Introduction to

Clastic Sedimentology

(Notes for a University level, second year, half-credit course in clastic sedimentology)

by

R.J. Cheel
Department of Earth Sciences
Brock University
St. Catharines, Ontario, Canada L2S 3A1
rcheel@brocku.ca
http://www.brocku.ca/sedimentology

© 2005 R.J. Cheel
Acknowledgements

The author thanks the following publishers for granting permission to reproduce figures for which they hold copyright:

Prentice Hall Inc., Englewood Cliffs, New Jersey, figures 2-2, 2-19, 2-14, 2-21, 4-17, 4-20, 5-15, 5-17, 5-5; SEPM (Society for Sedimentary Geology), Tulsa, Oklahoma, figures 2-15, 2-16, 2-17, 5-6, 5-12, 5-13, 5-14, 6-7, 6-8, 6-9, 6-10, 6-12, 6-17, 6-18; Academic Press, New York, figure 2-31A; Springer-Verlag, New York, figures 2-6, 2-39, 3-1, and table 3-5; The University of Chicago Press, figure 2-20; Chapman and Hall, U.K., figures 2-4 and 5-24. All permissions were granted free of charge.

Mike Lozon (Department of Earth Sciences, Brock University) is thanked for preparing several of the figures.
Table of Contents

Chapter 1. Introduction 5
Why study clastic sedimentology? 5
About this book 6
Comprehensive sedimentology textbooks 7

Chapter 2. Grain Texture 8
Introduction 8
Grain Size 8
Volume 8
Linear dimensions 9
Direct measurement 9
Sieving 10
Settling velocity 10
Stoke's Law of Settling 11
Grade scales 14
Displaying grain size data 16
Describing grain size distributions 18
Median 18
Mean 19
Sorting coefficient 19
Skewness 20
Kurtosis 20
Paleoenvironmental implications 20
Why measure grain size? 22
Grain Shape 22
Roundness 22
Wadell 22
Dobkins and Folk 22
Power's visual comparison chart 22
Sphericity 23
Wadell 23
Sneed and Folk 24
Riley 24
Clast form 24
Significance of grain shape 25
Source rock 25
Transport 25
Porosity and Permeability 28
Porosity 28
Controls on porosity 28
Packing density 28
Grain size 29
Sorting 30
Post-burial processes 30
Compaction 30
Cementation 30
Clay formation 30
Solution 31
Permeability (Darcy's Law) 31
Controls on permeability 34
Porosity and packing 34
Grain size and sorting 34
Post-burial processes 35
Directional variation in permeability 36
Grain Orientation 36
Introduction 36
Measuring grain orientation 36
Types of grain fabric 37
Isotropic fabric 37
Anisotropic fabric 37
a(t)b(i) 38
a(p)a(i) 38
Complex anisotropic fabric 38
The problem with measuring grain orientation on thin sections 39
Displaying directional data 39
Statistical treatment of directional data 42
Interpretation of grain orientation 44

Chapter 3. Classification of terrigenous clastic rocks 47
A fundamental classification of sediments 47
Terrigenous clastic sediments 49
Classification of sandstone 49
Basis of the classification 49
Genetic implications 52
Level of classification 54
Classification of rudite 54
Classification of lutite 54

Chapter 4. Unidirectional fluid flow and sediment transport 55
Introduction 55
Unidirectional fluid flows 55
Flow between two plates 55
Fluid gravity flows 56
Classification of fluid gravity flows 58
Shear stress and velocity in turbulent flows 59
Structure of turbulent flows 61
Organized structure of turbulent flows 63
Sediment Transport 66
Modes of transport 66
Quantitative interpretation of grain size curves 67
Threshold of movement 67
Threshold of grain suspension 71

Chapter 5. Bedforms and stratification under unidirectional flows 74
Introduction 74
Bedforms under unidirectional flows 74
Terminology 74
The sequence of bedforms 75
Bedform stability fields 85
Cross-stratification formed by bedforms under unidirectional flows 88
Terminology 88
<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origin of cross-stratification</td>
<td>90</td>
</tr>
<tr>
<td>Cross-stratification produced by asymmetrical bedforms</td>
<td>95</td>
</tr>
<tr>
<td>Ripple cross-lamination</td>
<td>96</td>
</tr>
<tr>
<td>Cross-stratification formed by dunes</td>
<td>97</td>
</tr>
<tr>
<td>Upper plane bed horizontal lamination</td>
<td>99</td>
</tr>
<tr>
<td>In-phase wave stratification</td>
<td>101</td>
</tr>
<tr>
<td><strong>Chapter 6. Flow, bedforms and stratification under oscillatory and combined flows</strong></td>
<td>102</td>
</tr>
<tr>
<td>Introduction</td>
<td>102</td>
</tr>
<tr>
<td>Characteristics of gravity waves</td>
<td>102</td>
</tr>
<tr>
<td>Bedforms and stratification under purely oscillatory currents</td>
<td>105</td>
</tr>
<tr>
<td>Initiation of motion</td>
<td>105</td>
</tr>
<tr>
<td>Bedforms under waves</td>
<td>106</td>
</tr>
<tr>
<td>Stratification formed by oscillatory currents</td>
<td>109</td>
</tr>
<tr>
<td>Bedforms and stratification under combined flows</td>
<td>113</td>
</tr>
<tr>
<td>The enigma of hummocky cross-stratification</td>
<td>114</td>
</tr>
<tr>
<td>HCS - description and associations</td>
<td>116</td>
</tr>
<tr>
<td>Characteristics of HCS</td>
<td>116</td>
</tr>
<tr>
<td>Grain size</td>
<td>116</td>
</tr>
<tr>
<td>Morphology and geometry</td>
<td>116</td>
</tr>
<tr>
<td>HCS associations</td>
<td>118</td>
</tr>
<tr>
<td>Discrete HCS sandstone</td>
<td>118</td>
</tr>
<tr>
<td>Amalgamated HCS sandstone</td>
<td>119</td>
</tr>
<tr>
<td>The HCS debate</td>
<td>119</td>
</tr>
<tr>
<td>Experimental evidence</td>
<td>121</td>
</tr>
<tr>
<td>Evidence based on grain fabric</td>
<td>121</td>
</tr>
<tr>
<td>The origin of HCS</td>
<td>122</td>
</tr>
<tr>
<td>Conclusion</td>
<td>124</td>
</tr>
<tr>
<td><strong>Appendix 1.</strong></td>
<td>125</td>
</tr>
<tr>
<td><strong>Appendix 2.</strong></td>
<td>127</td>
</tr>
<tr>
<td><strong>References</strong></td>
<td>129</td>
</tr>
</tbody>
</table>
Chapter 1. Introduction to Clastic Sedimentology

Clastic sedimentology is the branch of geology that studies sediment and sedimentary rocks that are made up of particles that are the solid products of weathering at or near the Earth’s surface. Thus, clastic sedimentology is concerned with gravel, sand and mud and the rocks that form by the induration (formation into rocks) of these particulate materials (rudites, sandstones and shales; see Chapter 3). The goal of this book is to introduce the terminology and fundamental concepts that are necessary for the description and interpretation of sediment and sedimentary rocks.

Why Study Clastic Sedimentology?

There are at least two good reasons for studying clastic sedimentology. The first is because humans, and most other species on the planet, interact with the Earth largely at its surface. Sedimentary rocks make up only 7.9% of the total crust of the Earth which is dominated by igneous and metamorphic rocks (Fig. 1-1). However, the surface of the Earth is dominated by sedimentary rocks and almost 50% of that surface is made up of clastic sedimentary rocks (predominantly shale and sandstone). Humans are not uniformly distributed over the Earth’s surface and if we were to further consider the proportion of the human population that lives immediately on clastic sediments we would find that almost all of us interact with the Earth’s surface through a cover of clastic sediments and/or sedimentary rocks. We interact with this sedimentary surface in a variety of ways. We grow food within it and raise livestock on it so that it is crucial to global food requirements. We build our homes on it and take water and other resources from it. At the same time we hide our garbage in it and we modify its physical and chemical properties in such a way as to render it unsuitable for many of our needs. Thus, given our uses and abuses of the Earth's surface it is particularly important that we understand the various properties of sediments and have systematic methods of describing these properties.

A second reason for studying clastic, and all other, sedimentary rocks is because they preserve the record of changing environmental conditions at or near the Earth’s surface over almost the whole of geologic time. All sediment and sedimentary rocks were deposited at the Earth’s surface, either in the oceans or on the continents. As such, these deposits were influenced by processes that were acting on the Earth’s surface, in their environments of deposition. A large part of clastic sedimentology is devoted to the development of criteria for the recognition of the action of various processes on sediments in their environment of deposition. By developing tools for the recognition of the signature of these processes in a sediment we can unravel the history of environmental change that is preserved in the stratigraphic sequence of rocks that has been laid down over geologic time.

![Figure 1-1. Relative abundance of rock types in the Earth's crust and at the Earth's surface.](image-url)
About these notes

These notes were first compiled in 1992 from the author's lecture notes that were prepared over six years of teaching Clastic Sedimentology at the Junior Undergraduate level, first at Brandon University and later at Brock University, and are meant to provide an inexpensive "text" to support this half-credit second year course. Sedimentologists will notice that these notes contain material similar to that in some of the "classic" sedimentology textbooks but also includes much of my own bias and understanding. I was fortunate enough to have been (and will likely always be) a student of Gerry Middleton at McMaster University and a significant proportion of Chapters 2, 3 and 4 are derived from an understanding (or perhaps misunderstanding in some cases) of the great experiences that I have had with one of the father's of modern sedimentology. At McMaster I was also provided the opportunity to learn much from Roger Walker, another Canadian sedimentologist of significant stature. Despite these opportunities, any shortcomings within these notes reflect my own limitations and are certainly despite the input of these two great educators.

These notes do not aim to cover all of the important aspects of clastic sedimentology but only those that the author has decided to stress in this one semester, introductory course. A list of more comprehensive texts is given at the end of this introductory chapter. Some of the examples and figures in these notes were modified from these texts and they will provide a more detailed treatment of several topics that are covered in this course. These notes are expected to evolve with time as new sections are added and old ones dropped, although sections that are removed from the course will remain in the notes, provided that the cost to students remains reasonable. In an earlier addition of these notes I added several colour plate. Unfortunately these plates resulted in a doubling of the cost of the notes. For that reason I have not included the plates here.

In 2005 I began to put Power Point lecture presentations that I created for the course onto the World Wide WEB. I subsequently added the full course notes to the Web in the hope that they would provide a resource for students at other Universities. These notes, and the Power Point presentations are available free of charge to anyone who wants to download them; they are available at www.brocku.ca/sedimentology. In some cases the notes may be downloaded and provided to students by a third party. My condition for such downloading and reproduction is that under no circumstances will a profit be added to the cost of the notes to students, other than a charge of up to 20% of reproduction costs for distribution by a University book store or similar service that prints the notes for sale to students. There will be no charge that incurs a profit to any other person or group, including myself. The reason for these notes is to provide an inexpensive but useful resource for students. If your school would like to reproduce these notes for sale to students I ask that I be approached for permission to do so. Please direct such requests to me at rcheel@brocku.ca with the subject line "SedNotes Request" and include the per unit reproduction costs and the proposed sale price. I will respond to such requests promptly.

The notes begin with a section on the most fundamental properties of clastic sediments, those properties that collectively make up the "texture" of a sediment. The next section reviews the criteria for classifying sediment and sedimentary rocks, criteria that are commonly based on the texture of the rocks. The remainder of the notes focus on the behaviour of sediments in response to processes in subaqueous settings, the most common settings in which sediments are deposited. This begins with an examination of some of the important characteristics of unidirectional fluid motion (like the currents in a river) and the manner in which sediment is moved by such fluid motion. This is followed by a section that examines the bulk response of a sediment to unidirectional fluid motion (i.e., bedforms) and the criteria for interpreting hydraulic condition on the basis of the internal structure of sediments and sedimentary rocks (i.e., internal stratification and cross-stratification). The final chapter briefly considers all of these aspects of fluid motion and sediment response but for currents that reverse in direction over relatively short periods (seconds to tens of seconds) and are generated by water surface waves that are common in many marine and lacustrine environments.
Comprehensive sedimentology textbooks


Introduction to Sedimentology. Sediment Transport and Sedimentary Environments. Authors. Sedimentology is the study of sedimentary rocks and their formation. The subject covers processes which produce sediments, such as weathering and erosion, transport and deposition by water or air, and also the changes which take place in sediments after their deposition (diagenesis). Changes in sedimentary rocks at temperatures of over 200–250°C are called metamorphic processes and are not dealt with here. Introduction. Why study clastic sedimentology? About this book Comprehensive sedimentology textbooks. Chapter 2. Grain Texture. Introduction Grain Size. Volume Linear dimensions. Direct measurement Sieving Settling velocity Stoke’s Law of Settling Grade scales Displaying grain size data Describing grain size distributions Median Mean Sorting coefficient Skewness Kurtosis Paleoenvironmental implications Why measure grain size?