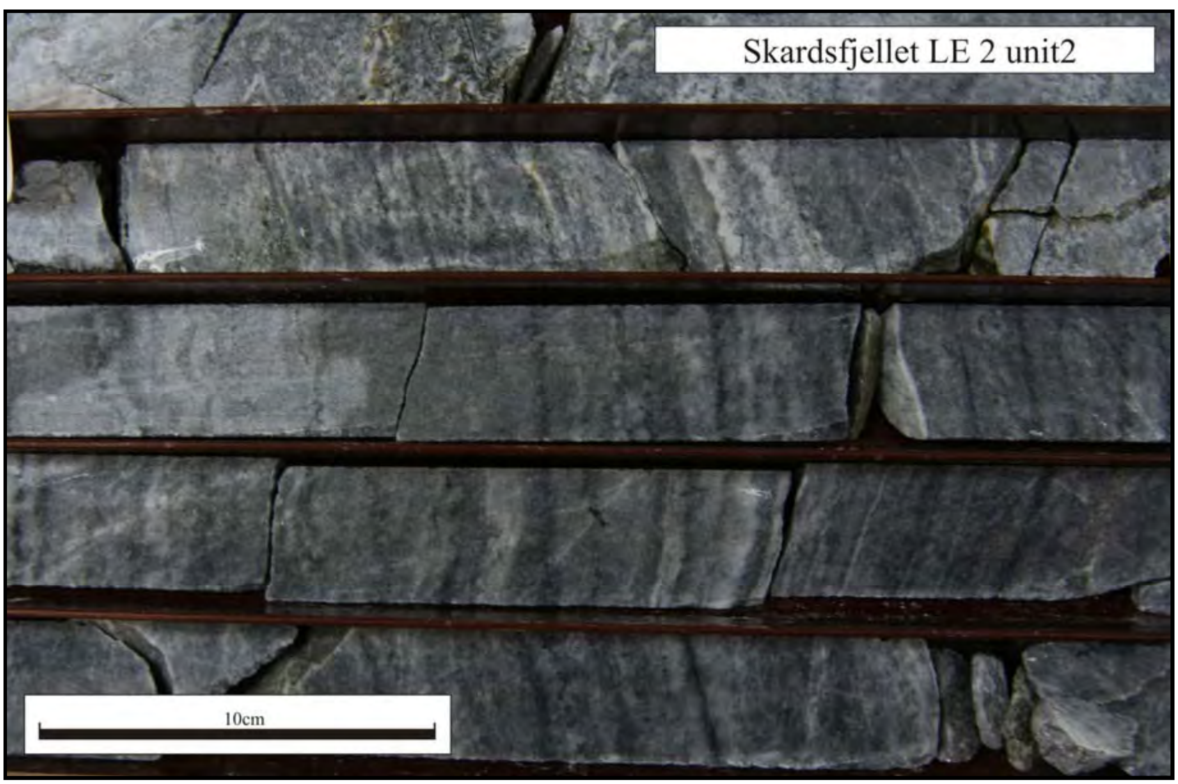


Figure 16: Photo of banded grey to dark grey calcite-dolomite marble.

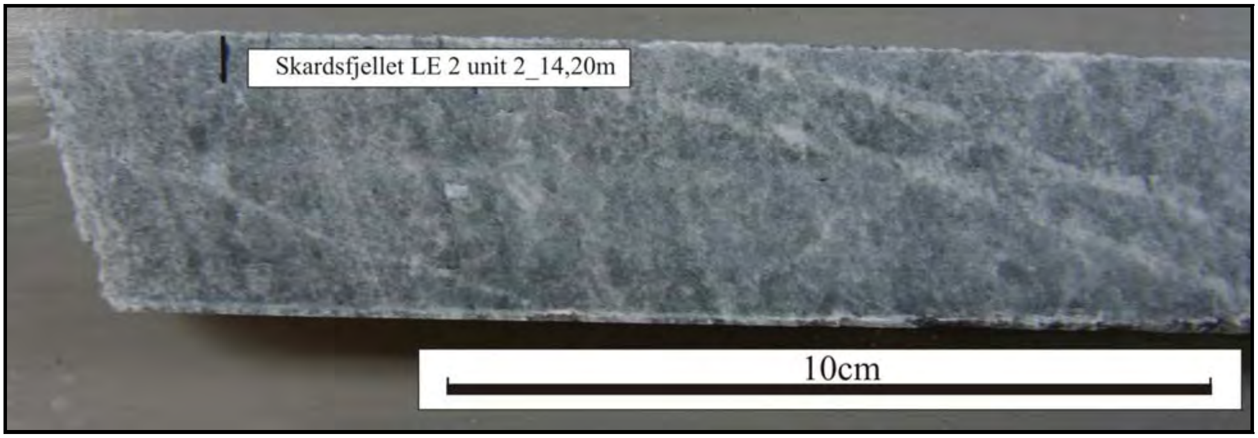


Figure 17: Photo of grey, weakly banded calcite-dolomite marble cut by thin calcite veins.

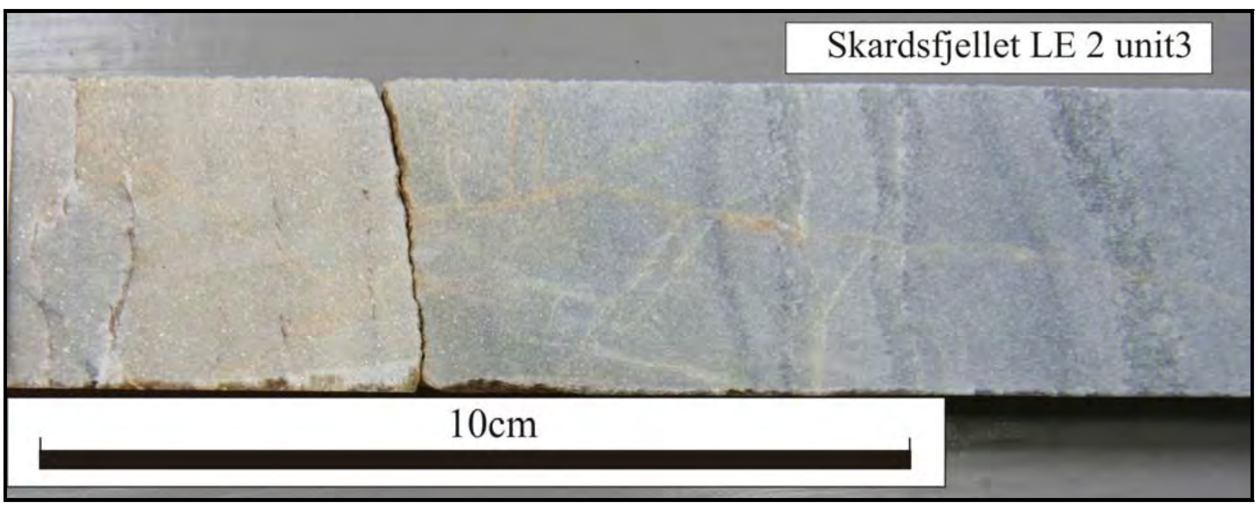


Figure 18: Photo of fine-grained and weakly yellowish dolomite (left) and slightly banded dolomite-bearing calcite marble (right).

2.4 Micropgraphs LE2

2.4.1 Thin section LE2-07.4 m

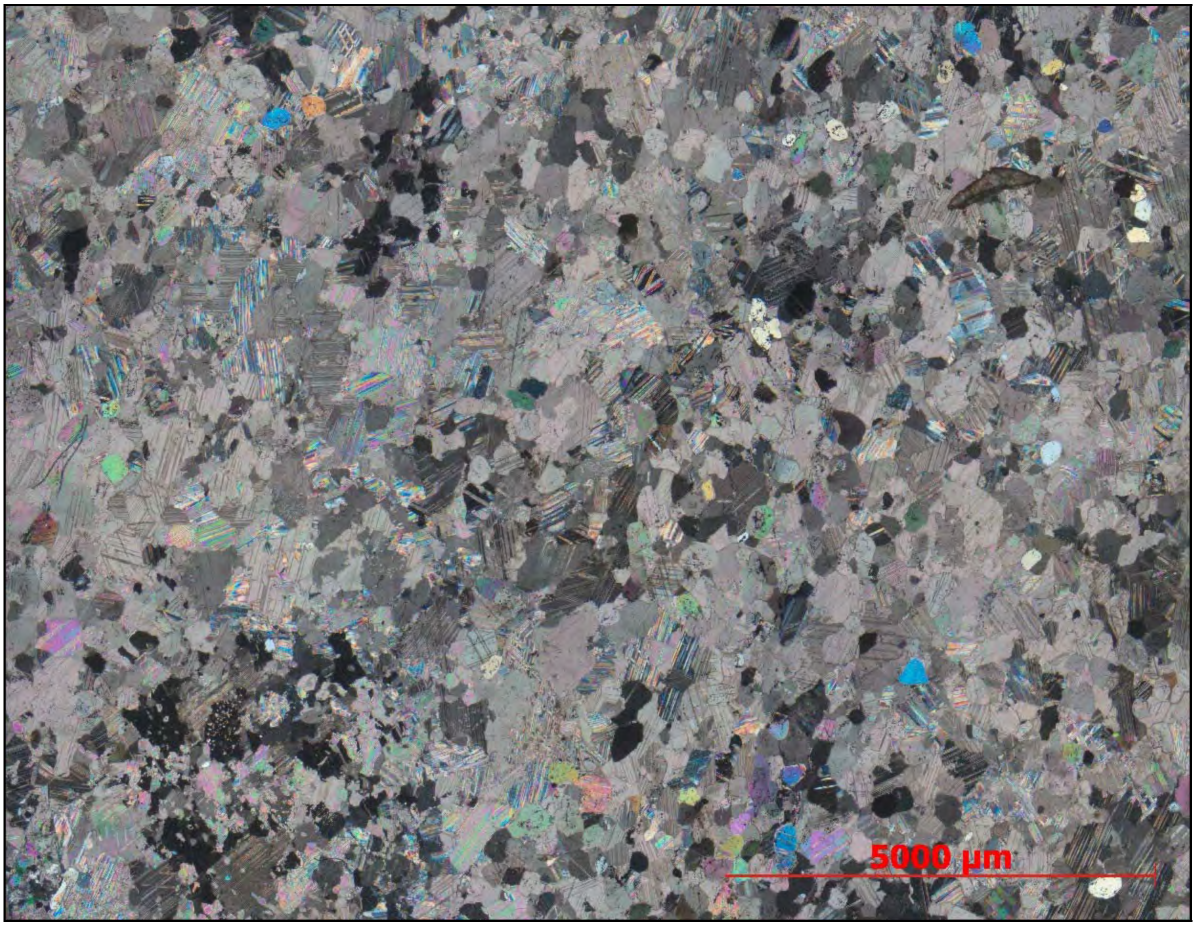


Figure 19: Mosaic microphotograph of fairly fine-grained dolomite-calcite marble; partly crossed polarized light. Thin section LE2-07.4 m.

Fine-grained calcite (< 1mm) is dominating the LE2 7.4 thin section. Also present are quartz, dolomite (rare), apatite (rare, mainly present to dolomite), graphite, olivine diopside-tremolite and phlogopite.

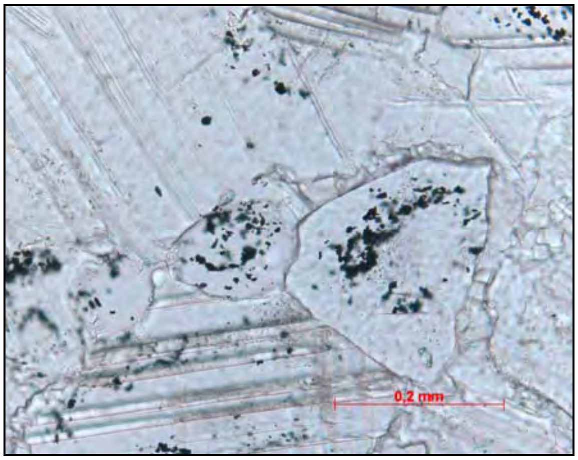


Figure 20: Microphotograph showing graphite (black) inclusions in carbonate. Thin section LE2-07.4 m.

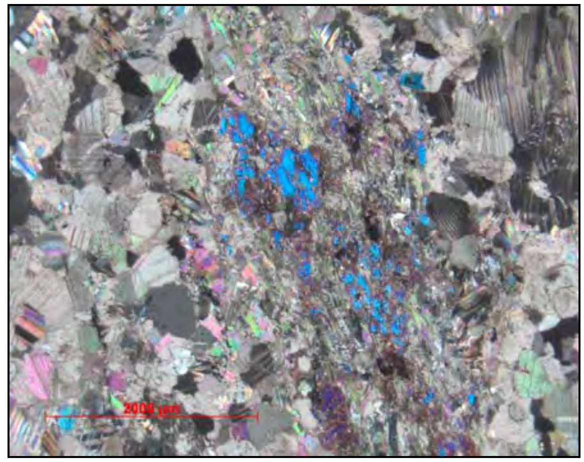


Figure 21: Microphotograph showing silicate minerals in carbonate (mainly diopside and tremolite, blue interference colours); crossed polarized light.
Thin section LE2-07.4 m.

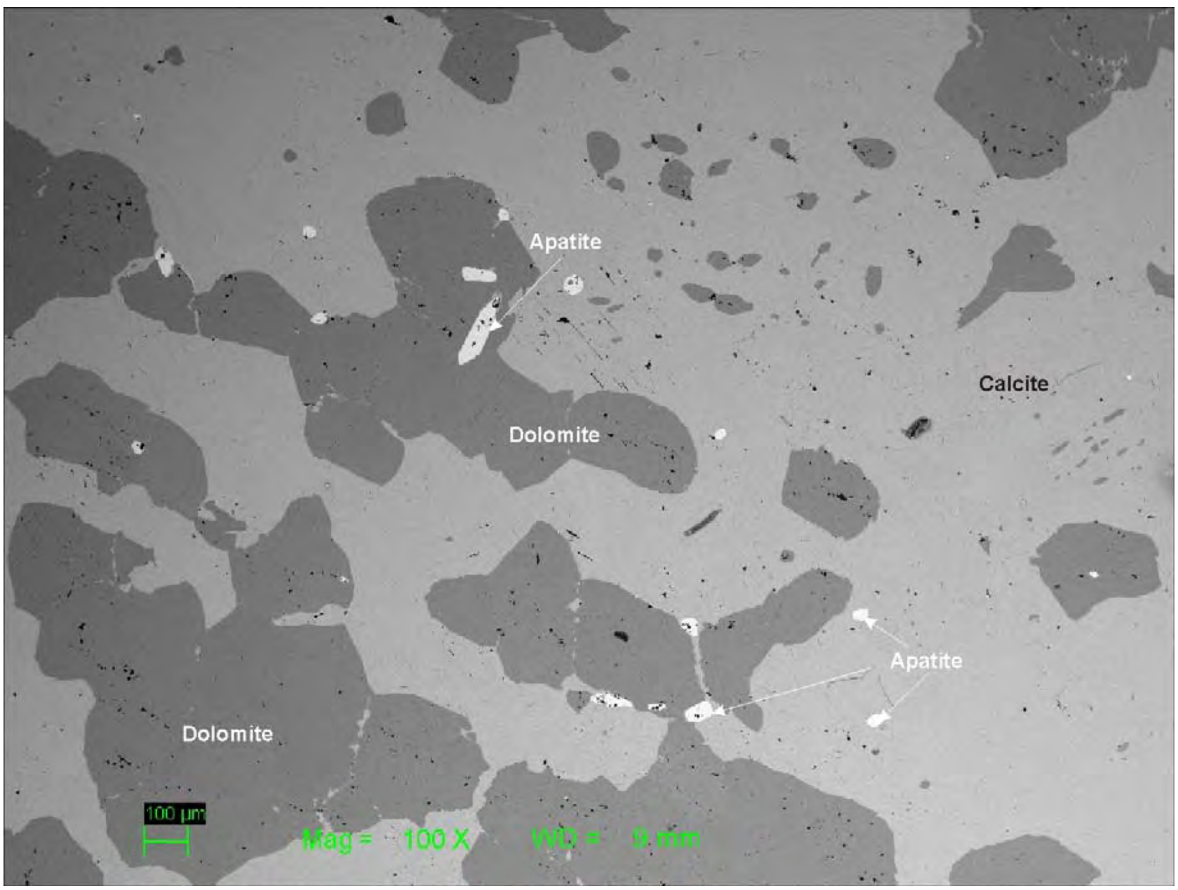


Figure 22: SEM BSE-image of dolomite (dark grey) and calcite (grey); apatite (white) and graphite (black) occur as inclusions in dolomite and calcite. Thin section LE2-07.4 m.

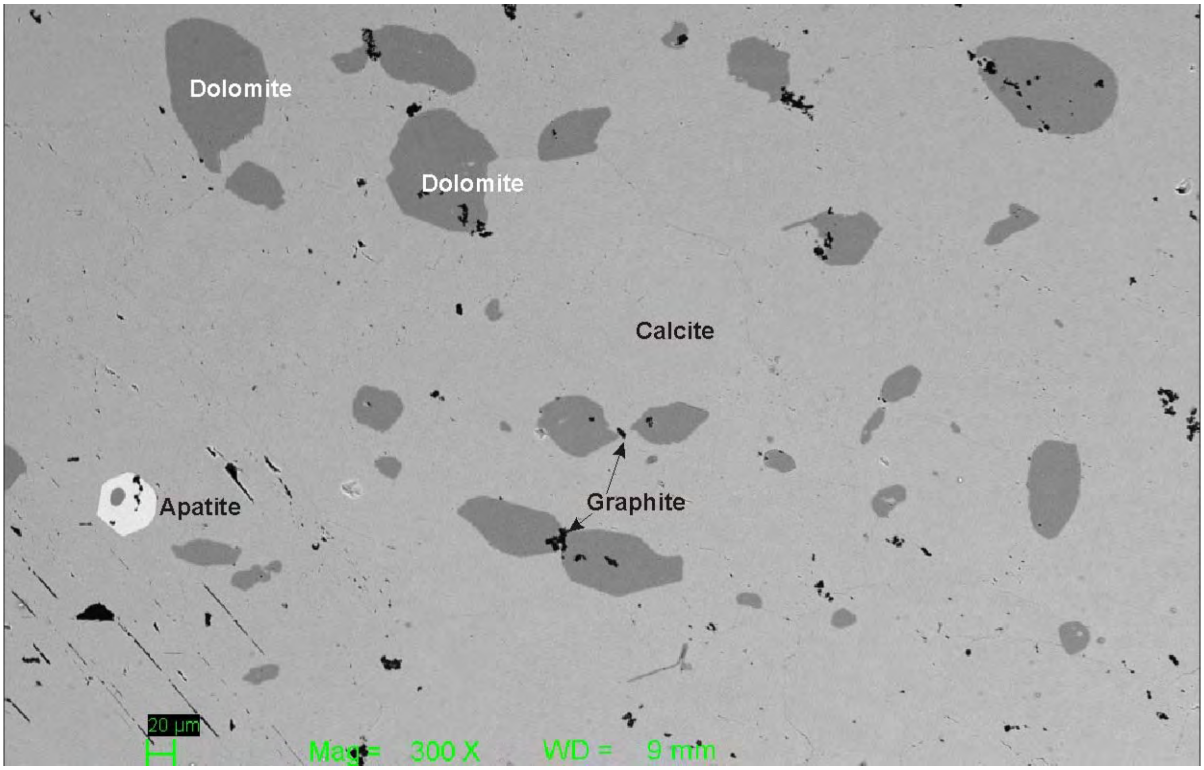


Figure 23: SEM BSE-image with batches of dolomite (dark grey) in calcite (grey) with inclusions of graphite (black); the white mineral is apatite. Some of the dark grey grains are quartz (not distinguishable from dolomite). Thin section LE2-07.4 m.

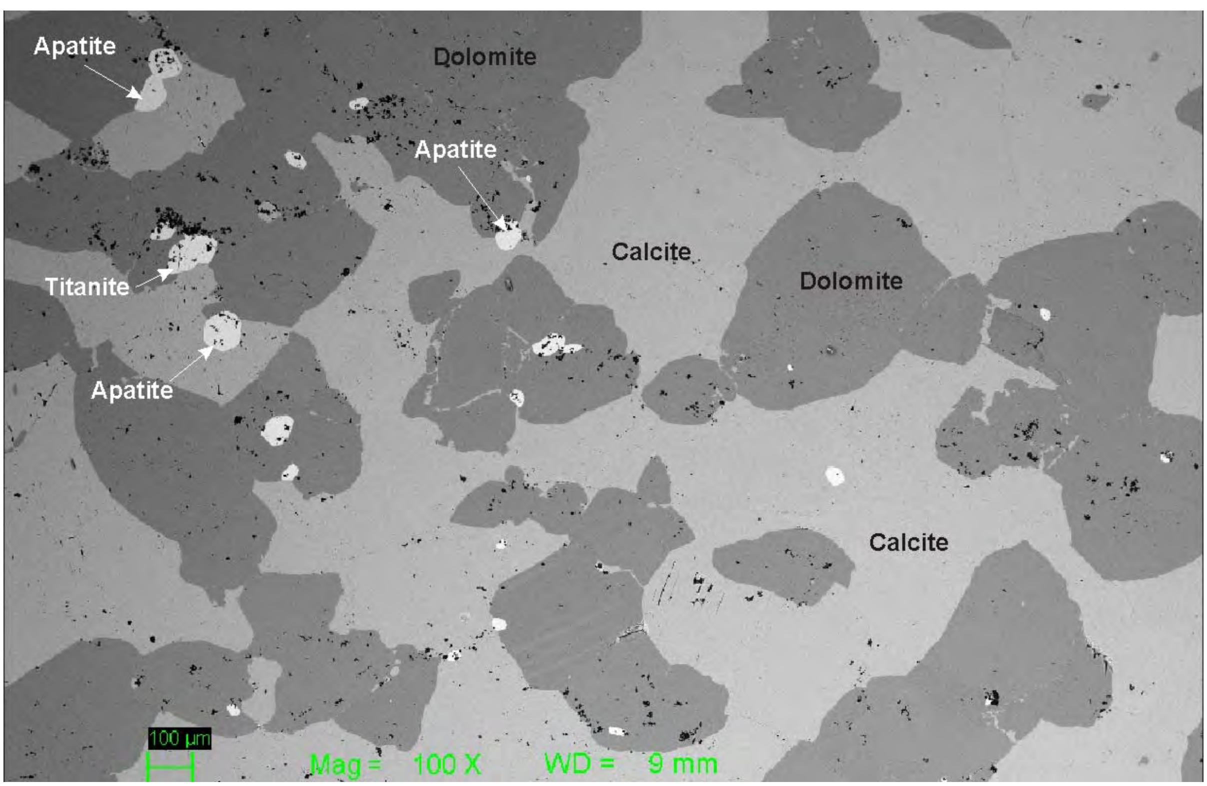


Figure 24: SEM BSE-image of dolomite (dark grey) - calcite (grey) marble with graphite (black) and apatite (white). Thin section LE2-07.4 m.

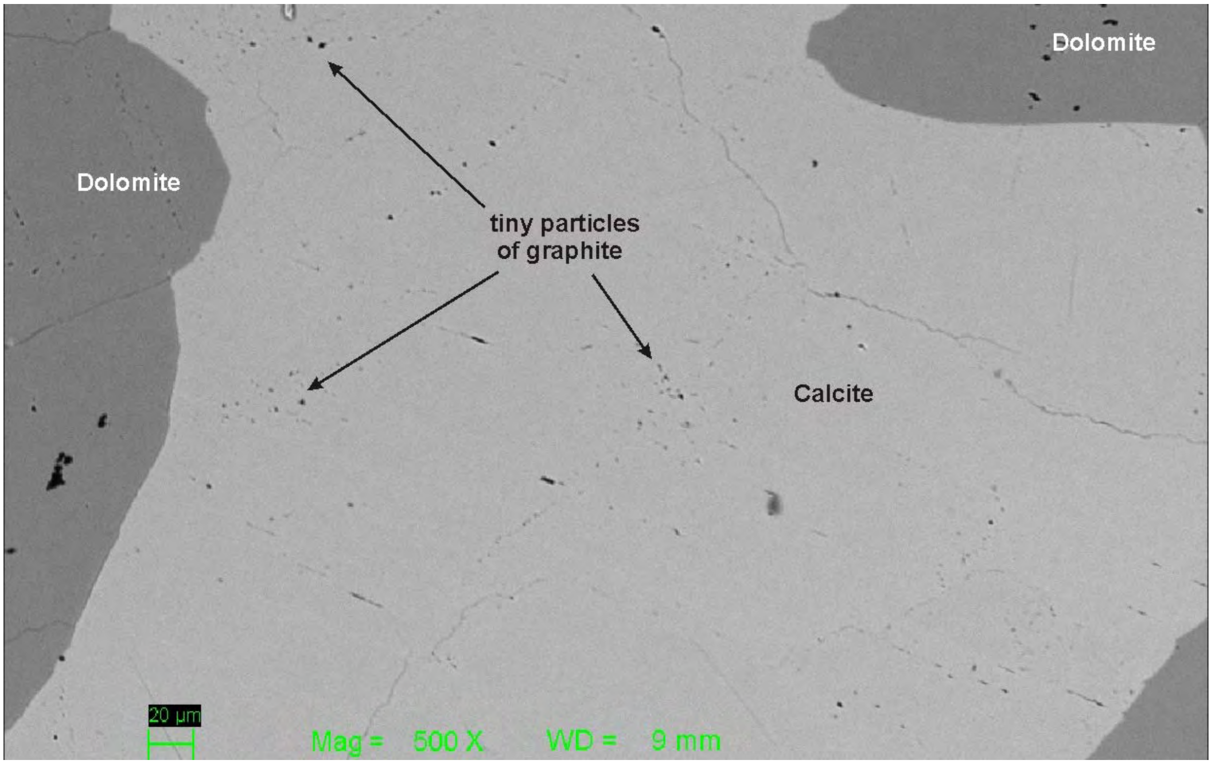


Figure 25: SEM BSE-image close-up of Figure 1.24. Calcite with very tiny graphite particles.

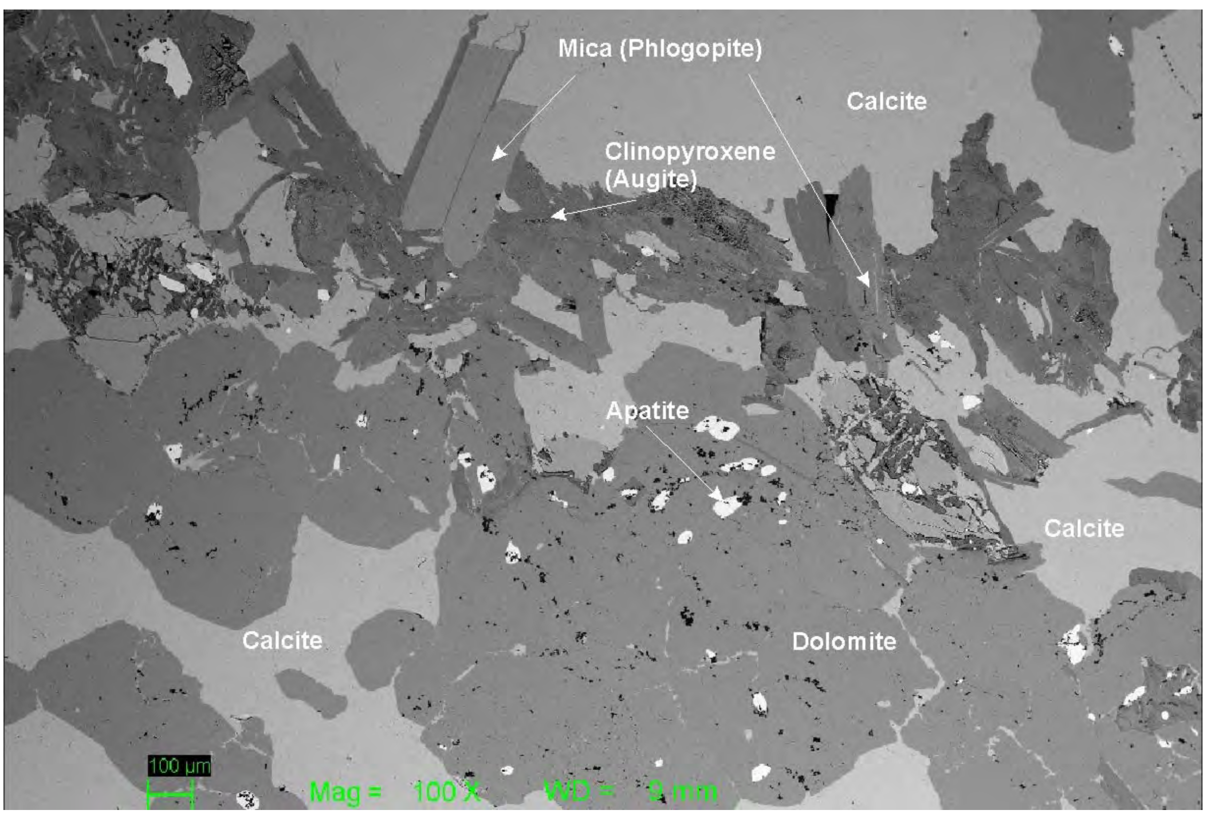


Figure 26: SEM BSE-image of impure dolomite-calcite marble with graphite (black), apatite (white) and phlogopite (medium grey, elongated). Thin section LE2-07.4 m.

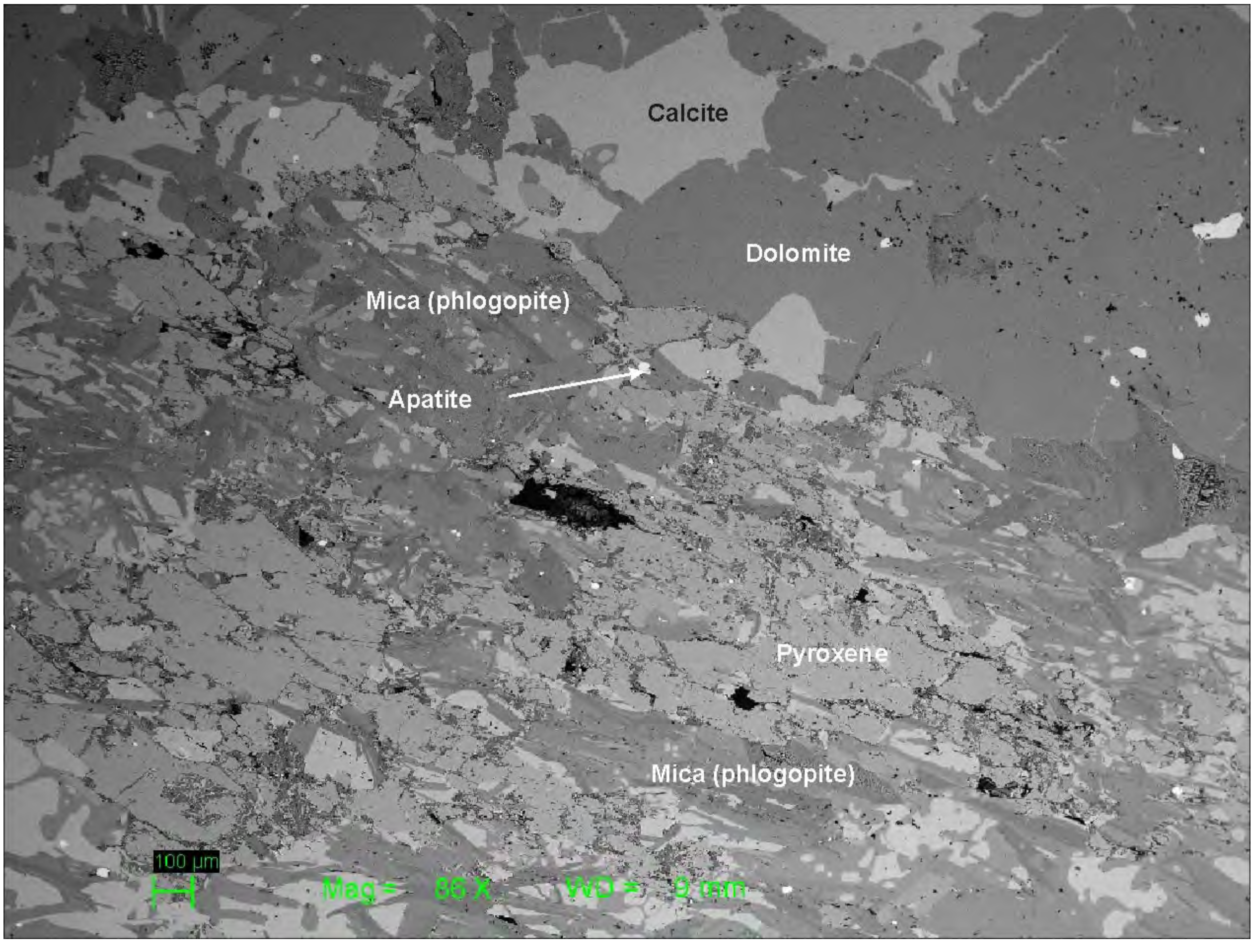


Figure 27: SEM BSE-image of impure dolomite, high amount of silicate minerals such as pyroxenes and mica. Thin section LE2-07.4 m.

2.4.2 Thin section LE2-21.9 m

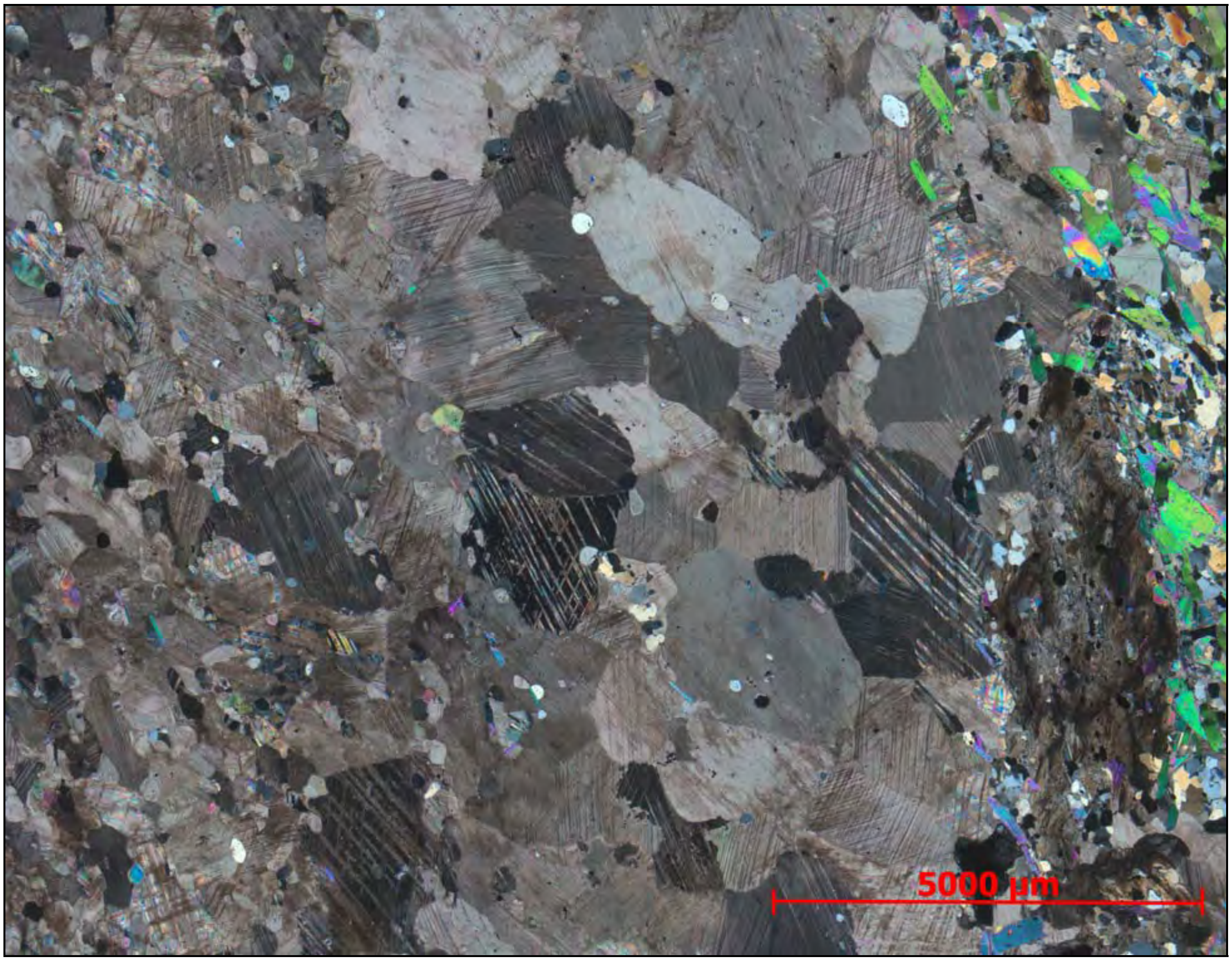


Figure 28: Mosaic microphotograph of dolomitised calcite marble; cross-polarized light. Thin section LE2-21.9 m.

The calcite grain boundaries (variable grain size) are partly straight and partly sutured. Also present are quartz, graphite, muscovite, phlogopite, accessorial sulphides (pyrite and sphalerite) and possibly augite, zircon and rutile.

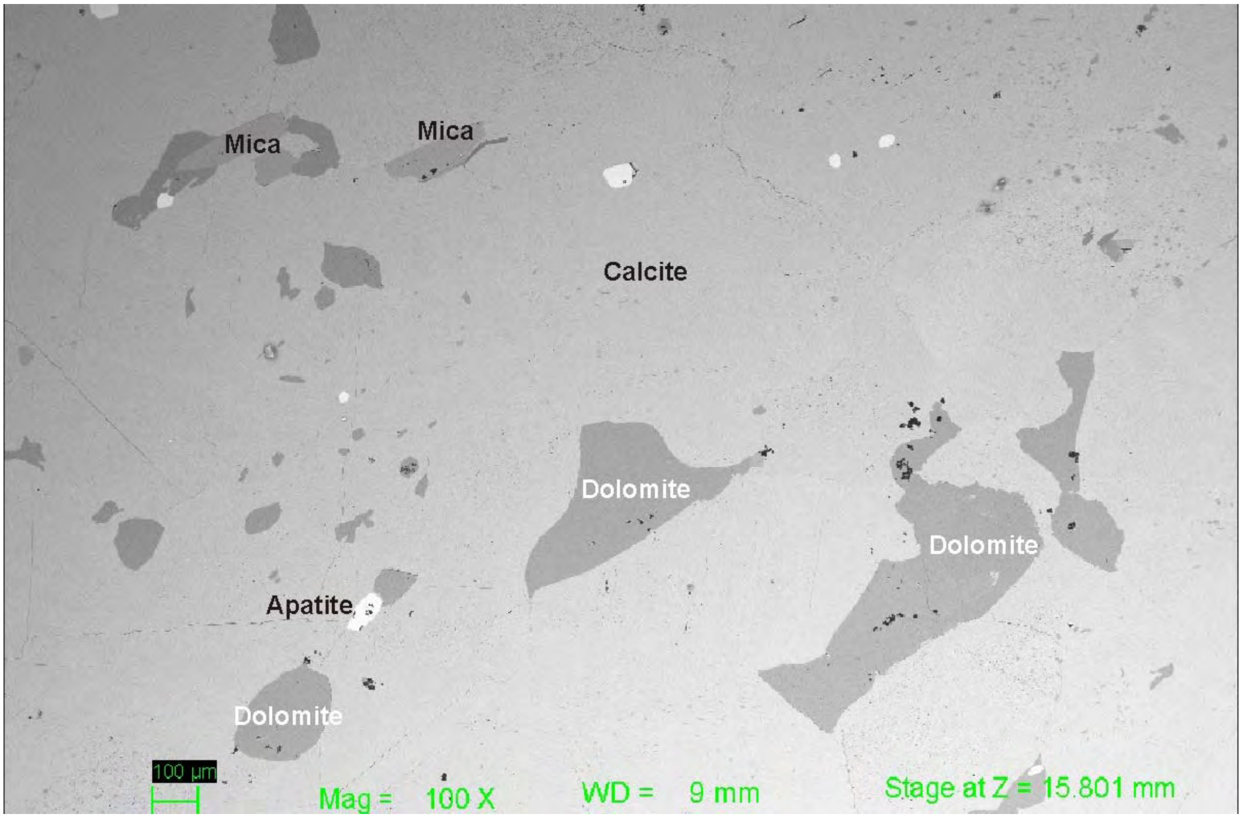


Figure 29: SEM BSE-image showing dolomite inclusions (dark grey) in calcite (grey); other minerals present is graphite (black) and apatite (white). Thin section LE2-21.9 m.

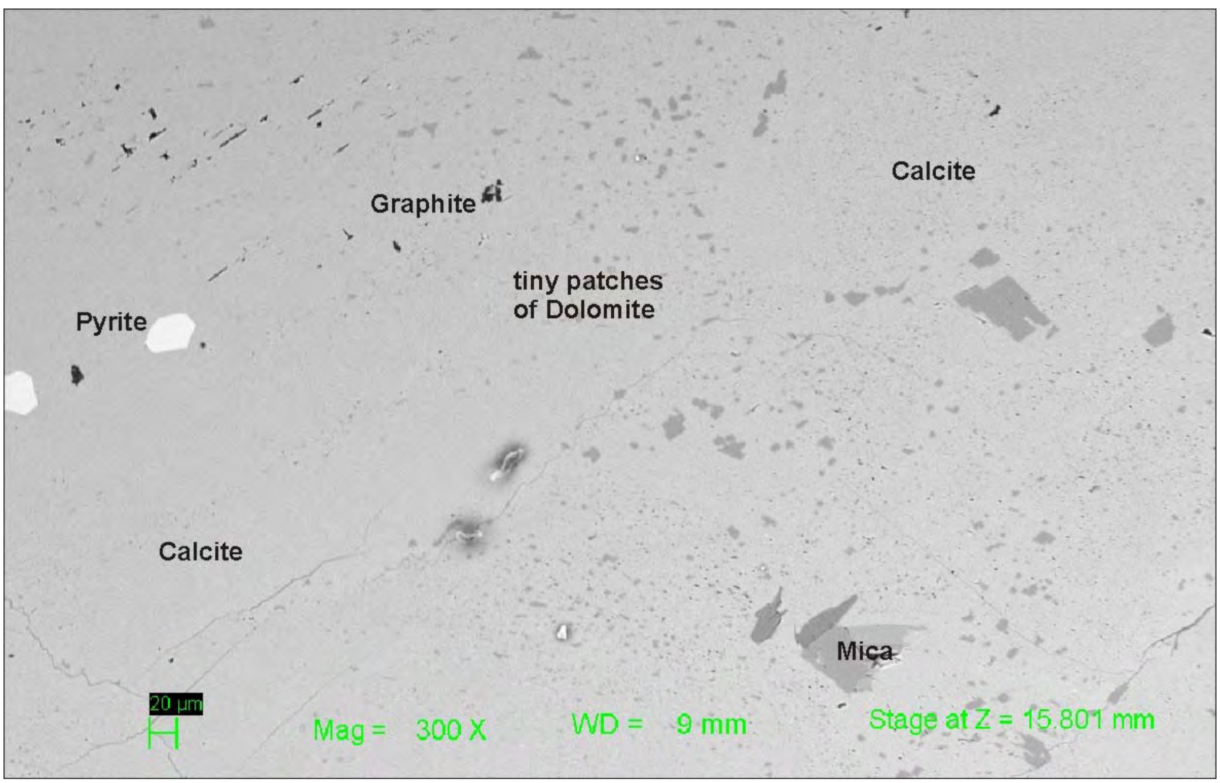


Figure 30: SEM BSE-image of tiny dolomite inclusions (dark grey) in calcite (grey). Thin section LE2-21.9 m.

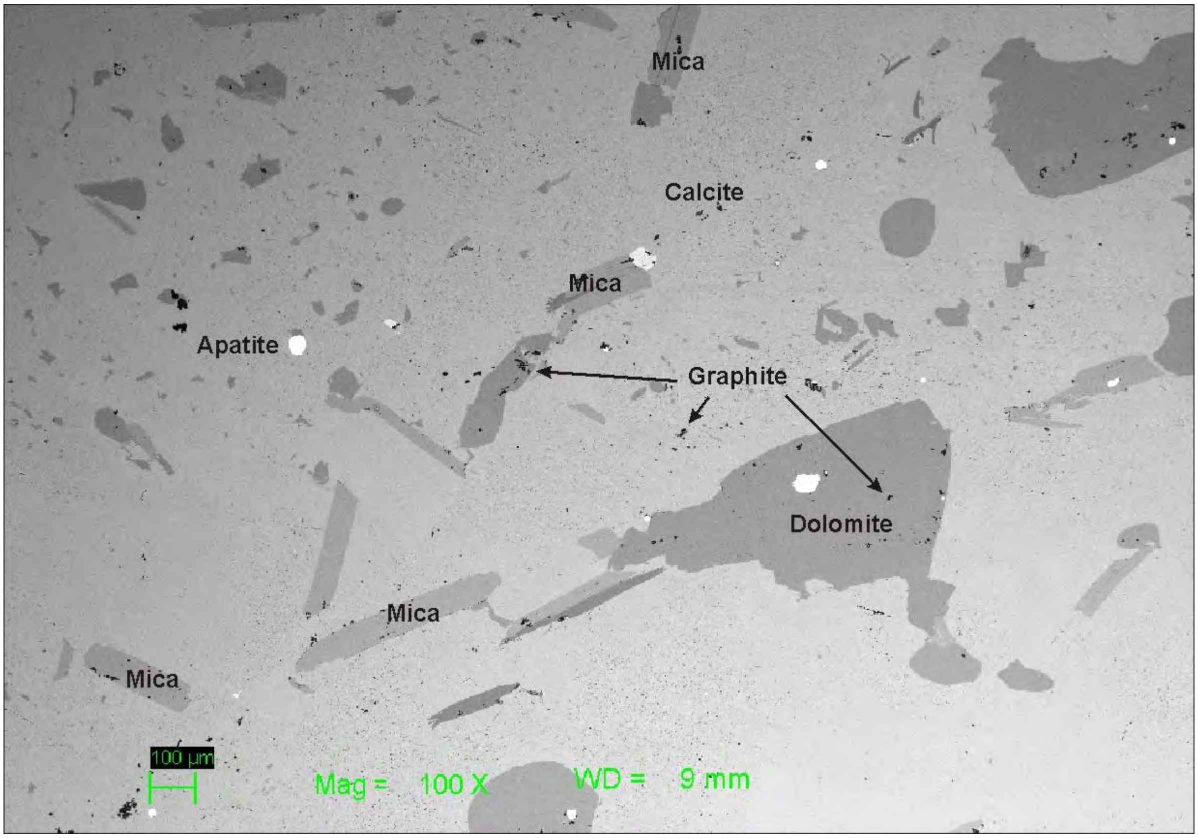


Figure 31: SEM BSE-image of calcite with inclusions of dolomite and graphite. Phlogopite and sulphide minerals are also present. Thin section LE2-21.9 m.

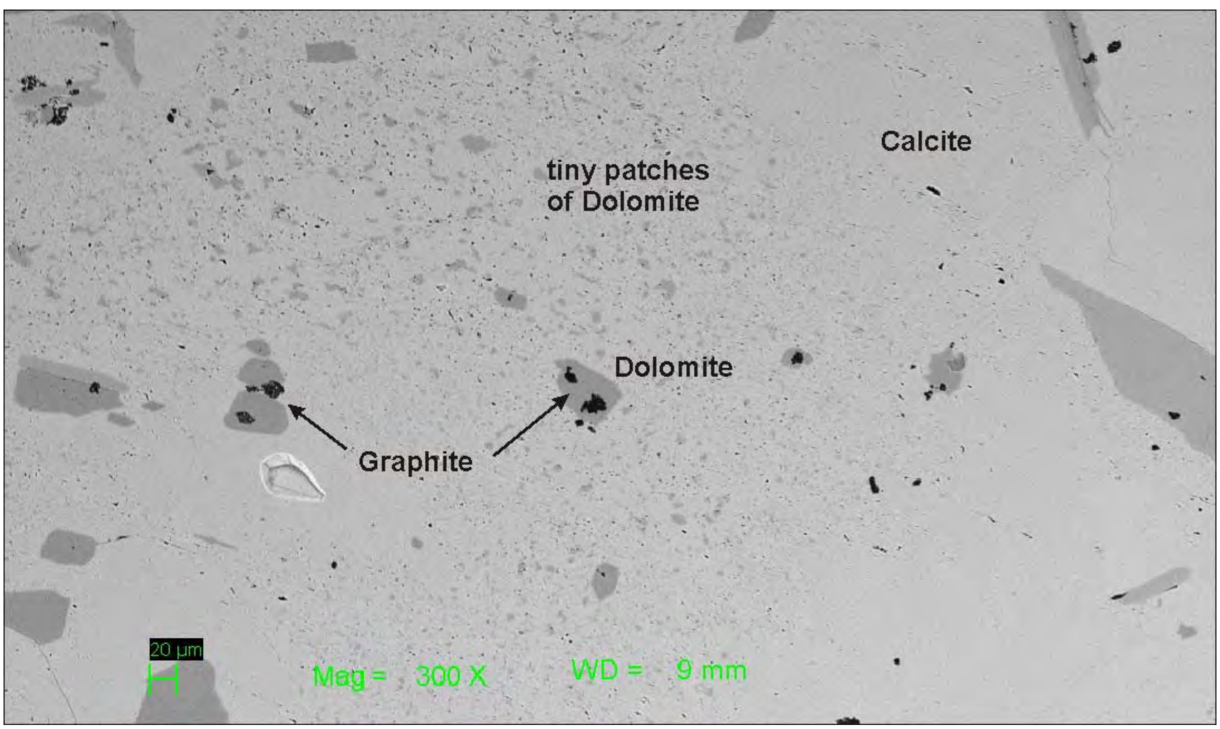


Figure 32: SEM BSE-image of dolomite inclusions in calcite. Thin section LE2-21.9 m.

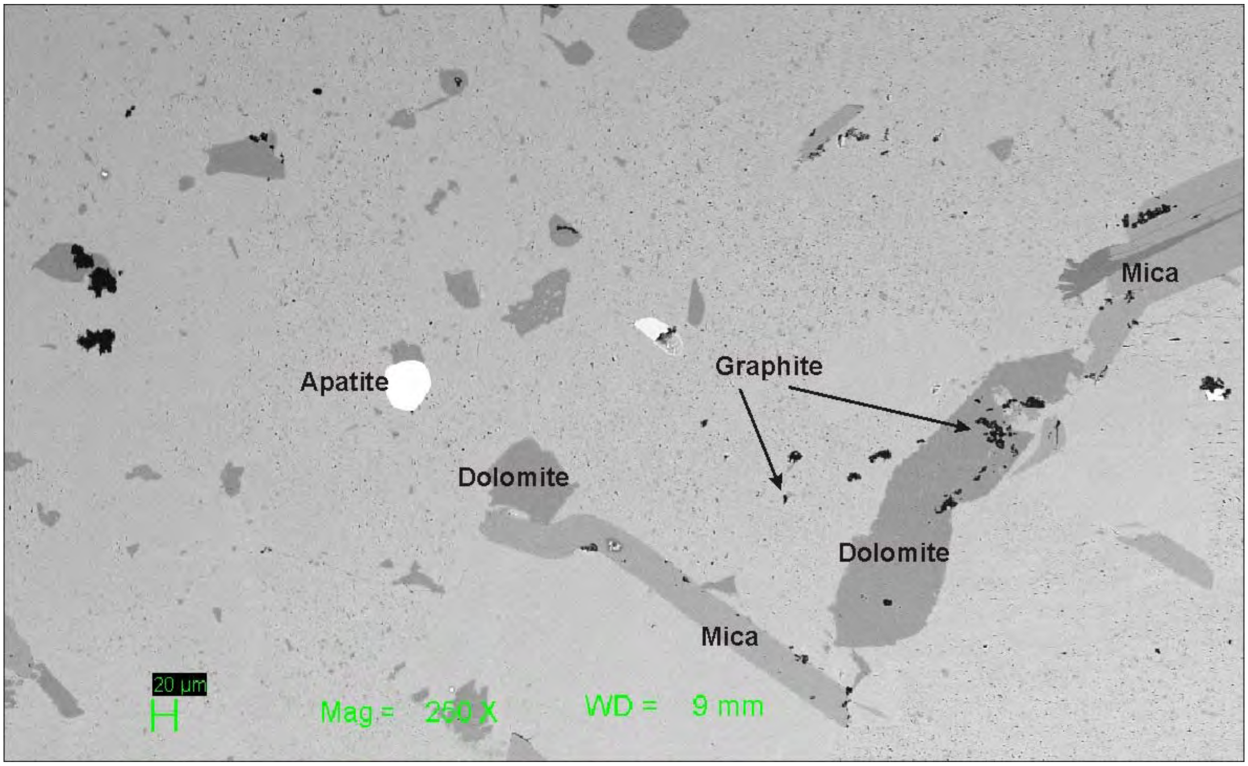


Figure 33: SEM BSE-image showing calcite, mica (phlogopite and muscovite), dolomite, quartz, sulphides (most likely pyrite) and graphite. Thin section LE2-21.9 m.

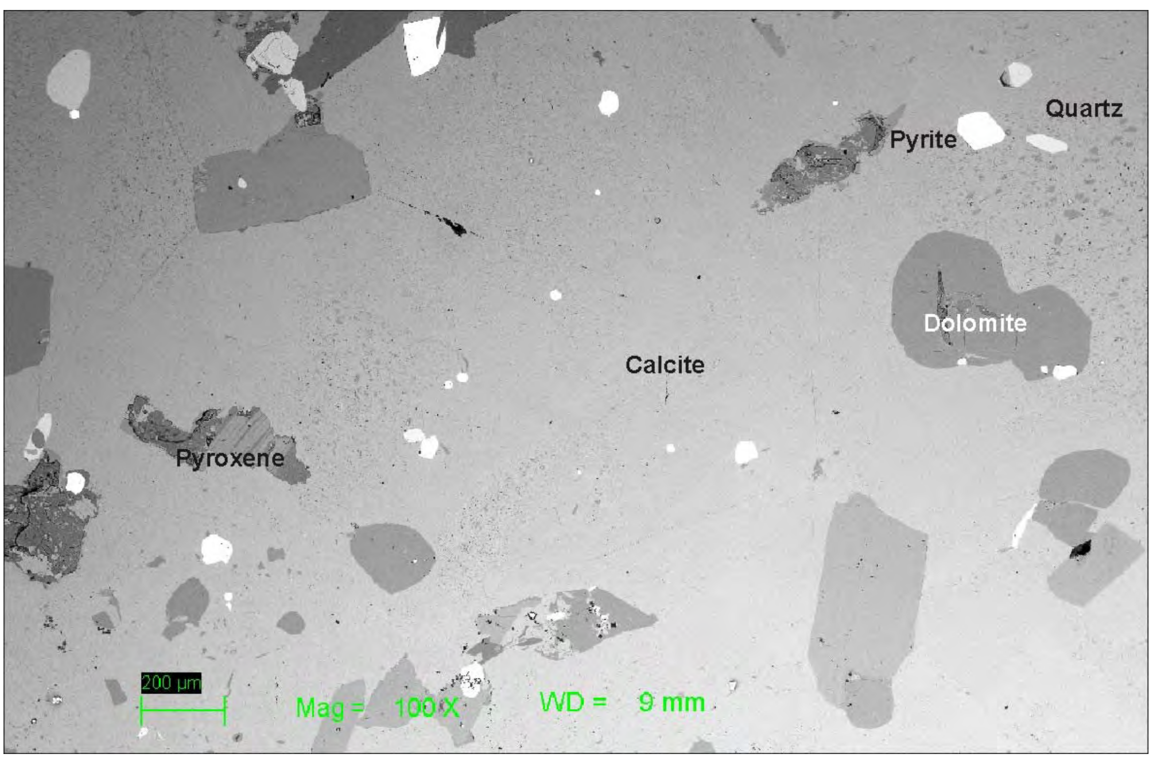


Figure 34: SEM BSE-image of calcite with inclusions of dolomite and graphite. I addition there are phlogopite and muscovite, augite (dark grey) and sulphides (white). Thin section LE2-21.9 m.

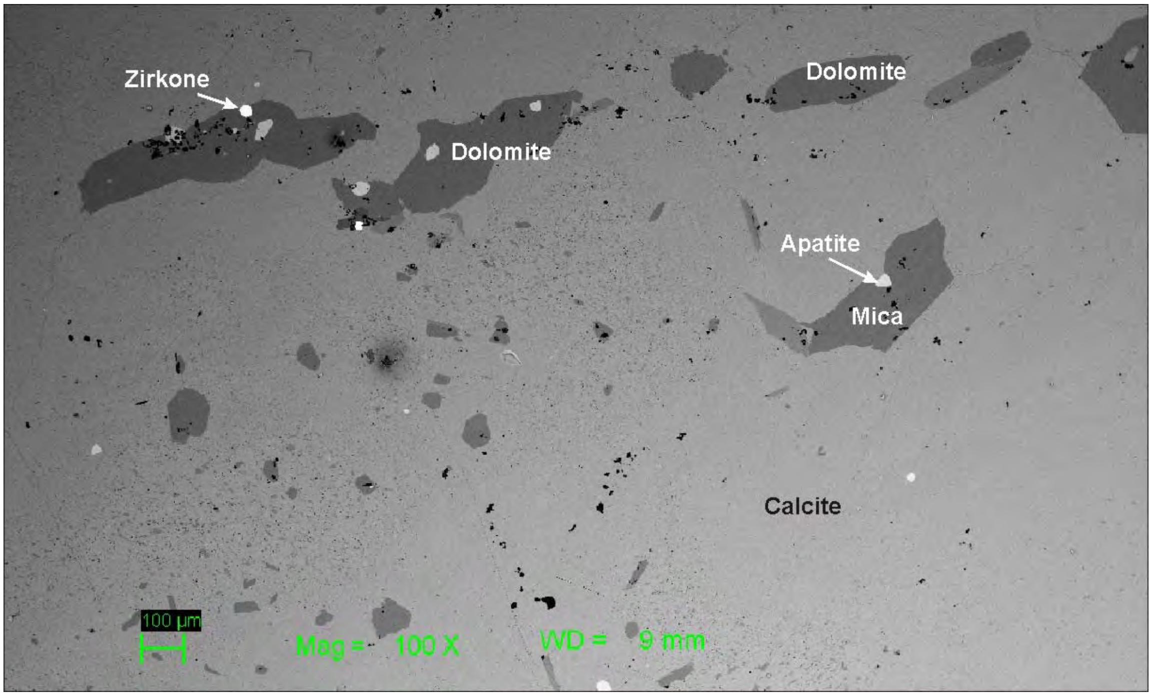


Figure 35: SEM BSE-image showing calcite with inclusions of dolomite and graphite. Other minerals present are mica, pyroxene (augite), apatite and pyrite. Thin section LE2-21.9 m.

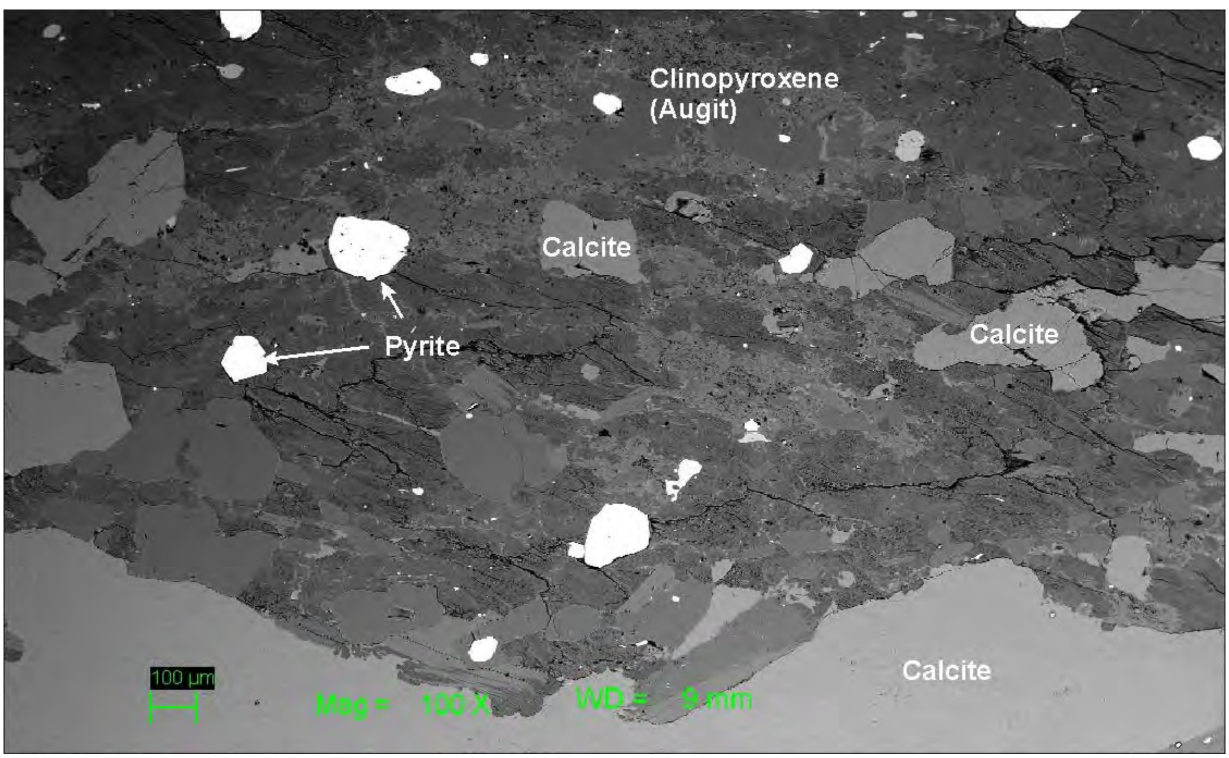


Figure 36: SEM BSE-image showing pyroxenes (augite), mica, feldspar, pyrite and sphalerite (white).
Thin section LE2-21.9 m.

3. Borehole LE4 Bjørnåsen

3.1 Core description LE4

Table 7: Comments on borehole LE 4 Bjørnåsen.

Unit	Location [m]	Rock-description
1	0-6,20	Thin-layered, light grey to dark grey (dominant) marble. The grain size varies between fine and coarse-grained. Locally, the sulphides (pyrite) content is distinct. White, coarse-grained calcite segregations (mobilisations) are common.
2	6,20- 7,54	Light pale grey to medium grey marble that appear very heterogeneous in grain size. The changes between coarse-grained, fairly homogeneous marble to fine-grained and thin-layered marble are significant. Distinct sulphur smell has been recognised. Sulphide (pyrite) and graphite is clearly visible.
3	7,54-9,28	This unit is similar to the previous units. Coarse-grained calcite marbles follows dark grey, variably fine to coarse-grained.
4	9,28- 9,90	Same as unit 1.White, pale grey to dark grey, coarse-grained marble that are followed by a thin layered variety.
5	9,90- 14,5	Similar to unit 3. Dark grey, fine-grained and coarse-grained thin-layered marble. The sulphide content is distinct. *Thin section *LE4_12.5*
6	14,5-18,64	The grain-size changes from fine to middle grained, variably banded, light grey to dark grey, calcite and calcite-dolomite mixed marble. The pyrite content is distinct. There are thin-layered parts, which are coarse-grained. Mica (phlogopite) is concentrated in layers which are also enriched in quartz and feldspar.
7	18,64-19,10	Light grey to dark grey, coarse-grained marble, quartz-rich.
8	19,10- 25,4	Similar to unit 2 and 3. Banded/layered light to dark grey, recrystallised calcite marbles that are mainly coarse-grained. Darker parts are enriched in graphite and sulphides (pyrite). *Thin section *LE4_23.8*

3.2 Chemical analyses

Table 8: Summarized analyses LE4 Bjørnåsen.

Locality		Bjørnåsen	Bjørnåsen	Bjørnåsen	Bjørnåsen	Bjørnåsen
Borehole		LE4	LE4	LE4	LE4	LE4
Sample		LE4-00-05	LE4-05-10	LE4-10-15	LE4-15-20	LE4-20-25.2
NGU identification no		101676	101677	101678	101679	101680
From-to (m)		0-5	5-10	10-15	15-20	20-25.2
SiO_2 XRF	%	4,02	8,97	11,60	11,80	5,04
Al_2O_3 XRF	%	0,10	0,41	0,59	0,59	0,30
Fe_2O_3 XRF	%	0,08	0,18	0,21	0,26	0,18
TiO_2 XRF	%	-0,01	0,02	0,03	0,03	0,02
MgO XRF	%	3,31	6,00	8,10	8,08	5,72
CaO XRF	%	50,10	43,90	40,30	40,10	46,60
Na_2O XRF	%	-0,10	-0,10	-0,10	-0,10	-0,10
K_2O XRF	%	0,03	0,13	0,25	0,16	0,12
MnO XRF	%	-0,01	-0,01	-0,01	-0,01	-0,01
P_2O_5 XRF	%	0,17	0,16	0,15	0,12	0,09
LOI XRF	%	42,10	39,90	38,80	38,40	41,90
SUM XRF	%	99,79	99,56	99,91	99,43	99,84
Ca ICP	ppm	341000	295000	266000	265000	308000
CaO ICP	%	47,71	41,27	37,21	37,07	43,09
CaO ICP vs. CaO XRF	%	95	94	92	92	92
Mg ICP	ppm	17600	31500	40700	41200	30000
MgO ICP	%	2,92	5,22	6,75	6,83	4,97
MgO ICP vs. MgO XRF	%	88	87	83	85	87
Fe ICP	ppm	524	1286	1433	1803	1244
Fe ICP	ppm	115	221	290	202	307
Mn ICP	ppm	nd	nd	nd	nd	nd
Mn ICP	ppm	34	50	43	61	52
Fe+Mn XRF	ppm	524	1286	1433	1803	1244
Fe+Mn ICP	ppm	149	271	333	263	359
Fe+Mn ICP vs. Fe+Mn XRF	%	28	21	23	15	29
P ICP	ppm	636	587	551	453	399
Ba ICP	ppm	4,1	2,7	< 2	< 2	< 2
Sr ICP	ppm	337	348	390	440	435
Dolomite Calculated	%	13,4	23,9	30,9	31,3	22,8
Calcite Calculated	%	77,6	60,4	49,4	48,9	64,3
Others Calculated	%	9,1	15,7	19,7	19,8	13,0
S LECO	%	0,011	0,011	0,050	0,031	0,032
TC LECO	%	11,84	10,89	11,11	10,92	12,13
TOC LECO	%	0,12	0,18	0,23	0,12	0,19

Table 9: Semi-quantitative analyses by Niton portable XRF, borehole LE4, Bjørnåsen.

Bh	Pos. (m)	% SiO_2	% CaO	ppm Fe	Pos. (m)	% SiO_2	% CaO	ppm Fe	Pos. (m)	% SiO_2	% CaO	ppm Fe
LE4	0,5	1,5	52,0	420	10,5	13,5	37,4	870	20,5	1,6	48,4	670
LE4	1,5	1,4	55,3	250	11,5	30,1	21,5	1860	21,5	7,6	51,3	1150
LE4	2,6	0,7	56,2	200	12,5	11,8	36,7	2100	22,5	5,1	51,5	760
LE4	3,5	7,9	52,1	300	13,5	13,8	35,8	1150	23,5	3,1	53,6	430
LE4	4,5	3,7	52,4	430	13,5	15,1	34,9	1120	24,5	2,0	51,5	520
LE4	5,5	25,3	27,1	680	14,5	1,4	52,3	310				
LE4	6,5	1,0	56,5	230	15,5	17,0	24,8	2160				
LE4	7,5	1,9	48,6	550	16,5	15,1	32,4	2290				
LE4	8,5	32,2	22,6	4190	17,4	4,7	53,6	350				
LE4	9,5	0,6	56,2	320	18,5	12,6	42,5	960				
					19,5	3,0	46,7	580				

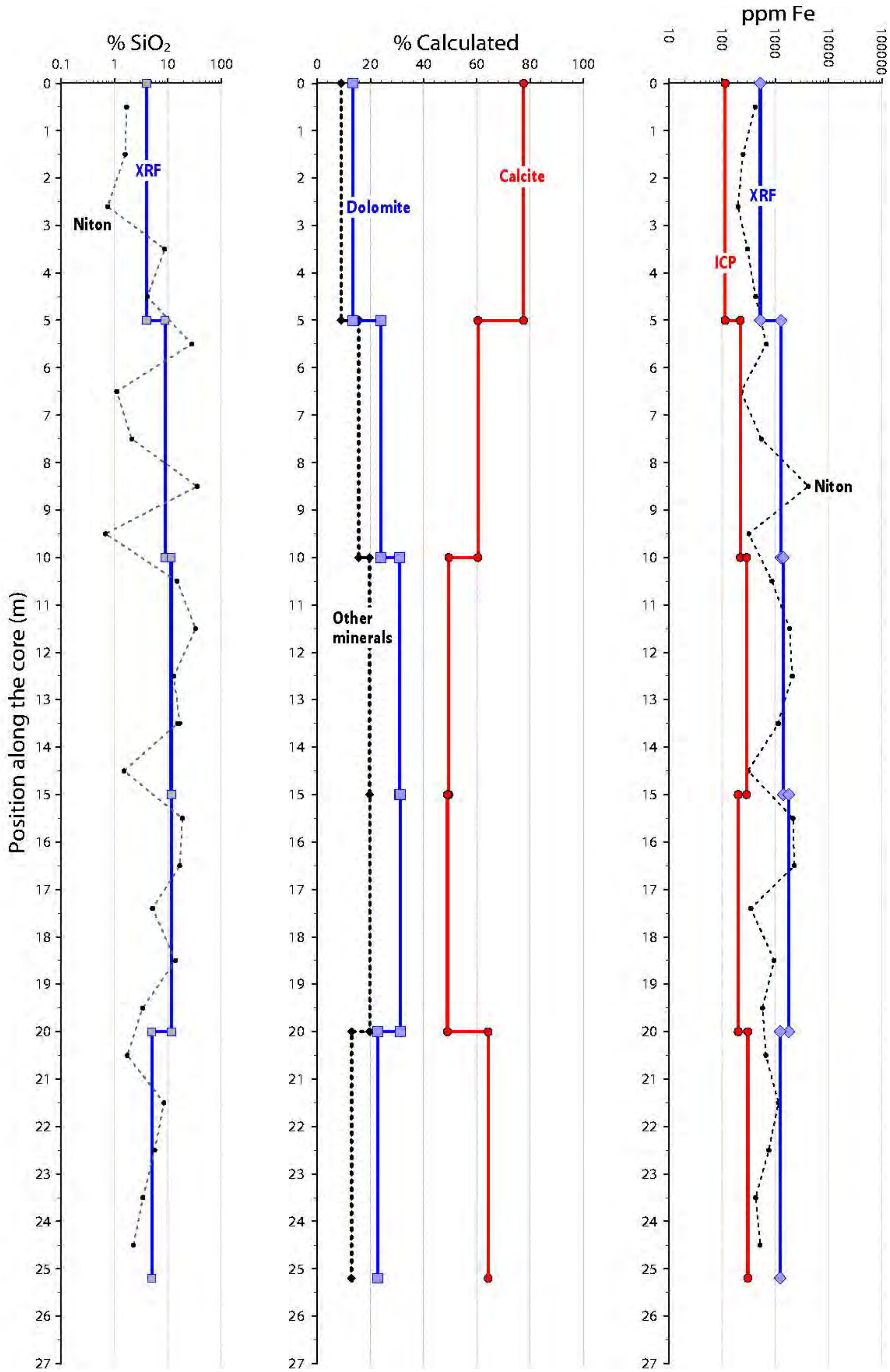


Figure 37: Variations in SiO_2, Fe and major minerals along borehole LE4, Bjørnåsen

3.3 Core photographs LE4

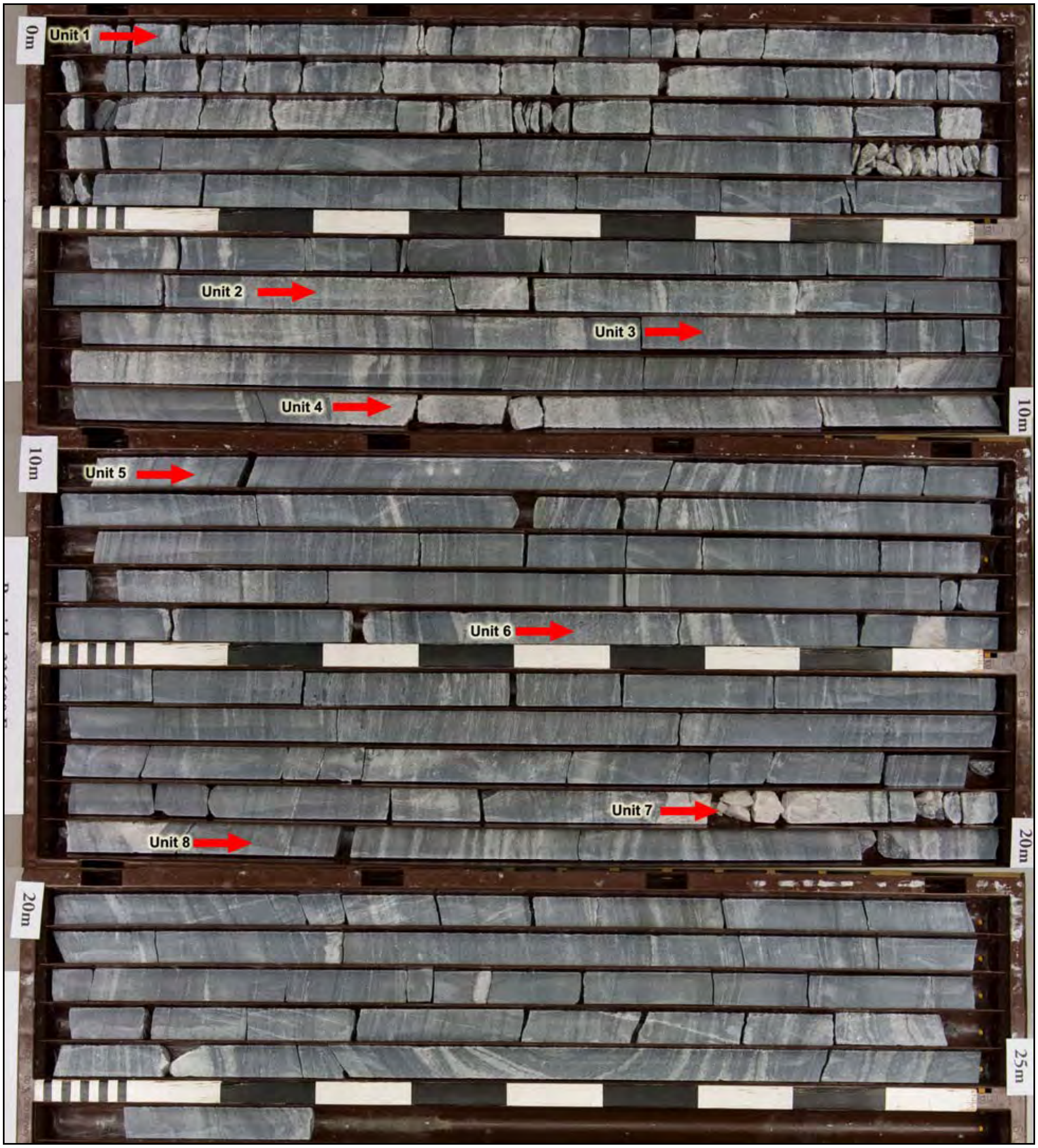


Figure 38: Overview photo of core LE4, Bjørnåsen.

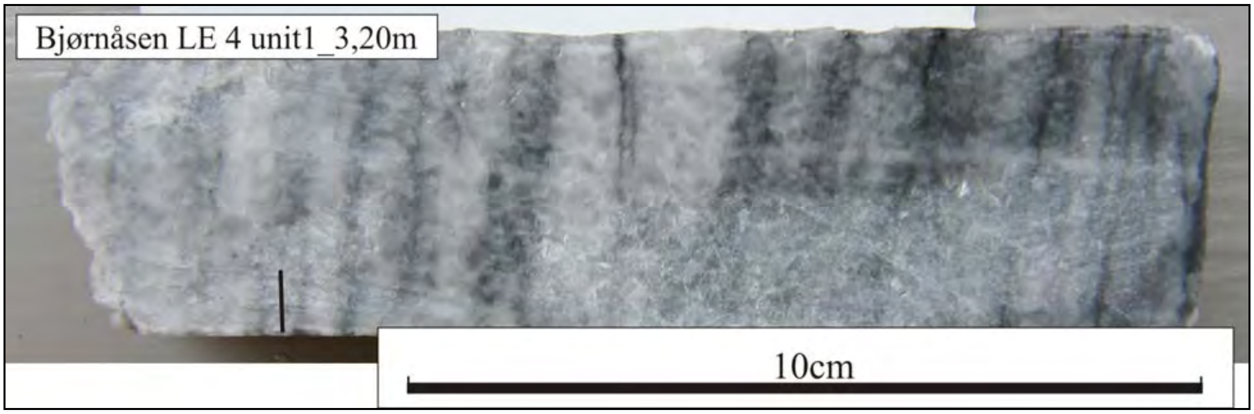


Figure 39: Photo of banded light to dark grey calcite-dolomite marble, Bjørnåsen LE4 unit 1 at 3,2 m.

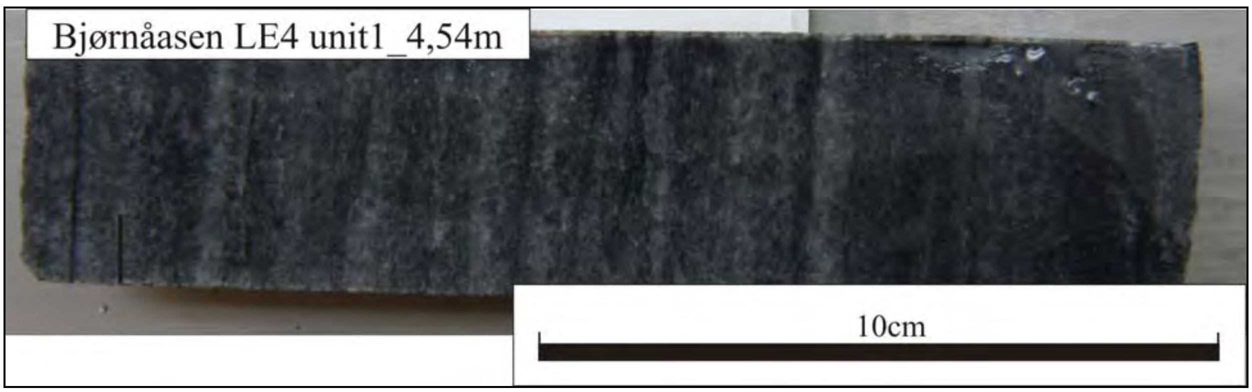


Figure 40: Photo of dark grey, banded calcite-dolomite marble, Bjørnåsen LE4 unit 1 at 4,5 m.

Figure 41: Photo of heterogeneous banded light grey to dark grey calcite-dolomite marble, Bjørnåsen LE4 unit 2 at 7,0 m.

Figure 42: Photo of weakly banded light grey to dark grey marble, Bjørnåsen LE4 unit 4 at 9,5 m.

Figure 43: Photo of dark grey, fine-grained thinly banded and strongly dolomitised marble, Bjørnåsen LE4 unit 5 at 13,3 m.

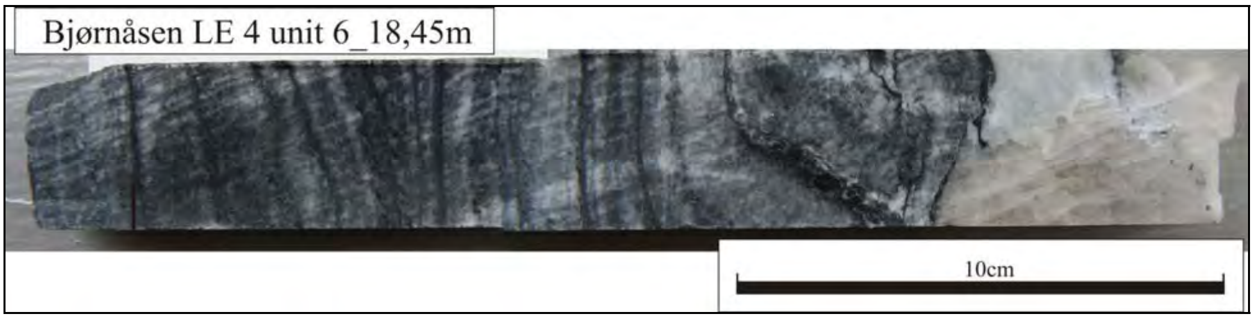


Figure 44: Photo of banded fairly dark marble with a calcite vein (right), Bjørnåsen LE4 unit 6 at 18,5 m.

3.4 Micrographs LE4

3.4.1 Thin section LE4-12.5 m

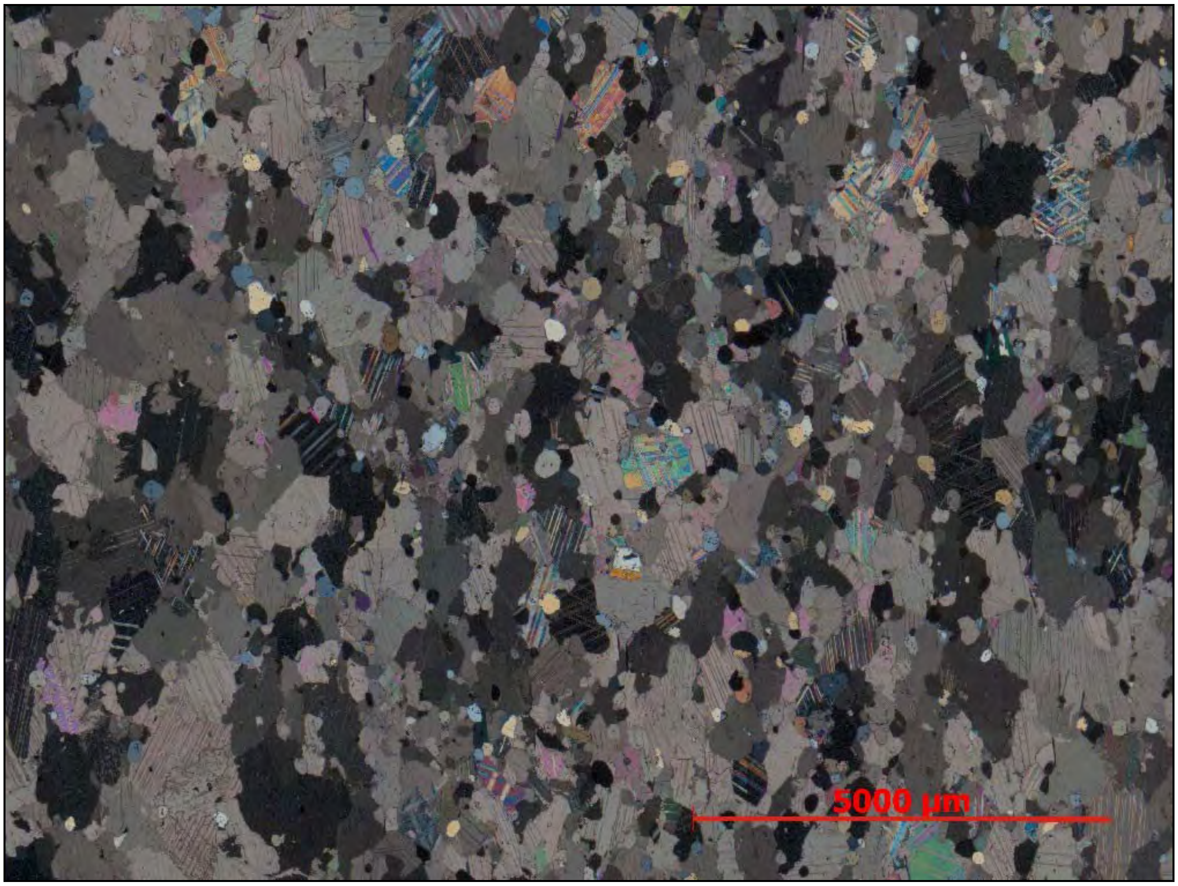


Figure 45: Mosaic microphotograph of carbonate with numerous inclusions of other minerals; partly crossed polarized light. Thin section LE4-12.5 m.

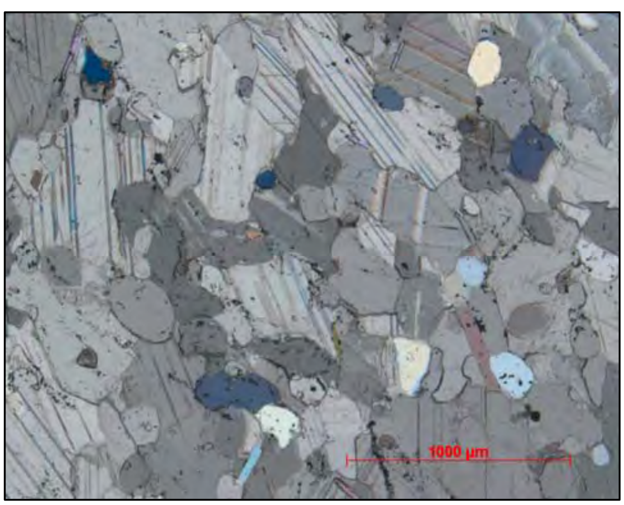


Figure 46: Microphotograph showing inclusions of other minerals (mainly quartz) in carbonate; partly crossed polarized light. Thin section LE4-12.5 m.

Main minerals in LE4 12,5 are calcite, but dolomite, quartz and apatite are also present. Accessorial there are also graphite, phlogopite, pyrite and feldspar (albite). Apatite, quartz and pyrites appear as inclusions.

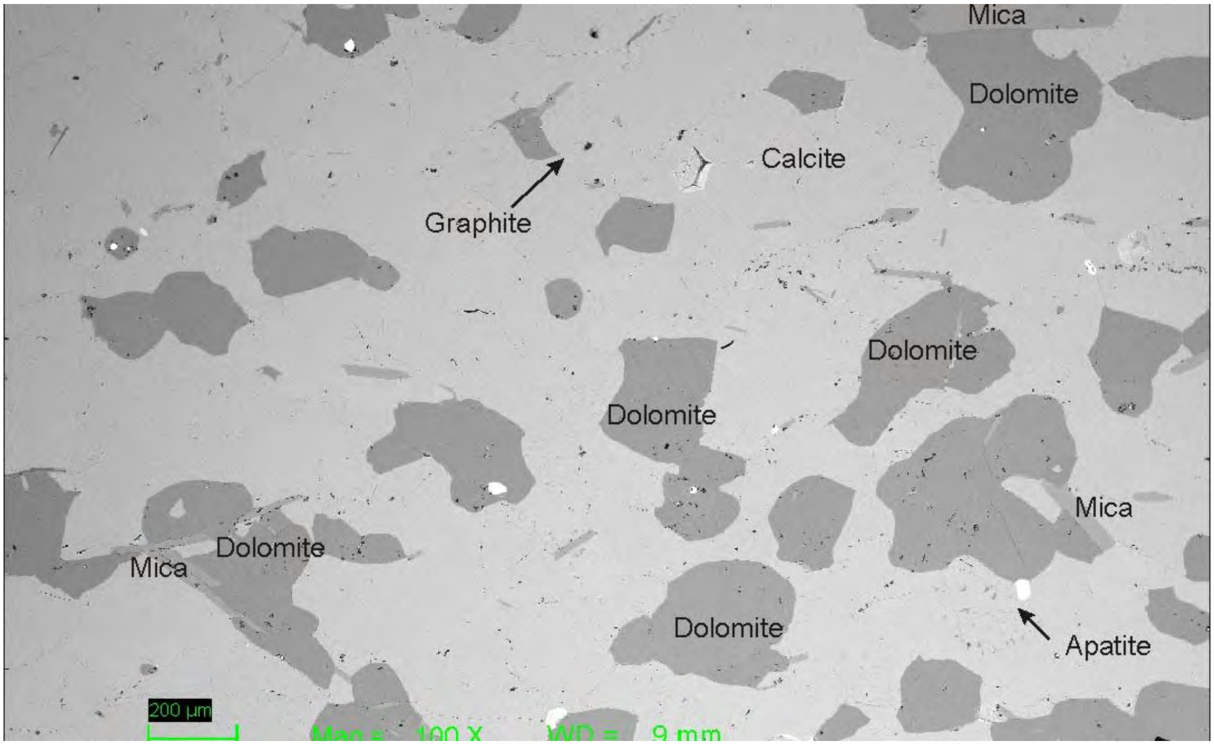


Figure 47: SEM BSE-image of calcite (main grey) and dolomite (dark grey), some mica (medium grey) pyrite (white), apatite (light grey) and graphite (black). Thin section LE4-12.5 m.

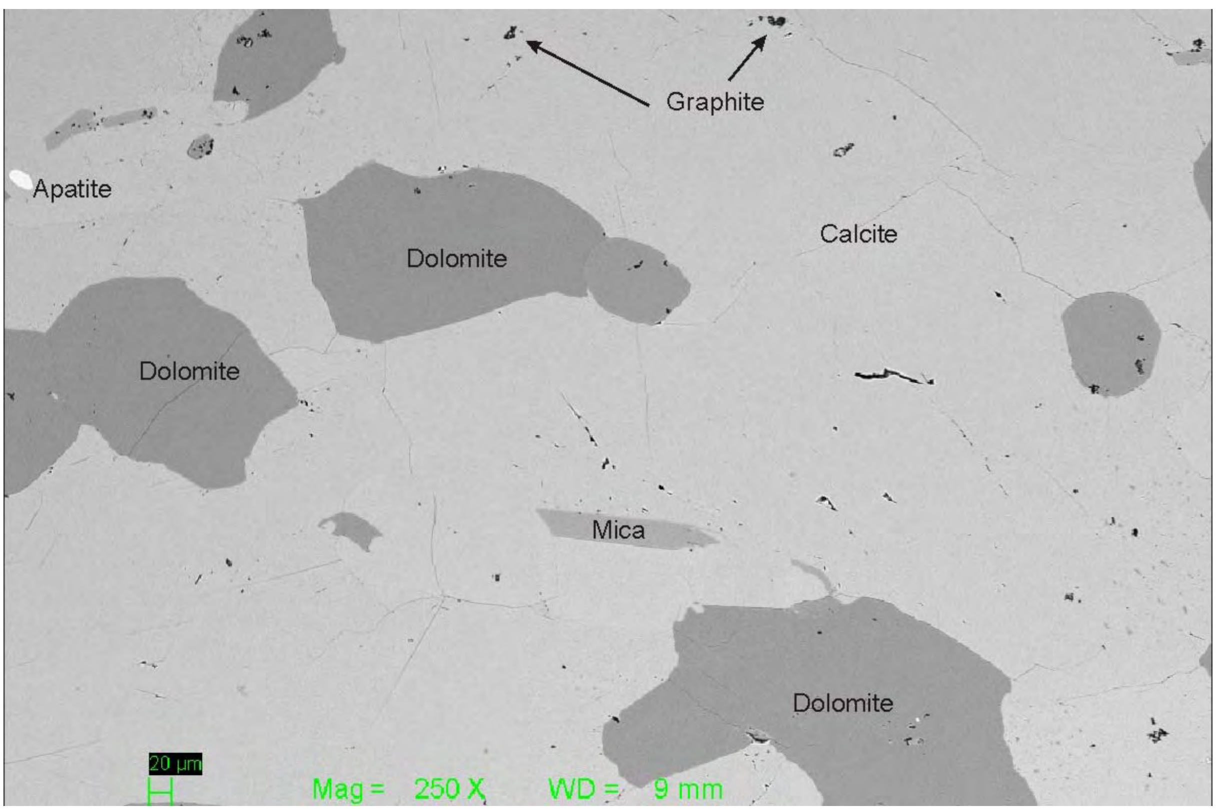


Figure 48: SEM BSE-image, close-up from Figure 1.47.

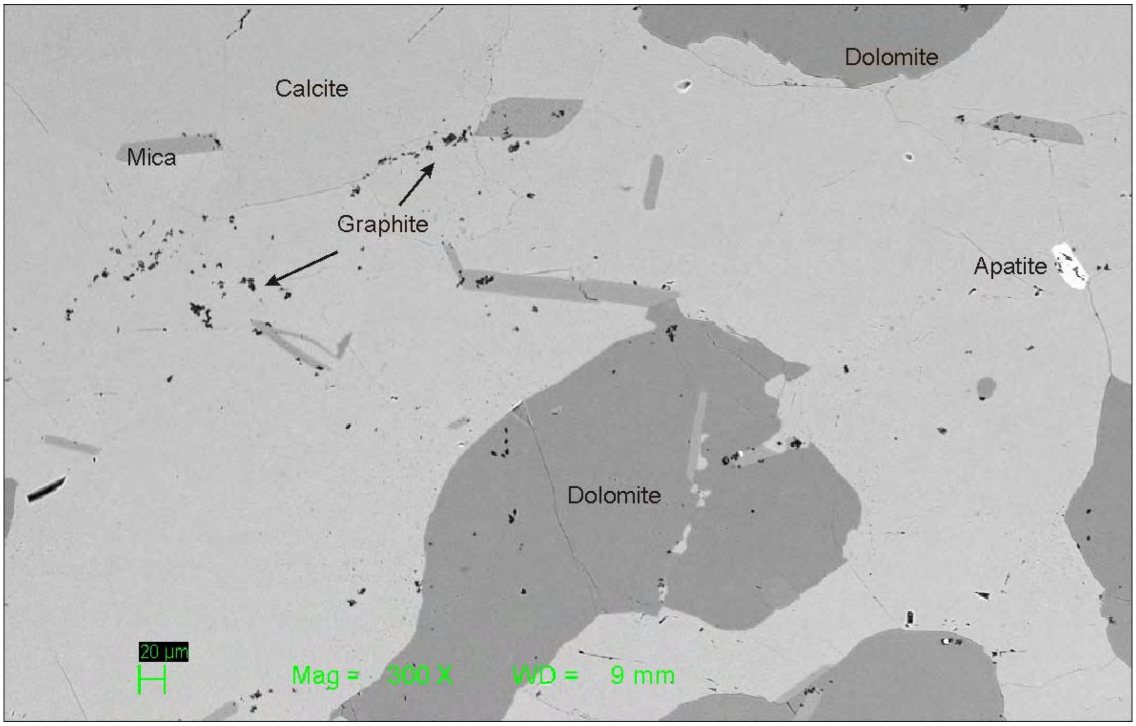


Figure 49: SEM BSE-image, close-up of Figure 1.48. Patches of dolomite and calcite as well as mica and phlogopite crystals within the calcite.

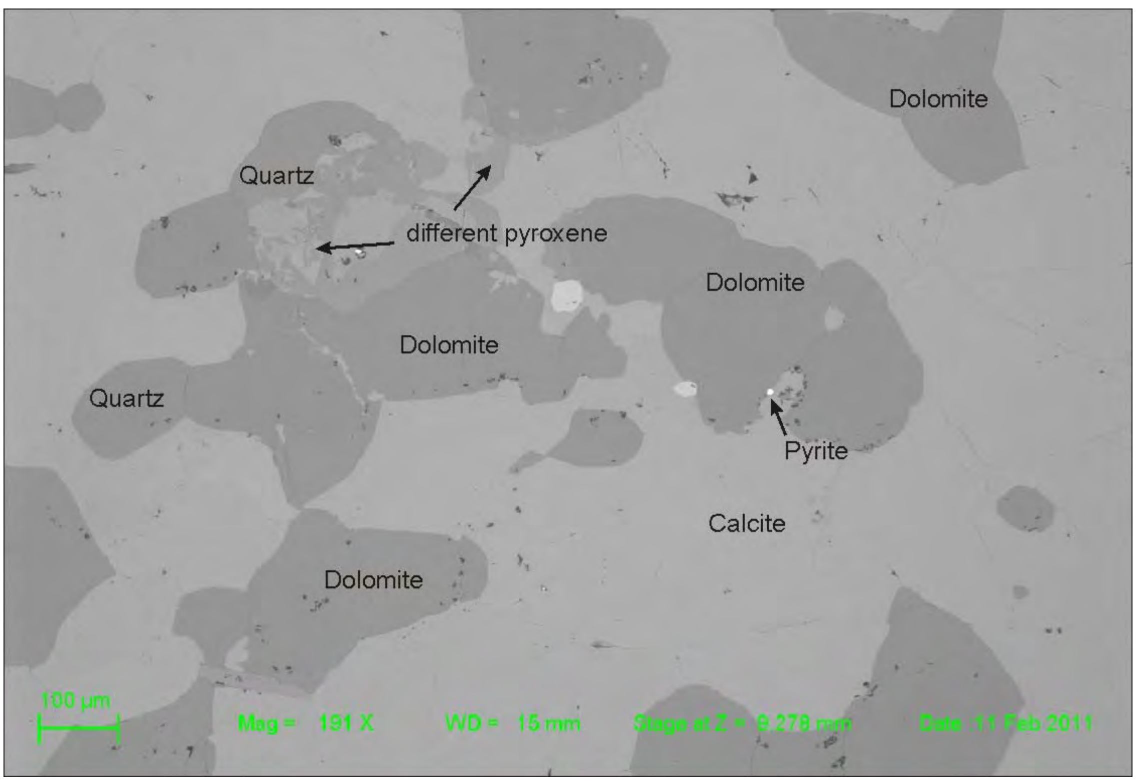


Figure 50: SEM BSE-image showing calcite, dolomite, unidentified silicate minerals, apatite and graphite. Thin section LE4-12.5 m.

3.4.2 Thin section LE4-23.8

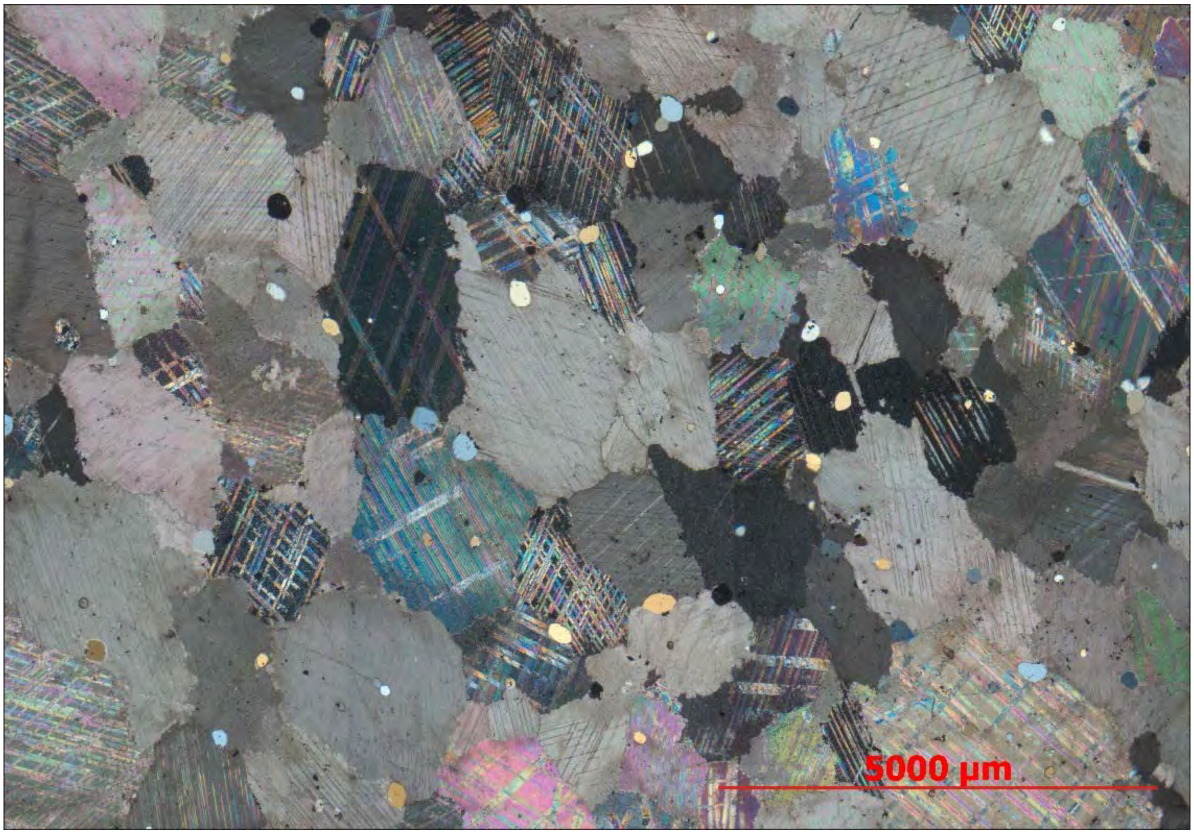


Figure 51: Mosaic microphotograph of coarse-grained carbonate with inclusions of other minerals; partly crossed polarized light. Thin section LE4-23.8 m.

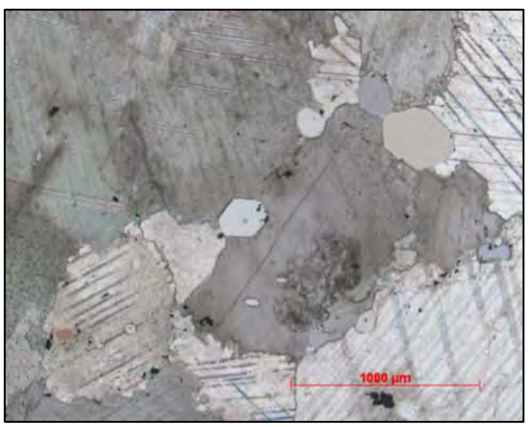


Figure 52: Microphotograph showing quartz inclusions in carbonate; partly crossed polarized light. Thin section LE4-23.8 m.

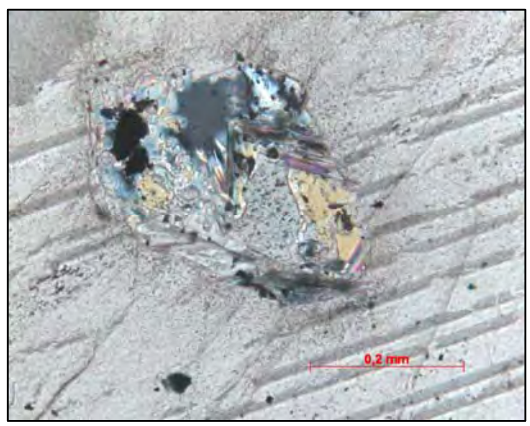


Figure 53: Microphotograph of inclusion of intergrown quartz, mica and graphite in carbonate; partly crossed polarized light. Thin section LE4-23.8 m.

Medium to coarse-grained calcite crystals with sutured grain boundaries dominates the LE4 23,8 thin section. Accessory quartz, graphite, pyrite, rutile (possibly titanite) appear both as inclusions and along grain boundaries.

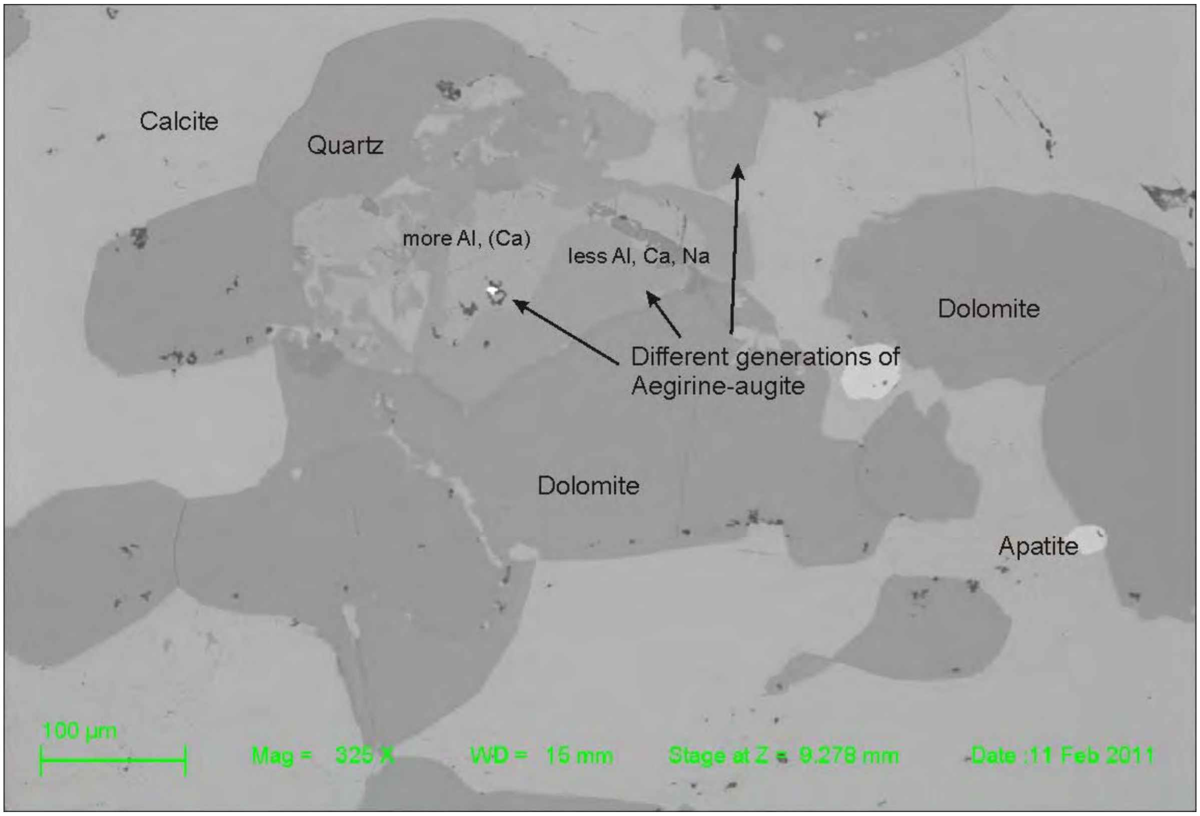


Figure 54: SEM BSE-image, close-up from thin section LE4-23.8 m

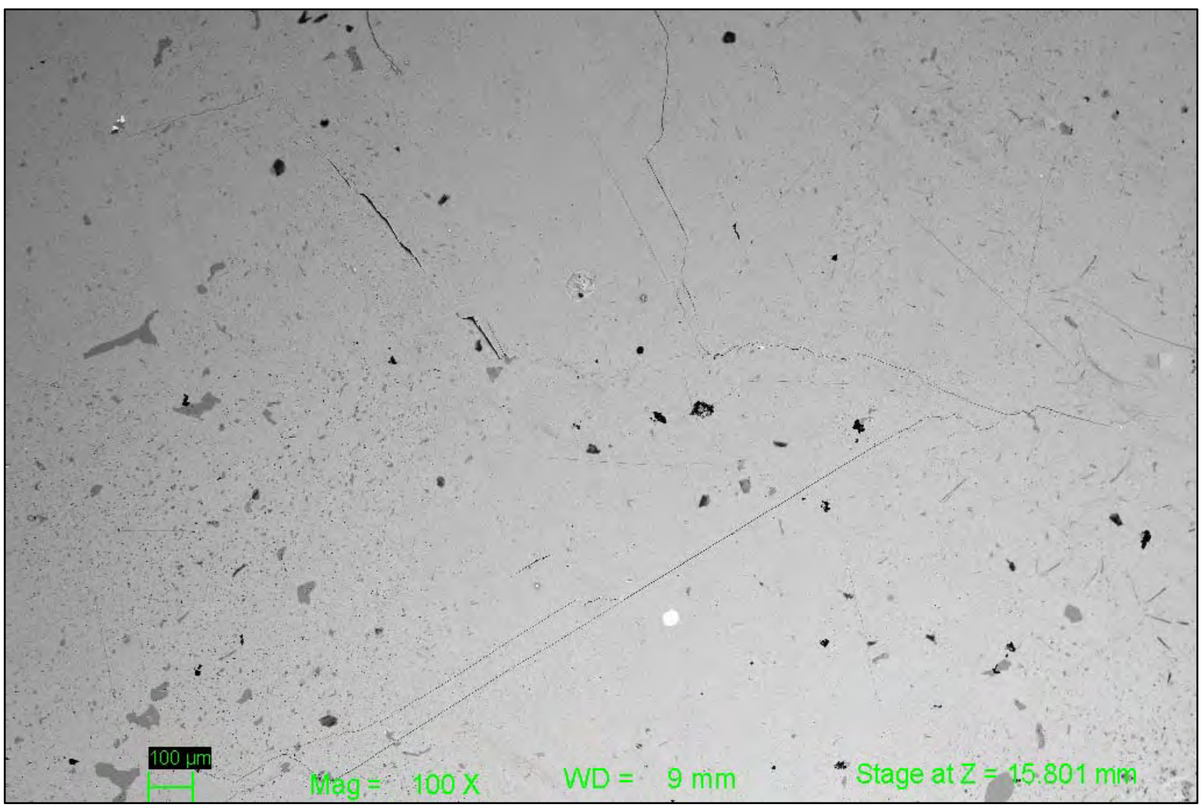


Figure 55: SEM BSE-image of calcite impregnated with dolomite. Black spots are graphite, white is pyrite. Thin section LE4-23.8 m.

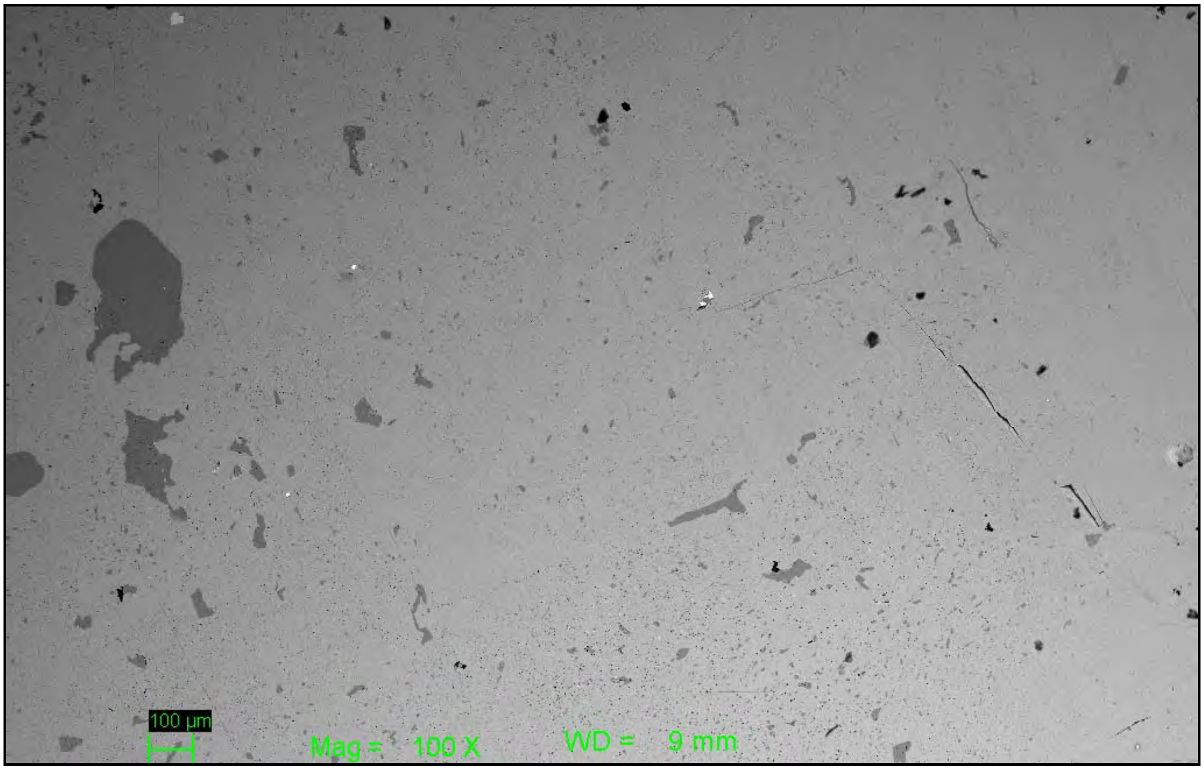


Figure 56: SEM BSE-image of calcite impregnated with dolomite as well as graphite. Thin section LE4-23.8 m.

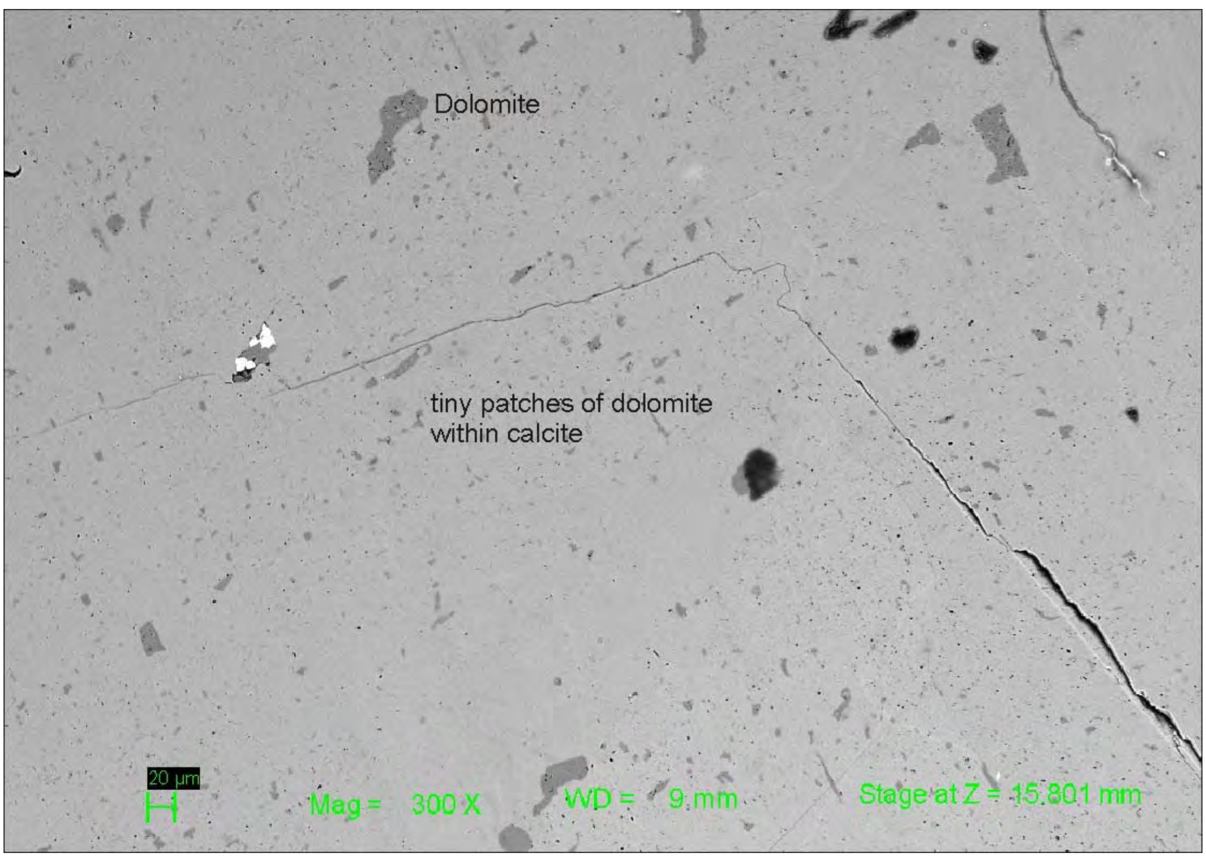


Figure 57: SEM BSE-image, close-up of Figure 1.56.

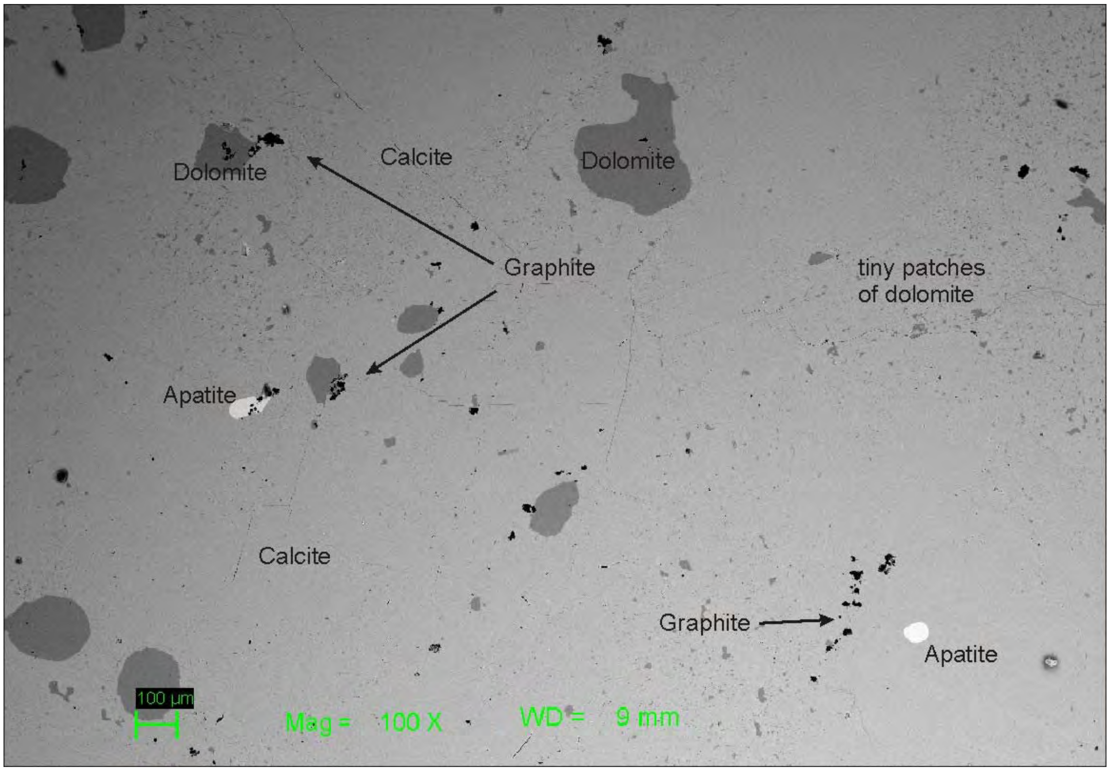


Figure 58: SEM BSE-image showing calcite (grey), quartz (rounded dark grey), dolomite (dark grey, finely disseminated in calcite in addition to some larger grains), graphite (black) and pyrite (white). Thin section LE4-23.8 m.

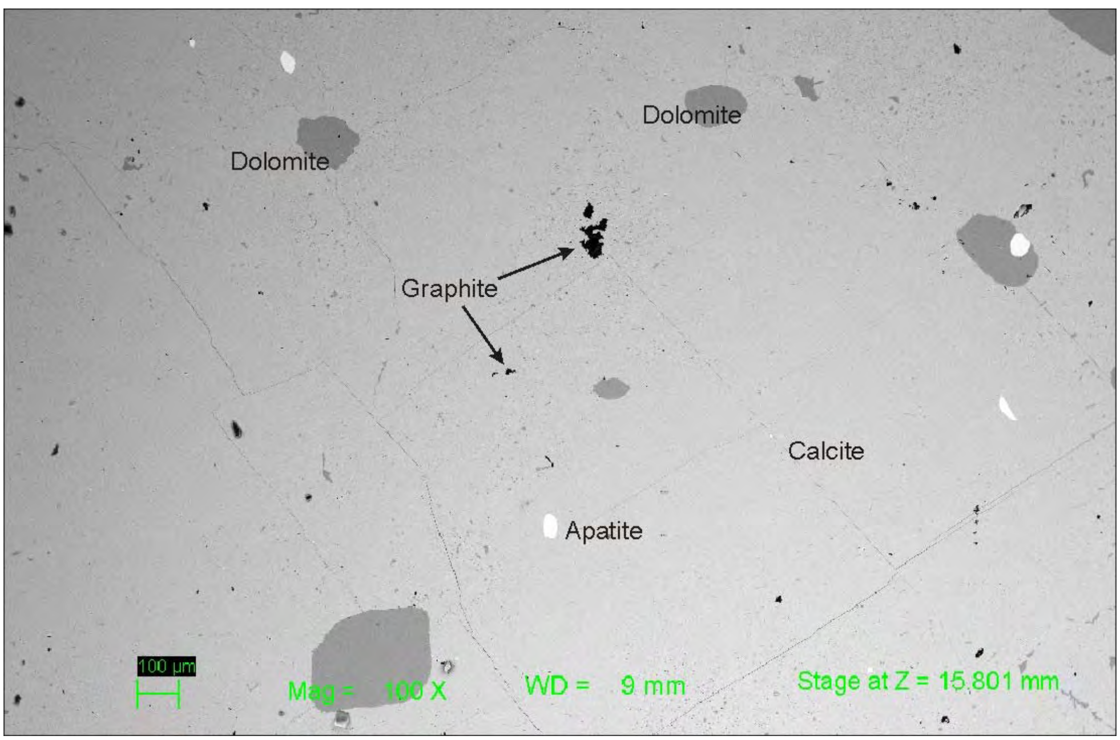


Figure 59: SEM BSE-image of calcite (grey), quartz (rounded dark grey), dolomite (dark grey, mainly finely disseminated in calcite), graphite (black) and pyrite (white). Thin section LE4-23.8 m.

4. Borehole LE5 Kvantokollen

4.1 Core description LE5

Table 10: Comments on borehole LE 5 Kvantokollen

Unit	Location [m]	Rock-description
1	0-1,5	The colour of this unit varies from light to dark grey. White calcite veins are cutting the coarse-grained calcite-dolomite marble. The darker parts are enriched in graphite; according to Melezhik et al. (2003) such dark bands may represent relicts of primary bedding.
2	1,5- 2,2	Beige-yellow, fine-grained dolomitic marble.
3	2,2- 4	Very heterogeneous unit, similar to the previous units, with a mixture of coarse-grained, pale to dark grey calcite marble with fine-grained beige-yellowish dolomitic marble. Thin layers are enriched in quartz and reddish to brownish mica (phlogopite), and darker parts are enriched in graphite.
4	4-5,73	Very heterogeneous unit as well. Pale grey to dark grey, banded and distinctly folded, fine to coarse-grained marble, and locally reddish with an enrichment of mica. The unit contains partly quartz and feldspar. White calcite veins are cutting the coarse-grained calcite-dolomite marble. *Thin section *LE5_04.8*
5	5,73-8,5	Similar to unit 2. Heterogeneous beige-yellow to light grey, fine to medium grained dolomitic marble, mica-rich. *Thin section *LE5_08.4*
6	8,5-9,6	Pale to dark grey, coarse-grained mixed calcite-dolomite marble, enriched in mica (phlogopite) particularly within thin layers.
7	9,6-14,3	Very heterogeneous unit. Distinct change between white, pale grey to dark grey predominantly calcite marble, and beige, fine-grained predominantly dolomitic marble. The variation in colour and grain size is significant. The fine-grained parts are usually mica-rich.
8	14,3-15,6	Heterogeneous unit as well. Mixture of white, coarse-grained and grey to dark grey, fine-grained marbles.
9	15,6-16	Very heterogeneous as the previous units. Mixture of brown and pale grey to dark grey, fine-grained mica-rich marble. There are fine-grained parts as well as dark grey; the coarse-grained parts tend to be enriched in sulphides. This unit is similar to unit 1.
10	16-17,25	Similar to unit 8. White, coarse-grained marble with some darker grey parts enriched in graphite and mica.
11	17,25-23,2	Dark grey and brown, medium to coarse-grained mica-rich marble, occasionally yellowish-pinkish. Mica (phlogopite) is distinctly enriched. Coarse grained layers consists of white calcite (for instance at 21.2-21.4 m), occurring in between darker more fine-grained layers.
12	23,2-25,4	Light grey to dark grey, variably grains-sized, calcite marble. Darker parts are enriched in graphite. *Thin section *LE5_23.7*

4.2 Chemical analyses LE5

Table 11: Semi-quantitative analyses by Niton portable XRF, borehole LE5.

Bh	Pos. (m)	% SiO_2	% CaO	ppm Fe	Pos. (m)	% SiO_2	% CaO	ppm Fe	Pos. (m)	% SiO_2	% CaO	ppm Fe
LE5	0,6	2,4	26,9	1810	10,3	3,0	43,7	2100	18,5	20,1	41,2	2330
LE5	1,3	23,8	43,2	430	10,6	4,4	34,3	2130	19,3	13,8	35,0	6260
LE5	1,7	4,5	29,7	2130	10,8	0,9	55,9	520	19,8	6,1	47,6	2070
LE5	2,8	1,4	54,2	570	11,5	2,7	31,4	2070	20,3	10,8	37,9	4650
LE5	3,4	0,9	57,5	420	12,5	6,6	34,7	3270	20,7	6,2	47,0	3430
LE5	4,5	15,9	27,7	5780	12,5	6,7	35,0	3400	21,3	1,2	55,4	940
LE5	5,3	1,6	41,1	2190	13,4	6,1	29,5	4200	21,6	1,7	56,5	870
LE5	5,7	4,2	47,0	1580	13,7	1,8	53,3	740	22,3	3,7	53,1	1320
LE5	5,7	4,2	47,2	1670	14,5	5,4	51,1	1150	22,6	5,7	44,3	2170
LE5	6,3	18,2	26,2	3830	15,3	1,7	54,6	660	22,8	6,4	41,8	2500
LE5	6,6	6,8	31,2	3300	15,5	1,2	56,6	450	23,3	1,3	56,6	680
LE5	7,5	4,4	41,5	2330	15,8	20,0	36,2	7420	23,8	1,1	56,3	700
LE5	8,3	4,7	31,8	2350	16,5	0,8	56,8	530	24,5	1,0	55,0	830
LE5	8,7	1,6	56,0	540	17,5	2,9	49,7	2850				
LE5	9,5	1,3	56,7	560	17,8	23,6	31,3	6980				

Table 12: Summarized analyses, borehole LE5 Kvantokollen.

Locality		Kvantokollen	Kvantokollen	Kvantokollen	Kvantokollen	Kvantokollen
Borehole		LE5	LE5	LE5	LE5	LE5
Sample		LE5-00-05	LE5-05-10	LE5-10-15	LE5-15-20	LE5-20-25.3
NGU identification no		101681	101682	101683	101684	101685
From-to (m)		0-5	5-10	10-15	15-20	20-25.3
$SiO_{2\ XRF}$	%	4,58	4,17	3,86	9,91	4,85
$Al_2O_{3\ XRF}$	%	0,64	0,91	0,59	1,67	0,78
$Fe_2O_{3\ XRF}$	%	0,22	0,36	0,25	0,63	0,30
$TiO_{2\ XRF}$	%	0,04	0,06	0,03	0,10	0,05
MgO_{XRF}	%	8,57	11,70	9,68	6,24	5,65
CaO_{XRF}	%	43,10	39,70	42,10	42,30	46,30
Na_2O_{XRF}	%	-0,10	-0,10	-0,10	-0,10	-0,10
K_2O_{XRF}	%	0,34	0,48	0,35	0,93	0,49
MnO_{XRF}	%	-0,01	0,01	-0,01	0,01	0,01
$P_2O_{5\ XRF}$	%	0,01	0,02	0,01	0,03	0,02
LOI_{XRF}	%	42,40	42,90	42,80	38,30	41,80
SUM_{XRF}	%	99,79	100,20	99,55	100,01	100,14
Ca_{ICP}	ppm	290000	262000	279000	277000	311000
CaO_{ICP}	%	40,57	36,65	39,03	38,75	43,51
CaO_{ICP} vs. CaO_{XRF}	%	94	92	93	92	94
Mg_{ICP}	ppm	45900	63300	52700	28100	29300
MgO_{ICP}	%	7,61	10,50	8,74	4,66	4,86
MgO_{ICP} vs. MgO_{XRF}	%	89	90	90	75	86
Fe_{ICP}	ppm	1566	2495	1713	4411	2076
Fe_{ICP}	ppm	964	1730	1210	1740	1210
Mn_{ICP}	ppm	nd	93	nd	85	85
Mn_{ICP}	ppm	52	81	58	78	72
$Fe+Mn_{XRF}$	ppm	1566	2588	1713	4496	2161
$Fe+Mn_{ICP}$	ppm	1016	1811	1268	1818	1282
$Fe+Mn_{ICP}$ vs. $Fe+Mn_{XRF}$	%	65	70	74	40	59
P_{ICP}	ppm	67	92	60	136	86
Ba_{ICP}	ppm	10,4	3,8	18,5	10,9	< 2
Sr_{ICP}	ppm	179	169	166	311	240
$Dolomite_{Calculated}$	%	34,9	48,1	40,0	21,4	22,3
$Calcite_{Calculated}$	%	53,2	39,1	47,7	57,3	65,3
$Others_{Calculated}$	%	11,9	12,8	12,3	21,3	12,5
S_{LECO}	%	< 0,01	< 0,01	0,011	0,013	0,024
TC_{LECO}	%	11,68	11,79	11,67	10,18	11,59
TOC_{LECO}	%	< 0,1	< 0,1	< 0,1	< 0,1	< 0,1

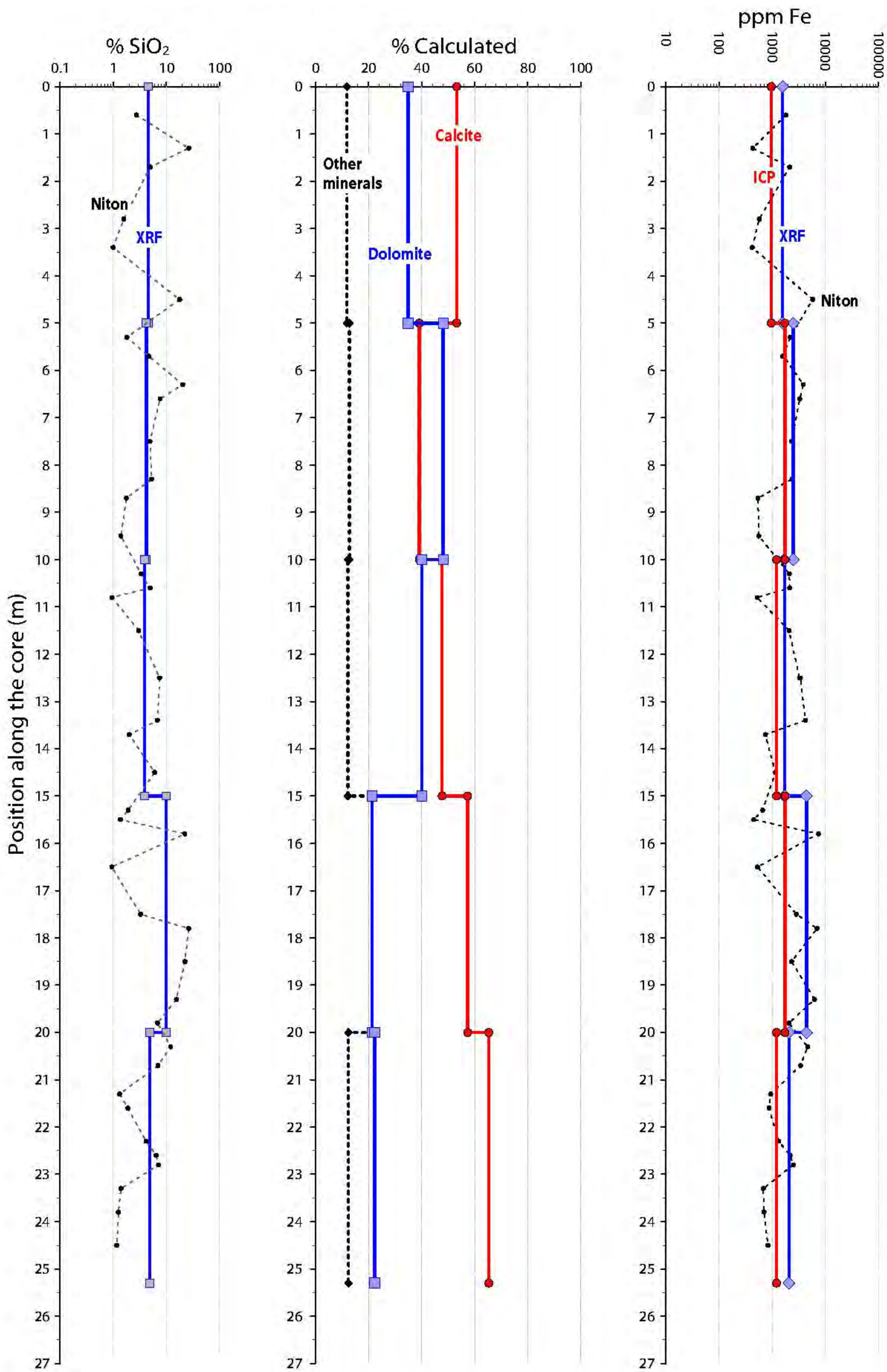


Figure 60: Variations in SiO_2, Fe and major minerals along borehole LE5 Kvantokollen.

4.3 Core photographs LE5

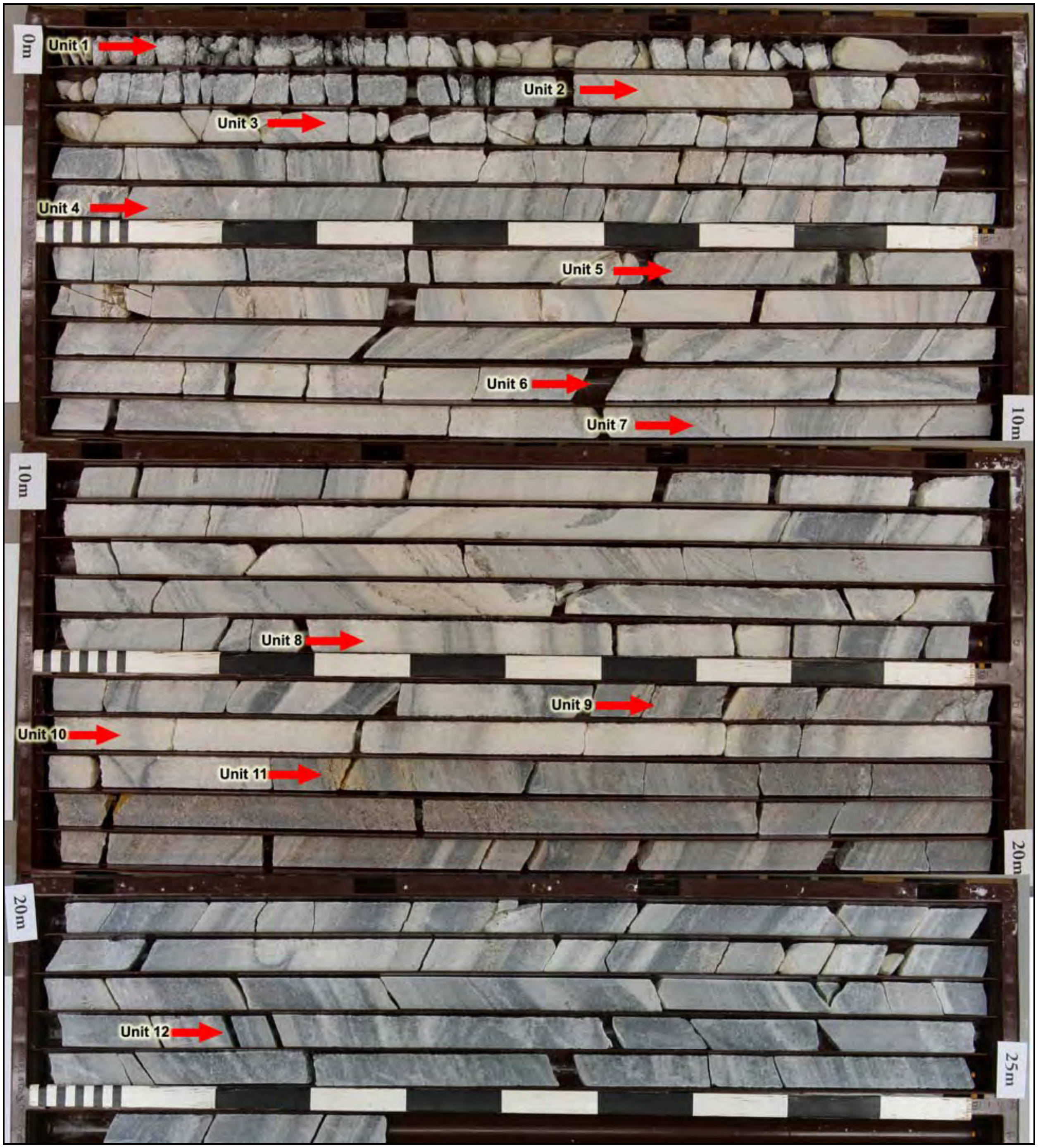


Figure 61: Overview photo of core LE5, Kvantokollen.

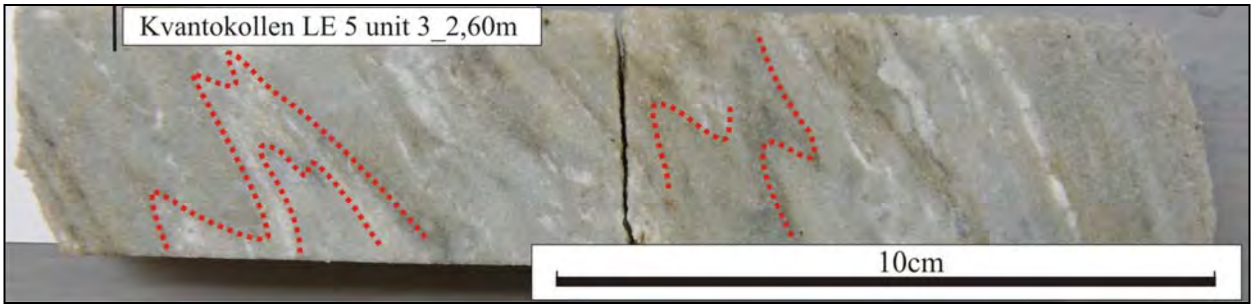


Figure 62: Photo of tiny folds (marked with dotted line) within beige to medium grey calcite-dolomite marble, LE5 unit 3 at 2,6 m.

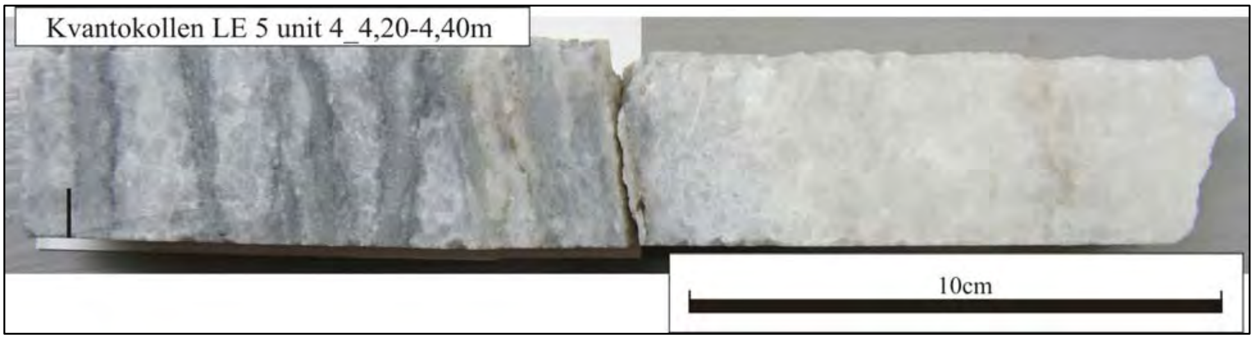


Figure 63: Photo of coarse grained, banded calcite marble, LE5 unit 4 at 4,3 m.

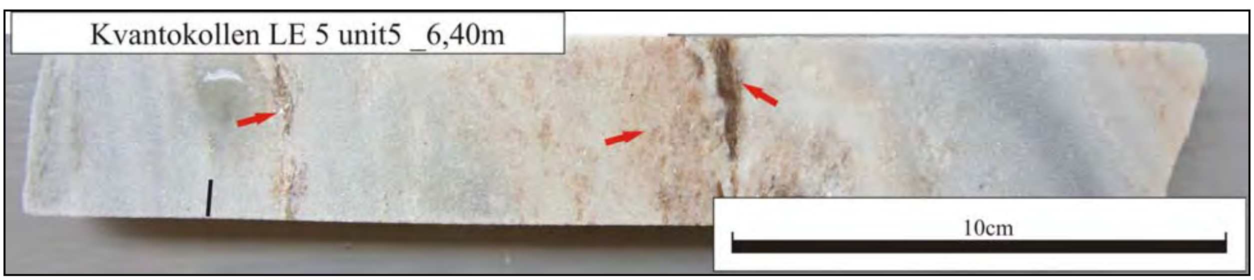


Figure 64: Photo of dolomitic marble locally enriched in pinkish mica, LE5 unit 5 at 6,4 m.

Figure 65: Photo of very heterogeneous, alternating pinkish and grayish calcite-dolomite marble, LE5 unit 7 at 13,1 m.

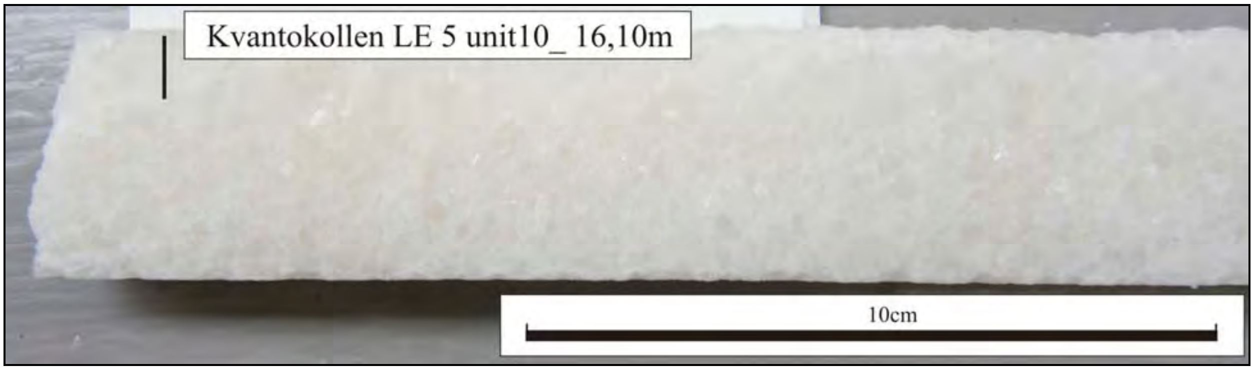


Figure 66: Photo of white, very pure, massive and coarse grained calcite marble, LE5 unit 10 at 16,1 m.

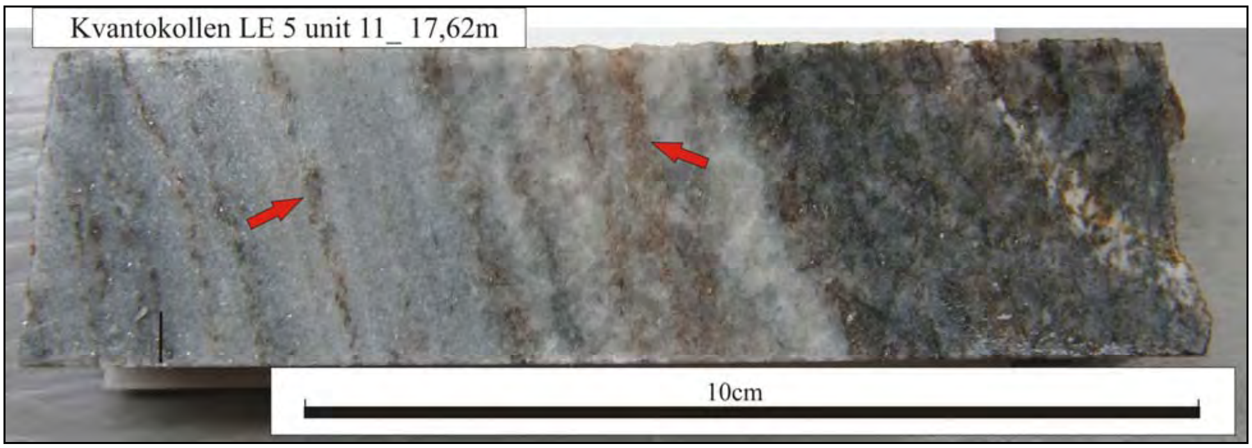


Figure 67: Photo of banded, grey, impure marble, with distinct mica-layers and enrichment of graphite in the darker parts.

Figure 68: Photo of heterogeneous white to grey marble, LE5 unit 11 at 19,4 m.

Figure 69: Photo of heterogeneous white to dark grey calcite-dolomite marble, LE5 unit 12 at 23,2 m.

4.4 Micrographs

4.4.1 Thin section LE5-04.8 m

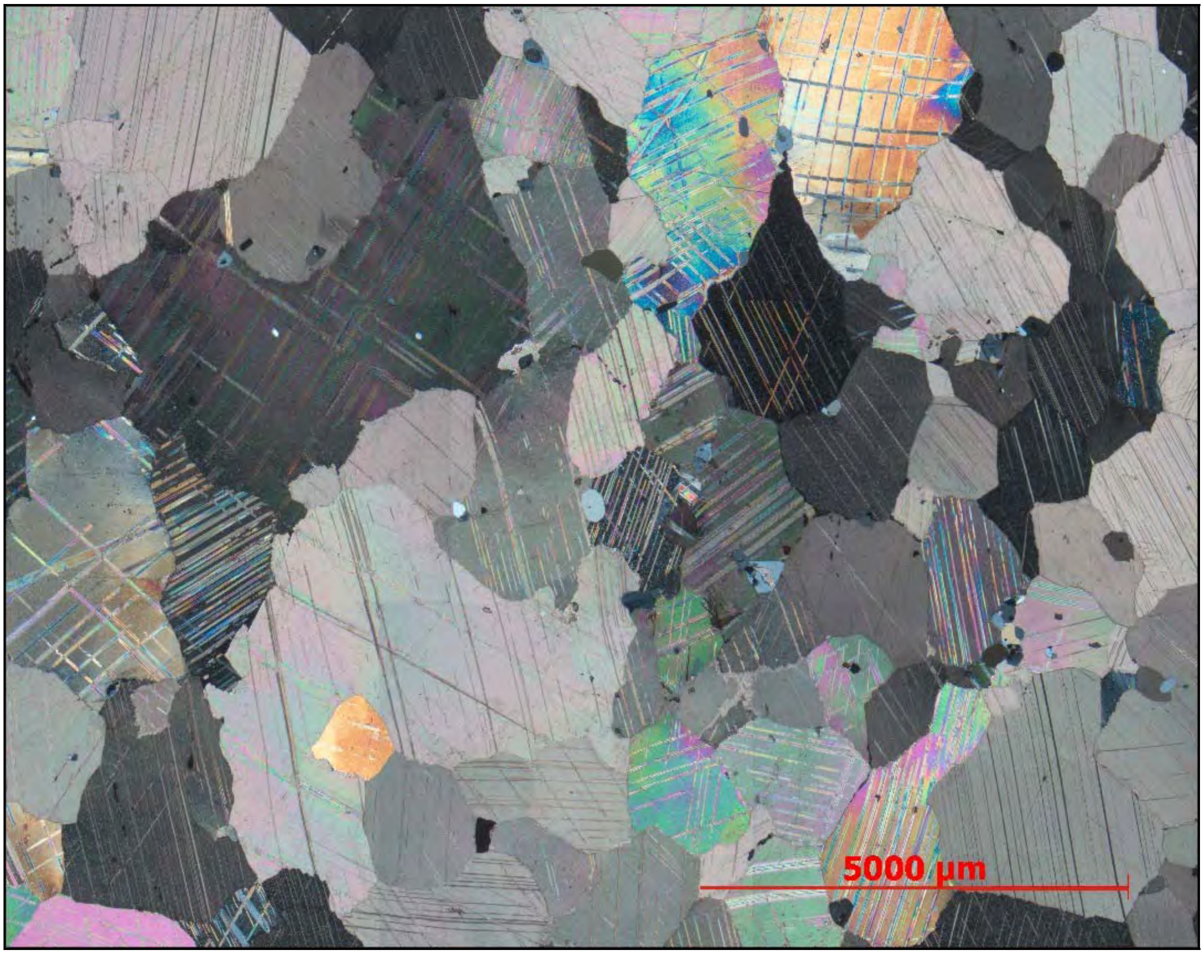


Figure 70: Mosaic microphotograph of coarse-grained carbonate; crossed polarized light. Thin section LE5 04.8 is dominated by calcite (lobate grain boundaries) and some quartz with accessorial graphite (very rare), rutile (titanite) and possibly zircon, pyrite, feldspar or augite (very small crystals which may be hard to determine).

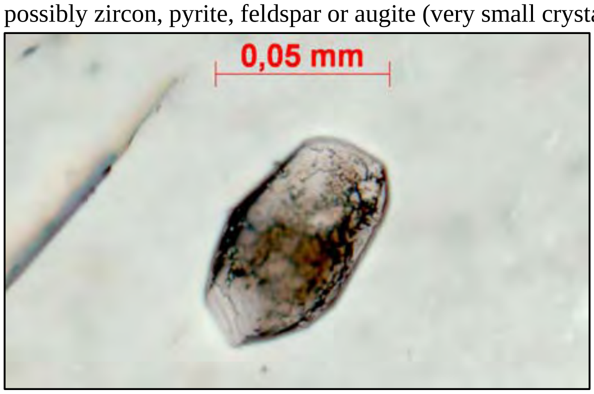


Figure 71: Microphotograph of zircon within carbonate; parallel-polarized light. Thin section LE5-04.8 m.

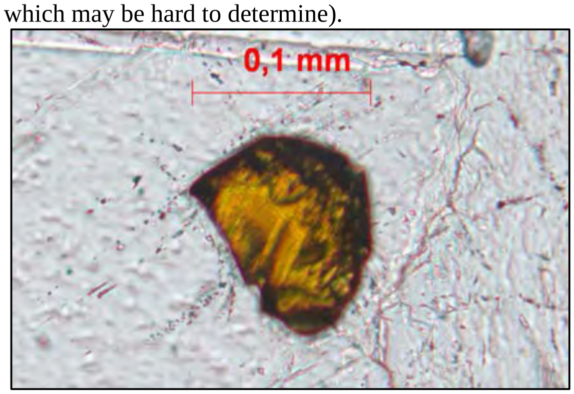


Figure 72: Microphotograph of rutile within carbonate; parallel- polarized light. Thin section LE5-04.8 m.

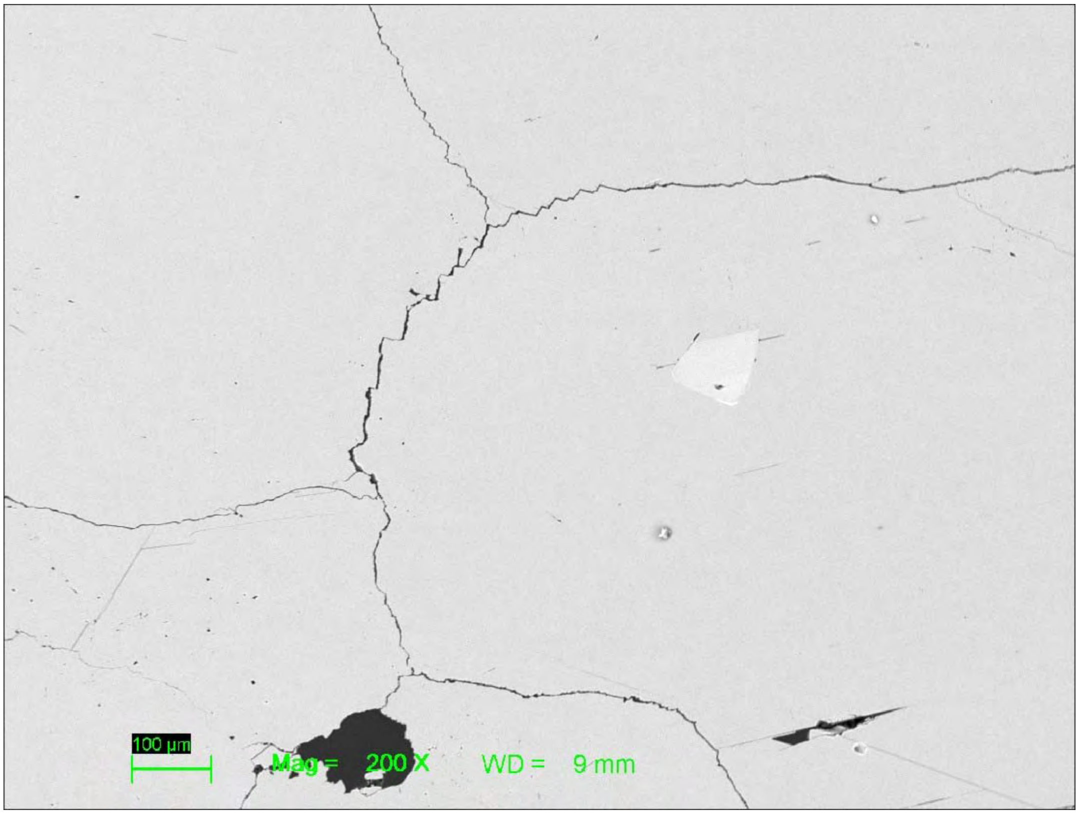


Figure 73: SEM BSE-image showing graphite inclusions in calcite. Thin section LE5-04.8 m.

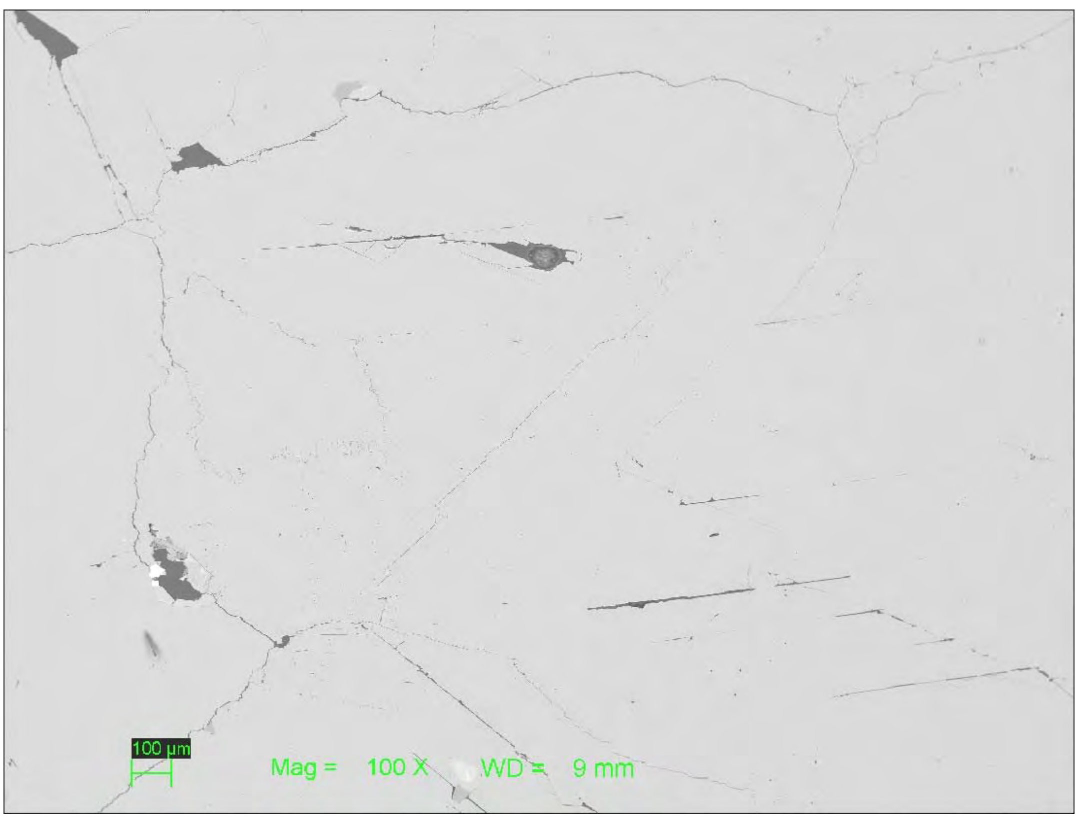


Figure 74: SEM BSE-image showing graphite inclusions (black) in calcite. Thin section LE5-04.8 m.

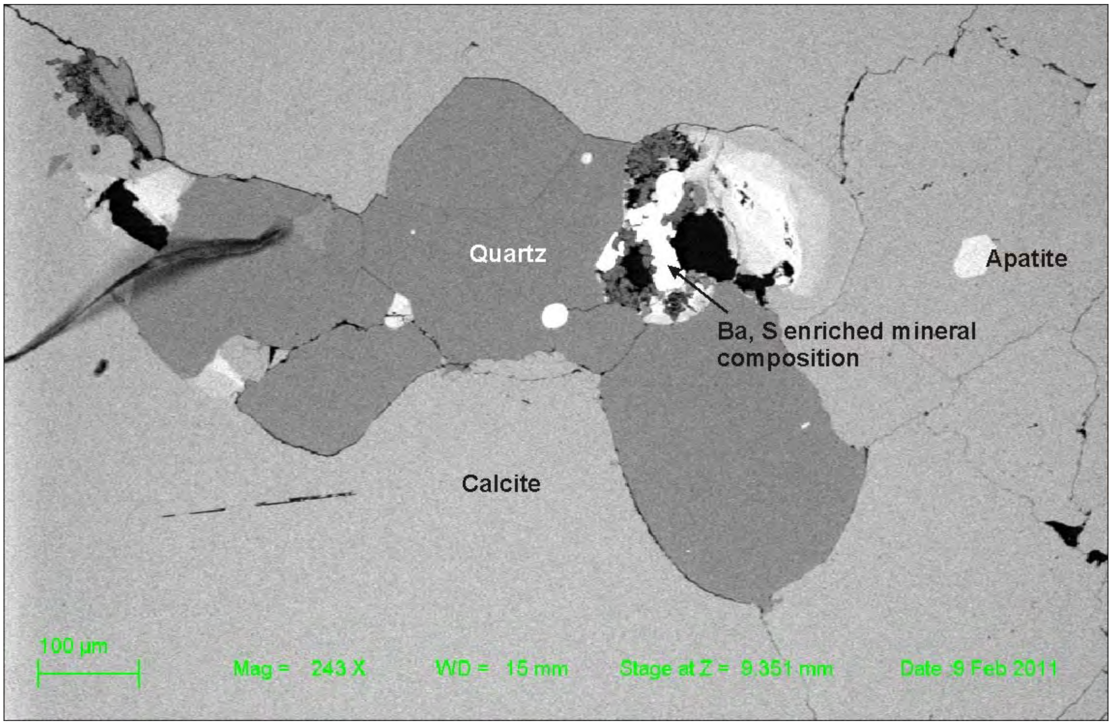


Figure 75: SEM BSE-image showing inclusions of other minerals in calcite (dominant grey); quartz (rounded dark grey), graphite (black), apatite (light grey). The very bright colours indicate sulphide minerals which are enriched in Ba and S. Thin section LE5-04.8 m.

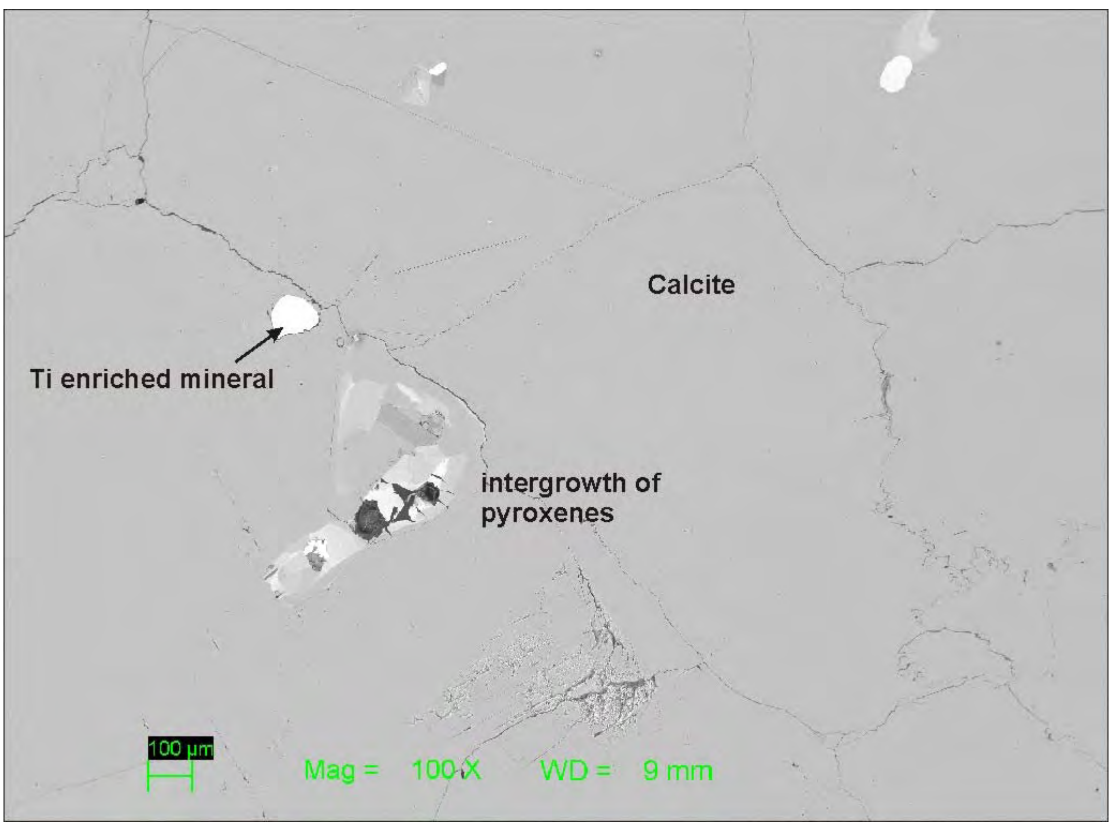


Figure 76: SEM BSE-image showing inclusions of other minerals in calcite (dominant grey). Thin section LE5-04.8 m.

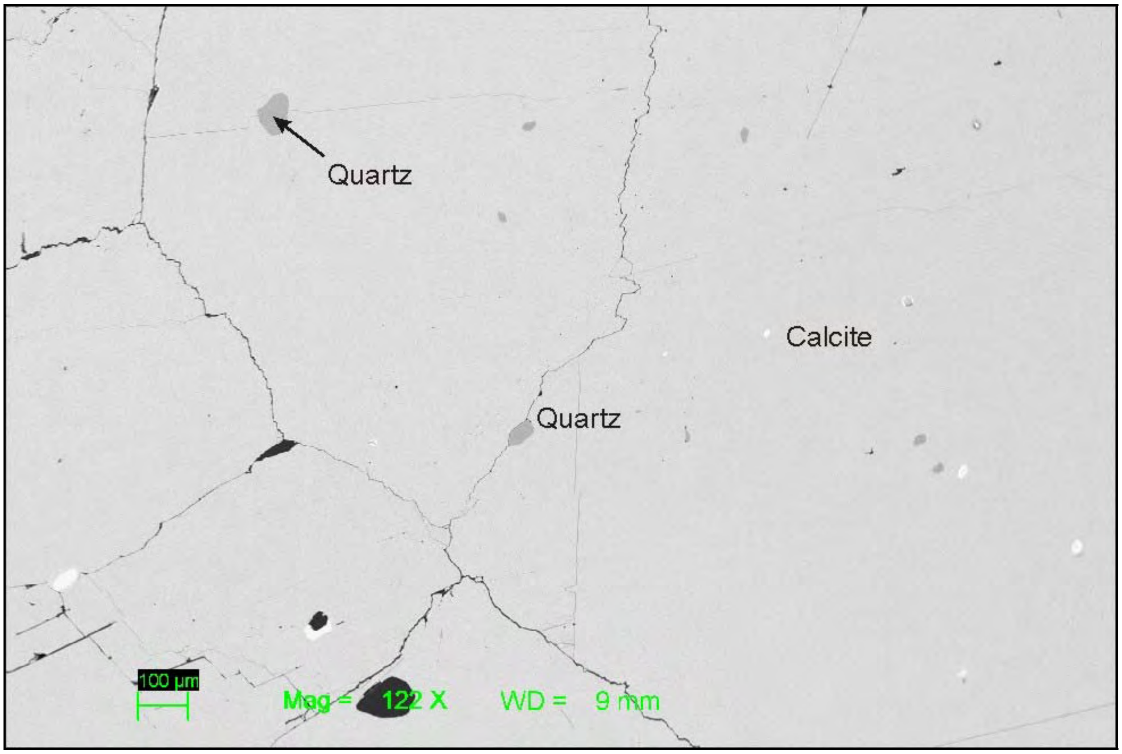


Figure 77: SEM BSE-image showing inclusions of silicate minerals in calcite (dominant grey). Thin section LE5-04.8 m.

4.4.2 Thin section LE5-08.4 m

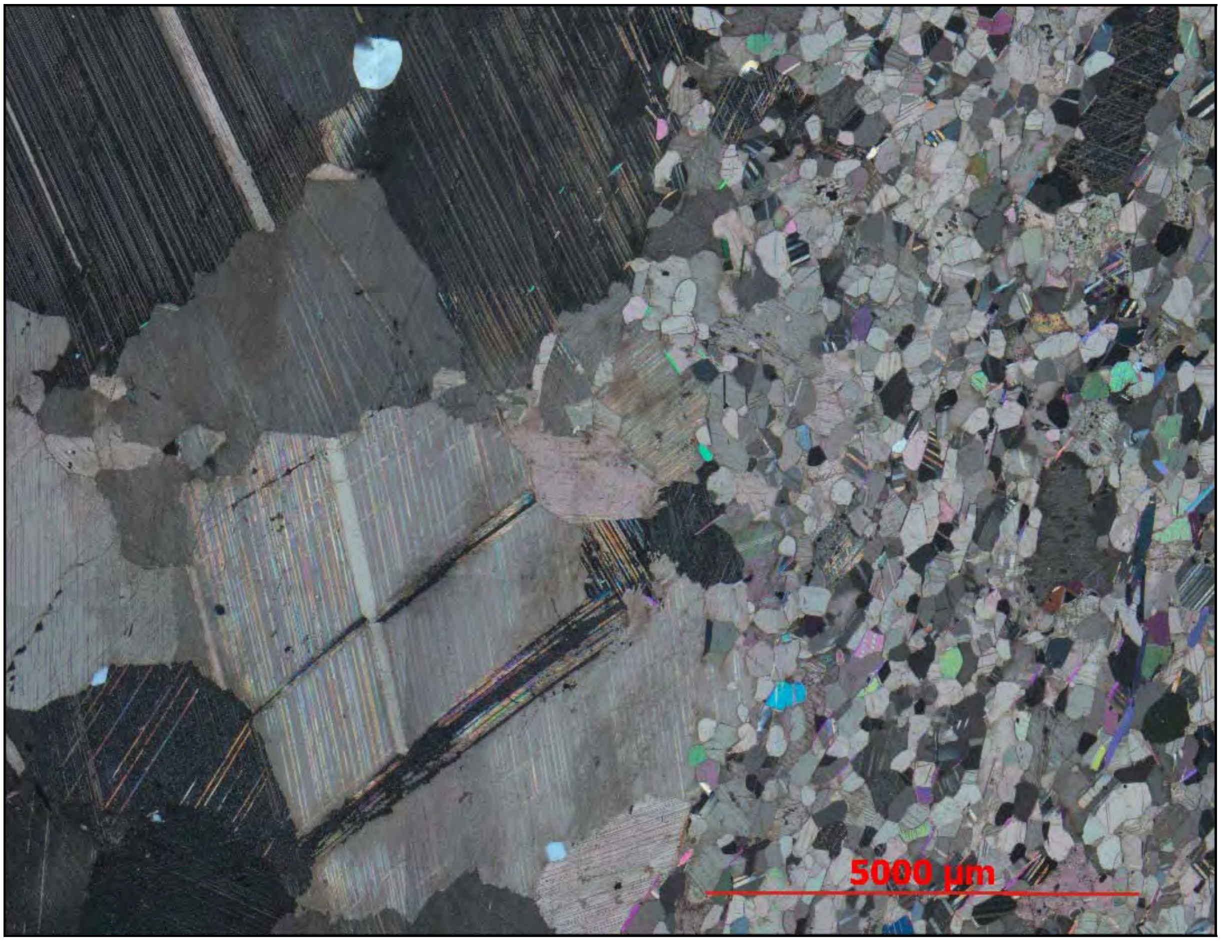


Figure 78: Mosaic microphotograph showing of coarse-grained calcite (left) and fine-grained dolomite (right); crossed polarized light.Thin section LE5-08.4 m.

The carbonate crystals of LE5 08,4 have a bimodal composition. The coarse calcites are 4-7 mm across, while the finer section is only 0,2-1 mm across. Apart from calcite, also present dolomite (particularly in the fine-grained part of the transition zone), and graphite is distinctly present as well as accessorial apatite, mica, small opaque minerals and some rutile.

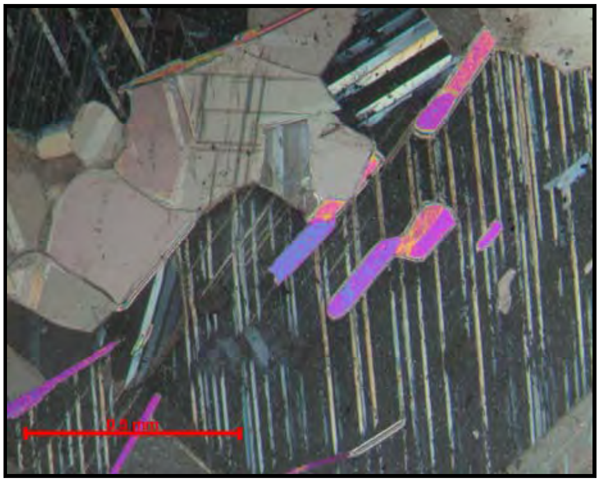


Figure 79: Microphotograph showing inclusions of mica in carbonate; cross-polarized light. Thin section LE5-08.4 m.

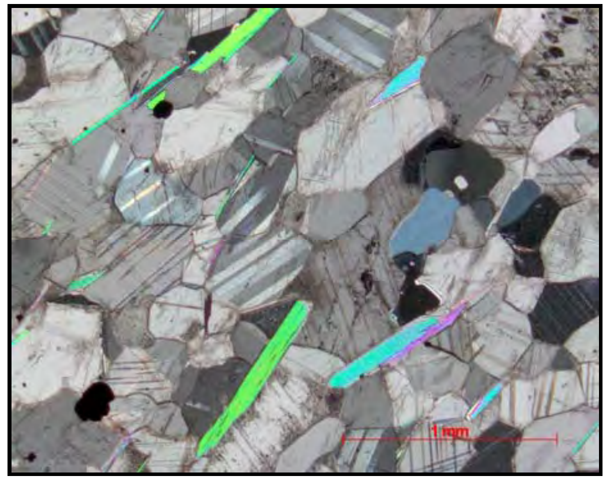


Figure 80: Microphotograph showing inclusions of mica in carbonate; partly cross-polarized light. Thin section LE5-08.4 m.

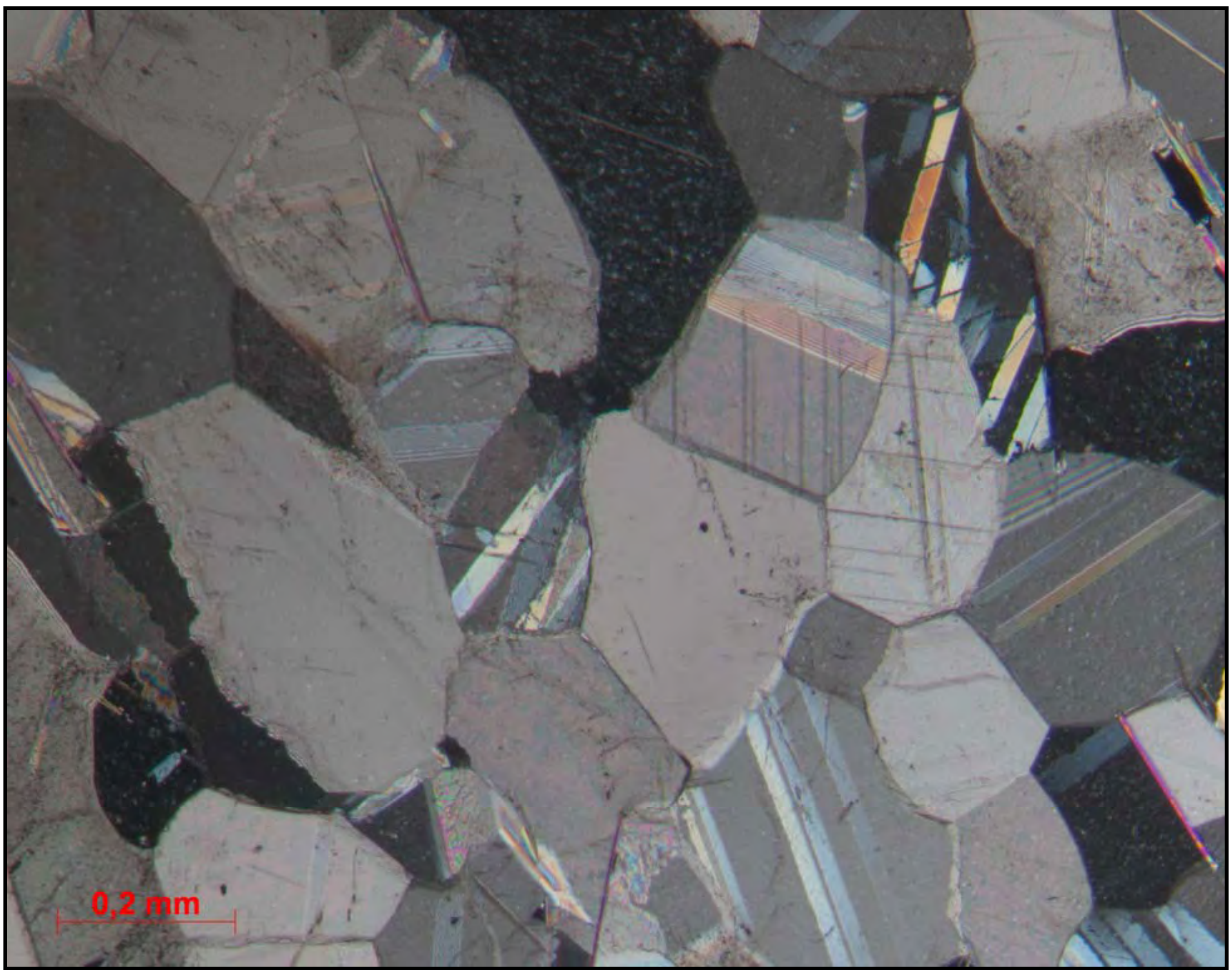


Figure 81: Microphotograph of calcite crystals with relatively straight grain boundaries; cross-polarized light. Thin section LE5-08.4 m.

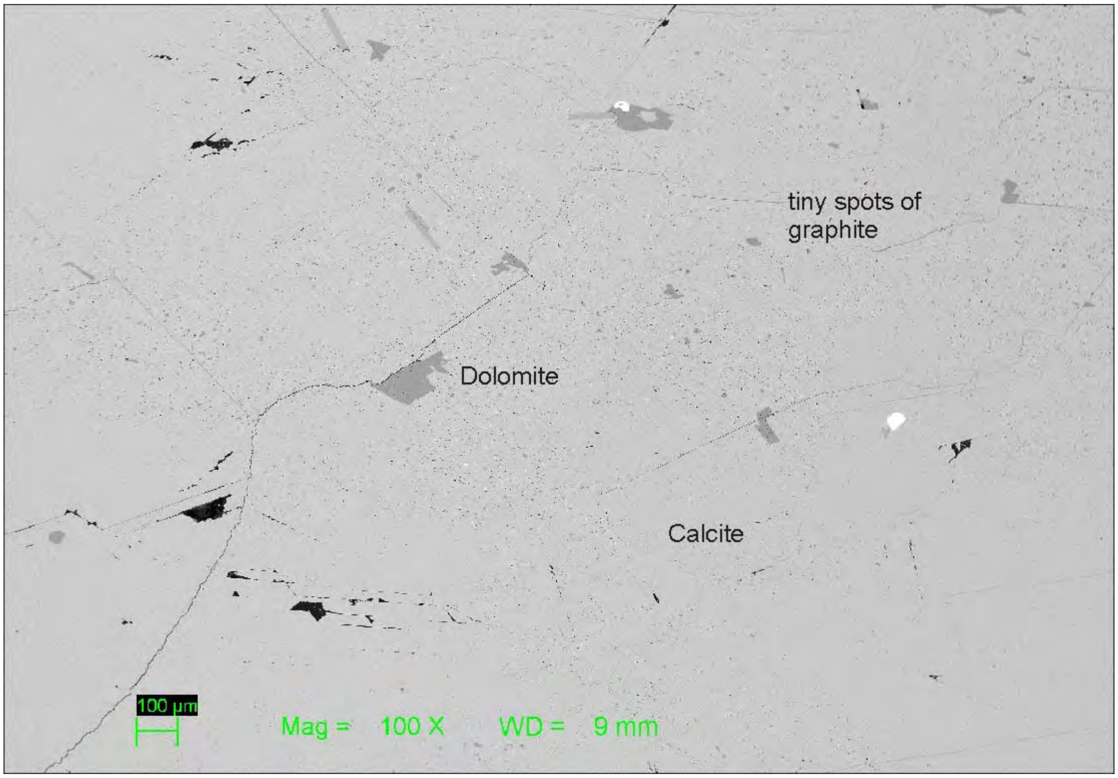


Figure 82: SEM BSE-image of calcite with inclusions of mainly dolomite (dark grey) and graphite (black) and rutile (bright colour). Thin section LE5-08.4 m.

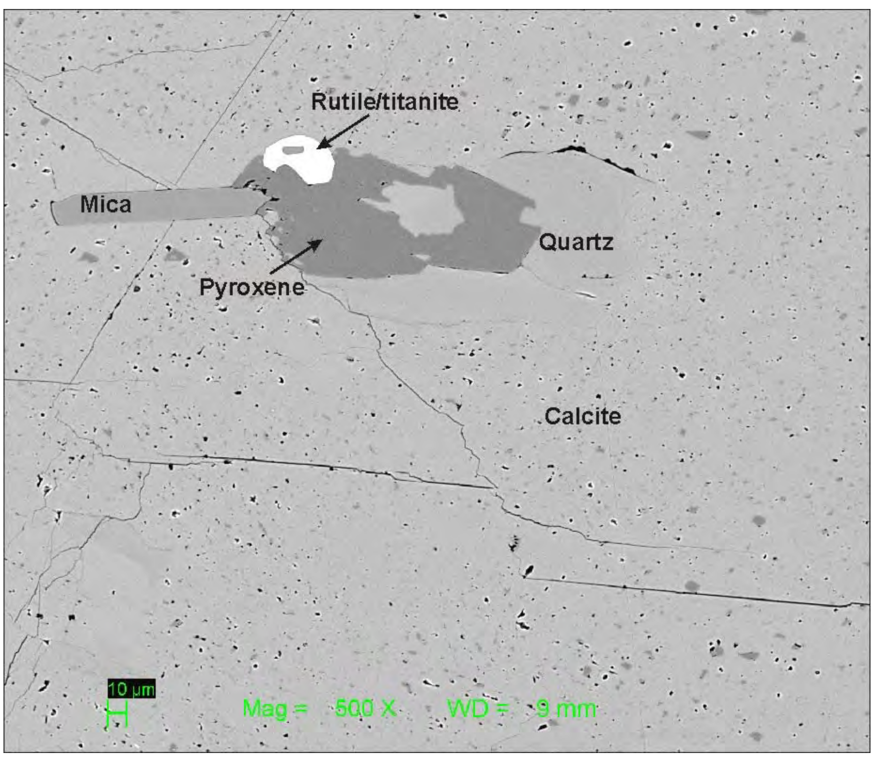


Figure 83: SEM BSE-image showing numerous tiny inclusions of dolomite (dark grey) and graphite (black) in calcite; close-up of Figure 1.88.

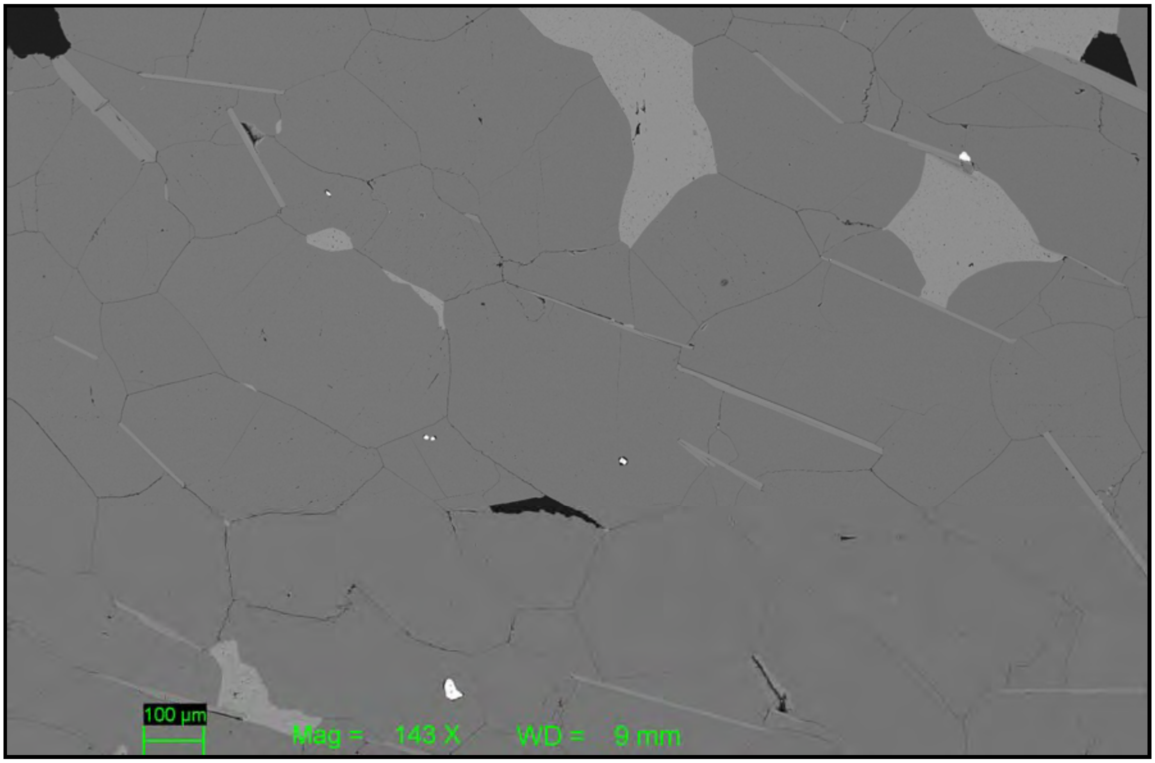


Figure 84: SEM BSE-image showing dolomite (dark grey), calcite (grey), mica (muscovite, elongate grey), graphite (black) and pyrite (white). Thin section LE5-08.4 m.

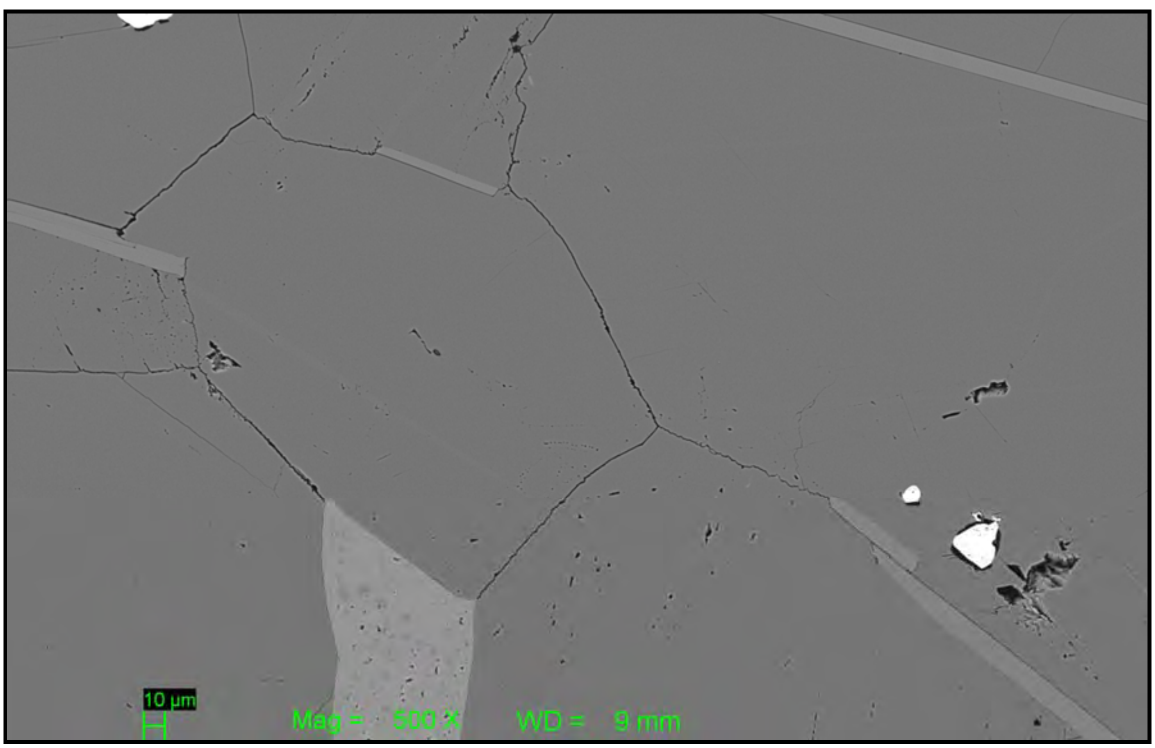


Figure 85: SEM BSE-image close-up on grain boundaries between dolomite grains (dark grey).
The calcite (grey) contains tiny inclusions of dolomite. Thin section LE5-08.4 m.

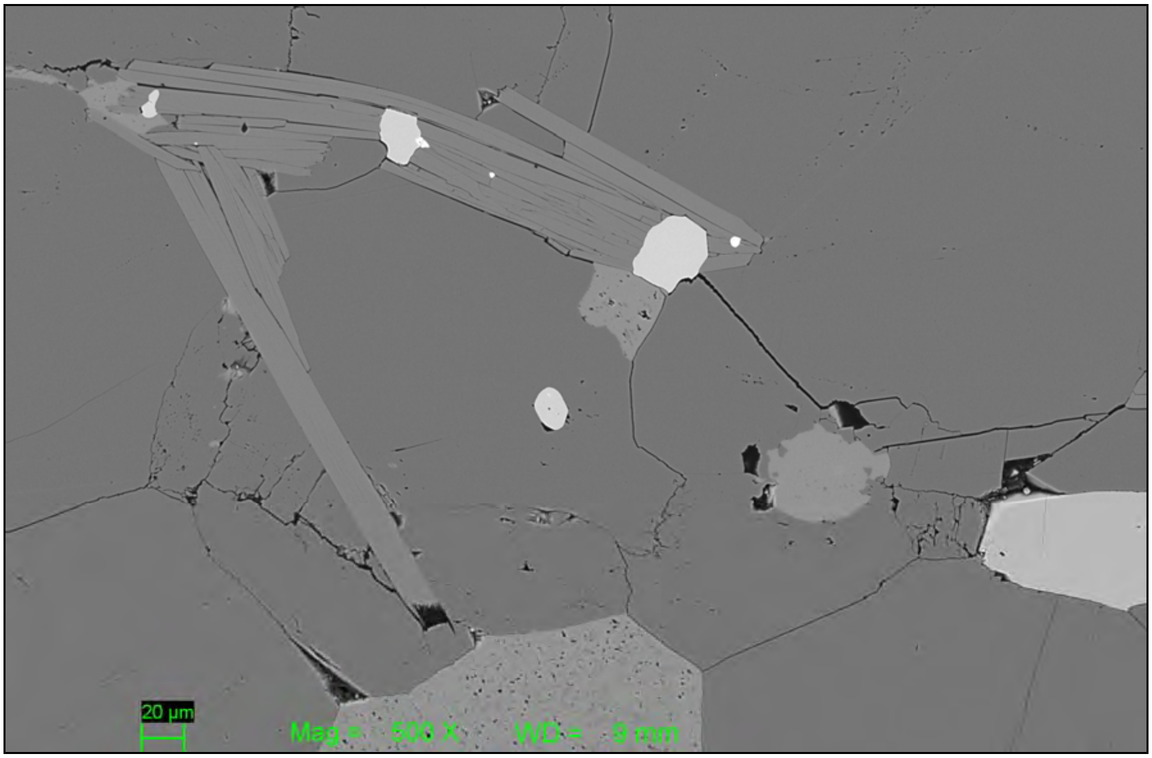


Figure 86: SEM BSE-image showing dolomite (dominant dark grey), calcite (grey), muscovite (medium grey, elongated grains) and rutile (light grey). Thin section LE5-08.4 m.

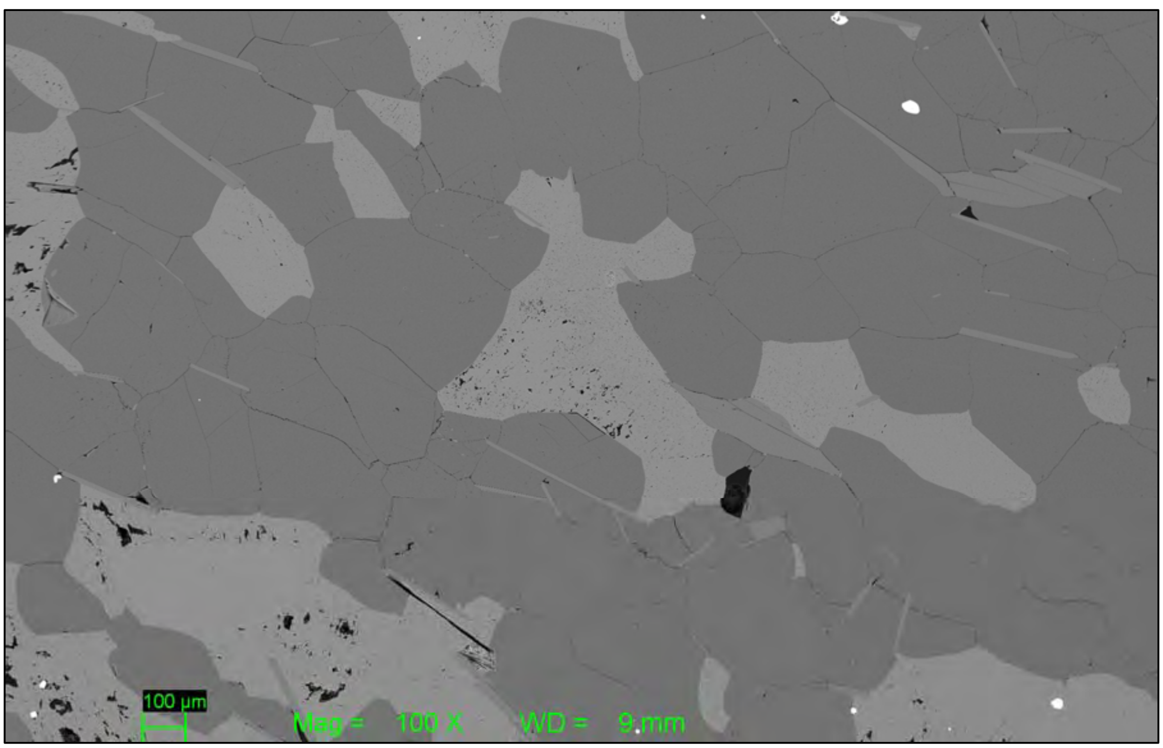


Figure 87: SEM BSE-image of dolomite (dark grey), calcite (grey), muscovite (elongate grey), graphite (black) and pyrite (white). Thin section LE5-08.4 m.

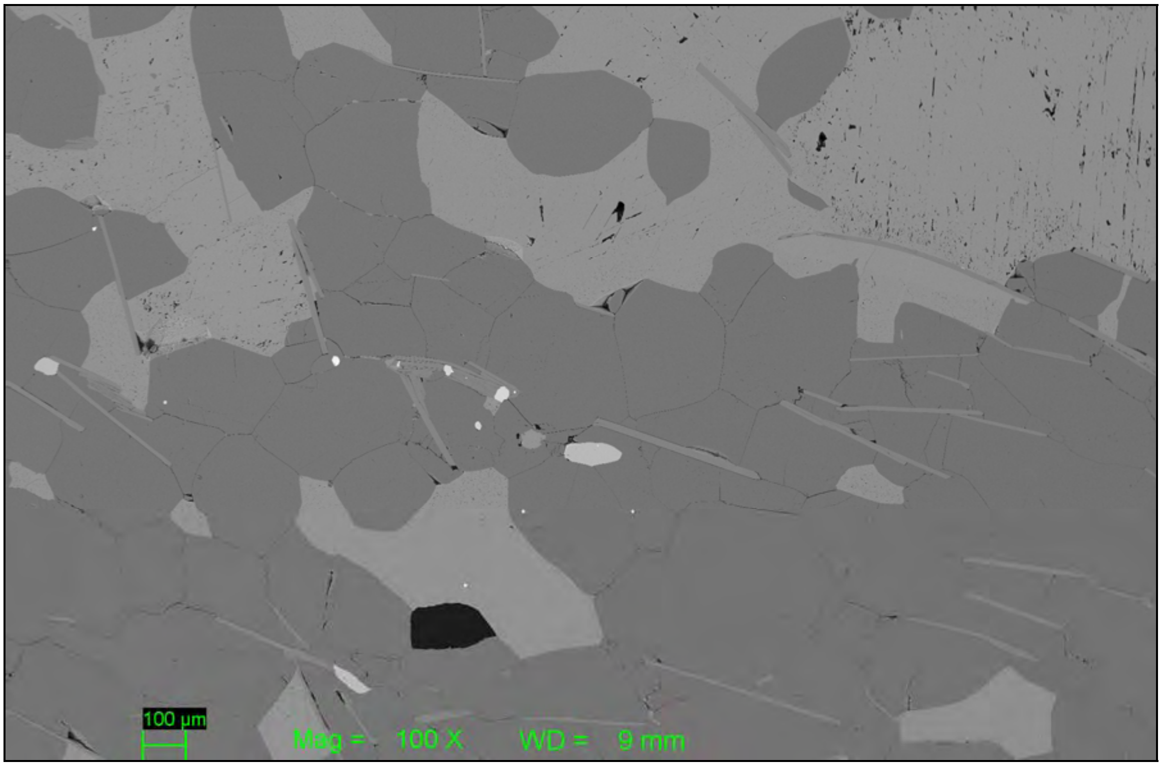


Figure 88: SEM BSE-image showing dolomite (dark grey), calcite (grey), graphite (black), apatite (light grey) and pyrite (white). Thin section LE5-08.4 m.

4.4.3 Thin section LE5-23.7 m

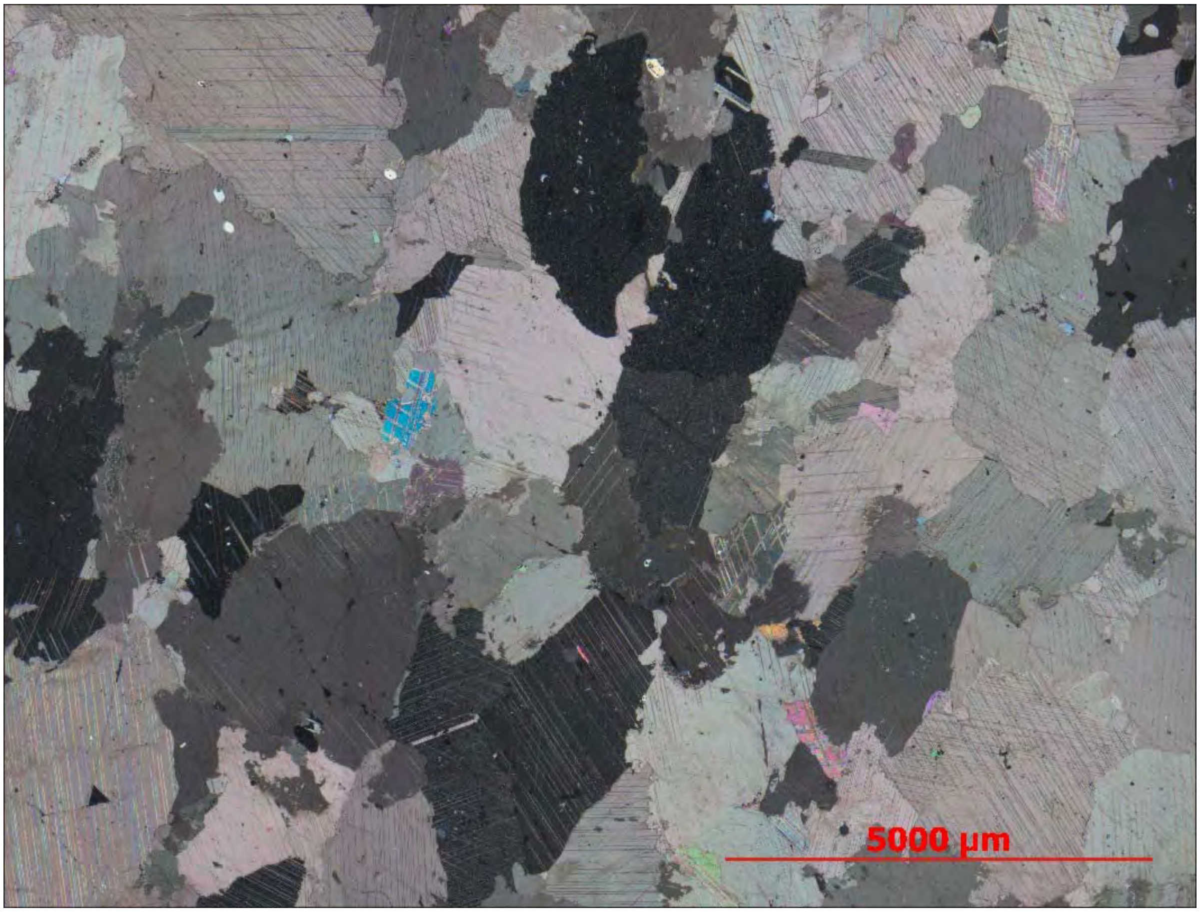


Figure 89: Mosaic microphotograph of dolomite-bearing calcite carbonate; cross-polarized light.
Thin section LE5-23.7 m.

Calcite crystals: Notice the difference in the grain boundaries from previous pictures as these are more sutured as opposed to the straight or lobate grain boundaries in the previous thin sections.

The calcites of LE4 23,7 have very irregular and sutured grain boundaries. Small crystals of opaque minerals (most likely sulphides such as pyrite and sphalerite) and accessory minerals such as quartz, muscovite, zircon and graphite appear partly as inclusions and partly along grain boundaries of the calcite.

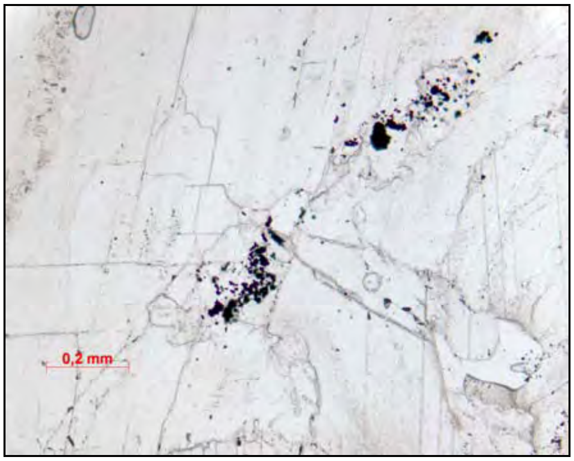


Figure 90: Close-up microphotograph of opaque inclusions (mainly pyrite) in calcite; cross-polarized light. Thin section LE5-23.7 m.

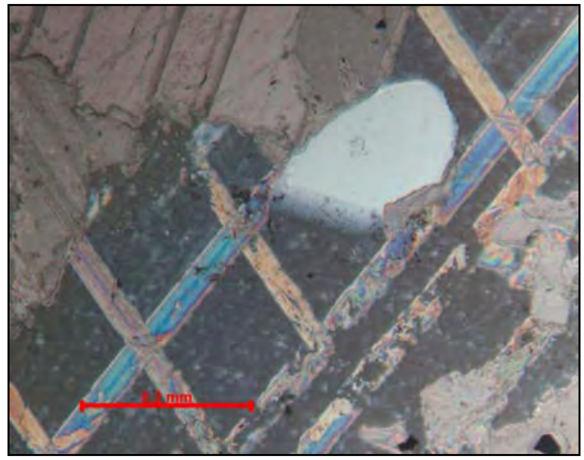


Figure 91: Close-up microphotograph showing twins in calcite crystals and a quartz inclusion; cross-polarized light. Thin section LE5-23.7 m.

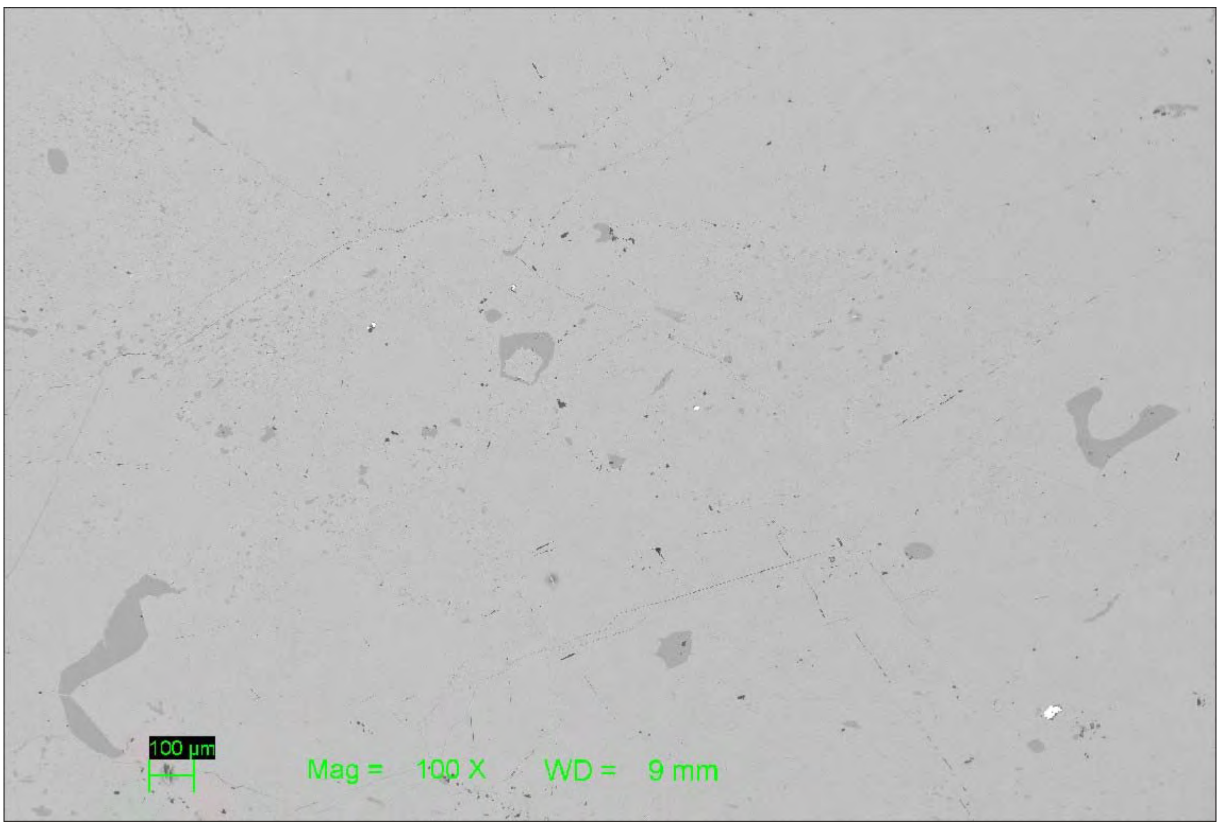


Figure 92: SEM BSE-image of calcite (grey) with inclusions of dolomite (dark grey) and graphite (black). Thin section LE5-23.7 m.

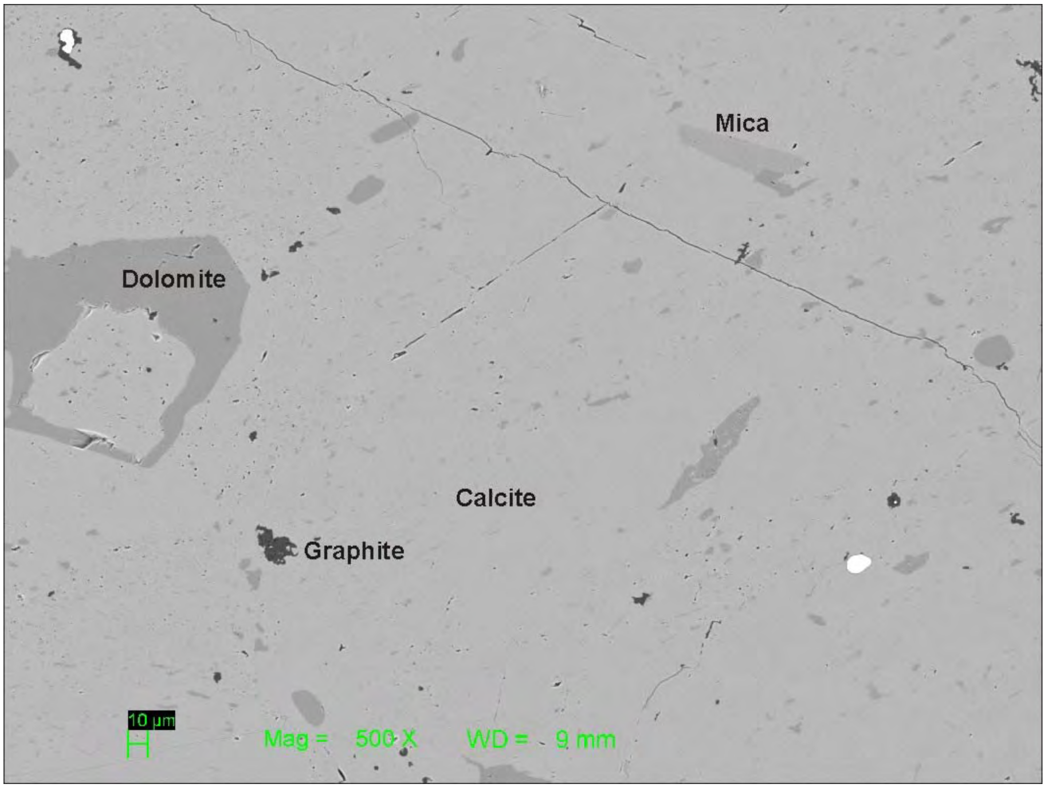


Figure 93: SEM BSE-image of calcite (grey), dolomite (dark grey), graphite (black) and pyrite (white)., close-up from Figure 92.

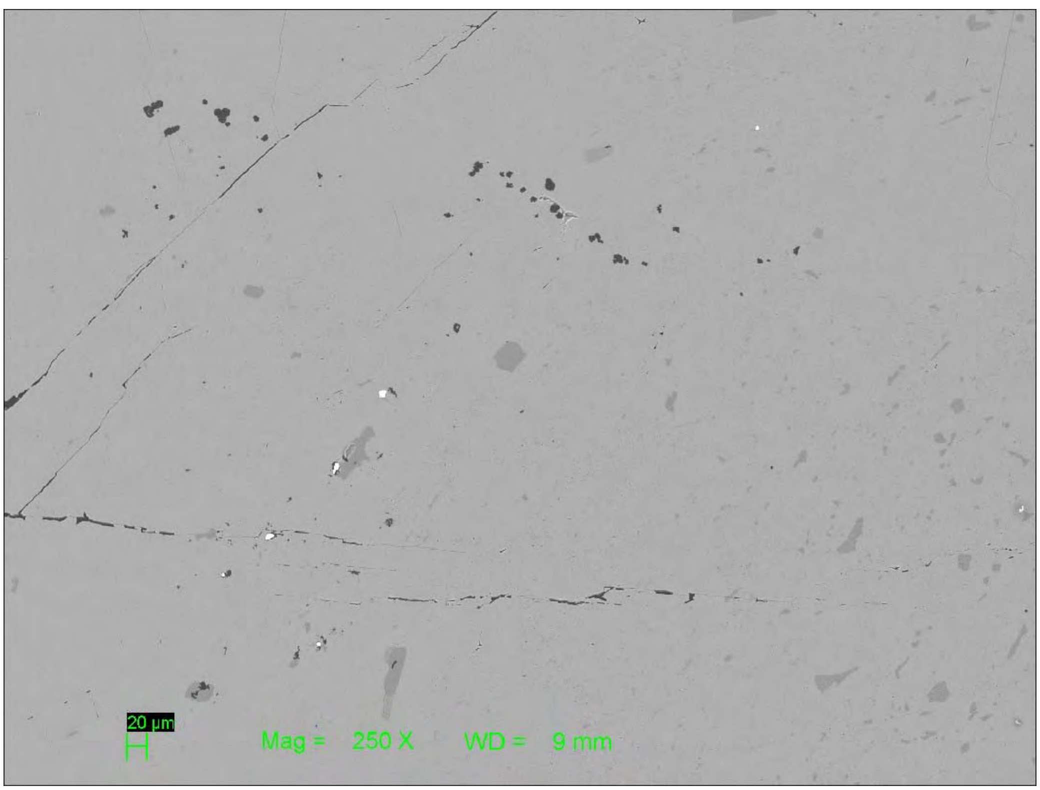


Figure 94: SEM BSE-image of calcite with patches of dolomite and inclusions of graphite (black), pyrite (white). Thin section LE 5 23,7m.

Appendix II:

Core descriptions, Rolla

Chemical and mineralogical characteristics of carbonate rocks in drill cores from Rolla. Supplementary information to NGU-report 2011.041 “Forekomster av kalsiumkarbonat i Breivollområdet på Rolla” (Korneliussen, Raaness, Schaller & Gautneb 2011b).

CONTENTS

FIGURES

TABLES

1. Borehole LR1 Breivollia

1.1 Core description LR1

Table 1: Comments on borehole LR1 Breivollia.

Unit	Location [m]	Rock-description
1	0-3,9	Pale grey to medium grey, slightly banded, coarse-grained calcite marble, partly reddish coloured. The unit is locally enriched in sulphide particles (pyrite); some of them are corroded. Mica (phlogopite) and graphite are distinct non-carbonate minerals.
2	2,9-15	Dark greenish, banded amphibolite. The main minerals are quartz, amphibole (hornblende), pyroxene and mica (biotite and phlogopite). The first few meters of this section are reddish coloured. The layers show partly large crystals of quartz and pyroxenes for instance between 9.60-9.80m and 10.10-10.20m. Between 14 and 15 m there is a change to more mica-rich layers. It seems there is variation between the different minerals: at first amphibole and pyroxene-rich and then from 6,60m more quartz and mica-rich. Garnet grains occur as well.

1.2 Chemical analyses LR1

Table 2: Semi-quantitative analyses by Niton portable XRF, LR1 Breivollia.

Bh	Pos. (m)	% SiO_2	CaO	ppm Fe	Pos. (m)	% SiO_2	CaO	ppm Fe
LR1	0,5	4,5	54,62	980	10,5	67,0	5,20	42840
LR1	1,5	1,2	49,12	780	11,5	64,1	1,66	50930
LR1	1,9	1,8	55,47	390	12,5	74,4	0,72	46950
LR1	2,6	20,7	42,39	2250	13,4	79,6	0,84	36510
LR1	3,5	3,1	54,58	530				
LR1	4,5	35,3	23,24	43480				
LR1	5,5	58,0	4,94	181660				
LR1	6,5	65,0	8,39	67940				
LR1	7,6	69,8	4,98	38410				
LR1	8,5	73,9	4,84	33590				
LR1	9,3	72,5	3,21	42510				

Table 3: Analyses, borehole LR1 Breivollia.

Locality		Breivollia	Breivollia	Breivollia
Borehole		LR1	LR1	LR1
Sample		LR1_00-05	LR1_05-10	LR1_10-14.5
NGU identification no		101686	101687	101688
From-to (m)		0-5	5-10	10-14.5
$SiO_{2\ XRF}$	%	19,80	60,40	62,50
$Al_2O_{3\ XRF}$	%	4,09	10,70	16,70
$Fe_2O_{3\ XRF}$	%	2,78	11,40	8,04
$TiO_{2\ XRF}$	%	0,24	0,67	0,86
MgO_{XRF}	%	2,31	4,17	3,00
CaO_{XRF}	%	39,40	7,44	2,24
Na_2O_{XRF}	%	0,61	1,95	1,92
K_2O_{XRF}	%	0,84	2,45	3,27
MnO_{XRF}	%	0,08	0,07	0,10
$P_2O_{5\ XRF}$	%	0,11	0,45	0,13
LOI_{XRF}	%	28,80	0,58	1,25
SUM_{XRF}	%	99,05	100,29	100,02
Ca_{ICP}	ppm	249000	11600	2590
CaO_{ICP}	%	34,84	1,62	0,36
CaO_{ICP} vs. CaO_{XRF}	%	88	22	16
Mg_{ICP}	ppm	4390	3290	2880
MgO_{ICP}	%	0,73	0,55	0,48
MgO_{ICP} vs. MgO_{XRF}	%	32	13	16
Fe_{ICP}	ppm	19432	79686	56200
Fe_{ICP}	ppm	1220	11500	6090
Mn_{ICP}	ppm	588	573	805
Mn_{ICP}	ppm	95	89	44
$Fe+Mn_{XRF}$	ppm	20020	80259	57005
$Fe+Mn_{ICP}$	ppm	1315	11589	6134
$Fe+Mn_{ICP}$ vs. $Fe+Mn_{XRF}$	%	7	14	11
P_{ICP}	ppm	467	2000	540
Ba_{ICP}	ppm	12,3	104,0	55,3
Sr_{ICP}	ppm	1410	48	11,3
$Dolomite_{Calculated}$	%	3,3	2,5	2,2
$Calcite_{Calculated}$	%	60,1	1,5	< 0,54
$Others_{Calculated}$	%	36,5	96,0	98,4
S_{LECO}	%	0,121	0,213	0,341
TC_{LECO}	%	8,31	0,16	0,12
TOC_{LECO}	%	0,13	< 0,1	0,16

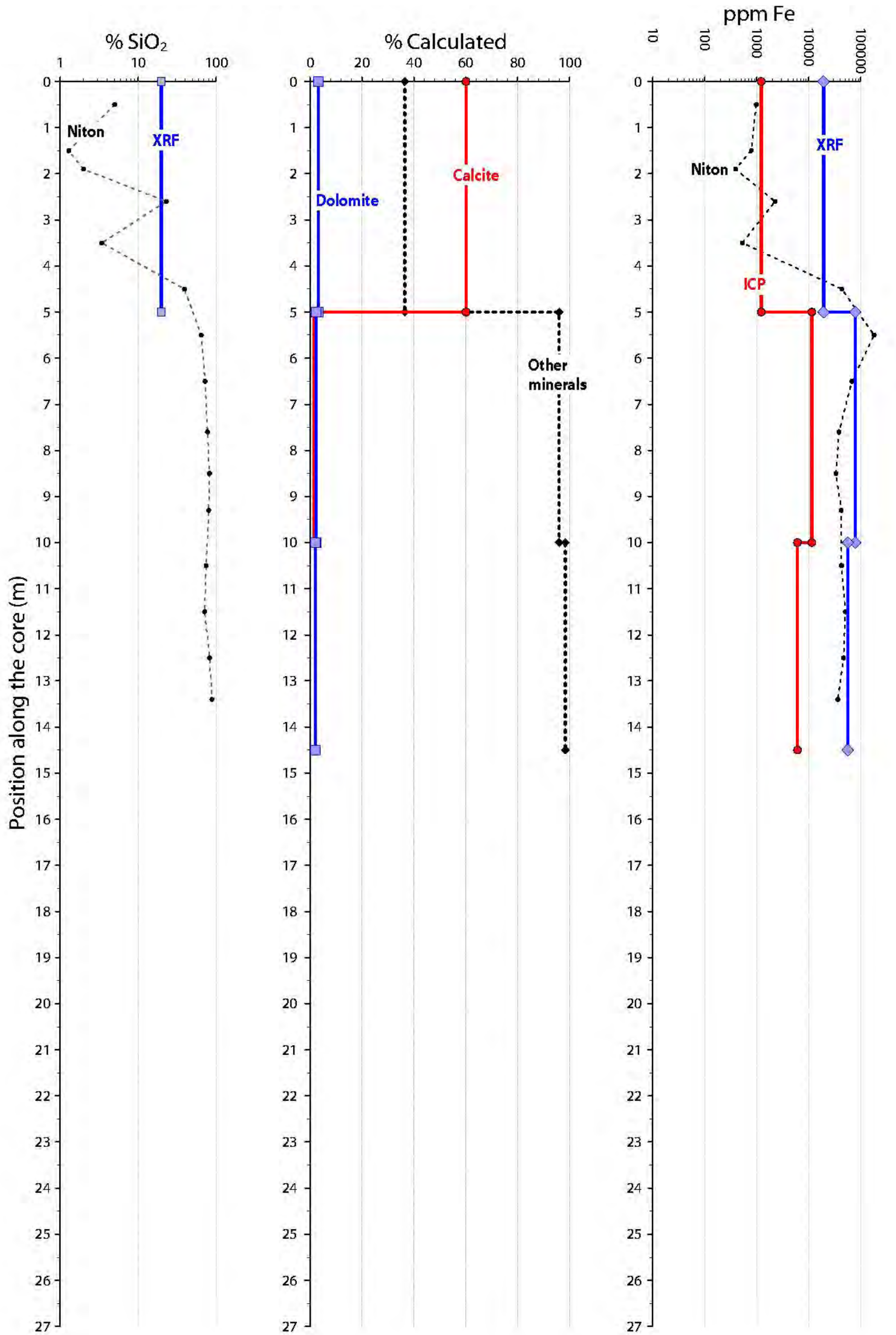


Figure 1: Variations in SiO_2, Fe and major mineral content along borehole LR1.

1.3 Core photographs LR1

Figure 2: Overview photo of core LR1, Breivollia. Unit 1 is white or greyish calcium carbonate marble while unit 2 is amphibolitic gneiss.

Figure 3: Photograph of white coarse-grained marble with dark bands, LR1 at 1,3 m.

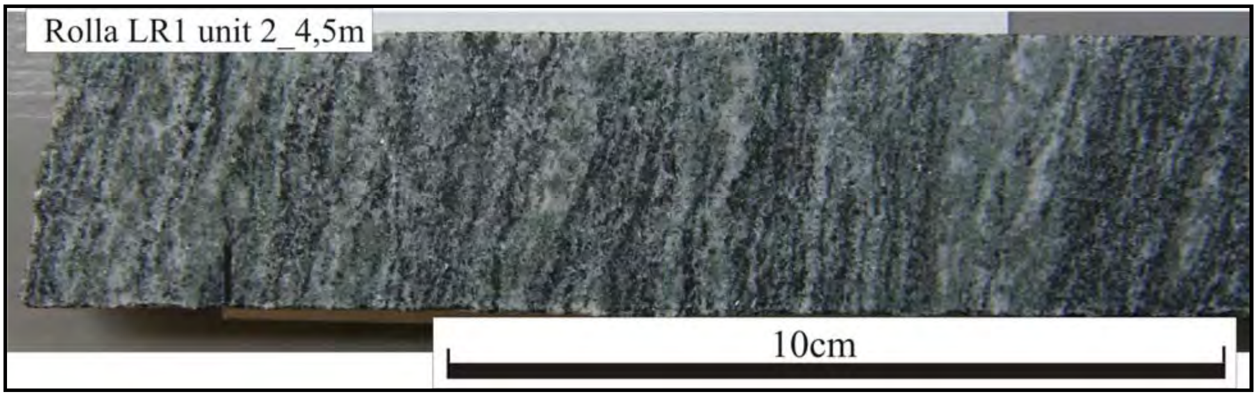


Figure 4: Photograph of amphibolitic gneiss, LR1 at 4,4 m.

Figure 5: Photograph of massive amphibolite within the amphibolitic gneiss, LR1 at 5,45 m.

Figure 6: Photograph of quartz vein (left) in amphibolitic gneiss/schist, LR1 at 9,6 m.

2. Borehole LR2 Breivollia

2.1 Core description LR2

Table 4: Comments on borehole LR2 Breivollia.

Unit	Location [m]	Rock-description
1	0- 3,90	Dark grey, fine to medium grained greyish and slightly banded calcite marble with distinct content of silicate minerals (mainly quartz, mica and diopside). First few meters contain oxidized sulphides, which colour the marble reddish. The graphite content is distinct. Some layers/bands are distinctly enriched in mica (phlogopite) and quartz. At 1.28 to 1.32m there is feldspar-quartz-mica pegmatite. The present of pyroxene (diopside) and quartz is particularly distinct around 3.5 m.
2	3,90- 4,25	White coarse-grained quartz-mica rich pegmatite with altered (weathered?) sulphides, mainly pyrite.
3	4,25- 6,52	Dark grey, medium to coarse-grained calcite marble with micas aligned in layers. Thus, there is distinct sub-horizontal layering.
4	6,52- 6, 62	Brownish quartz-rich zone (pegmatite?) enriched in sulphide (pyrite), feldspar and mica (phlogopite).
5	6,62- 10,10	Silicate-rich, heterogeneous, dark green to grey, banded, fine to medium grained impure marble. Bands/layers are enriched in quartz, flaky mica, pyroxene (diopside, distinctly greenish) and graphite. *Thin section *LR2_7.0m*
6	10,10- 12,6	Mainly pale to dark grey, medium to coarse-grained, graphite-bearing marble.
7	12,60-12,75	Dark green to black amphibolites with distinct content of mica (biotite), epidote and quartz. The same rock also occurs at 10.78-10.82m and 11.92-11.94m; they probably represent basic dykes.
8	12,75-13,20	Similar to unit 6: Pale to dark grey, medium to coarse-grained, graphite-bearing marble. *Thin section *LR2_12.9*
9	13,20-13,40	Layer within the marble with calcite, quartz, feldspar, garnet, pyroxene and unknown purple mineral (suggestion: Spinel ($MgAl_2O_4$)).
10	13,40-14,10	Similar to unit 6.
11	14,10-14,18	Layer of a green, fine to middle grained schistose rock rich in calcite, epidote and diopside.
12	14,18-15,96	Similar to unit 6.
13	15,96-17,88	Grey, middle to coarse-grained calcite marble with layers enriched in quartz and mica (phlogopite) for instance at 16.20-16.40m. The content of sulphide (pyrite) and graphite is distinct.
14	17,88- 18,0	White, medium grained feldspatic pegmatite; mica-rich and with a distinct graphite content.
15	18,0- 19,67	Similar to unit 13.
16	19,67- 19,95	White-yellow, coarse-grained feldspatic pegmatite with a ~3 cm of a green layer on the base and top enriched in epidote and pyroxene (diopside).
17	19,95-25,2	Light to dark grey, medium to coarse-grained marble with scattered graphite and pyrite. At 24.3-24.32m there are tiny layers of diopside. There is a distinct smell of sulphur when core is broken.
18	22,38-22,94	Similar to unit 16¸ coarse-grained feldspatic pegmatite, yellowish..
19	22,94-25,2	Similar to unit 17.

2.2 Chemical analyses LR2

Table 5: Semi-quantitative analyses by Niton portable XRF, LR2 Breivollia.

Bh	Pos. (m)	% SiO_2	CaO	ppm Fe	Pos. (m)	% SiO_2	CaO	ppm Fe	Pos. (m)	% SiO_2	CaO	ppm Fe
LR2	0,5	10,9	42,86	8710	10,2	2,0	55,69	610	18,5	2,2	56,27	290
LR2	0,5	10,9	42,86	8710	10,5	2,4	56,06	240	19,5	1,1	53,60	290
LR2	1,5	16,9	37,76	8050	10,7	1,6	55,50	790	19,7	83,3	1,83	410
LR2	2,6	19,2	36,48	3300	10,8	18,8	41,05	14850	19,92	56,6	6,91	8380
LR2	3,5	11,9	38,96	2290	11,5	1,1	56,61	190	19,98	2,7	55,48	2190
LR2	3,9	61,0	3,31	570	12,4	2,0	55,52	580	20,2	3,0	49,60	35710
LR2	4,2	55,5	2,37	2880	12,5	1,3	55,27	650	20,5	2,1	49,20	710
LR2	4,5	10,8	46,21	2880	12,7	24,8	28,63	51120	20,8	1,5	57,47	780
LR2	5,2	12,6	42,49	2730	12,8	1,6	50,49	450	21,5	1,9	56,01	480
LR2	5,4	23,6	39,88	1320	13,3	43,1	13,83	14300	21,8	3,8	48,63	1220
LR2	5,5	21,7	40,54	1690	13,5	1,2	55,27	350	22,2	3,0	56,02	930
LR2	6,54	43,4	12,36	54330	13,7	1,2	52,62	510	22,3	2,4	55,07	950
LR2	6,7	11,7	48,65	3670	14,1	50,1	20,16	67330	22,6	62,5	4,32	300
LR2	6,7	11,7	48,65	3670	14,3	1,4	53,41	380	22,6	62,5	4,32	300
LR2	7,2	6,9	50,67	3720	14,5	1,2	56,56	240	22,8	78,7	2,66	5300
LR2	7,3	19,5	18,77	52210	15,2	1,5	55,58	560	22,95	6,3	52,50	3830
LR2	7,5	15,3	45,01	8440	15,6	0,9	54,79	410	23,2	3,9	54,98	1460
LR2	7,7	6,7	46,49	6160	15,8	3,5	55,18	400	23,5	1,5	57,62	580
LR2	7,8	11,4	44,35	6410	15,94	44,8	15,98	33540	23,8	1,7	53,70	430
LR2	8,2	72,5	2,02	10140	16,2	31,7	32,38	28980	24,5	1,2	56,41	330
LR2	8,4	6,4	37,44	14850	16,4	21,8	44,10	1380				
LR2	8,5	44,3	22,35	54180	16,5	6,3	53,18	1610				
LR2	8,6	25,3	35,45	21780	16,7	1,7	49,91	1700				
LR2	8,8	23,5	12,24	37590	17,2	2,0	55,59	690				
LR2	8,9	2,2	54,36	1370	17,5	1,6	53,93	3410				
LR2	9,2	13,5	45,53	4100	17,8	1,8	55,32	1100				
LR2	9,5	18,0	41,18	12110	17,94	65,7	4,35	250				
LR2	9,8	15,0	42,26	13000	18,2	4,0	54,45	1470				

Table 6: Analyses, borehole LR2 Breivollia.

Sample		LR2_00-05	LR2_05-10	LR2_10-15	LR2_15-20	LR2_20-25.1
NGU identification no		101689	101690	101691	101692	101693
From-to (m)		0-5	5-10	10-15	15-20	20-25.1
$SiO_{2\ XRF}$	%	18,70	22,50	5,03	11,30	8,13
$Al_2O_{3\ XRF}$	%	2,50	3,15	1,89	2,53	1,59
$Fe_2O_{3\ XRF}$	%	0,82	1,71	0,70	1,10	0,19
$TiO_{2\ XRF}$	%	0,09	0,19	0,08	0,15	0,03
MgO_{XRF}	%	4,22	4,22	0,92	1,25	0,38
CaO_{XRF}	%	41,50	39,10	51,30	46,10	49,70
Na_2O_{XRF}	%	0,60	0,40	0,24	0,44	0,53
K_2O_{XRF}	%	0,40	0,31	0,08	0,52	0,12
MnO_{XRF}	%	0,02	0,03	0,01	0,02	-0,01
$P_2O_{5\ XRF}$	%	0,14	0,18	0,08	0,08	0,07
LOI_{XRF}	%	30,70	27,40	39,50	35,30	38,80
SUM_{XRF}	%	99,68	99,18	99,84	98,79	99,53
Ca_{ICP}	ppm	257000	230000	329000	300000	331000
CaO_{ICP}	%	35,95	32,18	46,03	41,97	46,31
CaO_{ICP} vs. CaO_{XRF}	%	87	82	90	91	93
Mg_{ICP}	ppm	2320	2240	3100	3930	1820
MgO_{ICP}	%	0,38	0,37	0,51	0,65	0,30
MgO_{ICP} vs. MgO_{XRF}	%	9	9	56	52	79
Fe_{ICP}	ppm	5739	11953	4921	7689	1335
Fe_{ICP}	ppm	505	733	347	446	194
Mn_{ICP}	ppm	116	201	108	186	nd
Mn_{ICP}	ppm	92	127	56	162	44
$Fe+Mn_{XRF}$	ppm	5855	12154	5029	7875	1335
$Fe+Mn_{ICP}$	ppm	597	860	403	608	238
$Fe+Mn_{ICP}$ vs. $Fe+Mn_{XRF}$	%	10	7	8	8	18
P_{ICP}	ppm	607	729	371	351	351
Ba_{ICP}	ppm	7,0	6,3	10,4	8,1	11,1
Sr_{ICP}	ppm	2050	1720	2110	1950	2410
$Dolomite_{Calculated}$	%	1,8	1,7	2,4	3,0	1,4
$Calcite_{Calculated}$	%	63,0	56,3	80,6	73,0	81,6
$Others_{Calculated}$	%	35,3	42,0	17,1	24,0	17,0
S_{LECO}	%	0,039	0,090	< 0,01	0,061	0,013
TC_{LECO}	%	9,59	8,52	11,85	10,37	11,36
TOC_{LECO}	%	0,45	0,52	0,15	0,16	0,15

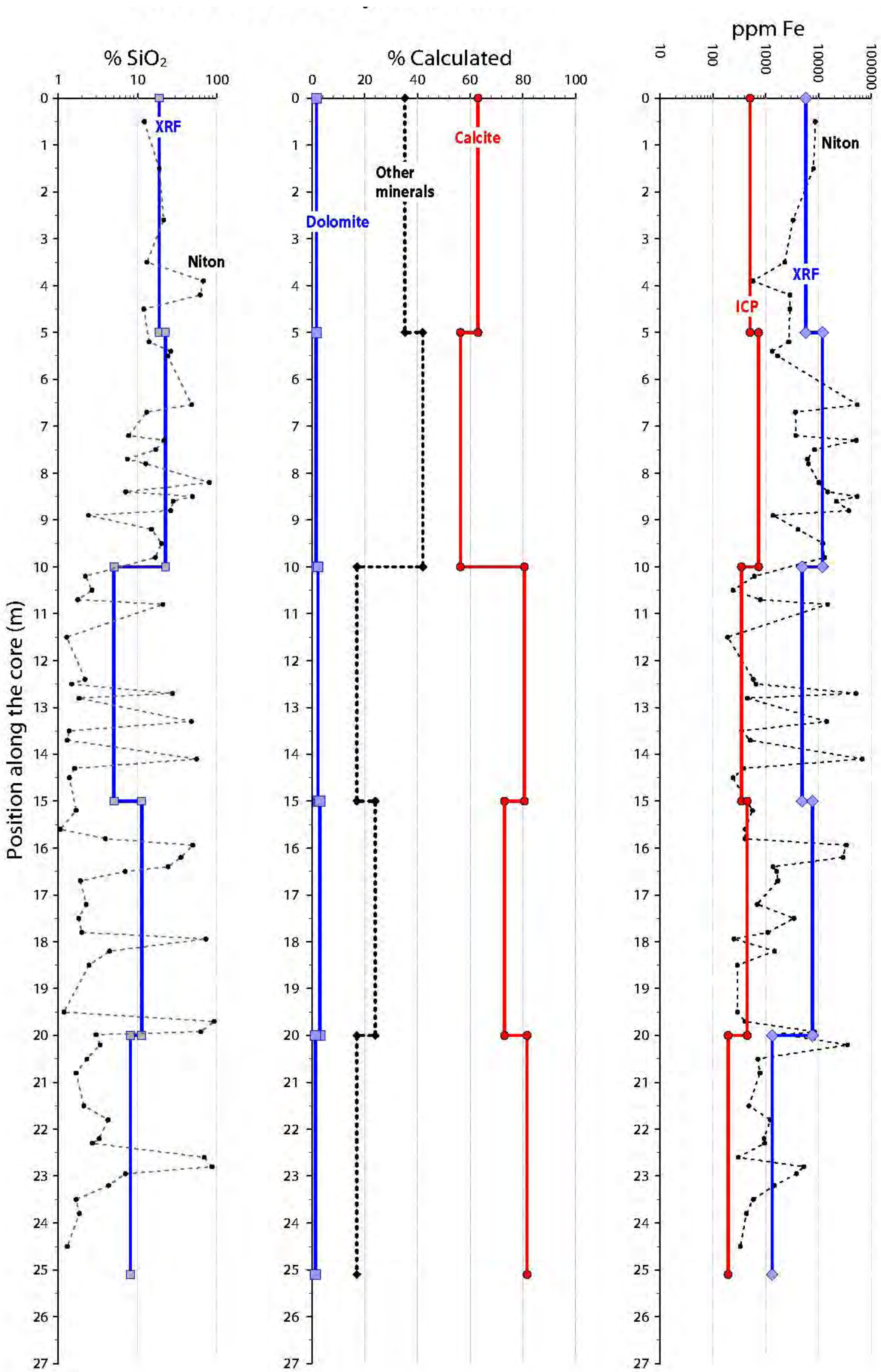


Figure 7: Variations in SiO_2, Fe and major mineral content along borehole LR2.

2.3 Core photographs LR2

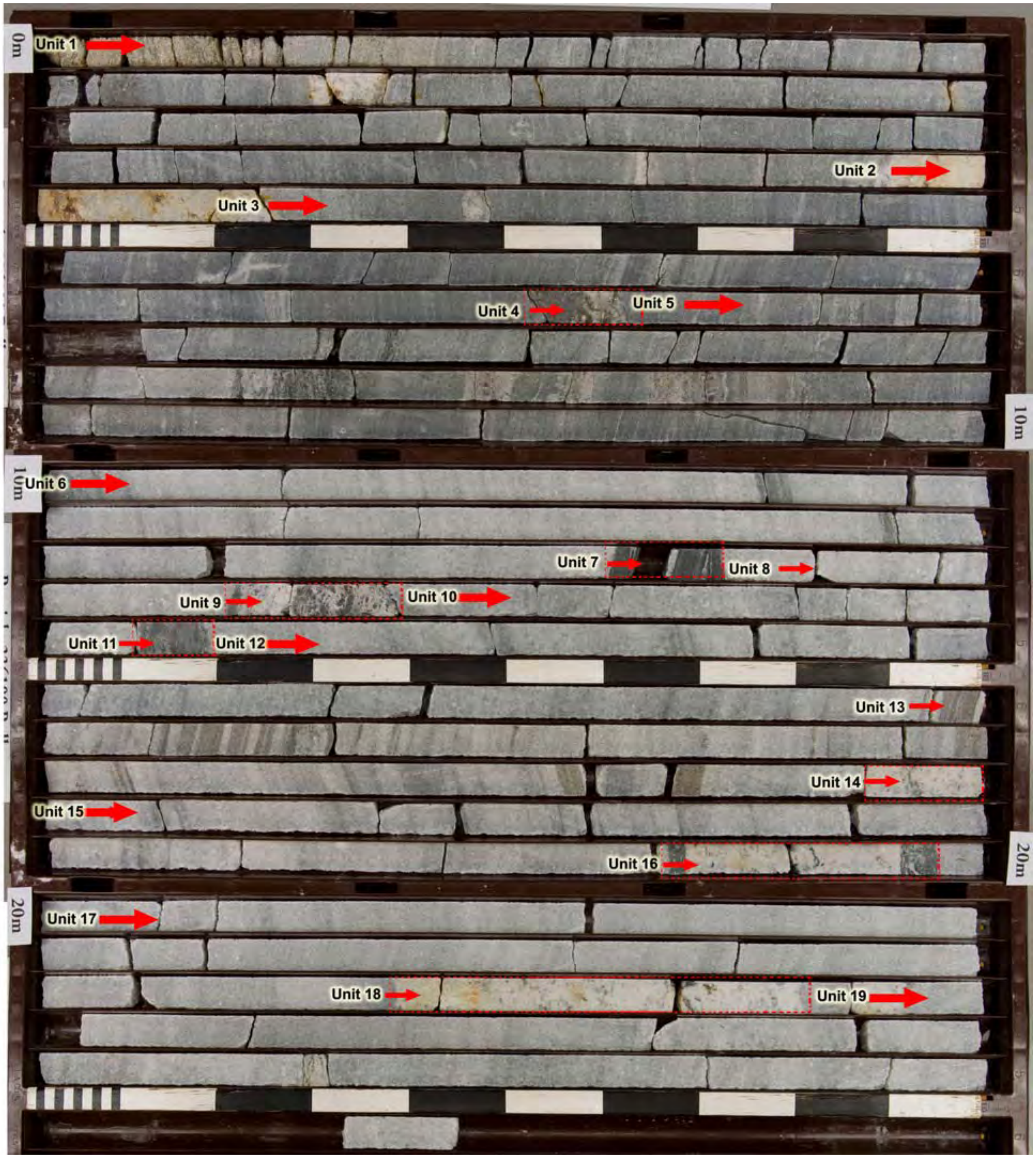


Figure 8: Overview photograph of the LR2 core.

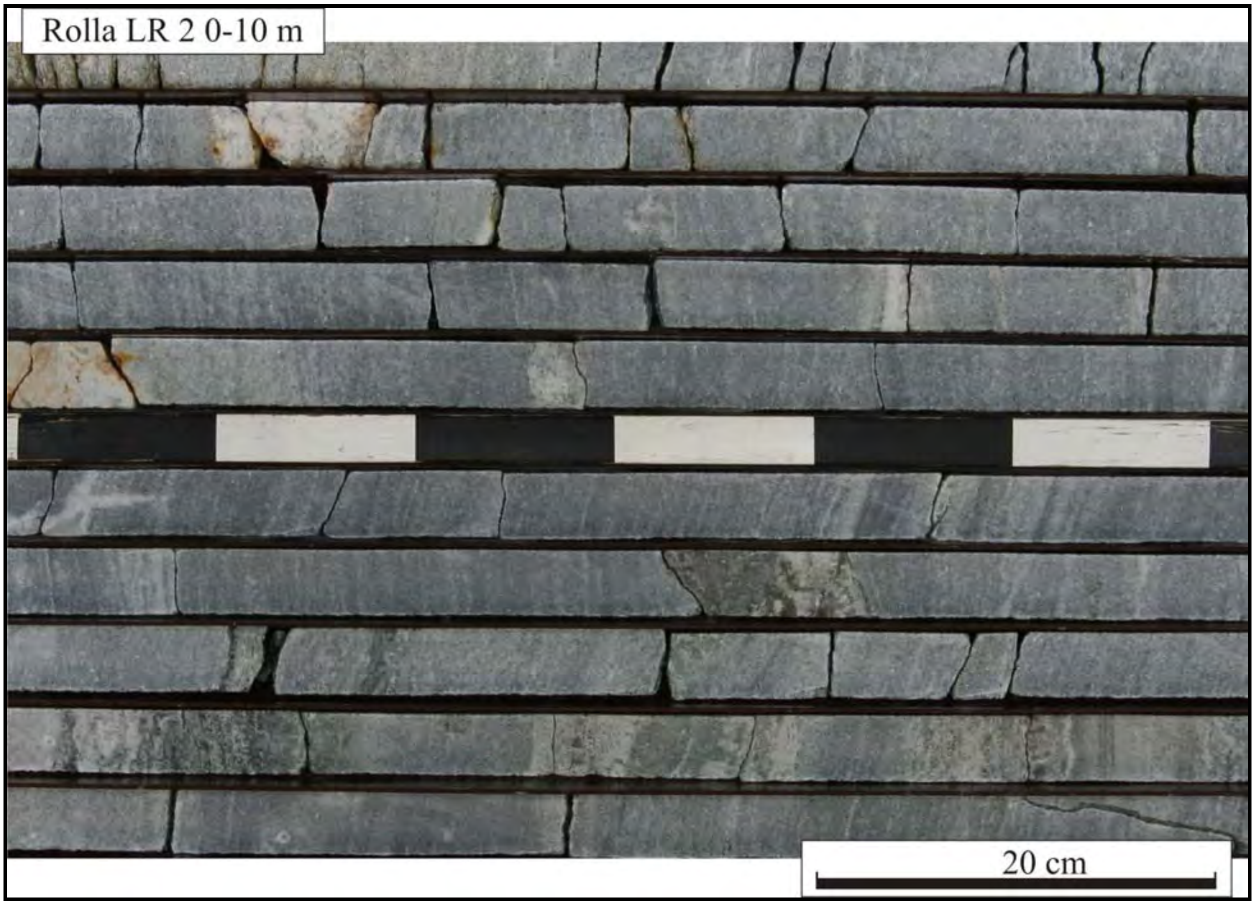


Figure 9: Photograph of fine to medium grained, variably banded, dark-greenish marble enriched in silicate minerals.

Figure 10: Weakly banded, dark grey marble enriched in silicate minerals, LR2 at 5,5 m.

Figure 11: Pale grey marble with mica-rich (mica schist) layers, LR2 at 16,3 m.

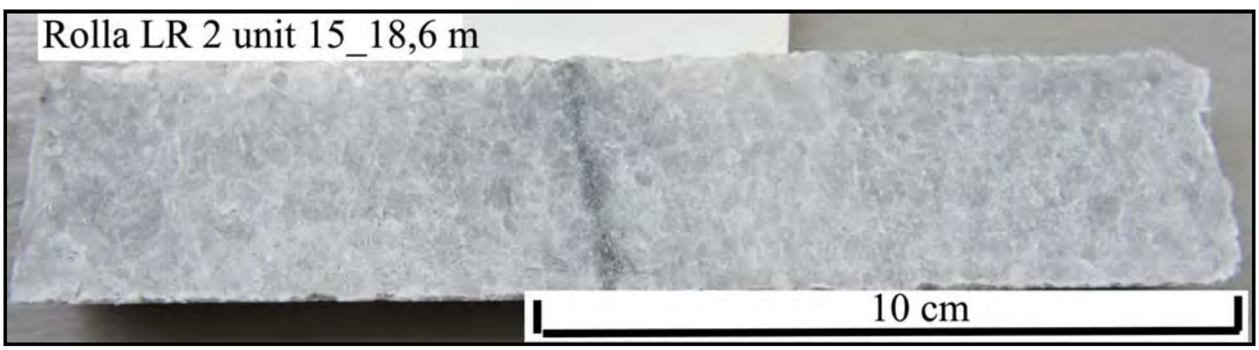


Figure 12: White coarse-grained, fairly pure marble, LR2 at 18,6 m.

2.4 Micrographs LR2

2.4.1 Thin section LR2-7.0 m

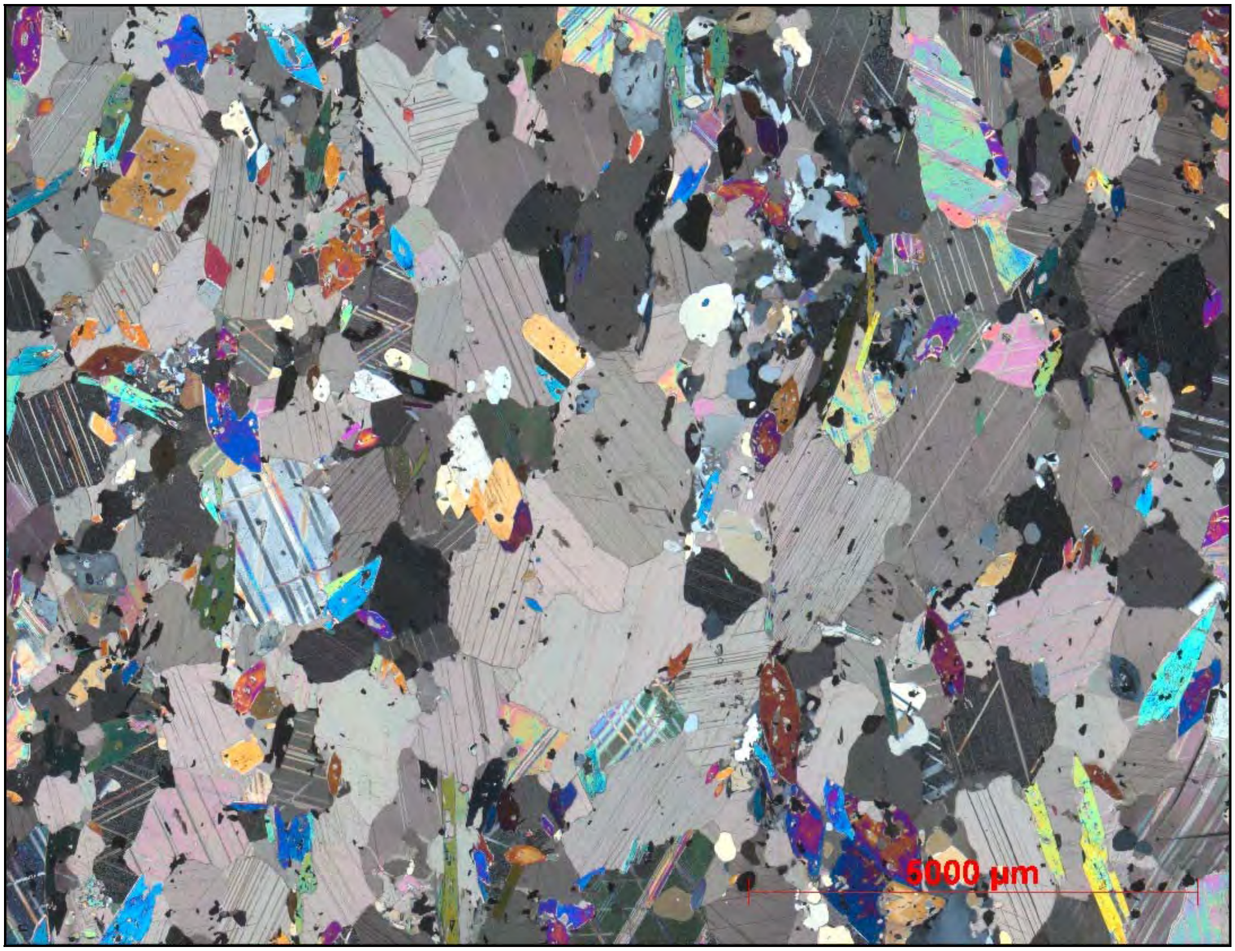


Figure 13: Mosaic microphotograph of impure marble, thin section LR2-07,0m. Characteristic non-carbonate minerals are mainly quartz, mica, pyroxene (diopside), graphite and pyrite.

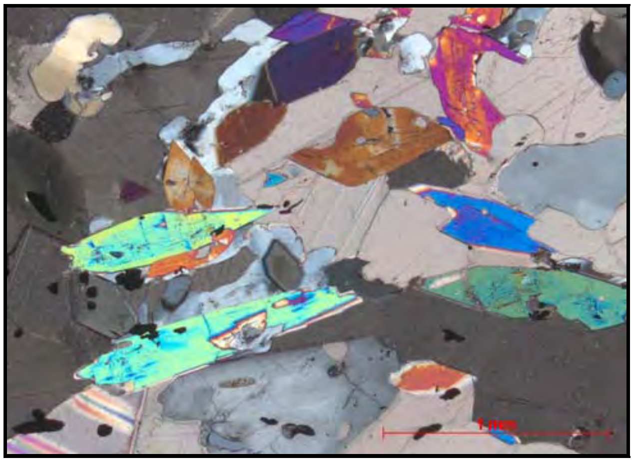


Figure 14: Microphotograph showing silicate minerals (mainly mica) and graphite (black) in calcite. Thin section LR2-07,0m.

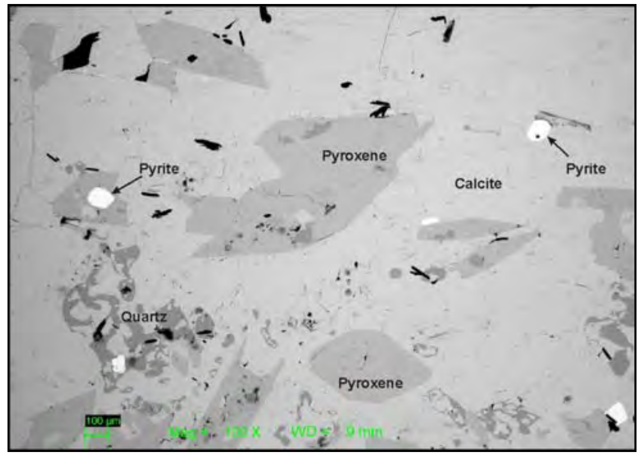


Figure 15: SEM BSE-image showing silicate minerals (shades of gray), pyrite (white) and graphite (black) in calcite (light grey). Thin section LR2-07,0m.

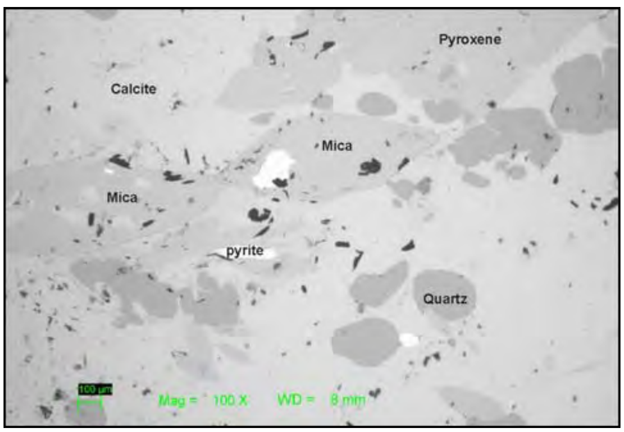


Figure 16: SEM BSE-image showing silicate minerals (shades of gray such as mica), pyrite (white) and graphite (black) in calcite (light grey). Thin section LR2-07,0m.

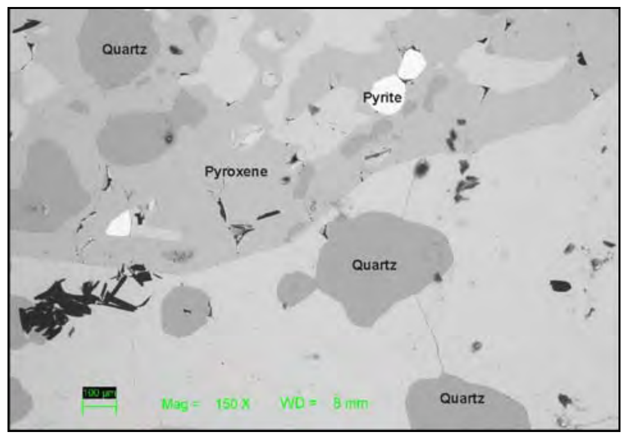


Figure 17: SEM BSE-image showing silicate minerals (shades of gray), pyrite (white) and graphite (black) in calcite (light grey). Thin section LR2-07,0m.

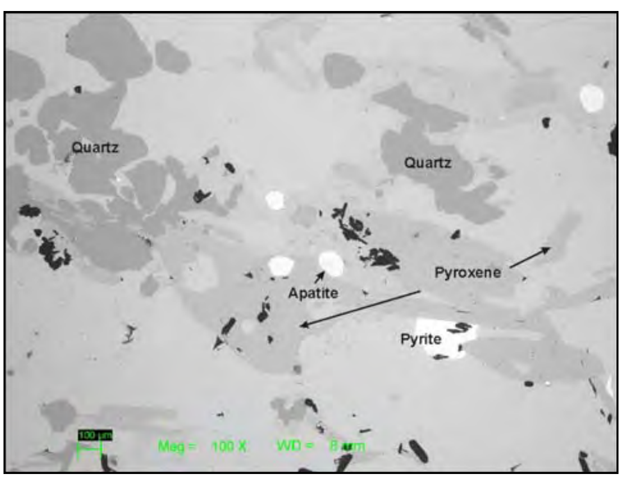


Figure 18: SEM BSE-image showing silicate minerals (shades of gray), pyrite (white) and graphite (black) in calcite (light grey). Thin section LR2-07,0m.

2.4.2 Thin section LR2-12.9

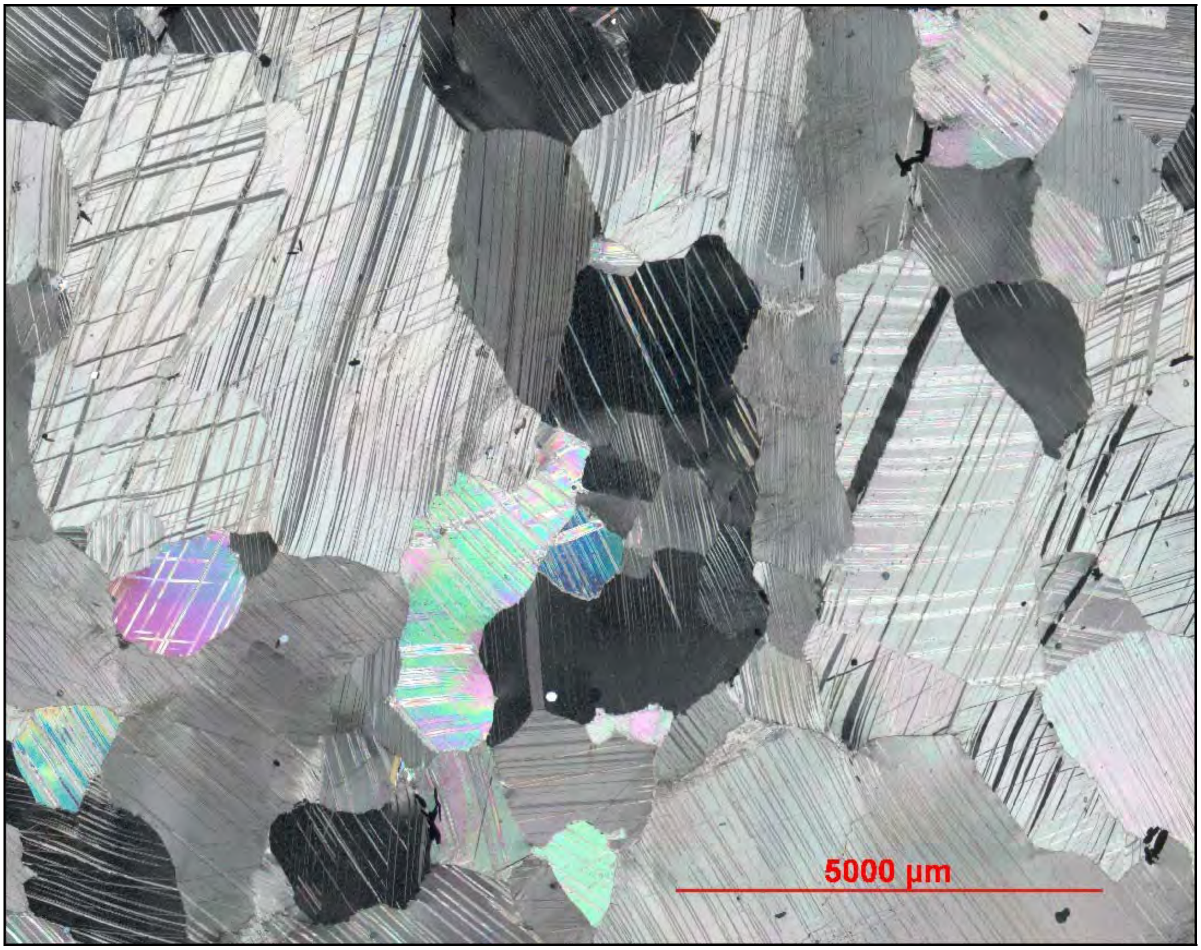


Figure 19: Mosaic microphotograph of very pure coarse-grained calcite marble with minor quartz, graphite, apatite and pyrite. Thin-section LR2-12.9m.

Figure 20: Microphotograph showing graphite (black) on calcite grain boundary. Thin-section LR2 12.9 m.

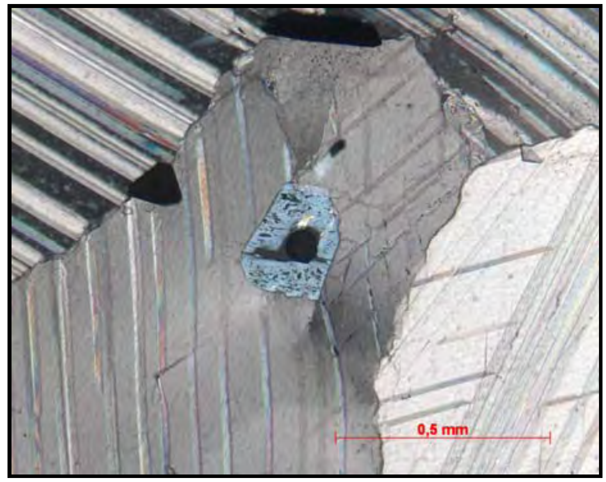


Figure 21: Microphotograph of unknown mineral (bluish) and graphite (black) within large calcite crystal. Thin-section LR2 12.9 m.

Figure 22: Microphotograph of unknown mineral within calcite. Thin-section LR2 12.9 m.

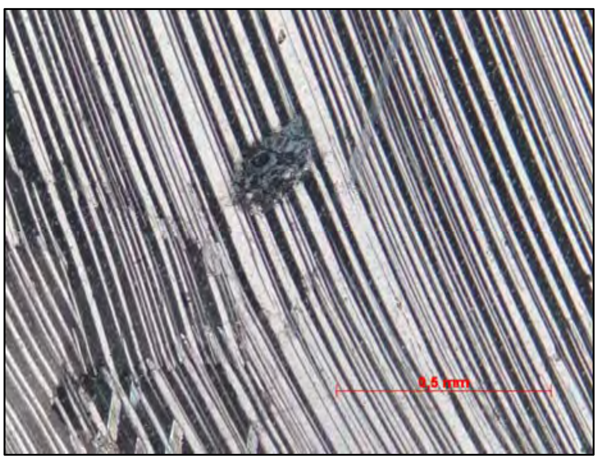
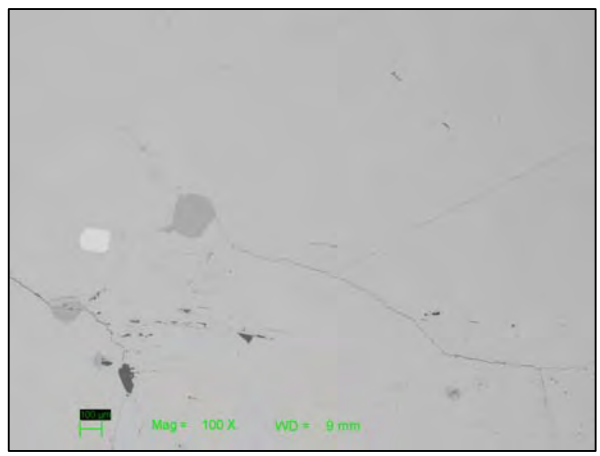


Figure 23: SEM BSE-image of tiny inclusions of silicate minerals in calcite. Thin-section LR2 12.9 m.



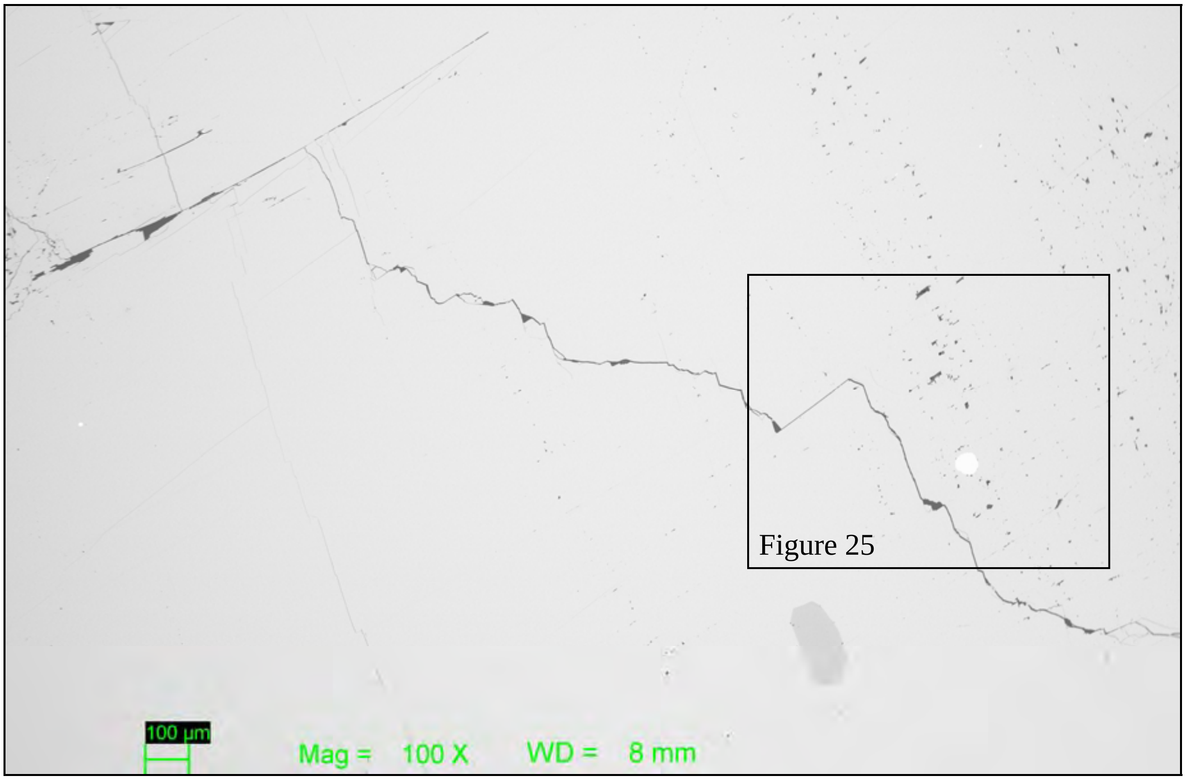


Figure 24: SEM BSE-image of coarse-grained calcite marble. Thin-section LR2 12.9 m.

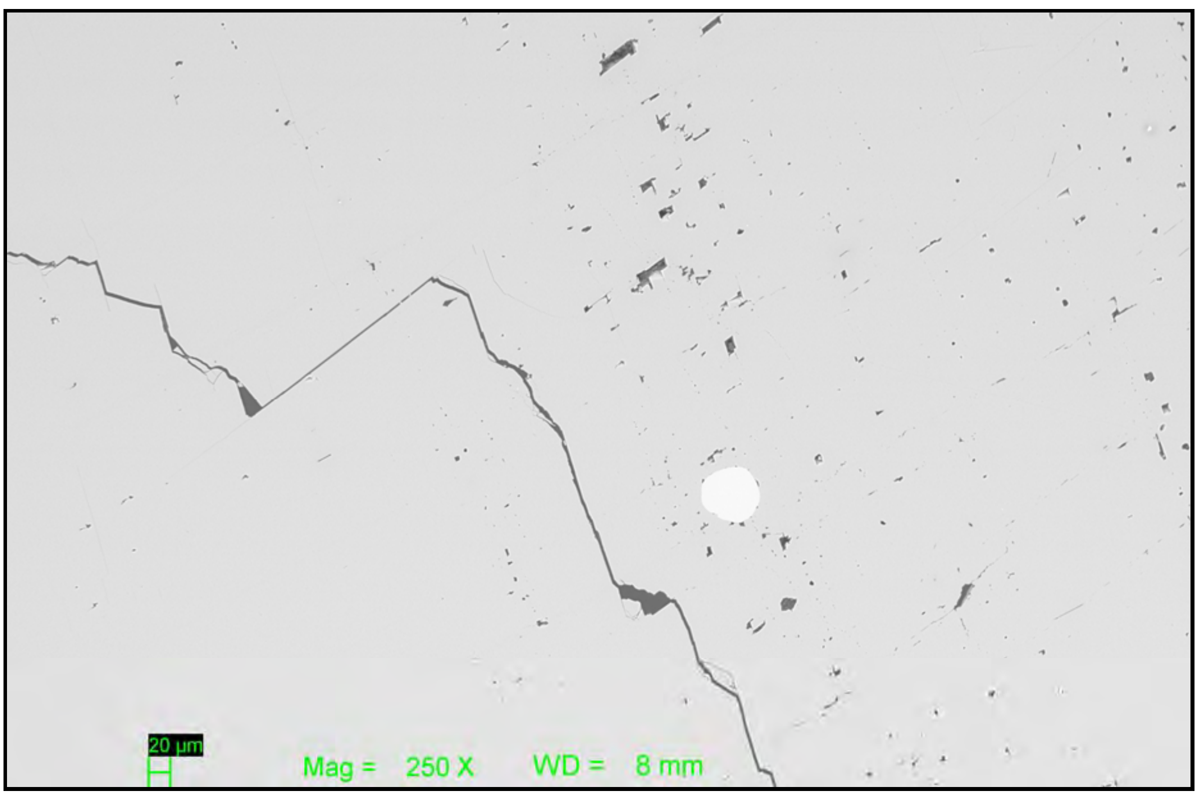


Figure 25: SEM BSE-image showing tiny graphite (black) inclusions in calcite. The rounded white grain is apatite. Thin-section LR2-12.9 m.

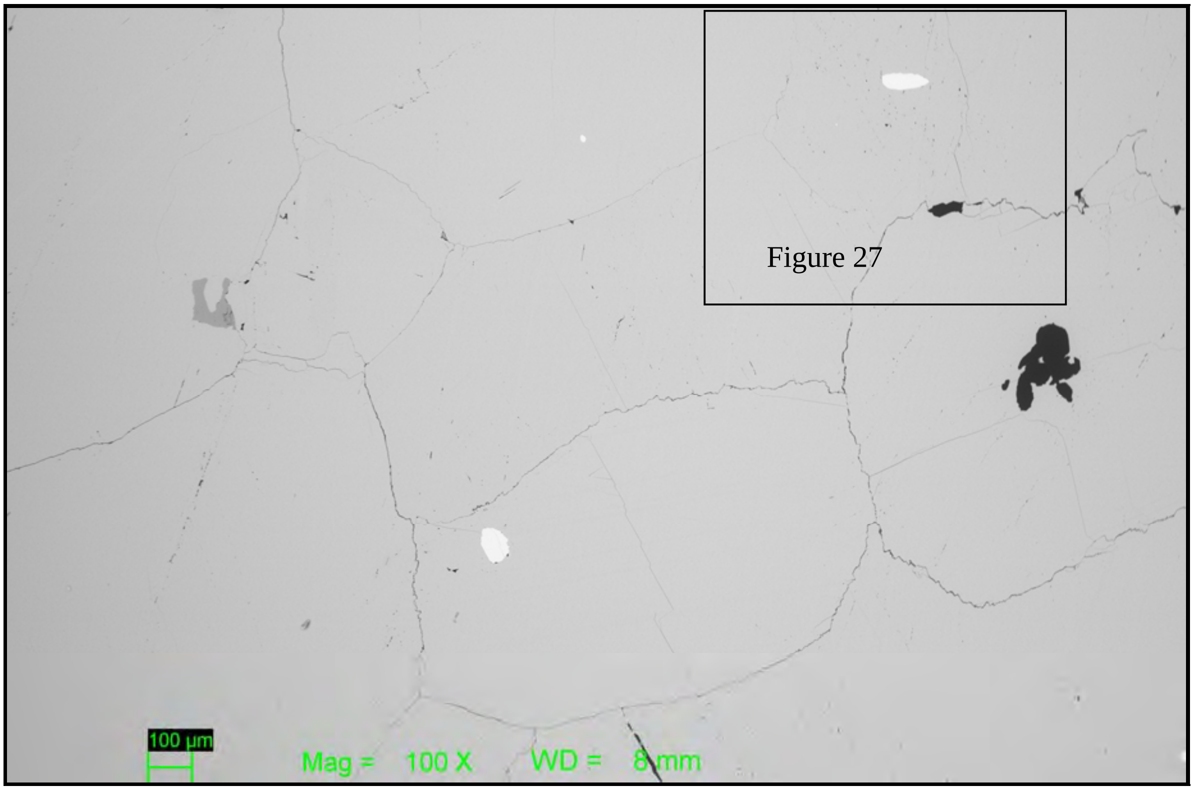


Figure 26: SEM BSE-image of coarce-grained calcite marble with tiny inclusions of graphite (black) and apatite (white). Thin-section LR2-12.9 m.

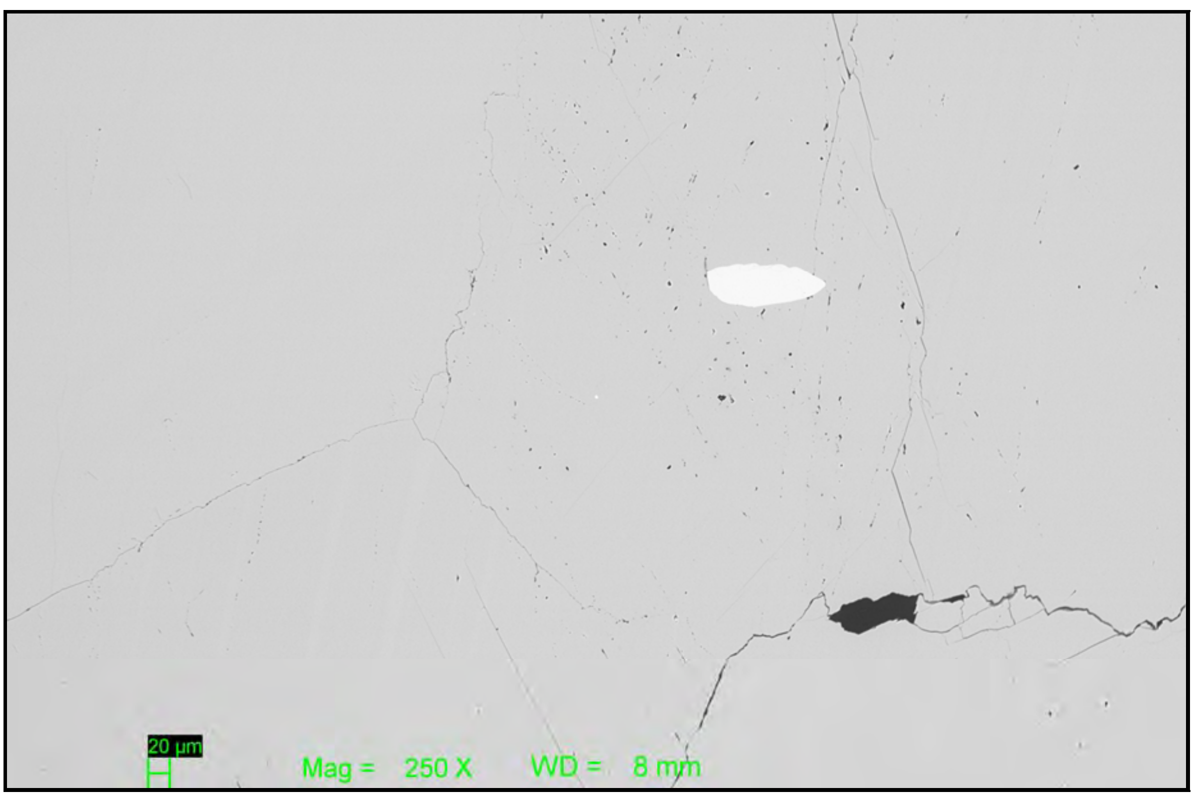


Figure 27: Section from the previous image showing tiny inclusions of graphite in calcite. Thin-section LR2-12.9 m.

3. Borehole LR3 Beivollia

3.1 Core description LR3

Table 7: Comments on borehole LR3 Breivollia.

Unit	Location	Rock-description
1	0- 8,9m	Impure dark grey, banded, fine- to medium grained calcite marble. Silicate minerals are mainly quartz, mica (phlogopite?), amphibole (hornblende?) and pyroxene (diopside). The sulphide (pyrite) and graphite content is distinct.
2	8,9-15,67m	White to pale grey, medium to coarse-grained calcite marbles with locally distinct graphite and pyrite content. Dark grey parts are presumably relics of the bedding in the previous stage carbonate before recrystallisation. Towards the next unit there is a significant increase in phlogopite content, and a sulphur-smell is distinctly noticeable when the rock is fractured. *Thin section LR3_12.7m*
3	15,67-16,5m	Dark green to black amphibolitic schist.
4	16,5-18,5	White to pale grey, medium to coarse-grained marble with locally distinct graphite (parallel oriented) and pyrite content. Towards the next unit there is a distinct increase in phlogopite. A sulphur-smell is distinctly noticeable when the rock is fractured
5	18,5-18,95m	Dark green to black amphibolitic schist appears to be the same as unit 3.
6	18,95 - 21,2	Similar to unit 2. Particularly mica-rich layers within the interval 20,2-21,2m
7	21,2-22,80m	Similar to unit 2. Pale to dark grey, banded, coarse-grained calcite marble. Distinct sulphur-smell is recognized when fracturing the rock. *Thin section LR3_21.9m*
8	22,80-23,64m	Similar to unit 3. Brown, medium grained amphibole-bearing quartz-mica schist, locally rich in sulphides and graphite.
9	23,64-25,2m	Very similar to unit 2 and 7. Grey, coarse-grained marble.
10	25,2-26,5m	Mixed mica-schist and marble. High amount of quartz was observed. The schist is altered (?) with green, very soft material consisting of amphibole, brucite or talc?

3.2 Chemical analyses LR3

Table 8: Analyses, borehole LR3 Breivollia.

Locality		Breivollia	Breivollia	Breivollia	Breivollia	Breivollia
Borehole		LR3	LR3	LR3	LR3	LR3
Sample		LR3_00-05	LR3_05-10	LR3_10-15	LR3_15-20	LR3_20-26.7
NGU identification no		101694	101695	101696	101697	101698
From-to (m)		0-5	5-10	10-15	15-20	20-26.7
$SiO_{2\ XRF}$	%	23,00	18,40	0,74	19,00	14,10
$Al_2O_{3\ XRF}$	%	2,64	1,84	0,13	4,25	2,93
$Fe_2O_{3\ XRF}$	%	2,03	1,32	0,06	1,84	0,91
$TiO_{2\ XRF}$	%	0,18	0,11	-0,01	0,24	0,19
MgO_{XRF}	%	5,36	4,11	0,70	1,16	2,88
CaO_{XRF}	%	38,00	42,10	52,90	40,60	42,80
Na_2O_{XRF}	%	0,41	0,34	-0,10	0,62	0,45
K_2O_{XRF}	%	0,24	0,22	0,01	0,93	0,69
MnO_{XRF}	%	0,04	0,03	-0,01	0,05	0,04
$P_2O_{5\ XRF}$	%	0,21	0,20	0,07	0,10	0,09
LOI_{XRF}	%	26,80	31,30	43,10	30,50	34,30
SUM_{XRF}	%	98,91	99,98	97,59	99,29	99,37
Ca_{ICP}	ppm	228000	260000	363000	259000	281000
CaO_{ICP}	%	31,90	36,37	50,78	36,23	39,31
CaO_{ICP} vs. CaO_{XRF}	%	84	86	96	89	92
Mg_{ICP}	ppm	2960	3670	3730	3100	10300
MgO_{ICP}	%	0,49	0,61	0,62	0,51	1,71
MgO_{ICP} vs. MgO_{XRF}	%	9	15	88	44	59
Fe_{ICP}	ppm	14190	9227	426	12862	6347
Fe_{ICP}	ppm	1400	1160	115	2260	1500
Mn_{ICP}	ppm	310	255	nd	418	294
Mn_{ICP}	ppm	210	179	43	117	239
$Fe+Mn_{XRF}$	ppm	14499	9482	426	13280	6641
$Fe+Mn_{ICP}$	ppm	1610	1339	158	2377	1739
$Fe+Mn_{ICP}$ vs. $Fe+Mn_{XRF}$	%	11	14	37	18	26
P_{ICP}	ppm	937	833	316	459	407
Ba_{ICP}	ppm	15,8	9,7	13,1	18,2	7,4
Sr_{ICP}	ppm	1640	1780	2290	1920	1110
$Dolomite_{Calculated}$	%	2,2	2,8	2,8	2,4	7,8
$Calcite_{Calculated}$	%	55,5	63,2	88,7	63,1	65,6
$Others_{Calculated}$	%	42,3	34,1	8,4	34,5	26,5
S_{LECO}	%	0,098	0,073	< 0,01	0,129	0,048
TC_{LECO}	%	8,27	9,58	12,68	8,92	9,77
TOC_{LECO}	%	0,72	0,72	0,17	0,12	0,23

Table 9: Semi-quantitative analyses by Niton portable XRF, LR3 Breivollia.

Bh	Pos. (m)	% SiO_2	CaO	ppm Fe	Pos. (m)	% SiO_2	CaO	ppm Fe	Pos. (m)	% SiO_2	CaO	ppm Fe
LR3	0,50	31,8	34,53	10310	12,30	1,1	54,49	320	20,60	2,2	53,20	1040
LR3	1,50	19,5	40,56	4800	12,80	1,3	56,16	450	21,50	1,3	33,30	2120
LR3	2,50	6,7	51,62	4720	13,50	1,1	54,70	260	22,50	2,8	54,31	1310
LR3	2,80	11,9	44,12	6790	14,50	1,1	56,86	370	22,50	1,4	56,08	720
LR3	3,20	15,5	40,13	16700	15,10	1,8	56,13	350	22,80	32,8	25,09	18580
LR3	3,50	22,6	33,78	29860	15,50	12,5	49,11	4430	22,90	37,4	21,91	15250
LR3	3,80	7,0	37,20	8060	15,60	5,4	50,03	4190	23,30	63,4	3,98	18660
LR3	4,20	11,2	29,60	24680	15,80	61,1	4,21	27040	23,60	59,0	8,84	9530
LR3	4,50	9,5	46,61	6190	15,80	67,1	4,08	25590	23,90	1,7	55,53	1220
LR3	5,50	12,1	42,55	11740	16,30	62,3	3,03	39940	24,50	0,8	55,97	440
LR3	5,80	20,6	41,98	2700	16,40	64,4	3,59	39730	25,30	3,5	54,63	5070
LR3	6,30	28,3	37,96	2360	16,60	2,1	50,42	4180	25,80	66,8	3,98	340
LR3	6,80	16,0	38,76	11280	16,80	3,0	57,02	610				
LR3	7,30	13,7	46,11	7100	17,50	2,2	56,51	540				
LR3	7,80	17,3	42,24	13420	18,30	1,6	55,27	400				
LR3	8,30	20,4	40,04	10660	18,50	2,8	52,95	2060				
LR3	8,80	14,5	47,42	2860	18,60	36,6	3,98	32700				
LR3	9,30	2,1	54,03	380	18,80	68,6	4,55	33660				
LR3	9,60	1,1	57,97	430	18,95	63,5	5,45	33540				
LR3	10,30	1,9	56,97	260	19,10	1,5	57,11	400				
LR3	11,50	1,2	56,65	350	19,50	1,3	55,79	290				

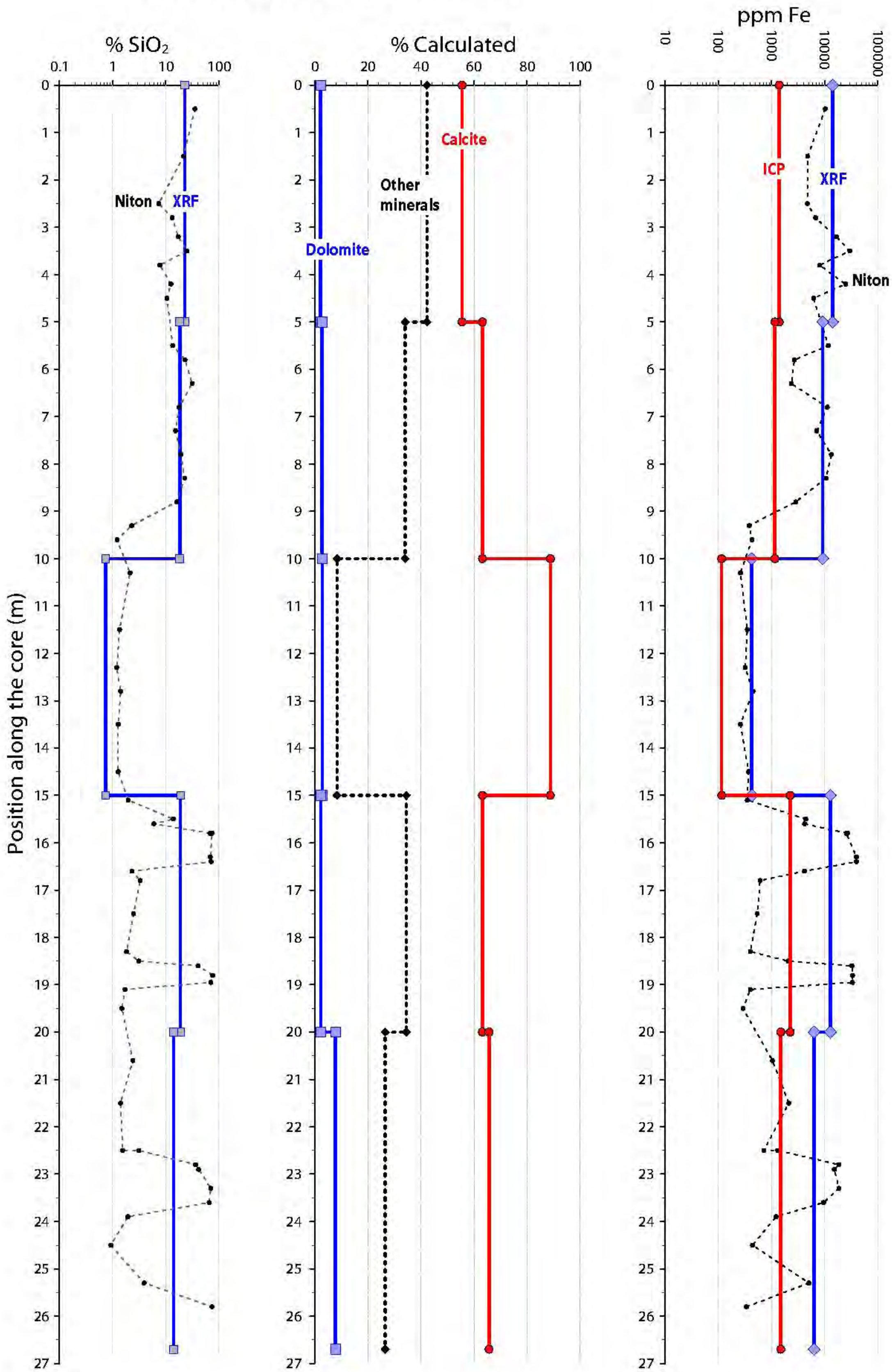


Figure 28: Variations in SiO_2, Fe and major mineral content along borehole LR3.

3.3 Core photographs LR3

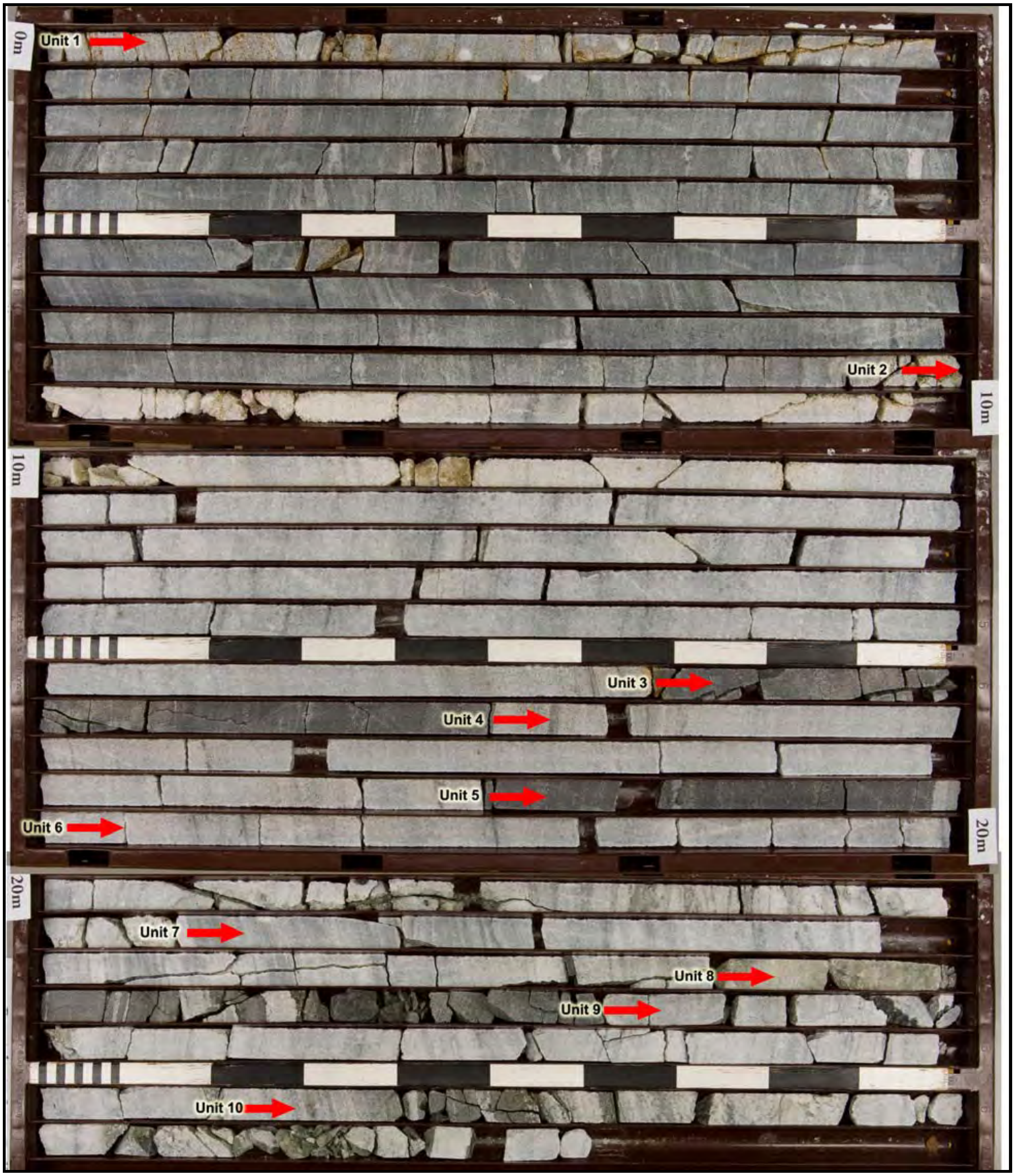


Figure 29: Overview photograph of core LR3.

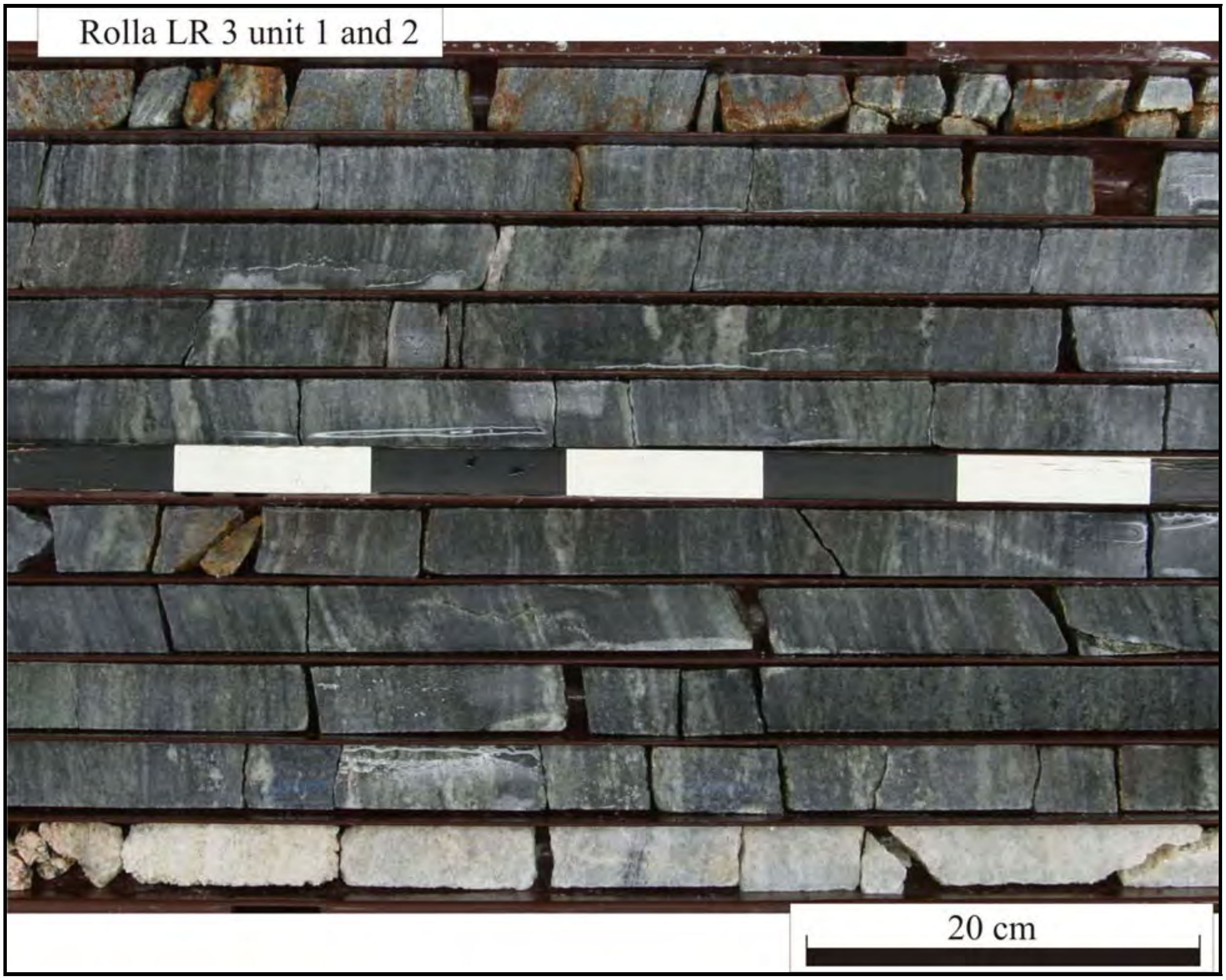


Figure 30: Core photograph of dark grey, banded marble (unit 1) and in lower row of white marble (unit 2), core LR3.

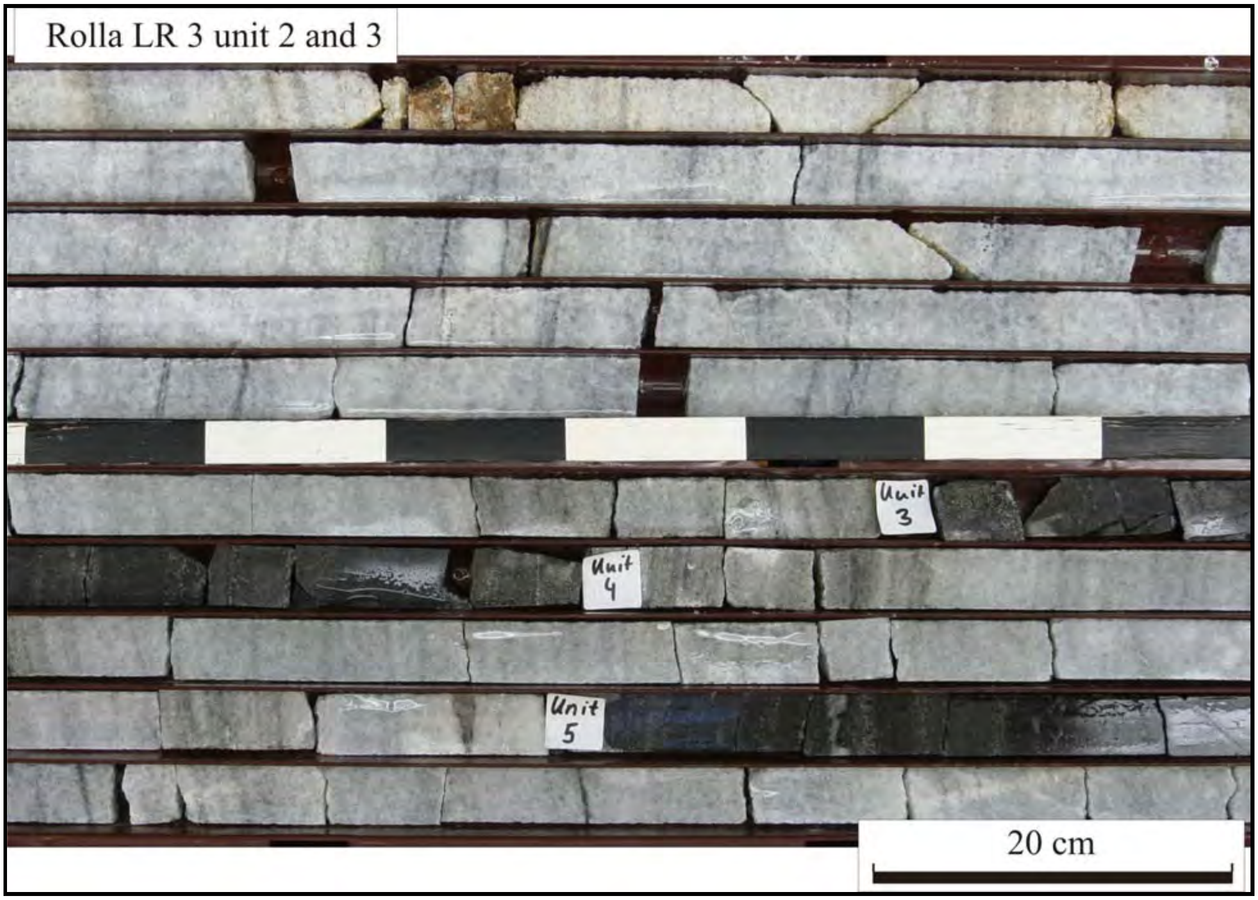


Figure 31: Core photograph of white marble with layers of amphibole-rich schist, core LR3.

Figure 32: Close-up core photograph of calcite-bearing, banded amphibole-rich schist, core LR3.

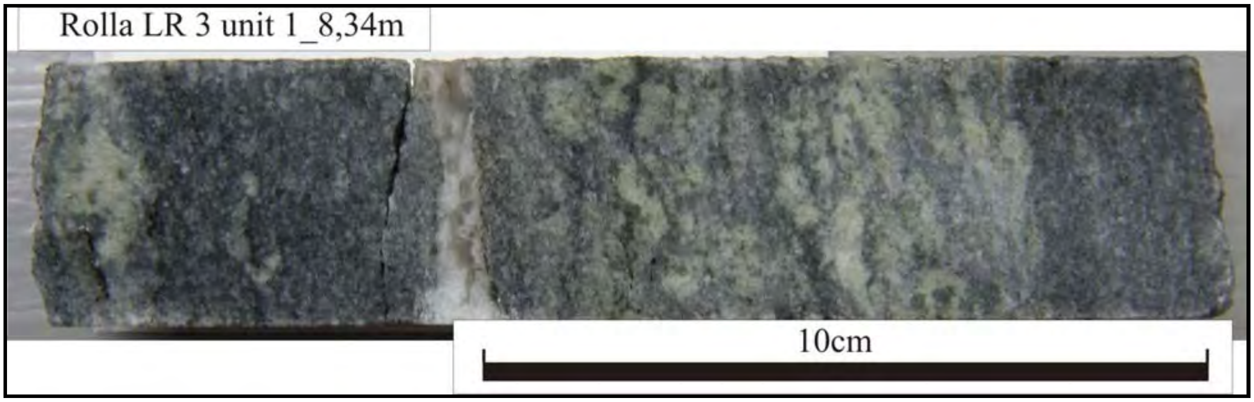


Figure 33: Close-up core photo of impure marble rich in silicate minerals. LR3 at 8,5 m, unit 1.

Figure 34: Close-up core photo of coarse-grained marble with diffuse layeres enriched in graphite. LR3 at 11,3 m, unit 2

Figure 35: Close up core photo of slightly banded pale grey marble with distinct graphite content. LR3 at 16,6 m, unit 4.

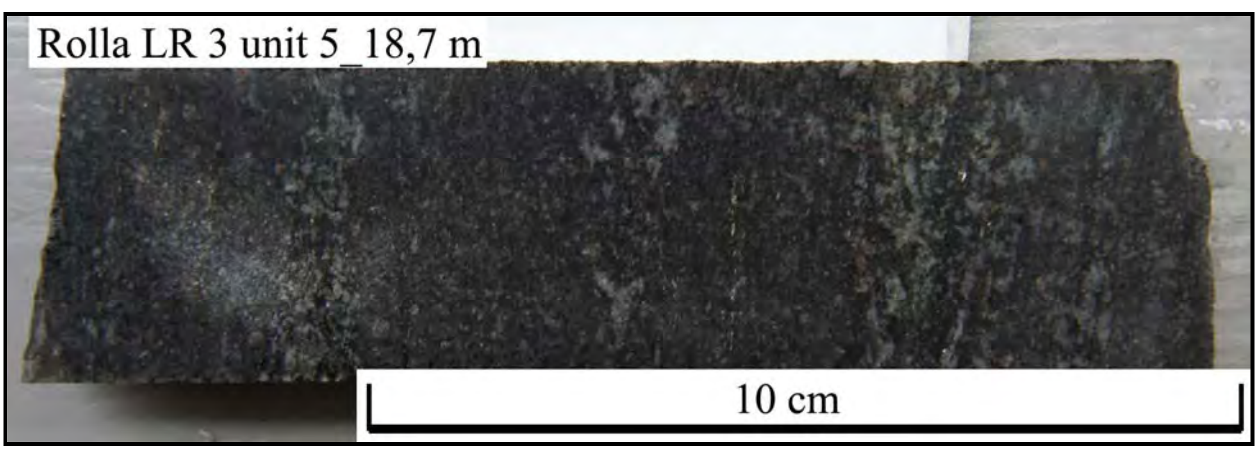


Figure 36: Close-up core photo of amphibolitic schist. LR3 at 18,7 m, unit 5.

3.4 Micrographs LR3

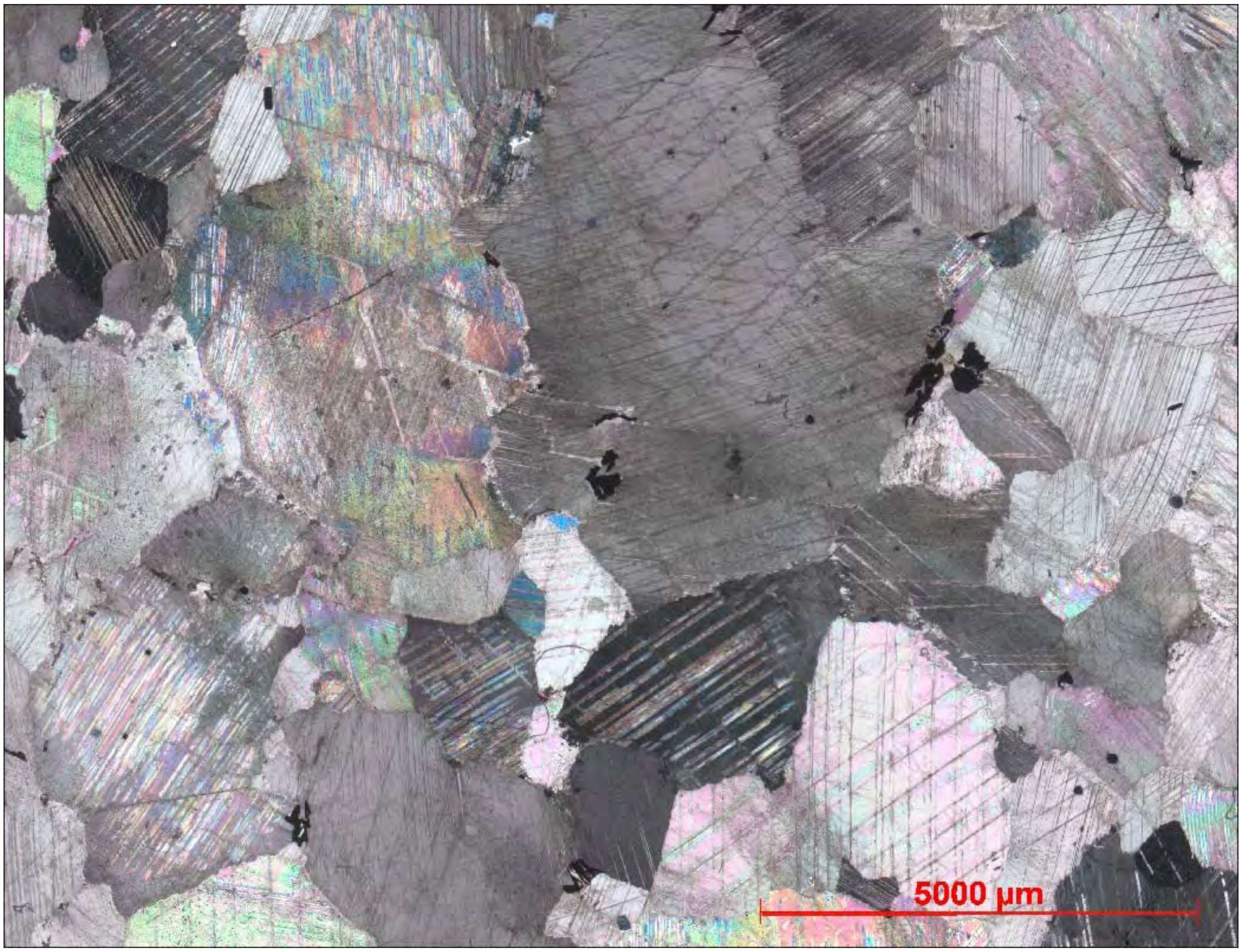


Figure 37: Mosaic-photograph of thin section LR 3 12.2m with calcite crystals. The crystal boundaries vary between very straight to irregular. Graphite and silicate minerals are interlocked with the calcite crystals.

3.4.1 Thin-section LR3-12.2 m

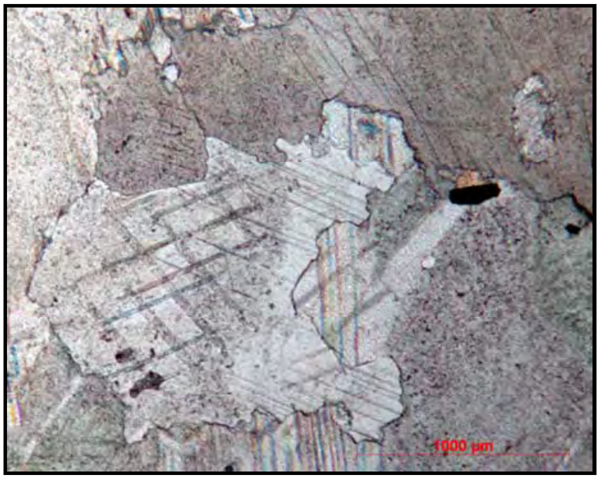


Figure 38: Microphotograph of irregular calcite crystal boundaries. Thin-section LR3-12.2 m.

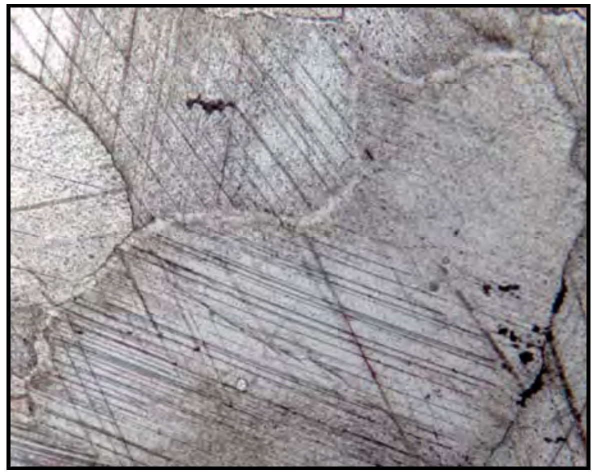


Figure 39: Microphotograph of recrystallisation effect (?) white rim along calcite grain boundaries. Thin-section LR3-12.2 m.

Figure 40: Microphotograph of partly recrystallised calcite carbonate. Thin-section LR3-12.2 m.

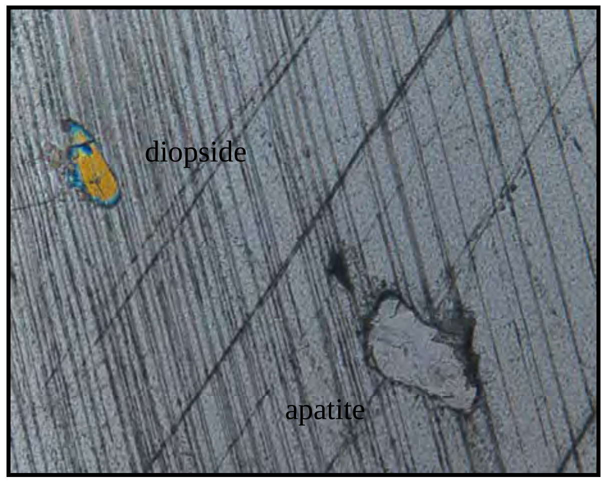


Figure 41: Microphotograph of mineral inclusions (diopside and apatite) in calcite. Thin-section LR3-12.2 m.

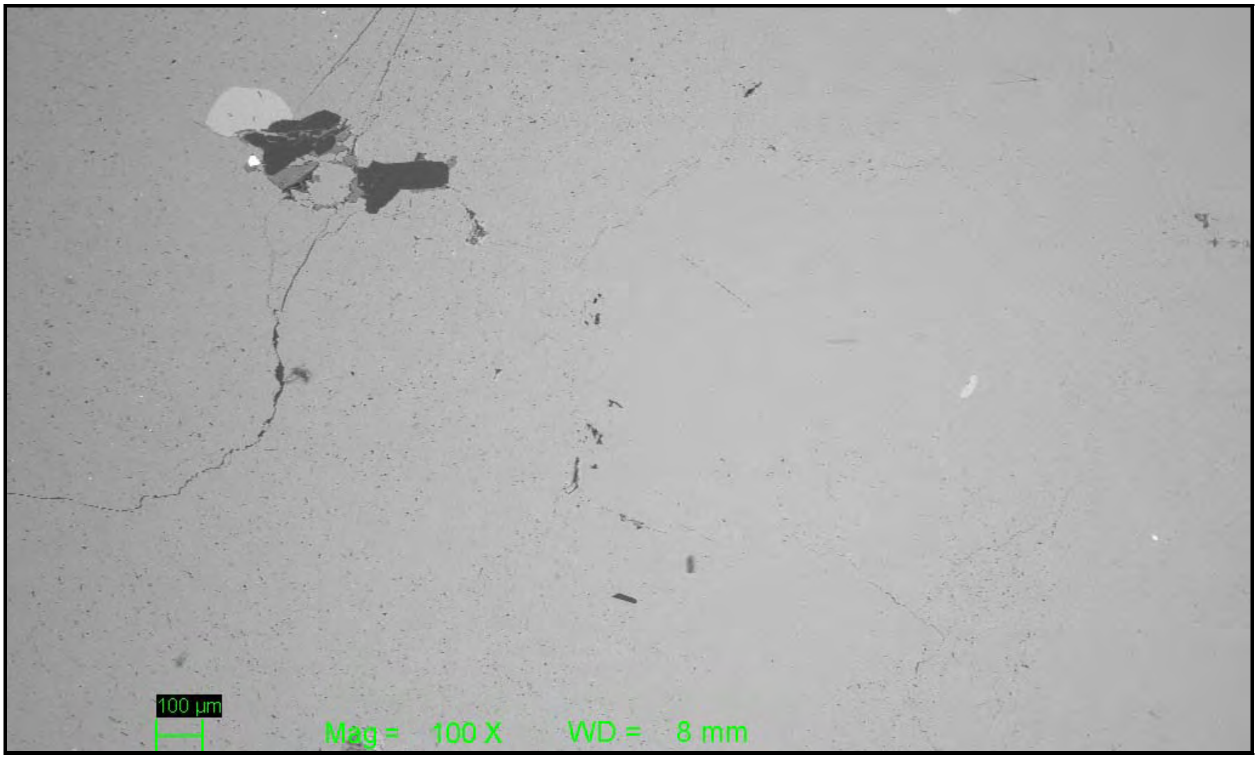


Figure 42: SEM BSE-image of calcite with inclusions of predominantly graphite (black). Thin-section LR3-12.2 m.

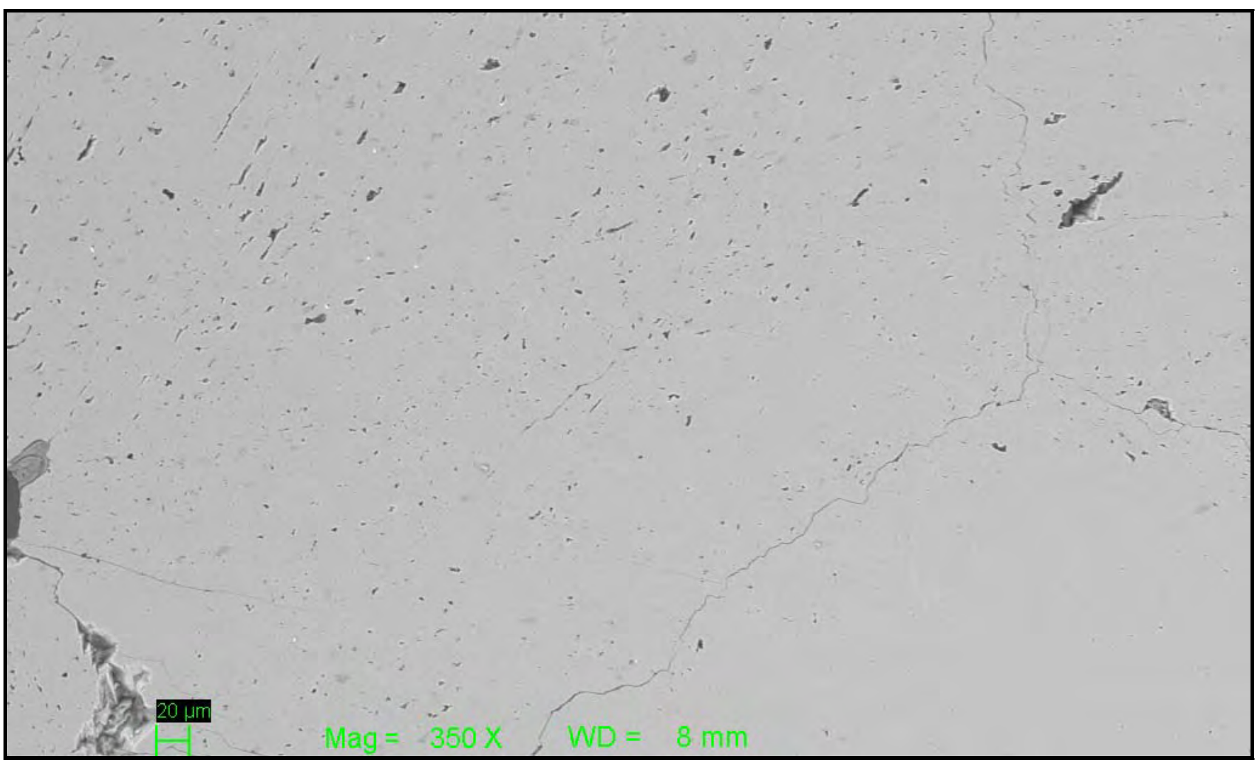


Figure 43: SEM BSE-image showing calcite with numerous tiny inclusions of graphite (black). Thin-section LR3-12.2 m.

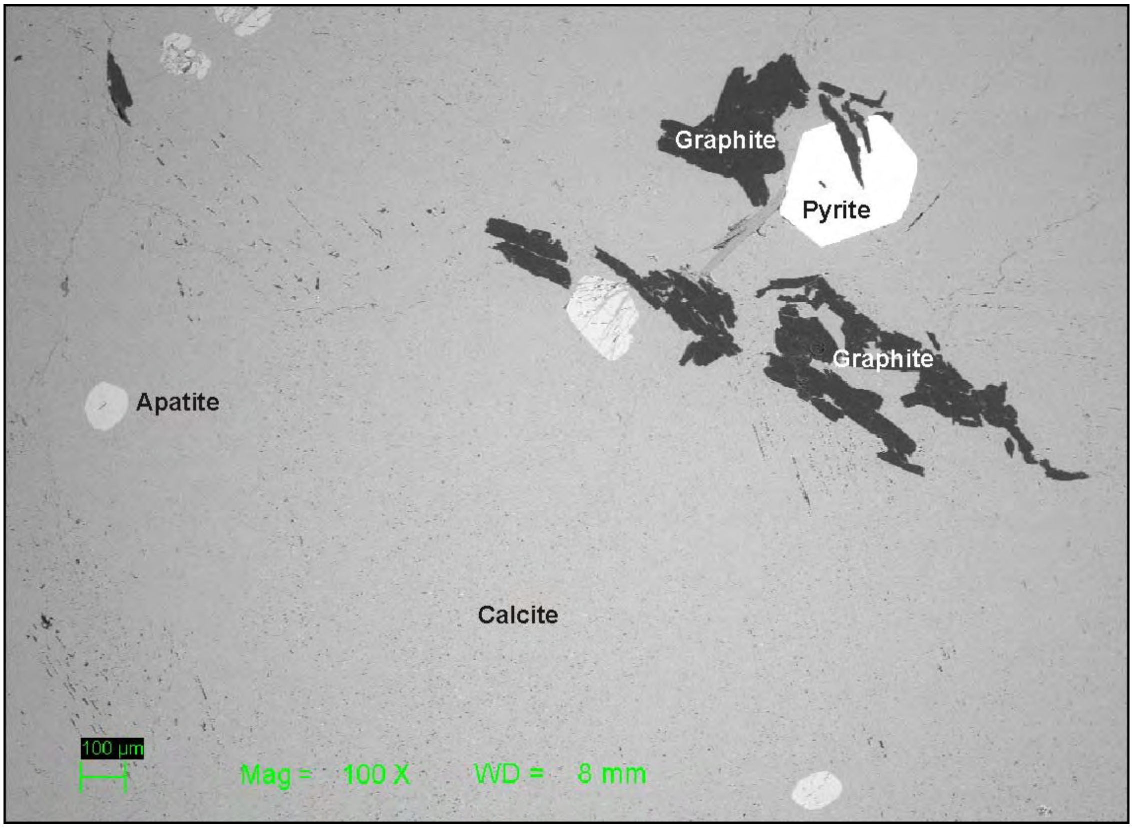


Figure 44: SEM BSE-image of silicate mineral inclusions in calcite; pyrite (white), apatite (light grey) and graphite (black). Thin-section LR3-12.2 m.

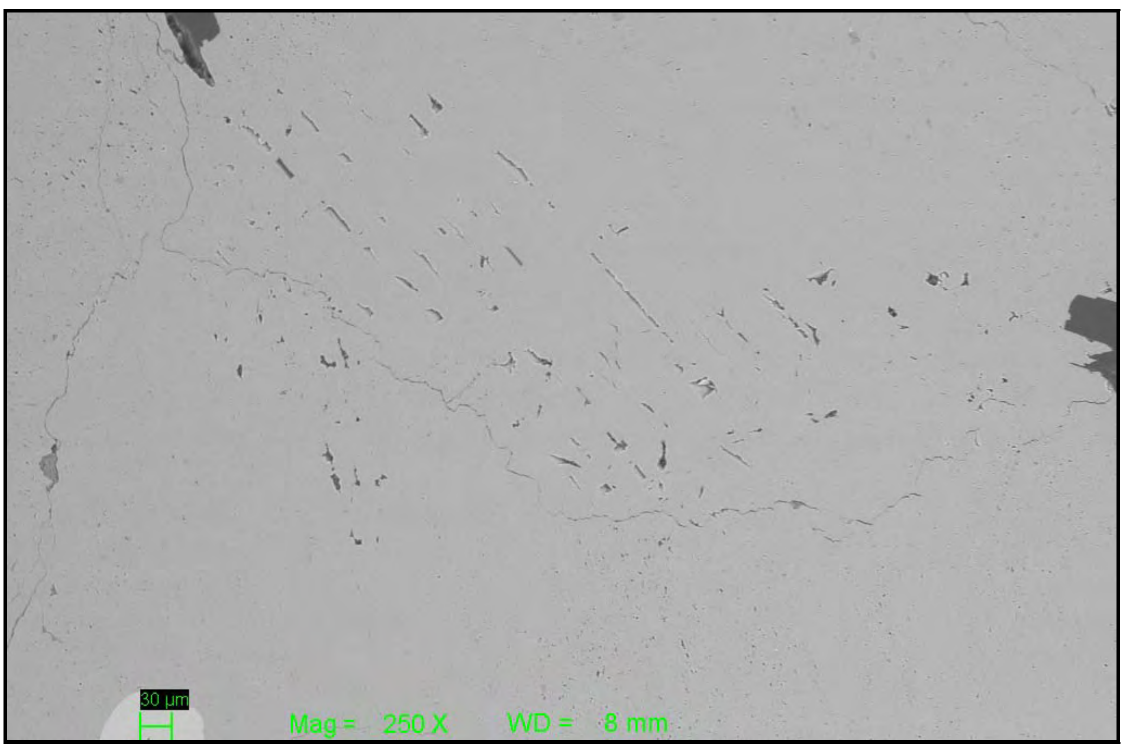


Figure 45: SEM BSE close-up image of the previous image showing numerous inclusions of tiny graphite in calcite. Thin-section LR3-12.2 m.

3.4.2 Thin-section LR3-21.9m

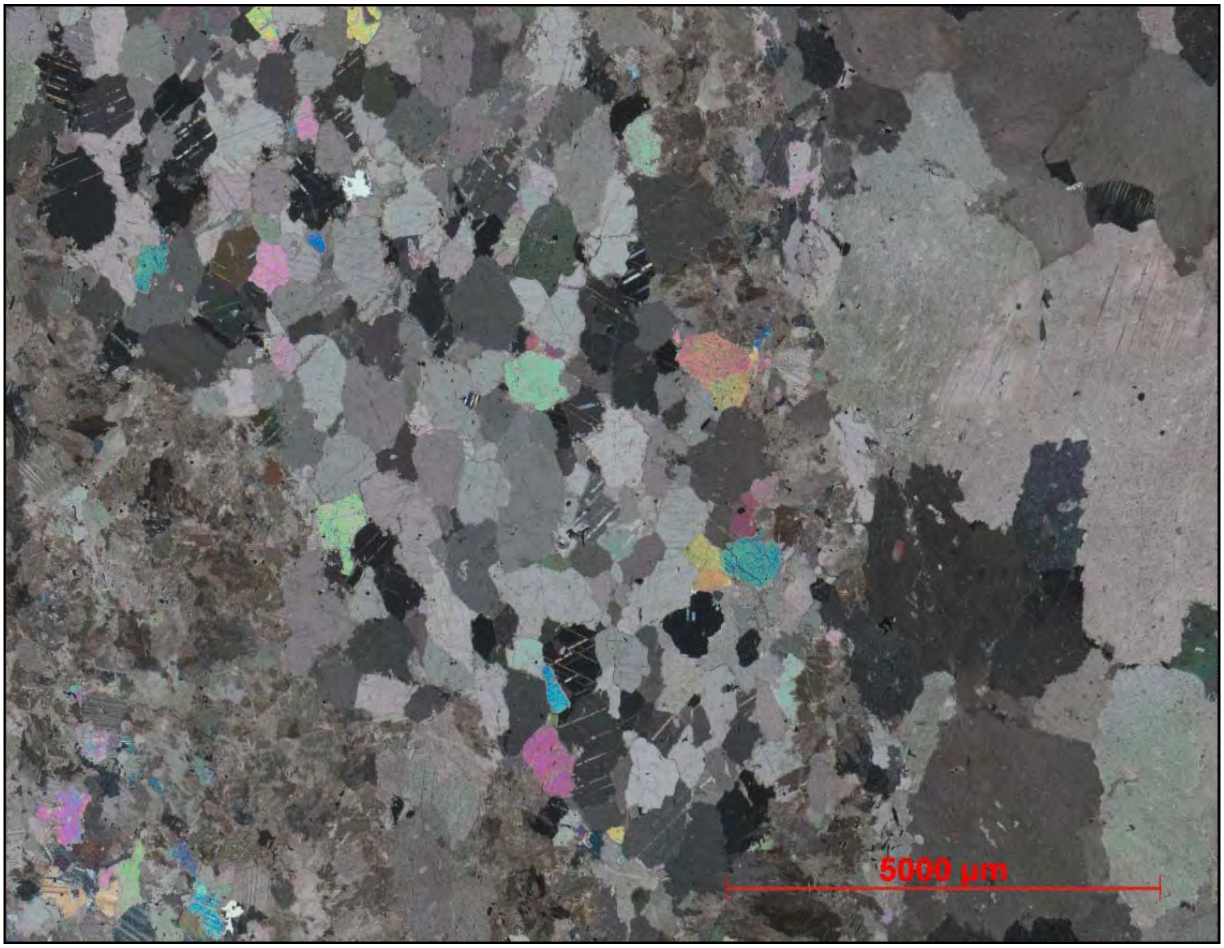


Figure 46: Mosaic microphotograph showing different generations of carbonate (calcite and dolomite). Thin-section LR3-21.9 m.

Calcite is the main mineral of this thin section. Both graphite and mica is present accessorily, but the partly altered minerals and dusty appearance makes it difficult to determine the mineralogy of the micro-inclusions.

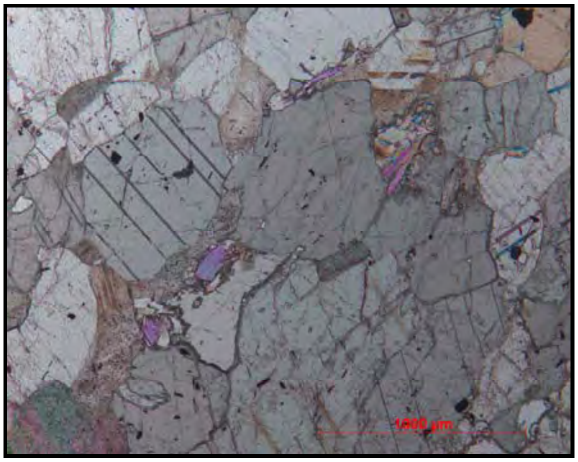


Figure 47: Microphotograph of carbonate with inclusions of other minerals. Thin-section LR3-21.9 m.

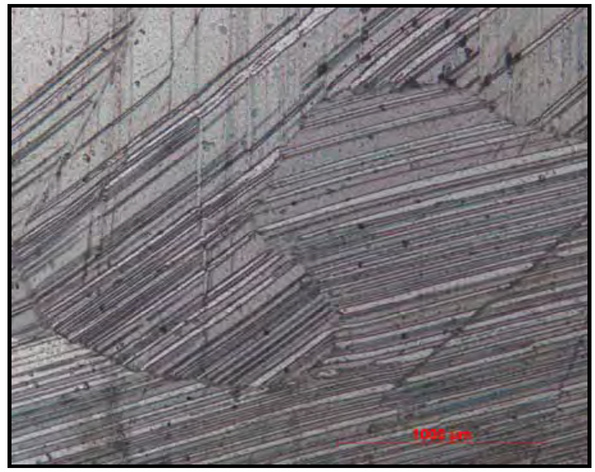


Figure 48: Microphotograph of carbonate crystals. Thin-section LR3-21.9 m.

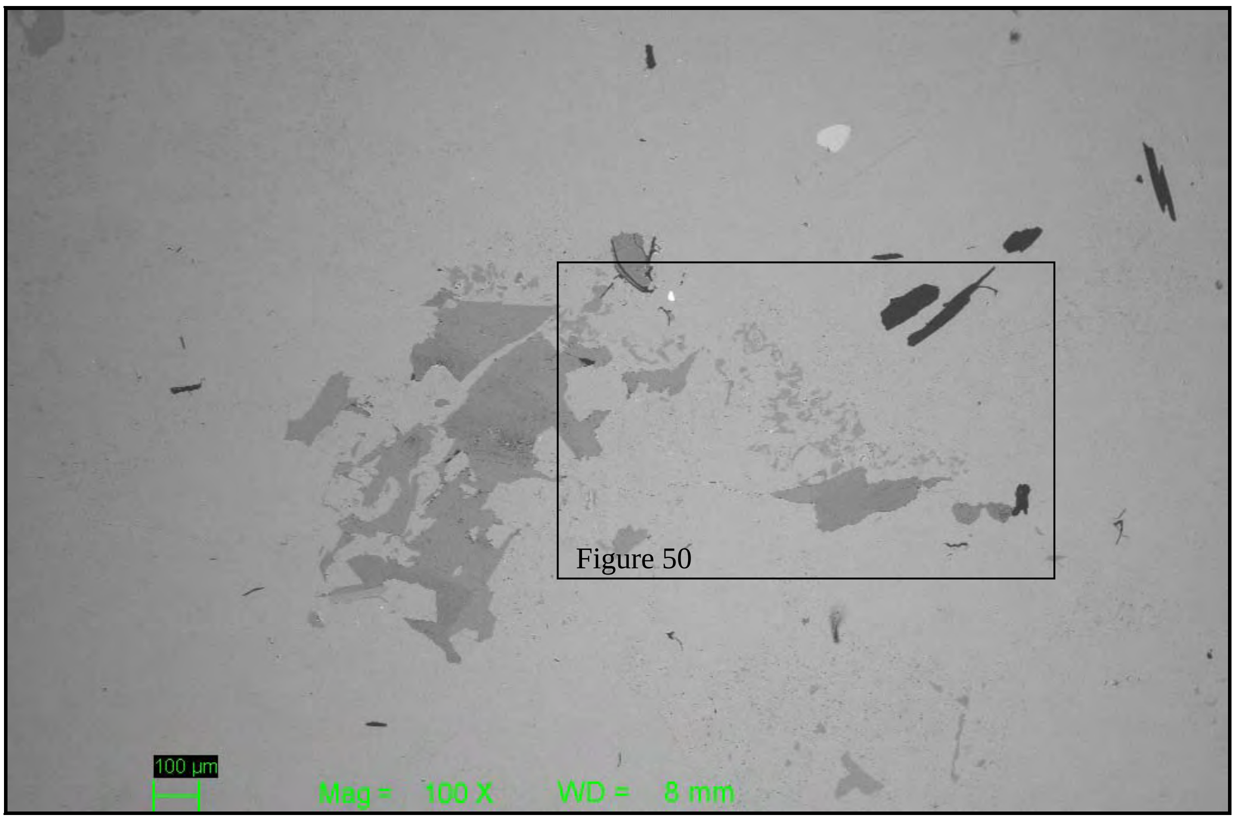


Figure 49: SEM BSE-image of silicate minerals (dark grey), dolomite (grey) and graphite (black) in calcite (light grey). Thin-section LR3-21.9 m.

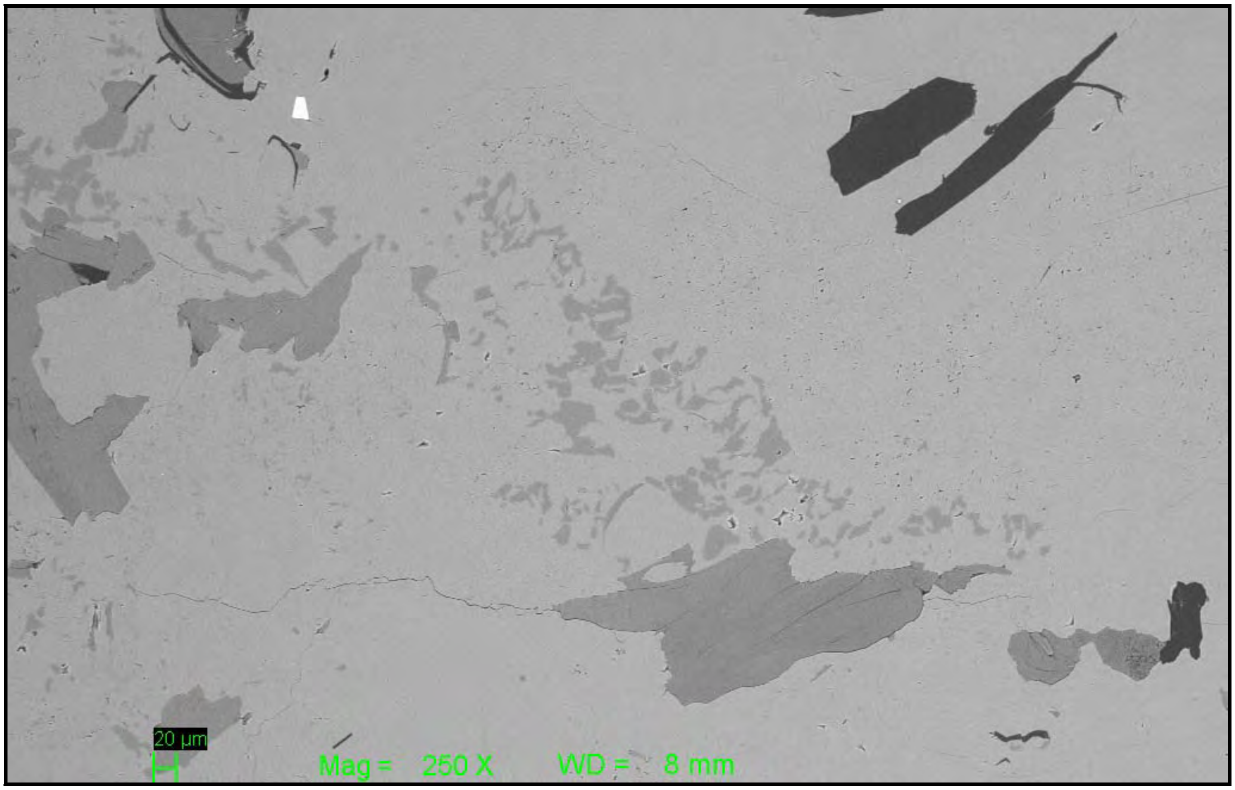


Figure 50: SEM BSE-image of silicate minerals (dark grey), dolomite (grey) and graphite (black) in calcite (light grey). Thin-section LR3-21.9 m.

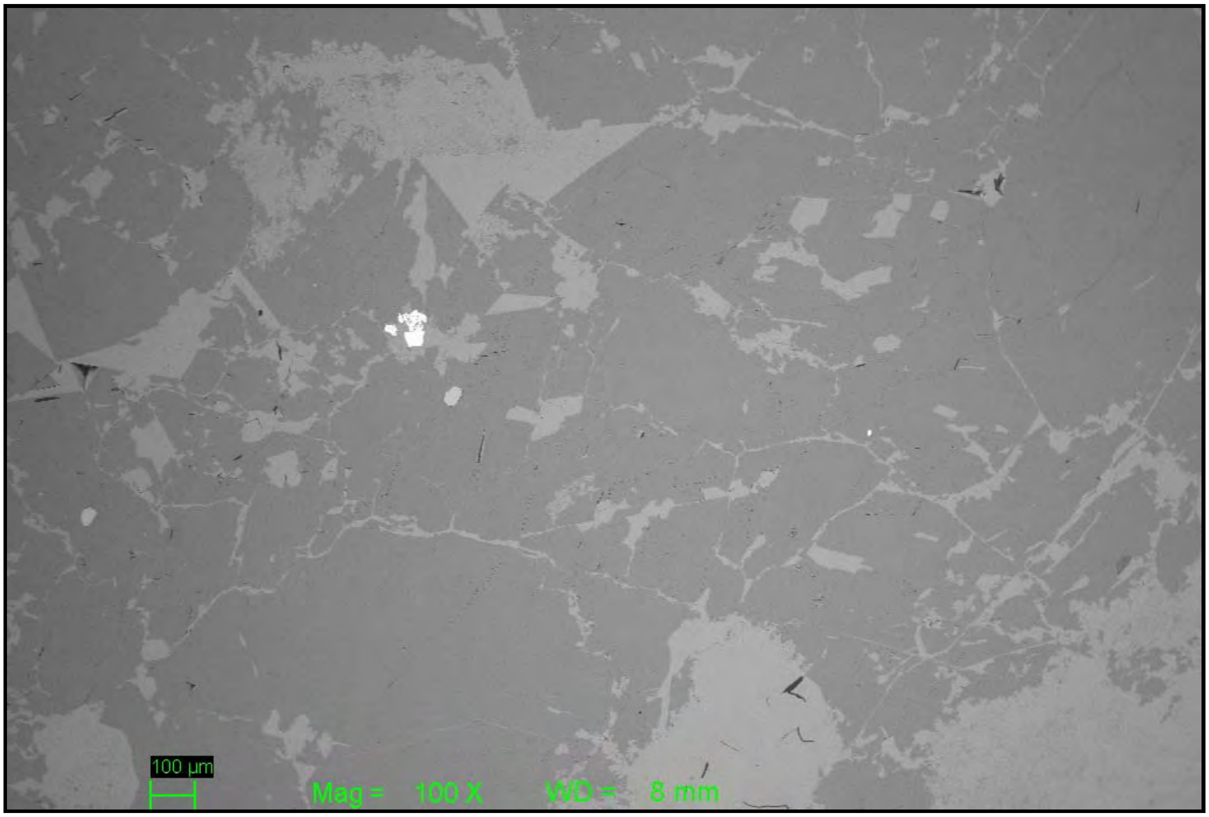


Figure 51: SEM BSE-image of dolomite (dark grey), calcite (grey), pyrite (white) and graphite (black). Thin-section LR3-21.9 m.

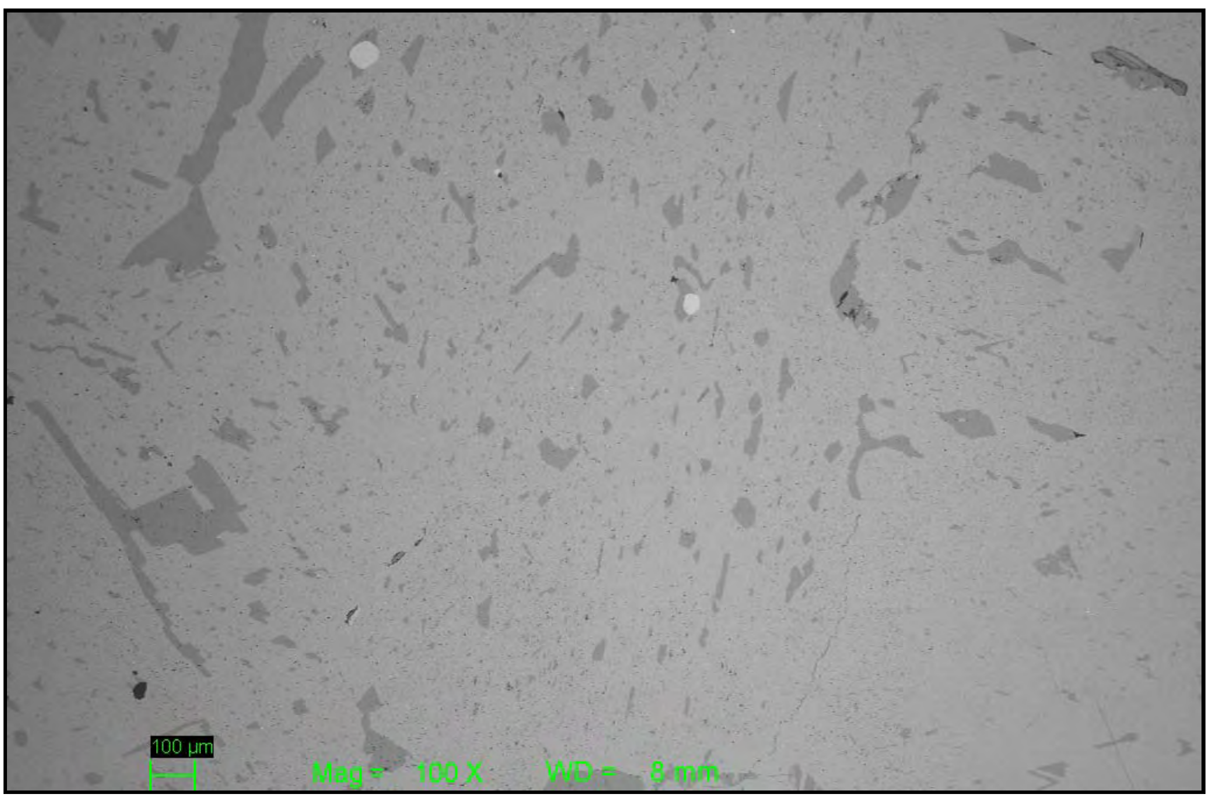


Figure 52: SEM BSE-image showing numerous dolomite inclusions (dark grey) in calcite (grey) and apatite (light grey). Thin-section LR3-21.9 m.

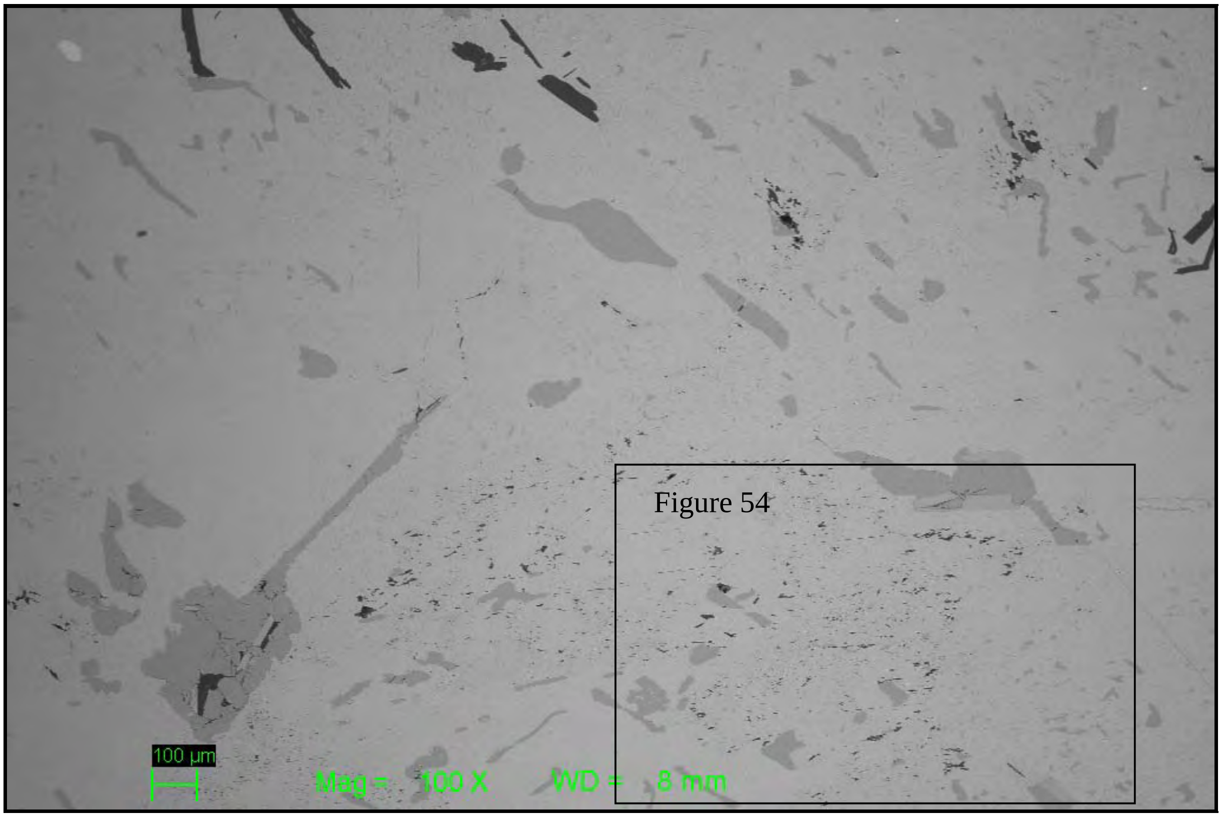


Figure 53: SEM BSE-image showing calcite (grey), dolomite (dark grey) and graphite (black). Thin-section LR3-21.9 m.

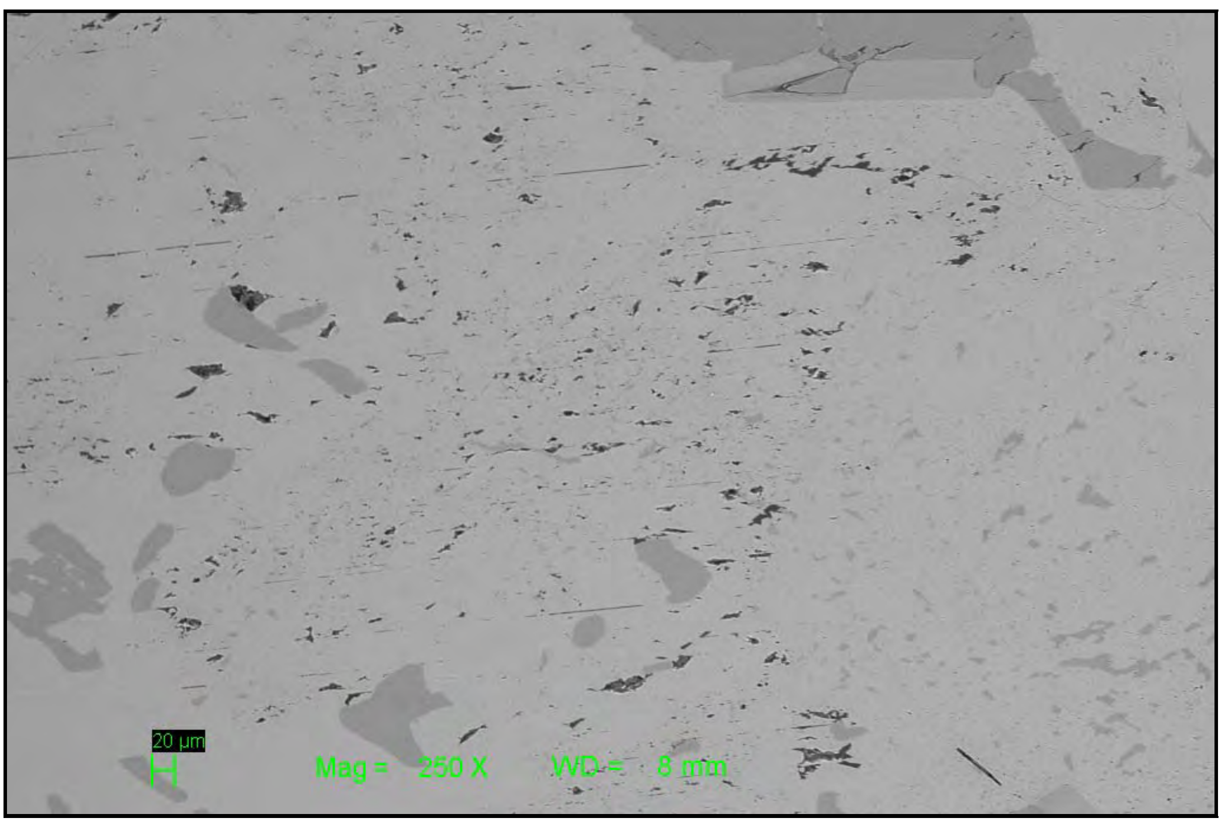


Figure 54: SEM BSE-image close-up of previous image showing numerous inclusions of dolomite (grey) and graphite (black) in calcite. Thin-section LR3-21.9 m.

4. Borehole LR5 Breivoll

4.1 Core description LR5

Table 10: Comments on borehole LR5 Breivoll.

Unit	Location [m]	Rock-description
1	0-5,2	Dominantly white to pale grey calcite marble, coarse-grained, with dark bands/layers. Dark layers are believed to represent relics from the previous calcium carbonate that has "survived" the recrystallising metamorphic process that formed the coarse-grained marble. Distinct minerals are mica (phlogopite), graphite and sulphides (pyrite), and there is a sulphur-smell when the rock is fractured. *Thin section *LR5_9.0*
2	5,2-6,7	Pale grey, coarse-grained calcite marble with thin layered brown-grey, medium grained mica-schist. Locally high content of sulphide/pyrite (locally visually estimated up to c. 10%). The schist layers consists of quartz, parallel oriented phlogopite and pyrite, and have slightly higher Fe-content compared with the previous unit based on analyses by the Niton portable XRF.
3	6,7- 15,9	Similar to unit 1. Light grey and very coarse-grained calcite marble with distinct sulphide content. Layering is marked by dark grey to black bands. The calcite crystals seem to be very pure calcite but interlocked with graphite grains. At 8.68m and 8.8m the marble show a reddish colour caused by oxidation of iron. In general there is a distinct sulphur-smell when fractured.
4	15,9-16,14	Grey and coarse-grained calcite-mica-quartz band.
5	16,14-19,0	Similar to units 1 and 3. Light grey and very coarse-grained calcite marble, locally distinctly sulphide enriched. Horizontal layering is marked by dark grey to black parts. The calcite crystals seem to be very pure calcite but interlocked with graphite grains. At 8.68 and 8.8m the marbles show a reddish colour caused by oxidation of Fe. Sulphur-smell when fractured. Distinct content of brown mica.
6	19,0-19,1	A thin layer of greenish, medium grained schist consisting mainly of quartz and diopside and/or epidote.
7	19,1-20,7	Similar to units 1, 3 and 5.
8	20,7-25,5	Dark grey, medium to coarse-grained marbles with fairly high graphite and pyrite content. Black parts form layers enriched in graphite. Within the marbles layers white mica flakes (muscovite) occur in sub-parallel alignment, for example at 20.7- 21.0m. At 22.6m there is distinct enrichment in quartz and mica (muscovite). Mica (muscovite), quartz, graphite and sulphide minerals mark the bedding of the marbles. Particularly distinct mica-rich layer at 24.45m and from 24.58 to 24.6m. Thin calcite veins intersect the bedding. *Thin section *LR5_23.9*

4.2 Chemical analyses LR5

Table 11: Analyses, borehole LR5 Breivoll.

Locality		Breivoll	Breivoll	Breivoll	Breivoll	Breivoll
Borehole		LR5	LR5	LR5	LR5	LR5
Sample		LR5_00-05	LR5_05-10	LR5_10-15	LR5_15-20	LR5_20-25.4
NGU identification no		101699	101700	61793	61794	61795
From-to (m)		0-5	5-10	10-15	15-20	20-25.4
SiO_2 $_{XRF}$	%	0,91	5,64	0,91	5,28	4,30
Al_2O_3 $_{XRF}$	%	0,17	1,29	0,11	1,17	0,90
Fe_2O_3 $_{XRF}$	%	0,08	0,84	0,07	0,41	0,37
TiO_2 $_{XRF}$	%	0,01	0,11	0,01	0,04	0,05
MgO $_{XRF}$	%	1,02	0,73	0,54	1,33	1,14
CaO $_{XRF}$	%	54,20	50,80	55,00	51,00	51,70
Na_2O $_{XRF}$	%	-0,10	0,12	-0,10	-0,10	0,11
K_2O $_{XRF}$	%	0,03	0,22	0,02	0,06	0,16
MnO $_{XRF}$	%	-0,01	0,02	-0,01	-0,01	-0,01
P_2O_5 $_{XRF}$	%	0,07	0,08	0,08	0,07	0,08
LOI $_{XRF}$	%	43,00	39,10	43,00	40,10	40,60
SUM $_{XRF}$	%	99,38	98,96	99,63	99,35	99,39
Ca $_{ICP}$	ppm	361000	334000	363000	343000	343000
CaO $_{ICP}$	%	50,50	46,73	50,78	47,99	47,99
CaO $_{ICP}$ vs. CaO $_{XRF}$	%	93	92	92	94	93
Mg $_{ICP}$	ppm	5080	2550	2820	5220	4040
MgO $_{ICP}$	%	0,84	0,42	0,47	0,87	0,67
MgO $_{ICP}$ vs. MgO $_{XRF}$	%	83	58	87	65	59
Fe $_{ICP}$	ppm	552	5886	475	2887	2600
Fe $_{ICP}$	ppm	74	272	71	297	170
Mn $_{ICP}$	ppm	nd	170	nd	nd	nd
Mn $_{ICP}$	ppm	25	123	24	32	38
Fe+Mn $_{XRF}$	ppm	552	6056	475	2887	2600
Fe+Mn $_{ICP}$	ppm	99	395	94	329	208
Fe+Mn $_{ICP}$ vs. Fe+Mn $_{XRF}$	%	18	7	20	11	8
P $_{ICP}$	ppm	321	369	334	309	336
Ba $_{ICP}$	ppm	11,0	8,4	13,0	15,0	13,2
Sr $_{ICP}$	ppm	2220	2350	2760	2050	2170
Dolomite $_{Calculated}$	%	3,9	1,9	2,1	4,0	3,1
Calcite $_{Calculated}$	%	87,7	82,0	89,1	83,2	83,6
Others $_{Calculated}$	%	8,4	16,0	8,7	12,9	13,3
S $_{LECO}$	%	0,012	0,097	< 0,01	0,039	0,041
TC $_{LECO}$	%	12,65	11,39	12,72	12,20	12,33
TOC $_{LECO}$	%	0,19	0,25	0,12	0,13	0,23

Table 12: Semi-quantitative analyses by Niton portable XRF, LR5 Breivoll.

Bh	Pos. (m)	% SiO_2	CaO	ppm Fe	Pos. (m)	% SiO_2	CaO	ppm Fe	Pos. (m)	% SiO_2	CaO	ppm Fe
LR5	0,50	1,0	55,17	340	10,20	2,6	54,88	450	18,80	5,3	50,57	570
LR5	1,50	1,1	56,07	310	10,50	3,2	54,33	1580	19,50	2,6	55,42	530
LR5	2,50	1,1	55,76	220	10,70	4,0	54,58	1280	20,50	3,4	55,00	650
LR5	3,50	1,0	55,33	250	11,20	1,4	52,86	390	21,20	3,1	53,34	1380
LR5	4,50	1,2	56,51	380	11,50	1,1	57,61	200	21,50	1,8	53,85	410
LR5	5,50	10,0	50,44	340	11,80	2,1	55,34	1090	21,80	2,0	55,26	420
LR5	5,60	2,7	53,68	1770	12,50	1,0	55,33	260	22,30	1,2	56,31	330
LR5	5,70	49,3	21,78	28170	13,30	1,0	56,93	250	22,50	1,7	56,14	400
LR5	5,90	15,5	43,47	15030	14,50	1,2	56,42	260	22,80	1,8	51,40	520
LR5	6,10	4,3	54,81	4350	14,50	1,3	56,93	170	23,20	1,6	55,12	420
LR5	6,40	1,2	56,70	1840	15,20	1,7	49,78	470	23,50	1,1	54,92	320
LR5	6,40	4,6	52,71	4270	15,30	1,5	56,87	270	23,80	2,3	56,01	490
LR5	6,50	20,4	31,20	15570	15,40	54,4	15,39	19620	24,30	1,3	51,84	420
LR5	6,60	2,4	47,35	660	15,70	2,2	54,47	840	24,90	2,5	54,98	710
LR5	6,80	3,1	48,67	450	15,95	49,0	23,10	26980				
LR5	7,30	1,7	55,97	300	16,20	2,8	53,07	990				
LR5	7,50	1,7	49,17	500	16,50	1,6	53,66	480				
LR5	7,80	1,9	55,97	540	16,80	1,7	55,03	540				
LR5	8,20	1,9	56,62	470	17,50	1,2	55,38	610				
LR5	8,50	2,3	55,84	730	17,80	3,2	54,92	780				
LR5	8,80	2,9	54,69	970	18,20	3,3	53,21	570				
LR5	9,50	2,1	55,91	1810	18,50	3,4	53,93	1300				

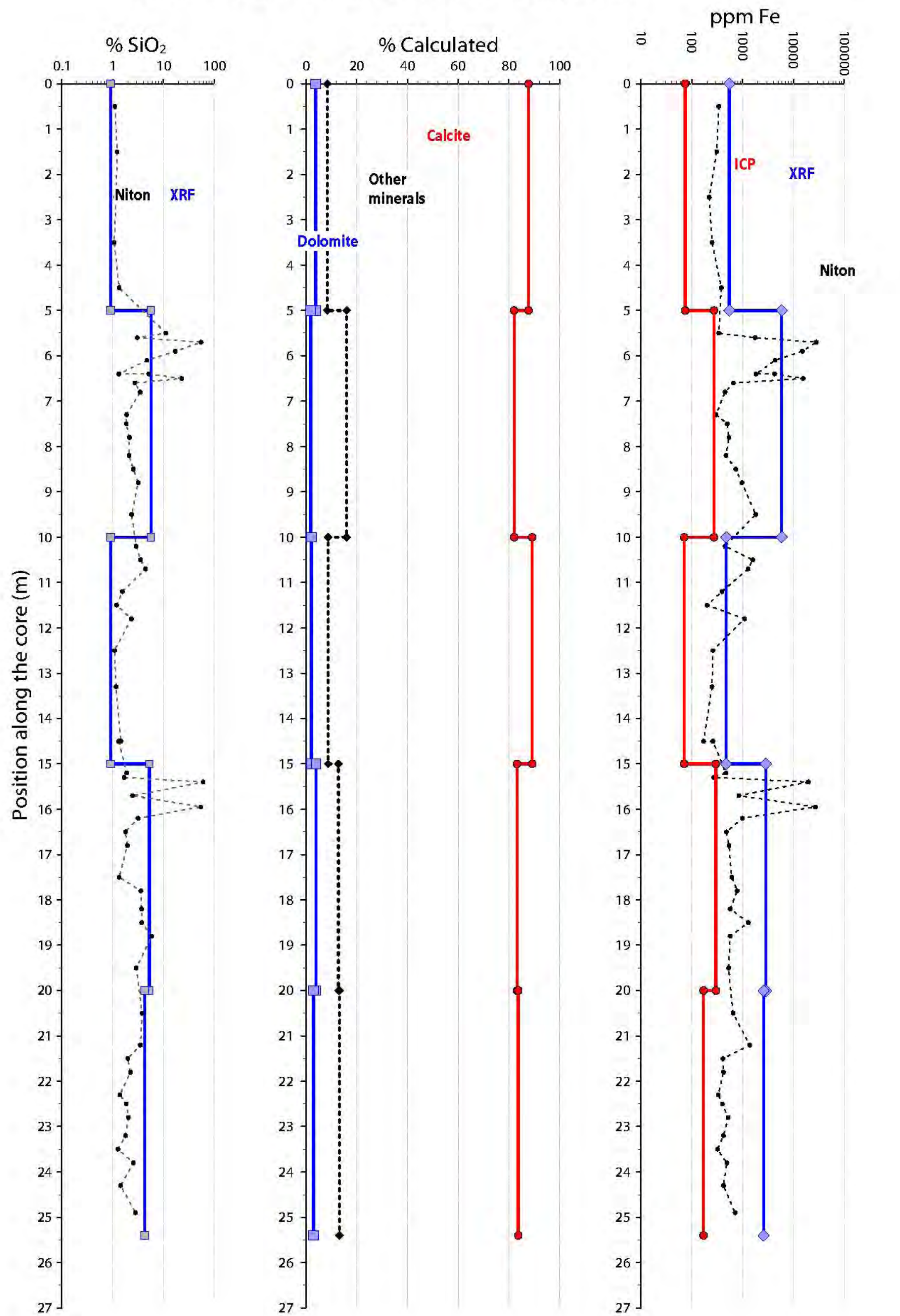


Figure 55: Variations in SiO_2, Fe and major mineral content along borehole LR5.

4.3 Core photographs LR5

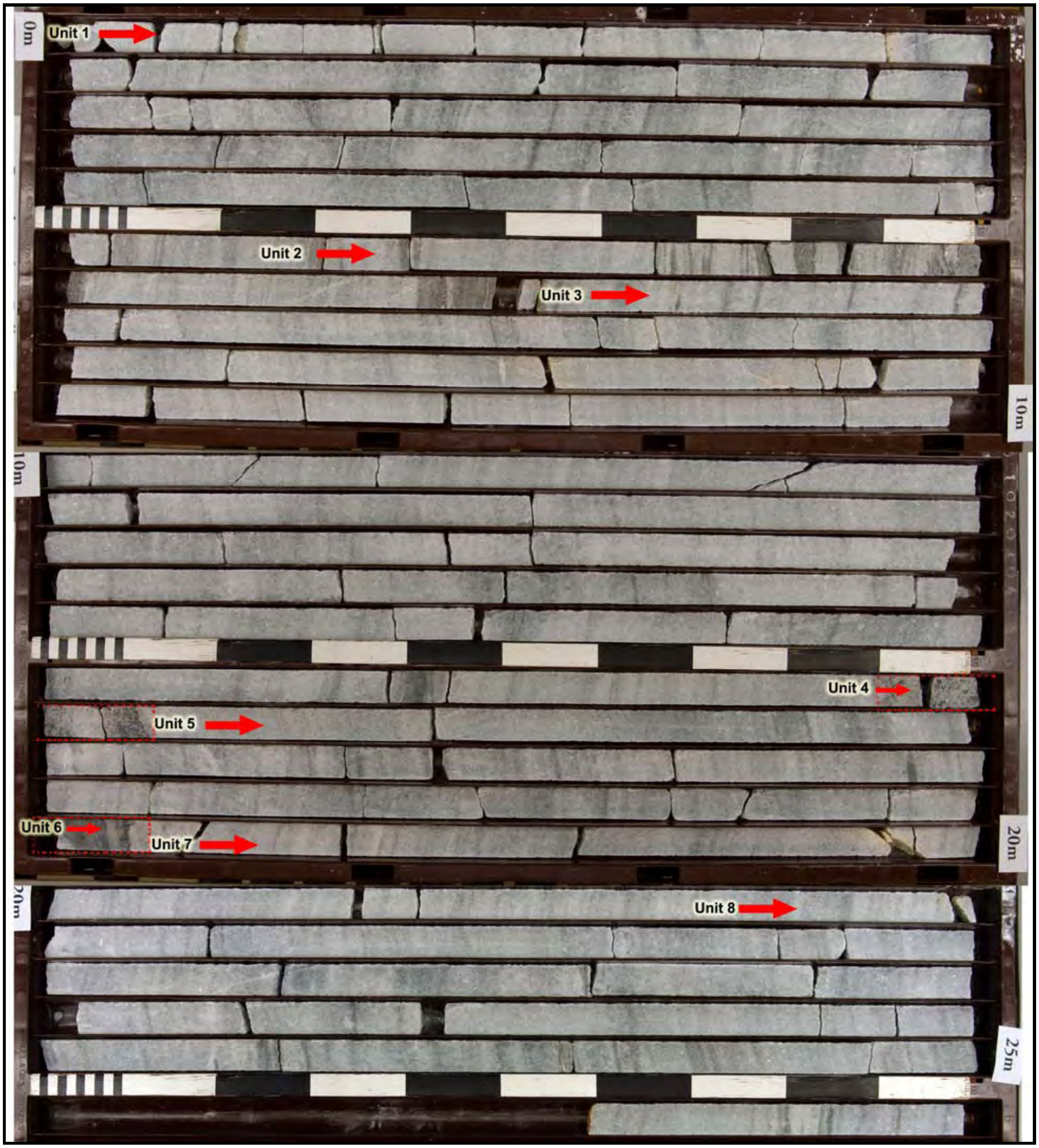


Figure 56: Overview photo of core LR5, Breivoll.

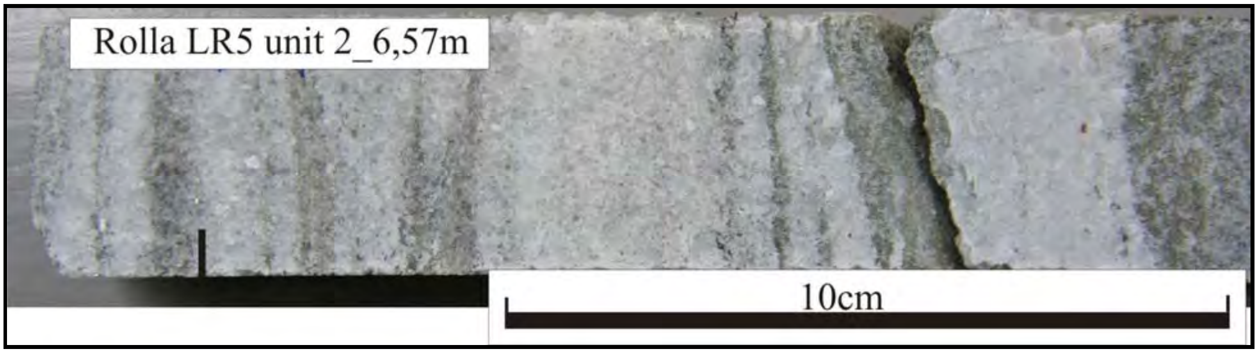


Figure 57: Calcite marble with mica-rich layers, LR5 at 6,6 m..

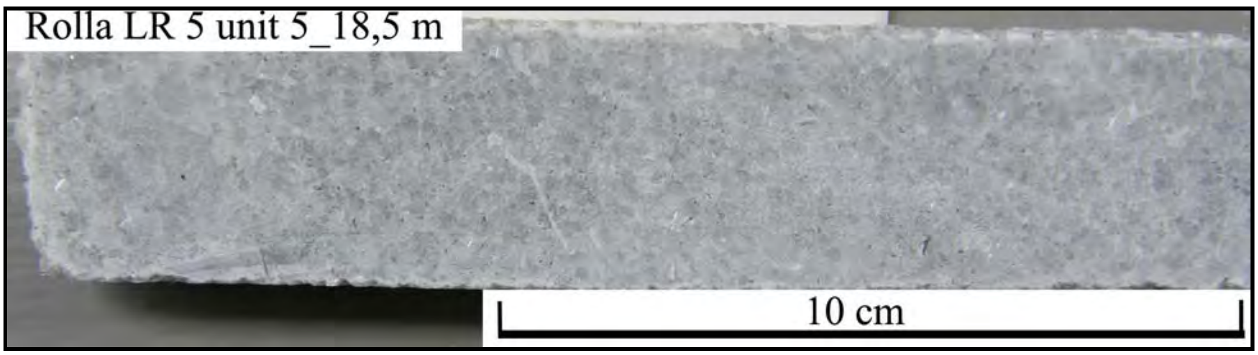


Figure 58: Fairly homogeneous calcite marble. LR5 at 18,5 m.

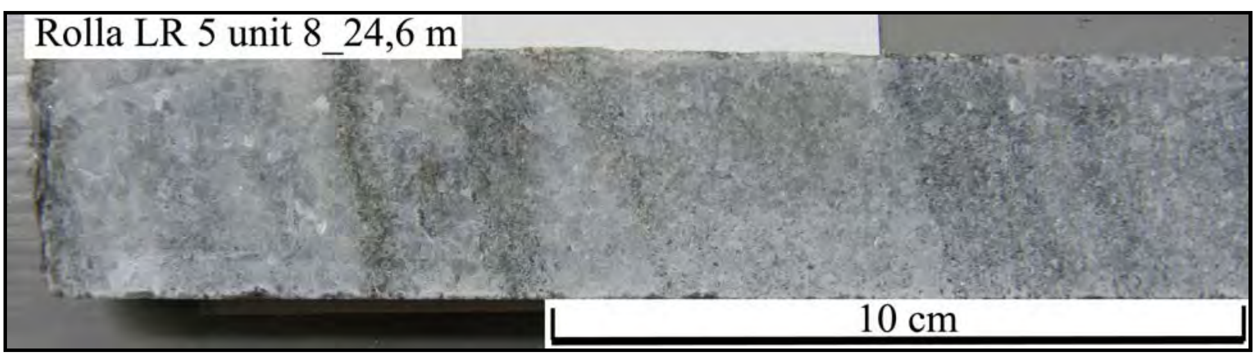


Figure 59: Calcite marble mica-rich layers. LR5 at 24,6 m.

4.4 Micrographs LR5

4.4.1 Thin-section LR5-09.0m

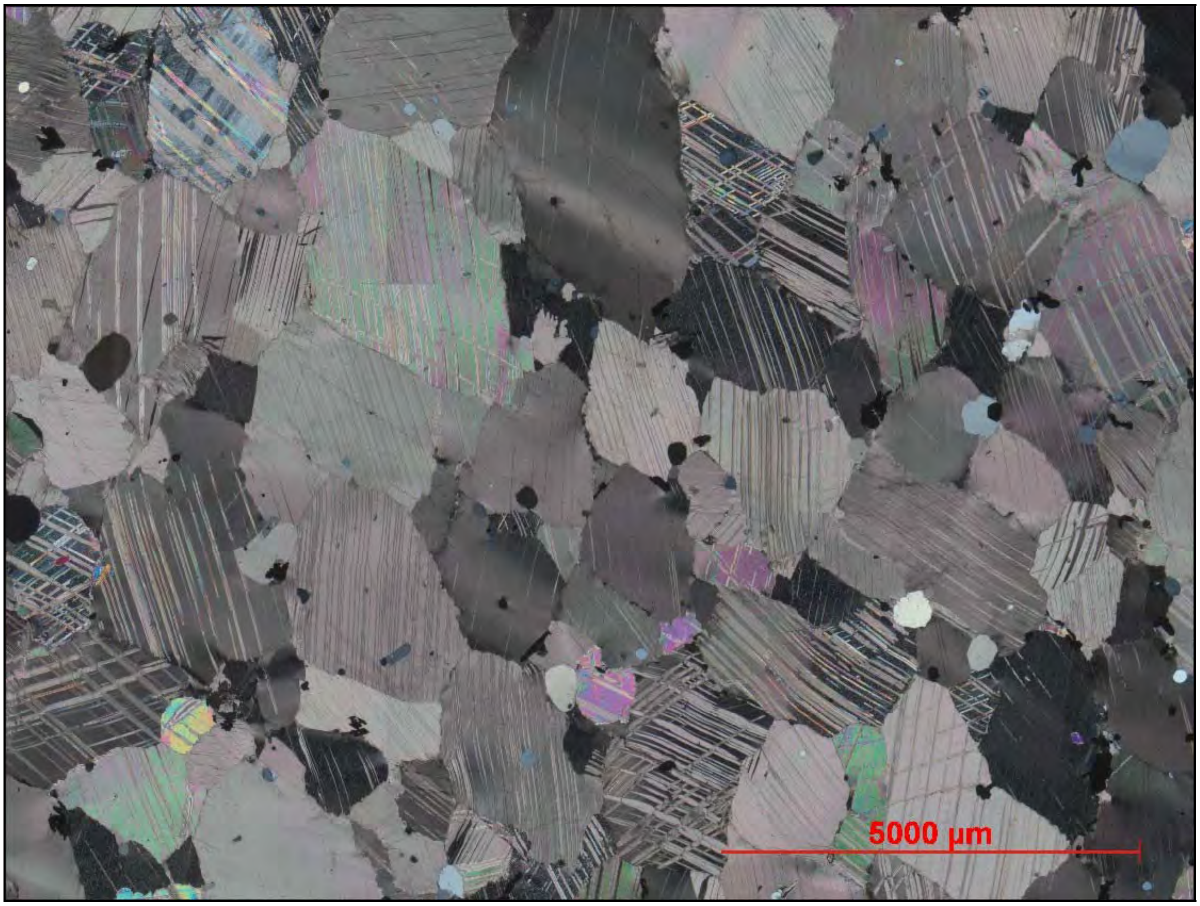


Figure 60: Mosaic microphotograph of fairly graphite-rich calcite marble. Thin-section LR5-09.0 m.

The calcite crystals, varying from 0,1 to 3-4 mm are dominating this thin section (app 90%). Accessory minerals appearing are also graphite, some sulphides, quartz and possibly amphiboles/pyroxene and epidote and apatite.

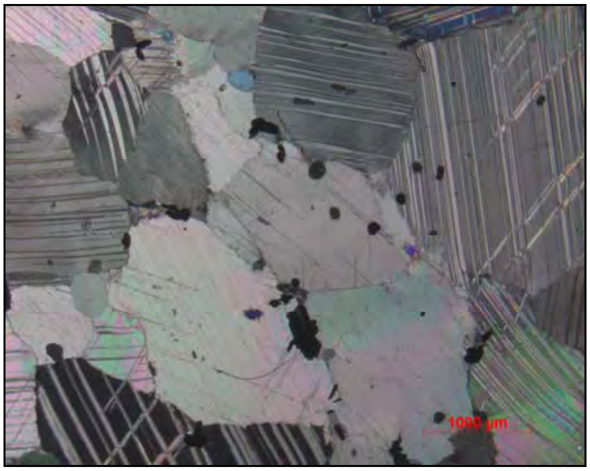


Figure 61: Microphotograph showing graphite inclusions (black) in calcite. Thin-section LR5-09.0 m.

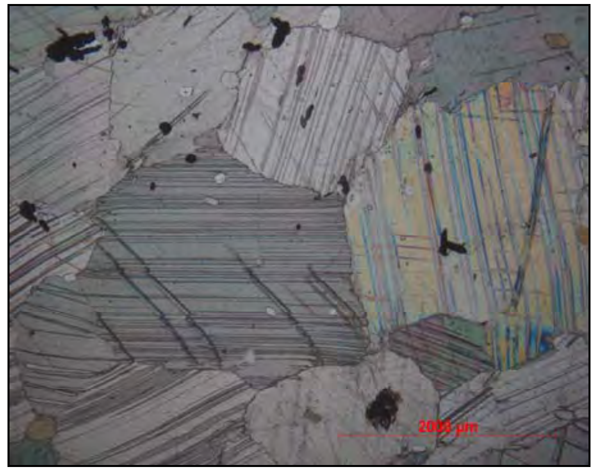


Figure 62: Microphotograph showing graphite (black) and quartz (white patches) within calcite.

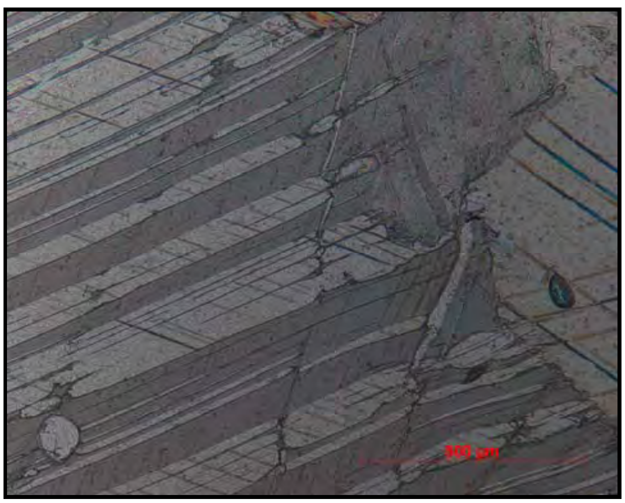


Figure 63: Microphotograph showing twins in in calcite crystals. Thin-section LR5-09.0 m.

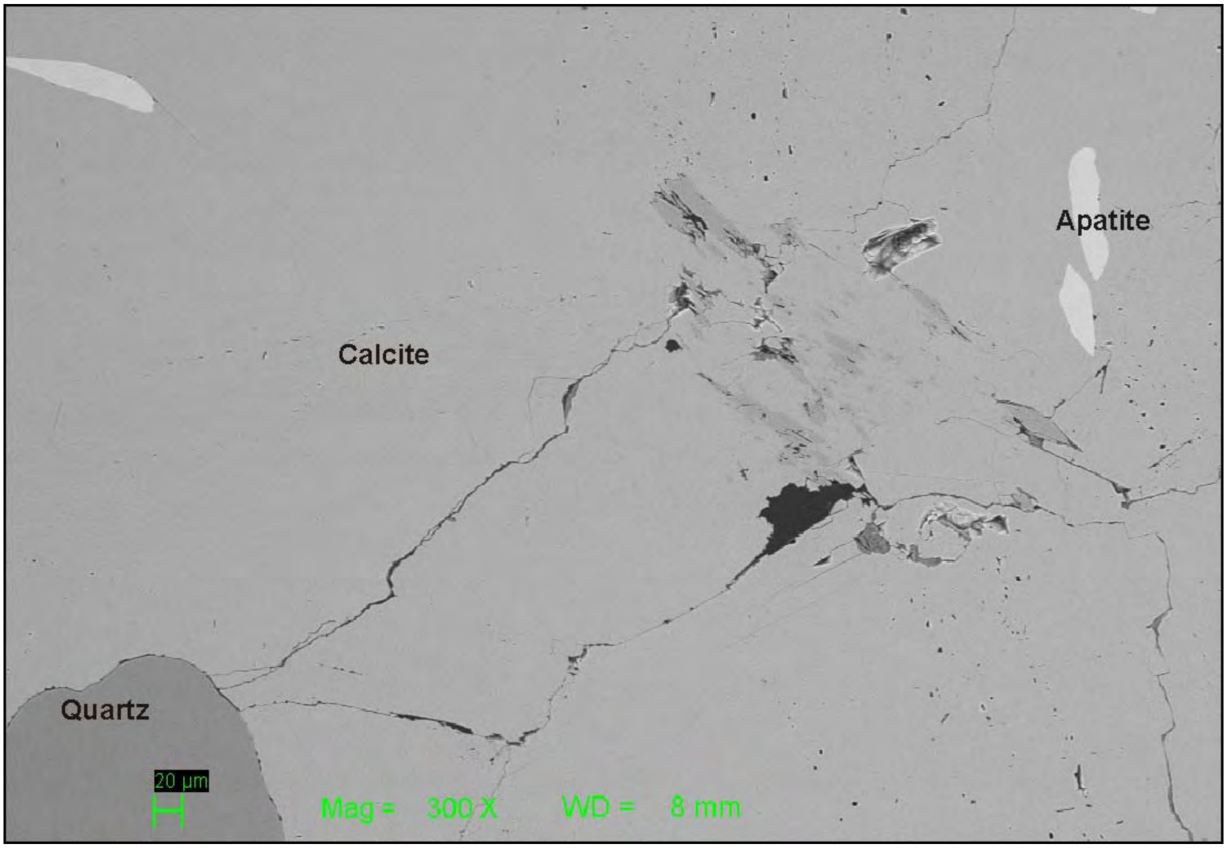


Figure 64: SEM BSE-image showing mineral impurities in calcite. Thin-section LR5-09.0 m.

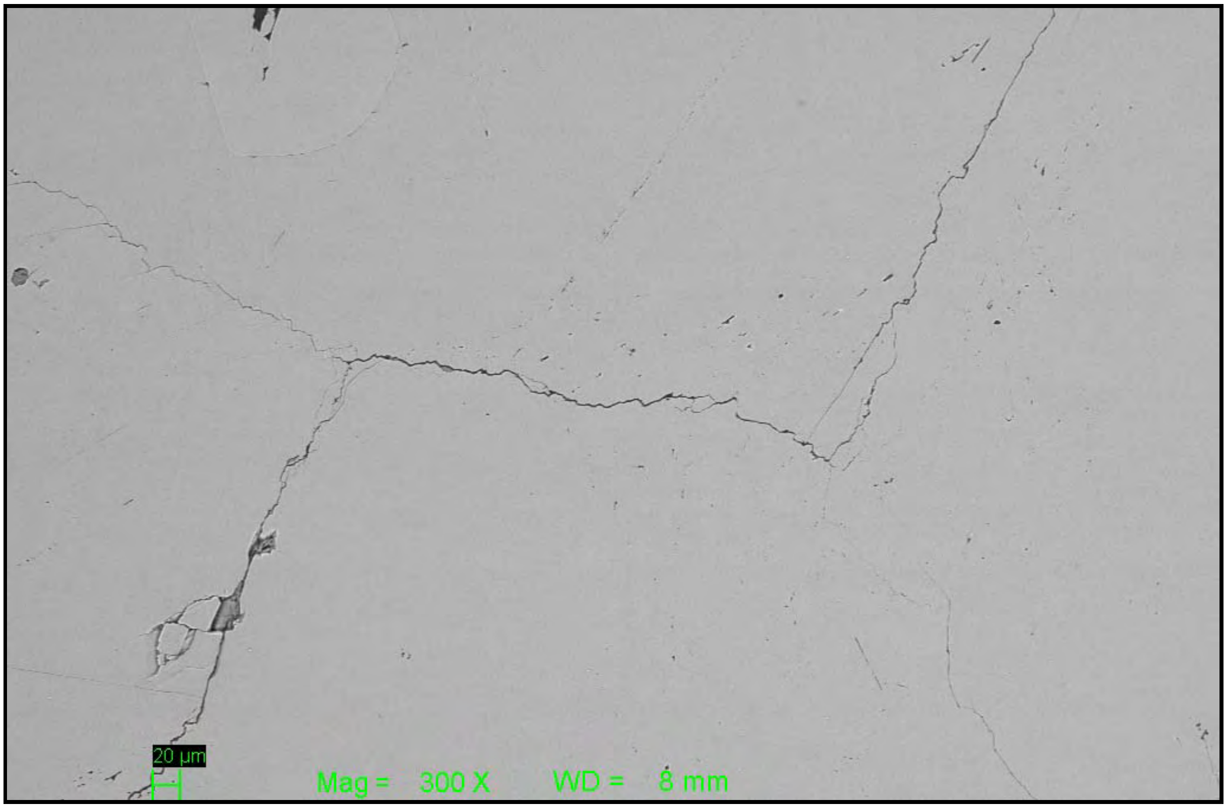


Figure 65: SEM BSE-image showing mineral impurities in calcite. Thin-section LR5-09.0 m.

Figure 66: SEM BSE-images showing inclusions of other minerals in calcite; graphite (black), quartz (dark grey), apatite (light grey) and calcite (medium grey). Thin-section LR5-09.0 m.

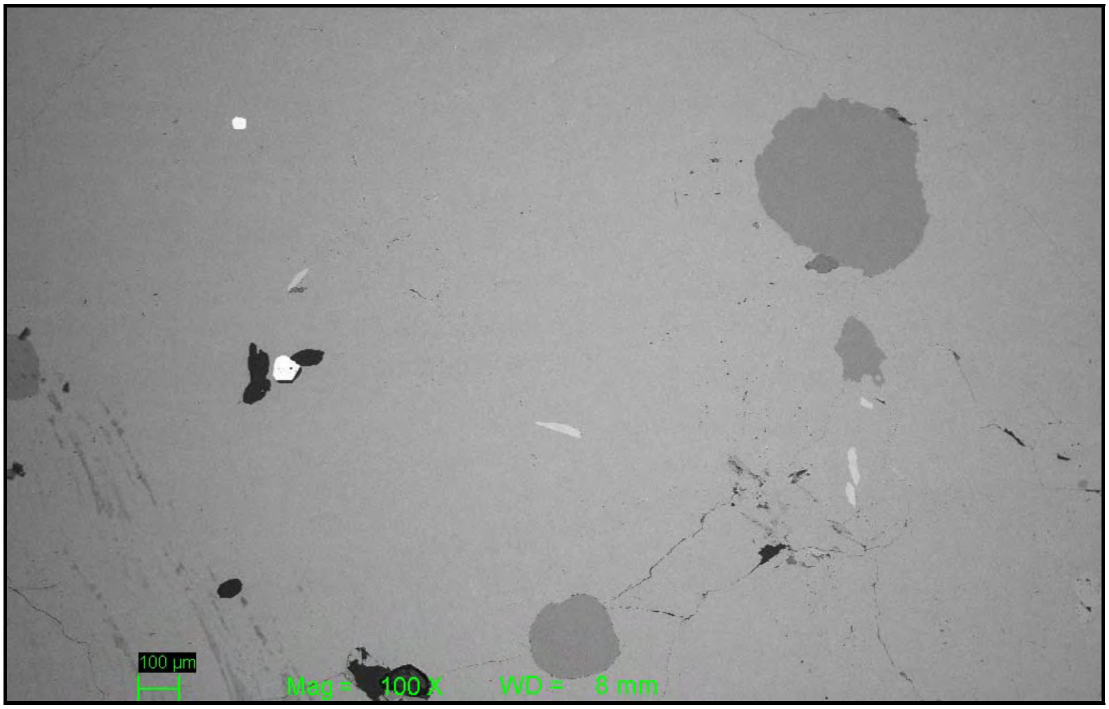


Figure 67: SEM BSE-image of mineral impurities in calcite; graphite (black), quartz (dark grey), apatite (light grey), pyrite (white) and calcite (medium grey). Thin-section LR5-09.0 m.

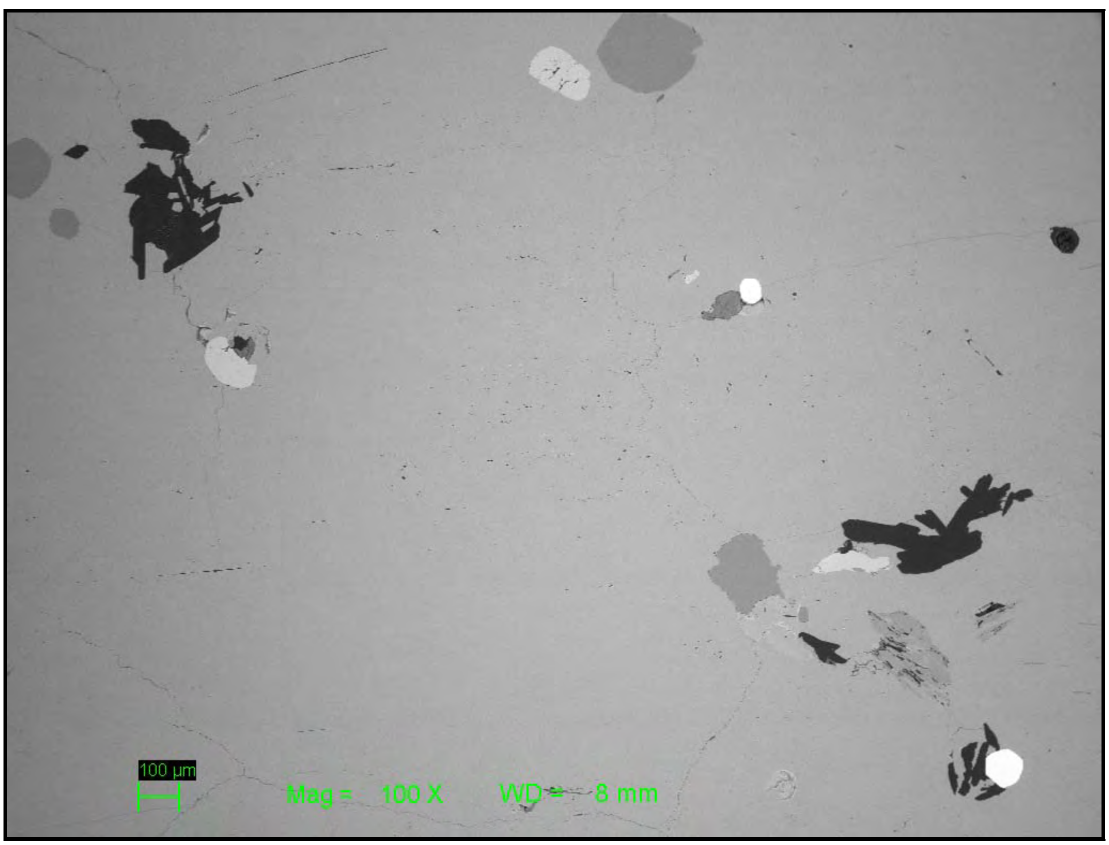


Figure 68: SEM BSE-image of mineral impurities in calcite; graphite (black), dolomite (dark grey), pyrite (white), apatite (light grey) and calcite (medium grey). Thin-section LR5-09.0 m.

4.4.2 Thin-section LR5-23.9m

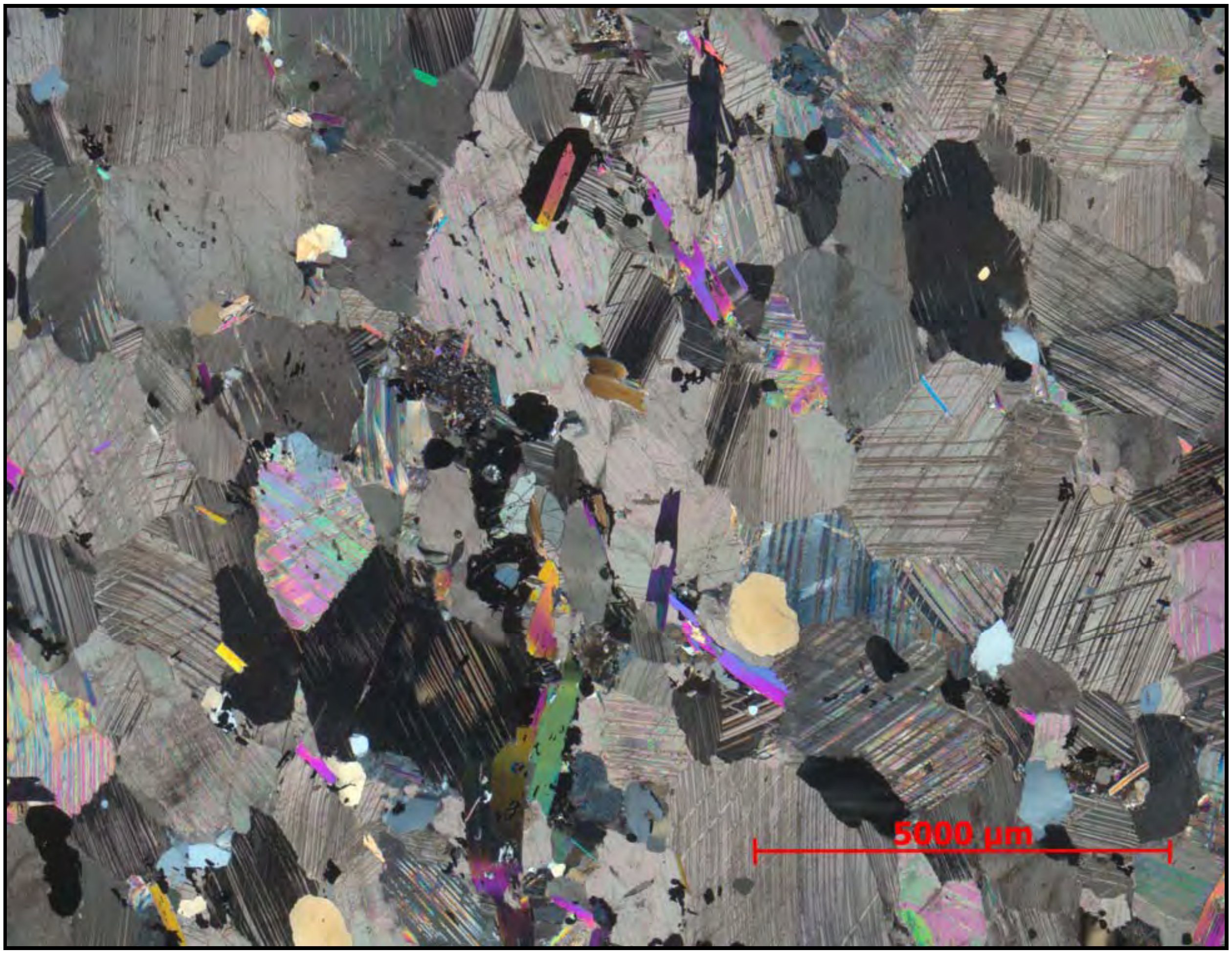


Figure 69: Mosaic microphotograph of impure calcite carbonate with numerous inclusions of other minerals.

Main minerals in this thin section are calcite (estimated 80-90 %), quartz (estimated 10-15%), app. 5 % mica (muscovite) and 3% other minerals – mainly graphite, some olivine and sulphide minerals. Phlogophite and possibly pyroxene have also been observed.

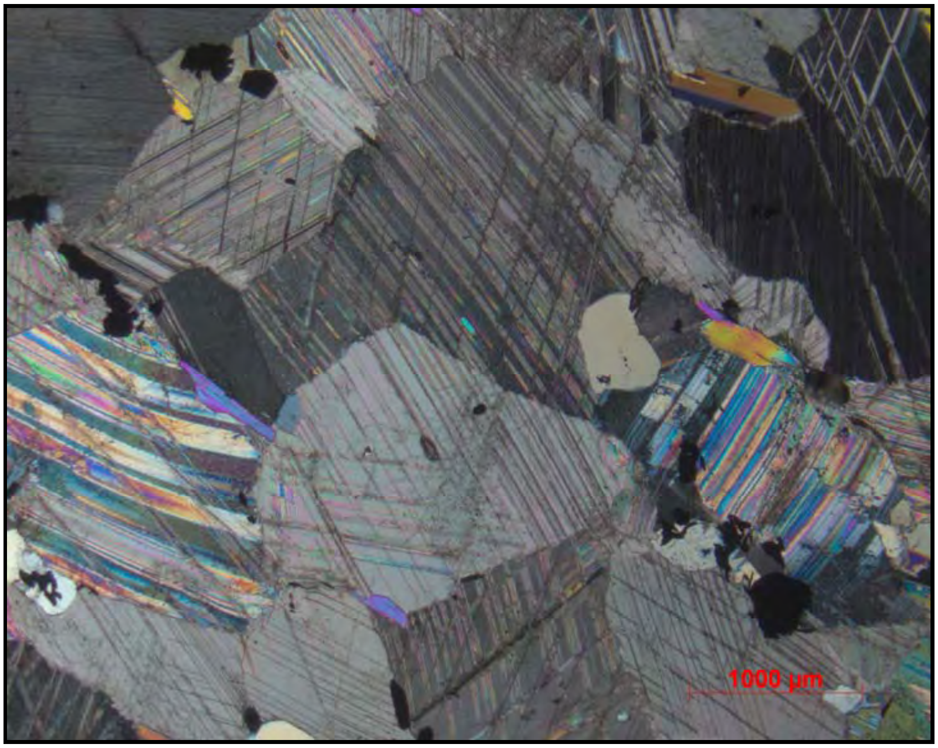


Figure 70: Microphotograph of calcite carbonate (grey) with inclusions of other minerals. Thin-section LR5-23.9m.

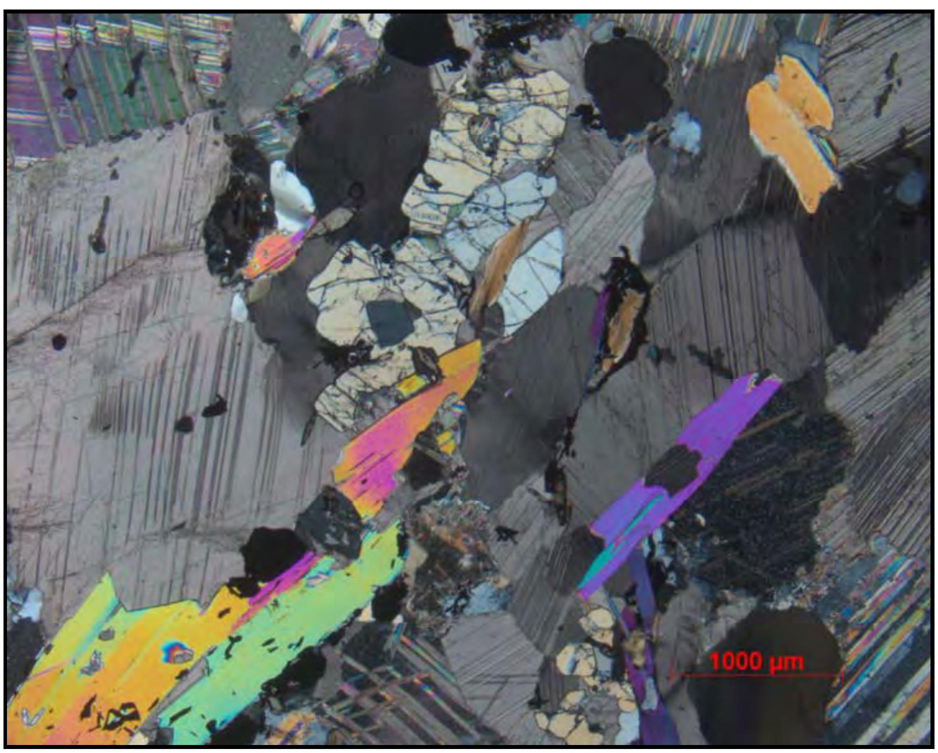


Figure 2: Microphotograph of calcite carbonate (grey) with fairly large amounts of other minerals. Thin-section LR5-23.9 m.

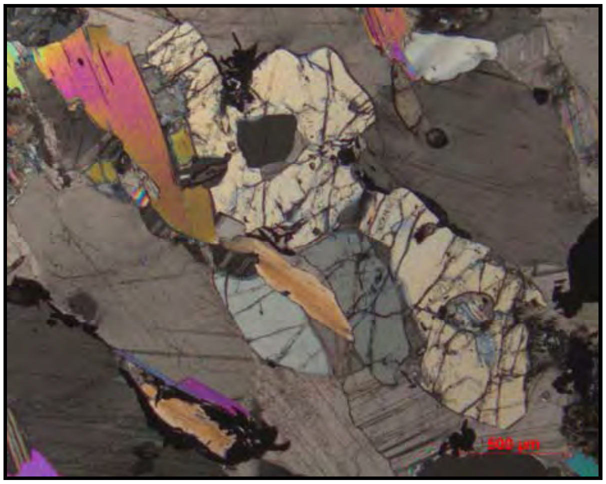


Figure 71: Microphotograph of calcite carbonate with fairly large amounts of other minerals. Thin-section LR5-23.9 m.

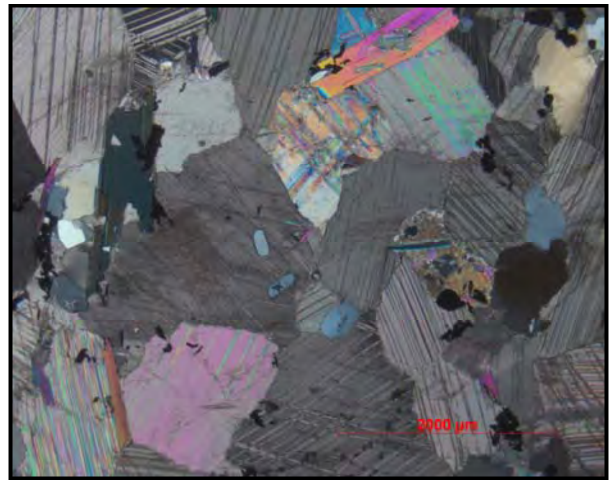


Figure 72: Microphotograph of calcite carbonate with fairly large amounts of other minerals. Thin-section LR5-23.9 m.

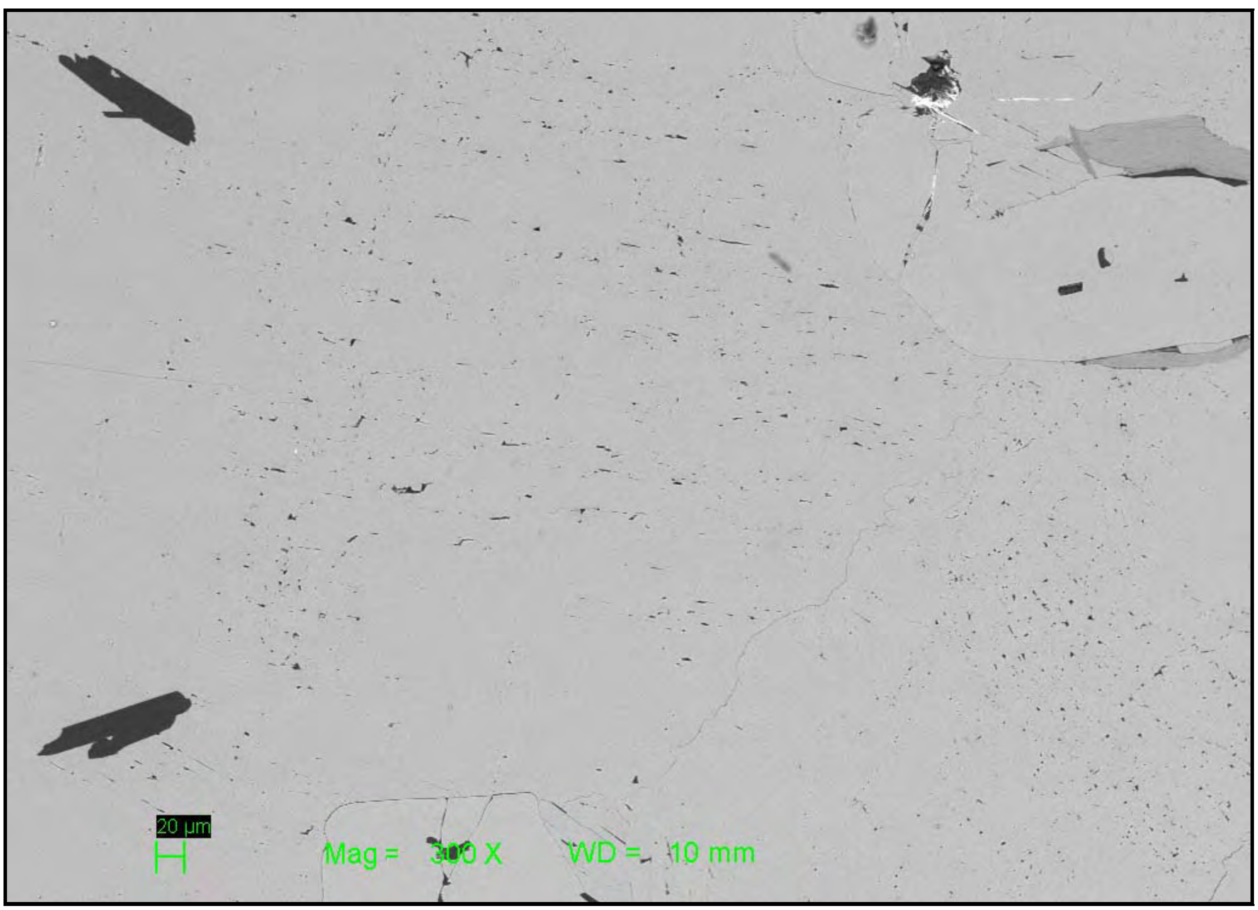


Figure 73: SEM BSE-image with inclusions of other minerals in calcite; graphite (black) and mica (medium grey). Thin-section LR5-23.9 m.

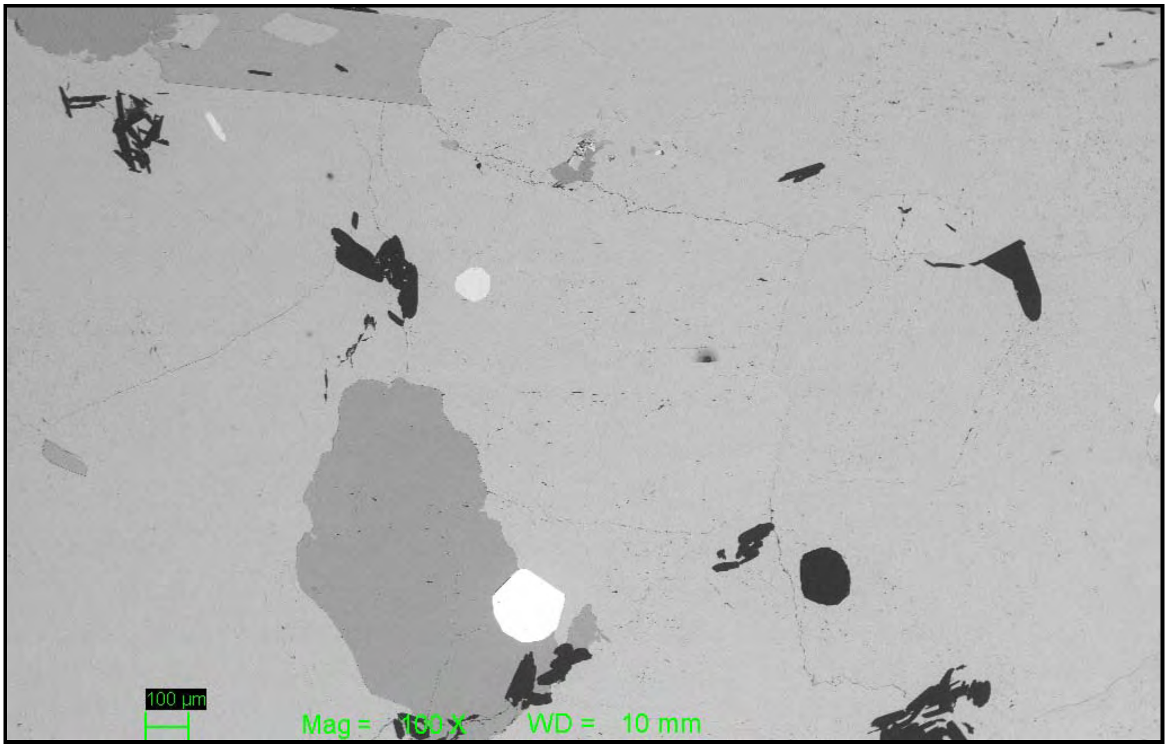


Figure 74: SEM BSE-image of calcium carbonate ; graphite (black), dolomite (dark grey), mica (medium grey, elongated), pyrite (white), apatite (light grey, rounded grain) and titanite (light grey, elongated grain). Thin-section LR5-23.9 m.

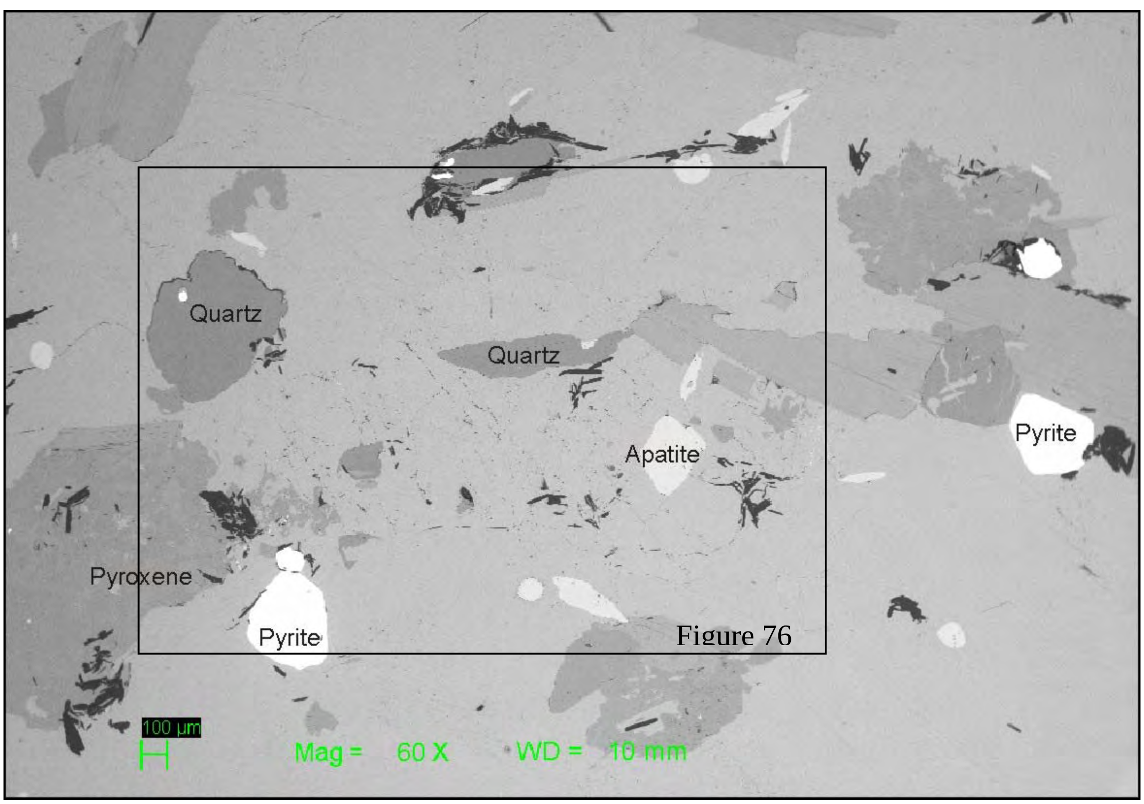


Figure 75: SEM BSE-image of calcite (dominant grey), various silicate minerals including mica, albite and quartz (gray to dark grey), graphite (black) and pyrite (white). Thin-section LR5-23.9 m.

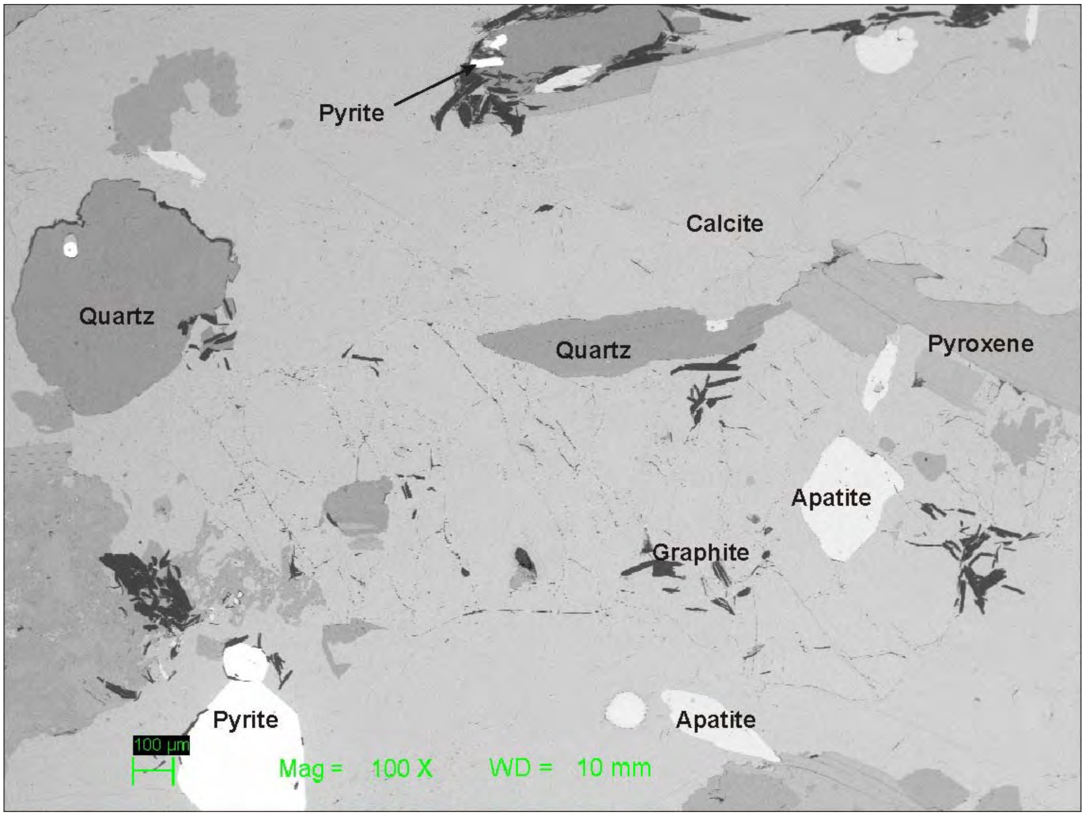


Figure 76: SEM BSE-image (close-up of previous image) of calcite (dominant grey), various silicate minerals including mica, albite and quartz (gray to dark grey), graphite (black) and pyrite (white). Thin-section LR5-23.9 m.

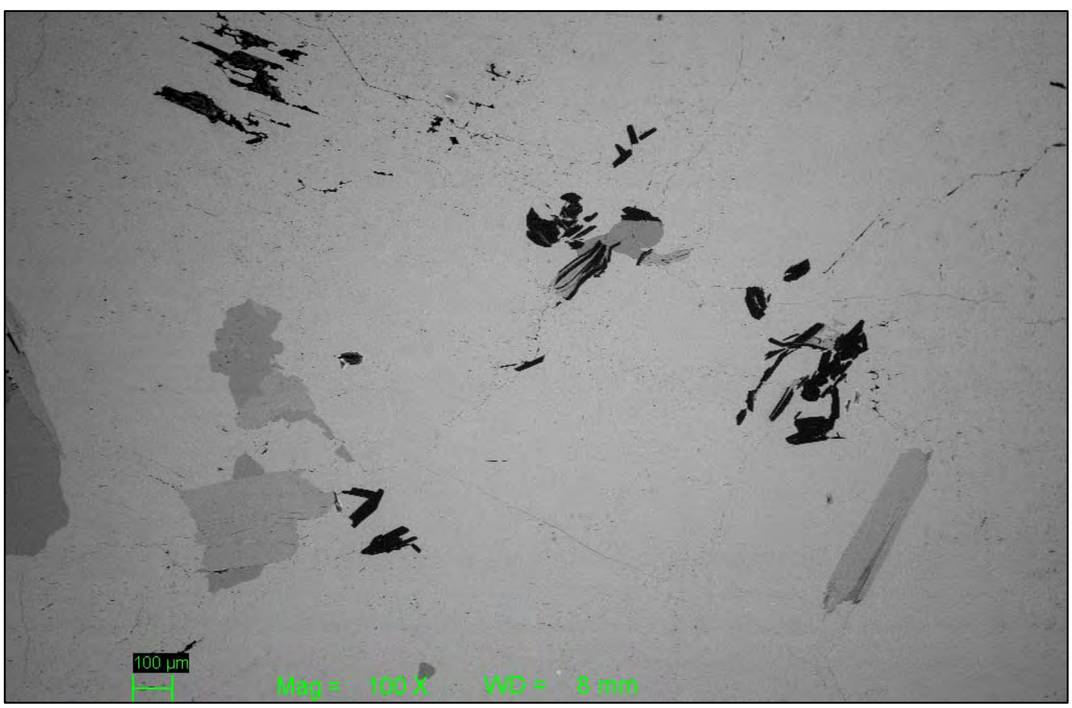


Figure 77: SEM BSE-image of calcite, mica (elongated medium grey minerals), feldspar and quartz (dark grey) and graphite (black). Thin-section LR5-23.9 m.

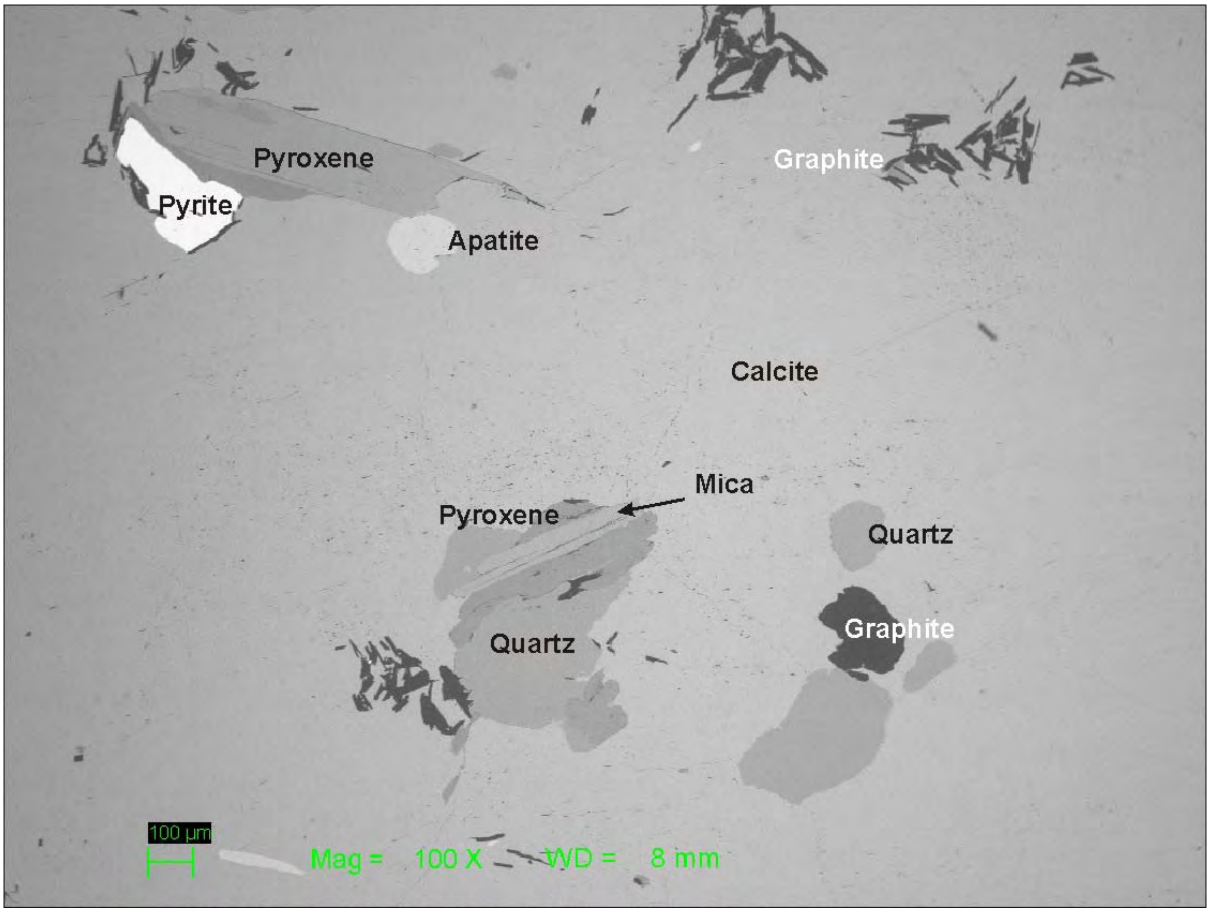


Figure 78: SEM BSE-image showing inclusions of other minerals in calcite; mica (elongated medium grey), quartz (darker grey), pyrite (white), graphite (black), apatite (light grey) and pyrite (white). Thin-section LR5-23.9 m.

5. Borehole LR6 Storskog

5.1 Core description LR6

Table 13: Comments on borehole LR 6 Skog

Unit	Location [m]	Rock-description
1	0-9,38	Pale to dark grey, medium to coarse-grained calcite marble with a distinct layering. The marble is enriched in graphite (locally visually estimated to 10%) and sulphides (locally visually estimated to 5%); some layers are distinctly mica-rich, and in addition to mica (phlogopite), graphite, quartz and sulphides are distinct minerals. Such mica-rich layers do for example occur within the intervals 1.23-1.4m and 4.55-4.6m. At 4.73m there is a 4cm thick quartz layer (vein?). Partly Fe-oxidation appears within the marbles probably caused by alteration of sulphide minerals. Thin bands of fine-crystalline mica and sulphides occur at 5.52m and 5.75m. *Thin section *LR6_2.1*
2	9,38-14,64	Similar to unit 1. Dark grey, coarse-grained calcite marbles with thin-layered dark parts enriched in mica, sulphide and graphite. At 9,40m: very distinct mica-rich part with distinct high Fe-content measured by portable XRF. *Thin section *LR6_13.0*
3	14,64- 20,17	Pale to dark grey, coarse-grained calcite marble, partly distinctly layered. The layering is marked by dark grey to black bands enriched in graphite (locally visually estimated to 10%) and sulphides. Thin white calcite veins cut across the layering. At 14,50 to 14,60m: interlayered marble-mica-schist sequence, and at 19,55m: light brown cacite-quartz-mica schist with a high Fe-content. The schist is fine to medium grained.
4	20,17- 25,3	Green, greyish to brownish silicate-rich calcite marble with variable grain-size. Identified silicate minerals are mica (phlogopite), pyroxenes (diopside), quartz, epidote, plagioclase and olivine. Distinct high Fe-content was detected by portable XRF. *Thin section *LR6_22.0*

5.2 Chemical analyses

Table 14: Analyses, borehole LR6 Skog.

Locality		Skog	Skog	Skog	Skog	Skog
Borehole		LR6	LR6	LR6	LR6	LR6
Sample		LR6_00-05	LR6_05-10	LR6_10-15	LR6_15-20	LR6_20-25.3
NGU identification no		61796	61797	61798	61799	61800
From-to (m)		0-5	5-10	10-15	15-20	20-25.3
$SiO_{2\ XRF}$	%	6,10	3,55	4,46	3,50	16,90
$Al_2O_{3\ XRF}$	%	1,27	0,49	0,95	0,78	2,39
$Fe_2O_{3\ XRF}$	%	0,53	0,20	0,48	0,43	1,77
$TiO_{2\ XRF}$	%	0,07	0,03	0,06	0,06	0,16
MgO_{XRF}	%	0,93	2,13	1,05	1,08	3,53
CaO_{XRF}	%	50,40	51,50	51,60	52,40	43,20
Na_2O_{XRF}	%	0,16	-0,10	0,13	0,13	0,46
K_2O_{XRF}	%	0,20	0,08	0,14	0,15	0,16
MnO_{XRF}	%	-0,01	-0,01	-0,01	-0,01	0,04
$P_2O_{5\ XRF}$	%	0,08	0,07	0,08	0,08	0,16
LOI_{XRF}	%	39,50	41,50	40,40	41,00	30,90
SUM_{XRF}	%	99,23	99,44	99,33	99,60	99,66
Ca_{ICP}	ppm	334000	337000	345000	345000	252000
CaO_{ICP}	%	46,73	47,15	48,27	48,27	35,25
CaO_{ICP} vs. CaO_{XRF}	%	93	92	94	92	82
Mg_{ICP}	ppm	3200	8460	4080	4720	2300
MgO_{ICP}	%	0,53	1,40	0,68	0,78	0,38
MgO_{ICP} vs. MgO_{XRF}	%	57	66	64	72	11
Fe_{ICP}	ppm	3691	1419	3362	3006	12372
Fe_{ICP}	ppm	269	123	326	163	1740
Mn_{ICP}	ppm	nd	nd	nd	nd	317
Mn_{ICP}	ppm	40	20	51	40	200
$Fe+Mn_{XRF}$	ppm	3691	1419	3362	3006	12690
$Fe+Mn_{ICP}$	ppm	309	143	377	203	1940
$Fe+Mn_{ICP}$ vs. $Fe+Mn_{XRF}$	%	8	10	11	7	15
P_{ICP}	ppm	338	297	346	347	622
Ba_{ICP}	ppm	5,8	10,5	8,6	13,3	16,7
Sr_{ICP}	ppm	2020	1370	1940	2110	1610
$Dolomite_{Calculated}$	%	2,4	6,4	3,1	3,6	1,7
$Calcite_{Calculated}$	%	81,8	80,3	84,1	83,9	61,7
$Others_{Calculated}$	%	15,8	13,2	12,8	12,6	36,5
S_{LECO}	%	0,124	0,026	0,070	0,036	0,036
TC_{LECO}	%	11,72	12,17	11,95	12,15	9,23
TOC_{LECO}	%	0,31	< 0,1	0,24	0,15	0,44

Table 15: Semi-quantitative analyses by Niton portable XRF, LR6 Skog.

Bh	Pos. (m)	% SiO_2	CaO	ppm Fe	Pos. (m)	% SiO_2	CaO	ppm Fe	Pos. (m)	% SiO_2	CaO	ppm Fe
LR6	0,20	1,6	57,10	680	10,20	2,8	54,03	1860	21,20	10,0	47,20	13200
LR6	0,50	1,9	55,70	560	10,50	3,2	54,54	820	21,50	12,0	47,68	10810
LR6	0,80	5,6	53,56	810	11,50	6,6	51,65	1770	21,50	12,8	45,32	12170
LR6	1,30	15,9	43,61	6890	12,50	6,5	51,49	1900	21,80	20,6	40,41	16590
LR6	1,50	3,7	52,49	16340	12,88	38,7	27,24	9840	22,20	17,8	44,22	16520
LR6	2,30	6,4	51,71	2310	13,20	7,2	50,49	1630	22,40	19,5	42,38	10320
LR6	2,60	1,9	55,73	550	13,50	8,2	50,50	440	22,50	24,9	39,70	24640
LR6	3,40	1,3	55,14	570	14,20	1,7	55,58	550	22,70	16,4	44,34	17020
LR6	3,80	4,4	54,99	630	14,50	4,7	52,00	2660	23,20	19,9	43,31	13400
LR6	4,20	1,8	56,08	1460	14,80	1,5	56,27	540	23,50	16,4	43,67	9950
LR6	4,50	6,5	52,32	2690	15,70	1,0	55,45	340	23,60	23,4	40,05	14190
LR6	4,80	69,0	12,25	500	16,60	1,0	56,20	280	24,30	10,9	47,48	3160
LR6	4,95	6,7	51,81	420	17,60	0,8	55,42	280	24,50	26,5	38,36	7060
LR6	5,20	2,5	56,11	510	18,20	3,3	53,41	510	24,60	12,0	48,17	6250
LR6	5,60	10,1	47,77	320	18,60	2,0	53,33	840	24,80	21,9	42,66	4120
LR6	5,80	4,4	54,04	2420	18,80	1,9	51,50	420	25,70	13,7	47,78	4040
LR6	6,20	2,8	56,75	970	19,50	1,3	55,92	430				
LR6	6,60	1,1	54,60	410	19,60	60,2	3,82	40460				
LR6	7,50	1,0	53,78	260	19,70	4,8	54,71	1440				
LR6	8,50	1,5	52,09	250	20,10	1,9	57,11	440				
LR6	9,20	3,2	54,96	700	20,30	2,5	56,68	1290				
LR6	9,40	18,4	42,68	1940	20,50	10,7	46,36	14970				
LR6	9,50	3,8	50,09	1370	20,70	10,8	47,68	12900				
LR6	9,80	3,6	54,71	1090	20,90	29,2	32,33	16330				

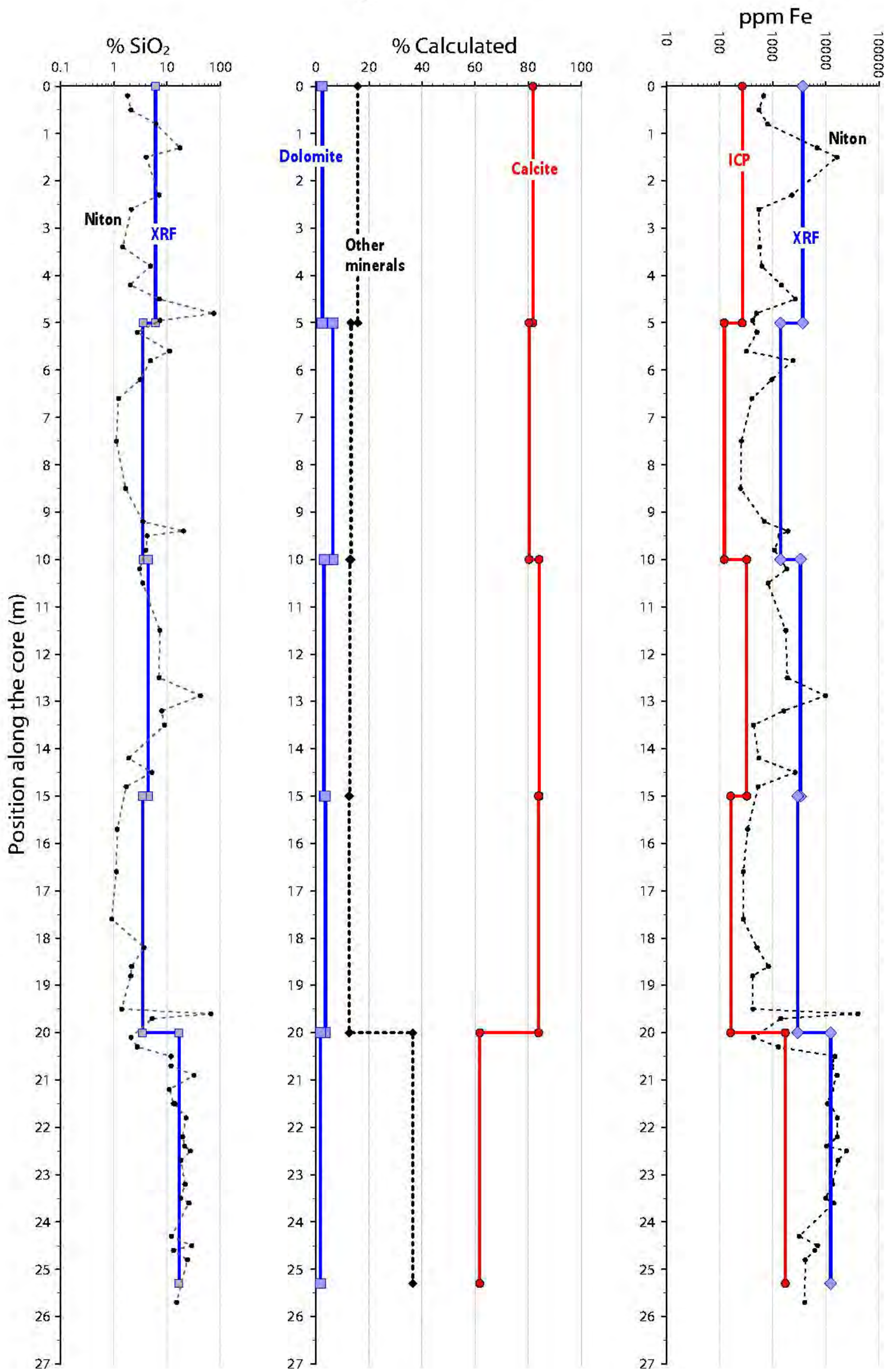


Figure 79: Variations in SiO_2, Fe and major mineral content along borehole LR6.

5.3 Core photographs LR6

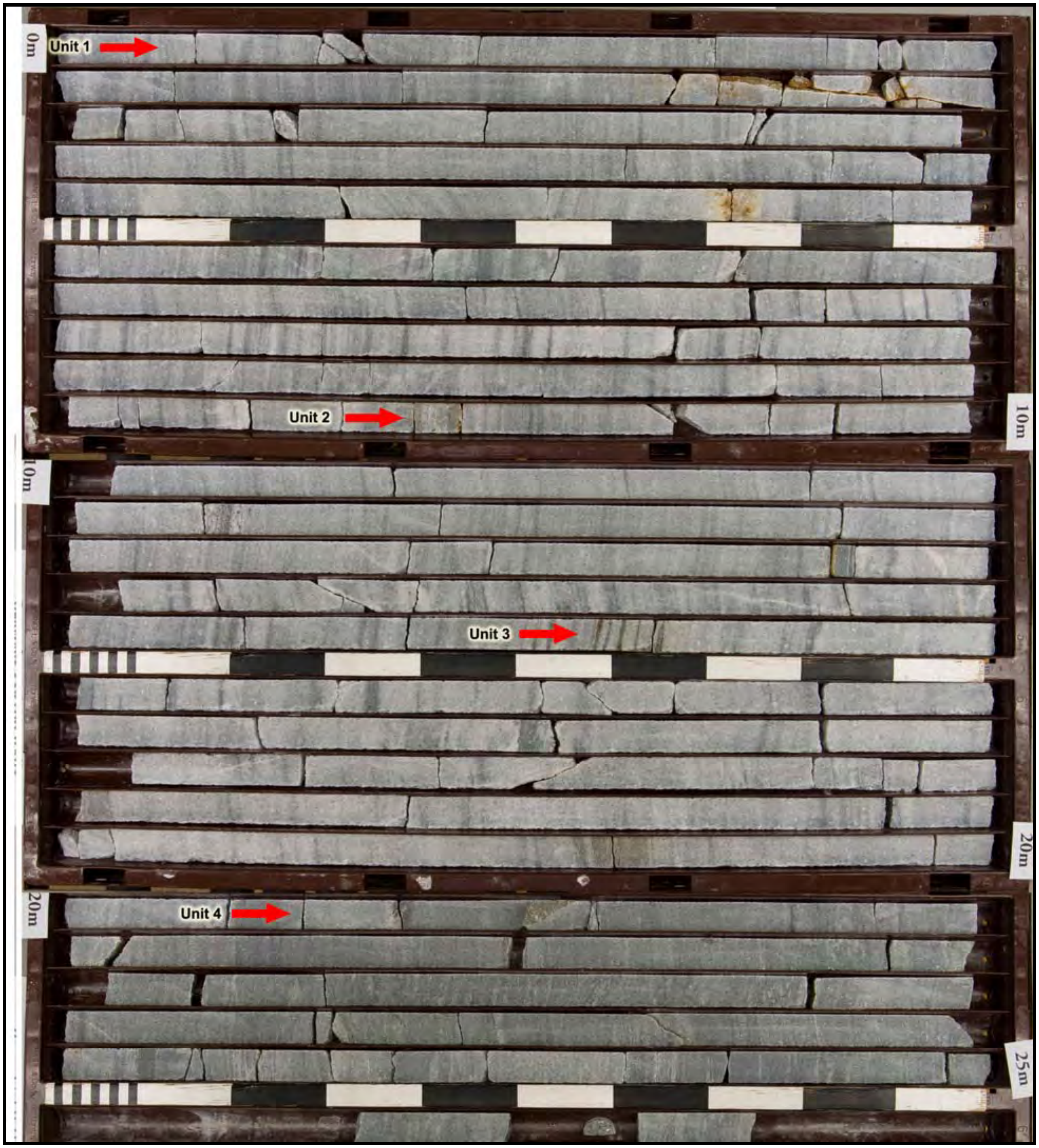


Figure 80: Overview photo of core LR6, Skog.

Figure 81: Core photograph showing white to pale grey distinctly banded calcite marble (units 2 and 3).

Figure 82: Close-up core photo of weakly banded calcite marble. LR6 at 10,5 m.

Figure 83: Close-up core photo of weakly banded calcite marble. LR6 at 14,6 m.

Figure 84: Close-up core photo of grey-green, medium to fine grained impure carbonate. LR6 at 20.6 m.

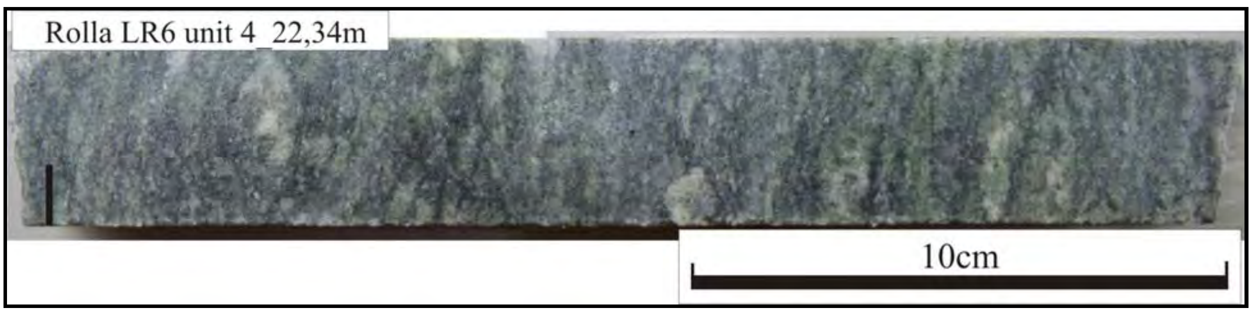


Figure 85: Close-up core photo of impurte carbonate / gneiss. LR6 at 22,3 m.

5.4 Micrographs LR6

5.4.1 Thin-section LR6-02.1m

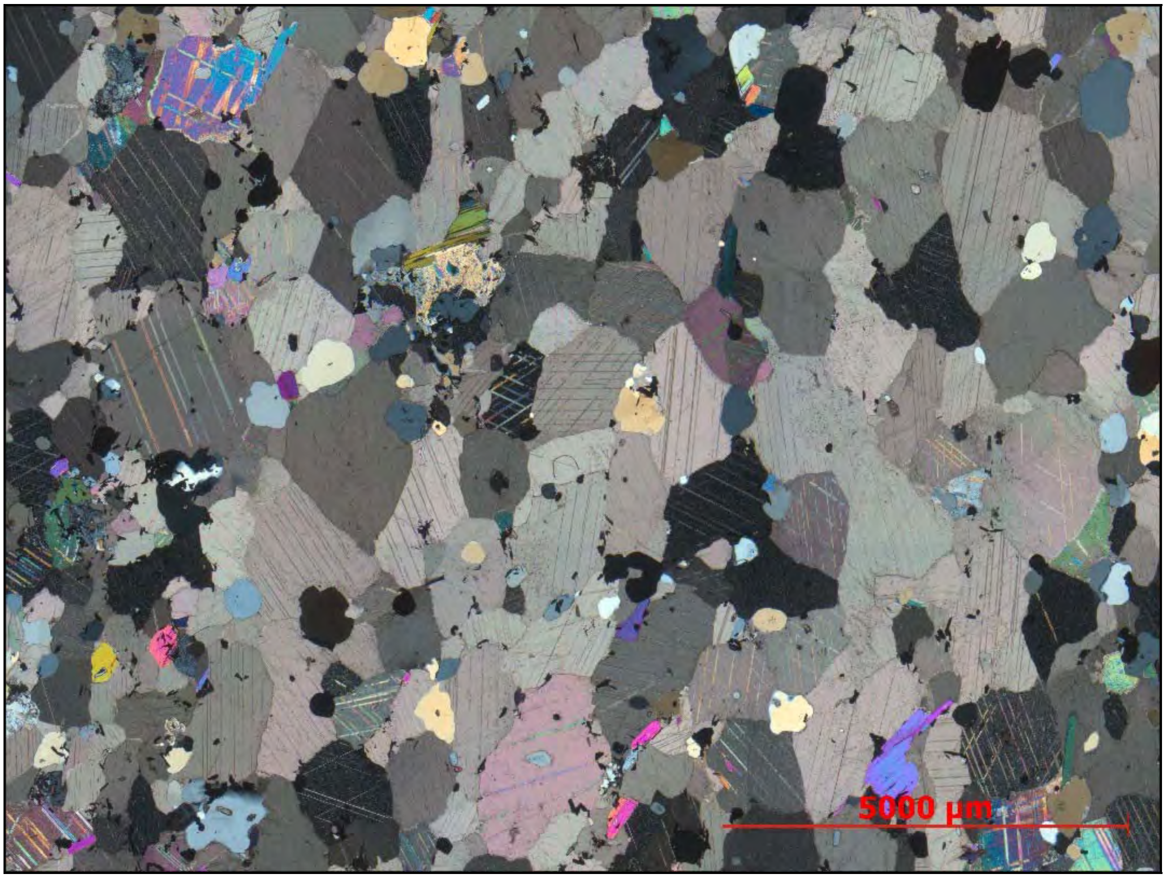


Figure 86: Mosaic microphotograph image of calcium carbonate with numerous inclusions of other minerals. Thin-section LR6-02.1m.

Main minerals in this thin-section are calcite (visually estimated to 80-90 %), quartz (visually estimated to 10%), app. 5 %-10% mica (muscovite, visually estimated to) and 8% other minerals – mainly graphite (visually estimated to 3%) and some olivine and sulphide minerals. Phlogopite and pyroxene are possibly also present.

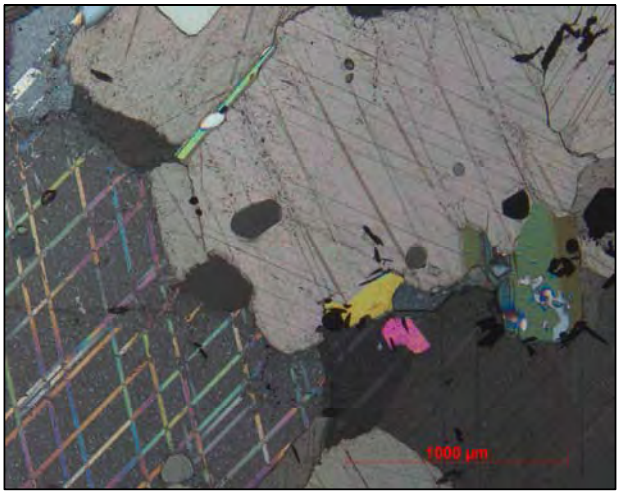


Figure 87: Microphotograph showing inclusions of other minerals in calcite. Thin-section LR6-02.1m.

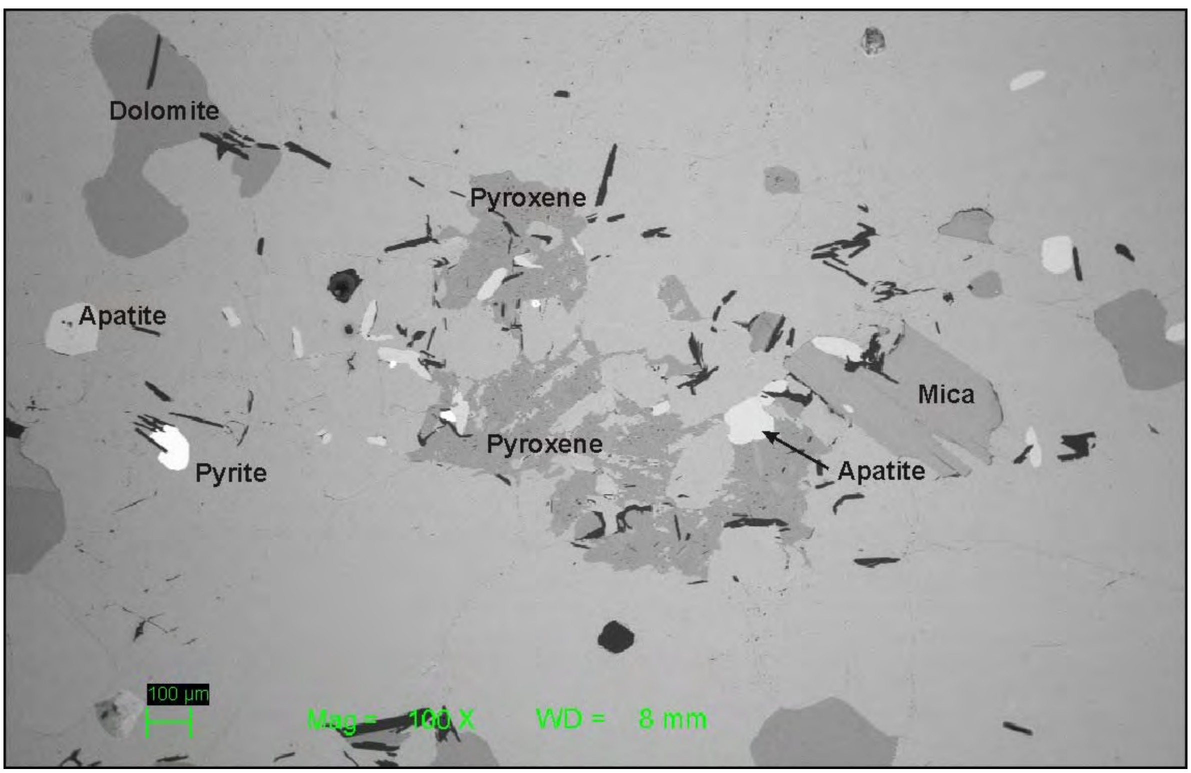


Figure 88: SEM BSE-image of calcite (medium grey), graphite (black), dolomite (darker grey), apatite (brighter gray), pyrite (white) and some mica (elongated medium gray grains) and other silicate minerals (light grey) such as augite or diopside. Thin-section LR6-02.1m.

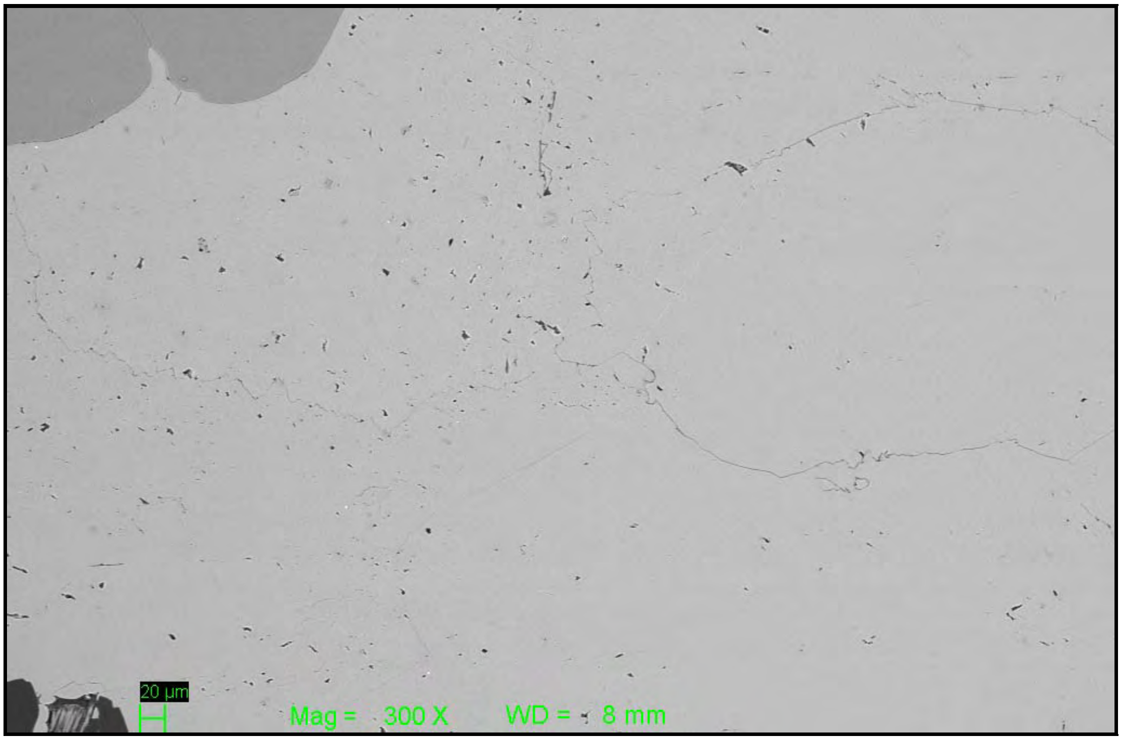


Figure 89: SEM BSE-image showing numerous tiny inclusions of graphite within calcite. Thin-section LR6-02.1m.

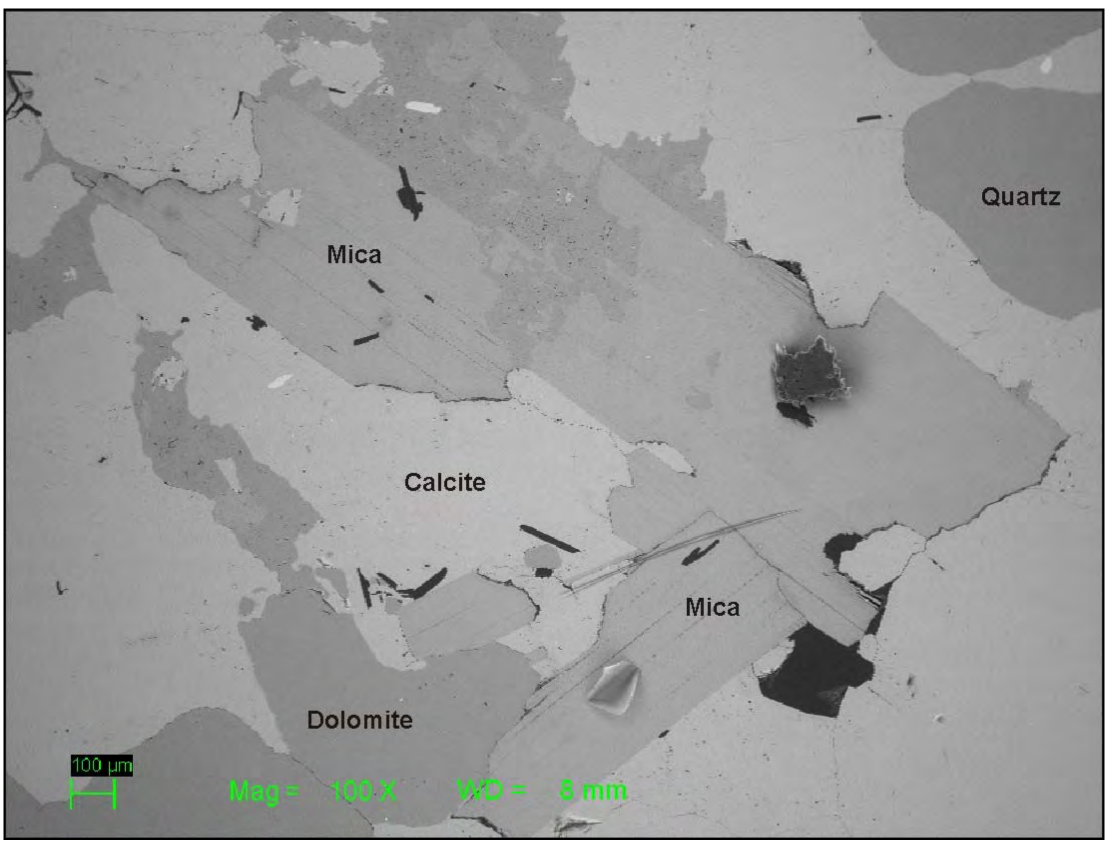


Figure 90: SEM BSE-image of a variety of silicate minerals (various shades of grey) in calcite (light grey). Thin-section LR6-02.1m.

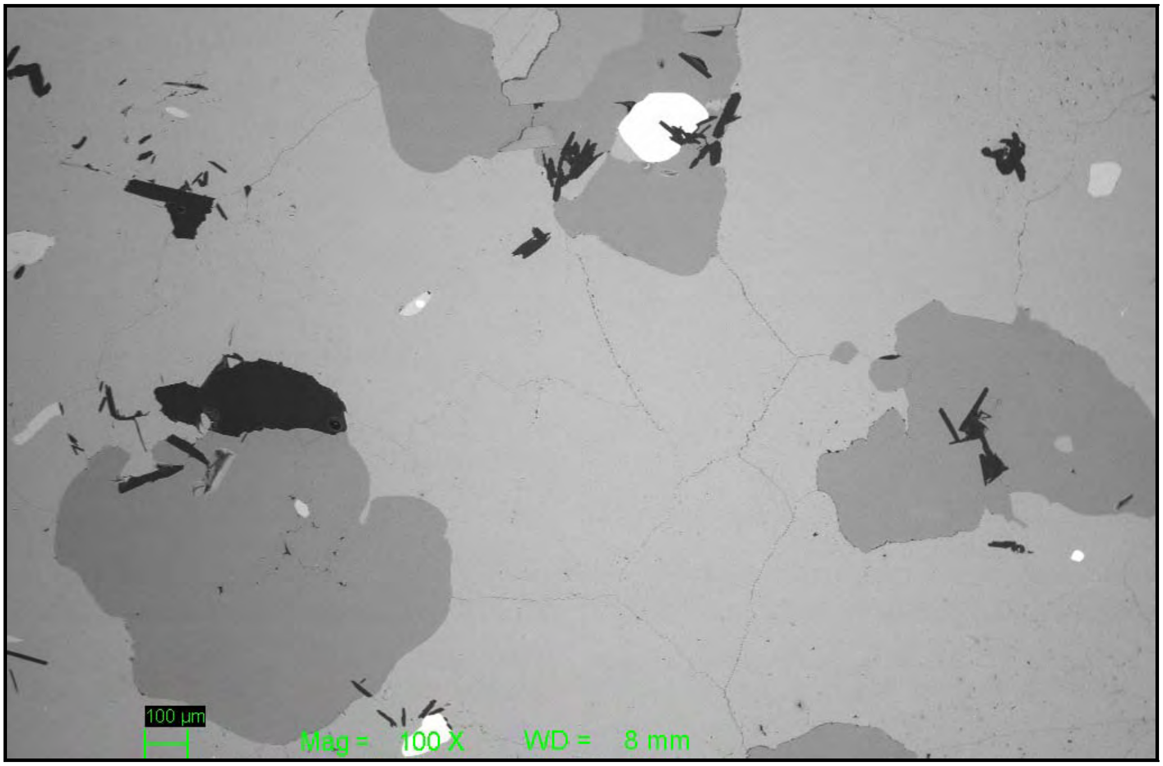


Figure 91: SEM BSE-image showing silicate minerals (mainly quartz, dark grey), graphite (black), apatite (light grey) and pyrite (white) in calcite. Partly intergrowth of quartz and pyroxene minerals. Thin-section LR6-02.1m.

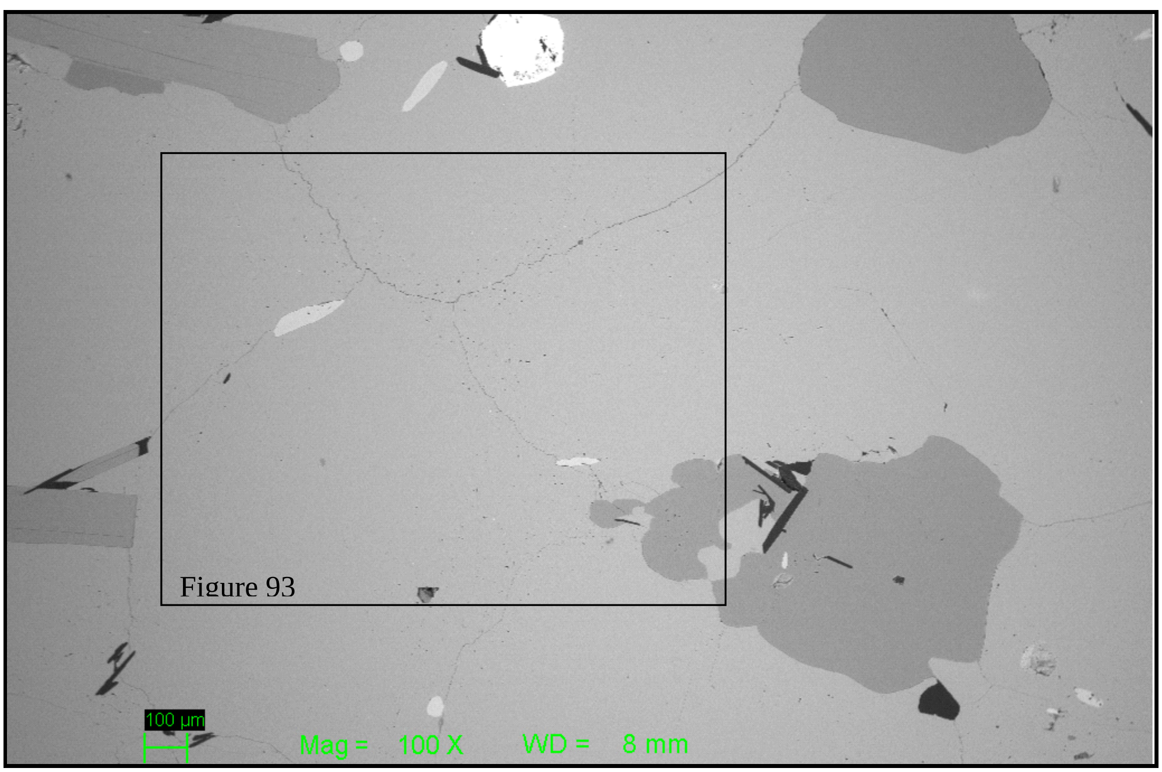


Figure 92: SEM BSE-image showing silicate minerals (quartz and mica; dark grey), graphite (black), apatite (light grey) and pyrite (white) in calcite. Thin-section LR6-02.1m.

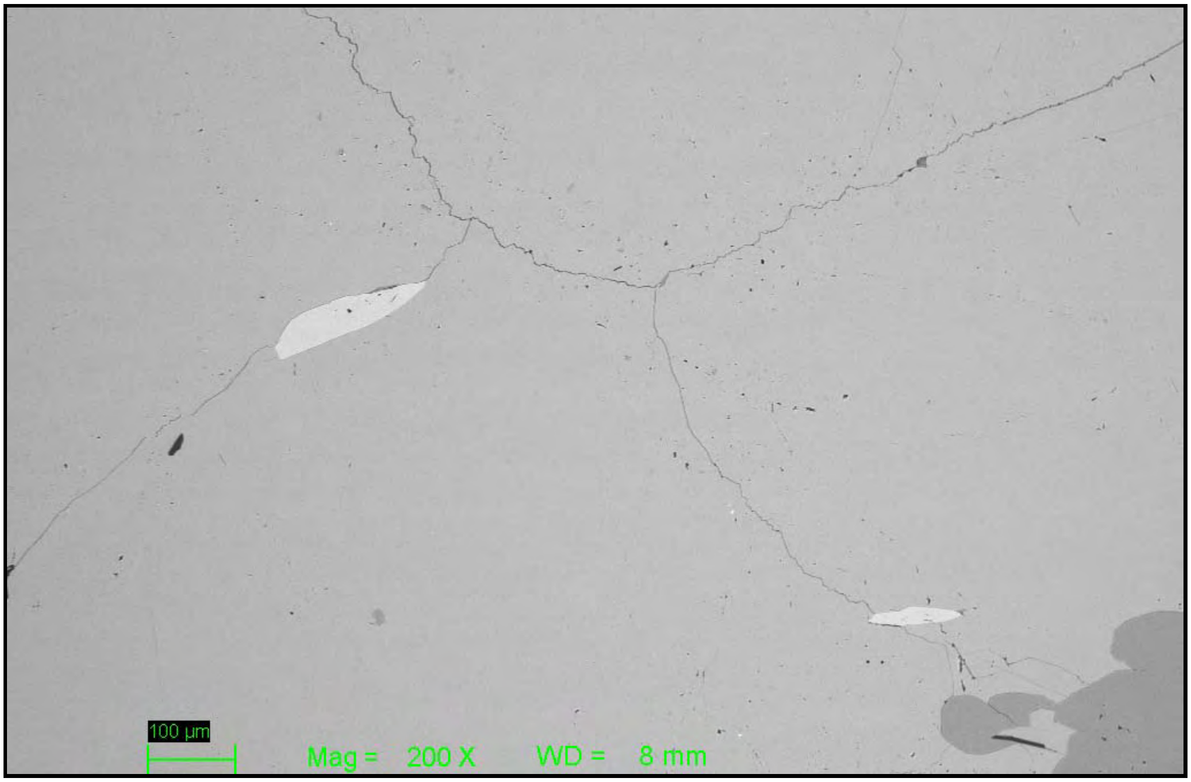


Figure 93: SEM BSE-image close-up of Figure 92 showing tiny graphite inclusions in calcite. Irregular crystal boundaries. Thin-section LR6-02.1m.

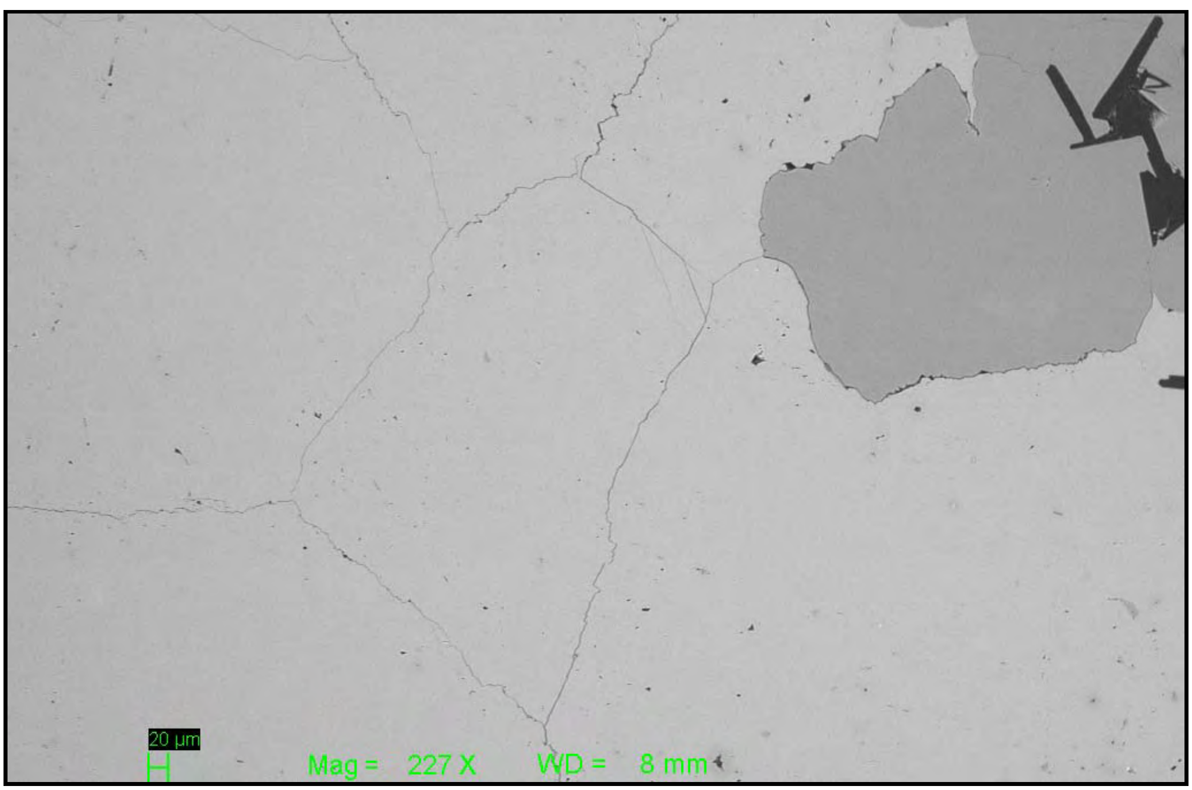


Figure 94: SEM BSE-image showing calcite (grey) and a large quartz grain (dark grey) with graphite inclusions (black). Thin-section LR6-02.1m.

Thin-section LR6-13.0 m

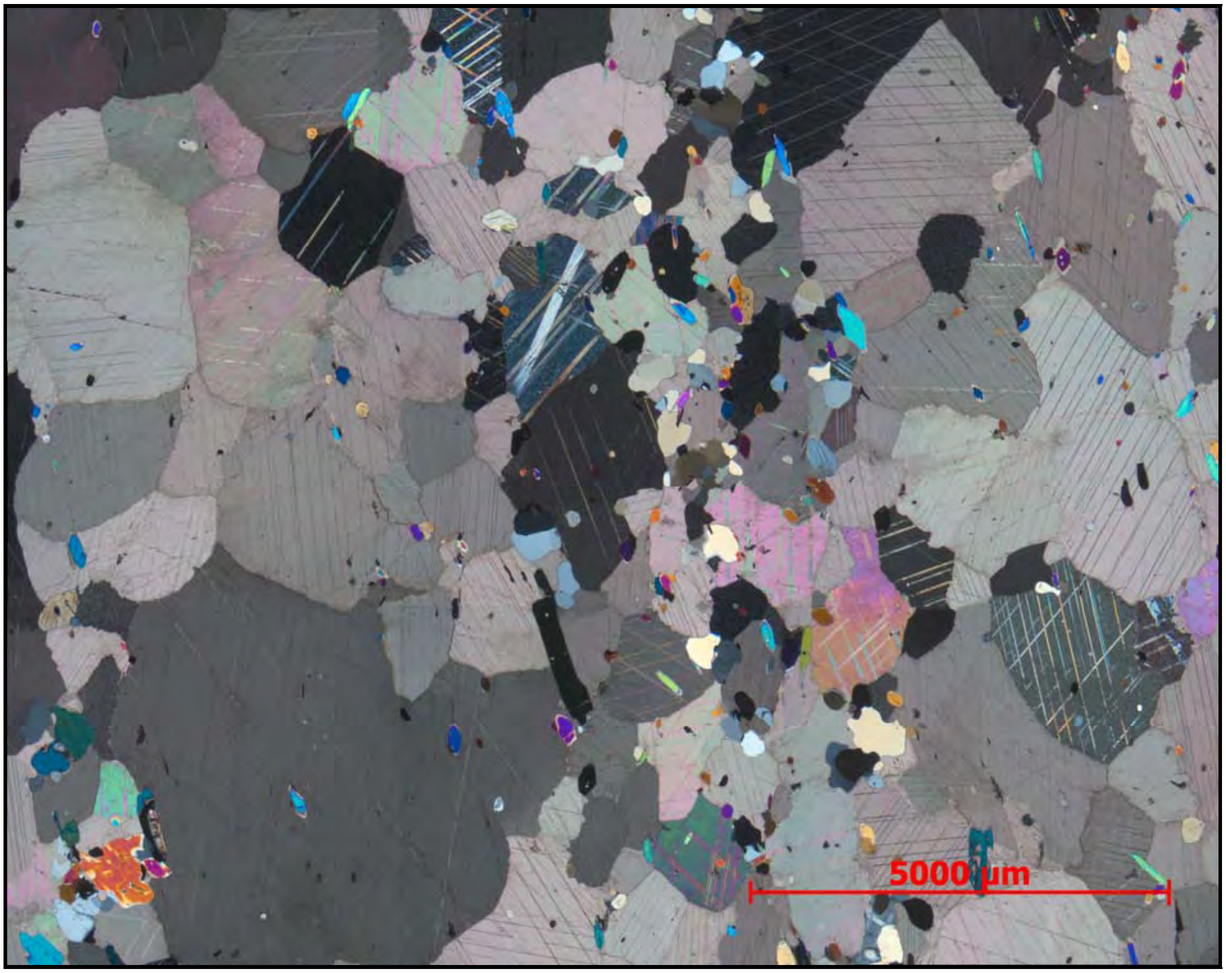


Figure 95: Mosaic microphotograph of coarse-grained calcite marble with inclusions of silicate minerals and graphite.

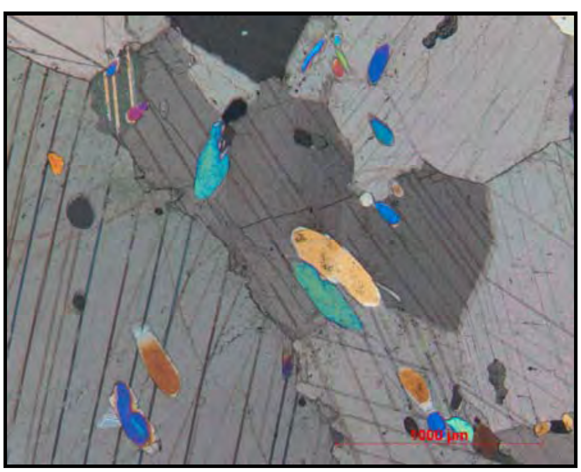


Figure 96: Microphotograph showing inclusions of other minerals in calcite crystals. Thin-section LR6-13.0m.

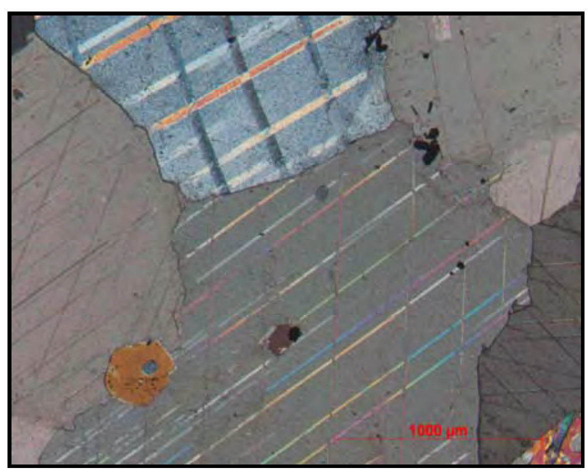


Figure 97: Microphotograph showing inclusions of other minerals in calcite crystals. Thin-section LR6-13.0m.

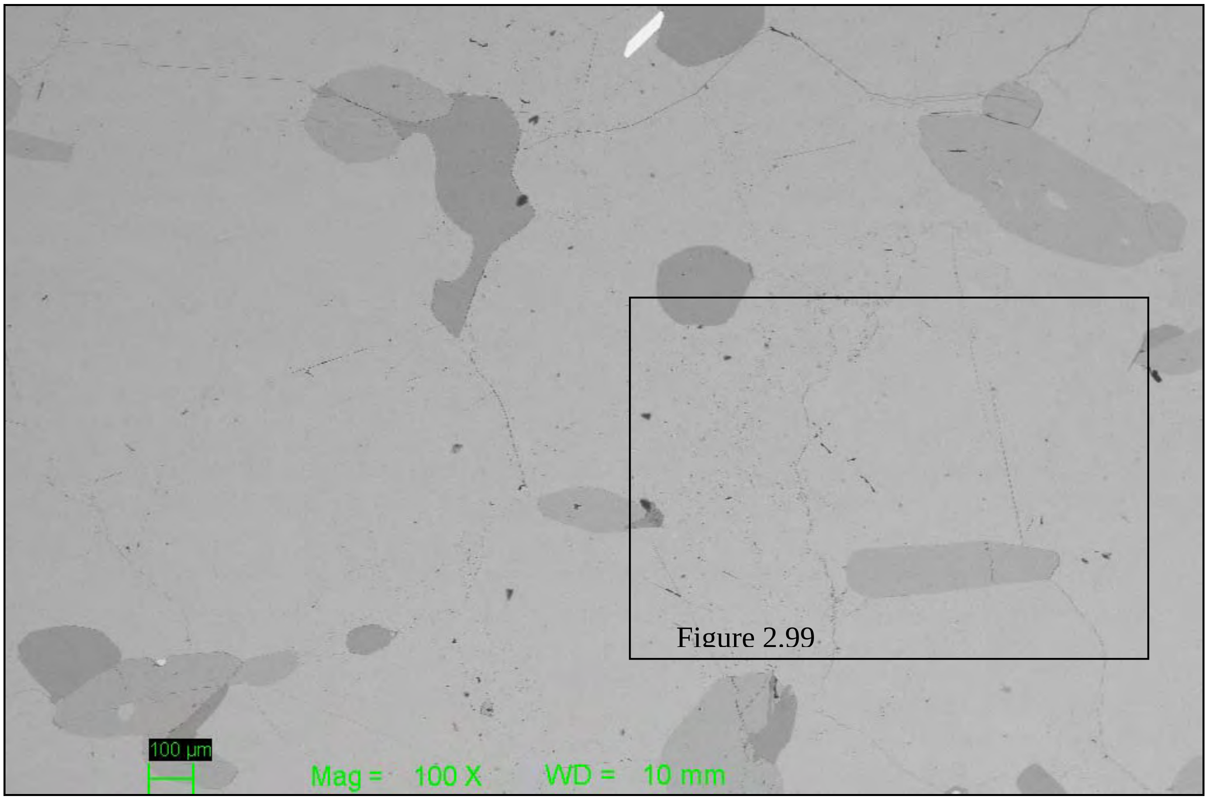


Figure 98: SEM BSE-image showing inclusions in calcite of silicate minerals (mainly quartz, mica and pyroxene) and graphite (black) and pyrite (white). Thin-section LR6-13.0m.

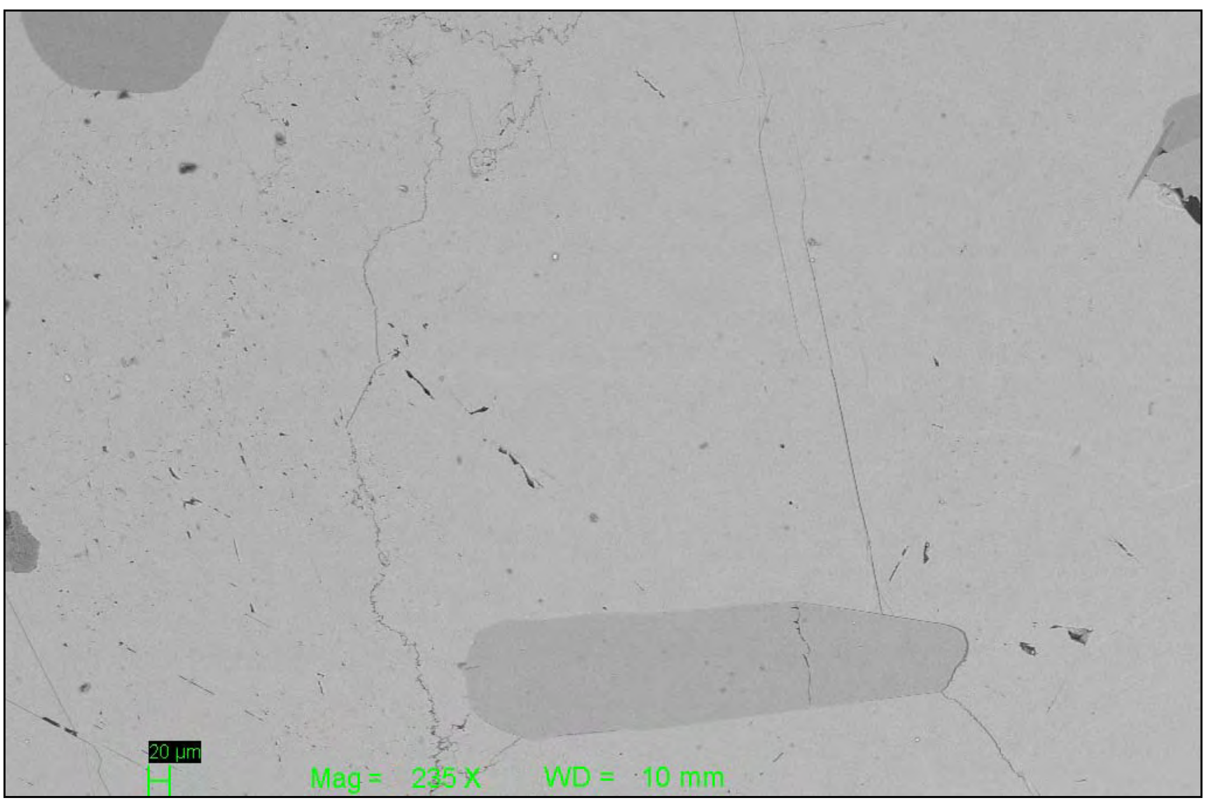


Figure 99: SEM BSE-image close-up of Figure 98. Thin-section LR6-13.0m.

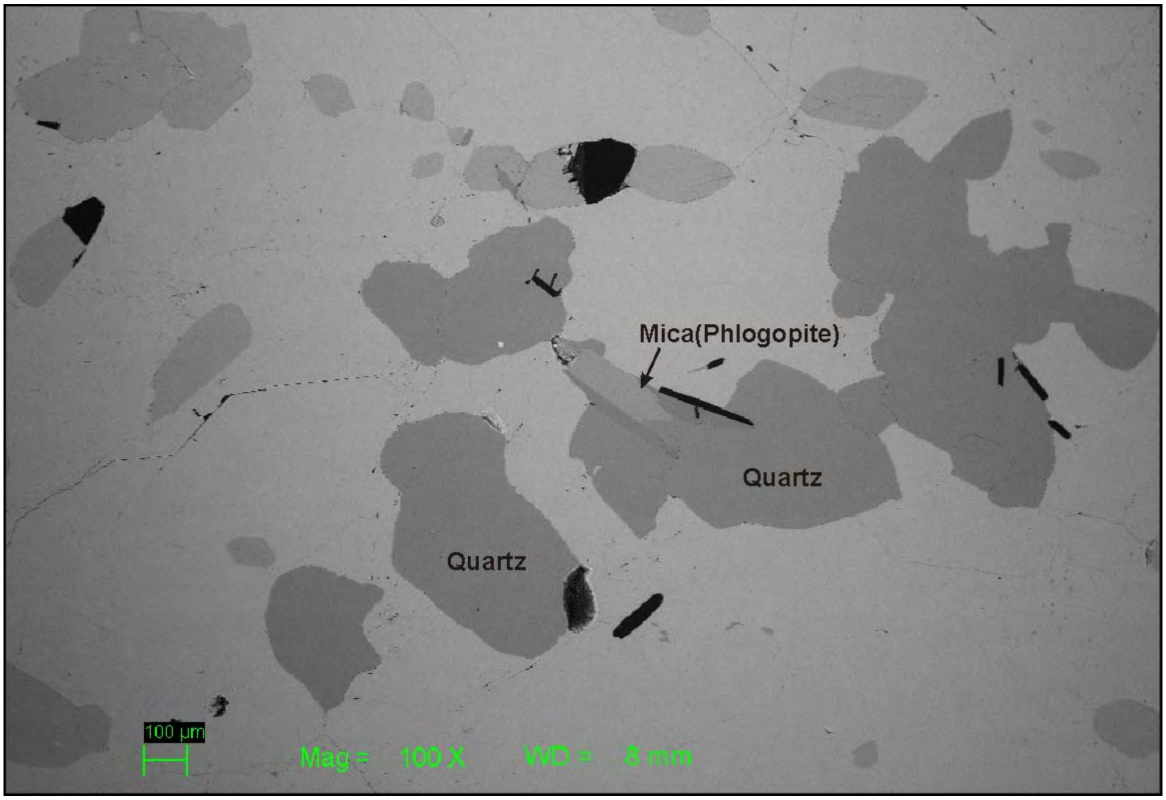


Figure 100: SEM BSE-image showing silicate minerals (mainly quartz) and graphite in calcite. Thin-section LR6-13.0m.

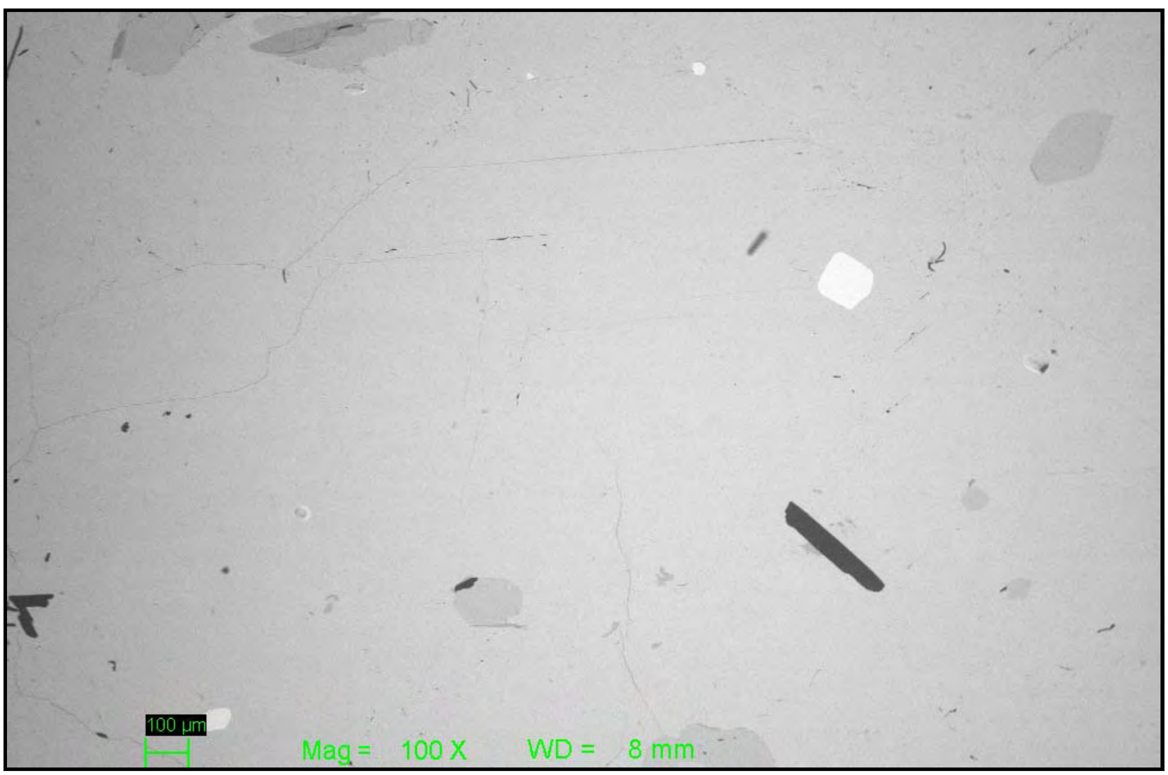


Figure 101: SEM BSE-image showing silicate minerals (mainly quartz and mica), graphite and pyrite in calcite. Thin-section LR6-13.0m.

5.4.2 Thin section LR6-22.0 m

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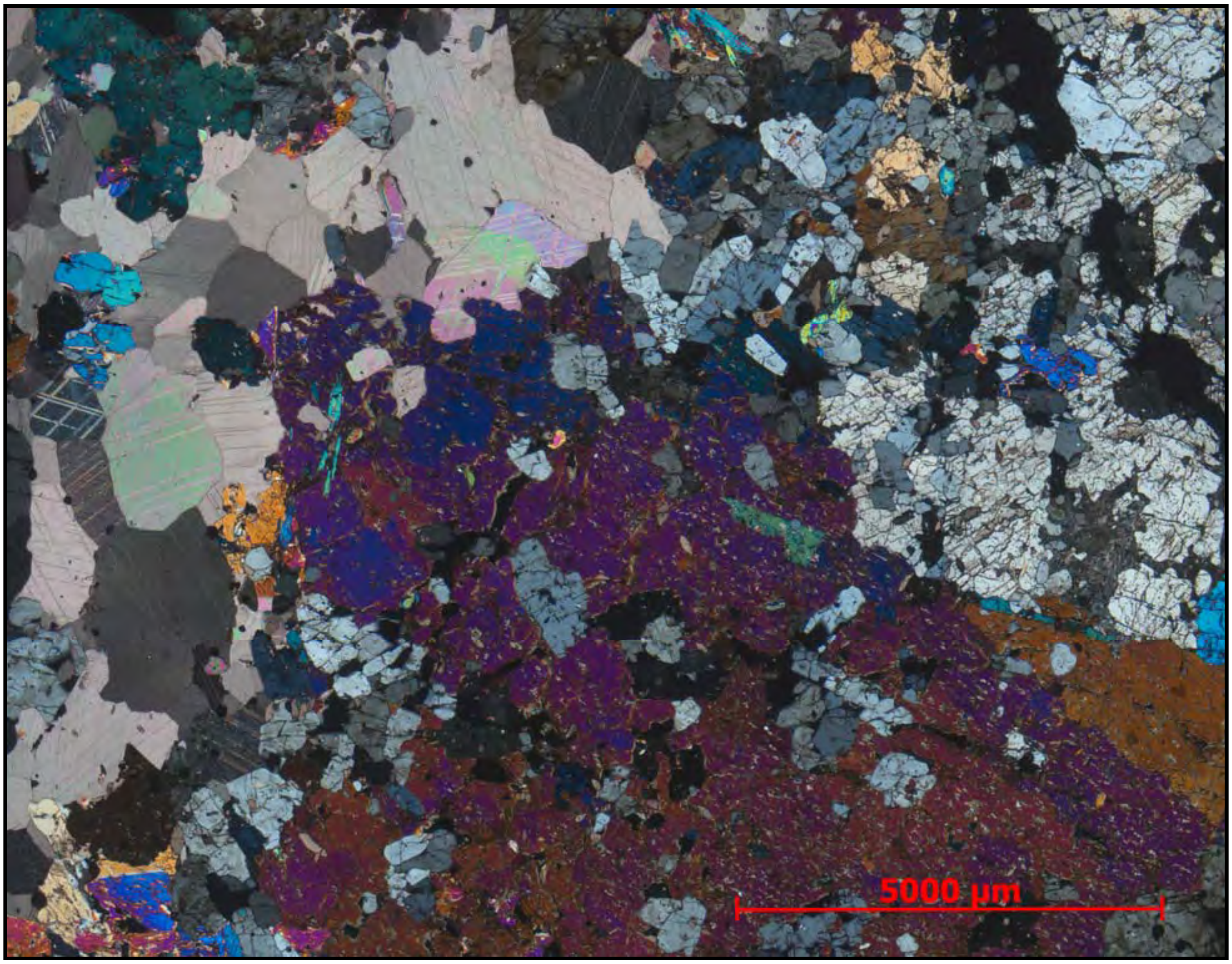

Figure 102: Mosaic microphotograph of highly impure marble with significant content of pyroxenes (mainly diopside). Thin section LR6-22.0 m.

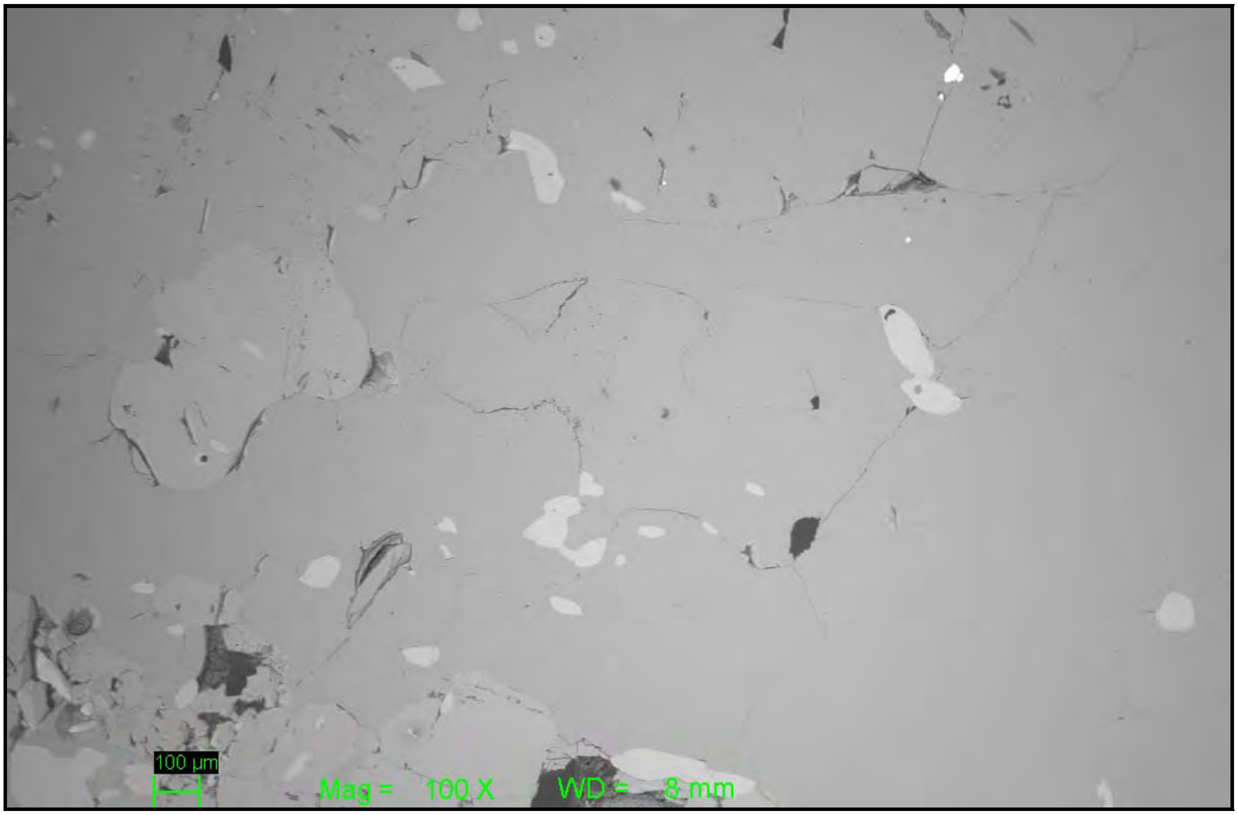

Figure 103: SEM BSE-image showing inclusions of other minerals (quartz, Ti-rich minerals) in calcite. Thin section LR6-22.0 m.

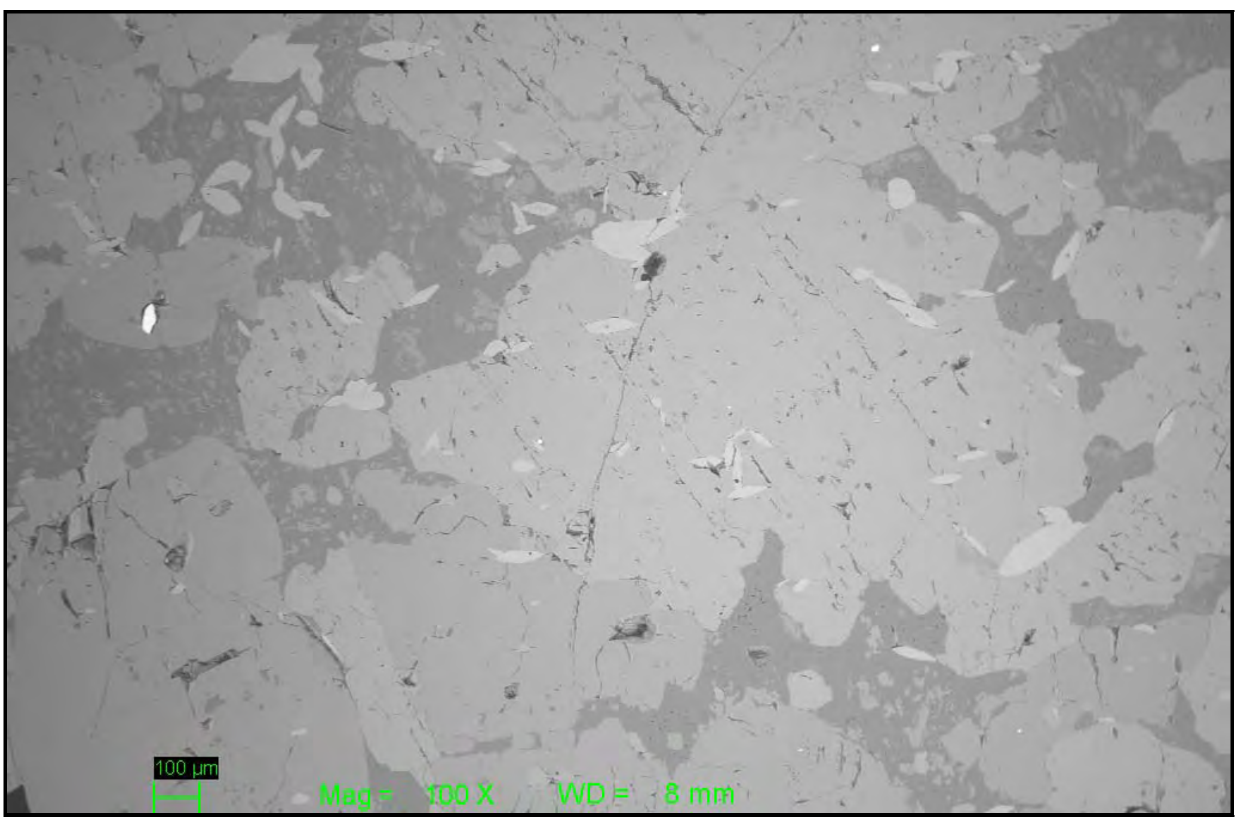

Figure 104: SEM BSE-image showing a complex association of silicate minerals. Thin section LR6-22.0 m.

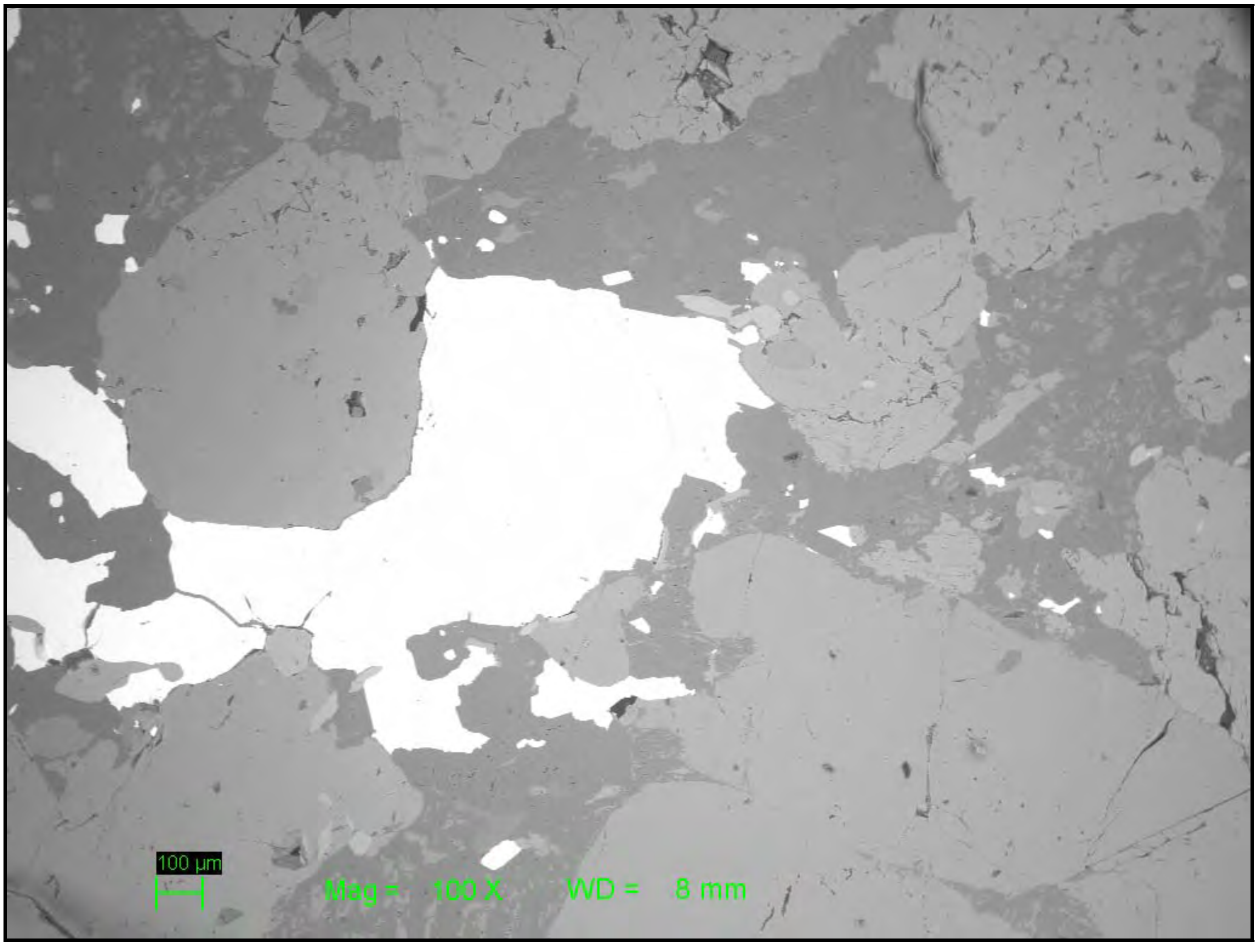

Figure 105: SEM BSE-image showing a complex association of minerals. Thin section LR6-22.0 m.