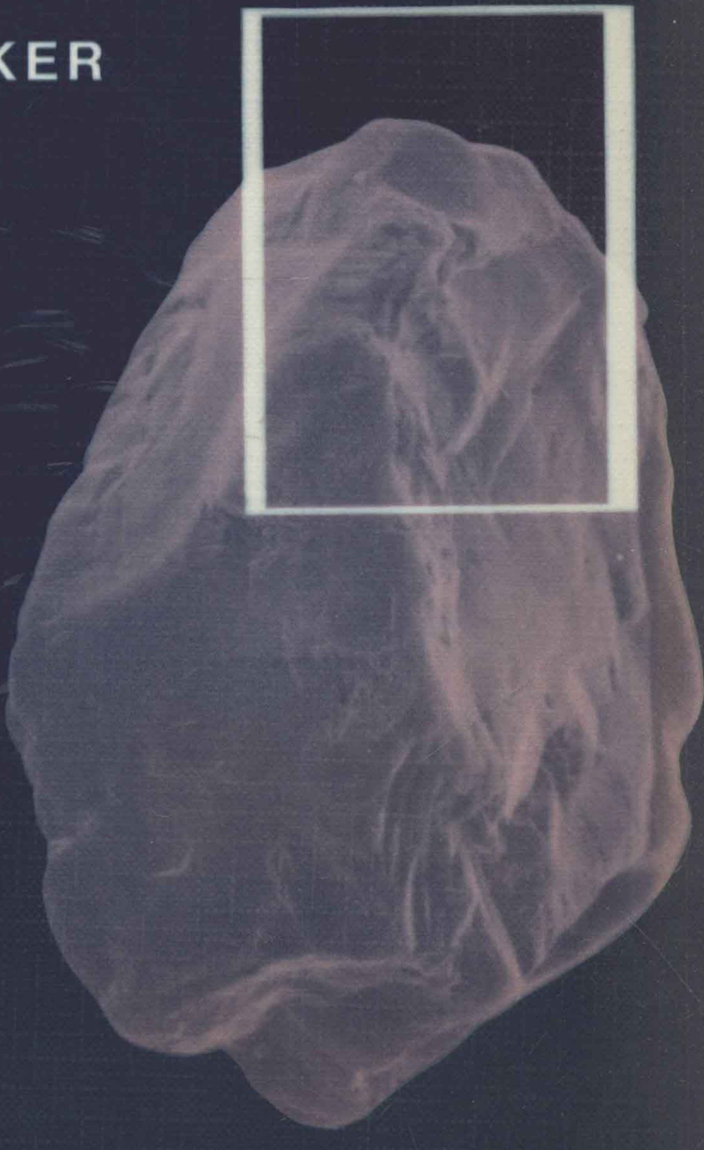
Techniques in Sedimentology

Edited by
MAURICE TUCKER



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Edited by
MAURICE TUCKER
BSc, PhD
Department of Geological Sciences
University of Durham
Durham DH1 3LE
UK

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3 Cambridge Center, Suite 208
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667 Lytton Avenue, Palo Alto
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Techniques in Sedimentology

Preface

Sedimentologists are keen to discover the processes, conditions and environments of deposition and diagenesis of their rocks. They currently use a whole range of quite sophisticated instruments and machines, in addition to routine fieldwork and microscopic study. Although geologists have been making field observations for nearly 200 years, in the last two decades there have been many new approaches to the collection and processing of field data. New sedimentary structures and relationships are still being found in 'classic', well-studied rocks. The microscopic examination of sediments is an essential tool in the description and interpretation of sediments, but there are ways to maximize the information a thin slice of rock will yield. Chemical analyses are being increasingly used to prise the stories out of sedimentary minerals and rocks and many of the analytical procedures have come from other branches of the earth sciences or are more frequently used by other geologists.

This book aims to cover all the various techniques used in the study of sedimentary rocks. It aims to provide instructions and advice on the various approaches and to give examples of the information obtained and interpretations possible.

One chapter is concerned with the collection of field data, with the emphasis on how these data can be analysed and presented. The following chapter looks at grain size analyses, and grain size parameters and their interpretation. Two chapters deal with microscopic studies: one being concerned with the production of thin sections, peels and slices, and the other with the description and interpretation of sedimentary minerals and depositional and diagenetic textures. The now popular technique of cathodoluminiscence, which can reveal hidden structures, follows. The X-ray diffraction of mudrocks, carbonates and cherts, providing information on mineralogy and composition, is treated in some depth. A chapter on Scanning Electron Microscopy explains how the machine works and how samples are best prepared and viewed, and then gives examples of SEM uses in soft-rock geology. A final chapter reviews the principles behind the chemistry of sedimentary rocks and discusses the collection and preparation of samples, followed by the techniques of electron beam microanalysis, XRF, AAS, ICP, INAA and stable isotope MS. Sections are included on analytical quality and the reporting of results and the chapter concludes with examples of the application of chemcial analysis to sedimentary problems. This book is a multi-authored volume and so naturally there are different levels of treatment and emphasis throughout the text.

Techniques in Sedimentology is written for final year undergraduates and postgraduates, to give them information and ideas on how to deal with their rocks in the field and samples in the laboratory during dissertation and thesis research. Much useful background material is also provided which will be relevant to lecture courses. The book will also be invaluable to professional sedimentologists, in industry and academia alike, and to other earth scientists, as a source book for the various techniques covered and for tips and recipes on extracting information from sedimentary rocks.

Maurice Tucker
Durham, March 1988

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Contents

List of contributors

IAN FAIRCHILD
Department of Geological Sciences, The University, Birmingham B15 2TT.

JOHN GRAHAM
Department of Geology, Trinity College, Dublin, Eire.

RON HARDY
Department of Geologial Sciences, The University, Durham DH1 3LE.

GILL HARWOOD
Department of Geology, The University, Newcastle upon Tyne NE1 7RU.

GRAHAM HENDRY
Department of Geological Sciences, The University, Birmingham B15 2TT.

JOHN MCMANUS
Department of Geology, The University, Dundee DD1 4HN.

JOHN MILLER
Grant Institute of Geology, The University, Edinburgh EH9 3JW.

MARTIN QUEST
Department of Geological Sciences, The University, Birmingham B15 2TT.
Present address: Core Laboratories, Isleworth, Middlesex TW7 5AB.

NIGEL TREWIN
Department of Geology and Mineralogy, The University, Aberdeen AB9 1AS.

MAURICE TUCKER
Department of Geological Sciences, The University, Durham DH1 3LE.

1 Introduction

MAURICE TUCKER

1.1 INTRODUCTION AND RATIONALE

The study of sediments and sedimentary rocks has come a long way from the early days of field observations followed by a cursory examination of samples in the laboratory. Now many sophisticated techniques are applied to data collected in the field and to specimens back in the laboratory. Some of these techniques have been brought in from other branches of the earth sciences, while some have been specifically developed by sedimentologists.

Research on sediments and sedimentary rocks is usually a progressive gathering of information. First, there is the fieldwork, an essential part of any sedimentological project, from which data relating to the conditions and environments of deposition are obtained. With modern sediments, measurements can be made of the various environmental parameters such as salinity, current velocity and suspended sediment content, and the sediments themselves can be subject to close scrutiny and sampling. With ancient sediments, the identification of facies types and facies associations follows from detailed examination of sedimentary structures, lithologies, fossil content etc., and subsequent laboratory work on representative rocks. After consideration of depositional environment, the larger scale context of the sequence in its sedimentary basin may be sought, necessitating information on the broad palaeogeographical setting, the tectonics of the region, both in terms of synsedimentary and post-sedimentary movements, and the subsurface structure, perhaps with input from seismic sections. With an understanding of a sedimentary rock's deposition and tectonic history, leading to an appreciation of the rock's burial history, the diagenetic changes can be studied to throw light on the patterns of cementation and alteration of the original sediment, and on the nature of pore fluids which have moved through the sedimentary sequence. Although much information on the diagenesis can be obtained from petrograpic microscopic examination of thin sections of the rock, sophisticated instruments are increasingly used to analyse the rocks and their components for mineralogical composition, major, minor and trace elements, isotopic signatures and organic content. The data obtained provide much useful information on the diagenesis, and also on the original depositional conditions.

Which techniques to use in sedimentological research depend of course on the questions being asked. The aims of a project should be reasonably clear before work is commenced; knowing what answers are being sought makes it much easier to select the appropriate technique. There is usually not much point in hitting a rock with all the sophisticated techniques going, in the hope that something meaningful will come out of all the data. It may be that the problem would be solved with a few simple field measurements or five minutes with the microscope on a thin section, rather than a detailed geochemical analysis giving hundreds of impressive numbers which add little to one's understanding of the rock.

The techniques available to sedimentologists, and those covered in this book, often cannot be used for all sedimentary rock types. It is necessary to be aware of what all the various instruments available in a well-found earth sciences department can do and how they can be used with sedimentary rocks. Many such instruments are more frequently used and operated by hard rocks petrologists and geochemists, but they can be used with great success on sedimentary rocks, as long as one is still seeking an answer to a particular question rather than just another analysis. Certain techniques are best suited to specific sedimentary rock types and cannot be used generally to analyse any rock. In the next sections of this introduction (1.2 to 1.9), the techniques covered in this book, in Chapters 2 to 9 are briefly reviewed. Not all the possible techniques available are included in this book and Section 1.10 notes what is omitted and where to find details. It also indicates where new techniques in soft-rock geology are frequently published, so that the keen student can keep up to date with developments in this field.

1.2 COLLECTION AND ANALYSIS OF FIELD DATA: CHAPTER 2

In Chapter 2, John Graham examines the rationale behind fieldwork, and the various ways in which field data can be collected and presented in graphic form are shown. The various sedimentary structures and the identification of lithologies and fossils are not described in detail since there are textbooks on these topics (e.g. Collinson & Thompson, 1982; Tucker, 1982), but the problems of recognizing certain structures are aired. The collection and analysis of palaeocurrent data (described in Section 2.3) are important in facies analysis and palaeogeographical reconstruction and statistical treatments are available to make the data more meaningful. There are many ways in which to examine a sedimentary sequence for rhythms and cycles (Section 2.4) and again the field data can be manipulated by statistical analysis to reveal trends. This chapter also shows the many ways in which information from the field can be presented for publication.

1.3 GRAIN SIZE DETERMINATION AND INTERPRETATION: CHAPTER 3

It is very important to know quite precisely what the grain size distribution is in a sediment sample and the procedures here are described by John McManus. Sample preparation varies from the unnecessary to having to break up the rock into its constituent grains, dissolve out the cement in acid, or make a thin section of the sample. Sieving, sedimentation methods and Coulter counter analysis can be used for unconsolidated or disaggregated samples, but microscopic measurements are required for fully lithified sandstones and most limestones. With a grain size analysis at hand, various statistical parameters are calculated. From these, with care, it is possible to make deductions on the sediment's conditions and environment of deposition.

1.4 MICROSCOPIC TECHNIQUES I: SLICES, SLIDES, STAINS AND PEELS: CHAPTER 4

The rock thin section is the basis of much routine description and interpretation but all too often the production of the slide is not given thought. John Miller explains how the best can be achieved by double-polished thin sections and describes the various techniques of impregnating, staining and etching to encourage the slide to give up more of its hidden secrets. Acetate peels are frequently made of limestones and the manufacture of these is also discussed.

1.5 MICROSCOPIC TECHNIQUES II: PRINCIPLES OF SEDIMENTARY PETROGRAPHY: CHAPTER 5

This chapter is by Gill Harwood and follows on from the previous one by explaining how the various minerals and textures in sedimentary rocks can be recognized and interpreted. The chapter is written in such a way so that it is applicable to all sedimentary rock types, rather than discussing each separately, as is frequently the case in sedimentary petrography texts. There is a huge textbook literature on 'sed. pet.' and many of the books will be readily available in a university or institute library (see, e.g. Folk, 1966; Scholle, 1978, 1979; Tucker, 1981; Blatt, 1982). Thus, in depositional fabrics (Section 5.2), grain identification, modal composition, point counting techniques, grain morphology, size and orientation, and provenance studies are briefly treated with pertinent literature references and many diagrams, photomicrographs and tables. In diagenetic fabrics (Section 5.3), again a topic with a voluminous literature, the various diagenetic environments and porosity types are noted, and then compaction-related fabrics are described and illustrated. Here, compaction is divided into that resulting from mechanical processes, from chemical (solution) processes between grains, and from chemical processes in lithified sediments. Cementation is a major factor in a rock's diagenesis and Section 5.3.3 demonstrates the variety of cements in sandstones and limestones, their precipitational environments and how the timing of cementation can be deduced. Typical fabrics of dissolution, alteration and replacement are described and illustrated, with emphasis on how these can be distinguished from other diagenetic fabrics. This overview of microscopic fabrics shows what can be seen, how they can be described, and their significance in terms of depositional and diagenetic processes. Sound microscope work is a fundamental prerequisite for geochemical analyses, and of course it provides much basic information on the nature, origin and history of a sedimentary rock.

1.6 CATHODOLUMINESCENCE: CHAPTER 6

This chapter is presented by John Miller and describes a technique which has been very popular amongst carbonate sedimentologists for the last few years. Very pretty colour photographs can be obtained with CL and these have enhanced many a lecture and published paper. The specimen in a vacuum chamber is bombarded with electrons and light is emitted if activator elements are present. An explanation of the luminescence is given, with a consideration of excitation factors and luminescence centres, and then a discussion of equipment needs and operation. Sample preparation is relatively easy; polished thin sections (or slabs) are used. General principles of the description and interpretation of CL results are given, along with applications to sedimentology. It is with carbonate rocks that CL is most used and here it is particularly useful for recognizing different cement generations and for distinguishing replacements from cements. In sandstones it can differentiate between different types of quartz grain, help to spot small feldspar crystals, and reveal overgrowths on detrital grains. Good photography is important in CL studies and hints are provided on how the quality of photomicrographs can be improved. These days, a study of carbonate diagenesis is not complete without consideration of cathodoluminescence and the textures it reveals.

1.7 X-RAY DIFFRACTION OF SEDIMENTARY ROCKS: CHAPTER 7

X-ray diffraction is a routine technique in the study of mudrocks and is frequently used with carbonate rocks too, and cherts. Ron Hardy and Maurice Tucker provide a brief general introduction to XRD, the theory and the instrument. XRD is the standard technique for determining clay mineralogy and various procedures are adopted to separate the different clay minerals. Examples are given of how XRD data from muds can be used to infer palaeoclimate, transport direction, conditions of deposition, and the pattern of diagenesis. With carbonates, XRD is mostly used to study the composition of modern sediments, the Mg content of calcite, and the stoichiometry and ordering of dolomites. The procedure is relatively straightforward and the precision is good, and much useful information is provided. Fine-grained siliceous rocks are often difficult to describe petrographically, but XRD enables the minerals present, opal A, opal C-T or quartz, to be determined readily. It has been especially useful in documenting the diagenesis of deep sea siliceous oozes through to radiolarian and diatom cherts.

1.8 SCANNING ELECTRON MICROSCOPY IN SEDIMENTOLOGY: CHAPTER 8

The SEM has become popular for studying fine-grained sedimentary rocks and for examining the ultrastructure of grains, fossils and cements. Nigel Trewin briefly describes the microscope and provides an account of how sedimentary materials are prepared for the machine. The SEM is a delicate machine and often the picture on the screen or the photographs may not be as good as expected. Comments are given on how such difficulties can be overcome or minimized. The SEM also has the facility for attachments providing analysis, EDS and EDAX, and these can be most useful when the elemental composition of the specimen is not known. An SEM can also be adjusted to give a back-scattered electron image and with mudrocks this can reveal the nature of the clay minerals themselves. The SEM has been applied to many branches of sedimentology, particularly the study of the surface textures of grains, both carbonate and clastic. In diagenetic studies, the SEM is extensively used with sandstones, to look at the nature of clay cements, evidence of grain dissolution and quartz overgrowths. In carbonates too, the fine structure of ooids and cements is only seen with SEM examination.

1.9 CHEMICAL ANALYSIS OF SEDIMENTARY ROCKS: CHAPTER 9

In many branches of sedimentology, chemical analyses are made to determine major, minor and trace element concentrations and stable isotope signatures, to give information on the conditions of deposition and diagenesis, and on long- and short-term variations in seawater chemistry and elemental cycling. In this chapter, largely written by Ian Fairchild, with contributions from his colleagues Graham Hendry and Martin Quest, and Maurice Tucker, a quite detailed background is given on some of the important principles of sedimentary geochemistry: concentrations and activities, equilibrium, adsorption, incorporation of trace elements and partition coefficients, and stable isotope fractionation This chapter should help the reader appreciate some of the problems in interpreting geochemical data from rocks where, commonly, inferences are being made about the nature of fluids from which precipitation took place. In sedimentary geochemistry much emphasis is now placed on the sample itself since there is a great awareness of the chemical inhomogeneities in a coarse-grained, well-cemented rock. Individual grains or growth zones in a cement are now analysed where possible, rather than the bulk analyses of whole rocks.

The techniques covered in this chapter are X-ray fluorescence, atomic absorption spectrometry, inductively-coupled plasma optical emission and mass spectrometry, electron microbeam analysis, neutron activation analysis and stable isotope (C.O.S) analysis. With the treatment of most of these techniques, the accent is not on the instrument operation, or theory — since there are many textbooks covering these aspects (e.g. Potts, 1987) — but on how sedimentary rocks can be analysed by these methods and the sorts of data that are obtained. A further section discusses precision and accuracy, the use of standards and how data can be presented.

To illustrate the use of geochemical data from sedimentary rocks, applications are described to the study of provenance and weathering, the deduction of environmental parameters, diagenesis and pore fluid chemistry, and elemental cycling.

1.10 TECHNIQUES NOT INCLUDED

This book describes most of the techniques currently employed by sedimentologists in their research into facies and diagenesis. It does not cover techniques more in the field of basin analysis, such as seismic stratigraphic interpretation, and decompaction, backstripping and geohistory analysis. A recent book on this which includes wire-line log interpretation and the tectonic analysis of basins is published by the Open University (1987). The measurement of porosity-permeability is also not covered.

This book does not discuss the techniques for collecting modern sediments through shallow coring, including vibracoring. The latter is described by Lanesky *et al.* (1979). Smith (1984) and others. There are many papers describing very simple inexpensive coring devices for marsh, tidal flat and shallow subtidal sediments (see, e.g. Perillo *et al.*, 1984). Also with modern deposits (and some older unconsolidated sands), large peels can be taken to demonstrate the sedimentary structures. Cloth is put against a smoothed, usually vertical surface of damp sand and a low viscosity epoxy resin sprayed or painted on to and through the cloth to the sand. On drying and removal, the sedimentary structures are neatly and conveniently preserved on the cloth. This technique is fully described by Bouma (1969).

The techniques used by sedimentologists are constantly being improved and new ones developed. Many sedimentological journals publish the occasional accounts of a new techique or method, and in many research papers there is often a methods section, which may reveal a slightly different, perhaps better, way of doing something. The *Journal of Sedimentary Petrology* publishes many 'research-methods papers', all collected together into one particular issue of the year. It is useful to keep an eye out for this section for the latest developments in techniques in sedimentology.

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2 Collection and analysis of field data

JOHN GRAHAM

2.1 INTRODUCTION

Much of the information preserved in sedimentary rocks can be observed and recorded in the field. The amount of detail which is recorded will vary with the purpose of the study and the amount of time and money available. This chapter is primarily concerned with those studies involving sedimentological aspects of sedimentary rocks rather than structural or other aspects. Common aims of such studies are the interpretation of depositional environments and stratigraphic correlation. Direction is towards ancient sedimentary rocks rather than modern sediments, since techniques for studying the latter are often different and specialized, and are admirably covered in other texts such as Bouma (1969). In fieldwork the tools and aids commonly used are relatively simple, and include maps and aerial photographs, hammer and chisels, dilute acid, hand lens, penknife, tape, camera, binoculars and compass-clinometer.

During fieldwork, information is recorded at selected locations within sedimentary formations. This selection is often determined naturally such that all available exposures are examined. In other cases, e.g. in glaciated terrains, exposure may be sufficiently abundant that deliberate sampling is possible. The generation of natural exposures may well include a bias towards particular lithologies, e.g. sandstones tend to be exposed preferentially to mudrocks. These limitations must be considered if statements regarding bulk properties of rock units are to be made. For many purposes, vertical profiles of sedimentary strata are most useful. In order to construct these, continuous exposures perpendicular to dip and strike are preferred. With such continuous exposures, often chosen where access is easy, one must always be cautious of a possible bias because of an underlying lithological control.

The main aspects of sedimentary rocks which are likely to be recorded in the field are:

Lithology:	mineralogy/composition and colour of the rock.
Texture:	grain size, grain shape, sorting and fabric.
Beds:	designation of beds and bedding planes, bed thickness, bed geometry, contacts between beds.
Sedimentary structures:	internal structures of beds, structures on bedding surfaces and larger scale structures involving several beds.
Fossil content:	type, mode of occurrence and preservation of both body fossils and trace fossils.
Palaeocurrent data:	orientation of palaeocurrent indicators and other essential structural information.

In some successions there will be an abundance of information which must be recorded concisely and objectively. Records are normally produced in three complementary forms and may be augmented by data from samples collected for further laboratory work. These are:

(i) Field notes: These are written descriptions of observed features which will also include precise details of location. Guidance on the production of an accurate, concise and neat notebook is given in Barnes (1981), Moseley (1981) and Tucker (1982).

(ii) Drawings and photographs: Many features are best described by means of carefully labelled field sketches, supplemented where possible by photographs. All photographs must be cross referenced to field notes or logs and it is important to include a scale on each photograph and sketch.

(iii) Graphic logs: These are diagrams of measured vertical sections through sedimentary rock units. There are a variety of formats which are discussed below (Section 2.2.9). Although many logs are constructed on pre-printed forms, additional field notes accompany them in most cases.

2.2 RECORDING IN THE FIELD

2.2.1 Lithology identification and description

The ability to recognize different sedimentary rock types is embodied in most geology courses and is amply covered in texts such as Tucker (1981) and Blatt (1982). Such identification is generally quicker and more reliable with increased experience in the field, acquired initially under controlled conditions, i.e. with supervision and laboratory back up. Although there is a huge range of sedimentary rock types, by far the majority of successions contain only mudrocks, sandstones, conglomerates, limestones and dolomites, evaporites, and their admixtures. Thus some comments are made here on the recording of these major rock types.

MUDROCKS

Mudrocks can be subdivided in the field according to a simple objective scheme such as the widely accepted one shown in Table 2.1 (Ingram, 1953). It involves only the approximate determination of grain size and fissility. Colour, which is also particularly useful in mudrocks, is generally employed as a prefix. Application of more sophisticated laboratory techniques is necessary to obtain compositional information (Chapters 7, 8 and 9).

SANDSTONES

The lithology of sandstones, in terms of the grains/matrix ratio, the main detrital constituents, and the type of cement, can commonly be identified in the field, although detailed description and classification require thin section analysis (Chapters 4 and 5). The problem of matrix percentage and origin is difficult, even in thin section (Blatt, 1982), but it is often possible in a crude way to distinguish matrix-rich (wackes) from matrix-poor (arenites) sandstones in the field. This is most difficult when lithic grains are dominant and the sandstones are dark coloured and slightly metamorphosed and/or deformed.

Table 2.1. Scheme for nomenclature of fine-grained clastic sedimentary rocks

		Breaking characteristic	
Grain size	General terms	Non-fissile	Fissile
Silt + clay	Mudrock	Mudstone	Shale
Silt ≫ clay	Siltrock	Siltstone	Silt shale
Clay ≫ silt	Clayrock	Claystone	Clay shale

CONGLOMERATES

Conglomerates contrast with other rock types in that most of the measurement, description and classification is undertaken in the field, and laboratory study often takes a secondary role. A full description will involve measurement of size, determination of clast or matrix support, description of internal fabric and structures and data on composition (Fig. 2.1). Some commonly used descriptive terms for these coarse grained sedimentary rocks are:

Diamictite: a non-genetic term referring to any poorly sorted, terrigenous, generally non-calcareous, clast-sand-mud admixture regardless of depositional environment.

Breccia: a term used when the majority of the clasts are angular (in the sense of Section 2.2.2).

Extraformational: a term to describe clasts from source rocks outside the basin of deposition.

Intraformational: a term to describe clasts from fragmentation processes that take place within the basin of deposition and that are contemporaneous with sedimentation.

Oligomict: a term to describe conglomerates where one clast type, usually of stable, resistant material, is dominant.

Polymict (petromict): a term to describe conglomerates where several clast types are present.

Description can be enhanced by using the dominant clast size and clast type as prefixes, e.g. granite boulder conglomerate. A special series of terms is used where volcanic processes are involved in conglomerate formation (Lajoie, 1984).

Further information on the sedimentary structures present in conglomerates can be conveyed by use of the concise lithofacies codes as developed by Miall (1977, 1978), Rust (1978) and Eyles, Eyles & Miall (1983) (Table 2.2). Although these have been developed specifically for alluvial fan, fluvial and glacial lithofacies, there is every likelihood that they will and can be used for all conglomerates. These

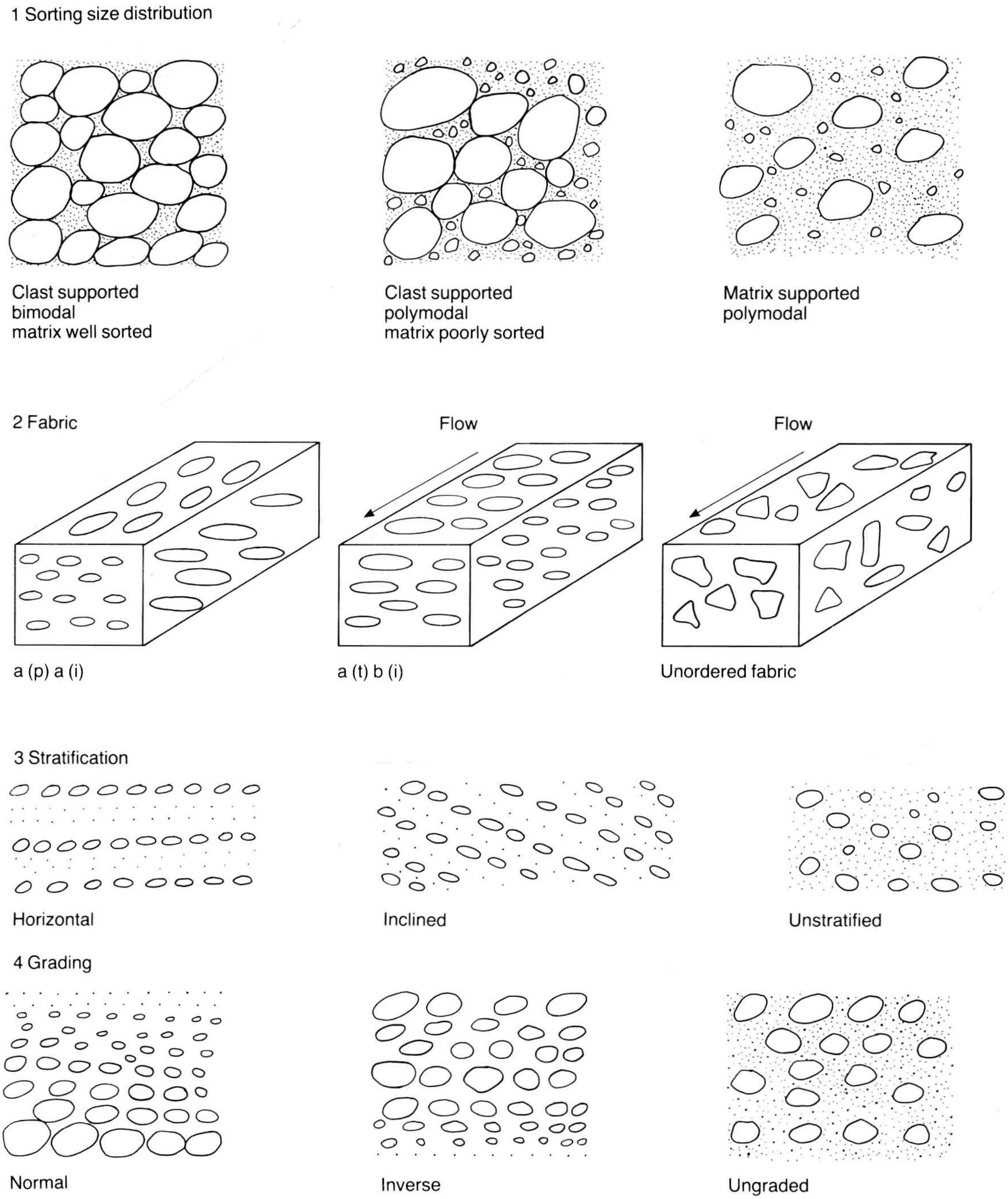

Fig. 2.1. Features used in a textural and structural classification of conglomerate (from Harms, Southard & Walker, 1982). Under fabric, codes a and b refer to long and intermediate axes respectively; p = parallel to flow, t = transverse to flow, i = imbricate. (Reproduced by permission of SEPM.)

Table 2.2. Use of concise lithofacies codes in field description

(a) Criteria used for low sinuosity and glaciofluvial stream deposits (modified from Miall, 1977)

Code	Lithofacies	Sedimentary structures
Gms	Massive, matrix-supported gravel	None
Gm	Massive or crudely bedded gravel	Horizontal bedding, imbrication
Gt	Gravel, stratified	Trough crossbeds
Gp	Gravel, stratified	Planar crossbeds
St	Sand, medium to coarse, may be pebbly	Solitary (theta) or grouped (pi) trough crossbeds
Sp	Sand, medium to coarse, may be pebbly	Solitary (alpha) or grouped (omicron) planar crossbeds
Sr	Sand, very fine to coarse	Ripple marks of all types
Sh	Sand, very fine to very coarse, may be pebbly	Horizontal lamination, parting or streaming lineation
Sl	Sand, fine	Low angle (10°) crossbeds
Se	Erosional scours with intraclasts	Crude crossbedding
Ss	Sand, fine to coarse, may be pebbly	Broad, shallow scours including eta cross-stratification
Sse, She, Spe	Sand	Analogous to Ss, Sh, Sp
Fl	Sand, silt, mud	Fine lamination, very small ripples
Fsc	Silt, mud	Laminated to massive
Fcf	Mud	Massive with freshwater molluscs
Fm	Mud, silt	Massive, dessication cracks
Fr	Silt, mud	Rootlet traces
C	Coal, Carbonaceous mud	Plants, mud films
P	Carbonate	Pedogenic features

(b) Diagnostic criteria for recognition of common matrix-supported diamict lithofacies (from Eyles *et al.*, 1983)

Code	Lithofacies	Description
Dmm	Matrix-supported, massive	Structureless mud/sand/pebble admixture
Dmm(r)	Dmm with evidence of resedimentation	Initially appears structureless but careful cleaning, macro-sectioning, or X-ray photography reveals subtle textural variability and fine structure (e.g. silt or clay stringers with small flow noses). Stratification less than 10% of unit thickness

Code	Lithofacies	Sedimentary structures
Dmm(c)	Dmm with evidence of current reworking	Initially appears structureless but careful cleaning, macro-sectioning, or textural analysis reveals fine structures and textural variability produced traction current activity (e.g. isolated ripples or ripple trains). Stratification less than 10% of unit thickness
Dmm(s)	Matrix-rupported, massive, sheared	Dense, matrix supported diamict with locally high clast concentrations. Presence of distinctively shaped flat-iron clasts oriented parallel to flow direction, sheared
Dms	Matrix-supported, stratified diamict	Obvious textural differentiation or structure within diamict. Stratification more than 10% of unit thickness
Dms(r)	Dms with evidence of resedimentation	Flow noses frequently present; diamict may contain rafts of deformed silt/clay laminae and abundant silt/stringers and rip-up clasts. May show slight grading. Dms(r) units often have higher clast content than massive units; clast clusters common. Clast fabric random or parallel to bedding. Erosion and incorporation of underlying material may be evident
Dms(c)	Dms with evidence of current reworking	Diamict often coarse (winnowed) interbedded with sandy, silty and gravelly beds showing evidence of traction current activity (e.g. ripples, trough or planar cross-bedding). May be recorded as Dmm, St, Dms, Sr etc. according to scale of logging. Abundant sandy stringers in diamict. Units may have channelized bases
Dmg	Matrix-supported, graded	Diamict exhibits variable vertical grading in either matrix or clast content; may grade into Dcg
Dmg(r)	Dmg — with evidence of resedimentation	Clast imbrication common

schemes are still being refined and modified (cf. Eyles *et al.*, 1983 with McCabe, Dardis & Hanvey, 1984 and Shultz, 1984) and the overlap between the D (diamictite) and G (gravel) codes needs further clarification. The codes should not be regarded as all that is needed for environmental interpretation

(Dreimanis, 1984; Kemmis & Hallberg, 1984) but simply a concise and convenient shorthand description of some of the main observable features.

In addition to information on depositional processes and environments, polymict conglomerates can yield some information on the relative contribution of various source lithologies. However, there are many factors which affect the presence and size of clasts in conglomerates. The initial size of fragments released from the source area varies with lithology, being related to features such as bed thickness, joint spacing and resistance to weathering. In addition clasts have varying resistances to size reduction during transport. To avoid spurious size-related effects, compositional data can be compared at constant size. This can be achieved either by counting the clast assemblage for a given size class or by a more detailed analysis in which the proportion of clast types is examined over a spectrum of size classes at a single site.

To determine the distribution of clast types by size, an area of several square metres should be chosen on a clean exposure surface on which all clasts can be identified easily. Areas of strong shape selection, common in some proximal fluvial and beach environments, should be avoided since this can introduce a bias towards anisotropic clast lithologies. Preliminary observations and the nature of the study will determine the number of lithological types to which clasts are assigned. Often crude discriminants, e.g. granite porphyry, etc., will suffice. More detailed studies require more subtle subdivision and may involve thin section checks on field identification.

Clast counting should proceed from the finest clast size interval. It is important that all clasts are counted to eliminate bias; repetition may be avoided by using chalk to mark counted clasts. As coarser size clasts are counted, the area over which clasts are counted may be increased as a representative clast population (>100) is sampled. These data can be summarized by constructing a plot of percentage clast types against grain size. The proportion of any clast type at a given grain size can easily be read from the plot, allowing direct comparison from locality to locality (Fig. 2.2). To present data from many localities, stratigraphic columns can be used to show changes in clast composition, or a map can be devised to show the regional distribution of clast types (Figs 2.3 and 2.4).

Many published studies of clast composition are of limited value, either due to lack of specification of clast size or to problems of how the clasts to be measured were selected. Techniques of random selection of clasts involve the placing of a sampling grid, for example chalked squares or a piece of fish net, over the exposure and measuring either at grid intersections or within small grid squares. The former may be difficult to apply if only certain sizes are accepted; the latter may introduce bias if only a limited number of clasts per square are to be measured. It is important that the method of data collection is clearly stated so that its limitations can be assessed by later workers.

LIMESTONES AND DOLOMITES

Field distinction of carbonate rocks is possible, but detailed description is best performed in the laboratory using thin sections and acetate peels (Chapter 4) although under favourable conditions the latter may be made in the field. Dilute 10% HCl is a standard field aid. Whilst limestones will react vigorously, most dolomites will show little or no reaction unless they are powdered. The addition of Alizarin red S in HCl will stain limestones but not dolomite (Chapter 4) and this can be used in the field. In addition many dolomites are yellow or brown weathering, harder than limestones and may show poor fossil preservation. In sequences of alternating

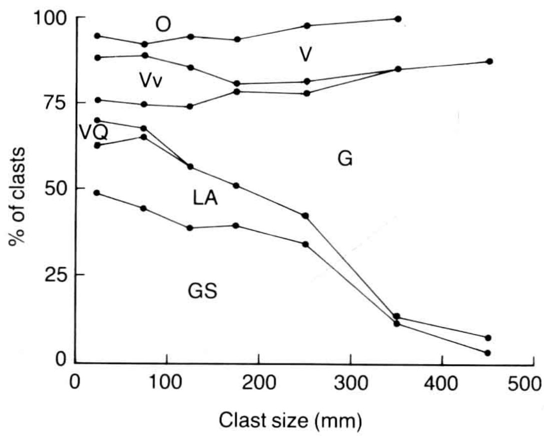

Fig. 2.2. Plot of percentage clast types versus grain size for one locality for a Lower Devonian fluvial conglomerate (diagram kindly supplied by Peter Haughton, University of Glasgow). Key to clast types: GS = greenschist, LA = lithic arenite, VQ = vein quartz, G = granite, Vv = vesicular volcanics, V = other volcanics, O = other.

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