

**QEMSCAN[®] ANALYSIS OF
SELECTED BOREHOLE
SAMPLES FROM
KEFALONIA, GREECE**

Report No. XXXX/Iqs

Project No. Iqs/QE181

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MAY 2012



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*QEMSCAN® Analysis of Selected Borehole Samples from Kefalonia, Greece***CHAPTER 1****Introduction**

This study aims to provide an insight into the mineralogy of selected sample depths from shallow borehole cores drilled in Kefalonia, Greece, through the use of QEMSCAN (Quantitative Evaluation of Minerals by Scanning Electron Microscopy).

As part of the ongoing collaboration between John Underhill at Edinburgh University and Fugro, QEMSCAN analysis may provide valuable information in the determination of sediment type and mineralogy in the ongoing search for Ithaca, which has been proposed to potentially exist on the Paliki peninsular on the most western side of present day Kefalonia.

It has been suggested that a small narrow channel/seaway may have existed between the Paliki peninsular and the main island of Kefalonia at the time Ithaca existed, which would match historical references of the setting in Homers Odyssey. As part of ongoing efforts to test this theory, samples of sediment have been taken from boreholes in and around the location of the supposed pre-existing seaway.

One of the possible aims of the QEMSCAN analysis was to link ratios and abundances of heavy mineral assemblages to previous volcanic eruptions in the area, including Mount Etna in Italy and the Hellenic Arc volcanoes of Santorini, Kos and Milos. This tephrostratigraphic data may then be compared to biostratigraphic ages, core descriptions and QEMSCAN mineralogical and textural data.

After the core description and micropaleontological works on the cores had taken place, key depths were highlighted by Dr Paul Marshall as containing clastic sediment, which was unexpected given the hypothesis that a seaway existed there, as deeper marine sediments would be expected.

These key sample depths chosen for whole rock analysis, selected by Dr Paul Marshall, were analysed by QEMSCAN® at 10 µm resolution over the following intervals:

C4c	- 0.75m
C5a	- 4.50m
	- 5.25m
C6a	- 0.50m
	- 9.75m
C6c	- 18.25m
	- 18.75m
C2006	- 6.35m
	- 19m
	- 27.60m

Whole rock analysis on the above ten samples was conducted on core chips or pieces straight from the core box, without any processing. The samples were dried and mounted in resin. See chapter 1.1 for details on whole rock sample preparation methodology.

Five of the above samples contained only small concentrations of detrital material, with the bulk of these five samples visibly consisting of clay sized particles. Therefore, QEMSCAN analysis on the processed residue of these samples was conducted at 10 µm resolution on the following depths:

C5a - 4.50m
 - 5.25m
C2006 - 6.35m
 - 19m
 - 27.60

Processed residue analysis was performed on samples which had high clay mineral content which effectively diluted the concentrations of detrital grains in the sample. The clay minerals were filtered out of the samples to leave a >53µm particle size residue, in order to analyse larger concentrations of the detrital grain fraction. See Chapter 1.1 for more details on the processed residue preparation methodology.

1.1 QEMSCAN METHODOLOGY

The system comprises a scanning electron microscope combined with four energy dispersive spectrometers (EDS), a microanalyser and an electronic processing unit, which integrates the scanned data using a powerful software suite (iDiscover) to provide information about the chemical and mineral composition of the sample.

Core pieces, as used in this project for whole rock analysis, were washed with detergent to remove oil and potential drilling mud sticking to the surface, rinsed with distilled water and dried in an oven at c. 40°C.

Core pieces used for processed residue analysis were selected from the core box. Larger samples than required for whole rock analysis were taken due to the subsequent removal of the bulk of the mineral assemblage (clay minerals) during processing. The nature of the sediment made grinding the samples unnecessary. Samples were manually worked through a 53µm sieve using only warm water and detergent. The remaining residue (>53µm) was then rinsed with distilled water and dried in an oven at c. 40°C.

Prior to QEMSCAN[®] analysis, the samples were placed in a 30 mm mould with enough Epofix Resin to produce a 1.5 cm thick block. This mould was then placed in a Struers Citovac for four 5 minute vacuum cycles to remove any trapped air before transferring the blocks to a pressure vessel. The blocks were allowed to harden in the pressure vessel before grinding/polishing the surface of each block using a Tegrasystem grinder/polisher machine and 4 progressively finer grinding discs. Finally, the polished blocks were carbon-coated before transfer to the QEMSCAN[®] for analysis.

Each sample was divided by the machine into a series of fields which were analysed individually. Initially the back scatter electrons were measured, this equating the surface detections to atomic weight, with the brightness of the image reflecting chemical composition. A back scatter cut-off was then used to identify the rock fragments and these were then further analysed by the EDS detectors to provide a mineralogical map of each sample. This analysis was carried out at 12,000 points per minute with measurements taken at every 10 µm step. Typically, this 10 µm analysis contains approximately 720,000 point counts. The data can then be manipulated by the software to produce a breakdown of the mineralogical content of the rock, grain size, porosity, pore size distribution and textural information.

*QEMSCAN[®] Analysis of Selected Borehole Samples from Kefalonia, Greece***CHAPTER 2****Sample summaries****2.1 BOREHOLE C4C 0.75M (WHOLE ROCK)****Mineralogical Comments**

The Sample 0.75m from well C4c is primarily calcareous mud (45.51%) and to a lesser extent ankerite at 10.03% as well as quartz at 9.25% and plagioclase feldspar at 3.70%. Heavy minerals in sample 0.75m make up 7.01% of the whole sample. The most prominent heavy mineral in the sample is Hornblende (5.66%), other heavy minerals such as pyroxene, rutile/anatase, tremolite-actinolite and apatite are present in trace amounts.

2.2 BOREHOLE C5A 4.50M (WHOLE ROCK)**Mineralogy Comments**

Heavy minerals are the dominant component of sample C5a 4.50m at 20.74%. Hornblende is the dominant heavy mineral within the sample at 19.11%. Other heavy minerals such as pyroxene, rutile/anatase and tremolite-actinolite are present in trace amounts within this sample. The rest of the sample is composed of calcareous mud (20.12%), illite/muscovite (17.29%), ankerite (9.30%), siliceous mud (8.83%), smectite (8.28%), quartz (5.68%) and plagioclase feldspar (2.41%).

2.3 BOREHOLE C5A 4.50M (PROCESSED RESIDUE)**Mineralogy Comments**

As can be seen from appendix 1.3, in sample C5a 4.50m there is a significant difference in the amount of clay minerals, such as smectite, kaolinite, illite/muscovite, calcareous mud and siliceous mud, compared to the unwashed sample. Calcite (56.68%) has increased in the sample as well as quartz (22.68%) and plagioclase feldspar (5.13%). The heavy mineral content in the sample has also decreased, but the most abundant heavy mineral is still hornblende (0.38%).

2.4 BOREHOLE C5A 5.25M (WHOLE ROCK)**Mineralogy Comments**

In a similar fashion to sample C5a 4.50m, the heavy minerals make up 20.81% of the sample. Hornblende is the dominant mineral within the heavy minerals at 18.92% while other heavy minerals such as pyroxene, rutile/anatase and tremolite-actinolite all appear in the sample in trace amounts. Illite/muscovite is the other dominant mineral within the sample at 20.59% with calcareous mud (16.15%), siliceous mud (9.12%), smectite (8.34%), quartz (7.05%), k-feldspar (2.51%) and plagioclase feldspar (2.93%).

2.5 BOREHOLE C5A 5.25M (PROCESSED RESIDUE)

Mineralogy Comments

As the sample has been washed, there is some reduction in the abundance of clay minerals such as illite/muscovite, smectite, siliceous mud and calcareous mud, although the washed sample sees an increase in kaolinite. Quartz has the highest mineral abundance in the sample (32.46%) and there are also high amounts of calcite (8.22%) compared to the previous unwashed sample. The amount of heavy minerals has been reduced (6.28%) and hornblende remains the dominant heavy mineral within the sample.

2.6 BOREHOLE C6A 0.50M (WHOLE ROCK)

Mineralogy Comments

Samples from borehole C6a provides a contrast to the previous samples as the abundances of heavy minerals are relatively low. In sample C6a 0.5m the heavy minerals make up just 1.74% of the whole sample, with Rutile/Anatase being dominant at 0.54%. Sample 0.5m has high abundances of smectite (25.43%), quartz (23.28%) and illite/muscovite (21.32%). The content of kaolinite within the sample is 9.11%, the content of siliceous mud is 6.88% and the content of chlorite is 3.24%. Plagioclase feldspar and K-feldspar occur within the sample at 2.67% and 2.85% respectively.

2.7 BOREHOLE C6A 9.75M (WHOLE ROCK)

Mineralogy Comments

Similar to the 0.5m sample from this borehole, the heavy minerals do not play a significant role within the mineralogy of sample 9.75m. Rutile/anatase is the principal heavy mineral, with an abundance of 0.35% of the whole sample. Overall, kaolinite is dominant within the sample, with an abundance of 33.80%. Smectite (17.98%), quartz, (15.67%), illite/muscovite (12.68%), chlorite (11%) and siliceous mud (3.64%) all occur to a lesser extent within sample 9.75m.

2.8 BOREHOLE C6C 18.25M (WHOLE ROCK)

Mineralogy Comments

Quartz is dominant within sample C6c 18.25m at 39.94%. Kaolinite has an abundance of 16.80%, whereas K-feldspar, plagioclase feldspar, illite/muscovite, chlorite, smectite, calcite, siliceous mud and calcareous mud all occur within the sample with abundances below 10%. The heavy minerals make up 3.57% of sample C6c 18.25m. Hornblende is the dominant heavy mineral at 2.20%, whereas the other minerals all occur in trace amounts. The occurrence of olivine within the sample is notable, although it only has an abundance of 0.33%, it could be used as a good indicator of the provenance of mafic minerals within the sample.

2.9 BOREHOLE C6C 18.75M (WHOLE ROCK)

Mineralogy Comments

In a similar fashion to sample 18.25m from borehole C6c, sample 18.75m is dominated by quartz at 35.17%. There is an increase in calcite (33.08%) compared to sample 18.25m (7.93%). There is also a slight increase in calcareous mud (9.51%) in sample 18.75m which ties in with the increase in calcite

in the sample. The illite/muscovite content has decreased compared with the previous sample to 3.98%. The heavy mineral content makes up 2.89% of the whole sample, with hornblende being dominant within the heavy mineral assemblage at 1.87%.

2.10 BOREHOLE C2006 6.35M (WHOLE ROCK)

Mineralogy Comments

Samples from borehole C2006 show high percentages of calcareous mud and also heavy minerals. Sample 6.35m is a clay sample and this shows in the QEMSCAN results as it has an abundance of clay minerals, such as 24.78% calcareous mud, 15.66% illite/muscovite, 9.20% siliceous mud, 3.43% smectite and 2.33% kaolinite. The sample also has 12.93% quartz and 12.20% heavy minerals. The heavy minerals comprise of mainly hornblende, which has an abundance of 9.92% and other minerals such as pyroxene, rutile/anatase, tremolite-actinolite and olive, which all occur in trace amounts.

2.11 BOREHOLE C2006 6.35M (PROCESSED RESIDUE)

Mineralogy Comments

The washed sample provides a greater insight into the mineralogy of the original rock prior to weathering. The percentage of clay minerals is greatly reduced due to washing of the sample and it is now predominantly quartz, showing an abundance of 41.34%. The calcite content in the whole rock sample is low at 2.88% whereas in the washed sample it is a lot higher at 16.84%. There is also an increased amount of pyrite (9.27%) over the whole rock sample but the heavy mineral content has been reduced to 1.17% of the whole sample.

2.12 BOREHOLE C2006 19M (WHOLE ROCK)

Mineralogy Comments

In a similar fashion to sample 6.35m, clay minerals are dominant within sample 19m. Calcareous clay is the dominant mineral within sample 19m (47.70%), illite/muscovite (8.41%) and siliceous mud (7.94%). Interestingly, the ankerite (6.49%) and gypsum (1.01%) content has increased compared to the previous sample. The gypsum clasts can be seen in appendix 1.13 and are clearly the largest clasts in the sample. The heavy minerals make up 9.29% of the whole sample with hornblende being the dominant heavy mineral at 8.11% and other minerals such as pyroxene (0.46%), rutile/anatase (0.30%) and tremolite-actinolite (0.21%) all occurring in trace amounts.

2.13 BOREHOLE C2006 19M (PROCESSED RESIDUE)

Mineralogy Comments

After washing, the larger gypsum clasts have been left behind and therefore are the dominant mineral within the residual sample at 59.86%. The appearance of such large amounts of gypsum within this samples suggest that the rock was deposited under marine conditions and then later was subjected to exposure for the gypsum to have formed. There is quite a high percentage of quartz in the sample (18.58%)

2.14 BOREHOLE C2006 27.60M (WHOLE ROCK)**Mineralogy Comments**

Just as the other samples from borehole C2006, sample 27.60m has a high percentage of calcareous mud at 25.03%. There are also significant abundances of illite/muscovite (16.44%), quartz (9.75%), siliceous mud (7.80%), ankerite (5.71%), kaolinite (3.16%), smectite (3.00%) and calcite (2.69%). There is a high abundance of heavy minerals in sample 27.60m and in a similar fashion to other samples from borehole C2006, hornblende is the most dominant heavy mineral (13.26%). Pyroxene, rutile/anatase, olivine, garnet and apatite all occur in trace amounts.

2.15 BOREHOLE C2006 27.60M (PROCESSED RESIDUE)**Mineralogy Comments**

The residue from sample C2006 27.60m shows an increase in quartz and calcite to 43.05% and 9.74% respectively. In a similar fashion to the previous samples which have been washed, there is a decrease in the amount of calcareous mud from 25.03% in the whole rock sample to 8.34% in the washed sample. A decrease in clay minerals such as illite/muscovite (4.17%), kaolinite (2.03%), smectite (0.36%) and chlorite (0.58%) can be seen in the washed sample compared to the whole rock sample. There is a decrease in heavy minerals from 15.66% in the whole rock sample to 1.68% in the washed sample. In the washed sample, the heavy minerals are mainly comprised of hornblende (0.72%), pyroxene (0.42%), apatite (0.17%), olivine (0.14%) and rutile/anatase (0.13%).

*QEMSCAN® Analysis of Selected Borehole Samples from Kefalonia, Greece***CHAPTER 3****Biostratigraphic
Correlation**

With the data provided from a previous study undertaken by Fugro Robertson Ltd, named ‘Kefalonia: Onshore Shallow Drilling Programme – Stratigraphic investigation of the Recent – Late Cretaceous sediments in 17 boreholes,’ it was possible to cross correlate the samples in this study with stratigraphic ages according to the previous study. The following table was produce in accordance with the data provided:

Table 1:

Borehole	Sample No.	Stratigraphic Age
C4c	0.75	Pleistocene
C5a	4.50	Pliocene
C5a	4.50 SR	Pliocene
C5a	5.25	Pliocene
C5a	5.25 SR	Pliocene
C6a	0.5	Recent
C6a	9.75	Early Pliocene
C6c	18.25	Pleistocene
C6c	18.75 SR	Pleistocene
C2006	6.35	Pliocene
C2006	6.35 SR	Pliocene
C2006	19	Pliocene
C2006	19 SR	Pliocene
C2006	27.60	Pliocene
C2006	27.60 SR	Pliocene

*QEMSCAN[®] Analysis of Selected Borehole Samples from Kefalonia, Greece***CHAPTER 4****Mafic Derivation**

The occurrence of mafic minerals (olivine, pyroxene and biotite) within the samples from the boreholes in this study, allows us to consider how these minerals had originally been deposited and from what source. It could be said that these mafic minerals were deposited in some form of a tuff due to volcanic ash being ejected from a nearby eruption.

Mount Etna is approximately 500km to the west of Kefalonia and has had Strombolian and Plinian eruptive styles. Mount Etna's lava composition is predominantly basaltic, Hawaiitic and basic mugearitic. The mineral assemblages in these types of lava consist of minerals such as olivine, plagioclase, clinopyroxene and glauconite (Del Carlo et al. 2004). Of these minerals, only olivine has been detected in this study. The average age of the samples from the boreholes in this study are Pliocene/Pleistocene and it is believed that the earliest eruption of Mount Etna occurred just over 300ka, so does therefore not correlate with the samples from this study. As well as the geological and biostratigraphical indicators, it would have to be assumed that the paleo-wind direction at the time of eruption was west to east which would then carry the ash fall from Mt Etna and deposit them in Kefalonia. Another major assumption that would need to be taken into account is that there had been an eruption big enough for the ash deposits to have been carried over 500km between Mt Etna and the island of Kefalonia. Considering the age of the earliest eruption of Mount Etna, the mineralogy of its erupted lava, the unknown paleo-wind direction and the distance of Mount Etna to Kefalonia, it is highly unlikely that Mount Etna is the source of the mafic minerals seen in this study.

With this in mind, a different volcanic source needs to be considered. The Hellenic Arc (also known as the Aegean Arc) is an area of recent and extinct volcanic activity, spreading from the island of Rhodes in the east to the Ionian Islands in the west. The main centres of active volcanism are Santorini, Kos, Milos and Nisyros. Although these volcanoes are active now, the late Neogene and Quaternary periods were a time of intense volcanism within this area. (L.Francalanci et al. 2005)

The main areas of volcanic activity in the Neogene and Quaternary were the volcanoes of Santorini, Kos and Milos, all of which have produced dacitic lavas (L.Francalanci et al. 2005) that have similar mineralogy to those seen in the sample studies (i.e. contain plagioclase, hornblende, biotite, pyroxene and quartz). All of these volcanoes are close enough to Kefalonia to have deposited volcanic debris on the island (Milos is the closest at 376km), but it is unclear exactly which of the volcanoes deposited the rocks seen in the samples taken from Kefalonia for this study. It could also be said that the volcanic source for these samples could be derived to multiple sources from different eruptive periods.

Further analysis of the samples from this study. Suggested radiometric dating would provide the information for accurate dating of the rock, which could then be correlated to the biostratigraphic ages of the samples and the eruptions of each of the volcanoes in the area.

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CHAPTER 5

Conclusions

- The samples taken from boreholes at various sites across Kefalonia show an array of different minerals and lithologies such as quartz, calcite, calcareous mud, siliceous mud, illite/muscovite and ankerite.
- The presence of heavy minerals, such as olivine, suggests the input of dacitic lava.
- The washed samples provided a more detailed insight into the original mineralogy of the samples before weathering and reworking took place.
- Biostratigraphy correlation shows that the ages of the samples were Pliocene and Pleistocene.
- Mount Etna was ruled out as a volcanic source as the oldest dated rocks did not correlate with the biostratigraphical ages of the samples.
- A more feasible volcanic source for the samples seen in the Kefalonia boreholes are the volcanoes which make up the Hellenic Arc.
- Santorini, Kos and Milos are the most likely volcanic source for the material found in the Kefalonia samples as they were all active volcanoes during the Pliocene and Pleistocene epochs and they have all produced dacitic lava.

QEMSCAN[®] Analysis of Selected Borehole Samples from Kefalonia, Greece

CHAPTER 6

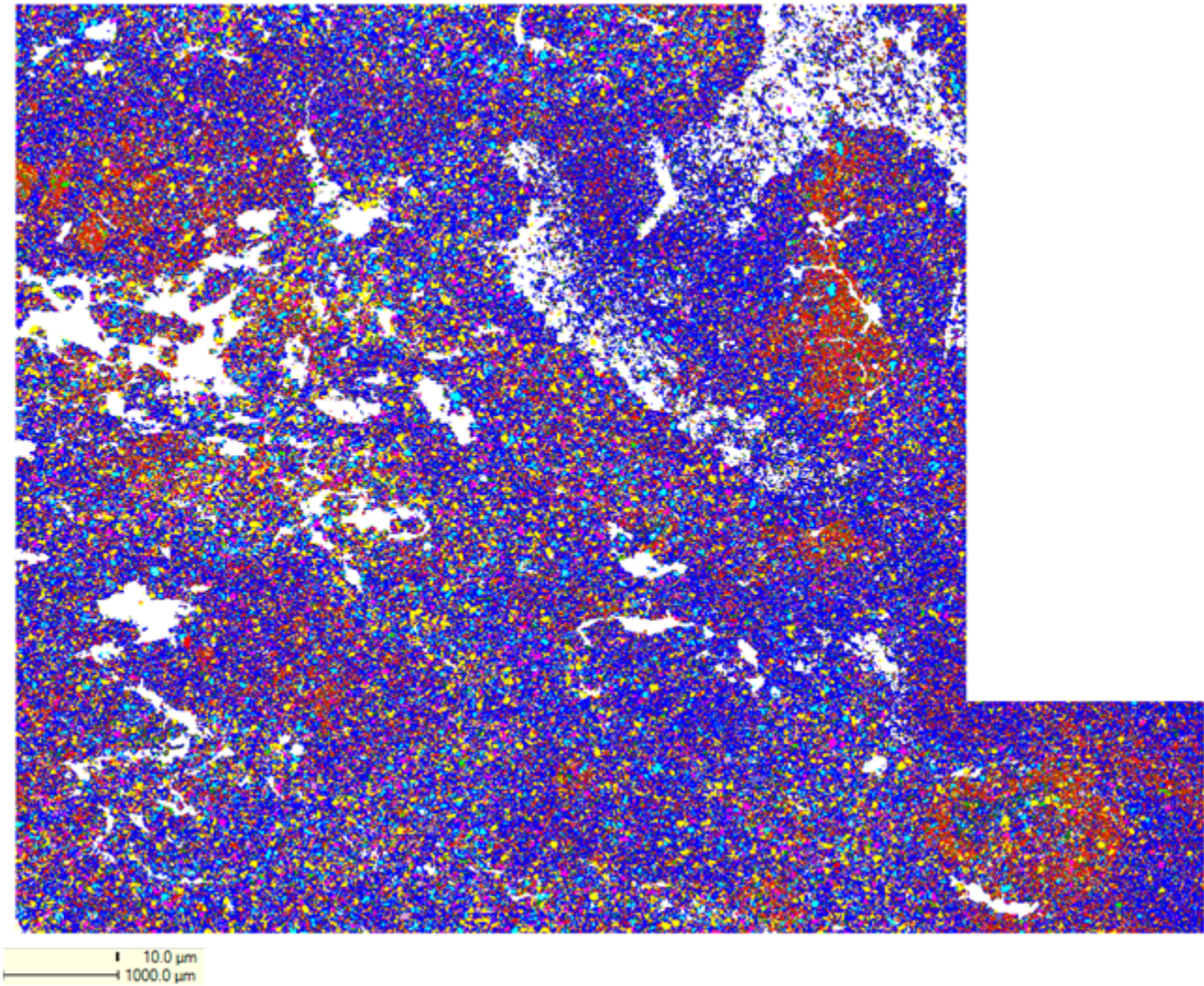
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QEMSCAN[®] Analysis of Selected Borehole Samples from Kefalonia, Greece

APPENDIX 1

QEMSCAN[®] Images of Samples in Well C4c



Mineral	Area %
Background	7.35
Quartz	9.25
K-Feldspar	0.95
Plagioclase Feldspar (undiff.)	3.70
Chlorite	0.57
Illite/Muscovite	4.51
Glauconite	0.13
Smectite	0.56
Kaolinite	2.14
Biotite/Phlogopite	0.05
Pyrite	0.01
Calcite	5.71
Dolomite	3.02
Siderite	0.05
CaFeCO3/Ankerite	10.03
Ca-SO4/Anhydrite/Gypsum	0.00
Silicious mud	6.60
Calcareous mud	45.51
Heavy Minerals	7.01
Others/Contaminants	0.21

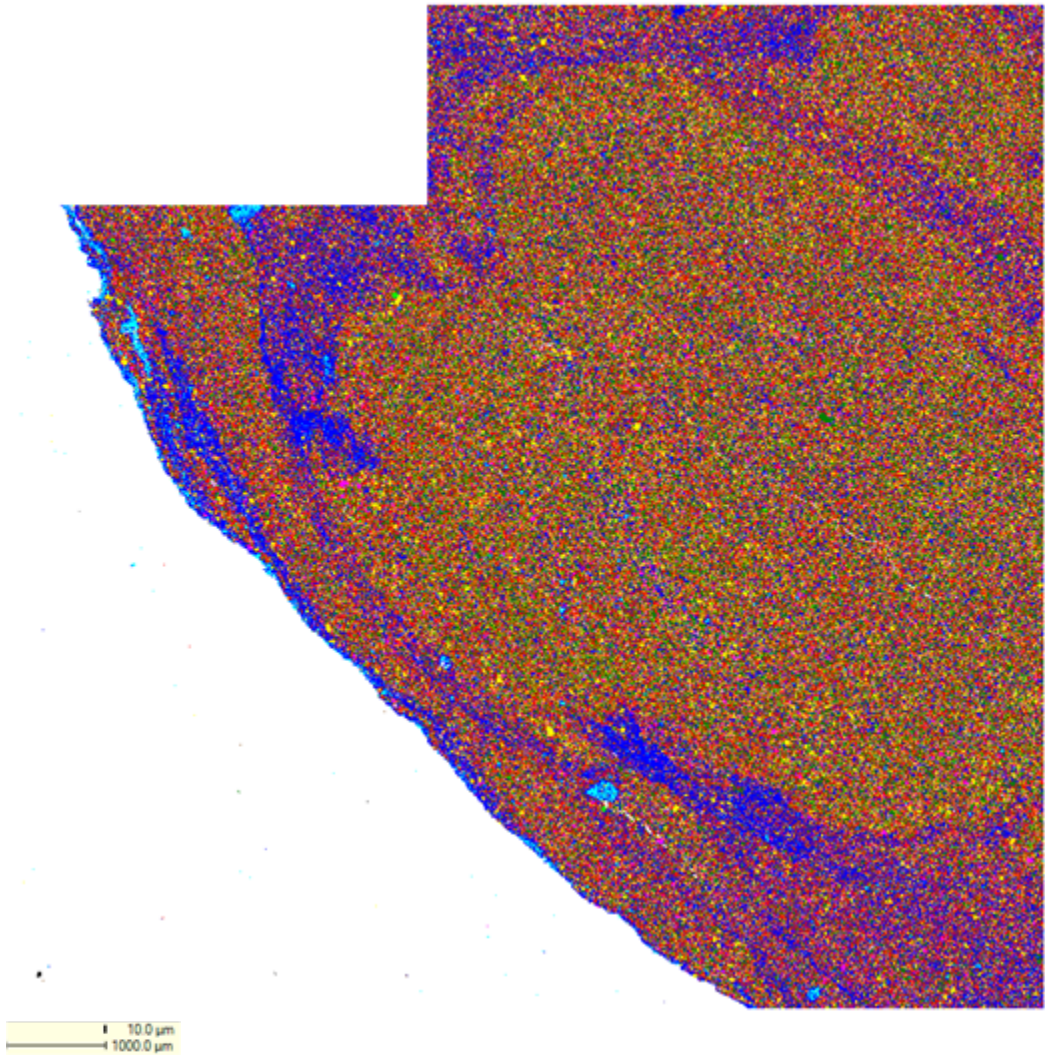
Appendix 1.1 QEMSCAN image of sample C4c 0.75m (Whole Rock)



QEMSCAN[®] Analysis of Selected Borehole Samples from Kefalonia, Greece

APPENDIX 2

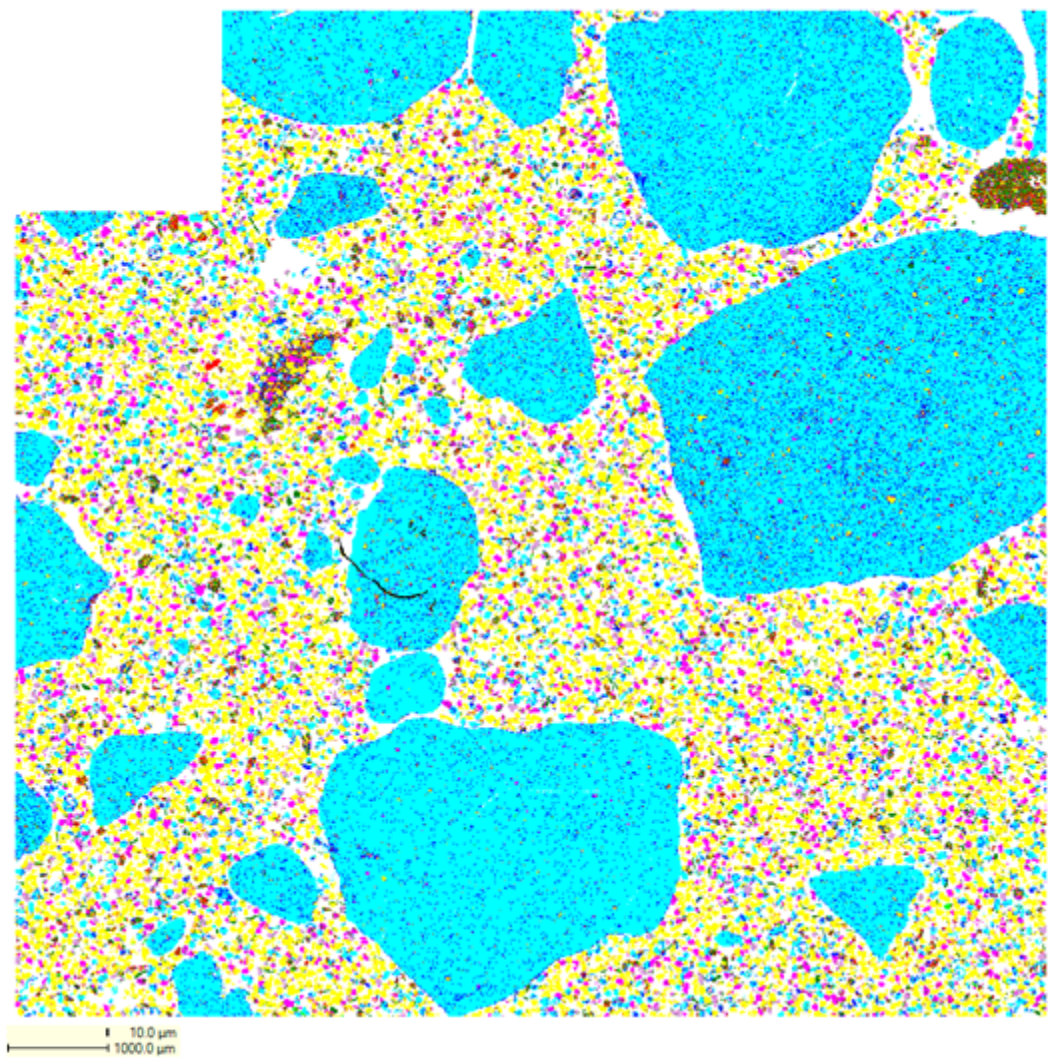
QEMSCAN[®] Images of Samples in Well C5a



Mineral	Area %
Background	0.13
Quartz	5.68
K-Feldspar	1.90
Plagioclase Feldspar (undiff.)	2.41
Chlorite	0.51
Illite/Muscovite	17.29
Glauconite	0.77
Smectite	8.28
Kaolinite	2.61
Biotite/Phlogopite	0.17
Pyrite	0.00
Calcite	1.18
Dolomite	0.06
Siderite	0.02
CaFeCO3/Ankerite	9.30
Ca-SO4/Anhydrite/Gypsum	0.00
Silicious mud	8.83
Calcareous mud	20.12
Heavy Minerals	20.74
Others/Contaminants	0.12

Appendix 1.2 QEMSCAN image of sample C5a 4.50m (Whole Rock)

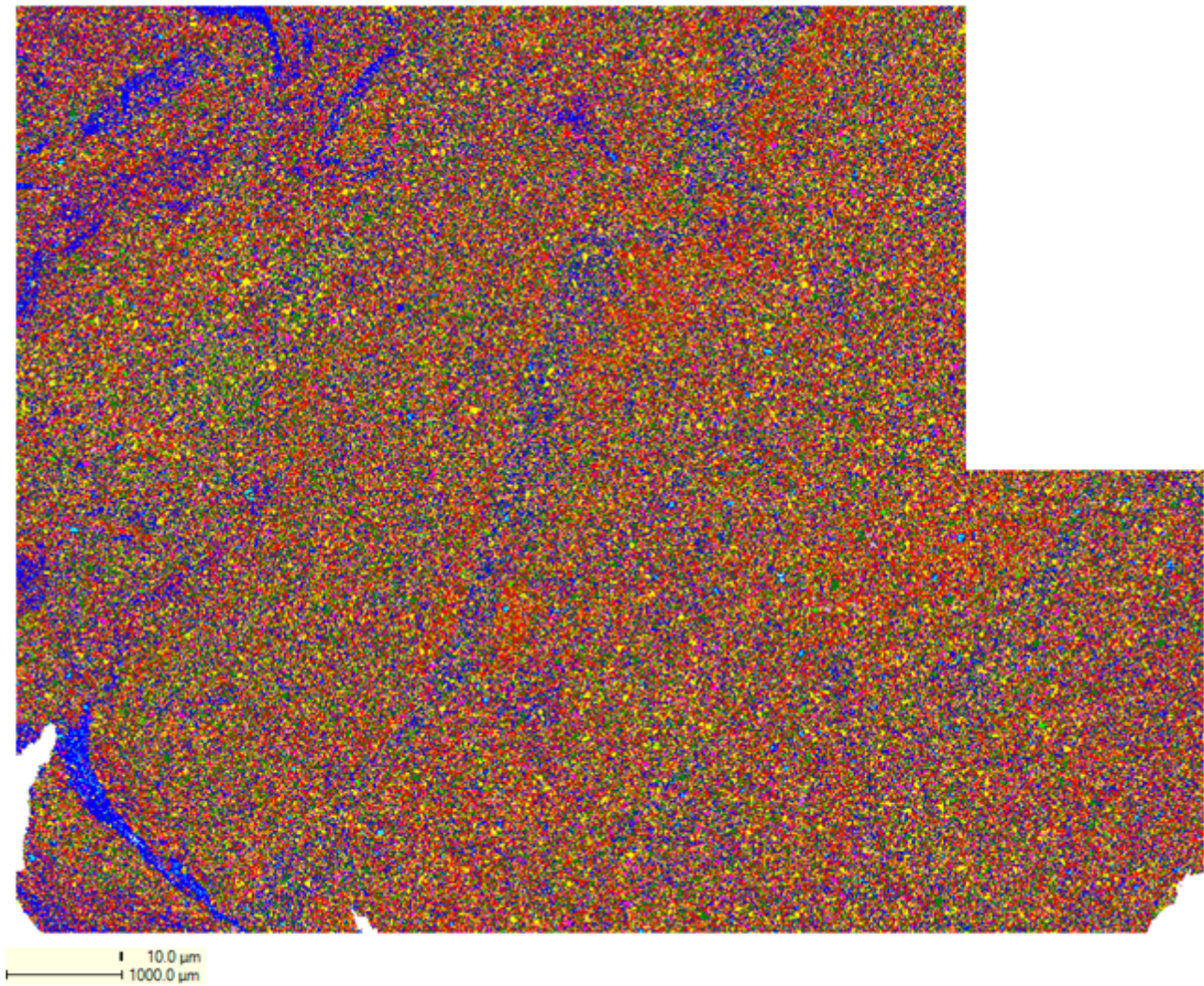




Mineral	Area %
Background	1.21
Quartz	22.68
K-Feldspar	2.14
Plagioclase Feldspar (undiff.)	5.13
Chlorite	0.26
Illite/Muscovite	1.90
Glauconite	0.12
Smectite	0.22
Kaolinite	1.27
Biotite/Phlogopite	0.03
Pyrite	0.04
Calcite	56.68
Dolomite	0.07
Siderite	0.06
CaFeCO3/Ankerite	0.59
Ca-SO4/Anhydrite/Gypsum	0.01
Silicious mud	0.73
Calcareous mud	7.10
Heavy Minerals	0.81
Others/Contaminants	0.16

Appendix 1.3 QEMSCAN image of sample C5a 4.50m (Sample Residue)

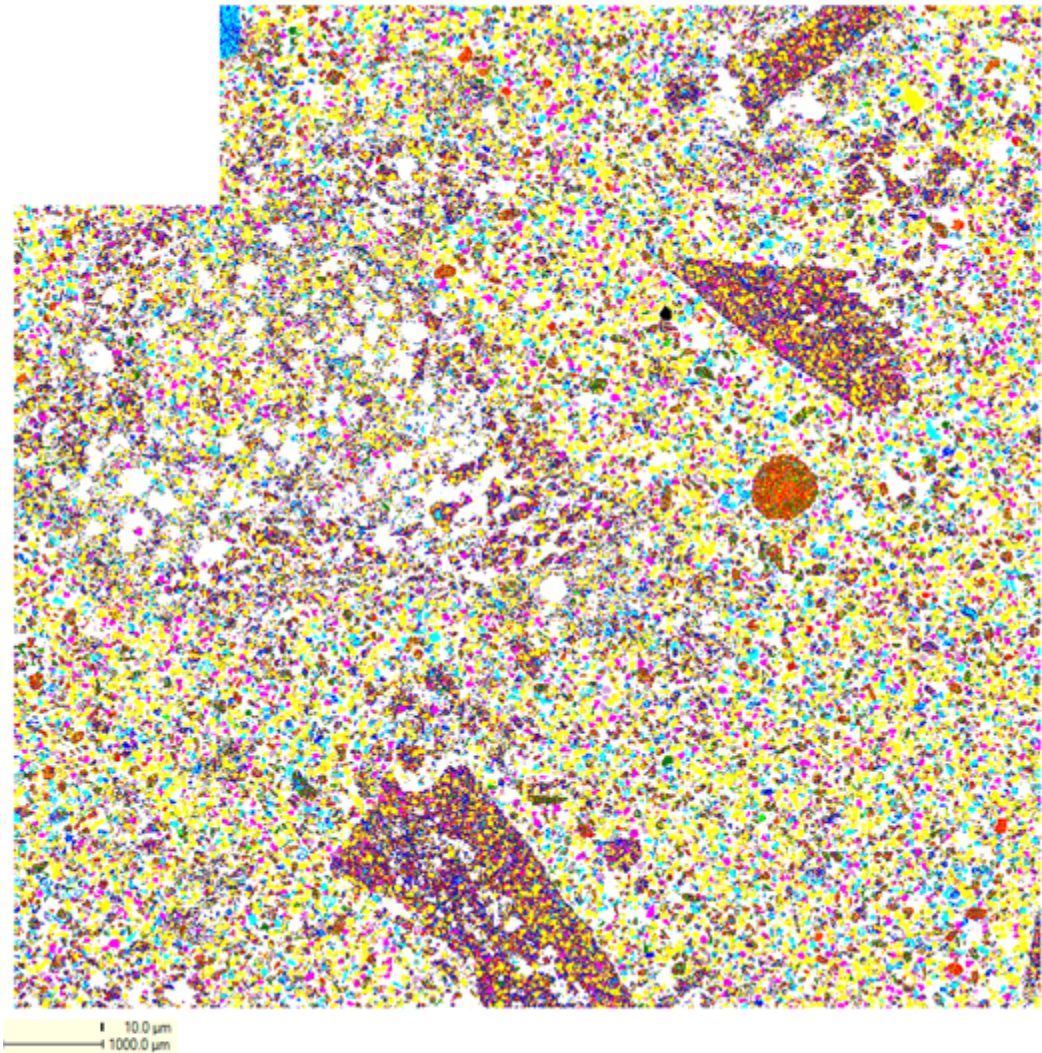




Mineral	Area %
Background	0.03
Quartz	7.05
K-Feldspar	2.51
Plagioclase Feldspar (undiff.)	2.93
Chlorite	0.65
Illite/Muscovite	20.59
Glauconite	0.90
Smectite	8.34
Kaolinite	2.70
Biotite/Phlogopite	0.28
Pyrite	0.00
Calcite	0.84
Dolomite	0.05
Siderite	0.05
CaFeCO3/Ankerite	6.91
Ca-SO4/Anhydrite/Gypsum	0.00
Silicious mud	9.12
Calcareous mud	16.15
Heavy Minerals	20.81
Others/Contaminants	0.12

Appendix 1.4 QEMSCAN image of sample C5a 5.25m (Whole Rock)





Mineral	Area %
Background	4.07
Quartz	32.46
K-Feldspar	3.42
Plagioclase Feldspar (undiff.)	7.89
Chlorite	0.74
Illite/Muscovite	7.09
Glauconite	0.53
Smectite	1.35
Kaolinite	6.49
Biotite/Phlogopite	0.14
Pyrite	0.06
Calcite	8.22
Dolomite	0.38
Siderite	0.96
CaFeCO3/Ankerite	6.12
Ca-SO4/Anhydrite/Gypsum	0.08
Silicious mud	4.02
Calcareous mud	13.29
Heavy Minerals	6.28
Others/Contaminants	0.49

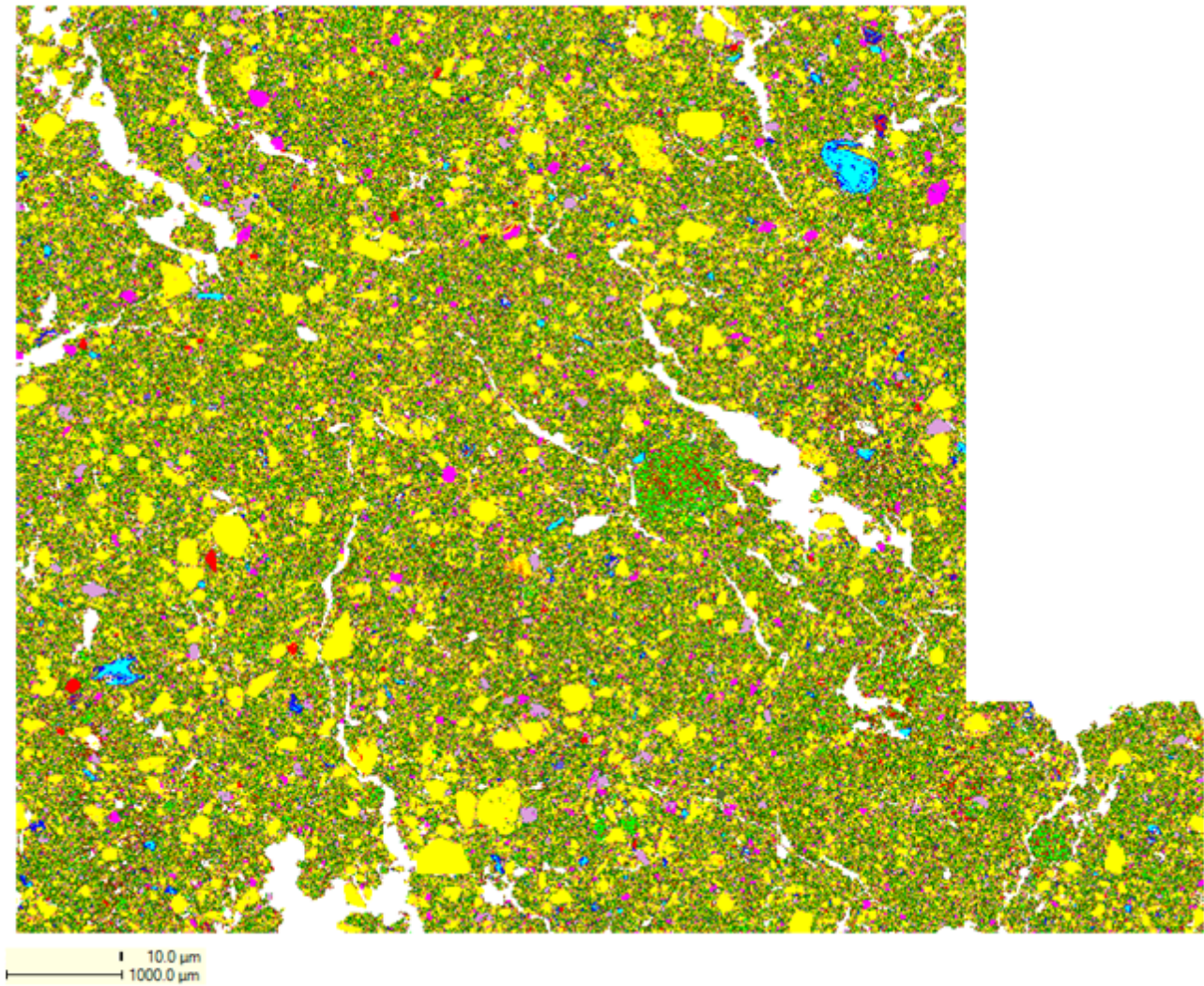
Appendix 1.5 QEMSCAN image of sample C5a 5.25m (Sample Residue)



QEMSCAN[®] Analysis of Selected Borehole Samples from Kefalonia, Greece

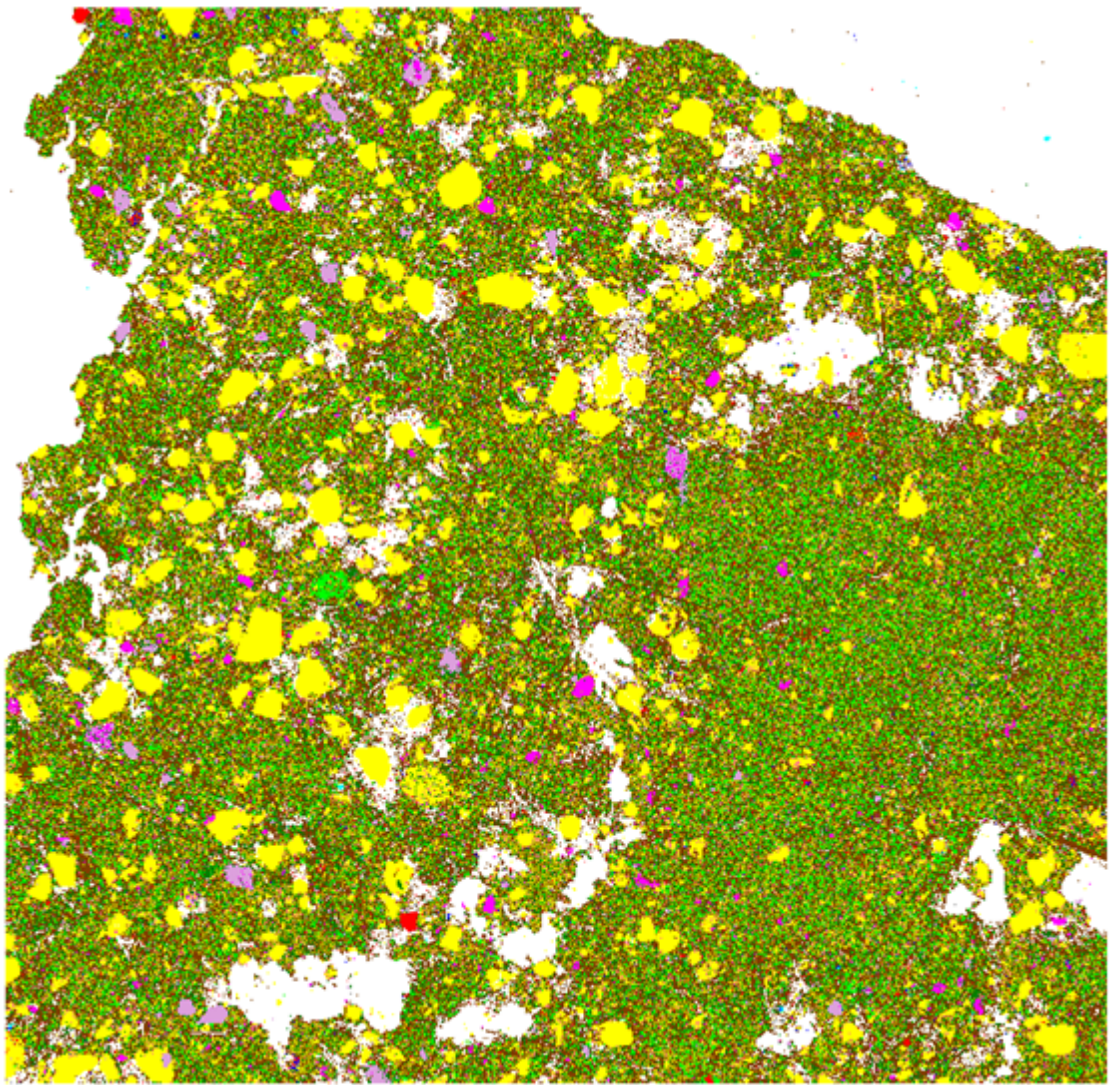
APPENDIX 3

QEMSCAN[®] Images of Samples in Well C6a



Mineral	Area %
Background	5.58
Quartz	23.28
K-Feldspar	2.85
Plagioclase Feldspar (undiff.)	2.67
Chlorite	3.24
Illite/Muscovite	21.32
Glauconite	1.18
Smectite	25.43
Kaolinite	9.11
Biotite/Phlogopite	0.29
Pyrite	0.01
Calcite	0.56
Dolomite	0.06
Siderite	0.09
CaFeCO3/Ankerite	0.21
Ca-SO4/Anhydrite/Gypsum	0.00
Silicious mud	6.88
Calcareous mud	0.96
Heavy Minerals	1.74
Others/Contaminants	0.11

Appendix 1.6 QEMSCAN image of sample C6a 0.5m (Whole Rock)



10.0 μm
1000.0 μm

Mineral	Area %
Background	11.49
Quartz	15.67
K-Feldspar	1.49
Plagioclase Feldspar (undiff.)	1.21
Chlorite	11.00
Illite/Muscovite	12.68
Glauconite	1.03
Smectite	17.98
Kaolinite	33.80
Biotite/Phlogopite	0.14
Pyrite	0.01
Calcite	0.03
Dolomite	0.02
Siderite	0.10
CaFeCO3/Ankerite	0.04
Ca-SO4/Anhydrite/Gypsum	0.00
Silicious mud	3.64
Calcareous mud	0.12
Heavy Minerals	0.85
Others/Contaminants	0.19

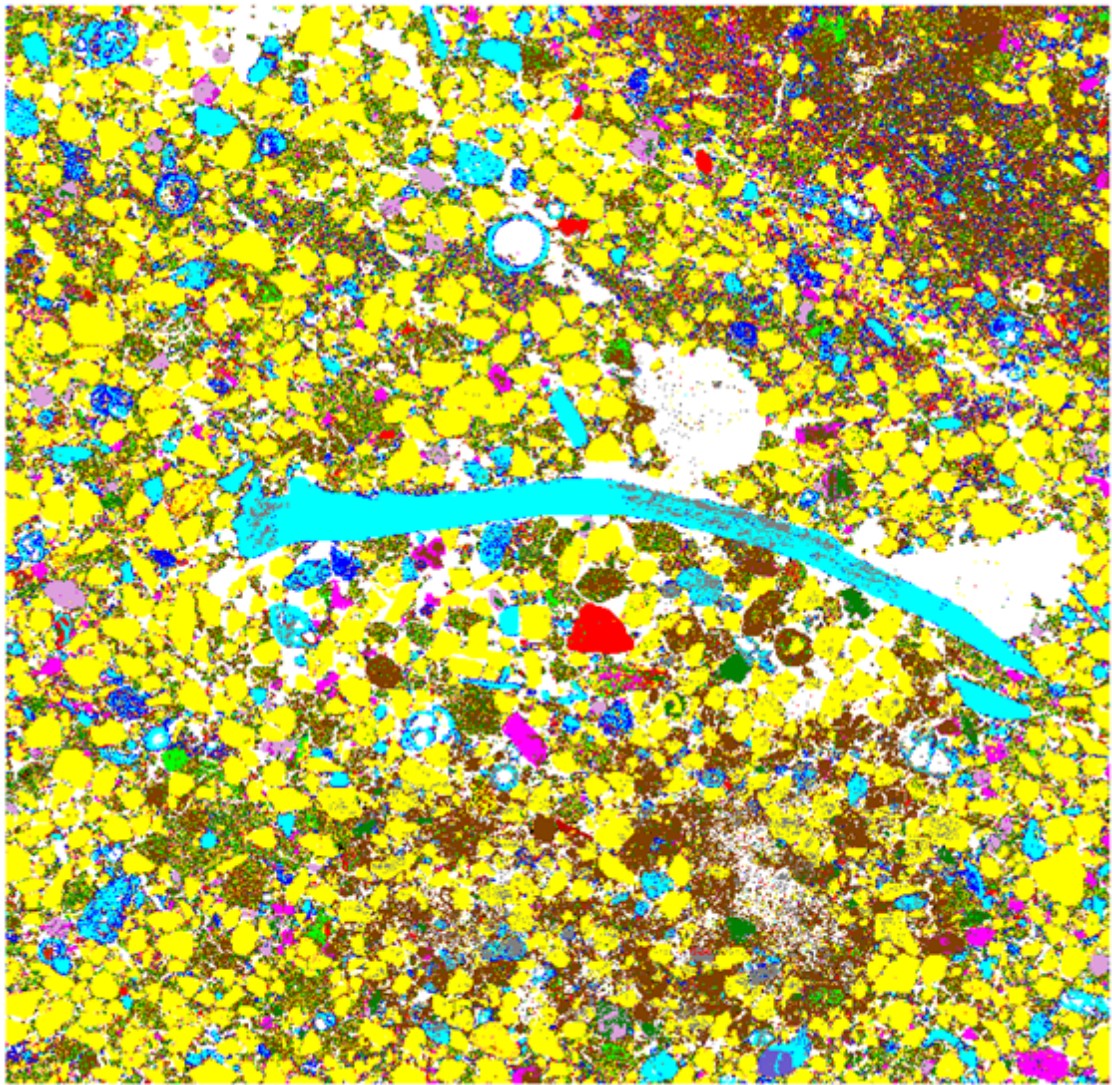
Appendix 1.7 QEMSCAN image of sample C6a 9.75m (Whole Rock)



QEMSCAN[®] Analysis of Selected Borehole Samples from Kefalonia, Greece

APPENDIX 4

QEMSCAN[®] Images of Samples in Well C6c

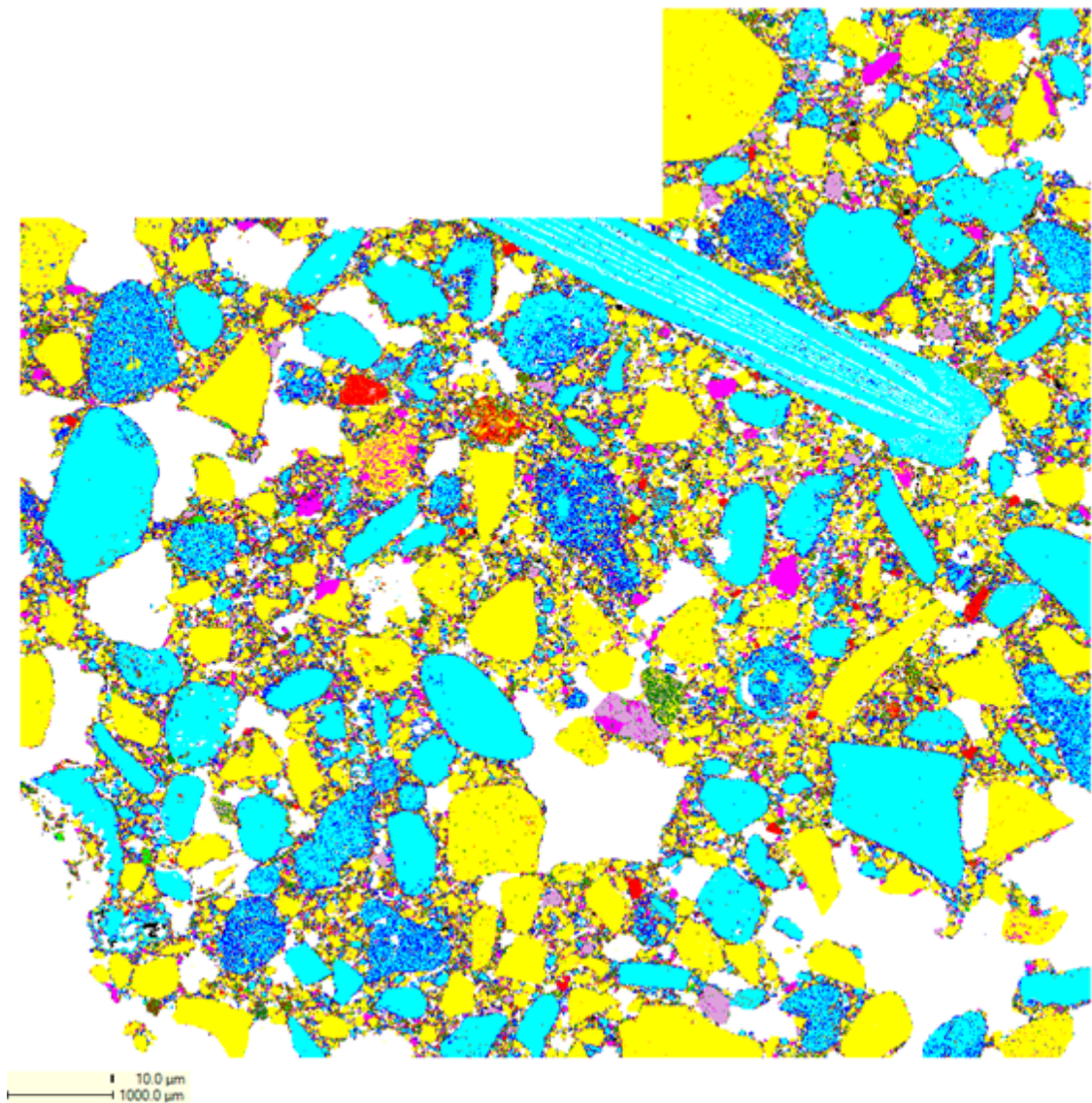


10.0 μm
1000.0 μm

Mineral	Area %
Background	17.68
Quartz	39.94
K-Feldspar	1.47
Plagioclase Feldspar (undiff.)	2.11
Chlorite	1.85
Illite/Muscovite	7.20
Glauconite	0.71
Smectite	5.87
Kaolinite	16.80
Biotite/Phlogopite	0.19
Pyrite	0.30
Calcite	7.93
Dolomite	0.33
Siderite	0.08
CaFeCO3/Ankerite	1.19
Ca-SO4/Anhydrite/Gypsum	0.00
Silicious mud	2.95
Calcareous mud	5.41
Heavy Minerals	3.57
Others/Contaminants	2.10

Appendix 1.8 QEMSCAN image of sample C6c 18.25m (Whole Rock)





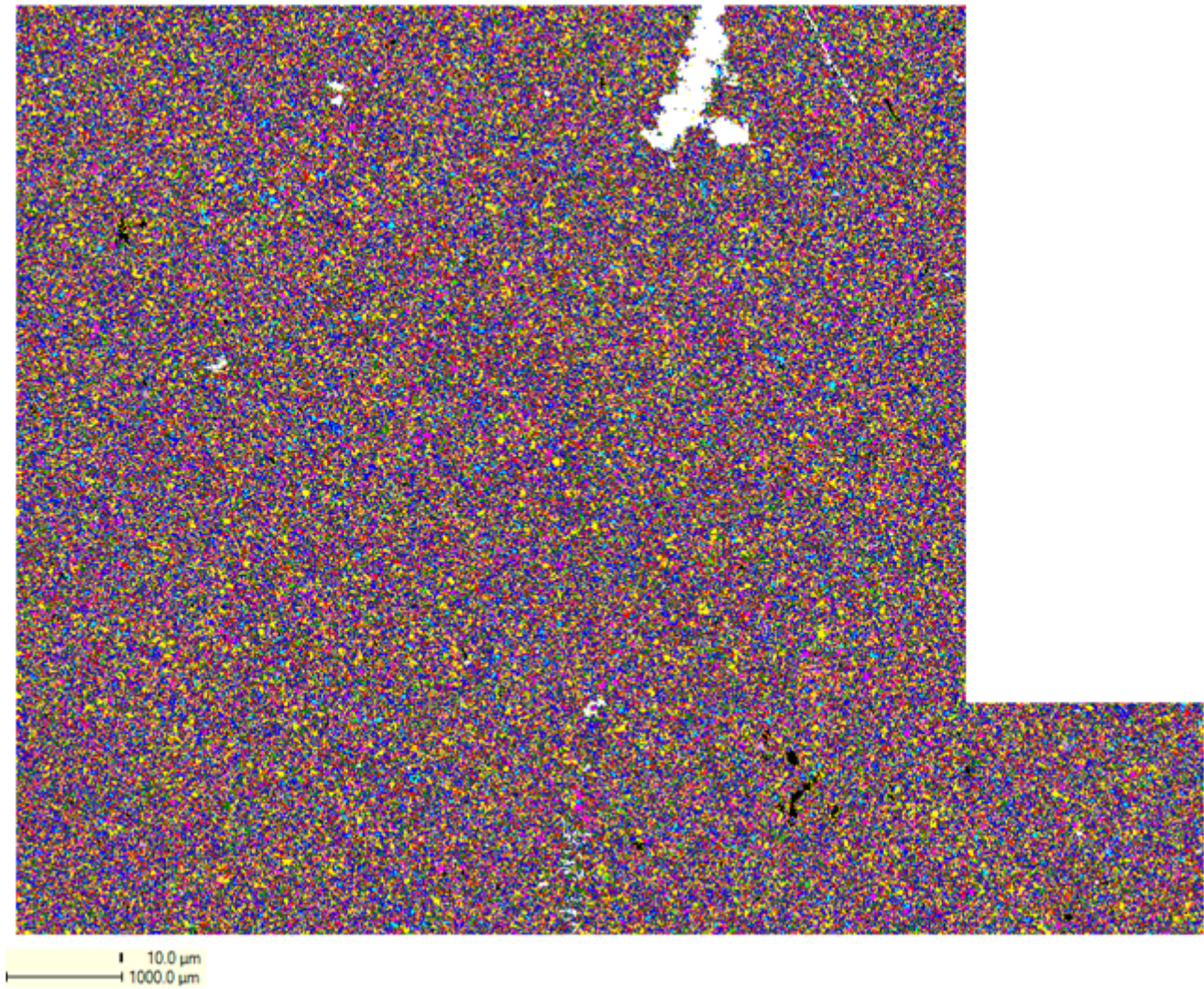
Mineral	Area %
Background	20.46
Quartz	35.17
K-Feldspar	1.58
Plagioclase Feldspar (undiff.)	2.82
Chlorite	0.65
Illite/Muscovite	3.98
Glauconite	0.25
Smectite	2.62
Kaolinite	3.01
Biotite/Phlogopite	0.05
Pyrite	0.37
Calcite	33.08
Dolomite	0.23
Siderite	0.16
CaFeCO3/Ankerite	1.08
Ca-SO4/Anhydrite/Gypsum	0.01
Silicious mud	2.46
Calcareous mud	9.51
Heavy Minerals	2.89
Others/Contaminants	0.07

Appendix 1.9 QEMSCAN image of sample C6c 18.75m (Whole Rock)

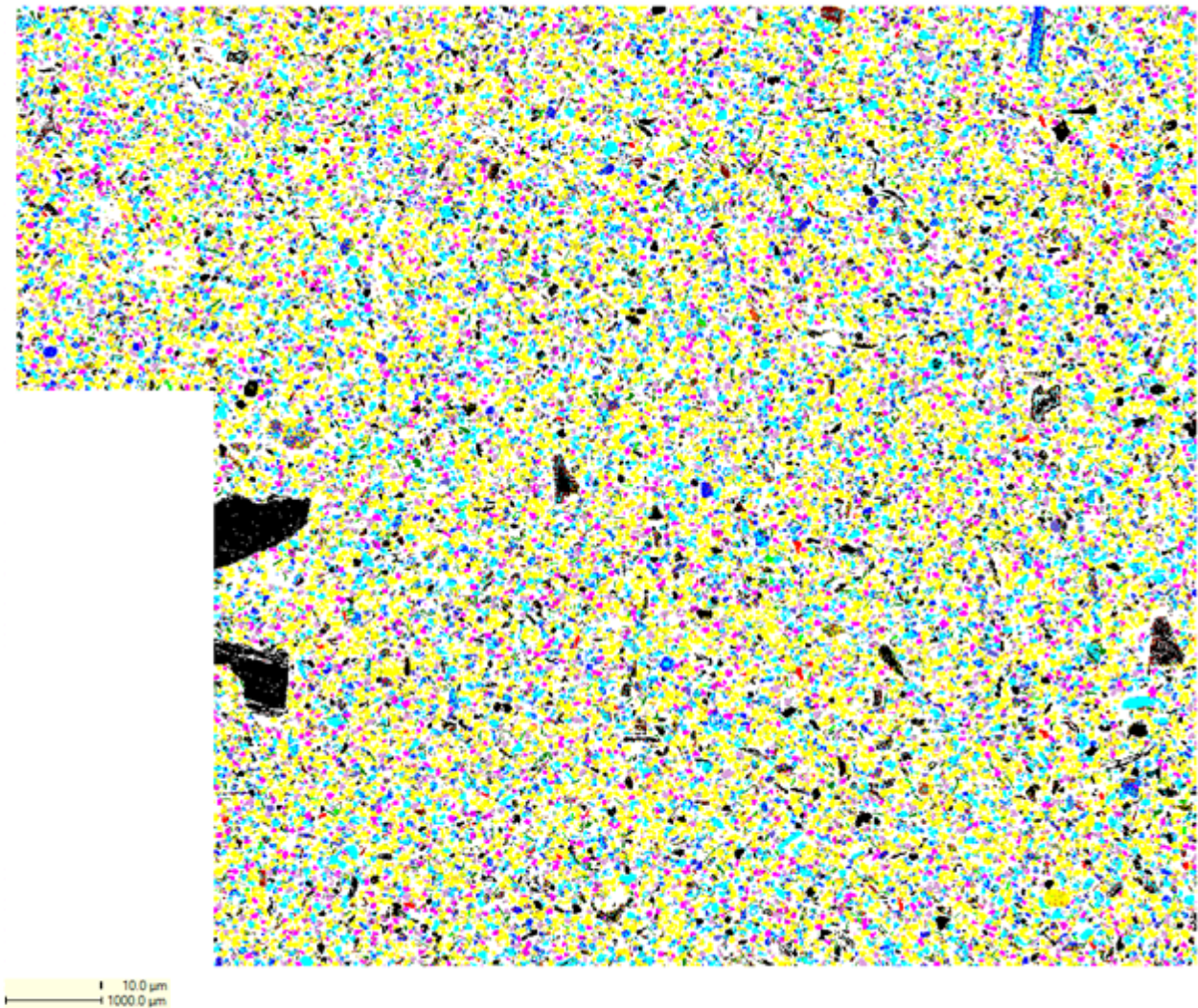
QEMSCAN[®] Analysis of Selected Borehole Samples from Kefalonia, Greece

APPENDIX 5

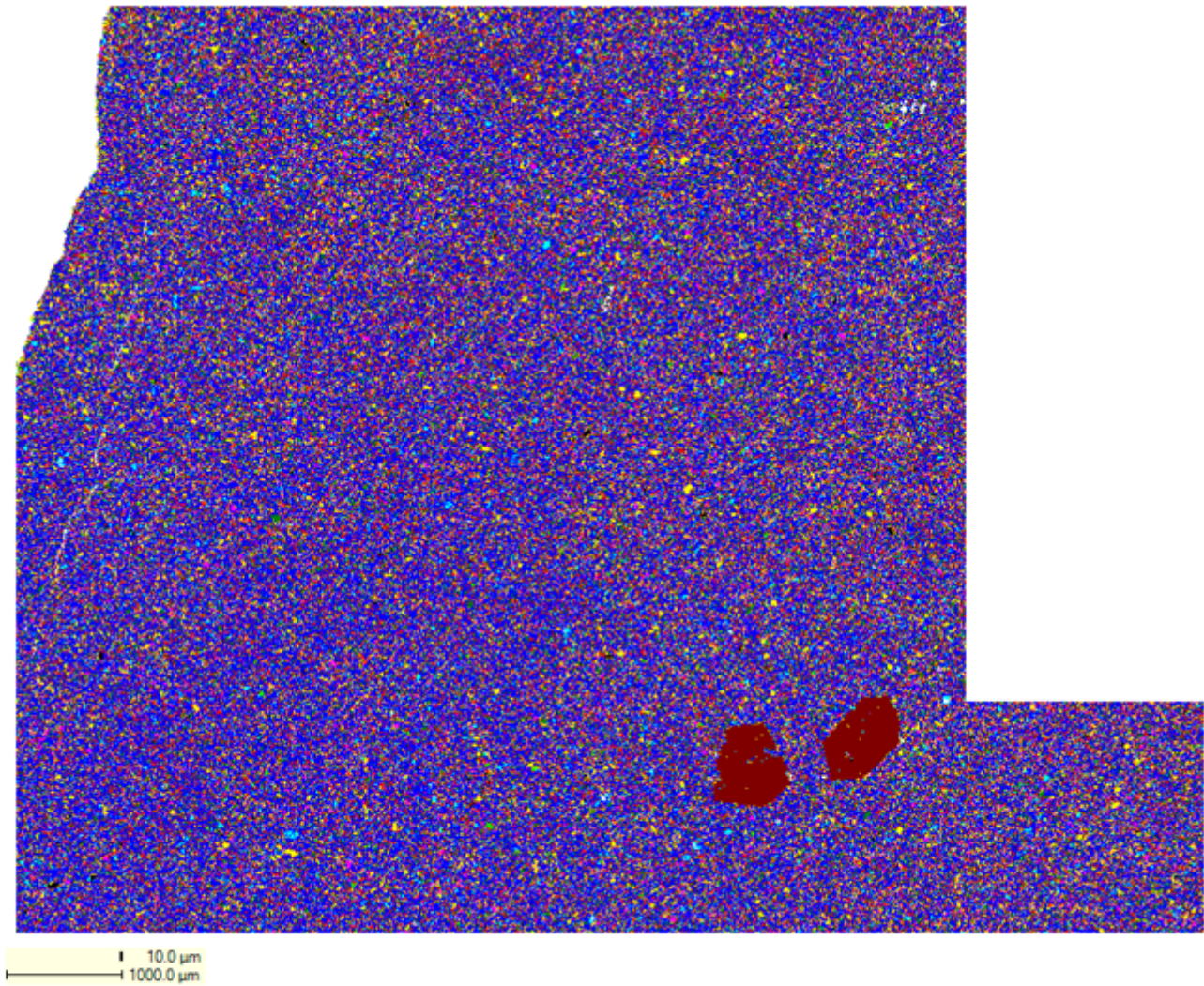
QEMSCAN[®] Images of Samples in Well C2006



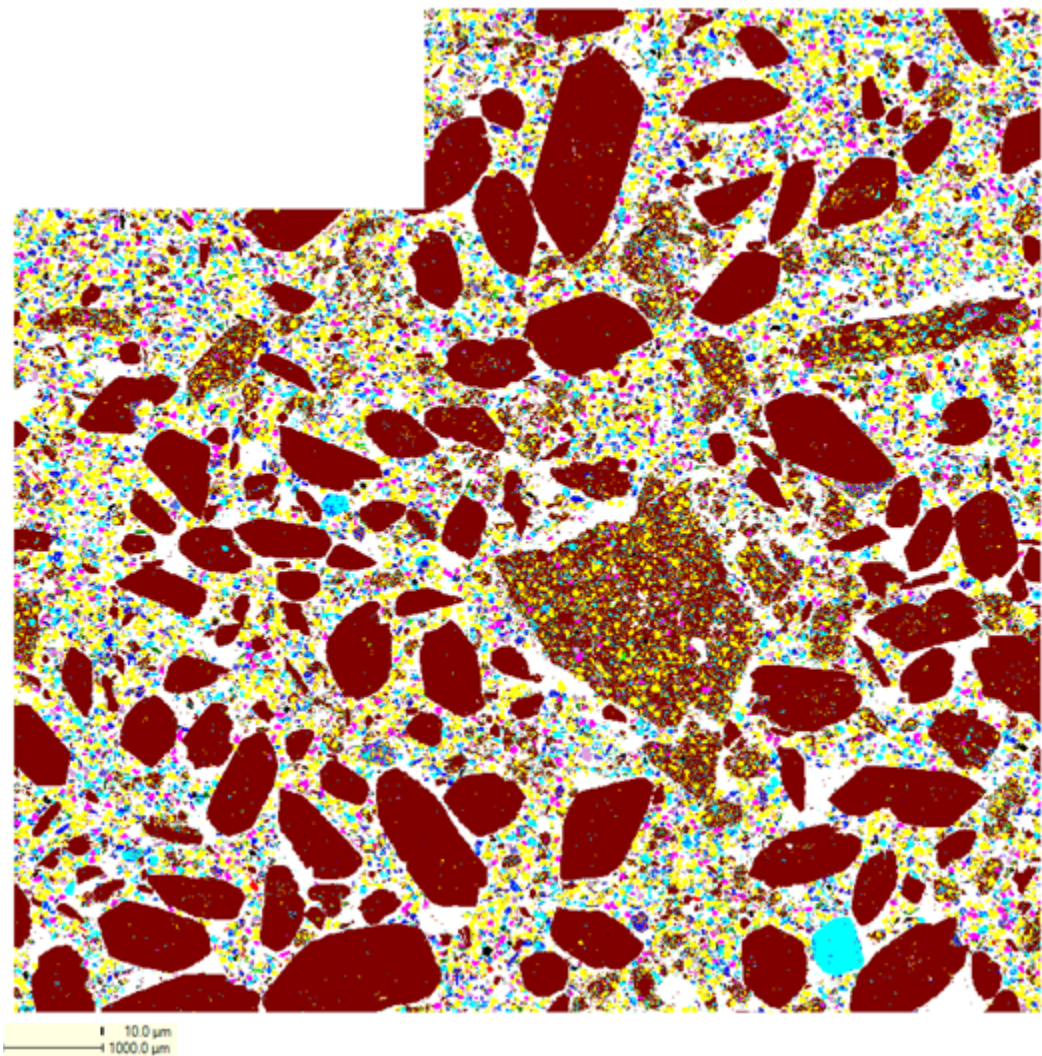
Mineral	Area %
Background	0.32
Quartz	12.93
K-Feldspar	2.16
Plagioclase Feldspar (undiff.)	4.90
Chlorite	1.19
Illite/Muscovite	15.66
Glauconite	0.72
Smectite	3.43
Kaolinite	2.33
Biotite/Phlogopite	0.38
Pyrite	1.20
Calcite	2.88
Dolomite	1.78
Siderite	0.01
CaFeCO3/Ankerite	3.95
Ca-SO4/Anhydrite/Gypsum	0.02
Silicious mud	9.12
Calcareous mud	24.78
Heavy Minerals	12.20
Others/Contaminants	0.36



Mineral	Area %
Background	2.24
Quartz	41.34
K-Feldspar	6.11
Plagioclase Feldspar (undiff.)	8.02
Chlorite	0.70
Illite/Muscovite	4.31
Glauconite	0.22
Smectite	0.22
Kaolinite	1.97
Biotite/Phlogopite	0.20
Pyrite	9.27
Calcite	16.84
Dolomite	1.04
Siderite	0.06
CaFeCO3/Ankerite	0.27
Ca-SO4/Anhydrite/Gypsum	1.07
Silicious mud	0.85
Calcareous mud	6.17
Heavy Minerals	1.17
Others/Contaminants	0.17



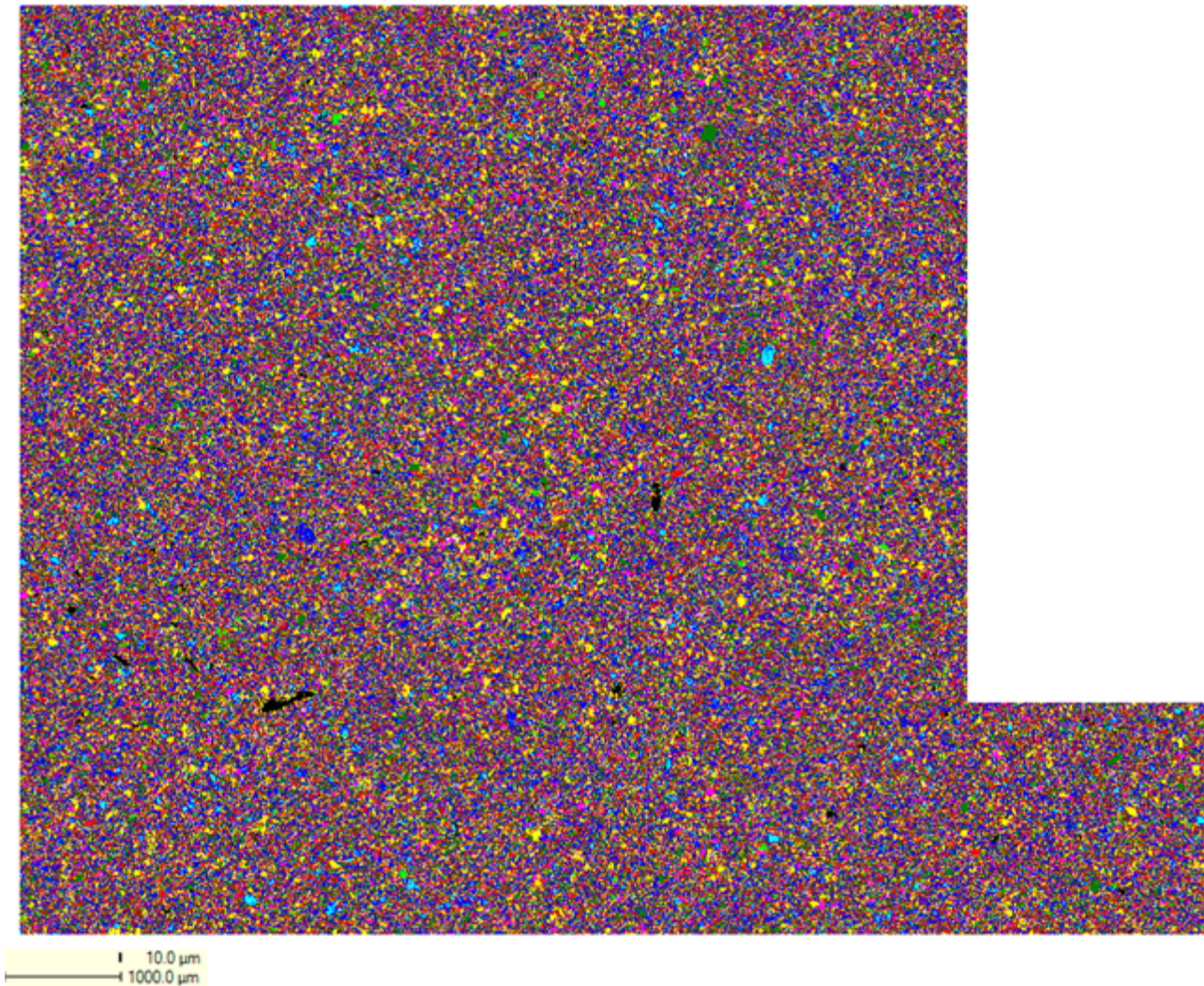
Mineral	Area %
Background	0.16
Quartz	6.21
K-Feldspar	0.80
Plagioclase Feldspar (undiff.)	2.12
Chlorite	0.56
Illite/Muscovite	8.41
Glauconite	0.21
Smectite	1.25
Kaolinite	1.53
Biotite/Phlogopite	0.11
Pyrite	0.96
Calcite	3.08
Dolomite	2.16
Siderite	0.00
CaFeCO3/Ankerite	6.49
Ca-SO4/Anhydrite/Gypsum	1.01
Silicious mud	7.94
Calcareous mud	47.70
Heavy Minerals	9.29
Others/Contaminants	0.15



Mineral	Area %
Background	2.94
Quartz	18.58
K-Feldspar	1.40
Plagioclase Feldspar (undiff.)	3.00
Chlorite	0.14
Illite/Muscovite	1.48
Glauconite	0.05
Smectite	0.10
Kaolinite	0.96
Biotite/Phlogopite	0.03
Pyrite	1.08
Calcite	7.87
Dolomite	0.65
Siderite	0.01
CaFeCO3/Ankerite	0.14
Ca-SO4/Anhydrite/Gypsum	59.86
Silicious mud	0.60
Calcareous mud	3.48
Heavy Minerals	0.53
Others/Contaminants	0.05

Appendix 1.13 QEMSCAN image of sample C2006 19m (Sample Residue)





Mineral	Area %
Background	0.04
Quartz	9.75
K-Feldspar	1.78
Plagioclase Feldspar (undiff.)	3.53
Chlorite	1.34
Illite/Muscovite	16.44
Glauconite	0.69
Smectite	3.00
Kaolinite	3.16
Biotite/Phlogopite	0.40
Pyrite	1.00
Calcite	2.69
Dolomite	1.60
Siderite	0.01
CaFeCO3/Ankerite	5.71
Ca-SO4/Anhydrite/Gypsum	0.04
Silicious mud	7.80
Calcareous mud	25.03
Heavy Minerals	15.66
Others/Contaminants	0.37

Appendix 1.14 QEMSCAN image of sample C2006 27.60m (Whole Rock)





Mineral	Area %
Background	2.76
Quartz	43.05
K-Feldspar	4.64
Plagioclase Feldspar (undiff.)	9.74
Chlorite	0.58
Illite/Muscovite	4.17
Glauconite	0.20
Smectite	0.36
Kaolinite	2.03
Biotite/Phlogopite	0.14
Pyrite	5.67
Calcite	14.87
Dolomite	2.02
Siderite	0.02
CaFeCO3/Ankerite	0.46
Ca-SO4/Anhydrite/Gypsum	0.56
Silicious mud	1.26
Calcareous mud	8.34
Heavy Minerals	1.68
Others/Contaminants	0.20

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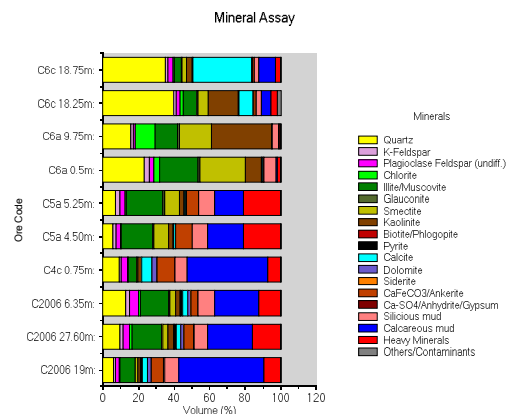
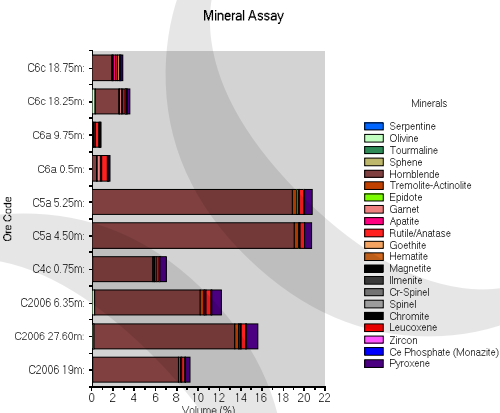
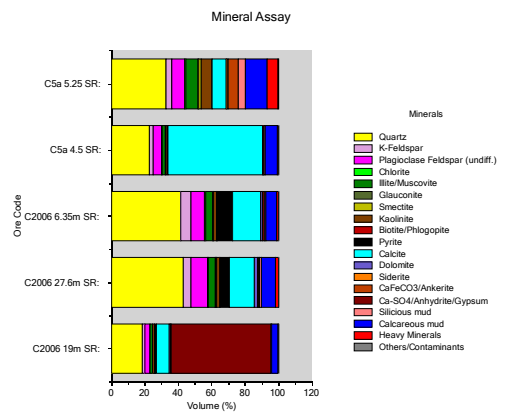
QEMSCAN® Analysis of Selected Borehole Samples from Kefalonia, Greece

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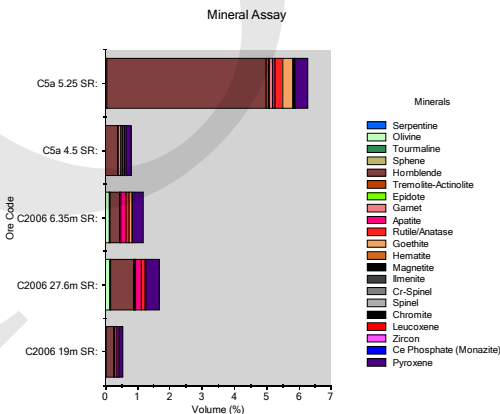
DATE: FEBRUARY, 2011
AUTHORS: Dean Rigby
REPORT NO: 10099/lqs
SOFTWARE: EXCEL



BOREHOLES: C4c, C5a, C6a, C6c, C2006

[illegible][illegible]

Bulk Mineralogy (Sample Pridgen)														
Sample Id.	Quartz	(Feldspar + Pyroxene) (weight percent)	Ilite/Muscov (weight percent)	Chlorite	Smectite	Kaolinite	Black Phop op	Pyrite	Calcite	Dolomite	Siderite	CaFeCO ₃ An kerite	On - Siderite	Other Minerals
C009-19	18.56	1.40	0.30	0.14	4.48	0.05	0.10	0.96	0.03	1.08	7.87	0.85	0.01	0.14
C009-27	18.55	4.64	0.74	0.68	4.17	0.30	0.36	0.20	0.14	5.67	1.87	2.02	0.07	0.48
C009-35	31.44	6.11	0.02	0.70	4.31	0.22	0.22	0.97	0.20	9.27	11.84	1.04	0.06	0.27
C009-36	14.18	5.13	0.32	0.50	4.80	0.10	0.22	1.27	0.05	0.04	56.68	0.37	0.05	0.59
C009-52	42.36	4.62	7.89	0.74	7.09	0.53	1.35	4.49	0.14	0.06	6.28	3.96	6.12	0.08
C009-53	31.40	6.11	0.02	0.70	4.31	0.22	0.22	0.97	0.20	9.27	11.84	1.04	0.06	0.27
C009-54	14.18	5.13	0.32	0.50	4.80	0.10	0.22	1.27	0.05	0.04	56.68	0.37	0.05	0.59
C009-55	42.36	4.62	7.89	0.74	7.09	0.53	1.35	4.49	0.14	0.06	6.28	3.96	6.12	0.08
C009-56	31.40	6.11	0.02	0.70	4.31	0.22	0.22	0.97	0.20	9.27	11.84	1.04	0.06	0.27
C009-57	14.18	5.13	0.32	0.50	4.80	0.10	0.22	1.27	0.05	0.04	56.68	0.37	0.05	0.59
C009-58	42.36	4.62	7.89	0.74	7.09	0.53	1.35	4.49	0.14	0.06	6.28	3.96	6.12	0.08
C009-59	31.40	6.11	0.02	0.70	4.31	0.22	0.22	0.97	0.20	9.27	11.84	1.04	0.06	0.27
C009-60	14.18	5.13	0.32	0.50	4.80	0.10	0.22	1.27	0.05	0.04	56.68	0.37	0.05	0.59
C009-61	42.36	4.62	7.89	0.74	7.09	0.53	1.35	4.49	0.14	0.06	6.28	3.96	6.12	0.08
C009-62	31.40	6.11	0.02	0.70	4.31	0.22	0.22	0.97	0.20	9.27	11.84	1.04	0.06	0.27
C009-63	14.18	5.13	0.32	0.50	4.80	0.10	0.22	1.27	0.05	0.04	56.68	0.37	0.05	0.59
C009-64	42.36	4.62	7.89	0.74	7.09	0.53	1.35	4.49	0.14	0.06	6.28	3.96	6.12	0.08
C009-65	31.40	6.11	0.02	0.70	4.31	0.22	0.22	0.97	0.20	9.27	11.84	1.04	0.06	0.27
C009-66	14.18	5.13	0.32	0.50	4.80	0.10	0.22	1.27	0.05	0.04	56.68	0.37	0.05	0.59
C009-67	42.36	4.62	7.89	0.74	7.09	0.53	1.35	4.49	0.14	0.06	6.28	3.96	6.12	0.08
C009-68	31.40	6.11	0.02	0.70	4.31	0.22	0.22	0.97	0.20	9.27	11.84	1.04	0.06	0.27
C009-69	14.18	5.13	0.32	0.50	4.80	0.10	0.22	1.27	0.05	0.04	56.68	0.37	0.05	0.59
C009-70	42.36	4.62	7.89	0.74	7.09	0.53	1.35	4.49	0.14	0.06	6.28	3.96	6.12	0.08
C009-71	31.40	6.11	0.02	0.70	4.31	0.22	0.22	0.97	0.20	9.27	11.84	1.04	0.06	0.27
C009-72	14.18	5.13	0.32	0.50	4.80	0.10	0.22	1.27	0.05	0.04	56.68	0.37	0.05	0.59
C009-73	42.36	4.62	7.89	0.74	7.09	0.53	1.35	4.49	0.14	0.06	6.28	3.96	6.12	0.08
C009-74	31.40	6.11	0.02	0.70	4.31	0.22	0.22	0.97	0.20	9.27	11.84	1.04	0.06	0.27



Heavy Mineral (Sample Residue)																					
Sample No.	Serpentine	Olivine	Tourmaline	Spinel	Norrbende	Tremolite-Acidinolite	Epidote	Garnet	Apatite	Rutile-Annite -Fe	Gothite	Nonsilicate	Magnetite	Ilmenite	Co-spinel	Spinel	Chemite	Leucocrane	Zircon	Ca Phosphate (Monazite)	Pyrrhane
C0006 19	0.00	0.02	0.00	0.01	0.22	0.01	0.00	0.01	0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41
C0006 27	0.00	0.14	0.00	0.00	0.72	0.02	0.00	0.01	0.17	0.13	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C0006 28	0.00	0.12	0.00	0.02	0.30	0.01	0.02	0.01	0.17	0.10	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.33
C0006 35	0.00	0.01	0.00	0.01	0.20	0.09	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.16
C0006 5.2	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 5.3	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 5.4	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 5.5	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 5.6	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 5.7	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 5.8	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 5.9	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 6.0	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 6.1	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 6.2	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 6.3	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 6.4	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 6.5	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 6.6	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 6.7	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 6.8	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 6.9	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 7.0	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 7.1	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 7.2	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 7.3	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 7.4	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 7.5	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 7.6	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 7.7	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 7.8	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 7.9	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
C0006 8.0	0.00	0.02	0.00	0.04	0.94	0.07	0.01	0.11	0.00	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04