QEMSCAN Analysis of Various Lithologies from Tight- and Shale-Gas Plays in Alberta
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C.D. Rokosh, S.D.A. Anderson and J.G. Pawlowicz

Alberta Energy Regulator
Alberta Geological Survey

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Abstract

This report includes analytical results from a summary report from SGS Canada Inc. with the results of Quantitative Evaluation of Materials by Scanning Electron Microscopy (QEMSCAN) mineralogical analyses of 12 samples collected by the Alberta Geological Survey from various strata in tight- and shale-gas plays in Alberta. Samples were collected from selected drill cores of the following geological strata: Duvernay, Muskwa, Exshaw, lower Banff, Montney, First and Second White Specks. For each sample, data on bulk mineralogical abundance, mean mineral size, calculated grain density, estimated macroporosity, and mineral spatial distribution are reported.
1 Introduction

In 2007, the Alberta Geological Survey (AGS) initiated a project to determine the quantity and spatial extent of shale gas resources in Alberta. Since then, this project has expanded to include shale- and siltstone-hosted hydrocarbons (oil, gas, and natural gas liquids) in the province (Rokosh et al., 2012). The AGS is releasing reports and digital data to disseminate knowledge from the project. These data and reports can be accessed from the AGS website (http://ags.aer.ca).

This report disseminates the results from Quantitative Evaluation of Materials by Scanning Electron Microscopy (QEMSCAN) analysis conducted by the Advanced Reservoir Quality Services Team at SGS Canada Inc. on 12 samples from various geological units in Alberta being investigated for tight- and shale-gas potential (Appendix 1).

2 Sample Locations and Descriptions

Table 1 lists the identification and location information of the 12 samples that were submitted to SGS. Figure 1 displays the geographic locations of the sites from where the samples originate.

Table 1. Identification and location information of samples submitted for QEMSCAN analysis.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>UWI Core Depth (metres)</th>
<th>Geological Unit</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>8125</td>
<td>100/12-27-080-13W6/00</td>
<td>Montney Sandstone</td>
<td>Sandstone</td>
</tr>
<tr>
<td>8840</td>
<td>100/16-23-057-06W6/00</td>
<td>Montney Siltstone</td>
<td>Siltstone</td>
</tr>
<tr>
<td>8902</td>
<td>100/06-14-066-06W6/00</td>
<td>Montney Siltstone</td>
<td>Siltstone</td>
</tr>
<tr>
<td>9210</td>
<td>100/09-06-052-11W5/00</td>
<td>Duvernay Shale</td>
<td>Shale</td>
</tr>
<tr>
<td>9238</td>
<td>100/06-14-037-07W5/00</td>
<td>Duvernay Shale</td>
<td>Shale</td>
</tr>
<tr>
<td>9367</td>
<td>100/02-04-126-11W6/00</td>
<td>Muskwa Shale</td>
<td>Shale</td>
</tr>
<tr>
<td>6904</td>
<td>102/11-32-017-11W4/00</td>
<td>Second White Specks</td>
<td>Shale</td>
</tr>
<tr>
<td>8518</td>
<td>102/03-14-018-11W4/00</td>
<td>First White Specks</td>
<td>Shale and sandstone</td>
</tr>
<tr>
<td>8656</td>
<td>100/07-19-045-06W5/00</td>
<td>Second White Specks</td>
<td>Mudstone</td>
</tr>
<tr>
<td>6934</td>
<td>100/04-23-072-10W6/00</td>
<td>Lower Banff Shale</td>
<td>Shale</td>
</tr>
<tr>
<td>8682</td>
<td>100/02-14-082-02W6/00</td>
<td>Lower Banff Shale</td>
<td>Shale</td>
</tr>
<tr>
<td>8688</td>
<td>100/06-04-084-07W6/00</td>
<td>Exshaw Shale</td>
<td>Shale</td>
</tr>
</tbody>
</table>

3 Summary

Twelve samples from geological strata in Alberta under investigation for their tight- and shale-gas potential were submitted to SGS Canada Inc. for QEMSCAN mineralogical analysis. Strata sampled include those of the Duvernay, Muskwa, Exshaw, lower Banff, and Montney formations, and the Colorado Group (Second White Specks Formation and First White Specks Member of the Niobrara Formation). This report publishes the summary report of the results, including data on bulk mineralogical abundance, mean mineral size, calculated grain density, estimated macroporosity, and mineral spatial distribution for each sample.
Figure 1. Locations of sample sites for this report. Locations are identified by the sample number from Table 1.
4 References

Appendix 1 – SGS Report
QEMSCAN analysis of tight / shale gas samples from various plays in Alberta

Summary Report

for

ERCB

Project Reference: MI5045-Aug09

October, 2010
Project Outline

As part of a research project, ERCB provided 12 samples from a number of different tight gas and shale gas plays throughout Alberta. These were then submitted to SGS’s Advanced Reservoir Quality Services team for mineralogical and textural characterisation using QEMSCAN. The aim of the project was to mineralogically characterise a number of different gas producing formations with a view to improve the understanding of the mineralogy and texture of these formations, especially with respect to engineering properties such as frac performance.

In order to mineralogically and texturally characterise the core samples, the following test programme was undertaken:

- QEMSCAN analysis on a transverse section through all samples to provide a mineralogical image of the samples, detailed mineralogical characterisation and to determine the nature and distribution of fine grained components.

**Project deliverables**

Advanced Reservoir Quality Services (ARQS) is a lithological, mineralogical and textural analysis service which draws on a number of different analytical methods depending on the study. For this study, ARQS involved QEMSCAN analysis to mineralogically characterise the material provided.

Data outputs for this study include, for each sample:

- Quantitative bulk mineralogical abundance data (mass and area %)
- Mean mineral size data for each reported mineral
- Calculated grain density
- Macroporosity estimation
- Mineralogical images (i.e. mineral maps) for each sample
Samples supplied
As part of this study, a total of 12 samples comprising a variety of lithologies from tight gas and shale gas plays across Alberta were submitted for ARQ Services using QEMSCAN; a complete listing of all samples together with summary sample details is presented in the table below.

<table>
<thead>
<tr>
<th>Lab Reference</th>
<th>Formation</th>
<th>Lithology</th>
<th>Sample</th>
<th>Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>MI5045-AUG09:01</td>
<td>Montney Sandstone</td>
<td>8125 M33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MI5045-AUG09:02</td>
<td>Montney Siltstone</td>
<td>8840 M2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MI5045-AUG09:03</td>
<td>Montney Siltstone</td>
<td>8902 M8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MI5045-AUG09:04</td>
<td>Duvernay Shale</td>
<td>9210 D10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MI5045-AUG09:05</td>
<td>Duvernay Shale</td>
<td>9238 D1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MI5045-AUG09:06</td>
<td>Muskwa Shale</td>
<td>9367 D34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MI5045-AUG09:07</td>
<td>Colorado 2WSP Shale</td>
<td>6904 C37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MI5045-AUG09:08</td>
<td>Colorado 1WSP Dark grey shale and very fine sandstone with fossils</td>
<td>8518 C35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MI5045-AUG09:09</td>
<td>Colorado 2WSP Dark grey mudstone</td>
<td>8656 C20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MI5045-AUG09:10</td>
<td>Exshaw/Lower Banff Black shale</td>
<td>6934 B04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MI5045-AUG09:11</td>
<td>Exshaw/Lower Banff Dark grey calcareous shale</td>
<td>8682 B02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MI5045-AUG09:12</td>
<td>Exshaw/Lower Banff Dark grey shale</td>
<td>8688 B05</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sample preparation
All samples were submitted as oil free core samples and were therefore prepared as 30 mm polished epoxy resin blocks using standard preparation methodologies.

Sample measurement and data processing parameters
A full description of the QEMSCAN methodology is provided in the attached Appendix. The sample measurement and data processing parameters are briefly summarised below.

QEMSCAN analytical parameters
All of the samples were analysed by the FieldImage technique, an analysis methodology in which the electron beam is moved across the sample on a field-by-field basis at a pre-determined stepping interval; at each step a mineralogical determination is made based on the resultant BSE and X-ray signals. This results in a mineralogical “image” with a resolution equal to the beam stepping interval. For this study, the FieldImage measurements were set up to optimise both textural and modal mineralogical information and so the samples were analysed at a beam stepping interval (resolution) of 5 microns.

Data processing
Using the QEMSCAN image analysis software (iDiscover), all of the FieldImage frames were stitched together to form mineralogical images of the samples.
Mineral Descriptions

Multiple mineral lists can be used to define the mineralogy, simplify reporting or to highlight specific mineral textures. In this study two detailed mineral lists were required to capture the diversity of textures and the mineral assemblage. A description of these mineral lists and the minerals that may report to each category together with some of the mineralogical overlaps that may occur is given below.

Mineral list used to define the mineralogical data in all samples:

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>Silica group of minerals (e.g. quartz, cristobalite, etc). Also includes silica minerals with a low backscattered electron coefficient such as hydrated silica minerals including opal and chert.</td>
</tr>
<tr>
<td>K Feldspar</td>
<td>K-rich alkali feldspar including orthoclase, sanidine &amp; microcline.</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>Albite to Anorthite solid solution. May include Na-rich alkali feldspars.</td>
</tr>
<tr>
<td>Muscovite</td>
<td>Muscovite mica. May also include white micas such as &quot;sericite&quot;.</td>
</tr>
<tr>
<td>Biotite</td>
<td>Biotite mica and phlogopite.</td>
</tr>
<tr>
<td>Kaolinite</td>
<td>Kaolin group such as halloysite &amp; kaolinite ss. This category represents pure kaolinite; kaolinite may also be present finely intermixed with a variety of other clays.</td>
</tr>
<tr>
<td>Chlorite</td>
<td>Chlorite generally Fe-rich. May include Fe-smectite and some specific compositions of almandine garnet and tourmaline.</td>
</tr>
<tr>
<td>Iilitite &amp; illite-smectite</td>
<td>Iilitite and illite-dominant illite-smectite. Small amounts of ferroan illite and ferroan illite-dominant illite-smectite are included. This category may also include illite finely intermixed with smectite and or kaolinite.</td>
</tr>
<tr>
<td>Glaucnite</td>
<td>Glaucnite. May include specific compositions of biotite mica (trace amounts).</td>
</tr>
<tr>
<td>Smectite</td>
<td>Smectite and smectite-dominant illite-smectite. May also include physical mixtures of smectite and kaolinite.</td>
</tr>
<tr>
<td>Calcite</td>
<td>Calcite and aragonite. Non-ferroan. May also include mineralogically impure calcite where calcite contains minor (&lt; 10%) sub micron silica and/or clay inclusions.</td>
</tr>
<tr>
<td>Dolomite</td>
<td>Non-ferroan dolomite. May also include mineralogically impure dolomite where dolomite contains minor (&lt; 10%) sub micron silica and/or clay inclusions.</td>
</tr>
<tr>
<td>Ferroan Dolomite</td>
<td>Ferroan dolomite.</td>
</tr>
<tr>
<td>Siderite</td>
<td>Siderite. May also include Fe hydroxides such as goethite.</td>
</tr>
<tr>
<td>Pyrite</td>
<td>Pyrite and marcasite. Pyrrhotite, jarosite and any other sulphides are also included for brevity.</td>
</tr>
<tr>
<td>Halite</td>
<td>Halite and sylvite (if present).</td>
</tr>
<tr>
<td>Gypsum &amp; Anhydrite</td>
<td>Gypsum and anhydrite.</td>
</tr>
<tr>
<td>Barite</td>
<td>Barite and, if present, celestine.</td>
</tr>
<tr>
<td>Tourmaline</td>
<td>Fe tourmaline such as schorf. May include specific compositions of chlorite and garnet.</td>
</tr>
<tr>
<td>Rutile &amp; Ti Silicates</td>
<td>Ti-bearing phases, mainly rutile or anatase. May include titanite.</td>
</tr>
<tr>
<td>Apatite</td>
<td>Apatite and Ca-phosphates. May also include hydro-apatite and bone.</td>
</tr>
<tr>
<td>Zircon</td>
<td>Zircon. Monazite and xenotime etc are also included for brevity.</td>
</tr>
<tr>
<td>Undifferentiated</td>
<td>Undifferentiated mineral phases (trace quantities).</td>
</tr>
</tbody>
</table>
Mineral list used to highlight textural detail in the 3 carbonate-dominant samples:

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>Silica group of minerals (e.g. quartz, cristobalite, etc). Also includes silica minerals with a low backscattered electron coefficient such as hydrated silica minerals including opal and chert.</td>
</tr>
<tr>
<td>K Feldspar</td>
<td>K-rich alkali feldspar including orthoclase, sanidine &amp; microcline.</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>Albite to Anorthite solid solution. May include Na-rich alkali feldspars.</td>
</tr>
<tr>
<td>Muscovite</td>
<td>Muscovite mica. May also include white micas such as “sercite”.</td>
</tr>
<tr>
<td>Biotite</td>
<td>Biotite mica and phlogopite.</td>
</tr>
<tr>
<td>Kaolinite</td>
<td>Kaolin group such as halloysite &amp; kaolinite ss. This category represents pure kaolinite; kaolinite may also be present finely intermixed with a variety of other clays.</td>
</tr>
<tr>
<td>Chlorite</td>
<td>Chlorite generally Fe-rich. May include Fe-smectite and some specific compositions of almandine garnet and tourmaline.</td>
</tr>
<tr>
<td>Illite &amp; illite-smectite</td>
<td>Illite and illite-dominant illite-smectite. Small amounts of ferroan illite and ferroan illite-dominant illite-smectite are included. This category may also include illite finely intermixed with smectite and or kaolinite.</td>
</tr>
<tr>
<td>Glaucnite</td>
<td>Glaucnite. May include specific compositions of biotite mica (trace amounts).</td>
</tr>
<tr>
<td>Smectite</td>
<td>Smectite and smectite-dominant illite-smectite. May also include physical mixtures of smectite and kaolinite.</td>
</tr>
<tr>
<td>Calcite + silica</td>
<td>Calcite finely intermixed with sub-micron grains and crystals of silica (e.g. microcrystalline silica cement).Silica comprises approximately 5-10%.</td>
</tr>
<tr>
<td>Calcite + illite</td>
<td>Calcite finely intermixed with sub-micron grains and crystals of illitic clays. Illitic clay content comprises approximately 20%.</td>
</tr>
<tr>
<td>Calcite</td>
<td>Calcite and aragonite. Non-ferroan.</td>
</tr>
<tr>
<td>Dolomite</td>
<td>Non-ferroan dolomite.</td>
</tr>
<tr>
<td>Ferroan Dolomite</td>
<td>Ferroan dolomite.</td>
</tr>
<tr>
<td>Siderite</td>
<td>Siderite. May also include Fe hydroxides such as goethite.</td>
</tr>
<tr>
<td>Pyrite</td>
<td>Pyrite and marcasite. Pyrrhotite, jarosite and any other sulphides are also included for brevity.</td>
</tr>
<tr>
<td>Halite</td>
<td>Halite and sylvite (if present).</td>
</tr>
<tr>
<td>Gypsum &amp; Anhydrite</td>
<td>Gypsum and anhydrite.</td>
</tr>
<tr>
<td>Barite</td>
<td>Barite and, if present, celestine.</td>
</tr>
<tr>
<td>Tourmaline</td>
<td>Fe tourmaline such as schorl. May include specific compositions of chlorite and garnet.</td>
</tr>
<tr>
<td>Rutile &amp; Ti Silicates</td>
<td>Ti-bearing phases, mainly rutile or anatase. May include titanite.</td>
</tr>
<tr>
<td>Apatite</td>
<td>Apatite and Ca-phosphates. May also include hydro-apatite and bone.</td>
</tr>
<tr>
<td>Zircon</td>
<td>Zircon. Monazite and xenotime etc are also included for brevity.</td>
</tr>
<tr>
<td>Undifferentiated</td>
<td>Undifferentiated mineral phases (trace quantities).</td>
</tr>
</tbody>
</table>
Sample: 8125
Formation: Montney
Depth: 1751

Mineralogical image of the surface of the sample block showing distribution of the main mineral species.

Laminated very fine (to fine) subarkosic sandstone. Lamination is predominantly defined by grain size variations but is also defined by preferential alignment of mica flakes and concentration of clay minerals and pyrite. Dolomite is abundant and appears to occur as detrital grains and/or grain replacive cement. Ferroan dolomite is also present and typically occurs rimming non-ferroan dolomite grains/crystals. Patchy gypsum & anhydrite (in this case anhydrite) cement occurs throughout. Heavy minerals are also noted and include zircon, apatite, tourmaline and Ti minerals.
Mineralogical image of the surface of the sample block showing distribution of the main mineral species.

Weakly laminated subarkosic very fine sandstone to siltstone. The weak lamination is defined by subtle grain size variations, preferential concentration of clays and slight preferential alignment of mica flakes. Dolomite is abundant and appears to occur as detrital grains and/or grain replaceive cement. Ferroan dolomite is essentially absent. Heavy minerals are noted and include zircon, apatite, tourmaline and Ti minerals.

Sample: 8840
Formation: Montney
Depth: 2489.3

Mineral Name | Area % | Mass %
--- | --- | ---
Background | 0.01 | 0.00
Quartz | 46.73 | 45.58
K Feldspar | 8.21 | 7.73
Plagioclase | 7.44 | 7.17
Muscovite | 0.55 | 0.56
Biotite | 0.21 | 0.22
Kaolinite | 0.05 | 0.05
Chlorite | 0.62 | 0.75
Illite & illite-smectite | 4.97 | 4.92
Glauconite | 0.01 | 0.00
Smectite | 0.45 | 0.41
Calcite | 0.54 | 0.54
Dolomite | 28.00 | 29.18
Ferroan Dolomite | 0.04 | 0.04
Siderite | 0.00 | 0.00
Pyrite | 0.91 | 1.31
Halite | 0.00 | 0.00
Gypsum & Anhydrite | 0.28 | 0.28
Barite | 0.00 | 0.00
Tourmaline | 0.04 | 0.04
Rutile & Ti Silicates | 0.23 | 0.34
Apatite | 0.68 | 0.80
Zircon | 0.04 | 0.07
Undifferentiated | 0.00 | 0.00
Mineralogical image of the surface of the sample block showing distribution of the main mineral species.

Weakly laminated subarkosic siltstone. A very weak lamination is defined by slight preferential alignment of mica flakes along with subtle grain size variations (lamination runs top left - bottom right). Dolomite is abundant and appears to occur as detrital grains and/or grain replacive cement. Ferroan dolomite is present but uncommon. Again, heavy minerals are noted and include zircon, apatite, tourmaline and Ti minerals.
Sample: Deppth:
Mineralogical image of the surface of the sample block showing distribution of the main mineral species.

Laminated calcareous siltstone. The sample is dominated by abundant calcite which occurs both as bioclasts (preferentially aligned parallel to the lamination) and as mineralogically impure calcareous matrix (see detailed textural image). Quartz is also abundant and occurs (along with minor plagioclase) as silt-sized grains throughout. Illitic clays are also present and are weakly concentrated in certain laminae. The heavy mineral assemblage is restricted and comprises apatite and minor Ti phases. Pyrite infills voids within bioclasts.

### Background
- Quartz: 62.51%
- Calcite: 62.78%
- Gypsum & Anhydrite: 0.45%
- Heavy Mineral: 0.71%
- Halite: 0.70%
- Ferroan Dolomite: 0.24%
- Barite: 0.00%
- Chlorite: 0.09%
- Illite & Illite-smectite: 0.09%
- Illite: 0.00%
- Kaolinite: 0.00%
- Glauconite: 0.00%
- Kaolinite: 0.00%
- Chlorite: 0.00%
- Illite: 0.00%
- Illite-smectite: 0.00%
- Smectite: 0.00%
- Calcite: 0.00%
- Dolomite: 0.00%
- Siderite: 0.00%
- Pyrite: 0.00%
- Rutile & Ti Silicates: 0.00%
- Apatite: 0.00%
- Zircon: 0.00%
- Undifferentiated: 0.00%

Advanced Reservoir Quality Services, SGS Canada Inc., 50-655 W. Kent Avenue N., Vancouver, BC, V6P 6T7, Canada. Tel: +1 604 324 1166
Sample: 9210
Formation: Duvernay
Depth: 3020.1

Mineralogical image of the surface of the sample block optimised to show detailed textures.

Laminated calcareous siltstone. The sample is dominated by abundant calcite which occurs both as bioclasts (pale blue) and as mineralogically impure calcareous matrix comprising calcite mixed with sub-micron grains of silica ("Calcite + silica") and calcite finely mixed with illitic clay minerals ("Calcite + illite"). Calcite + illite partially defines the lamination. These mixtures of calcite and fine silicates essentially represent mineralogically impure micrite.
Sample:

Laminated calcareous illitic mudstone. Sample is dominated by illitic clays but contains abundant calcareous bioclasts which are aligned parallel to the lamination. Calcite is also present as a component of the calcareous matrix (see detailed textural image). Non-ferroan dolomite is also relatively common and occurs as detrital grains and/or grain replacive cement. Quartz and K feldspar are present throughout as fine silt sized grains. A sparse heavy mineral assemblage comprises Ti phases and apatite. Pyrite is finely disseminated throughout although may be preferentially concentrated parallel to the lamination.
Sample:

Formation: Duvernay
Depth: 3649.7

Mineralogical image of the surface of the sample block optimised to show detailed textures.

Laminated calcareous illitic mudstone. The image optimised to highlight the distribution of calcite finely intermixed with illite ("Calcite + illite") and calcite finely intermixed with silica ("Calcite + silica") reveals that a strong lamination is defined by calcareous mudstone laminae interbedded with more silica-rich calcareous laminae. The lamination is further defined by relatively abundant calcareous bioclasts which are aligned parallel to the lamination.
**Sample:** 9367  
**Formation:** Muskwa  
**Depth:** 1517.4

Mineralogical image of the surface of the sample block showing distribution of the main mineral species.

Illitic mudstone. Sample is dominated by abundant illitic clays together with silt grade quartz and minor K feldspar and plagioclase. Illite is the dominant clay species but smectite, chlorite and kaolinite are also present and may be finely intermixed. Glauconite is also noted. Kaolinite and chlorite also occur as discrete grains / aggregates of crystals suggesting a grain replacive origin. Micas are rare but where present are aligned parallel to bedding. Pyrite is relatively common and occurs as disseminated grains and also larger aggregates (e.g. framboids) throughout.
Mineral image of the surface of the sample block showing distribution of the main mineral species.

Laminated very fine subarkosic calcite cemented sandstone to siltstone with illitic mudstone laminae. The strong lamination is defined by both grain size and mineral composition; the coarser grained laminae are dominated by quartz, feldspar and mica clasts cemented by calcite and also contain patchy kaolinite and siderite cements. Rare, rounded glauconite pellets also occur within the sandstone laminae. In contrast, the finer grained laminae comprise mixed illite, smectite and fine silt-sized quartz. Heavy minerals are noted and include sporadic zircon, tourmaline and Ti phases along with more common elongate apatite grains aligned parallel to the lamination (possibly bone fragments). Blank areas represent organic / coal laminae which are not measured during routine analysis. Similarly, abundant gypsum & anhydrite is present and is related to the abundance of organic matter.
Sample: Deppth:
Mineralogical image of the surface of the sample block showing distribution of the main mineral species.
Laminated micaceous sandy mudstone. Texturally diverse sample dominated by smectite, kaolinite and abundant biotite. Elongate apatite-rich bioclasts (e.g. bone) are common and preferentially aligned parallel to the lamination. This lamination is broadly defined by alternations between carbonate-rich and argillaceous laminae. The carbonate-rich laminae contain abundant plagioclase that is partially altered and replaced by calcite. Dolomite is also preferentially concentrated within these laminae. Within the more argillaceous laminae, kaolinite often occurs as discrete grains / aggregates of crystals indicative of a grain replacive origin. Silt sized quartz is also abundant within the argillaceous laminae.

## Mineral Composition

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<th>Mass %</th>
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<td>Muscovite</td>
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**Sample:** 8518  
**Formation:** Colorado 1WSP  
**Depth:** 407.5  

Mineralogical image of the surface of the sample block showing distribution of the main mineral species.
Sample:
Deppth:
Mineralogical image of the surface of the sample block showing distribution of the main mineral species.

Laminated illitic mudstone - siltstone. Sample is dominated by abundant illitic clays intermixed with lesser amounts of kaolinite, smectite and chlorite. Individual laminae are graded from medium to fine silt up to very fine silts and clay minerals. Minor calcite occurs as elongate grains (bioliths) orientated parallel to the lamination. Pyrite occurs as abundant silt-grade disseminated grains whilst small siderite nodules are widely distributed throughout.
Laminated carbonate-rich siltstone. Lamination is defined by grain size variations (from medium to fine silt) and by mineralogical variations (calcite-rich to dolomite-rich). Broadly, fine grained laminae are dominated by calcite whilst coarser grained laminae are dominated by quartz and dolomite. Both ferroan and non-ferroan dolomite are present; non-ferroan dolomite occurs as detrital grains and/or grain replacive cements with ferroan dolomite rims. Pyrite is disseminated throughout but often concentrated as small lenses parallel to the lamination. The heavy mineral assemblage comprises scattered silt-grade grains of apatite and Ti phases.
Sample:

Laminated carbonate-rich siltstone: image optimised to highlight the lamination. The lamination is strongly defined by the distribution of calcite finely intermixed with silicates e.g. the "Calcite + illite" and "Calcite + silica" categories. These categories represent calcareous mudstone and/or mineralogically impure micrite and are preferentially concentrated in the finer laminae. Rare calcitic bioclasts are also present. In contrast, dolomite (ferroan and non-ferroan) is preferentially concentrated in the coarser laminae.

Advanced Reservoir Quality Services, SGS Canada Inc., 50-655 W. Kent Avenue N., Vancouver, BC, V6P 6T7, Canada. Tel: +1 604 324 1166
Sample: 8682  
Formation: Lower Banff  
Depth: 1962.9

Mineralogical image of the surface of the sample block showing distribution of the main mineral species.

Well laminated carbonate-rich siltstone. Thin coarse silt laminae and elongate lenses comprising quartz and ferroan dolomite (which at least locally occurs as a cement) are interbedded with thicker but finer siltstone laminae comprising quartz, feldspar, illitic clays. Non-ferroan dolomite occurs throughout as detrital grains / grain replacive cement whilst ferroan dolomite typically occurs as larger crystals and aggregates (probably cements). Calcite is also present throughout and may occur as elongate grains parallel to the lamination. Similarly, pyrite is widely disseminated but may be concentrated parallel to the lamination.
Sample:

Dept:
Mineralogical image of the surface of the sample block showing distribution of the main mineral species.

Laminated fine illitic siltstone. Sample is dominated by abundant illitic clays intermixed with minor to trace amounts of smectite, kaolinite and chlorite. The lamination is defined by thin silt to very fine sand-grade laminae and lenses which are preferentially calcite cemented. The thicker, fine laminae comprise illitic clays with medium silt-size quartz grains. Ferroan dolomite is scattered throughout the sample and may occur as euhedral, rhombic crystals. Pyrite occurs as abundant silt-grade disseminated grains as well as larger frambooidal aggregates.

Sample: 8688
Formation: Exshaw
Depth: 2247.3

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Advanced Reservoir Quality Services, SGS Canada Inc., 50-655 W. Kent Avenue N., Vancouver, BC, V6P 6T7, Canada. Tel: +1 604 324 1166
### All Samples
**QEMSCAN Bulk Mineralogy (Mass %) v. Sample**

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<th>Sample</th>
<th>Mass % Mineral</th>
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**Legend:**
- Quartz
- K Feldspar
- Plagioclase
- Muscovite
- Biotite
- Kaolinite
- Chlorite
- Illite & illite-smectite
- Glaucnite
- Smectite
- Calcite
- Dolomite
- Ferroan Dolomite
- Siderite
- Pyrite
- Halite
- Gypsum & Anhydrite
- Barite
- Tourmaline
- Rutile & Ti Silicates
- Apatite
- Zircon
- Undifferentiated
### All Samples

#### QEMSCAN Mineral Size v. Sample

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- **Quartz**
- **K Feldspar**
- **Plagioclase**
<table>
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<th>Grain Density (g/cm³)</th>
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<tr>
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<td>9367</td>
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<td>6904</td>
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**QEMSCAN Grain Density v. Sample**

Density (g/cm³)
All Samples
QEMSCAN Porosity v. Sample

Sample

Macro Porosity (area%)

0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5

Montney

8125

8840

8902

9210

9238

9367

6904

8518

8656

6934

8682

8688

Muskwa

Duvernay

Colorado

Exshaw/Lower Banff
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<tr>
<th>Lab Reference</th>
<th>UWI</th>
<th>Formation</th>
<th>Lithology</th>
<th>Depth</th>
<th>Sample</th>
<th>Site</th>
<th>Grain Density (g/cm³)</th>
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<th>K Feldspar (wt%)</th>
<th>Plagioclase (wt%)</th>
<th>Muscovite (wt%)</th>
<th>Biotite (wt%)</th>
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## Advanced Reservoir Quality Services

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Appendix 1  Sample preparation
App. 1.1 Sample Preparation

Samples that are heavily contaminated with drilling fluids and especially those contaminated with oil based muds have to be cleaned prior to routine sample preparation. Cleaning involves emptying the sample on to a 63 µm sieve, mixing with detergent and washing vigorously with water. The samples are then dried at 50°C prior to further preparation. If soluble minerals are expected or suspected, samples are washed with alcohol rather than water.

App. 1.1.1 Ditch Cuttings

Routine sample preparation of ditch cutting samples involves sieving (screening) of the samples to separate out the 63 µm to 2 mm size fraction used for analysis. This size fraction is used as comparison with sidewall core has shown that this gives a good representation of the mineralogy and textures of the lithologies that are being drilled through. In comparison, coarser (e.g. > 2mm) size fractions commonly contain significant amounts of aggregated grains, cavings and are also dominated by the more cohesive and better cemented lithologies (e.g. mudstones typically survive the drilling process better than sandstones). Furthermore, as the residence time in the drilling fluid is partially controlled by particle size, analysing a limited size range minimises the depth error induced by differing particle size.

Therefore in order to characterise the mineralogy and lithological variation down-hole, analysis of the < 2 mm size fraction is preferred whilst for porosity estimation, coarser grained particles are preferred. However, although direct porosity measurement from cuttings particles is very desirable there are a number of caveats including:

- The ratio of grain size to cuttings particle size strongly controls the apparent porosity value (e.g. Figure 1). Therefore, to derive an accurate porosity estimation from a coarse sandstone, much larger cuttings particles are required than for porosity estimation of a fine grained sandstone.
- Weakly cemented and/or compacted lithologies may have a very high porosity but easily fragment during drilling resulting in, for instance in a sandstone, loose sand grains with no apparent porosity.
- Leading on from point 2, well-cemented and/or compacted lithologies tend to survive the drilling process better and therefore porosity estimation may be possible. Therefore, as an extreme example, when sampling variably cemented lithologies, it is possible that the apparent porosity trends are exactly the opposite to reality i.e. no apparent porosity in the high porosity / permeability streaks and relatively high apparent porosity in the cemented, low porosity zones.

To this effect, all samples are routinely screened at 63 µm, 2 mm and 4 mm; the < 63 µm, the 2 mm to 4 mm and the >4 mm fractions are archived for possible future analysis whilst the 63 µm to 2 mm size fraction is prepared for analysis.
A1.1.1 Sample impregnation

For QEMSCAN analysis, samples must be impregnated with resin and formed into a 30 mm diameter polished epoxy resin block. Therefore, the 63 µm to 2 mm size fraction is weighed and micro-riffled to sub-sample weights of ca. 2 g using a Quantachrome Rotary Micro-Riffler in order to produce representative aliquots for analysis. Subsequently, the subsamples are impregnated with 2.5 g of two part epoxy resin in 30 mm diameter plastic moulds. A combination of vacuum and pressure impregnation is used to ensure optimal resin uptake. This involves mixing the samples with resin, placing them in a vacuum vessel to degas for 20 minutes and then transferring them to a pressure vessel where they are left to cure for at least 5 hours. Once cured, the sample blocks are labelled and backfilled with epoxy resin to produce blocks of sufficient thickness for QEMSCAN analysis, and allowed to cure at 50°C for 3 hours.

App. 1.1.2 Core samples

Poorly cemented and friable core samples are initially impregnated with resin under vacuum to consolidate the sample and prevent any further disintegration of the sample. The samples are then cut using a diamond saw to small tablets measuring approximately 20 x 20 x 5 mm size so that they fit into a circular 30 mm mould. These tablets are placed into a 30 mm round mould and impregnated with resin under vacuum in order to maximise the impregnation of resin. After approximately 20 minutes in the vacuum chamber, the samples are transferred to a pressure vessel where they were left to cure for at least 5 hours. Once cured, the sample blocks are labelled and backfilled with epoxy resin to encapsulate the labels and produce blocks of sufficient thickness for QEMSCAN analysis, and allowed to cure at 40°C for at least 3 hours.
App. 1.1.3 Sample polishing

Once fully cured, the analytical face of each block is ground back to expose the sample and this surface is re-impregnated with resin to further consolidate the sample and minimise loss of material during the subsequent grinding and polishing stages. After re-impregnation, the sample blocks are lightly ground, polished to a flat surface and examined optically to ensure adequate particle separation and polish. Finally, they are carbon coated and stored in a desiccating cabinet prior to analysis.

In all cases, water is avoided during polishing and grinding; ethylene glycol, light oil and alcohol are used as suspensions and lubricants throughout.
Appendix 2 QEMSCAN Methodology
App. 2.1 QEMSCAN technology

QEMSCAN is an automated mineral analysis system that provides rapid, statistically reliable, repeatable mineralogical and compositional data from any chemically distinct inorganic sample. The system works by mineralologically ‘imaging’ a polished section through the sample so that mineralogical textures are preserved. For particulate samples, populations of particles can be classified on the basis of their mineralogy and texture. Therefore, this method is particularly well suited to the analysis of samples where a wide range of particle types are present and which may exhibit a range of mineralogical, chemical and textural styles. Samples of this type can be enormously difficult and time consuming to examine using traditional methods of analysis such as light microscopy and manual scanning electron microscopy, and often these traditional methods do not provide statistically reliable data, even with an experienced operator.

![Diagram of QEMSCAN system components]

**Figure 2 Summary diagram of the component parts of a QEMSCAN system.**

The QEMSCAN system uses a scanning electron microscope (SEM) coupled with up to four energy dispersive X-ray spectrometers (Figure 2) to rapidly image and mineralologically map samples. The latest generation is based on a Zeiss EVO 50 SEM fitted with four Bruker Si drift energy dispersive X-ray spectrometers. Multiple energy dispersive spectrometers are used in order to maximise the X-ray acquisition rate but have the added advantage that the system is tolerant to sample surface imperfections.
The system can be run in a variety of measurement modes although for the analysis of core chips and coarse particulate samples (such as ditch cuttings), the FieldImage mode is used exclusively. In this mode, the surface of the sample is divided into a number of fields of view (Figure 3). Each field is then divided into a virtual grid, the size of which is determined by the vertical and horizontal pixel spacings designated by the system operator and can be set at anything from 0.2 µm upwards. The instrument then rasters the electron beam over each field at this pre-defined beam stepping interval.

**Figure 3 How QEMSCAN identifies minerals.**

QEMSCAN uses the level of backscatter electron brightness to distinguish the sample from the epoxy resin (then assigned as background) in the sample block. Therefore, at each stepping interval, a backscatter electron (BSE) brightness reading is taken and, if above a ‘background’ threshold, an X-ray spectrum is acquired. Conversely, if the BSE value is below the threshold, no X-ray spectrum is acquired. The resultant X-Ray spectrum is compared with a look-up table of known mineral compositions and chemical compositions (this table is known as the species identification protocol or SIP) and an identification is made. If a previously unclassified mineral phase is encountered during analysis, it is marked as ‘other’ and the chemical signature stored; a new mineral entry can then be made in the SIP. Each analysis point (or pixel in the mineralogical image) takes between approximately 1 and 4 ms and therefore, taking stage movements into account, over 1 million mineral determinations can be made in an hour. In this way, a mineralogical map of the sample is very rapidly built up (e.g. Figure 3) and allows determination of the bulk mineralogy and texture of the sample.
The beam stepping interval (pixel spacing) determines the resolution of the textures within the mineralogical image but the smaller the pixel size, the longer the analysis time (e.g. Figure 4). A pixel spacing is therefore chosen to best resolve the textural information of the sample based upon the type of sample submitted, the information that the client requires and the amount of system time available. However, for routine geoscience applications, a stepping interval of 10 µm has been found to be optimal to capture both the textural and mineralogical detail within a reasonable time frame (Figure 4).

**Figure 4 Effect of pixel resolution on analytical time and modal mineralogy.**

The actual volume of the sample from which X-rays are produced relates to the mean atomic number of the material under the electron beam but for the standard QEMSCAN operating conditions it is inferred to be of the order of 4 microns for calcite (less for heavier minerals such as pyrite). It must be noted that the actual beam size is essentially constant and therefore an analysis using a beam stepping interval of 100 microns represents a spot analysis at the node of a virtual grid with horizontal and vertical lines spaced at 100 microns. It does not represent an averaged X-ray spectrum over an area of 100 x 100 microns.
Once a measurement is complete, the individual field images are stitched together to form a mineralogical image of the surface of the sample block (Figure 5). In the case of particulate samples, this mineralogical image is then electronically fragmented so that the individual particles are extracted from the image enabling modal mineralogy and textural information, such as average mineral sizes and mineral associations, to be collected.

Data collection is operator independent and routinely involves the collection of >>500,000 individual X-ray spectra and, in the case of particulate samples, several hundred to several thousand individual particles (each one comprising numerous data points). This therefore results in statistically reliable and reproducible mineralogical analyses.

**App. 2.2 QEMSCAN® Mineral Identification and Data Processing**

Mineral identification is made on the basis of the chemistry of the individual spot analyses; the acquired X-ray spectrum is compared against the SIP and a mineral or compositional name assigned. The SIP typically contains over 500 mineral species, mixed compositional and chemical groupings (although there is no limit to the possible size of the SIP) so, as long as a mineral is chemically distinct, a positive
identification can be made. However, polymorphs such as anatase and rutile or chemically similar minerals such as quartz and opal cannot easily be distinguished.

The resulting raw data are typically too detailed and complex to be directly interpreted, so the data processing software (iDiscover) allows for the simplification of these mineral species into a manageable format by the creation of mineral and compositional groupings (mineral lists).

**App. 2.3 Mineral Lists**

Although well over 500 individual mineralogical or compositional groupings are routinely identified by QEMSCAN®, the resulting data are typically too detailed to be directly interpreted. Simplification of these mineral species into a more manageable format is accomplished by the creation of two stages of simplified mineral lists where chemically similar analysis points are grouped together.

The first level of mineral list (the “Primary” mineral list) is a detailed mineral list, typically up to 50 entries long that allows very detailed characterisation of the mineral assemblage and helps account for mineral grain boundaries (i.e. where an analysis point lies on the boundary between two different mineral phases). Ideal, calculated or inferred mineral densities and chemistry can be assigned to the mineral groupings within the Primary list allowing mineralogical data to be expressed as mass percent mineral and also allowing a chemical composition of the rock to be determined if required. As the Primary list is also too complex for reporting, one or more second level mineral lists (the “Secondary” mineral list) are used for reporting. The exact form of the Secondary mineral lists, and the mineral categories reported, is dependent on the abundance of individual phases within a sample batch and the importance of particular mineral phases.

**App. 2.4 Boundary Conditions**

Due to the volume of interaction of the electron beam with the sample, X-rays may be generated from more than one discrete mineral phase and a mixed X-ray profile will be acquired. This is particularly true for very finely intergrown minerals (such as mixed clays) and may also occur at the boundary between two or more different mineral phases. For instance, where quartz (SiO₂) and pyrite (FeS₂) are finely intergrown, some analysis points will have a spectrum that is dominated by Si and O but may contain small amounts of S and Fe. These “boundary” conditions are broadly dealt with in three ways:

1. The SIP typically contains a large number of entries that characterise these “boundary” pixels. For instance, following the above example, a SIP may have an entry called “Pyrite + trace silica”; this SIP entry would get assigned to the “pyrite” category (and vice versa) for final reporting.

2. If a boundary condition results in a mixed spectrum that is coincidentally the same composition as another known mineral, a “boundary phase processor” image processing routine can be used in the software. This allows isolated pixels of one mineral phase to be assigned, depending on composition etc,
to the dominant surrounding mineral phase. For instance, a boundary between covellite (CuS) and pyrite (FeS₂) may, in certain circumstances, give the same chemical profile as chalcopyrite (CuFeS₂). In these circumstances, the boundary phase processor can be set up to assign isolated pixels of chalcopyrite to either pyrite or covellite depending on which is the dominant.

3. In many circumstances, the boundary conditions can provide additional mineralogical and textural information and so are reported as mixed phases. Most notably, although “micrite” sensu stricto refers to pure calcite mud (i.e. calcite with a grain size < 2 μm), in many cases it contains significant micron to sub-micron sized silicate inclusions such as clays, microcrystalline quartz and opal. It can therefore be possible to distinguish this impure micrite from the typically purer sparry calcite and allow detailed textural information from chemically similar materials to be extracted. Similarly, finely intermixed clays can provide additional textural information and so categories such as “kaolinite + illite” may be presented.

App. 2.5 Rock chip and particulate images

Although QEMSCAN is primarily a mineralogical analysis system, because of the way the instrument measures the sample, mineral images are typically generated for each analysis. The mineral images allow particles to be categorised into different particle types (lithotypes) but are also invaluable for visualising the samples. This can be particularly informative if the samples are contaminated with drilling mud or other drilling additives (e.g. mica, crushed calcite etc) as it is possible to determine from the images if, for instance, barite is real or a drilling component. Contaminant phases can then either be completely removed from the dataset (i.e. all instances of a particular mineral are discarded) or selectively removed. For instance, where a mica additive has been introduced, only loose mica flakes can be selectively filtered from a dataset leaving any mica associated with (for instance) micaceous sandstone intact.

App. 2.6 QEMSCAN mineral data

Once the mineral analysis is complete, the mineralogical images are interrogated to determine the bulk modal mineralogy. Modal mineralogical data are routinely expressed as both area percent mineral and mass percent mineral. Area percent data is essentially calculated in a similar way to traditional optical point count data (except that >>500,000 mineral determinations are made rather than ~300) and is calculated from the total the number of analysis points of a particular mineral expressing as a percentage of the total number of analysis points. The mass percent data are calculated from the area percent data by assigning a density to each of the mineral components. This is done internally within the software and at a very detailed level so that mineral grain boundaries (i.e. where the analysis point lies between two minerals) can be factored into the data.

Both mass percent and area percent data are routinely included in the datasheet because the area percent data are comparable with optical analyses whereas the mass percent data are comparable with
methodologies such as XRD where outputs are expressed as mass percent mineral. In reality, because the more common sedimentary minerals have broadly similar densities, there is usually relatively little difference between the two data sets although where heavy mineral grains, pyrite or barite are abundant (for instance), the two datasets may start to diverge.

The electron beam is scanned across the sample in a series of horizontal lines spaced at 10 µm (or whatever specified). An analysis is taken at 10 µm steps along each line to produce mineralogical map (Only approx. every 10th line shown for clarity)

The mineral size is calculated from the average horizontal intercept length through a specific mineral. In this example, the intercept length is the length of the horizontal line through the pink mineral between the Xs. These intercept distances are averaged for the entire sample to give an average mineral size.

Each cutting particle can be treated as an individual grain and so the dimensions of the particle can be derived (e.g. width, height, aspect ratio etc). However, the component parts of the particle (i.e. the mineral grains / clasts within such as quartz etc) are treated as individual pixels rather than shapes.

Figure 6: Method of calculation of mineral size

**App. 2.7 QEMSCAN mineral size data**

In order to clarify what the QEMSCAN mineral size data represent, the following terms are used:

- **Particle**: an individual fragment such as a cuttings particle which may comprise a small rock fragment or disaggregated rock fragments (e.g. sand grains).
- **Grain**: an individual grain represents the original sedimentary grain. For instance in siliciclastic rocks, may include quartz or lithic clasts whilst for carbonates, grains include ooids and individual bioclasts.
- **Mineral grains**: Mineral grains have the same mineralogical composition but are discrete crystals / crystallites. For instance in siliciclastic rocks, a mineral grain includes a quartz clast together with any quartz overgrowth whilst for carbonate rocks represents individual crystals such as individual dolomite rhombs.
- **Mineral**: This is essentially a contiguous region within the sample mineral composition. For instance, vein quartz comprises numerous mineral grains but is essential monomineralic and
Similarly, a heavily compacted and quartz cemented sandstone, comprises numerous grains and/or mineral grains but only one mineral. Similarly, a dolostone may comprise numerous individual idiomorphic mineral grains but only comprises one mineral.

Average mineral size data (expressed in microns) for each mineral phase are derived from the QEMSCAN analysis. These average mineral size data are calculated from a mean of the horizontal intercept lengths through all of the specified mineral particles within a sample (Figure 6). This provides a robust average mineral size that is consistent between samples and, assuming random orientation of particles, is not affected by different mineral geometries. The mineral size data can be expressed as bulk mineral size (i.e. average mineral size of a specified mineral for all particles in a sample) or by lithotype (i.e. the average mineral size of a specified mineral for each lithotype). It should be borne in mind that chemically similar mineral overgrowths (e.g. quartz cements) are included in the mineral size calculation and therefore although the mineral size data are consistent with optical derived grain size data, they are not directly comparable (Figure 7).

For cuttings particles, parameters such as minimum and maximum elongation can be extracted to provide information such as aspect ratio etc. However, the enclosed grains (e.g. clasts) within these particles are not treated as individual grains, merely as a series of pixels and so at present, it is not normally possible to derive grain size distribution data. Nevertheless, the variation of average mineral size with depth is consistent and can show gross grain size trends with depth and also can highlight the onset of significant quartz cementation and/or compaction as the measured quartz grain size relative to other clast phases (e.g. K feldspar) increases markedly.
App. 2.8 Porosity estimation

In the case of core samples, macro-porosity estimation is usually possible. Similarly, in some cases, macro-porosity estimation is possible from cuttings particles although the caveats concerning grain vs particle size should be borne in mind.

During sample preparation, pores are filled with resin and therefore, macroporosity is defined as an analysis point where the BSE coefficient is below a specified “background” threshold (i.e. equivalent to resin) contained within a particle; these points are marked as “internal background”. Subsequent data processing allows these pixels of “internal background” to be classified as “porosity” and treated in the same way as a mineral allowing an area percent porosity to be calculated.

As the volume of analysis in resin for measurement parameters used in this study is approximately 2 to 4 microns, macroporosity essentially comprises pores > 2 to 4 µm in diameter. However, because of the 10 µm stepping interval used, the textural representation of fine grained macroporosity (i.e. pores < 10 µm) in the porosity images will be an approximation although the value is precise (cf. point counting).

Microporosity is where the analysed volume is greater than the pore size; this results in a measurement where the BSE coefficient is less than expected for a given mineral but greater than the “background” threshold. By creating several BSE – mineral groupings, it is possible to assign different levels of microporosity to each BSE - mineral grouping and therefore estimate total microporosity.

Figure 7 Comparison of optical grain size data with QEMSCAN mineral size data
The different BSE – mineral groupings have been amalgamated into one “Microporous Calcite” grouping for ease of visualisation and reporting.

**App. 2.9 Density determination**

As a mineral density is assigned to each analysis point (in order to derive the mass percent mineral data), it is possible to derive a bulk density for the sample. For instance, if an analysis point is tagged as quartz, a density of 2.65 gcm$^{-3}$ is normally assigned. This is done at a detailed level in the data processing where there are many more mineral entries than those in the final, reported mineral list and therefore microporosity, grain edge effects, solid solutions etc can be accounted for. Although the data are typically expressed as bulk average density, for cuttings samples, the density data can also be derived as an average for a population of particles (i.e. lithotype) or even for specific particles if required.

Bulk rock density is typically derived by assigning a null value to any voids enclosed within a sample (i.e. porosity) and therefore the density value is comparable with a matrix or grain density value. However, it is also possible to assign a density value to the porosity and derive a total density value (i.e. including porosity); this allows the QEMSCAN density data to be compared with wireline density data. In this case, a density value of 1 gcm$^{-3}$ is typically assigned to the porosity although this can be any value (e.g. to simulate pores filled with salt water, hydrocarbons etc). Certain minerals may also contain significant microporosity and therefore will have a reduced density. Although microporosity is not directly measured, it is possible to estimate the degree of microporosity and therefore apportion a lower density to any microporous phases.

Barite can have a significant effect on the calculated density so if barite is determined to be a contaminant (i.e. derived from the drilling mud), it can be excluded from the dataset and a corrected density value derived.