SEDIMENTOLOGY AND DIAGENESIS OF POTENTIAL PERMIAN RESERVOIR SANDSTONES, NORTH PERTH BASIN, WESTERN AUSTRALIA.

BY
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This thesis is submitted in partial fulfilment of the requirements for the Honours Degree of Bachelor of Science in Petroleum Geology at the National Centre for Petroleum Geology and Geophysics, University of Adelaide.

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ABSTRACT

Permian sediments constitute the beginning of an extensive basin-wide depositional period, and the sediment base of the whole North Perth Basin. Phanerozoic basin-forming tectonic extension has played a role in the distribution of these sediments and post-depositional burial has lead to their diagenesis.

The High Cliff Sandstone was deposited at the top of a regressive sequence as the Tethyan Ocean retreated. The well sorted shoreline sands gave way to the fluvial deposition of the Irwin River Coal Measures as waters drained from the Northampton and Yilgarn Blocks. The quartz arenites observed in the Mountain Bridge area have undergone two pronounced stages of diagenesis and a later stage of extensive fracturing. The first stage of diagenesis is characterised by quartz overgrowth cementation and the beginning of feldspar alteration and subsequent illite production. This stage of diagenesis is associated with fluid movement through the rock due to burial. The second stage of diagenesis is characterised by deeper burial effects such as the formation of saddle dolomite and further alteration of feldspars and rock fragments to illite. Three distinct stages of fracturing have been identified as being after the main stages of cementation. The diagenesis of the other Permian units at Mountain Bridge is relatively similar to that of the High Cliff Sandstone given their respective depths of burial.

The suggestion that apparent fault transfer zones in the basin fill are controlled by deep-seated basement fractures is questioned by a series
of experiments which show the "transfer zones" to be a natural consequence of simple extension.
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# CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>i</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>iii</td>
</tr>
<tr>
<td>CONTENTS</td>
<td>iv</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>vi</td>
</tr>
<tr>
<td>LIST OF PLATES</td>
<td>vi</td>
</tr>
<tr>
<td>1 INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>1.1 Aims of Thesis</td>
<td>3</td>
</tr>
<tr>
<td>2 GEOLOGY OF THE PERTH BASIN</td>
<td>6</td>
</tr>
<tr>
<td>3 EXPLORATION</td>
<td>9</td>
</tr>
<tr>
<td>3.1 Exploration History</td>
<td>9</td>
</tr>
<tr>
<td>3.2 Exploration Problems</td>
<td>9</td>
</tr>
<tr>
<td>4 THE HIGH CLIFF SANDSTONE</td>
<td>11</td>
</tr>
<tr>
<td>4.1 Mountain Bridge #1</td>
<td>11</td>
</tr>
<tr>
<td>4.1.1 Core Description</td>
<td>13</td>
</tr>
<tr>
<td>4.1.2 Thin Section Description</td>
<td>15</td>
</tr>
<tr>
<td>4.2 Arrowsmith #1</td>
<td>17</td>
</tr>
<tr>
<td>4.2.1 Cuttings Description</td>
<td>17</td>
</tr>
<tr>
<td>4.3 Diagenetic Sequence for the High Cliff Sandstone</td>
<td>19</td>
</tr>
<tr>
<td>4.3.1 Thin Section Evidence</td>
<td>21</td>
</tr>
<tr>
<td>4.3.2 Cathodoluminescence Thin Section Analysis</td>
<td>35</td>
</tr>
<tr>
<td>4.3.3 Scanning Electron Microscope Evidence</td>
<td>42</td>
</tr>
<tr>
<td>4.3.4 Ultra-violet Light Fluid Inclusion Analysis</td>
<td>47</td>
</tr>
<tr>
<td>4.3.5 Diagenetic Model for the High Cliff Sandstone</td>
<td>50</td>
</tr>
<tr>
<td>5 THE PERMIAN SEQUENCE</td>
<td>56</td>
</tr>
<tr>
<td>5.1 Sedimentology and Hydrocarbon Potential</td>
<td>56</td>
</tr>
<tr>
<td>5.1.1 The Holmwood Shale</td>
<td>56</td>
</tr>
<tr>
<td>5.1.2 The Irwin River Coal Measures</td>
<td>57</td>
</tr>
<tr>
<td>5.1.3 The Carynginia Formation</td>
<td>58</td>
</tr>
<tr>
<td>5.1.4 The Beekeeper Limestone</td>
<td>58</td>
</tr>
<tr>
<td>5.1.5 The Wagina Sandstone</td>
<td>59</td>
</tr>
<tr>
<td>5.2 Correlation of Well Logs and Log Character</td>
<td>60</td>
</tr>
<tr>
<td>5.3 Interpretation and Diagenesis of Sidewall Cores</td>
<td>63</td>
</tr>
<tr>
<td>5.4 Reservoir characteristics of the Permian Sequence at MB#1</td>
<td>77</td>
</tr>
</tbody>
</table>
List Of Figures

Figure 1. The North Perth Basin. ................................. 2
Figure 2. Well Correlation Section ......................... 5
Figure 3. Stratigraphic Column ............................... 7
Figure 4. Seismic Line S84-11................................. 12
Figure 5. Carbonate variation .................................. 14
Figure 6. Diagenetic sequence ................................. 20
Figure 7. Siderite SEM plot .................................. 44
Figure 8. Dolomite SEM plot .................................. 44
Figure 9. Chlorite SEM plot .................................. 46
Figure 10. Depth vs. Temp ..................................... 52
Figure 11. Dolomite d-spacing plot ......................... 54
Figure 12. Development of authigenic minerals .......... 54
Figure 13. Top Wagina isopach map ......................... 61
Figure 14. Postulated transfer zones ......................... 80
Figure 15. Half graben units ................................ 83
Figure 16. Arching and extension clay experiments .... 83
Figure 17. Wrench produced conjugates ................. 86
Figure 18. Clay stresses ................................... 86
Figure 19. Block diagram of fault associated ramp structures 88

List Of Plates

Plate 1. Siderite in overgrowth ............................... 23
Plate 2. Pre-quartz overgrowth cements .................. 23
Plate 3. Feldspar to illite ................................... 25
Plate 4. Quartz overgrowth ................................ 25
Plate 5. Dolomite ........................................... 27
Plate 6. Pressure solution effects ......................... 27
Plate 7. Bow-tie effects ................................... 29
Plate 8. Glauconite ......................................... 29
Plate 9. Three stages of fracturing (ppl) ................. 31
Plate 10. Three stages of fracturing (xpl) ............... 31
Plate 11. Barite fracture ................................... 33
Plate 12. Barite cement .................................... 33
Plate 13. Barite cement .................................... 35
Plate 14. Fault ............................................. 35
Plate 15. Calcite replacing feldspar (xpl) ................ 37
Plate 16. Calcite replacing feldspar (CL) ............... 37
Plate 17. Quartz overgrowth (ppl) ......................... 39
Plate 18. Quartz overgrowth (CL) ......................... 39
Plate 19. Quartz on fault (ppl) ......................... 41
Plate 20. Quartz on fault (CL) ......................... 41
Plate 21. Siderite ........................................ 43
Plate 22. Illite on dolomite ................................. 43
Plate 23. Overgrowth on feldspar ......................... 43
Plate 24. Illite on dolomite ................................. 43
| Plate 25. | Dolomite on overgrowth. | 43 |
| Plate 26. | Illite on dolomite. | 43 |
| Plate 27. | Illite rosette. | 45 |
| Plate 28. | Saddle dolomite. | 45 |
| Plate 29. | Illite. | 45 |
| Plate 30. | Illite on chlorite. | 45 |
| Plate 31. | Quartz crystals. | 45 |
| Plate 32. | Illite in porosity. | 45 |
| Plate 33. | Fluid inclusions. | 48 |
| Plate 34. | Fluid inclusions. | 48 |
| Plate 35. | SWC #5. | 64 |
| Plate 36. | SWC #9. | 64 |
| Plate 37. | SWC #14. | 66 |
| Plate 38. | SWC #19. | 66 |
| Plate 39. | SWC #26. | 68 |
| Plate 40. | SWC #27. | 68 |
| Plate 41. | SWC #30. | 70 |
| Plate 42. | SWC #32. | 70 |
| Plate 43. | SWC #39. | 72 |
| Plate 44. | SWC #42. | 72 |
| Plate 45. | SWC #45. | 74 |
| Plate 46. | SWC #47. | 74 |
| Plate 47. | SWC #48. | 76 |
| Plate 48. | SWC #57. | 76 |
| Plate 49. | Clay model #1. | 89 |
| Plate 50. | Clay model #2. | 90 |
| Plate 51. | Clay model #3. | 91 |
| Plate 52. | Clay model #4. | 92 |
| Plate 53. | Clay model #5. | 93 |
| Plate 54. | Clay model #9. | 94 |
| Plate 55. | Rift on Venus. | 95 |
1 Introduction

The Perth Basin (Figure 1) is a north-south elongate extensional rift basin that represents the tectonics in action during the continental breakup of Gondwanaland. It is over 1000km long, north to south, and covers 45000km$^2$ onshore and 55000km$^2$ offshore. Separating the Archean Western Australian Shield from the basin and representing the eastern boundary of the basin is the controlling Darling Fault with a displacement in excess of ten kilometres. On the western margin, the basin is bounded by the Leeuwin Block in the south and the Edward Island Block in the north. The Basin is separated from the Carnarvon Basin to the north by the Northhampton Block. Its onshore basins include the dominant Dandaragan Trough to the north which at some points is over 15 kilometres deep, and the Bunbury Trough to the south separated by the Harvey Ridge. Offshore basins include the Abrolhos Sub-basin in the north and the Vlaming Sub-basin in the south.

The reservoirs of the Dongara and Mount Horner regions, which supply the Perth district with mainly gas and some oil, produce from basal Triassic sandstone units in structurally shallow areas which are sourced by the younger Catamarra Coal Measures. Most of the exploration and study in the Perth Basin to date, has therefore concentrated on these Triassic sequences and little is known about the potential reservoirs in the Permian sequence.
Figure 1. The Perth Basin with the area of the North Perth Basin highlighted
(Taken from Hall and Kneale, 1992)
1.1 Aims of thesis

Development of the SAGASCO Resources Ltd. gas field Beharra Springs, which occur in the top-Permian Beekeeper Limestone (formerly the Carynginia Limestone Member), has led explorers in the North Perth Basin to look closer at potential Permian reservoirs in more recent years. This study includes a close look at the Permian sequences, with particular interest in the shoreline, High Cliff Sandstone, the primary target of the recently completed SAGASCO wildcat well Mountain Bridge #1. Spurred by the significant porosities of the High Cliff Sandstone on the surface and good log porosity and hydrocarbon saturation from Arrowsmith #1, much hope is held for this rock unit as a potential hydrocarbon-producing reservoir. The High Cliff Sandstone's close proximity to the organic-rich Irwin River Coal Measures increases the possibility of hydrocarbon occurrence. It is the main aim of this study that the High Cliff Sandstone be analysed for its reservoir potential.

Potential reservoir sands have been detected throughout the Permian sequence in the North Perth Basin but have remained largely untested despite reservoir porosities for these units being seen in wells such as Robb #1 and Wicherina #1. Another aim of this thesis is to test the various Permian sandstones at Mountain Bridge #1 for reservoir suitability through sidewall core analysis.

Structurally, the Perth Basin has undergone typical rift extension. The basin structure is largely controlled by the eastern bounding Darling Fault, which separates the basin from the pre-Cambrian Yilgarn Block. The structural habit of the north Perth Basin is currently under
question by the Darling Fault Work Group, a group of researchers in Western Australia who have noted a change in fault character through the basin. Two zones of transfer have been postulated by Dr L Harris of the Darling Fault Work Group (Hall and Kneale 1992), which strike at different angles to the controlling Darling Fault. Consequently, the nature of the transfer zones was studied to assess the potential influence on sedimentation patterns and reservoir integrity. Research of previous studies of rift settings was conducted to find any analogous "transfer zones" in similar extensional settings. Clay model experiments were conducted to establish a new theory for the change of fault character observed.
Figure 2. Well correlation section through the North Perth Basin. (Hall and Kneale 1992)
2 GEOLOGY OF THE PERTH BASIN

The evolution of the Perth Basin is typical of any existing rift basin. The development of the basin is categorised in three phases (Cockbain 1990);

(1) Silurian to Carboniferous (pre-rift phase)
(2) Permian to Early Cretaceous (syn-rift phase)
(3) Early Cretaceous to Holocene (post-rift phase).

(1) Silurian to Carboniferous (pre-rift phase)
In typical pre-rift fashion, the North Perth Basin was the focus of intracratonic downwarping which allowed intermittent sedimentation of the Tumbalagooda Sandstone during the Silurian, a unit which has no southern counterpart (Figure 3). Little is known about the units deposited during the Devonian to Carboniferous. Sedimentation due to the continent-wide ice cap at the end of the Carboniferous is thought to be basin-wide in extent with the Nangetty Formation as the example of this.

(2) Permian to Early Cretaceous (syn-rift phase)
The rifting of the Perth Basin occurred as part of the separating of the Indian sub-continent from Australia. The effect of this was to uplift the West Australian Shield and create the rift Dandaragan Trough (Hall 1989). This was followed by a series of marine transgressions that first saw the deposition of the Holmwood Shale in the Early Permian. A retreat of sea-level gave way to the deposition of the fluvial-deltaic Irwin River Coal Measures through the shoreline High Cliff Sandstone. A return to marine conditions saw the deposition of the Carynginia Formation. Uplift and erosion at the end of the Early Permian saw the
<table>
<thead>
<tr>
<th>PERIOD</th>
<th>EPOCH</th>
<th>MIL YRS</th>
<th>FORMATION</th>
<th>LITHOLOGY</th>
<th>ENVIRONMENT/HYCARB</th>
</tr>
</thead>
<tbody>
<tr>
<td>QUATERNARY &amp; TERTIARY</td>
<td></td>
<td></td>
<td>COASTAL LST</td>
<td>MARINE SHELF</td>
<td>MARINE SHELF</td>
</tr>
<tr>
<td></td>
<td>LATE</td>
<td>67</td>
<td>POISON HILL GREEN SAND</td>
<td>MARINE SHELF</td>
<td>MARINE SHELF</td>
</tr>
<tr>
<td>CRETACEOUS</td>
<td></td>
<td></td>
<td>GININ CHALK</td>
<td>OPEN MARINE</td>
<td>MARINE SHELF</td>
</tr>
<tr>
<td></td>
<td>EARLY</td>
<td>135</td>
<td>MOLECAP GREEN SAND</td>
<td>SHALLOW MARINE</td>
<td>PARALIC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>OSBORNE FM</td>
<td></td>
<td>MARINE SHELF</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>LEEDERSVILLE FM</td>
<td></td>
<td>MARINE SHELF</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SOUTH PERTH SHALE GAGE SST</td>
<td>SHALLOW MARINE</td>
<td>MARINE SHELF</td>
</tr>
<tr>
<td>Jurassian</td>
<td>LATE</td>
<td>192</td>
<td>YARRAGADEE FM</td>
<td>FLUVIAL</td>
<td>OCEAN Floor</td>
</tr>
<tr>
<td></td>
<td>MIDDLE</td>
<td></td>
<td>CADDA FM</td>
<td>MARINE FLUVIAL</td>
<td>MARINE FLUVIAL</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CATAMARRA COAL MEASURES MBR</td>
<td>FLUVIAL-COAL SWAMP</td>
<td>MARINE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ENNEABA MBR</td>
<td>ALLUVIAL TO FLUVIAL</td>
<td>MARINE</td>
</tr>
<tr>
<td>TRIASSIC</td>
<td>LATE</td>
<td>235</td>
<td>LESUEUR SST</td>
<td>FLUVIAL</td>
<td>MARINE FLUVIAL</td>
</tr>
<tr>
<td></td>
<td>MIDDLE</td>
<td></td>
<td>WOODADA FM</td>
<td>SHALLOW MARINE</td>
<td>MARINE</td>
</tr>
<tr>
<td></td>
<td>EARLY</td>
<td>290</td>
<td>KOCKATEA SHALE</td>
<td>BEACH</td>
<td>MARINE FLUVIAL</td>
</tr>
<tr>
<td>PERMIAN</td>
<td></td>
<td></td>
<td>SARMA SST</td>
<td>SHALLOW MARINE</td>
<td>SHALLOW MARINE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>WAGINA ?</td>
<td>MARINE FLUVIAL</td>
<td>MARINE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CARYNGINIA FM</td>
<td>MARINE FLUVIAL</td>
<td>MARINE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>IHWIN RIVER COAL MEASURES</td>
<td>MARINE</td>
<td>MARINE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HIGH CLIFF SST</td>
<td>MARINE FLUVIAL</td>
<td>MARINE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HOLMWOOD SHALE</td>
<td>MARINE FLUVIAL</td>
<td>MARINE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NANGSETTY FM</td>
<td>MARINE FLUVIAL</td>
<td>MARINE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MINERAL MARINE FLUVIAL LAUGUSTINE</td>
<td>MARINE</td>
<td>MARINE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>BASEMENT</td>
<td>CONTINENTAL RIFTING SEQUENCE</td>
<td>?</td>
</tr>
</tbody>
</table>

Figure 3. Stratigraphic column of the onshore Perth Basin (SAGASCO Resources Ltd)
production of an unconformity and then deposition of the Beekeeper Limestone and the Wagina Sandstone in the Late Permian. Basinal down-warping in the early Triassic saw the return to marine conditions once again and the deposition of the Kockatea Shale basin wide.

Movement along the Darling Fault in the middle to Late Triassic created north to north-west trending faults with the development of an active graben. Marine conditions then gave way to the fluvial sands of the Lesueur Sandstone, as the Dandaragan Trough sank and water drained off the Pre-Cambrian shield. Renewed uplift of the Yilgarn Block lead to the deposition of the Eneabba Member and the Cattamarra Coal Measures in the Early Jurassic.

By the Late Cretaceous, major half-graben faulting had been established within the Abrolhos Sub-basin and the Dandaragan Trough due to the uplift of the Beagle and Turtle Dove Ridges.

(3) Late Cretaceous to Holocene (Post-rift phase)
Separation between Australia and Antarctica continued after the separation from India was complete. The Tertiary and Quaternary was a sustained tectonically inactive period which saw the deposition of carbonates on the continental shelf and the stabilisation of sea level to the west of the basin.
3 EXPLORATION

3.1 Exploration History

In the years between 1954 and 1958, West Australian Petroleum Pty. Ltd. carried out the first exploration program in the Perth Basin applying modern geophysical techniques such as seismic, gravity and aeromagnetics. The Bureau of Mineral Resources drilled the first well in the basin in 1959 in the form of the stratigraphic hole BMR 10A.

There have been three major periods of exploration in the Perth Basin since then. The first stage in the early 1960's saw the first successful hydrocarbon find at Yardarino #1 in 1964 with 15.3 MMCFD gas and some associated oil. This was followed by discoveries in at Gingin, Mt Horner, Dongara, Mondarra and then Walyering in 1971. The second exploration spree occurred in 1979 when political actions in Iran saw the oil price rise dramatically and saw the consequent discovery of the Woodada Gas Field in 1980. West Australian Government regulation of the gas price saw the closure of this field in 1984. Conversely, the deregulation of the gas price in 1988 spurred exploration again which culminated in the significant gas field discovery at Beharra Springs.

3.2 Exploration Problems

It has been shown (Thomas 1979) that porosity of reservoirs in the North Perth Basin decreases with increasing depth. Due to the enormous thickness of sediment in the Dandaragan Trough and the unusually low geothermal gradient (<2.0°C/100m), the porosity of Jurassic reservoirs drops to below 10% at 3500m, before the generation
of commercial hydrocarbons occurs at 3800-5000m, at a temperature of 115°C (Hall 1989). Commercial recoveries of hydrocarbons in the North Perth Basin have been made where geothermal gradients increase around basement highs such as the Beagle Ridge and the Dongara Saddle to the side of the Northhampton Block. In these areas, hydrocarbons have been generated before reservoir porosity and quality has dropped off significantly. This is the main reason why the deeper Permian sequence has been overlooked in the past in terms of hydrocarbon productivity.

The Permian source rocks thought to charge the High Cliff Sandstone with hydrocarbons are principally the underlying Holmwood Shale and the younger Irwin River Coal Measures. The Holmwood Shale has an average total organic carbon (TOC) content of 1.2% (Hall 1989) but its source rocks are mostly humic and thus gas prone at the best. The Irwin River Coal Measures contains TOC of up to 14%, but it too is gas prone. Lack of knowledge about the Permian units as hydrocarbon producers has generally discouraged exploration concentration.

Surface limestones and abundant coal sequences have been the main cause of poor seismic data and limited exploration success in the Perth Basin. The Perth Basin has a notorious reputation for exploration wells in the past being drilled off-structure. Resolution of the potential reservoir Permian High Cliff Sandstone has suffered particularly since it is beneath both the Cattamarra and Irwin River Coal Measures.
4 THE HIGH CLIFF SANDSTONE

On the surface, the High Cliff Sandstone has been described as a coarse to fine grained, well sorted and subrounded quartz arenite (Tupper 1992). The surface samples collected from Coal Seam Reserve, Perth Basin, Western Australia, were observed to have possible early siderite cement and only minor compaction and re-arrangement indicating that the samples were never significantly buried. The absence of many unstable rock fragments likely to degrade to clays was seen as encouragement for porosity being preserved in the subsurface. Porosity in the surface samples was measured at up to 32.1% and permeability was measured at up to 20.475 Darcies. The detrital composition and excellent sorting and rounding of the High Cliff Sandstone indicates that it is from a high energy beach or shoreface depositional environment. The sandstones representative of the overlying Irwin River Coal Measures, however, are characterised by poor sorting, angular grains and carbonaceous content, indicative of a meandering stream environment of deposition. In light of these environmental conclusions, the High Cliff Sandstone is thought to be laterally continuous with good horizontal and vertical reservoir continuity.

4.1 Mountain Bridge #1

The Mountain Bridge #1 wildcat well was drilled within the EP 100 (1) permit area for SAGASCO Resources Ltd in early 1993, on a lowside fault trap structure detailed by seismic line S84-11 (Figure 4). The position of the Mountain Bridge #1 well is represented on Figure 4 as a vertical green line, the bottom of which represents the total depth of
Figure 4. Seismic line S84-11 defining a lowside fault trap. The Mountain Bridge #1 well is indicated in green.
this hole. The fault involved in this trap is the Beagle Fault that defines the edge of the Beagle Ridge in the west of the North Perth Basin. On the basis of the encouraging results from the nearby Arrowsmith #1 well and from analysis on surface samples, the High Cliff Sandstone was the primary objective for this well.

During the drilling of the well, a gas show of 692 units was detected in the Beekeeper Formation at 2677 metres depth. This was tested by a conventional bottom hole drill stem test (DST), but produced a dry result. An off-bottom straddle DST over the interval 3185 to 3235 metres, covering the bottom of the Irwin River Coal Measures (IRCM) and the top of the High Cliff Sandstone, flowed 2000 BWPD plus an estimated 0.25 MMCFD of gas through fractures. Another DST was conducted over the interval between 3184 to 3217.5 metres, testing the base of the IRCM in an attempt to isolate the gas that flowed in the earlier DST, but no flow was recorded.

4.1.1 Core Description

One core was cut over the interval 3211.3 to 3228.8 metres (100%), during the Mountain Bridge #1 well. This core represents a regressive phase of deposition with outer marine sediments of the High Cliff Sandstone, grading upwards to well-sorted shoreline sandstones which in turn are overlain by poorly-sorted IRCM back-bar lagoon deposits. Overall, the High Cliff Sandstone is a light grey coloured, well sorted, sub-rounded quartz sandstone that has been substantially cemented by quartz overgrowths, authigenic illite growth and different stages of carbonate cementing. Identification by XRD of increasing carbonate levels down through the core (Figure 5, Appendix
Variation in Carbonate cements in Core #1 from XRD data

Figure 5
1B) and the occurrence of glauconite pellets in core samples of the lower High Cliff Sandstone, offers supporting evidence for marine conditions. This is further supported by bioturbation, mainly burrowing, which increases dramatically with depth within the cored interval. It appears that either the outcropping High Cliff Sandstone, or the section seen in Mountain Bridge #1, is not representative of the unit. Comparison with the log signature in other wells (Enclosure 1), suggests that the outcrop does not reflect the usual state of the formation.

The core is frequently fractured between 3223 and 3225 metres. The fractures are commonly cemented with quartz cement, some being filled with barite cement and show relict fracture porosity of mostly vuggy form. Most fractures show no displacement and are thus probably stress fractures. This is a probable scenario as the seismic line S84-11 (Figure 4) clearly defines several small faults associated with the Beagle Fault to the west. Without the orientation of the core in the well, little can be done to analyse these fractures. A detailed description of core #1 is provided in Appendix 1A.

4.1.2 Thin Section Description

Ten samples were taken from the Mountain Bridge #1 core, for preparations of thin sections, XRD, SEM and other analysis. The samples were selected at the following depths:

- 3211.6m (IRCM)
- 3216.2m (IRCM)
- 3218.9m (High Cliff Sandstone)
- 3219.4m (""
- 3220.35m (""
- 3222.28m (""
- 3223.2m (""
The samples from the IRCM are both texturally and mineralogically immature containing high amounts of clay and feldspar, indicating deposition close to sediment origin (Appendix 1B). These samples are both feldsarenites, but the upper sample has a mean grain size of 1.5 mm and the sample nearer the shoreline transition has a mean grain size of 0.5 mm. The grain size of both the feldspar and the quartz in these rocks is approximately the same but the feldspar shows more post-burial alteration effects and then replacement by calcite cement. Both also contain significant amounts of authigenic illite cement and various calcareous cements, indicative of a fluvial origin.

The samples from the High Cliff Sandstone are texturally and minerallogically mature. They are all well sorted and generally sub-rounded to sub-angular quartz arenites. The quartz frequently exhibits undulose extinction indicating a metamorphic origin, but rare garnets are a feature of a plutonic origin. The samples show a high degree of quartz overgrowth cementation and further cementation by dolomite increases down the core. Authigenic illite was also a diagenetic feature that appeared to be a progressive event.

Three stages of fracturing were observed lower in the High Cliff with the intermediate stage being associated with an infilling of barite cement. The barite probably results from the alteration of barium-bearing feldspars. The final stage of fracturing which broke the barite cement, opened up considerable porosity but was partly cemented by quartz, exhibiting large euhedral crystals in some fracture voids. A detailed description of these samples is included in Appendix 1B.
4.2 Arrowsmith #1

Arrowsmith #1 well was drilled for West Australian Petroleum Pty. Limited in 1965. This well was drilled 1 km south and structurally down-dip from Mountain Bridge #1. It had 2-90% oil fluorescence throughout the Irwin River Coal Measures and upper High Cliff Sandstone and oil fluorescence from sandstone lenses in the Carynginia Formation. A drill stem test over a 3 metre sandstone interval in the Carynginia Formation produced gas at a rate of 4 MMCFD. After two days, pressure dropped off and it was concluded that this reservoir was limited in extent. From analysis of wireline logs from this well, SAGASCO determined that the High Cliff Sandstone had promising hydrocarbon saturations and encouraging reservoir type porosities but limited permeability.

4.2.1 Drilling Cuttings Description

Drilling cuttings from the High Cliff Sandstone interval intersected at Arrowsmith #1 were obtained from the Western Australian Department of Mines and Energy and submitted for X-Ray Diffraction analysis to check that the mineralogy was similar to that seen at Mountain Bridge #1. There are several problems associated with this analysis. The first problem is that the cuttings selected for crushing and XRD analysis may include foreign chips and the XRD trace may therefore be erroneous. The clays present in the formation are usually washed out of the drilling cuttings and the clays of the drilling mud will often be anomalous on the XRD trace. Another problem is that the carbonates in the formation may also be dissolved out in the collection process.
The drilling cuttings might also be mixed up with other cuttings either in the hole, mixed in the drilling mud, or on the shale shakers where they are collected, and therefore might not be wholly representative of the interval from which they originate.

The average diameter of the analysed cuttings from Arrowsmith #1, was approximately two millimetres. Close examination of the drilling cuttings (Appendix 2) from 10705 to 10750 feet, showed that they were texturally and mineralogically mature, being of clean, well sorted and quartz rich composition. The lack of any significant amounts of rock fragments or feldspar is consistent with the High Cliff Sandstone being from a shoreline depositional environment. There was more plagioclase content in this rock, however, than in the High Cliff Sandstone at Mountain Bridge #1, indicating that at that point, although now further basinward than MB #1, it was perhaps at the time closer to the sediment source. The cuttings were however, well cemented (up to 30%) with a light coloured silica cement and showed insignificant porosity. There were trace amounts of clay included in the matrix of cuttings at the top of the sampled interval, which were possibly associated with bioturbation in the graduation interval from back-bar lagoon (Irwin River Coal Measures) to shoreline environment. Further down the interval, below 3266.8 metres, there were indications of dolomite in the cuttings and on XRD, verifying the transition from shoreline depositional environment to deeper marine. This is similar to the situation in Mountain Bridge #1, where dolomite increases as the sediment shows a slightly deeper marine character.
4.3 Diagenetic Sequence for the High Cliff Sandstone

At depths greater than 3000 metres, the potential reservoir unit is heavily cemented by several different stages of pore-occluding cement. All the samples taken from the High Cliff Sandstone in this study show the same sequence of diagenetic events.

The mineral content of the rocks was first determined via X-Ray Diffraction methods (XRD). This determination was then used as an aid to identify the different diagenetic stages by plain light, Cathodoluminescence (CL) and reflected Ultra-Violet light thin section microscopy as well as using Scanning Electron Microscopy analysis (SEM). The diagenetic events for the High Cliff were identified in the following sequence.

Early Events-
(1) Emplacement of siderite cement.
(2) Minor grain coating quartz and illite cement.
(3) Minor compaction and grain settling.
(4a) Alteration of feldspar to porosity and authigenic illite (from extensive alteration of feldspars in the above Irwin River Coal Measures). This stage is probably coincident with the main stage silica cement.
(4b) Thick rims of Quartz overgrowth (sometimes up to 20% of rock).

Late Events-
(5) Dolomite cement, some saddle form (90°-120°C)-etching the quartz overgrowths (sometimes up to 20% of the rock).
(6) Compaction causing extensive suturing of quartz
(7a) Mica alteration to chlorite, chlorite as a cement.
(7b) Alteration of glauconite pellets to chlorite.
Diagenetic sequence - timing of events

BURIAL HISTORY

EARLY DIAGENESIS

- Siderite cement
- Minor grain coating quartz and clay cement
- Minor compaction and grain settling
- Feldspar alteration and illite development
- Quartz overgrowths

- Dolomite cement
- Compaction and suturing of quartz grains
- Mica alteration and chlorite production
- Glauconite alteration and chlorite production
- Fracturing then quartz cement
- Fracturing then barite cement
- Fracturing with healing megacrystic quartz and pyrite

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LATE DIAGENESIS

- - - - - - - -

00X

FRACTURE ASSOCIATED

000

000

0000

LEGEND

--- > Certain event

--- > Uncertain event

---- > Certain event

---- > Uncertain event
Fracture Associated (3222m-3224m) -

(8) First stage fracturing.

(8a) Shattering and dissolution of dolomite in fracture zones healed by quartz cement.

(9) Second stage fracturing

(9a) Healed by barite cement (from associated feldspar dissolution).

(10) Third stage of fracturing shattering barite and opened considerable porosity.

(10a) Cementing by silica, healing fractured barite and megacrystic habit in voids plus associated pyrite.

(11) Last stage quartz "dust" on megacrystic quartz.

4.3.1 Thin Section Evidence

Detailed descriptions for the thin sections obtained from the Mountain Bridge #1 core are given in Appendix 1B. As mentioned before, XRD was used to determine the mineralogy of the rock before thin section investigation was carried out. Any variation seen in the mineralogy within this cored interval is easily explained by the depositional and diagenetic environment. A short succession of colour thin section photographs is given here to explain the diagenetic sequence.
Early Diagenesis

(1) Emplacement of elongate brownish siderite crystals. Evidence that this is the first diagenetic event is seen when the siderite crystals are included in the quartz overgrowth stage (Plate #1, 3219.4m). The siderite exhibits minor etching of the original quartz grains.

(2) Grain coating cements, such as allogenic clays and thin quartz cement, are evident included in the thick quartz overgrowths (Plate 2, 3220.35m).

(3) Minor compaction and grain compaction has occurred due to the effects of initial burial. The effects of this are seen as quartz grains are pushed up against one another (Plate 2, 3220.35m).
Plate 1. Siderite crystals are included in quartz overgrowth cement (I8) indicating early emplacement. 3219.4m. 10X magnification. The field of view is 1mm wide.

Plate 2. Quartz grains are coated with clay cement before quartz overgrowth (C12 & C1). Grains with no overgrowth are also pushed together as part of minor compaction (G3). 3220.35m 10X magnification. The field of view is 1mm wide.
(4a) Alteration of feldspar, predominantly plagioclase, to illite is well developed and extensive in the IRCM because of the greater feldspar content. The feldspar in the cored interval has altered to produce significant amounts of secondary porosity as well as illite (Plate 3, 3223.3m). The feldspar in the IRCM has subsequently been in-filled by calcite cement, identified by its characteristic fluorescence under CL. As seen under SEM, authigenic illite is extensive and in some cases even post-dates the production of late stage chlorite.

(4b) Most quartz grains in the cored interval show thick rims of quartz overgrowth cement. This is the most abundant cement in the upper High Cliff making up approximately 30% of the rock. The quartz rims bind most grains except in areas of allogenic clay concentration and in dolomite cemented areas (Plate 4, 3222.28m). At least two stages of quartz overgrowth have been observed. These are most clearly defined in the CL section to follow where the two stages fluoresce different colours. Quartz cements develop by the direct precipitation of silica from aqueous solutions circulating within the rock (Hurst and Irwin 1982).
Plate 3. All feldspar grains in the cored interval have altered to illite and produced secondary porosity (G8). 3223.3m. 10X magnification. The field of view is 1mm wide.

Plate 4. Most areas within the cored interval show large amounts of quartz overgrowth cement, seen here near preserved primary porosity (H3). 3222.28m 10X magnification. The field of view is 1mm wide.
Late diagenesis

(5) Dolomite cement decreases in content up the core as the indicated depositional environment shallows. It has the natural rhombic crystal habit and a characteristic speckled light orange appearance in contrast to the siderite. The dolomite etches both quartz overgrowth cement and quartz grains and is therefore thought to be almost coincident with the quartz overgrowth stage (Plate 5, 3220.35m).

(6) The main stage of compaction is observed as post-dating the dolomite cement stage as it enhances the etching of the quartz. Other effects of this compaction include making the quartz contacts concavo-convex and sutured, as well as suturing of quartz by compressing against authigenic illite (Plate 6, 3211.6m) and other similar pressure solution features. Grain suturing was observed to be limited in extent in the higher and lower parts of the core where clay content is higher. Suturing was more abundant at the top of the High Cliff where the sand was cleaner and had less clay to absorb the compaction.
Plate 5. Dolomite crystal (E10) seen etching surrounding quartz, enhanced due to compaction. 3220.35m. 10X magnification. The field of view is 1mm wide.

Plate 6. Quartz exhibiting suturing edges after being compressed onto authigenic illite (G7). 3211.6m 10X magnification. The field of view is 1mm wide.
(7a) The trace amounts of mica seen in the cored interval have partially altered to chlorite (clinochlore) after compaction. Most of the mica occurs in the IRCM as muscovite and often exhibits classic bow-tie form due to the compaction (Plate 7, 3216.2m). Identification of chlorite by plain light microscopy is made difficult by the fact that it is similar in appearance to illite which abounds throughout the cored interval. Chlorite is most easily seen in characteristic hexagonal platelet form via the Scanning Electron Microscope (SEM).

(7b) Glauconite is observed lower down in the High Cliff Sandstone. It replaces faecal pellets and is thus an indicator of bioturbated marine conditions. It is observed as having been squashed and cemented before characteristic shrinking took place due to increased temperature. (Plate 8, 3222.28m). Glauconite shrinkage generally occurs when the glauconite is cemented in so that compaction does not reduce its volume and thus condense it. The glauconite pellet can then dehydrate and shrink due to temperature increase associated with burial.
Plate 7. Classic bow-tie mica as a result of compaction (G12). 3216.2m. 10X magnification. The field of view is 1mm wide.

Plate 8. Glauconite (green F13) is encroached upon by quartz overgrowth (G14) and cemented in by this and siderite (F12) and allowed to shrink. 3222.28m 10X magnification. The field of view is 1mm wide.
Most fracturing seen in the core is observed lower in the High Cliff Sandstone in the interval between 3222 and 3225 metres. The first stage of fracturing can be seen fracturing the quartz framework and cement as well as the dolomite cement common in that part of the High Cliff, reducing all of these constituents to rubble. The fractured rubble has then been cemented together by quartz cement leaving little fracture porosity (Plates 9 and 10, 3224.5m).
Plate 9. Photograph showing all three stages of fracturing. First producing rock "hash" (I7-D14), then healed by barite (D11), re-fractured and healed by large quartz crystals sticking into the barite (E10). Note the fracture porosity (blue D2). 3224.3m 10X magnification. The field of view is 1mm wide.

Plate 10. Same view in cross-polars, with barite at extinction (E9-B14) and quartz and dolomite fine grained "hash" more clearly defined in several places. 3224.3m 10X magnification. The field of view is 1mm wide.
(9) The first stage of fracturing has provided points of weakness for a second stage of fracturing which has opened up the healed quartz fractures and partially cemented the opening with barite cement. The barite is also observed cementing fractures not created by the first phase (Plate 11, 3219.4m), as well as cementing other porosity in areas not extensively fractured (Plate 12, 3218.9m).
Plate 11. Solidly barite cemented fracture (B1-H15) and barite cementing fracture associated porosity (112). 3219.4m. 2X magnification, the field of view is 4.8mm wide.

Plate 12. Barite healing fractured group of siderite crystals (E12) in an area that has been crushed and not extensively fractured. 3224.3m 6.3X magnification. The field of view is 1.5mm wide.
The third stage of fracturing can be seen breaking the fractures already cemented by barite. The healing of barite cement gives the barite a bubbled appearance in thin section (Plate 13, 3223.3m). This stage of fracturing is again characterised by healing quartz cement and the opening of significant fracture porosity in which quartz cement has formed large euhedral crystals (Plates 9 and 10). This megacrystic void-filling quartz shows perfect zoning due to sequential growth as seen under CL. As mentioned before, most of the fractures in this core show no evidence of displacement. One exception to this was observed in the thin section at 3224.3 metres. The fault observed juxtaposes two rocks with markedly different compositions (Plate 14, 3223.4m). One side of the fault is a rock more substantially dolomite cemented, presumably displaced from a deeper position richer in carbonate. The other side still includes a dolomite cement phase but is more cemented by quartz overgrowth.

The third fracturing stage is also characterised by disseminated of pyrite, seen in several places throughout the core and also in thin section. The pyrite is associated with this phase because it has not been fractured or displaced in any way by further fracturing as earlier stages have been.

The last stage quartz "dust" is so fine as to be only observed under SEM.
Plate 13. Fractured barite being healed by latest stage quartz cement and thus exhibiting bubbly appearance (B9). 3223.3m. 10X magnification, the field of view is 1mm wide.

Plate 14. A clearly defined fault (I1-C15) separating the cleaner-looking less dolomitic rock (upper left) and the more dolomite cemented rock (lower right). 3224.3m 2X magnification. The field of view is 4.8mm wide.
4.3.2 Cathodoluminescence thin section analysis

Cathodoluminescence uses a high voltage electron beam fired onto the top of a thin section that does not have a cover slip but has a polished finish. The electron beam is at such a frequency that it excites some minerals tainted with elements such as manganese into fluorescence. Iron, in both ferrous and ferric states, has the opposite effect in that iron-rich minerals do not fluoresce, and thus iron is known as a quencher. This is now a commonly used tool in carbonate petrology as carbonates generally fluoresce bright orange unless they have a considerable iron content. This can also be used in siliciclastic petrology because quartz and feldspar fluoresce blue. In this study, five thin sections from the cored interval in Mountain Bridge #1 were chosen to be polished and have this analysis done on them. These were at; 3216.2m (from the Irwin River Coal Measures), 3220.35m, 3222.28m, 3223.3m and 3224.3m (from the High Cliff Sandstone).

The Irwin River Coal Measures is characterised by a high feldspar content which has mostly altered and has often been replaced by calcite. This calcite phase was first identified by XRD but its identification by plain light microscopy was difficult due to the fact it is very similar in appearance to dolomite. The identification of calcite by XRD shows that its distribution is only within the IRCM. Light microscopy shows that the emplacement of calcite cement postdates dolomite cementation because the calcite is only seen replacing the secondary porosity produced by feldspar alteration. The feldspar has a characteristic bright blue appearance and the replacing calcite has a red-orange colour under CL (Plate 16). The calcite is limited to the areas where the feldspar grains once existed and has very definite
Plate 15. Feldspar (F8:H2) altering and being replaced by calcite. Note the bow-tie mica (I8) post dating alteration and replacement. 3216.2m. 10X objective with 8X zoom.

Plate 16. Bright blue flourescing feldspar (F8) being replaced by red-orange calcite (H5&C12). 3216.2m 10X objective with 8X zoom. 19 Kvolts, 260μA, 17 seconds exposure.
edges indicating that the feldspar was cemented in by quartz overgrowth, then altered and replaced by the calcite. The early siderite stage, common in both the IRCM and the High Cliff, does not fluoresce, probably because of having a high iron content.

The CL technique also identified two different stages of quartz overgrowth cement as well as the early thin grain coating cements within the High Cliff Sandstone where neither the siderite or dolomite showed fluorescence. Plate 18 (3223.3m) shows the thin grain coating of quartz and clay as small anomalous bright specks and the late stage dolomite cement as a deep blue colour. The first stage of quartz overgrowth cement appears as a light purple colour which is then conformably overgrown by a cement stage that has a darker royal blue colour. Both cement stages are clearly seen in the centre of the photograph and for the purposes of the diagenetic sequence in the High Cliff, they combine to make the one thick overgrowth stage.
Plate 17. The High Cliff Sandstone is largely cemented by quartz overgrowth in this slide (F8). Note the dolomite cement (E4) and porosity (C13). 3223.3m. 10X objective with 10X zoom.

Plate 18. The first overgrowth stage rims most quartz grains and is a light purple colour (F8). The second stage fills in between cemented grains and is a royal blue colour (E9). The bright lines and points (F11) indicate initial grain coating cements and the dolomite has turned a deep blue (E4). 3223.3m 10X objective with 10X zoom. 18 Kvolts, 290μA, 5mins 31secs exposure.
Zoning of the megacrystic quartz crystals associated with the third stage of fracturing is clearly seen using the cathodoluminescence technique. Plate 20 (3224.5m) shows the expected deep blue zonation associated with the growth of these crystals into the fracture porosity. These crystals also exhibit some sort of stress condition in that under CL the zoning of the crystal is interrupted and the quartz is a pink purple colour. This picture also displays the fault seen in this thin section at 3224.5m. The fault is observed as a linear shattered zone running diagonally down through the slide. The rock in the lower left hand side of the photograph must be cemented with the fracture associated quartz as it has the same colour as the large crystals. The light coloured nature of the fractured material in the fault zone, more likely to be from the framework grains, confirms this.
Plate 19. The crushed fault zone (A6-J12) exhibits fractured material and has produced fracture porosity (D2) which has been burnt from its usual blue colour by the CL beam. 3224.3m. 4X objective with 10X zoom.

Plate 20. Megacrystic quartz (E5) exhibits growth zoning and unidentified pink-purple colouring (C6). The fractured zone (A6-J12) shows the same colouration as the rock to the upper right. Note the deep blue dolomite (C7). 3224.3m. 4X objective with 10X zoom. 18 KVolts, 235 μA, 10 mins 8 secs exposure time.
4.3.3 Scanning Electron Microscope Evidence.

The SEM, which operates in a vacuum utilises the effect of electron shell excitation in elements when bombarded with a beam of electrons. This microscope allows black and white photographs to be taken of three dimensional views up to very high magnifications. Using the SEM, we can observe minerals as they actually exist in the rock. This machine can also identify elements of particular minerals observed, in order to aid mineral identification.

Seven samples were selected for SEM analysis and underwent the customary gold-palladium coating preparation for use. These samples were; 3211.6m, 3216.2m (IRCM), 3220.35m, 3223.3m, 3224.3m and 3227.6m (High Cliff).

The SEM was helpful in determining the diagenetic sequence of events and their relative timing. Main discoveries gained from using this tool were the extent of the authigenic illite, the observation of saddle dolomite and the latest stage quartz dust. The implication of the saddle dolomite seen in Plate 28 (3224.3m) is that this stage is a late diagenesis stage. Saddle dolomite forms temperatures between 90 to 120°C implicating that burial was significant by the time that the dolomite was introduced to the rock as a cement.

The legend to the photographs from left to right is; bar scale length in mm or µm, operating voltage of machine kV, magnification as a multiple of an exponent of 10, photo identification number, well name abbreviation and depth (less 32- prefix) in metres. Accompanying elemental analysis plots are given where indicated.
Plate 21. Illite (E1) on Quartz crystals (B2) on typical siderite rhomb (C2 and Figure 7)

Plate 22. Wispy authigenic illite (C2) is seen on dolomite (B2) on quartz overgrowth (C/D2) on siderite (D2/3)

Plate 23. Quartz overgrowth (A2) encroaches on dissolving feldspar (E2)

Plate 24. Illite (B/C2) on rhombic ferroan dolomite (C3) on feldspar altering to illite (D3)

Plate 25. Illite (A3) on rhombic dolomite (C2) etching quartz overgrowth (D2/3)

Plate 26. Authigenic illite (C1) on dolomite rhomb (C3 and Figure 8)
Figure 7. Typical elemental distribution of siderite via SEM elemental analysis. Siderite rhomb in Plate 21, 3220.3m. The gold peaks are from the Au-Pd coating. Siderite FeCO₃

Figure 8. Elemental distribution for the ferroan dolomite in Plate 26, 3216.2m. Dolomite Ca(Mg,Fe)₁(CO₃)₂
Plate 27. Typical authigenic illite rosette (B2) on quartz overgrowth (D2).

Plate 28. Authigenic illite growth (B2/3) on saddle dolomite (C2) curved rhomb.

Plate 29. Illite (B1) precluding porosity (D2/3) on dolomite rhomb (D1).

Plate 30. Authigenic illite hairs (E4) on chlorite platelets (C3 and Figure 9).

Plate 31. Quartz dust (A4) on megacrystic quartz crystals in fracture porosity.

Plate 32. Bunches of authigenic illite needles invade porosity (D3).
Figure 9. Elemental distribution for the authigenic chlorite platelets seen in Plate 30, 3216.2m. Chlorite \((\text{Mg,Al,Fe})_2[(\text{Si,Al})_2\text{O}_5]\text{OH})_{16}\)
4.3.4 Ultra-violet light fluid inclusion analysis

Inclusions are often trapped within quartz overgrowth cement and they represent the material that adhered to the grain at the time of cementing and/or the fluid involved in cementation. The melting temperature of some fluid inclusions is now used to determine the salinity of the included fluid and thus the properties of the water in the rock at the time of quartz cementation. If hydrocarbons were present in the rock at the time of overgrowth cementation, they would naturally be included in the cement.

One of the fundamental tests done on formation drilling cuttings at the well site is to submit the cuttings to ultra-violet light to detect hydrocarbons. This technique takes advantage of the fact that hydrocarbons will fluoresce when exposed to this short wavelength light. Combining these two known facts, ultra-violet light analysis can be conducted on fluid inclusions to check for fluorescence and thus test if they are hydrocarbons.

Pink fluid inclusions were detected in the quartz overgrowths of the sands in the cored interval at Mountain Bridge #1 (Plates 33 and 34). In terms of hydrocarbon history, it was desirable to know if the High Cliff formation had had an early hydrocarbon charge.

This technique involves the projection of ultra-violet (UV) light from a powerful mercury lamp, onto the top of a polished thin section. Alternating from plane light microscopy to UV light mode increases the accuracy of analysis but makes eye-sight adjustment difficult. Because
Plate 33. Pink inclusions (F4&G15) define the boundary of original quartz grains.
3223.3m. 50X magnification.

Plate 34. Inclusions (C9-H7) within the quartz overgrowth cement, incorporate fluids and other materials present on the grain at the time of overgrowth cementation.
3223.3m. 50X magnification.
of the very dull nature of this technique, no photographs were able to be taken in UV mode.

Some inclusions within the quartz overgrowth were thought to fluoresce a very dull orange, a characteristic of mature to overmature hydrocarbons. This was to be expected if hydrocarbons were present at this point, one of the oldest positions in the rock. A dull green fluorescence, a characteristic of immature to mature hydrocarbons, was also observed at first, between quartz cement contacts. Further investigation of these initial observations found that illite clay within the rock also produced orange fluorescence, and was quite probably the source of that fluorescence observed in the quartz overgrowth. It was also found that the blue epoxy resin used to secure the rock in thin section preparation and a characteristic of porosity, fluoresced dull green under UV light. It was decided that this was the cause of the second fluorescence seen between grain cement boundaries. No early hydrocarbon charge was positively identified as a result of this analysis and it is thought that this did not occur.
4.3.5 Diagenetic Model for the High Cliff Sandstone

The sands of the High Cliff Sandstone were deposited as part of a regressive cycle as the Teythian sea retreated in the early Permian. The regional climate was one of humid subtropical nature allowing for intense biological activity in the shelf marine environment and later preservation of numerous coal beds as terrestrial sediments prograded into the basin. Examination of well log character (Chapter 5.2) indicates that basin subsidence and sediment supply were both at a relatively constant rate. The degree of bioturbation in some parts of the High Cliff, led to significant amounts of mud and clay being dispersed throughout the sediment. Despite this, the shoreline sands remained predominantly clean and well sorted. This would have ensured a moderate to high rate of fluid flow through the sediment and thus an open chemical system.

Siderite precipitation takes place in low-sulphate, fluvially-derived pore waters under reducing conditions (Cowan and Shaw, 1990). Early siderite cementation in the High Cliff Sandstone was probably the result of solutions filtering down through the sands from the overlying Irwin River Coal Measures.

Initial grain-coating cements were as a result of chemical re-equilibration of sediment constituents following the influx of reducing fluids.

Production of authigenic illite in the High Cliff Sandstone is extensive for a relatively clean shoreline sand. Initial illite production is most probably from the mobilisation of allogenic forms. Illite generally exists
in the 1Md disordered form in sediments and is converted by temperature to the 2M form (Foscolos, 1990), the type identified in this study by XRD. Illite production is generally associated with potassium influx and decomposition of kaolinite (Wilson and Pitman, 1977). This is most probably the case later in diagenesis when dissolution of feldspars and rock fragments provides the necessary cations for the production of illite.

Grain-coating quartz cement contains fluid inclusions and allogenic clays and provides some insight into the original sediment conditions. Quartz cement forms as silica precipitates directly from aqueous solutions circulating within sediment. Causes of silica precipitation likely in this case include lowering the pH of a saturated solution and mixing silica saturated solutions with more saline formation waters at a given pressure and temperature (McBride, 1989). It is possible that silica saturated solutions from more compacted areas were flushed to the basin margins by dewatering thus leading to the precipitation of silica in the Mountain Bridge area before compaction (Tarabbi, 1991).

Dolomite cementation is defined as late stage (90-120°C) due to the observation of saddle dolomite via SEM at 3224.3 metres. This correlates with a depth of burial at Mountain Bridge #1 of between 2500 and 2900 metres (Figure 10). Precipitation of late stage dolomite cement cannot be explained by conventional dolomite formation models. Pressure solution along solution seams and stylolites has been sited as a source of Mg$^{2+}$ and a cause of dolomitisation (Wanless, 1979). In this case Mg$^{2+}$ is cannibalised from pre-existing magnesian calcite and complete dolomitisation is thought to occur in concentrated zones along solution seams. Several stylolites are observed in the cored...
Figure 10. Depth versus temperature for the Mountain Bridge #1 well. (SAGASCO Resources)
interval and pressure solution effects are evident throughout the sampled thin sections but they generally post date the dolomite cementation.

As Figure 5 and Appendix 1B indicate, dolomite content increases down the High Cliff Sandstone with increasing marine conditions. A plot of dolomite crystal d-spacing from the Mountain Bridge #1 core against dolomite composition (Figure 11), indicates that this stage of dolomite is also relatively very iron rich. It is most likely that carbonate deposited with the marine sediment as a result of biological activity, has recrystallised at this late stage and included free iron and magnesium ions from chemical alteration of clays and rock fragments.

This carbonate and to a lesser extent, the early siderite, extensively etch quartz cement and grains when in contact. This etching has been enhanced by late stage compaction which also creates pressure solution effects throughout the rock. Most notable of these effects is that quartz shows a rough sutured appearance when in contact with authigenic illite.

Chlorite has previously been observed as an alteration product of kaolinite in the younger Cattamarra Coal Measures (Tarabbia, 1991). Chlorite content is sporadically observed throughout the core as a product of altered mica, increasing with depth of burial (Figure 12). Glauconite pellets also increase in number down the cored interval with the increase in marine affinities. The glauconite has been cemented in and then shrunk as a result of burial associated heat or altered to chlorite.
Figure 11. Dolomite crystal d-spacing is a product of iron and magnesium content in dolomite and can be measured via the position of the main dolomite peak on the XRD plot. An average d-spacing of 2.8792 was determined for the cored interval. This gives the dolomite identified in the core, a typical deep diagenesis iron rich average composition of 73.0% Mg and 27.0% Fe. Dolomite = Ca₁.₀ Mg₀.₇₃ Fe₀.₂₇ (CO₃)₂ (Original data from JCPDS).

Figure 12. Relation between depth of burial and development of authigenic minerals. (Foscolos 1990)
The three distinct stages of fracturing that have all occurred after the normal diagenetic events. This indicates that the fracturing was late stage, occurring after dolomite cementation at below 2900 metres and after later diagenetic events. The fracturing has timing only relevant in terms of the diagenetic sequence and it is difficult to correlate it to any major late structural event. The fracturing is significant however, in opening up the reservoir and increasing porosity.

The sequence of the fracturing stages themselves is clearly displayed from the history of associated cements. The mobilisation of silica-saturated fluids is commonly associated with fracturing and extensive pressure solution. Each fracturing event has a characteristic associated cement. The first cement is silica and the second a barite (barium sulphate) cement, probably precipitated by reducing fluids. The third stage, which has created most of the porosity, is associated with further silica cement and disseminated pyrite via acidic reducing fluid. Pyrite development is common in organic rich shales which indicates that even late stage fluids have been mobile within the Permian sequence.

All three stages of fracturing are likely to have been caused by an Early Neocomian (Late Cretaceous) deformation period that uplifted the Beagle and Turtle Dove Ridges and caused tilting of fault blocks in the Dandaragan Trough and Abrolhos Basin. Detailed analysis of the fractures was made difficult by the fact that the Mountain Bridge core was not orientated. A comprehensive analysis of these fractures is largely beyond the scope of this study but particular attention should be paid to the extent of this fracturing when considering further exploration.
5 THE PERMIAN SEQUENCE

Good hydrocarbon shows were obtained throughout the Permian sequence at Arrowsmith #1, and reservoir quality sandstones were expected at Mountain Bridge #1. The secondary targets for the Mountain Bridge #1 well were the sandstone and limestone beds within the Wagina Sandstone, Beekeeper Formation, Carynginia Formation, Irwin River Coal Measures and the Holmwood Shale. All of these Permian units have shown reservoir and hydrocarbon potential in one or more wells in the North Perth Basin.

5.1 Sedimentology and Hydrocarbon Potential

(The depth values indicated here are from the Mountain Bridge #1 well). The organic matter and reservoir data (Hall 1989) correlates basin wide. The log patterns referred to are illustrated in Enclosure 1.

5.1.1 The Holmwood Shale
- Early Permian, 3248.0 - 2285.0 metres

The regressive marine Holmwood Shale can be divided into three distinct units: a basal sandstone unit, a middle unit, from 3303 to 3373 metres, which coarsens upwards from claystones to argillaceous sandstones, and an upper unit which passes from shales to crinoidal limestones.

The Holmwood Shale has total organic carbon (TOC) contents ranging from 0.03 to 3.3% at an average of 1.2%. The organic matter is mostly humic and is therefore gas prone. Sandstone units present within the
Holmwood shale at Abbarwardoo #1, Wicherina #1 and Robb #1 showed porosities up to 27% and permeabilities of up to 1036 millidarcies, justifying this formation as one of the secondary objectives of the Mountain Bridge #1 well, but there were no indications of hydrocarbons.

The two sidewall cores analysed from the Holmwood Shale come from the sandstones of the upper and intermediate units at 3257.5m and 3315m respectively.

5.1.2 The Irwin River Coal Measures
- Early Permian, 2886.0 - 3218.0 metres

The regressive shoreline transition High Cliff Sandstone grades into the fluvial deltaic conditions of the Irwin River Coal Measures. Two distinct parts to this unit can be identified. Interbedded sandstones fining to coals form the fluvial lower unit up to 2989 metres. Above this, marine sandstones and claystones are arranged as regressive coarsening upwards sequences to the top of the formation.

The Irwin River Coal Measures (IRCM) contains organic-rich source rocks with up to 14% TOC in some of the coaly and carbonaceous shales. The organic matter from this is gas prone. This formation has porosities ranging from 2 up to 29% but is usually around 18%. Permeabilities are low at 5 to 10 millidarcies because of the argillaceous content, but gas has been produced from this formation in the Dongara region. The Irwin River Coal Measures showed trace oil fluorescence and moderate gas shows at Mountain Bridge #1.
Seven sidewall cores from the IRCM are analysed in this study. Six of which are located in the lower fining upward fluvial sequences and one at the top of the formation as part of the regressive coarsening upward units.

5.1.3 The Carynginia Formation
- Early Permian, 2679.0 - 2886.0 metres

The Carynginia Formation is a marine shale unit with predominantly claystones and interbedded sandstones and limestones. At Mountain Bridge #1 it forms a series of coarsening upward marine depositional system units.

The Carynginia Formation is an adequate source rock with TOC ranging from 0.25 to 11.4 %, at an average of 2.75 %. The organic matter in this formation is both humic and sapropelic and is therefore theoretically able to produce both oil and gas. Thin sandstones within the Carynginia Formation have porosities between 11 and 20 % but they are generally thought to be discontinuous (Hall 1989). Despite this, gas is produced from these sands in the Dongara area. Moderate gas shows were obtained from the Carynginia Formation in the Mountain Bridge #1 well.

Four sidewall cores from the tops of coarsening upward sequences in the Carynginia Formation were chosen for analysis.

5.1.4 The Beekeeper Limestone
- Late Permian, 2670.0 - 2679.0 metres
Formerly known as the Carynginia Limestone Member, the Beekeeper Limestone is thin at Mountain Bridge #1, but is up to 100 metres thick in the Woodada region to the south where it produces gas from secondary fracture porosity. To the north in the Beharra Springs area, this unit intertongues with the time-equivalent Wagina Sandstone. In some areas, the Beekeeper Limestone and the Wagina Sandstone are separated by a period of nondeposition or erosion, creating an unconformity. Both of these units are said to be unconformably overlying the Early Permian Carynginia Formation.

The Beekeeper Limestone has variable TOC which has previously been summarised as part of the Carynginia Formation. The dominant porosity observed is secondary fracture porosity varying from 0.01 to 0.5% at an average of 0.2%. The Beekeeper Limestone had trace oil fluorescence and moderate to strong gas shows at Mountain Bridge #1.

One sidewall core from the Beekeeper Formation was included in this study.

5.1.5 The Wagina Sandstone
- Late Permian, 2647.0 - 2670.0 metres

The Wagina Sandstone is a series of fining upwards sandstones interbedded with limestones that were deposited under near-shore marine conditions. The Wagina Sandstone is classified as a sporadically developed, time transgressive formation, the upper parts of which are Early Triassic (Hall and Kneale 1992), then unconformably overlain by the Triassic Kockatea Shale.
The Wagina Sandstone has porosities between 5 and 15% but tends to have low permeabilities due to clay content. Gas is produced from this unit in the Dongara and Mondarra Fields. Trace oil fluorescence and moderate to strong gas shows were obtained from this unit at Mountain Bridge #1.

No sidewall cores were taken from this unit for analysis in this study. An isopach map for the bottom Kockatea Shale around the Mountain Bridge #1 area, which equates to the top of the Wagina unit and the subsurface topography of the Permian units, is given as Figure 13.

5.2 Correlation of well logs and well log character

A sheet of gamma ray and sonic logs for the wells Robb #1, Mountain Bridge #1 and Arrowsmith #1 is included in Enclosure 1. The correlation of signatures of both logs between Mountain Bridge #1 and Arrowsmith #1 is predictably easy since the wells are only approximately one kilometre apart. The signature of individual sequences can be correlated between these wells so successfully that it could well be assumed that the rocks differ little over that distance. Robb #1 has been included as a reference that was stratigraphically higher at the time of deposition in the Permian. Log signature of some units can still be correlated to Robb #1 some seven kilometres to the northwest.

The Permian sequence is characterised by coarsening upwards sequences representing marine deposition and fining upward sequences representing fluvial deposition. Both types of sequences show regular repeatable log character and thickness in both the
Figure 13. Isopach map for the basal Triassic (top Wagina Sst.) in the Mountain Bridge area. (SAGASCO Resources)
Mountain Bridge #1 and Arrowsmith #1 wells. The coarsening upward marine sequences of the Holmwood Shale and the Carynginia Formation only vary in unit thickness from 30 to 60 metres. The fining upwards fluvial deposits vary even less in package thickness ranging from 20 to 30 metres thick. This regular pattern indicates that, throughout the Permian, there was a steady rate of basin subsidence and a steady rate of sediment supply to the basin. This assists sedimentological modelling and mapping the distribution of units throughout the basin.

5.3 Interpretation and Diagenesis of Sidewall Cores

In the sidewall core collection process, an explosive charge is used to fire a cylindrical sampler into the rock which nearly always shatters or distorts the sampled rock in some way. Penetration of drilling mud into the formation also inhibits observation of the original rock. Diagenetic analysis and porosity estimation of the cores is therefore very difficult.

Each sidewall core examined represents a potential reservoir unit which has an individual composition. Each one will thus be dealt with separately.

The cores sampled for this study were impregnated with blue epoxy resin to secure the rock and then had sections taken through them for preparation of thin sections. Detailed descriptions of these thin sections are included as Appendix 3.
(1) Sidewall core #5, 3315m, Holmwood Shale

This slightly muddy feldsarenite had high amounts of drilling mud infiltration which made clay determination difficult. Despite this it was mineralogically mature containing mostly quartz with no overgrowth cement evident. This may possibly be due to a high content of allogetic clays and mud preventing the penetration of post-depositional cement precipitating fluids. In this case, the interpreted foreign drilling mud may in fact be in situ clays but probably not porosity. Small amounts of feldspars and rock fragments are observed but have undergone only minor alteration to illite. A small amount of calcite cement is observed and is probably the recrystallised form of fossil fragments.

(2) Sidewall core #9, 3257.5m, Holmwood Shale

This rock is predominantly calcitic fossil fragments cemented heavily by dissolved and re-precipitated carbonate. Fossil fragment voids have been completely filled up with black mud and sparry calcite cement. This rock shows no remaining primary or secondary porosity and the porosity observed was induced by the coring technique. The matrix in this rock appears to be a slightly dolomitised carbonate mud and has no visual porosity. This rock has undergone late stage fracturing which has cleanly fractured the fossil fragments and the dolomite cement. These fractures have then been cemented by quartz cement and do not produce any secondary porosity. It is most likely that this fracturing is the same as the last stage of fracturing seen in the bottom of the cored interval and propagates through the interval in between, over thirty metres.
Plate 35. Angular quartz grains (B9) are mostly floating in illitic clay matrix (E7). Rare calcite cement (F10) etches quartz when in contact with it. Occasional feldspar (C5) and rock fragments alter very little to illite. SWC#5, 3315m. 10X magnification, field of view is 1mm.

Plate 36. Calcite fossil fragments (H11) show shattering due to coring. Fragment voids (D13) are filled with mud and sparry calcite cement. White quartz filled fractures break through fossil fragments and the supporting cement. SWC#9, 3257.5m. 2X magnification, field of view is 4.8mm.
(3) Sidewall core #14, 3195m, Irwin River Coal Measures

There is severe shattering of both the framework grains and the rock from the core. The quartz grains exhibit extensive quartz overgrowths which cements most of the rock. Production of authigenic illite from alteration of feldspars and illite, has precluded any original porosity. Compaction has compressed grain contacts to sutured status and caused pressure solution etching of quartz in contact with illite. No carbonate cement is visible in this rock.

(4) Sidewall core #19, 3160m, Irwin River Coal Measures

The quartz in this fluvial sand exhibits minor amounts of overgrowth cement and the feldspar and rock fragments show moderate to high amounts of alteration to authigenic illite which precludes any remaining porosity. Compaction has created sutured contacts and pressure solution effects. No carbonate cement was observed in this sample.
Plate 37. Extensive quartz overgrowth (E3) has shattered upon coring. Remaining primary porosity is precluded by authigenic illite (I6) produced from altering feldspar (D12). SWC#14, 395m., 4X magnification, field of view is 2.4mm. wide.

Plate 38. High amounts of authigenic illite have been produced and fills any possible porosity (F2). Moderately quartz overgrowth cemented grains are compressed together (E9) and feldspar alters to illite. SWC#19, 3160m. 4X magnification, field of view is 2.4mm wide.
(5) Sidewall core #26, 3083m, Irwin River Coal Measures

Quartz grains show only minor to moderate amounts of quartz overgrowth cement but sutured grain contacts are common. Authigenic illite is the main interstitial fill with only minor amounts of calcite cement which etches quartz. Compaction has produced bow-tie muscovite and slight pressure solution effects on quartz illite boundaries. There is no visible rock porosity.

(6) Sidewall core #27, 3068m, Irwin River Coal Measures

The thin section of this core shows almost complete illitisation. Recognition of other constituents is made difficult due to the fact that most grains are overgrown with authigenic illite. Any porosity that is observed in the thin section is induced by the coring method. Quartz is subjected to pressure solution etching along compressed contacts with illite. Unlike deeper samples, muscovite in this sample shows alteration and rarely exhibits bow-tie form except when abutting an existing grain.
Plate 39. Overgrowth cemented quartz (H4) is compressed together and muscovite is compressed to bow-tie form (F8). Minor calcite (G9) etches quartz and illite clay (H8) fills the interstices. SWC #26, 3083 m., 10X magnification, field of view is 1 mm. wide.

Plate 40. Authigenic illite consumes most things in this rock. Remnant quartz (E4) is observed along with altering muscovite. SWC #27, 3068 m. 10X magnification, field of view is 1 mm wide.
(7) Sidewall core #30, 3021m, Irwin River Coal Measures

This is a texturally immature rock with a diverse composition. The rock is still predominantly quartz with little overgrowth and much interstitial authigenic illite. Feldspars and rock fragments show only moderate alteration to illite which precludes any porosity. Two stages of carbonate cement have been identified. One is an early stage slightly altered form that nucleates in clumps and the other is a cleaner, late stage cement. Neither stage is extensive or consistent in occurrence. There was no visible porosity.

(8) Sidewall core #32, 3009m, Irwin River Coal Measures

The extensive quartz overgrowth cement in this rock has led to shattering of grains upon coring. Most quartz grains are tightly bound together by comprehensive quartz overgrowth cement. The intergrain volume is filled with authigenic illite and two relatively undefined carbonate stages. This rock was definitely tightly packed before coring as the shattering indicates. Relative timing of diagenetic events is speculative because of the core condition.
Plate 41. Feldspar alters slightly to illite (B14) which is the main interstitial constituent (C7). Early altered carbonate has nucleated in clumps (G3) and later carbonate (H8) appears as cleaner whole crystals. SWC #30, 3021m., 10X magnification, field of view is 1mm. wide.

Plate 42. Overgrowth cemented quartz has fractured due to coring (F12) as authigenic illite (F14) and carbonate cement remain the main interstitial fill. SWC#32, 3009m. 4X magnification, field of view is 2.4mm wide.
(9) Sidewall core #39, 2887m, Irwin River Coal Measures

This rock is a well sorted quartz sand exhibiting minor amounts of quartz overgrowth cement. Grain contacts are straight to sutured and feldspars and rock fragments have undergone slight alteration. The interstitial mud is much different in appearance to the previously observed authigenic illite and despite some sutured grain contacts, does not widely exhibit the pressure solution features when in contact with quartz. This may possibly mean that a lot of this interstitial clay is introduced drilling mud and that original rock porosity is as high as 30%.

(10) Sidewall core #42, 2827m, Carynginia Formation

This well sorted rock has minor amounts of binding quartz overgrowth cement but has compacted to produce sutured contacts. Feldspars and rock fragments have undergone moderate alteration to illite, which along with calcite cement, precludes any visible porosity. Absence of muscovite in bow-tie form indicates that compaction of this rock is not as severe as has been observed in deeper rocks. Relatively crystalline calcite cement is common as a late stage event but is not widespread.
Plate 43. Interstitial brown mud (F7) may be allogenic or perhaps introduced to the rock at the time of drilling. Feldspars (G9) and rock fragments (C3) show little alteration to illite. SWC #39, 2887m., 4X magnification, field of view is 2.4mm. wide.

Plate 44. Quartz overgrowth cement (H7) binds quartz grains together. Authigenic illite is once again produced by altering of rock fragments (F12). Late stage carbonate cement is also seen filling pore space. SWC#42, 2827m. 10X magnification, field of view is 1mm wide.
Quartz overgrowths are sporadic in this rock and often include small carbonate rhombs. Most quartz is surrounded by allogenic and authigenic clays and grain contacts are not common. There is not a notable amount of authigenic clay. Two stages of carbonate cement also occur within the interstices. Small crystals of colourful carbonate are dispersed throughout the rock in the cements and are often included in the quartz overgrowth (Plate 43). The later stage carbonate has a larger and cleaner appearance and is commonly seen in the middle of the pore fill.

This sediment has had significant quartz overgrowth cement, binding most of the framework grains. The overgrowth cement is not overwhelming as the rock is punctuated with areas with extensive diagenetic minerals. Quartz overgrowth cement is seen to include one stage of rhombic carbonate cement and has securely cemented feldspar grains and rock fragments which have later altered. A later stage cleaner carbonate is seen filling the rock and precluding any porosity.
Plate 45. Small carbonate rhombs are included in extensive quartz cement (F11). A high amount of allogenic material is postulated for the interstices of this rock with late stage carbonate cement occupying remaining porosity (F5). SWC #45, 2782.5, 10X magnification, field of view is 1mm wide.

Plate 46. Quartz overgrowth cement has incorporated early carbonate rhombs (H7) and isolated illite producing grains (C12). Late stage carbonate cement precludes any porosity. SWC#47, 2762m. 10X magnification, field of view is 1mm wide.
(13) Sidewall core #48, 2743m, Carynginia Formation

The grains in this rock have been consumed by a dolomitised mud matrix. This extensive carbonate cement has severely etched the quartz present in the rock and the dolomitisation has effected the calcitic fossil fragments also contained in the sediment. No dissolution has occurred and no visual porosity is detected.

(14) Sidewall core #57, 2675m, Beekeeper Limestone

This rock consists of calcitic fossil fragments and various clastic grains bound together by a strong carbonate cement. The clastic grains are severely etched by the recrystallised carbonate cement which fills all available space. This seems to be the extent of all diagenetic reactions in this rock. Feldspars and rock fragments, isolated by the carbonate cement, have not undergone any major alteration.
Plate 47. Severely etched clastic grains (D11) are isolated by comprehensive dolomite cement. Fossil fragments (G3) have undergone dolomitisation. SWC #48, 2743m, 10X magnification, the field of view is 1mm. wide.

Plate 48. Fossil fragments (E7) and clastic grains (E13) have been bound by extensive carbonate cement. SWC#57, 2675m., 10X magnification, field of view is 1mm wide.
5.4 Reservoir characteristics of the Permian Sequence at Mountain Bridge #1

The two sands sampled from the Holmwood Shale were not of reservoir quality. The sample from the top of the intermediate unit had extensive authigenic clay, destroying most porosity. Authigenic illite in this unit was most probably catalysed by the original clay content. Apart from this, there was little quartz overgrowth and carbonate cements were not extensive. The second unit was a well cemented limestone that showed evidence of the same fracturing as observed in the High Cliff Sandstone above. No porosity was created by this and there was no evidence for dissolution of the carbonate or creation of secondary porosity.

The six samples taken from the lower part of the Irwin River Coal Measures are all heavily illitised. Illite formation has been prevalent in the Irwin River Coal Measures due to the chemical immaturity of these sediments and the high original clay content. Throughout this sequence, carbonate cements of varying compositions have been detected, each indicative of its own environment of precipitation. The interpretation of particular carbonate type herein, in relation to diagenesis, is speculative when there is more than one stage identified. In general, iron content increases in carbonate composition with depth of burial (Figure 12, Foscolos, 1990), but fluid chemistry is the controlling factor. This part of the IRCM has pyrite dissemination associated with it, typical of organic-rich reducing conditions.

The sample taken from the top of the IRCM is by far the most promising in terms of reservoir quality but the rock's original clay content is presumed and relatively unknown. It contains only limited
amounts of quartz overgrowth in contrast with sediment just 20 metres below and has no pressure solution features of quartz on illite like those commonly seen throughout the Permian sequence. This may indicate that there is minimal clay present in the original rock. It can generally be assumed that the heat due to depth of burial experienced by this rock is on a regular gradient with the rocks above and below it and therefore has experienced the same relative temperatures. The main control of diagenesis, or lack of diagenesis in this case, is pore water chemistry. Because the original composition of this rock is not completely known, it can only be concluded that the fluid chemistry and relative diagenetic timing for the precipitation of authigenic minerals, did not coincide in this rock, as they did in the other Permian units in this area.

Extensive quartz overgrowth is developed early in the potential reservoir sands of the Carynginia Formation. This may be sourced by surface and shallow meteoric water and feldspar alteration. A range of carbonates is also identified in the Carynginia Formation with local carbonate beds probably exerting the control on composition since not a huge depth of burial is experienced by these sediments. Due to these cementation events, no reservoir type porosities were observed in this unit.

The Beekeeper Limestone was tightly cemented by the recrystallisation of its own carbonate. No secondary porosity via dissolution or fracturing, as is associated with this unit in other fields, is observed at Mountain Bridge.
6 STRUCTURAL ELEMENTS OF THE PERTH BASIN

6.1 Current Theories on the Perth Basin Structure

The Perth Basin is similar to most common rift or graben systems, bounded by normal faults in accordance with conventional shear failure criteria. The north-south trending Darling Fault defines the eastern edge of the basin and the fault direction in the basin, in that most faults dip east towards it. The fault character of the North Perth Basin is now under question by workers in that area.

In plan view, the faults in the North Perth Basin have been interpreted as changing character or habit across two zones deemed "Transfer Zones" (Figure 14) by Hall and Kneale (1992) and by workers of the Darling Fault Work Group. These postulated zones of "transfer" are said to have arisen from a 70 and 130 degree conjugate set of strike-slip faults created in the basement rock by an east-west compression event that produced wrenching on the Darling Fault during the Late Cambrian. According to Hall and Kneale (1992), this conjugate faulting of the Leeuwin Block has created inherent weakness in the thick Perth Basin sedimentary cover at the above mentioned angles. It is proposed that these basement strike-slip faults have displaced a nominal amount in each of the three major basin-forming periods of extension since the early Permian, thus offsetting the normal faults created by the extension events.

The basin structure as a whole, studied extensively by these workers, has been summarised as being classically extensional. It seems obvious from their 1992 paper, that Hall and Kneale have no real
Figure 14. The postulated transfer zones, to explain obvious change in fault character in the Perth Basin. (From Hall and Kneale 1992)
evidence that their postulated "transfer zones" are indeed zones of transfer and in fact have no evidence to define a Cambrian compression event from which the "transfer zones" have arisen. It is more likely that these zones are simply zones of accommodation in which fault character changes, a natural phenomenon that can be observed in all extensional regimes.

6.2 Previous Work in Extensional Regimes

In an attempt to explain the surface and cross-sectional fault patterns in both the Rhine and East African rift systems, DeSitter (1956) suggested a fanciful system of upper and lower tiers in the earth's crust that are unrelated and which were responsible for the fault displacement and surface patterns respectively.

Donath (1962) provided the most likely theory for extensional fault behaviour when explaining a complex dog-leg fault pattern in a basalt flow in south-central Oregon. He explained that the faults were originally formed as a conjugate set of strike-slip faults due to a compressive stress that works before and at right angles to the later direction of maximum extension. Donath proposed the formation of non-rotational conjugate strike-slip shears with virtually no displacement, by a compressive force, and then a greater extensional force, acting perpendicular to the first force, to dip-slip the blocks on the vertical fractures. The problem with Donath's proposal is that it requires two unlikely separate periods of opposite deformational stress that occurred at right angles, although it is suggested that these forces may have "followed closely in a nearly continuous sequence of deformation". It is deliberately pointed out that the faults in this area
are near vertical or have dips at least in excess of 60°, which probably do not continue in the subsurface. Donath's theory is quite plausible for the set of vertical fractures interpreted, but unlikely to be the result of two distinct deformations.

Kay (1942) in an attempt to unravel the structural history of the Ottawa-Bonnechere graben in Ontario, Canada, interpreted the plan-view dog-leg pattern of early Tertiary high angle normal faults as a result of movement on pre-Palaeozoic joints in the underlying rock. This was a satisfactory if undetailed explanation of the faulting in this particular area which can only be applied to areas in which close relationships with the basement rock exists.

In a region of homogeneous extension and rifting, Rosendahl et al (1986) studied the structural expressions in Lake Tanganyika, Africa. In an extensional basin scenario where there is no controlling fault such as the Darling Fault, Rosendahl et al mapped the faults of the Lake Tanganyika rift and observed alternation of half-grabens with particular associated fault character throughout the extent of the rift. These workers suggested that half-grabens were the fundamental rift-unit that link together to form a rift system in such a way as to minimise the work necessary to relieve the extensional stresses. In Lake Tanganyika, it was observed that the linking was accomplished by a sinusoidal alternation half-graben units of opposing direction (Figure 15) and that full-graben forms were seen only within the transitional intervals of the alternating half grabens. The unit linking was interpreted to take place where the controlling fault of one half-graben dies out, and its displacement is taken up by the adjacent opposing controlling fault.
Figure 15. A block diagram showing the alternation of half-grabens observed at Lake Tanganyika, East Africa. (From Rosendahl et al., 1986)

Figure 16. Experimentally produced relay and dog-leg patterns from arching and extension, and active compression at right angles (From Lowell 1987)
In an attempt to explain the consistent appearance of normal fault dog-legs, and what he observed as relay patterns in rifts, Lowell (1987) saw the need for a theory with a single phase of deformation without any pre-existing structure, so that it could be applied uniformly. He also noted that some graben systems resulted from both arching and lateral extension and that relay and dog-leg patterns could be produced experimentally by these movements (Figure 16). These experiments, also conducted by Withjack and Schiener (1982), involved clay supported by a wire mesh base that extended in one direction. This method, however, also applies an active compression perpendicular to the extension. Lowell also cited geological examples where the same patterns were produced through a combination of regional extensional and arching in previously undeformed rocks, but by his own admission acknowledged that it was unlikely that all rift systems had undergone both arching and extension. In his discussion of rifting mechanisms Lowell cited Ramberg et al (1978) as having conducted experiments with only extension which had produced both a dog-leg pattern and a modified relay pattern.

6.3 Clay Modelling Experiments

Experiments conducted in this study and analysis of other work, shows that the postulated "Transfer Zones" of Hall and Kneale (1992), are in fact just zones of accommodation where normal faults terminate or change character, and that they occur as natural phenomenon in purely extensional regimes.
Observations made by Rosendahl et al in the Lake Tanganyika region of the East African Rift, show that the slip direction and character of normal faults alternates naturally across zones of accommodation in a region of homogeneous extension and rifting. This is another clear example of the fact that the termination of normal faults, or at least their position relative to other faults, in a pure extensional regime is partly controlled by the intermediate $\sigma_2$ compressive stress. This is analogous to a wrench regime, where conjugate fault sets are produced by stresses acting at 30 degrees to the principal compressive stress directions (Figure 17). In the case of pure extension, conjugate zones, 60 degrees apart, are produced by the intermediate compressive stress $\sigma_2$, (the maximum compressive stress $\sigma_1$ operating vertically) that operates in the horizontal plane along with the principal tensional stress, but acts at right angles to it (Figure 18). Although random in overall placement, but perhaps basement controlled in certain cases, the distribution of normal faults in this regime is defined by the intermediate stress $\sigma_2$ in that this defines zones of accommodation where normal faults change terminate and begin again, often with opposing character. This changing of character has previously been described by Lowell (1987) as relay or dog-leg pattern.

After analysis of simple extension of clay slabs, conjugate accommodation zones approximately 60° apart can easily be interpreted where faults change character. In most cases, clay was rolled flat onto two overlapping metal trays and held down uniformly across both ends while the trays were pulled apart.

Nine clay experiments were conducted as part of this investigation, and in each case, zones of accommodation where faults changed character
Figure 17, Conjugate sets are produced at 30 degrees to the maximum compressive stress in a wrench assemblage.

Figure 18, In the clay experiment, the area is subjected to extension top and bottom, and the intermediate compressive stress $\sigma_3$ produces conjugate zones at 30 degrees.
can be easily interpreted at approximately 30° to the direction of intermediate compressive stress \( \sigma_2 \) (Plates 49 to 54). Verifying that compression occurs in this direction, the edges of each clay slab have clearly compressed inwards at the zone of deformation when the only force applied was one of extension. This is in contrast to Lowell's (1986) clay models where, due to the deformation technique, the clay was subjected to active compression in this direction. On close inspection, similar conjugate accommodation zones can be observed in these previous clay models produced. Also in support of this theory, the same conjugate zones of accommodation can be observed in the relay fault patterns observed in radar images of a rift on the Planet Venus (Plate 55).

6.4 Application to the Perth Basin

Applying this to the Perth Basin, the correlated "Abrolhos Transfer Zone", identified for its obvious linking of fault terminations, along a trend at 130° (Hall and Kneale) fits this theory well since the Darling Fault detachment heads at approximately 160° in the northern part of the basin. It is unlikely however, that the "Vlaming Transfer Zone" in the south of the basin actually exists, but accommodation zones heading at approximately 020° and 140° can easily be interpreted in the same area.

Zones of accommodation are formed at exactly the same time as the main extensional faults and are part of the basin structure that defines local sediment distribution. They are then inherently related to reservoir extent and trap occurrence. The accommodation zones are passive structures onto which the major faults perpendicular to \( \sigma_3 \), lap
rather than being cut, as if by a transfer fault. Towards the accommodation zones, faults decrease in throw and effectively die out. The displacement is then picked up by another fault in a position offset to the first (Figure 19). This creates a series of ramps that wrap around the two faults, creating a predictable migration pathway. The accommodation zone should contain ramped structures with closure that may not necessarily be breached by late faulting.

Figure 19. A block diagram illustrating the ramp structure produced by the termination of normal faults in an extensional regime. (From Walsh 1993)
Plate 49, Clay model #1
Both the photo and the interpretation are illuminated from the top
Actual size as shown

Key to interpretation

- shaded fault faces dipping in direction of illumination
- fault faces illuminated dipping towards illumination

Author's interpretation of accommodation zones is shown in red.
Plate 50. Clay model #2.
Plate 51. Clay model #3.
Plate 52. Clay model #4.
Plate 53. Clay model #5.
Plate 55. A satellite imaged rift on the surface of Venus (Newcott 1993)
7 CONCLUSIONS

The Holmwood Shale was deposited in a marine depositional environment and exhibits characteristic coarsening upwards character (Enclosure 1). The High Cliff Sandstone is the shoreline transition sand unit at the top of the regressive Holmwood Shale, which grades into the fining up fluvio-deltaic sediments of the Irwin River Coal Measures. The return to marine conditions can be seen at the top of the Irwin River Coal Measures where the coarsening upwards log signature continues into the Carynginia Formation. A period of non-deposition or erosion separates the Carynginia Formation from the above lying Beekeeper Limestone and the Wagina Sandstone.

All of the Permian formations contain potential reservoir sands at either the top of coarsening upwards units or at the bottom of fining upwards units. All of these units are distinctly repetitious in thickness throughout the Permian sequence at Mountain Bridge #1. The thickness of all of the Permian units decreases at Robb #1 on the Beagle Ridge (Enclosure 1).

The Holmwood Shale is not a renowned source rock but it is quite possible that it may charge local sandstones with gas although no reservoir quality sandstones were observed within this formation.

The gas prone organic matter in the Irwin River Coal Measures is quite likely to source the hydrocarbons in the High Cliff Sandstone as well as the sandstones within the Irwin River Coal Measures itself. Moderate hydrocarbon shows were observed from both of these units at Mountain.
Bridge #1, but no reservoir quality sandstones were found in the rocks from shoreline transition and fluvio-deltaic depositional environments.

A thin reservoir quality sandstone was observed at the top of the Irwin River Coal Measures in the gradation back to marine conditions. This may possibly be charged with either oil or gas from both the lower Irwin River Coal Measures or the above Carynginia Formation. The Carynginia Formation has an adequate humic and sapropelic content that may source reservoir quality sandstones at shallower depths.

Neither the Beekeeper Limestone or the Wagina Sandstone are very thick or have reservoir quality at Mountain Bridge #1, despite both indicating trace oil fluorescence and moderate to strong gas shows. These reservoirs are most likely sourced from the above Kockatea Shale, considered to be the major oil-source rock in the basin (Hall 1989). Both the Beekeeper Limestone and the Wagina Sandstone are main reservoirs elsewhere in the basin and are commonly associated with secondary fracture porosity in the Woodada region.

The rocks in the Mountain Bridge area are situated on the edge of the main depocentre in the Perth Basin (Figures 13 and 14). These rocks have been subjected to injection of dewatering fluids flushing out of the basin centre. The fluids have been saturated with freshly dissolved minerals from the deeper dewatering zone. This has cemented the Permian sequence with quartz and illite cement and has provided the chemical potential for other reactions involving in situ components to produce siderite and dolomite.
Characteristic siderite cement is observed in the fluvio-deltaic rocks and sporadically in the other Permian units. Early diagenesis is dominated by quartz overgrowth cement throughout the Permian sequence (Plates 1 and 2). This has originated from dewatering of these sediments and silica saturated fluids flushing from the basin. Feldspar alteration to illite was commonly observed with authigenic illite being produced at various stages of rock burial. Illite abundance in the Irwin River Coal Measures is analogous to authigenic illite observed in the younger Cattamara Coal Measures at approximately the same depth of burial (Tarabbia 1991).

Late stage diagenesis cementation has occurred throughout the Mountain Bridge Permian sequence, with relation to the depth of burial and content of the individual sediments. Dolomite cement is extensive in the lower parts of the Permian sequence and is attributed to recrystallisation of in situ carbonate in the presence of free Mg$^{2+}$ and Fe$^{2+}$ ions from clay alteration reactions and dewatering fluids (Plate 5). Other late stage diagenesis events, including the production of chlorite from biotite and glauconite, are seen sporadically through the Permian sequence (Plate 8).

As well as late stage diagenesis, the interval between 3257 and 3222 metres has undergone up to three stages of fracturing as a result of post-diagenetic structural deformation. Despite initially opening considerable secondary porosity, all three stages of fracturing have undergone associated quartz or barite cementation (Plates 9, 10 and 36). This fracturing probably occurred in the Early Neocomian as part of the uplift of the Beagle Ridge.
It is well accepted that fault character in the Perth Basin has a regular pattern to it. It is logical that fault accommodation zones are produced by the intermediate lateral compressive stress $\sigma_2$ in rift settings as a result of extension. In the case of the Perth Basin, accommodation zones have been developed at exactly the same time as the major faults in the basin and have effected sediment distribution, thus controlling reservoir occurrence and extent.

Accommodation zones are passive structures that occur naturally. Faults will decrease in displacement towards the zone and ramp structures with closure will be produced.
8 RECOMMENDATIONS

Since the Mountain Bridge #1 well is one of the first wells to have concentrated on the prospectivity of the Permian sequence, it is easy to suggest that further study be conducted. Permian sandstones have been substantially cemented in this area mainly as a product of depth of burial. In light of this, it is recommended that exploration for Permian sandstones should take place in areas where they are shallower and perhaps not as much cementation has occurred. Areas to the north, like the Dongara Saddle, are preferred because of their higher geothermal gradient and likelihood of hydrocarbon occurrence before cementation of reservoirs.

Permian reservoirs at over 2500m depth will mainly have fracture porosity like the Beekeeper Limestone at Woodada (Hall 1989). The fracturing of the High Cliff Sandstone, whilst highly cemented, significantly increased the flow rate from the rock in the Mountain Bridge #1 well. This is obviously something that is localised but its occurrence should be defined, along with fault character throughout the basin and considered when assessing future plays. Zones of accommodation where fault character changes, define sedimentation and thus stratigraphic as well as structural hydrocarbon traps.

Due to the ramping associated with fault termination, accommodation zones are likely to be areas of pronounced hydrocarbon entrapment. The zones of accommodation in the Perth Basin, once thought to be associated with intense fracturing (Hall and Kneale 1992), may in fact contain unfractured significant hydrocarbon traps. It is recommended that the nature of accommodation zones be researched further and that
the structure within these zones in the Perth Basin contemplated in future exploration.
APPENDIX 1A

Mountain Bridge #1

Core #1 Log Description
### Core Log - Mountain Bridge #1, Core #1

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Clay</th>
<th>Silt</th>
<th>Sand</th>
<th>Gravel</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>3211</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pale off white, coarse, upward cleaning, sub-rounded sandstone. Strong white siderite cement and illitic matrix. Mud filled stylolites. Pyrite dissemination, 1cm diammeter. Lag lithics at base. Lag lithic bed. Anastomosing shale partings (1-2mm thick). Dark shale laminations intertwining. Disseminated pyrite, shale laminations. Grey to off-white, coarse quartz and altered feldspar sand. Sub-horizontal (5 degree dip) bedding providing parting surface. Mud rip up clasts with gravel base. Thick (5cm) band of thin shale laminations. Increased sorting at this level. Poorly sorted lithic gravelly base. Fine to medium grained dirty sand. Swaley shale laminations.</td>
</tr>
<tr>
<td>3212</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>30 degree tilting to ripple defined shale laminations. Large (40-50cm long) subvertical clay filled fracture showing 5mm displacement. Bedding crossing back to tilt the other way. Coarse lithic and mud clast base layer. Thick (2cm) fine black shale tilting 2 degrees. Bedding alternating dip with current direction.</td>
</tr>
<tr>
<td>3213</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Black clay filled sub-vertical burrow. Thin (2mm) bands of coarse grains. Shale layers, 10mm apart, providing parting surface with slight dip. Ripple laminations. Trough cross bedding.</td>
</tr>
<tr>
<td>3214</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sub-horizontal (5 degrees) black shale band at the top of a swaley, medium grained cross bedded sandstone. Slight structurally imposed tilt on shale ripples. Off-white to grey, medium to coarse grained, fining upwards fluvial sand with high altered feldspar content and trace mica. Trough cross bedding defining zone of intense shale lamination.</td>
</tr>
<tr>
<td>3215</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Coarse base of point bar sequence.</td>
</tr>
</tbody>
</table>
### Core Log - Mountain Bridge #1, Core #1

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Clay</th>
<th>Silt</th>
<th>Sand</th>
<th>Gravel</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>3215</td>
<td></td>
<td></td>
<td>vfn</td>
<td>fine, med, crs, vcs</td>
<td>S1: Rippled sub-horizontal shale laminations up to 30mm thick, increase in frequency at the top of this moderate to well sorted quartz and feldspar sand.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sh: Rarely horizontally bedded massive well sorted sand.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sm: Sub-horizontal quartz cemented fracture.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Stylolite defined fracture, cemented by quartz cement.</td>
</tr>
<tr>
<td>3216</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sb: Extended lozenge shaped black clay filled horizontal burrows.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sr: Ripple laminated sand.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Coarse gravel lag base to predominantly massive sand.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>S1: Slight (10 degree) dip on shale laminations.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Small (10mm) black shale filled burrow.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Dark grey to black hard brittle micaceous shale with sharp upper contact.</td>
</tr>
<tr>
<td>3217</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fb: Rare small (5mm) sub-vertical burrows.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Abundant lighter coloured rip up clasts are spread throughout with surrounding swaley shale lamination.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Rip up clasts go through transformation from ellipsoid.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>F: to spherical shaped.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>and back to ellipsoid shaped.</td>
</tr>
<tr>
<td>3218</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fl: Fine sub-horizontal shale ripple laminations.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Gradual increase in floating quartz grains.</td>
</tr>
<tr>
<td>3219</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>S: Ripped up and reworked sand clasts.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Short and small burrow casts infilled with clay.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Clay lined fractures, not extensive.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Coarse quartz grain and lithics base.</td>
</tr>
<tr>
<td>Depth (m)</td>
<td>Clay</td>
<td>Silt</td>
<td>Sand</td>
<td>Gravel</td>
<td>Comments</td>
</tr>
<tr>
<td>----------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>--------</td>
<td>----------</td>
</tr>
<tr>
<td>3219</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3220</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3221</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3222</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3223</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Gravel**
  - **Sb**: Frequency of burrows and bioturbation varies with depth. This light grey, medium grained, well sorted sand becomes cleaner and coarser with depth. It contains sub-rounded spherical quartz grains with common overgrowths and argillaceous matrix bound by dolomite cement.
  - **SI**: Long (50mm) sub-vertical black clay defined burrows. Small (5mm) shale bands.
  - **SB**: A long (50cm) vertical fracture is filled by quartz cement.
  - **SM**: A long (50mm) and thin (2mm) rootlet cast is infilled with coarse quartz grains. Shale laminations decrease in frequency upwards.

- **Comments**
  - Mostly massive, well sorted, sub-rounded sand secured largely by quartz overgrowth and little dolomite cement.
  - Clasts of clay are more evidence of bioturbation.
  - A black clay filled stylolite provides parting for breaking of the core.
  - A shale lamination band defines a fracture across the core.

- **Sm**: Mostly massive light grey well sorted medium grained quartz sand with large amounts of quartz overgrowths. A quartz lined sub-vertical fracture is exposed on the edge of the core as the other side of the fracture has been chipped off.

- **Sb**: A sub-horizontal fracture causes core parting.

- **Sb**: Slightly bioturbated section with sub-vertical burrows.

- **Sb**: Fine swaley clay laminated bands provided fracture route.

- **Sb**: Highly bioturbated interval.

- **Sm**: Mostly massive well sorted quartz sand with quartz cemented fracture open at the bottom for euhedral quartz crystals.

- **Sm**: Massive medium grained, well sorted, sub-rounded, spherical quartz sand. The rock exhibits classic quartz overgrowths and is sometimes cemented with ferroan dolomite cement. Bedding is sometimes defined by small clay layers with trace heavy minerals and these often provide routes for fracturing.

- **Sm**: In this section of the core, there are two large fracture sets intersecting at right angles that cover the core and are infilled with silica cement. One set is sub-horizontal and is completely cemented and the sub-vertical set is predominantly cemented closed but is open at small voids which exhibit euhedral quartz crystals.

- **Sb**: There are two successive layers of increased bioturbation at the bottom of this metre of core that are separated by largely massive sandstone.

- **Pyrite dissemination**
<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Clay</th>
<th>Silt</th>
<th>Sand (vfin, fine, med, crs, vcs)</th>
<th>Gravel</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>3223</td>
<td></td>
<td></td>
<td></td>
<td>Sh</td>
<td>Layers with increased clay matrix content are associated with bioturbation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sb</td>
<td>A large sub-vertical fracture is filled with silica cement and is virtually the only feature in a massive to horizontally bedded sandstone occasionally punctuated by small clay layers</td>
</tr>
<tr>
<td>3224</td>
<td></td>
<td></td>
<td></td>
<td>Sm</td>
<td>Large (20mm) bioturbation burrow</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sb</td>
<td>Small upward widening coarse grain pocket defines a dewatering structure</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sb</td>
<td>Sub-vertical burrows</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sm</td>
<td>Sub-horizontal and sub-vertical quartz cemented fractures</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Strong brecciation causing slightly interconnected vugs lined with large euhedral quartz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A curve-linear sub-vertical quartz cemented fracture extends 40mm through a moderately bioturbated sand</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ferruginous cement appears in the matrix as dark dull red specs</td>
</tr>
<tr>
<td>3225</td>
<td></td>
<td></td>
<td></td>
<td>Sh</td>
<td>Clay filled burrows are the dominant mode of bioturbation in this sand zone which includes thin dark clay layer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sb</td>
<td>Large (7mm) scale burrow with associated clay infill and dewatering structures</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sb</td>
<td>Relatively large (10mm) disseminated pyrite</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sb</td>
<td>Concentrated finer silt layer</td>
</tr>
<tr>
<td>3226</td>
<td></td>
<td></td>
<td></td>
<td>Sl</td>
<td>Silt layers provide line of weakness for fracturing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sb</td>
<td>A thick (3mm) silt layer tops an interval with long (10mm) sub-vertical clay and sand filled burrows</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sb</td>
<td>A long (5mm) sub-vertical clay lined burrow defines the base of a zone of marked bioturbation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sb</td>
<td>Relatively mild zone of bioturbation is once again topped by a dark silt layer</td>
</tr>
<tr>
<td>3227</td>
<td></td>
<td></td>
<td></td>
<td>Sl</td>
<td>This massive but slightly shale laminated well sorted, sub-rounded predominantly quartz sand is punctuated by zones of intense and not so intense burrowing and other bioturbation</td>
</tr>
</tbody>
</table>
### Core Log - Mountain Bridge #1, Core #1

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>clay</th>
<th>silt</th>
<th>sand</th>
<th>gravel</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>3227</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3228</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Sb** A sub-vertical tightly quartz cemented fracture runs 50mm down through the core

**Sb** Extensive burrowing and bioturbation

Sub-horizontal clay layer with 10 degree tilt

The wear on this end of the core has degraded it to rubble. The rock is still dirty heavily bioturbated sand

---

**LEGEND**

- **G** = Gravel
- **S** = Sand
- **F** = Mud
- **h** = horizontal bedding
- **t** = trough cross bedding
- **m** = massive
- **l** = lamination
- **b** = bioturbation
- **r** = ripple cross lamination
- **Stylolites**
- **Shale lamination** (unless otherwise stated as fracture)
- **Burrows, other bioturbation and mud rip up clasts**
- **Cemented and open fracture** (noted in comments)
- **Pyrite dissemination**
- **Brecciation**
- **Reworked sand clasts and lag gravel**
APPENDIX 1B

Mountain Bridge #1

Core Thin Section Descriptions
Thin section Description

Mountain Bridge #1  core #1

**sample depth**: 3211.6m  
**max. grain size**: 4.2mm  
**min. grain size**: 0.3mm  
**ave. grain size**: \( \approx 1.5 \text{mm} \)  

**Rock**: feldsarenite  
**Sorting**: poorly sorted  
**Roundness**: angular→sub-angular  
**Sphericity**: medium

**Composition**:

<table>
<thead>
<tr>
<th>Framework</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>35.7</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>17.6</td>
</tr>
<tr>
<td>Microcline</td>
<td>.6</td>
</tr>
<tr>
<td>Muscovite</td>
<td>3.4</td>
</tr>
</tbody>
</table>

**Matrix**:  
Organics/Mud  1.4

**Cement**:

<table>
<thead>
<tr>
<th>Cement</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz overgrowth</td>
<td>19.3</td>
</tr>
<tr>
<td>Illite</td>
<td>10.6</td>
</tr>
<tr>
<td>Siderite</td>
<td>1.0</td>
</tr>
<tr>
<td>Calcite</td>
<td>7.0</td>
</tr>
<tr>
<td>Dolomite</td>
<td>2.0</td>
</tr>
</tbody>
</table>

**Porosity**:

- Secondary (Dissolution,Fracture)  1.4  
  (Measured porosity (includes micro-porosity) = 6.5)

**Measured Permeability**: 0.065 Darcies

**Comments**:
This rock is both texturally and minerallogically immature. The rock is predominantly of quartz and plagioclase content of igneous or metamorphic origin with a high amount of pore-filling authigenic illite. The high feldspar content indicates a short distance of sediment transport and indicative of a lagoonal or fluvial environment. The slide also features layers of high organic matter and mud composition as an indicator of the same environment. The feldspars have undergone alteration along cleavage to produce the pore-filling illite. Quartz overgrowth cement can often be seen infilling the space once occupied by the feldspar and in so doing engulfing the illite produced. Quartz cement thus postdating some of the feldspar alteration, also replaced by calcite. Late stage dolomite cement can also be seen replacing feldspar alteration secondary porosity and other porosity left. Dissolution of quartz cement and grains has occurred due to...
compaction when in contact with illite, giving some of the quartz a rough sutured finish. Compaction has also spurred the alteration of feldspars. The identification of calcite is made hard by the fact that it appears to be a lot like the dolomite cement. Since no calcite has been identified in the High Cliff section of the core, the timing of this stage is not so relevant here.

**Diagenetic events:**
- Emplacement of siderite cement
- Ongoing alteration of feldspars to illite
- Quartz overgrowth cement
- Emplacement of dolomite cement
- Replacement of feldspar with calcite
- Compaction→further dissolution of feldspar and quartz
Thin section Description

Mountain Bridge #1 core #1

**sample depth**: 3216.2m  **rock**: feldsarenite  
**max. grain size**: 2.0mm  **sorting**: very poorly sorted  
**min. grain size**: 0.1mm  **roundness**: sub-rounded→sub-angular  
**ave. grain size**: ≈0.5mm  **sphericity**: medium

**Composition**:

<table>
<thead>
<tr>
<th>Component</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Framework</strong></td>
<td></td>
</tr>
<tr>
<td>Quartz</td>
<td>42</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>8.9</td>
</tr>
<tr>
<td>Muscovite</td>
<td>0.5</td>
</tr>
<tr>
<td>Rock Fragments</td>
<td>0.7</td>
</tr>
<tr>
<td><strong>Matrix</strong></td>
<td></td>
</tr>
<tr>
<td>Organics/Mud</td>
<td>0.6</td>
</tr>
<tr>
<td><strong>Cement</strong></td>
<td></td>
</tr>
<tr>
<td>Quartz overgrowth</td>
<td>22.8</td>
</tr>
<tr>
<td>Illite</td>
<td>14.5</td>
</tr>
<tr>
<td>Siderite</td>
<td>0.5</td>
</tr>
<tr>
<td>Calcite</td>
<td>6.3</td>
</tr>
<tr>
<td>Dolomite</td>
<td>3.0</td>
</tr>
</tbody>
</table>

**Porosity**:

<table>
<thead>
<tr>
<th>Description</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary (dissolution)</td>
<td>0.2</td>
</tr>
</tbody>
</table>

(Measured porosity (includes micro-porosity) = 4.0)

**Measured Permeability**: 0.02 Darcies

**Comments**:

This rock is texturally and mineralogically immature. Of relatively high illite content, this rock also has high amounts of poorly sorted quartz of igneous and metamorphic origin. Quartz grain contacts are predominantly of a straight nature but also concavo-convex and sutured. Limited amounts of quartz cement once again includes illite, thereby defining the original quartz grains. Quartz grains and cement also display pressure solution features when in contact with illite producing a sutured appearance. Classic bow-tie muscovite can be observed in this slide indicating compaction after the dolomite cement stage, compaction which enhanced quartz and feldspar alteration. Calcite is observed replacing feldspar dissolution porosity only and thus must post date dolomite cement introduction.
Diagenetic events:
emplacement of siderite
alteration of feldspars to illite coincident with
quartz overgrowth cement securing feldspar grains
introduction of dolomite cement
calcite replacement of feldspar dissolution
compaction enhancing quartz dissolution and feldspar alteration to illite

Mountain Bridge #1, 3216.2m
**Thin section Description**

**Mountain Bridge #1  core #1**

- **sample depth**: 3218.95m
- **max. grain size**: 2.0mm
- **min. grain size**: 0.1mm
- **ave. grain size**: =0.5mm

**rock**: quartz arenite  
**sorting**: moderate to well sorted  
**roundness**: sub-rounded→sub-angular  
**sphericity**: medium

**Composition**:

<table>
<thead>
<tr>
<th>Framework</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>55</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>0.1</td>
</tr>
<tr>
<td>Muscovite</td>
<td>0.5</td>
</tr>
<tr>
<td>Rock Fragments</td>
<td>0.3</td>
</tr>
</tbody>
</table>

**Matrix**:  
Organics/Mud 0.8

**Cement**:

<table>
<thead>
<tr>
<th>Cement</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz overgrowth</td>
<td>23.9</td>
</tr>
<tr>
<td>Illite</td>
<td>8.5</td>
</tr>
<tr>
<td>Siderite</td>
<td>5.7</td>
</tr>
<tr>
<td>Dolomite</td>
<td>1.8</td>
</tr>
<tr>
<td>Barite</td>
<td>1.7</td>
</tr>
</tbody>
</table>

**Porosity**:

- Primary/Secondary 1.7

(Measured porosity (includes micro-porosity) = 4.7)

**Measured Permeability**: 0.096 Darcies

**Comments**:  
This is a typical shoreline-transition rock being texturally and mineralogically mature. The quartz grains show predominantly undulose nature and are thus from a metamorphic origin. The lack of feldspar and apparent amount of sediment working confirms the shoreline depositional environment. The rock consists of well sorted cemented quartz grains punctuated with occasional large quartz grains of approximately 2mm diameter. Grain contacts range from straight to dominantly sutured and effected by pressure solution due to the lack of supporting matrix. Quartz cement precludes most porosity but where there is illite and organic matter, some porosity still exists. Illite is once again seen included in quartz overgrowths. Barite is seen as the last stage cement with limited distribution between framework grains. In one instance, a clump of siderite has been observed as being fractured and then cemented by late stage barite.
Diagenetic events:
siderite cement
authigenic illite
quartz overgrowth cement
dolomite cement
compaction and grain suturing
fracturing and barite cementing

Mountain Bridge #1, 3218.95m

<table>
<thead>
<tr>
<th>Total Counts</th>
<th>Degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>1500</td>
<td>0</td>
</tr>
<tr>
<td>1000</td>
<td>5</td>
</tr>
<tr>
<td>500</td>
<td>10</td>
</tr>
<tr>
<td>0</td>
<td>15</td>
</tr>
</tbody>
</table>

Thermal analysis graph showing peaks at various degrees for different minerals.
Thin section Description

**Mountain Bridge #1 core #1**

- **Sample depth**: 3219.4m
- **Max. grain size**: 0.4mm
- **Min. grain size**: 0.1mm
- **Ave. grain size**: ≈0.2mm

**Rock**: quartz arenite  
**Sorting**: well sorted  
**Roundness**: sub-rounded→sub-angular  
**Sphericity**: medium

**Composition**:

<table>
<thead>
<tr>
<th>Framework</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>54</td>
</tr>
<tr>
<td>Muscovite</td>
<td>0.2</td>
</tr>
<tr>
<td>Rock Fragments</td>
<td>1.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Matrix:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organics/Mud</td>
</tr>
</tbody>
</table>

**Cement**:

- Quartz overgrowth: 29
- Illite: 5.3
- Siderite: 3.0
- Dolomite: 3.6
- Barite: 2.2

**Porosity**:

- Primary/Secondary(fracture): 1.0  
  (Measured porosity (includes micro-porosity) = 4.9)

**Measured Permeability**: 0.006 Darcies

**Comments**:

This predominantly quartz rock is texturally and mineralogically very mature. The heavily cemented grains are mainly involved in sutured contacts with some concavo-convex contacts observed. The quartz is of igneous or metamorphic origin and the working of this sediment indicates a shoreline environment of deposition. Any feldspars present have been totally altered to illite and the dissolution porosity has been filled in by quartz cement, including the authigenic illite which defines where the original grain existed. Quartz cement is often seen coming together to form characteristic tri-points. Pressure solution features on quartz cement boundaries indicating that compression occurred after silica cement placement. Illite also is often seen compressed between quartz cements confirming that illite input is ongoing and dolomite cement is after most of the illite. There is a wide (~2mm) fracture that cuts across the slide and includes broken quartz fragments healed by barite cement.
Diagenetic events:
siderite cement
authigenic illite produced
quartz overgrowth cement
dolomite emplacement
compaction causing grain suturing and pressure solution
fracturing and subsequent barite cementing
Thin section Description

Mountain Bridge #1  core #1

sample depth: 3220.35m  rock: quartz arenite
max. grain size: 0.8mm  sorting: well sorted
min. grain size: 0.08mm  roundness: sub-rounded→sub-angular
ave. grain size: ≈0.3mm  sphericity: medium to high

Composition:

Framework:
Quartz 44
Muscovite 0.6
Rock Fragments 0.8

Matrix:
Organics/Mud 2.0

Cement:
Quartz overgrowth 30.7
Illite 12.2
Siderite 3.5
Dolomite 4.0

Porosity:
Primary/Secondary(dissolution) 2.2
(Measured porosity (includes micro-porosity) = 7.0)

Measured Permeability: 0.007 Darcies

Comments:
This rock is again texturally and mineralogically mature being well sorted with occasional larger grains and predominantly well cemented quartz. The quartz is once again monocrystalline igneous in origin and from a well worked shoreline-shallow marine depositional environment. The grain contacts range from being concavo-convex to sutured and quartz overgrowths include pink fluid inclusions that were thought to be hydrocarbons but reflected ultra-violet light investigation showed otherwise. Early siderite cement is also sometimes included in the quartz overgrowth and later large rhombs of dolomite cement make up late stage porosity fill. Quartz cement is again observed as being sutured in appearance when in contact with illite as a result of dissolution due to compaction. The late stage dolomite cement is observed etching the quartz cement, this action being enhanced by compaction.

Diagenetic events:
siderite cement
authigenic illite introduced progressively
quartz overgrowth cement
dolomite cement
compaction producing suturing and enhancing etching of quartz

Mountain Bridge #1, 3220.35m
Thin section Description

**Mountain Bridge #1 core #1**

*sample depth*: 3222.28m  
*rock*: quartz arenite  
*max. grain size*: 0.8mm  
*sorting*: well sorted  
*min. grain size*: 0.08mm  
*roundness*: sub-rounded→sub-angular  
*ave. grain size*: ≈0.3mm  
*sphericity*: medium

**Composition**

<table>
<thead>
<tr>
<th>Framework</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>58.3</td>
</tr>
<tr>
<td>Muscovite</td>
<td>0.4</td>
</tr>
<tr>
<td>Glauconite</td>
<td>1.7</td>
</tr>
<tr>
<td>Rock Fragments</td>
<td>1.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Matrix</th>
<th>1.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organics/Mud</td>
<td></td>
</tr>
</tbody>
</table>

**Cement**

<table>
<thead>
<tr>
<th>Cement Type</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz overgrowth</td>
<td>22.3</td>
</tr>
<tr>
<td>Illite</td>
<td>11.2</td>
</tr>
<tr>
<td>Siderite</td>
<td>2.2</td>
</tr>
<tr>
<td>Dolomite</td>
<td>6.8</td>
</tr>
<tr>
<td>Pyrite</td>
<td>2.1</td>
</tr>
</tbody>
</table>

**Porosity**

*Primary/Secondary(dissolution)*  
2.8  
(Measured porosity (includes micro-porosity) = 6.6)

**Measured Permeability**: 0.008 Darcies

**Comments**

This rock is texturally and mineralogically very mature and is predominantly well cemented, well sorted quartz shoreline-marine rock. Concavo-convex and sutured contacts are dominant between the monocrystalline quartz grains. Authigenic illite once again is emplaced in the rock as an ongoing event. To confirm this, illite is included in some of the quartz cement and also after the quartz overgrowths infilling porosity. There is a small number of glauconite pellets that have had illite, quartz and dolomite cement grown around them and then have shrunk before or due to compaction creating small amounts of porosity. This slide also includes two fracture sets 130° apart which have broken the existing rock and have seen the introduction and dissemination of pyrite along them. This pyrite is most likely from deeper shales and has been mobilised in acidic reducing fluid.
Diagenetic events:
siderite cement
authigenic illite introduced progressively
quartz overgrowth cement
dolomite cement
fracturing and dissemination of pyrite

Mountain Bridge #1, 3222.28m
Thin section Description

Mountain Bridge #1  core #1

sample depth : 3223.3m  rock : quartz arenite
max. grain size : 0.5mm  sorting : very well sorted
min. grain size : 0.1mm  roundness : sub-rounded→sub-angular
ave. grain size : ≈0.3mm  sphericity : medium to high

Composition :

Framework :
  Quartz             47.6
  Muscovite          0.6
  Glauconite         1.7
  Rock Fragments    0.5

Matrix:
  Organics/Mud   1.3

Cement :
  Quartz overgrowth 29.6
  Illite            6.4
  Siderite          1.3
  Dolomite         5.9
  Barite           2.3

Porosity :
  Primary/Secondary(shrinkage/intercrystalline) 2.8
(Measured porosity (includes micro-porosity) = 7.7)

Measured Permeability : 0.018 Darcies

Comments :
This is a texturally and mineralogically mature very well sorted quartz dominant sand. Limited amounts of siderite cement is observed as the first stage of cementing. Extensive quartz cement has bound the framework grains and later compression has produced concavo-convex and sutured contacts. Pressure solution features once again in suturing the appearance of the quartz cement. The gradual build up of authigenic illite is detected both in the quartz overgrowth and between quartz cements. A small number of glauconite pellets are also included in the sediment, confirming marine depositional environment, and later shrunk and squashed to odd shapes due to compaction. This has created a minute amount of secondary shrinkage porosity. Late stage fracturing events have also been detected. In one fracture, quartz fragments have been re-healed by barite cement which has in turn
been refractured and healed together by quartz cement producing an effect appearing like barite bubbling out of quartz cement.

**Diagenetic events:**
siderite cement
first stage quartz overgrowth
authigenic illite introduced progressively
quartz overgrowth cement
rhombic dolomite cement in porosity
compaction and subsequent shrinkage of glauconite
fracturing and barite cementation
re-fracturing and re-healing of barite by quartz cement

[Diagram showing X-ray diffraction analysis of minerals]
Thin section Description

Mountain Bridge #1  core #1

sample depth : 3223.8m  rock : quartz arenite
max. grain size : 0.7mm  sorting : average to well sorted
min. grain size : 0.1mm  roundness : sub-rounded→sub-angular
ave. grain size : ≈0.3mm  sphericity : medium

Composition :

Framework :
Quartz  49.2
Muscovite  0.1
Glaucnite  0.0
Rock Fragments  1.0

Matrix:
Organics/Mud  0.6

Cement :
Quartz overgrowth  18.3
Illite  8.2
Siderite  3.3
Dolomite  14.4
Barite  1.1

Porosity :
Primary/Secondary(fracture)  3.8
(Measured porosity (includes micro-porosity) = 5.9)

Measured Permeability : 0.019 Darcies

Comments :
This is once again a texturally and mineralogically mature well sorted quartz sand. From the outset, there is obviously more late stage dolomite cement and less quartz overgrowth cement, which is confirmed by XRD analysis. Siderite is the first stage of cementing, sometimes being included in the rock as grain like clumps. More illite is detected as feldspar was once included in the sediment but has now been completely altered to illite. Grain on grain contacts are still concavo-convex and sutured and pressure solution is evident. Much etching of quartz by dolomite has occurred, probably enhanced by later compaction. Some plucking of grains has occurred in preparation of this slide, where quartz grains are not extensively cemented in. Late stage fracturing sees the original framework and later carbonate cement both broken up together and then later rehealed by quartz cement where there has been enough room created by fracturing. This
last stage quartz is sometimes megacrystic in habit when partially infilling voids.

**Diagenetic events:**
siderite cement
quartz overgrowth cement
authigenic illite introduced progressively
extensive rhombic dolomite cement in porosity
compaction and enhanced etching of quartz by carbonates
fracturing and cementation by quartz cement

---

**Mountain Bridge #1, 3223.8m**

<table>
<thead>
<tr>
<th>Total Counts</th>
<th>Degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>1500</td>
<td>5</td>
</tr>
<tr>
<td>1000</td>
<td>10</td>
</tr>
<tr>
<td>500</td>
<td>15</td>
</tr>
<tr>
<td>0</td>
<td>20</td>
</tr>
</tbody>
</table>

---

Iliite, Iliite/Muscovite, Dolomite, Siderite, Dolomite
Thin section Description

Mountain Bridge #1 core #1

sample depth: 3224.3m  rock: quartz arenite
max. grain size: 2.0mm  sorting: moderately well sorted
min. grain size: 0.08mm  roundness: sub-rounded→sub-angular
ave. grain size: ≈0.2mm  sphericity: medium to high

Composition:

**Framework:**
- Quartz: 38%
- Muscovite: 1.2%
- Glauconite: 0.2%
- Rock Fragments: 0.4%

**Matrix:**
- Organics/Mud: 0.8%

**Cement:**
- Quartz overgrowth: 23.3%
- Illite: 7.5%
- Siderite: 1.3%
- Dolomite: 22.4%
- Barite: 0.6%

**Porosity:**
- Primary/Secondary(fracture): 4.3%

(Measured porosity (includes micro-porosity) = 4.7)

**Measured Permeability:** 0.012 Darcies

Comments:
This rock is texturally and mineralogically mature high quartz and dolomite cement content. This slide juxtaposes 2 different types of rocks: an extensive dolomite cemented rock with little quartz overgrowths (55% of slide) and a well sorted mainly quartz overgrowth rock (50% of slide). These rocks are separated by a displacing fault but have the same paragenesis. The fault zone is thin (0.2mm wide) compared with previously observed fractures and is filled with fine shattered quartz and carbonate which is in some places rehealed by quartz.

Quartz rich rock-
This features concavo-convex to sutured grain contacts and dolomite from this rock appears to have undergone some amount of dissolution due to the fracturing stress.
Dolomite rich rock-
All quartz in this rock has been extensively etched with little quartz overgrowth cement but sutured contacts exist. The paragenesis of these rocks is much the same but this rock has less quartz overgrowth cement and more dolomite cement developed.

Three stages of fracturing also can be clearly seen post-dating all of the afore-mentioned diagenetic events. The first stage of fracturing shattering the existing rock and re-healing with quartz cement. The second stage refracturing this and emplacing barite cement. And the last stage fracturing the barite cement and opening porosity into which megacrystic quartz has been formed.

**Diagenetic events:**
siderite cement
authigenic illite introduced continually
quartz overgrowth cement
extensive dolomite cement in porosity
compaction and enhanced etching of quartz by dolomite
small fracturing and healing by quartz cement
re-fracturing and cementation by barite
third fracturing opening porosity and extensive quartz cementing

![Mountain Bridge #1, 3224.3m](image)
Thin section Description

Mountain Bridge #1  core #1

**sample depth**: 3227.6m  
**max. grain size**: 1.0mm  
**min. grain size**: 0.1mm  
**ave. grain size**: ≈0.3mm  
**rock**: quartz arenite  
**sorting**: well sorted  
**roundness**: sub-rounded → sub-angular  
**sphericity**: medium to high

**Composition**:

<table>
<thead>
<tr>
<th>Framework</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>43</td>
</tr>
<tr>
<td>Muscovite</td>
<td>1.5</td>
</tr>
<tr>
<td>Rock Fragments</td>
<td>0.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Matrix</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Organics/Mud</td>
<td>2.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cement</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz overgrowth</td>
<td>26.2</td>
</tr>
<tr>
<td>Illite</td>
<td>11.5</td>
</tr>
<tr>
<td>Siderite</td>
<td>1.2</td>
</tr>
<tr>
<td>Dolomite</td>
<td>11.3</td>
</tr>
<tr>
<td>Clinochlore</td>
<td>0.2</td>
</tr>
</tbody>
</table>

**Porosity**:

- Primary/Secondary(fracture) 2.8
- Measured porosity (includes micro-porosity) = 5.3

**Measured Permeability**: 0.016 Darcies

**Comments**: Moving further into marine conditions, this rock includes more mud and clay due to bioturbation and is texturally and mineralogically sub-mature to mature. Once again mono and polycrystalline quartz forms are observed, from igneous and metamorphic terrains and they are cemented by moderate amounts of quartz overgrowth. Most grain contacts are concavo-convex but sutured and straight contacts are evident in the more matrix supported areas. Another important observation is that there is little or no quartz overgrowth in the areas where there is more alloegenic clay content. Late stage dolomite is once again observed etching quartz. There is a late stage authigenic clay observed as being after dolomite which is quite probably chlorite and is probably more present in the above rock than has been observed in thin section. No fracturing is evident in this slide.

**Diagenetic events**: 
siderite cement
authigenic illite introduced continually adding to the alloogenic content
quartz overgrowth cement
dolomite cement in porosity
compaction and etching of quartz by existing dolomite
production of chlorite from glauconite and biotite alteration

Mountain Bridge #1, 3227.6m

![Graph showing mineral content]

Total Counts

500

1500

Q

Q

Q

Q

Degrees
Mountain Bridge #1 Core #1 XRD Main diagentic constituents

<table>
<thead>
<tr>
<th>Sample</th>
<th>Framework</th>
<th>Cements</th>
<th>Illite</th>
<th>Calcite</th>
<th>Dolomite</th>
<th>Clinchorile</th>
</tr>
</thead>
<tbody>
<tr>
<td>3211.6m</td>
<td>D</td>
<td>Quartz, Plagioclase, Siderite</td>
<td>tr</td>
<td>tr</td>
<td>tr</td>
<td>tr</td>
</tr>
<tr>
<td>3216.2m</td>
<td>D</td>
<td>tr</td>
<td>tr</td>
<td>tr</td>
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<td>tr</td>
</tr>
<tr>
<td>3218.9m</td>
<td>D</td>
<td>tr</td>
<td>tr</td>
<td>tr</td>
<td>tr</td>
<td>tr</td>
</tr>
<tr>
<td>3219.4m</td>
<td>D</td>
<td>tr</td>
<td>tr</td>
<td>tr</td>
<td>tr</td>
<td>tr</td>
</tr>
<tr>
<td>3220.35m</td>
<td>D</td>
<td>tr</td>
<td>m</td>
<td>tr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3222.28m</td>
<td>D</td>
<td>tr</td>
<td>tr</td>
<td>m</td>
<td>m</td>
<td></td>
</tr>
<tr>
<td>3223.3m</td>
<td>D</td>
<td>tr</td>
<td>tr</td>
<td>m</td>
<td>m</td>
<td></td>
</tr>
<tr>
<td>3223.8</td>
<td>D</td>
<td>tr</td>
<td>tr</td>
<td>m</td>
<td>m</td>
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</tr>
<tr>
<td>3224.3m</td>
<td>D</td>
<td>tr</td>
<td>tr</td>
<td>S</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>3227.6m</td>
<td>D</td>
<td>tr</td>
<td>tr</td>
<td>m</td>
<td>m</td>
<td></td>
</tr>
</tbody>
</table>

D = Dominant mineral (peak>1200 counts); S = Subsidiary mineral (600<main peak<1200)
m = minor mineral (400<main peak<600); tr = trace mineral (peak<400 counts); ? = Indication

**Peak Heights for carbonate cements**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Depth (m)</th>
<th>Frame</th>
<th>Siderite</th>
<th>Calcite</th>
<th>Dolomite</th>
</tr>
</thead>
<tbody>
<tr>
<td>c1</td>
<td>3211.6</td>
<td>D</td>
<td>0</td>
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<td>210</td>
</tr>
<tr>
<td>c2</td>
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<td>D</td>
<td>80</td>
<td>120</td>
<td>180</td>
</tr>
<tr>
<td>c3</td>
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<td>D</td>
<td>230</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>c4</td>
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<td>80</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>c5</td>
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<td>320</td>
<td>0</td>
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<tr>
<td>c6</td>
<td>3222.28</td>
<td>D</td>
<td>140</td>
<td>0</td>
<td>510</td>
</tr>
<tr>
<td>c7</td>
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<td>D</td>
<td>110</td>
<td>0</td>
<td>570</td>
</tr>
<tr>
<td>c8</td>
<td>3223.8</td>
<td>D</td>
<td>180</td>
<td>0</td>
<td>910</td>
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<tr>
<td>c9</td>
<td>3224.3</td>
<td>D</td>
<td>150</td>
<td>0</td>
<td>970</td>
</tr>
<tr>
<td>c10</td>
<td>3227.6</td>
<td>D</td>
<td>160</td>
<td>0</td>
<td>630</td>
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</tbody>
</table>

Variation in Carbonate cements in Core #1 from XRD data

![Graph showing variation in XRD identified carbonate cements from core #1](image)

**Figure 5**: Variation in XRD identified carbonate cements from core #1
<table>
<thead>
<tr>
<th>Sample</th>
<th>Quartz</th>
<th>Plagioclase</th>
<th>Muscovite</th>
<th>Glaucnite</th>
<th>Organics</th>
<th>Siderite</th>
<th>Illite</th>
<th>Calcite</th>
<th>Dolomite</th>
<th>Clinohlorite</th>
<th>Barite</th>
</tr>
</thead>
<tbody>
<tr>
<td>3211.6m</td>
<td>D</td>
<td>m</td>
<td>tr</td>
<td>-</td>
<td>?</td>
<td>-</td>
<td>tr</td>
<td>tr</td>
<td>tr</td>
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<tr>
<td>3216.2m</td>
<td>D</td>
<td>tr</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>tr</td>
<td>tr</td>
<td>tr</td>
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</tr>
<tr>
<td>3218.9m</td>
<td>D</td>
<td>-</td>
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<td>?</td>
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<td>tr</td>
<td>-</td>
<td>-</td>
<td>?</td>
<td>tr</td>
</tr>
<tr>
<td>3219.4m</td>
<td>D</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>?</td>
<td>-</td>
<td>?</td>
<td>-</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>3220.35m</td>
<td>D</td>
<td>-</td>
<td>?</td>
<td>-</td>
<td>?</td>
<td>tr</td>
<td>m</td>
<td>-</td>
<td>tr</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3222.28m</td>
<td>D</td>
<td>-</td>
<td>tr</td>
<td>tr</td>
<td>-</td>
<td>tr</td>
<td>m</td>
<td>-</td>
<td>m</td>
<td>-</td>
<td>tr</td>
</tr>
<tr>
<td>3223.3m</td>
<td>D</td>
<td>-</td>
<td>?</td>
<td>tr</td>
<td>?</td>
<td>?</td>
<td>tr</td>
<td>-</td>
<td>m</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3223.8</td>
<td>D</td>
<td>-</td>
<td>?</td>
<td>-</td>
<td>?</td>
<td>tr</td>
<td>tr</td>
<td>-</td>
<td>m</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3224.3m</td>
<td>D</td>
<td>-</td>
<td>tr</td>
<td>-</td>
<td>?</td>
<td>tr</td>
<td>-</td>
<td>S</td>
<td>?</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3227.6m</td>
<td>D</td>
<td>-</td>
<td>tr</td>
<td>-</td>
<td>?</td>
<td>m</td>
<td>-</td>
<td>m</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

D = Dominant mineral (peak > 1200 counts); S = Subsidiary mineral (800 < main peak < 1200)

m = Minor mineral (400 < main peak < 800); tr = Trace mineral (peak < 400 counts); ? = Indication

Organic matter is indicated by the raised base of the graph between 20 and 40 degrees.
APPENDIX 2

Arrowsmith #1

Cuttings Descriptions
APPENDIX 2

Cuttings description   Arrowsmith #1

interval : 10705 - 10710 feet

This is a fine to medium grained, well sorted, subrounded sub-
feldspar arenite. The framework of this rock is predominantly rounded
quartz grains of 2mm mean diameter. Most grains are in contact but
some appear to be surrounded by cement. There is a light grey
coloured silica cement binding the framework grains which occupies
approximately 20% of the rock. A small amount (-5%) of clays are
observed in the matrix of this rock. The clay is often observed in
concentrated clumps, which may be a product of bioturbation, but also
dispersed throughout the matrix. Crushed cuttings show very little
reaction with dilute hydrochloric acid (HCl) indicating perhaps a trace
of dolomite cement is present.

---

Cuttings description   Arrowsmith #1

interval : 10710 - 10715 feet

This is a moderate to well sorted, fine grained, sub-rounded to sub-
angular quartz arenite. The framework is made up of predominantly
quartz grains with a mean diameter of 0.15mm. Grain contacts are
common but grains floating in light grey silica cement are also observed. There are trace amounts (~1%) of lithic fragments of approximately 0.1mm size also included in the framework of this rock. There is also once again dispersed clay within the matrix constituting less than 5%. There is no reaction of selected crushed cuttings with dilute HCl indicating that there is little or no carbonate present.

Arrowsmith #1, drilling cuttings 10710'-10715'

(High Cliff sandstone)

Cuttings description Arrowsmith #1

interval: 10715 - 10720 feet

This is a fine grained, well sorted, sub-feldsparicite. The framework consists of sub-rounded quartz with some plagioclase grains of approximately 0.2mm mean diameter. There is considerable cement in this rock (~22%) and altogether less grain on grain contacts. The same light grey silica cement is still the dominant cement. A little amount (~2-5%) of dark clay exists dispersed in the matrix. Crushed cuttings from this interval show very little reaction indicating the unlikely possibility of dolomite cement being present in an unaltered form.
Cuttings description  

Arrowsmith #1

interval: 10720 - 10730 feet

This is a moderately well sorted, fine to medium grained sub-rounded, sub-felds arenite. The rock has mostly quartz and subdiary feldspar with a mean grain size of 0.25mm. Floating grains are common with the light grey silica cement occupying approximately 30% of the rock. Clay content in the matrix has dropped off to trace level (<1%). There are occasional lithic grains in various cuttings. There is a relatively large reaction of selected crushed cuttings with the dilute HCl indicating a large amount of unaltered carbonate cement present. Although unsighted on the XRD trace for this sample, this is most probably dolomite, seen on XRD in the following sample and common lower down in Mountain Bridge#1.
Cuttings description  

**Arrowsmith #1**

**interval**: 10730 - 10740 feet

This is a fine grained, well sorted, quartz arenite. The sub-rounded framework consists mainly of quartz grains of 0.2mm mean diameter which are mainly in contact with each other. The light grey silica cement still appears dominant occupying approximately 20% of the rock. There is still a trace amount (~1%) of dark coloured clay dispersed about the matrix. There is virtually no reaction of selected cuttings that are crushed and then tested with dilute HCl, despite the strong presence on the XRD trace.

![XRD trace](image)

**Cuttings description**  

**Arrowsmith #1**

**interval**: 10740 - 10750 feet

This is a fine to medium grained, well sorted quartz arenite. The sub-angular to sub-rounded quartz framework grains have a mean diameter of 0.25mm. There appears to be more grain on grain contacts and less silica cement (~15-20%). Trace amounts (<1%) clay and lithic grains are observed in this rock. There is very little reaction of crushed cuttings with dilute HCl indicating either lack, or just dissolution on collection of any carbonate cement.
**Arrowsmith #1, drilling cuttings 10740'-10750'**

(High Cliff sandstone)

<table>
<thead>
<tr>
<th>Framework</th>
<th>Cements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>Plagioclase</td>
</tr>
<tr>
<td>10705'-10710'</td>
<td>D</td>
</tr>
<tr>
<td>10710'-10715'</td>
<td>D</td>
</tr>
<tr>
<td>10715'-10720'</td>
<td>D</td>
</tr>
<tr>
<td>10720'-10730'</td>
<td>D</td>
</tr>
<tr>
<td>10730'-10740'</td>
<td>D</td>
</tr>
<tr>
<td>10740'-10750'</td>
<td>D</td>
</tr>
</tbody>
</table>

D = Dominant mineral (peak>1200 counts); S = Subsidiary mineral (800<main peak<1200)
m = minor mineral (400<main peak<800); tr = trace mineral (peak<400 counts); ? = indication
APPENDIX 3

Mountain Bridge #1

Sidewall Core Descriptions
Sidewall Core Description

Mountain Bridge #1  sidewall core # 5  Holmwood Shale

Core description: Mid to dark grey mottled off white, very fine to silt, sandstone. Moderate to well sorted, sub round, spherical with patchy strong calcareous cement. Abundant grey and off white argillaceous matrix. Common micae and trace altered feldspar.

Core condition in thin section: Bad to severe fracturing of rock with associated mud infiltration.

sample depth: 3315m
max. grain size: 0.2mm
min. grain size: 0.05mm
rock: slightly muddy feldsarenite
sorting: moderate
roundness: sub-angular
sphericity: medium

Composition:

Framework:
Quartz 56
Plagioclase 8.8
Muscovite 1.2
Rock Fragments 3.3

Matrix:
Organics/Mud 1.3

Cement:
Illite 5.2
Chlorite 4.2
Calcite 1.8

Porosity:
Secondary (Dissolution, induced Fracture) 2.1

Foreign drilling mud: 16.1

Comments:
Quartz grains exhibit undulose extinction and rarely include rutile and zircon, indicating a metamorphic or igneous origin. No quartz overgrowth is evident on any of the quartz grains. The framework grains are essentially floating in authigenic illite and, to a lesser extent, chlorite. There are very few grain contacts observed. Feldspar grains and rock fragments show only mild alteration to illite. Framework grains exhibit minor etching and pressure solution effects of being compressed onto the clay. Sporadic calcite observed between
framework grains pre-dating illite, probably recrystallised form of carbonate deposited with the sediment.

**Diagenetic events:**
- recrystallisation of carbonate to calcite cement
- illite and chlorite production due to the alteration of feldspars and rock fragments
- compaction causing slight pressure solution etching of grains

![Diagram of Mountain Bridge #1, sidewall core #5, 3315m (Holmwood Shale)]
Sidewall Core Description

Mountain Bridge #1  sidewalk core # 9  Holmwood Shale

Core description: Mottled off white and pale grey limestone. Very fine calcarenite with micritic matrix. Abundant crinoid fossil fragments recrystallised in part. Slightly argillaceous.

Core condition in thin section: Good to excellent preservation of carbonate with bad to severe rock fracturing and mud infiltration in the layered clastic region.

sample depth: 3257.5m
max. grain size: 4.0mm
min. grain size: 0.1mm

rock: calcarenite
sorting: poor
roundness: fossil fragments

Composition:

<table>
<thead>
<tr>
<th>Framework</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>10.0</td>
</tr>
<tr>
<td>Calcite</td>
<td>51</td>
</tr>
<tr>
<td>Muscovite</td>
<td>1.1</td>
</tr>
<tr>
<td>Rock Fragments</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Matrix:
Organics/Mud 2.3

Cement:
illite 2.8
Calcite 16.8
Dolomite 2?
Quartz (fracture associated) 1.2

Porosity:
Secondary (Dissolution, induced Fracture) 4.7

Foreign drilling mud: 6

Comments:
This core is separated into two distinct parts separated by a straight line that cuts across the core approximately one third of the way through. One third of the core is a stratified mud rich rock containing elongate fossil fragments up to 0.5mm length, with finer poorly sorted sub-angular clastic grains including quartz, feldspar and rock fragments. Aligned muscovite also defines this layering. This section of the core is highly infiltrated by drilling mud which fills fractures running parallel to the stratification. Feldspars, rock fragments and muscovite are all observed altering to illite and chlorite. The other two
thirds of the core is made up of large (5mm) to small (0.2mm) fossil fragments from crinoids. Original shapes of the fragments are well preserved by binding calcite cement. Voids inside the fossil fragments commonly contain mud which has had sparry calcite cement encroach upon it. This part of the core also contains approximately 3% quartz and rock fragments which have been consumed and etched by carbonate cement. Rock fragments show deterioration to illite which has mixed with the carbonate. Both sides of the core show late stage clean fracturing which has been infilled with quartz cement analogous with that seen in the lower High Cliff.

**Diagenetic events:**
progressive crystallisation of carbonate to calcite cement and sparry growth in voids, as well as limited dolomitisation
illite production due to the alteration of rock fragments
compaction enhancing etching of grains
fracturing and cementation by quartz

Mountain Bridge #1, Sidewall core #9, 3257.5m
(Holmwood Shale)
Sidewall Core Description

Mountain Bridge #1 sidewall core #14  Irwin River Coal Measures

Core description: White mottled grey, very fine to medium, poorly sorted, sub-angular sandstone. Scattered weak pyrite cement, with abundant white argillaceous matrix.

Core condition in thin section: Moderate mud infiltration throughout the core but severe shattering of whole rock and of grains.

<table>
<thead>
<tr>
<th>Sample depth</th>
<th>3195m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. grain size</td>
<td>0.6mm</td>
</tr>
<tr>
<td>Min. grain size</td>
<td>0.2mm</td>
</tr>
<tr>
<td>Ave. grain size</td>
<td>≈0.3</td>
</tr>
</tbody>
</table>

Composition:

**Framework:**
- Quartz: 44.5%
- Plagioclase: 10.6%
- Muscovite: 1.5%
- Rock Fragments: 1.9%
- Pyrite: 8.7%

**Matrix:**
- Organics/Mud: 0.2%

**Cement:**
- Quartz overgrowth: 11.6%
- Illite: 14.2%
- Chlorite: 2.8%

**Porosity:**
- Secondary (Dissolution, induced Fracture): 2.0

**Foreign drilling mud:**
- 2.0

Comments:
Large quartz overgrowths are present on most quartz grains. Grain contacts vary from straight to sutured. A significant amount of illite has been produced from alteration of feldspar and rock fragments. Feldspar has often completely altered to illite with the porosity produced being filled in with quartz overgrowth cement. In this way, the quartz overgrowth has included some illite within it but there is still a high amount of illite between quartz grains. Bow-tie muscovite is observed parting along cleavage as a result of compaction then
subsequent dissolution. The quartz illite contacts show etching due to pressure solution.

**Diagenetic events:**
illite and chlorite production due to the alteration of feldspars and rock fragments as an ongoing process
quartz overgrowth cementation
pyrite infiltration
compaction causing slight pressure solution etching of grains and bowtie mica

---

**Mountain Bridge #1, sidewall core #14, 3195m**
(Irwin River Coal Measures)
Sidewall Core Description

Mountain Bridge #1 sidewall core # 19 Irwin River Coal Measures

Core description: Pale brown, very fine to predominantly medium, moderately sorted, angular sandstone. Strong siderite cement with trace brown interstitial clay. Trace lithic grains and mica and rare feldspar.

Core condition in thin section: good with only minor fracturing of rock and associated mud infiltration.

sample depth: 3160m
max. grain size: 0.6mm
min. grain size: 0.2mm

Composition:

Framework:
Quartz 30
Plagioclase 14.0
Orthoclase 3.2
Muscovite 3.5
Rock Fragments 2.5
Pyrite 1.0

Matrix:
Organics/Mud 1.0

Cement:
Quartz overgrowth 8.7
Illite 28.8
Chlorite 0.8

Porosity:
Secondary (Induced Fracture) 4.5

Foreign drilling mud: 2

Comments: The quartz grains in this rock of metamorphic and plutonic origin, exhibit minor amounts of quartz overgrowth cement. Both the plagioclase and orthoclase show moderate to high amounts of alteration to illite. Most of the framework grains are effectively floating in authigenic illite but where grain contacts do exist they are concavo-convex to sutured. Most of the quartz to illite contacts exhibit pressure solution features due to compaction. Muscovite is commonly seen in
bow-tie form and interstitial clay is observed as being squeezed from pore spaces. Rare amounts of pore-filling pyrite are observed invading the rock. This core has an anomalously high amount of fracture porosity due to the coring technique.

**Diagenetic events:**
- beginning of alteration of feldspars and rock fragments to illite as an ongoing process
- small amounts of quartz overgrowth cementation
- significant illite production from alteration of high feldspar content and rock fragments
- pyrite infiltration
- compaction causing slight pressure solution etching of grains and bow-tie mica

---

**Mountain Bridge #1, sidewall core #19, 3160m**
(Lrwin River Coal Measures)
Sidewall Core Description

Mountain Bridge #1  sidewall core # 26Irwin River Coal Measures

Core description: Off white to light brown, very fine to occasionally fine grained, well sorted sandstone. Weak to moderate calcareous cement, abundant argillaceous matrix and trace mica.

Core condition in thin section: Bad to severe in part with rock and grain fracturing extensive as well as mud infiltration.

sample depth: 3083m
max. grain size: 0.5mm
min. grain size: 0.1mm
ave. grain size: ~0.3mm

rock: slightly muddy feldsarenite
sorting: moderate
roundness: sub-angular
sphericity: low to medium

Composition:

<table>
<thead>
<tr>
<th>Framework</th>
<th>%</th>
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<tbody>
<tr>
<td>Quartz</td>
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<tr>
<td>Plagioclase</td>
<td>19.1</td>
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<tr>
<td>Muscovite</td>
<td>1.2</td>
</tr>
<tr>
<td>Rock Fragments</td>
<td>4.2</td>
</tr>
<tr>
<td>Pyrite</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Matrix:
Organics/Mud 1.5

Cement:
<table>
<thead>
<tr>
<th></th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz overgrowth</td>
<td>9.2</td>
</tr>
<tr>
<td>Illite</td>
<td>16.5</td>
</tr>
<tr>
<td>Kaolinite</td>
<td>?</td>
</tr>
<tr>
<td>Calcite</td>
<td>5.0</td>
</tr>
<tr>
<td>Siderite</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Porosity:
Secondary (Dissolution, induced Fracture) 1.0

Foreign drilling mud: 4.5

Comments:
Quartz framework grains show only minor amounts of overgrowth cement but are often observed cemented together. Grain contacts are mainly concavo-convex to sutured where evident. A high illite content has again provided pressure solution effects on quartz grain and cement edges. Feldspar grains show moderate alteration to illite along cleavage and rock fragments exhibit alteration beginning from their outer edges. Quartz overgrowth cement also once again includes clay
indicating the possibility of an initially high content of alloogenic clay. There is a moderate amount of reasonably crystalline calcite cement that occasionally exhibits rhombic habit. This calcite stage also appears to have been subject to pressure solution and has sutured edges when in contact with illite. There is no chlorite observed in this sample but it is thought that the high illite content indicates a much too unstable environment for the existence of kaolinite.

**Diagenetic events:**
- beginning of alteration of feldspars to illite
- rock fragments as a continuous process
- quartz overgrowth cementation
- calcite emplacement before continuation of illite production
- possible pyrite infiltration
- compaction causing slight pressure solution etching of grains

---

**Mountain Bridge #1, sidewall core #26, 3083m**

(Irwin River Coal Measures)
Sidewall Core Description

Mountain Bridge #1  sidewall core # 27 Irwin River Coal Measures

Core description: Off white to predominantly grey brown, very fine to coarse, sub-angular, poorly sorted sandstone. Moderate ferro-calcitic cement, abundant white and grey clay matrix, abundant feldspar and common mica.

Core condition in thin section: Moderate to poor with some areas of the rock severely fractured and infiltrated by drilling mud

sample depth: 3068m
max. grain size: 0.2mm
min. grain size: 0.05mm

Composition:

<table>
<thead>
<tr>
<th></th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Framework</td>
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</tr>
<tr>
<td>Quartz</td>
<td>17</td>
</tr>
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<tr>
<td>Muscovite</td>
<td>8.9</td>
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<tr>
<td>Rock Fragments</td>
<td>3.2</td>
</tr>
<tr>
<td>Pyrite</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Matrix:
Organics/Mud
2.0

Cement:
Quartz overgrowth
0.2
Illite
52.7
Calcite
?
Siderite
?

Porosity:
Secondary (Dissolution, induced Fracture) 2.0

Foreign drilling mud:
1

Comments:
A small edge of this core consists of larger (0.7mm) quartz grains in a facies very different to the majority of the core and it is quite possible that this was the intended rock to be sampled. Most of this core is highly illitised. There are small areas of patchy amounts of quartz with evidence of limited amounts of quartz overgrowth cement. Rare grain contacts are predominantly of a straight nature and most of the quartz is significantly sutured due to pressure solution contacts with illite.
Feldspar grains and rock fragments where evident, appear to have mostly been altered to produce illite. This rock has a high muscovite content which has often been compressed and altered. Small amounts of sporadic pyrite have been observed throughout the rock. Most of the porosity observed is fracture porosity induced by the coring technique. Calcite and siderite have not been observed.

**Diagenetic events:**
- beginning of alteration of feldspars to illite
- rock fragments as a continuous process
- siderite emplacement (?)
- quartz overgrowth cementation
- calcite emplacement (?) before continuation of illite production
- possible pyrite infiltration
- alteration of muscovite
- compaction causing slight pressure solution effects

---

**Mountain Bridge #1, sidewall core #27, 3068m**

(Irwin River Coal Measures)
Sidewall Core Description

Mountain Bridge #1 sidewall core # 30 Irwin River Coal Measures

Core description: Off white, very fine grained, sub-round, well sorted sandstone. Strong calcareous cement in cleaner parts, elsewhere abundant white clay matrix and poorly cemented trace lithic grains.

Core condition in thin section: Bad to severe fracturing of rock and grains throughout with associated infiltration of mud.

sample depth : 3021m
max. grain size : 0.6mm
min. grain size : 0.1mm
ave. grain size : ≈0.3mm

Composition:

Framework:
- Quartz: 33%
- Plagioclase: 16%
- Muscovite: 0.3%
- Rock Fragments: 0.9%
- Pyrite: 0.2%

Matrix:
- Organics/Mud: 3.7%

Cement:
- Quartz overgrowth: 4.7%
- Illite: 28.1%
- Chlorite: 1.1%
- Calcite: 3.5%
- Dolomite: 4.5%

Porosity:
- Secondary (Dissolution, induced Fracture) 3.0

Foreign drilling mud:
- 1

Comments:
Quartz grains exhibit only minor amounts of quartz overgrowth cement. Where evident, grain contacts are concavo-convex to predominantly sutured. Grain edges once again show pressure solution effects when in contact with illite. Feldspars and rock fragments commonly show alteration to illite which is abundant in the interstices. Two different carbonate stages were identified in this rock. Dirty appearing crystals nucleating in clumps are probably calcite recrystallised from calcareous
material originally in the rock. These clumps are observed abutting quartz and etching it. Cleaner, more rhombic crystals are most probably dolomite introduced to the rock later in diagenesis. Dirty appearing bow-tie muscovite is observed splitting along cleavage to produce porosity and chlorite. Late stage pyrite is sporadic in occurrence.

**Diagenetic events:**
Recrystallisation of calcareous material to calcite (?)
beginning of alteration of feldspars to illite
rock fragments as a continuous process
quartz overgrowth cementation
more authigenic illite
dolomite emplacement (?)
further illite production
possible pyrite infiltration
compaction causing slight pressure solution effects and alteration of muscovite
Sidewall Core Description

Mountain Bridge #1 sidewall core #32  Irwin River Coal Measures

Core description: Off white, very fine to fine, sub-angular, well sorted sandstone. Moderate calcareous cement, abundant white clay matrix and trace mica.

Core condition in thin section: Grains and rock are severely fractured throughout with significantly infiltration by mud.

Sample depth: 3009m
max. grain size: 0.5mm
min. grain size: 0.05mm
ave. grain size: ≈0.3mm

Composition:

Framework:
Quartz: 45
Plagioclase: 7.0
Muscovite: 0.2
Rock Fragments: 0.6

Matrix:
Organics/Mud: 1.8

Cement:
Quartz overgrowth: 18.6
Illite: 12.3
Chlorite: 0.1
Calcite: 1.4
Siderite: 8.0

Porosity:
Secondary (Induced Fracture): 3

Foreign drilling mud:
2

Comments:
Predominantly quartz rock with significant amounts of quartz overgrowth cementing. Grain cements are observed as having concavo-convex to sutured contacts. Feldspar grains once again exhibit alteration to illite. Illite is once again common in the interstitial areas and is involved in pressure solution effects with quartz and carbonate. Two stages of carbonate have been identified in this rock. A pre-quartz overgrowth stage is very dark in appearance and displays slight effects of dissolution and is probably siderite. A less common, cleaner
appearing more crystalline carbonate exhibits late stage porosity fill habit and is probably calcite. This cleaner stage of carbonate is observed replacing porosity created by dissolution of feldspar. Both of these carbonate stages exhibit etching of quartz when in contact with it.

**Diagenetic events:**
- Emplacement of siderite cement
- Beginning of alteration of feldspars to illite
- Rock fragments as a continuous process
- Quartz overgrowth cementation
- More feldspar alteration and production of authigenic illite
- Calcite emplacement in interstices and feldspar dissolution porosity
- Compaction causing slight pressure solution effects

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**Mountain Bridge #1, sidewall core #32, 3009m**
(Irwin River Coal Measures)
Sidewall Core Description

Mountain Bridge #1 sidewall core #39  Irwin River Coal Measures

Core description: Off white mottled pale grey brown, very fine to fine, angular sandstone. Weak calcareous cement and abundant clay matrix.

Core condition in thin section: Moderate to bad rock fracturing and a high amount of mud infiltration.

sample depth: 2887m
max. grain size: 0.5mm
min. grain size: 0.2mm

rock: slightly muddy quartz arenite
sorting: well sorted
roundness: sub-angular
sphericity: high

Composition:

<table>
<thead>
<tr>
<th>Framework</th>
<th>%</th>
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</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>54.6</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>2.5</td>
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<tr>
<td>Muscovite</td>
<td>0.4</td>
</tr>
<tr>
<td>Rock Fragments</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Matrix:
Organics/Mud 0.8

Cement:
Quartz overgrowth 3.5
Illite 16
Chlorite ?
Dolomite 4.2

Porosity:
Secondary (Dissolution, induced Fracture) 5

Foreign drilling mud: 10

Comments:
The amount of clay infiltration in this rock makes it hard to determine actual clay content. The lighter coloured matrix, so called illite here, is darker than the authigenic illite seen in previous samples and is similar in appearance to the infiltrated mud. If this matrix is wrongly interpreted as authigenic illite, then this would give the rock a maximum porosity of 30%. The quartz in this rock is well sorted and exhibits only minor amounts of quartz overgrowth cement. Grains are usually isolated by brown mud matrix but contacts are sutured when they occur. Feldspars when present have undergone dissolution as
have rock fragments to produce illite. Many grain contacts with the brown matrix do not display sutured pressure solution effects as they have in previous samples. From this it may be concluded that there is not as much clay content in this sample as first thought. One stage of carbonate is observed, probably dolomite, and it appears as a possibly partly dissolved dirty crystals that is post quartz overgrowth. This carbonate is probably post illite production, it is observed replacing altered feldspar and etches quartz when in contact with it.

Diagenetic events:
beginning of alteration of feldspars to illite
rock fragments as a continuous process
quartz overgrowth cementation
more feldspar alteration and production of authigenic illite
dolomite emplacement
slight compaction enhancing dolomite etching of quartz

![Mountain Bridge #1, sidewall core #39, 2887m](image)
Sidewall Core Description

Mountain Bridge #1 sidewall core #42  Carynginia Formation

Core description: Pale grey brown, very fine grained, sub-rounded, well sorted sandstone. Common weak calcareous cement, common mica and abundant grey brown matrix with trace carbonaceous specks.

Core condition in thin section: Moderate to good with fracturing and mud infiltration being restricted to the core edges.

<table>
<thead>
<tr>
<th>Sample depth</th>
<th>2827m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. grain size</td>
<td>0.4mm</td>
</tr>
<tr>
<td>Min. grain size</td>
<td>0.02mm</td>
</tr>
<tr>
<td>Ave. grain size</td>
<td>~0.1mm</td>
</tr>
</tbody>
</table>

Composition:

Framework:
- Quartz: 41
- Plagioclase: 6.5
- Muscovite: 3.0
- Rock Fragments: 1.9

Matrix:
- Organics/Mud: -

Cement:
- Quartz overgrowth: 7.1
- Illite: 22.2
- Chlorite: 0.5
- Calcite: 10.8

Porosity:
- Secondary (Dissolution, induced Fracture) 2

Foreign drilling mud: 5

Comments:
Only minor amounts of quartz overgrowth cement are evident in this rock with grains exhibiting concavo-convex and sutured contacts. Feldspar and rock fragments are observed altering to illite which is the main interstitial component. Less alteration to illite from these precursors is seen than has been seen in previous sample. Moderate amounts of a predominantly clean appearing, relatively crystalline porosity filling carbonate are seen. This is interpreted as being calcite cement. Compaction has enhanced the etching of quartz by this
carbonate. Suturing pressure solution effect of illite compressed on quartz is limited in extent.

**Diagenetic events:**
beginning of alteration of feldspars and rock fragments to illite quartz overgrowth cementation
more feldspar alteration and production of authigenic illite calcite emplacement
slight compaction enhancing calcite etching of quartz

![Mountain Bridge #1, sidewall core #42, 2827m (Carynginia Formation)](image-url)
Sidewall Core Description

Mountain Bridge #1 sidewall core #45                      Carynginia Formation

Core description: Mottled pale to mid grey brown, very fine to fine, moderately sorted, sub-rounded sandstone. Strong calcareous cement, abundant clay matrix and trace mica.

Core condition in thin section: Moderate to bad fracturing of the rock throughout the core which has allowed mud infiltration around the edges.

sample depth: 2782.5m
max. grain size: 0.3mm
min. grain size: 0.05mm
rock: calcareous quartz arenite
sorting: well sorted
roundness: sub-angular
sphericity: low

Composition:

Framework:
- Quartz: 36%
- Plagioclase: 3.8%
- Muscovite: 5.0%
- Rock Fragments: 3.2%

Matrix:
- Organics/Mud: 3.0%

Cement:
- Quartz overgrowth: 10.0%
- Illite: 16.6%
- Chlorite: 0.6%
- Calcite: 12.0%
- Dolomite: 6.8%

Porosity:
- Secondary (Induced Fracture): 2%

Foreign drilling mud: 1%

Comments:
Predominantly quartz rock with little quartz overgrowth cement. The quartz overgrowth cement observed in this rock includes carbonate rhombs. This indicates that quartz overgrowth cementing was incident with carbonate cementation. The quartz grains are etched by the carbonate and have a rough sutured finish. Feldspar grains and rock fragments commonly alter to illite. Illite has a brown appearance to it which may indicate an originally high clay content. The early stage
small crystals of carbonate have a dirty appearance and may be mixed up with illite, and thus be coincident stages. There is a later stage larger crystalline carbonate cement that has a cleaner appearance. This later stage carbonate curiously is commonly seen enveloping muscovite plates and is most likely dolomite cement with the early stage cement being recrystallised calcite cement. None of the muscovite exhibits bow-tie form.

**Diagenetic events:**
- recrystallisation of calcareous material to calcite
- coincident quartz overgrowth cementation
- feldspar alteration and production of authigenic illite
- dolomite emplacement
- slight compaction

![Mountain Bridge #1, sidewall core #45, 2782.5m](chart)

(Carynginia Formation)
Sidewall Core Description

Mountain Bridge #1 sidewall core #47  Carynginia Formation

Core description: Grey brown mottled white, very fine to fine, well sorted, sub-rounded sandstone. Weak to moderate calcareous cement, common to abundant clay matrix with common lithic grains and trace mica.

Core condition in thin section: Moderate to good with rock fracturing and mud infiltration limited to the outer edges of the core.

sample depth: 2762.5m  
max. grain size: 0.3mm  
min. grain size: 0.05mm  
roundness: sub-angular

rock: quartz arenite  
sorting: well sorted

Composition:

Framework:
- Quartz: 36.2%
- Plagioclase: 8.0%
- Muscovite: 2.3%
- Rock Fragments: 6.9%

Matrix:
- Organics/Mud: 6.2%

Cement:
- Quartz overgrowth: 18.8%
- Illite: 8.1%
- Dolomite: 4.2%
- Siderite: 5.3%

Porosity:
- Secondary (Dissolution, induced Fracture): 3%

Foreign drilling mud: 1

Comments:
There is quite a lot of quartz cement in this rock which has bound most constituents. Quartz contacts are generally straight with some concavo-convex. The muscovite present in this rock shows no bow-tie form, from which it can be concluded that this rock has not undergone any great compaction. The quartz cement present in this rock has grown onto or around most things. There is still a high amount of alloogenic/authigenic illite within this rock in the interstices. Feldspar grains and rock fragments show minor alteration at edges and along cleavage. Illite that shows an authigenic appearance is cemented in
with quartz overgrowth. There is generally only one distinguishable type of carbonate cement. All carbonate cement in this rock is of a dark appearance and is seen between quartz cement that grew onto it. The carbonate is also seen in a smaller form included in the quartz overgrowth and all carbonates etch quartz when in contact with it.

**Diagenetic events:**
- Emplacement of siderite cement
- Coincident quartz overgrowth cementation
- Feldspar alteration and production of authigenic illite
- Dolomite emplacement
- Slight compaction

![Mountain Bridge #1, sidewall core #47, 2762.5m (Carynginia Formation)](image-url)
Sidewall Core Description

Mountain Bridge #1 sidewall core #48  Carynginia Formation

Core description: Mid grey, very fine to fine, well sorted, sub-angular sandstone. Weak to moderate calcareous cement, abundant silt and clay matrix and common mica.

Core condition in thin section: Bad to severe fracturing of rock throughout with bad infiltration of drilling mud at the edges.

sample depth: 2743m  rock: calcarenite
max. grain size: 0.2mm  sorting: moderate
min. grain size: 0.05mm  roundness: sub-angular

Composition:

Framework:
- Quartz: 38
- Plagioclase: 6.0
- Muscovite: 0.2
- Calcite (fossil fragments): 6.4
- Rock Fragments: 0.3

Matrix:  
Organics/Mud: 5.6

Cement:
- Quartz overgrowth: -
- Iillite: 8.0
- Dolomite: 25.5

Porosity:
Secondary (Dissolution, induced Fracture): 8

Foreign drilling mud: 2

Comments:
Most quartz grains in this rock are floating in a calcareous dolomite mud. All quartz grains are severely etched by the surrounding carbonate. Calcite is present in the rock as fossil fragments which are reasonably sparse. Allogenic illite is common along with other allogenic mud. Little diagenesis has taken place besides this. Porosity is actually quite high in the core but most of this is induced fracture porosity. Some of this porosity may in fact be due to the dissolution of dolomite but this is speculative.
Diagenetic events:
dolomitisation of carbonate mud
slight compaction enhancing etching of quartz
Sidewall Core Description

Mountain Bridge #1  sidewall core #57    Beekeeper Limestone

Core description: Off white to pale brown, very fine calcarenite limestone. Abundant micritic matrix, predominantly recrystallised fossil fragments.

Core condition in thin section: Good with only fracturing and mud infiltration at the edges of the core.

sample depth : 2675m    rock : fossiliferous limestone
max. grain size : 0.4mm    sorting : moderate
min. grain size : 0.05mm    roundness : sub-round

Composition:

Framework:
- Quartz: 21
- Plagioclase: 3.2
- Muscovite: 0.1
- Calcite (fossil fragments): 25
- Rock Fragments: 0.8

Matrix:
- Organics/Mud: 0.8

Cement:
- Illite: 1.7
- Calcite: 38
- Dolomite: 25.5

Porosity:
- Secondary (Dissolution, induced Fracture): 5

Foreign drilling mud: 2

Comments: The sediment for this rock was mostly fossil fragments with some included detrital clastic grains. Dissolution and recrystallisation of calcite has cemented most of the rock. All clastic grains have been etched by the carbonate. In some places the carbonate is observed etching some grains away almost completely to distorted eaten shapes. No quartz overgrowth is evident and feldspars and rock fragments show little alteration to illite. Genuine dissolution/ intercrystalline porosity exists but most of the porosity observed is coring induced.
Diagenetic events:
Dissolution and recrystallisation of sparry calcite cement causes and fills secondary porosity.
Carbonate cements etches clastic grains.

Mountain Bridge #1, Sidewall core #57, 2675m
(Beekeeper Limestone)
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<tr>
<th>Sample</th>
<th>Depth</th>
<th>Quartz</th>
<th>Plagioclase</th>
<th>Orthoclase</th>
<th>Muscovite</th>
<th>Organics</th>
<th>Illite</th>
<th>Calcite</th>
<th>Dolomite</th>
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<td>-</td>
<td>tr</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

D = Dominant mineral (peak>1200 counts); S = Subsidiary mineral (800<main peak<1200)
m = minor mineral (400<main peak<800); tr = trace mineral (peak<400 counts); ? = indication

Organic matter is indicated by the raised base of the graph between 20 and 40 degrees.