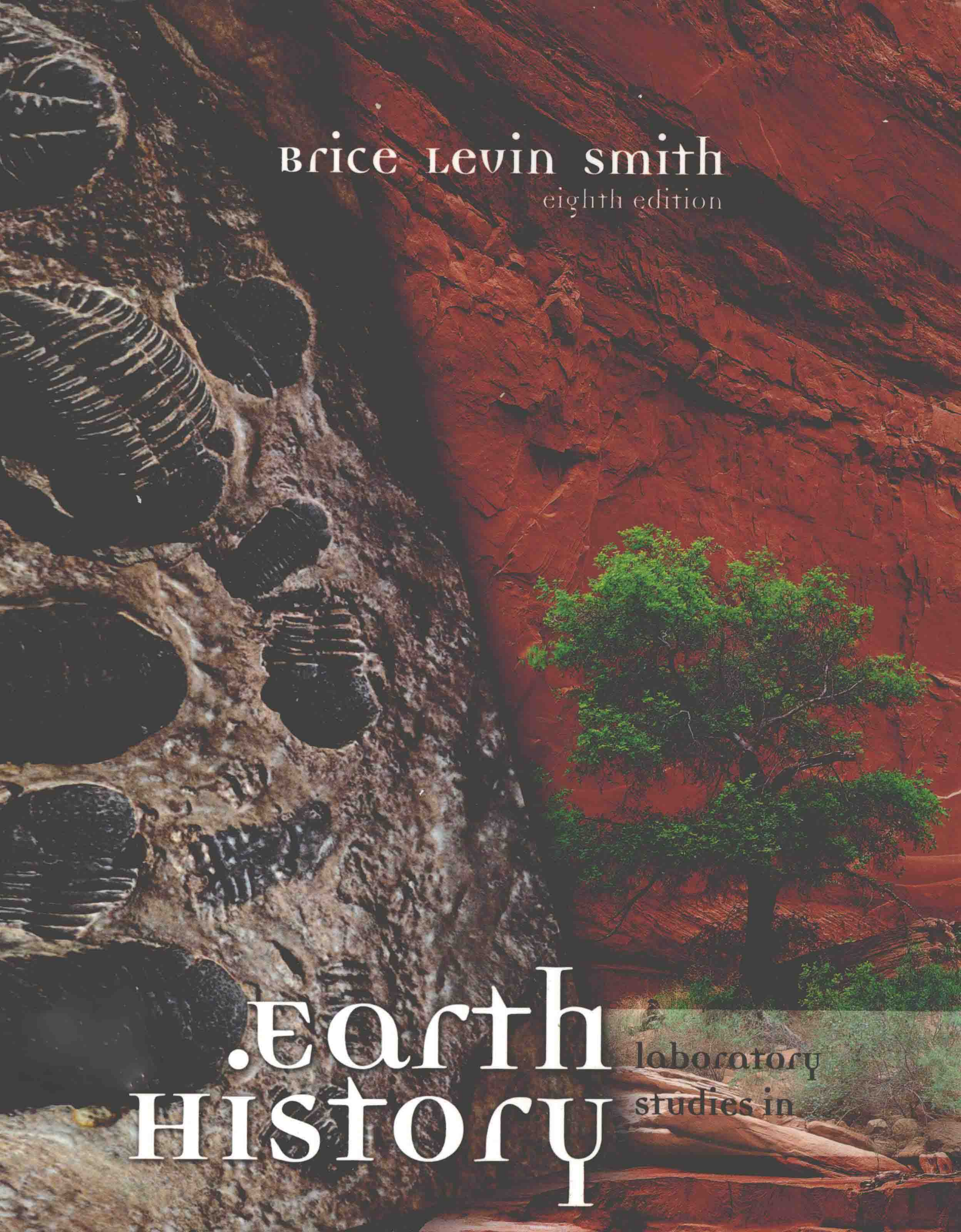


Brice Levin Smith

eighth edition

earth history

laboratory studies in

Laboratory Studies in

Earth History

Eighth Edition

JAMES C. BRICE

HAROLD L. LEVIN
Washington University

MICHAEL S. SMITH
*University of
North Carolina-Wilmington*

Higher Education

Boston Burr Ridge, IL Dubuque, IA Madison, WI New York San Francisco St. Louis
Bangkok Bogotá Caracas Kuala Lumpur Lisbon London Madrid Mexico City
Milan Montreal New Delhi Santiago Seoul Singapore Sydney Taipei Toronto

The McGraw-Hill Companies

Higher Education

LABORATORY STUDIES IN EARTH HISTORY
EIGHTH EDITION

Published by McGraw-Hill, a business unit of The McGraw-Hill Companies, Inc., 1221 Avenue of the Americas, New York, NY 10020.

This book is printed on recycled, acid-free paper containing 10% postconsumer waste.

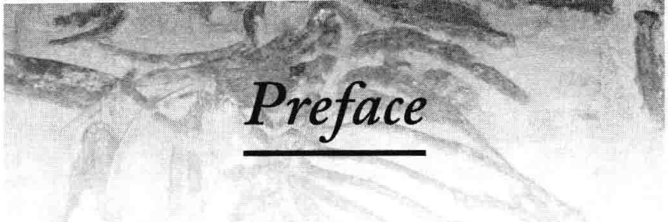
1 2 3 4 5 6 7 8 9 0 QPD/QPD 0 9 8 7 6 5 4 3

ISBN 0-07-252806-0

Publisher: *Margaret J. Kemp*
Sponsoring editor: *Thomas C. Lyon*
Developmental editor: *Fran Schreiber*
Executive marketing manager: *Lisa L. Gottschalk*
Project manager: *Joyce Watters*
Lead production supervisor: *Sandy Ludovissy*
Designer: *K. Wayne Harns*
Interior design: *Kathleen Theis*
Cover design: *Nathan Bahls*
Cover tree image: *Carr Clifton/Minden Pictures*
Cover Trilobite image: *Albert J. Copley/Getty Images*
Lead photo research coordinator: *Carrie K. Burger*
Compositor: *Shepherd Inc.*
Typeface: *10/12 Times Roman*
Printer: *Quebecor World Dubuque, IA*

Some of the laboratory experiments included in this text may be hazardous if materials are handled improperly or if procedures are conducted incorrectly. Safety precautions are necessary when you are working with chemicals, glass test tubes, hot water baths, sharp instruments, and the like, or for any procedures that generally require caution. Your school may have set regulations regarding safety procedures that your instructor will explain to you. Should you have any problems with materials or procedures, please ask your instructor for help.

www.mhhe.com



Preface

> *The past history of our planet is recorded in the rocks.*
> *We only need to learn how to read the message. What*
> *a joy to* know, *and sad to not ever* see, *or even* ask
> *about the rocks beneath our feet.*
> Arthur R. Green
> Chief Geoscientist, ExxonMobil Exploration Co.

Laboratory Studies in Earth History was first published in 1954 under the title *Historical Geology Laboratory Manual.* This eighth edition, therefore, encompasses nearly a half century of our effort to improve the quality of the manual as a teaching aid and to bring the most recent information to our students. Providing exercises and questions that help students understand how geologists determine what has occurred on Earth from the time of its origin to the present continues to be the primary objective of the manual. How can environmental conditions of bygone eras be read from rocks and the fossils embedded in rocks? How, by using geochronologic and stratigraphic methods, can the geologic history of the planet be ascertained?

As in previous editions, the exercises are designed for use in the laboratory component of an undergraduate course in Historical Geology. We have included information that will not only satisfy the needs of the student who will go no further in geology, but also those preparing for the advanced courses required for an academic major. The studies are arranged in developmental order so that each can build upon earlier information. However, they are sufficiently self-contained to permit rearrangement required by the instructor's preferred schedule of lecture topics. Some students will not have had a previous course in Physical Geology. These students may use Chapters 18 and 19 (igneous and metamorphic rocks) as background information. For those who have already learned about common igneous and metamorphic rocks, these chapters serve as a reference and convenient refresher. Chapters 1 through 3 provide practice in the identification and interpretation of sedimentary rocks based on their compositional and textural characteristics. The use of that information in determining the nature of ancient environments is emphasized in Chapters 5 and 6. Because of its relationship to so many events of the past, an examination of plate tectonics follows in Chapter 7. Students are now prepared to delve into aspects of geochronology and stratigraphy, presented in Chapters 8, 9, and 10. The identification, characteristics, and use of fossils comprise Chapters 10 through 13. The final chapters permit the student to put the knowledge gained into use, solving real problems as a geologist might.

We have retained the organization and approximate size of the previous edition. The exercise are designed so that they can be completed in approximately two hours, and many sections lend themselves well to homework assignments. Throughout the manual we have refashioned explanation, added text, provided new tables and line art, and refurbished many of the original photographs. Additional terms have been added to the glossaries at the end of each chapter. In response to reviewers suggestions, the treatment of cross-stratification has been expanded, and two colorplate geologic maps have been eliminated because of poorly discernable contour lines. Important colorplate maps for Appalachians and Cordillera locations are retained.

An instructor's manual containing exercise materials, lists, and answers resides on a password-protected site at www.mhhe.com/brice8e. Contact your McGraw-Hill sales representative for information and a password.

This eighth edition of *Laboratory Studies in Earth History,* has benefited from the constructive criticism of students, teaching assistants, and professors who have used the previous edition. We are also grateful for the many insightful suggestions of our reviewers:

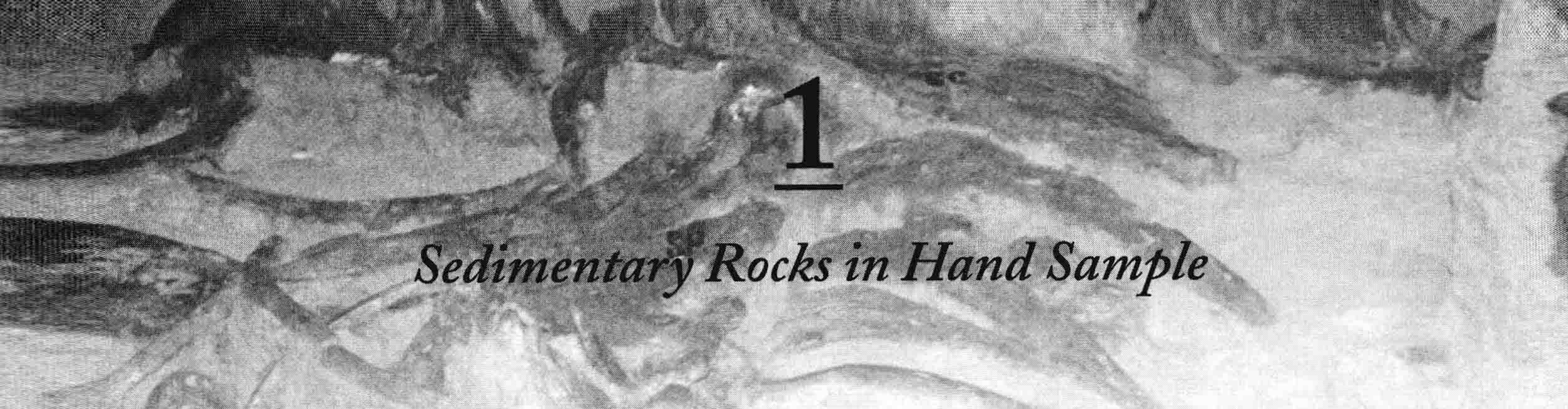
Larry E. Davis, *College of St. Benedict/St. Johns University*

Frank P. Florence, *Jefferson Community College*

Jared R. Morrow, *University of Northern Colorado*

Glenn B. Stracher, *East Georgia College*

Harry A. Wagner, *The Victoria College*



1

Sedimentary Rocks in Hand Sample

MATERIALS

1. Demonstration set and study set of common sedimentary rock—forming minerals: quartz, calcite and dolomite, gypsum and anhydrite, biotite and muscovite mica, garnet, plagioclase, and potassium feldspar.
2. Demonstration set and study set of common clastic, chemical and bioclastic sedimentary rocks: sandstone (various maturities), loess, chert and flint, limestone (fossiliferous and crystalline), dolostone, coquina, shale, siltstone and claystone (or mudstone), rock salt and rock gypsum, peat, and various types of coal (lignite, anthracite and bituminous).
3. Mohs hardness test materials: glass plate, steel nail, porcelain streak plate, and set of Mohs hardness minerals (see Table 1.2 on page 7).
4. 10X magnification hand lens or binocular microscope.
5. Dropper bottle of dilute (10%) HCl (hydrochloric acid).

INTRODUCTION

Sediments are derived from preexisting rocks (igneous, metamorphic, and sedimentary) on the earth's surface by mechanical and chemical weathering processes. The **detrital** material that composes sediments may consist of rock fragments (called **lithics**), mineral fragments, organic matter, the shells of ancient marine creatures, or the chemical precipitates of substances dissolved in oceans, lakes or ground water. These materials are *transported* by gravity, running water, or wind to locations where the sediments accumulate. In these areas of sediment deposition, sediment may be *compacted* and *cemented* over time into sedimentary rock. The process or series of processes by which an aggregate of sedimentary particles is transformed into an indurated rock mass is called **lithification.**

Much of earth history is interpreted from sedimentary rocks, and a particular kind of sedimentary rock can tell us something about the depositional conditions that existed where it was deposited. For example, a sedimentary rock composed of gravel-sized rock and mineral fragments is likely to have been deposited in a turbulent environment, as in a river channel or along a mountainous coastline.

In the following exercise, you will develop the skills to identify and classify the common sedimentary rocks found on the earth's surface.

TEXTURE

The term *texture* refers to the *size, shape,* and *arrangement* of the individual grains that make up the sedimentary rock. In hand sample, the texture of a sedimentary rock can be used to separate these rocks into three general categories: **clastic, chemical,** or **bioclastic.**

Clastic Sedimentary Rocks

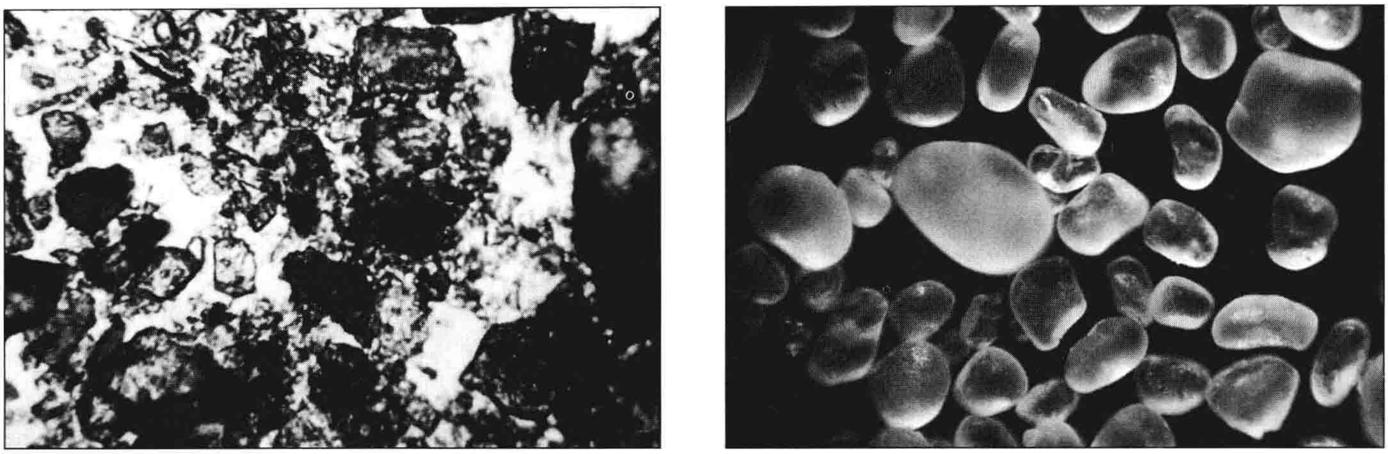
A sedimentary rock composed of fragments of rocks, minerals, or parts of fossils has a **clastic rock texture.** The individual grains that make up this rock are called **clasts** (Fig. 1.1). The size of these clasts is called the *grain size* and is the result of the processes of erosion and transportation, as well as chemical and mechanical resistivity of the material being transported and the environment of deposition in which the rock forms.

Clasts (see Chapter 2, Table 2.1 for details) can be *generally* classified into three grain sizes.

1. **Coarse** Particles larger than 2 mm (called *gravel*). Gravel is divided into pebbles (2 to 64 mm), cobbles (64 to 256 mm), and boulders (greater than 256 mm in size).
2. **Medium** Particles from 1/16 mm (0.063 mm) to 2 mm (called *sand size*). This size range is similar to that of granulated sugar.
3. **Fine** Particles smaller than 0.063 mm. In this case, the individual grains are too small to be visible to the eye (called *silt* or *clay size*).

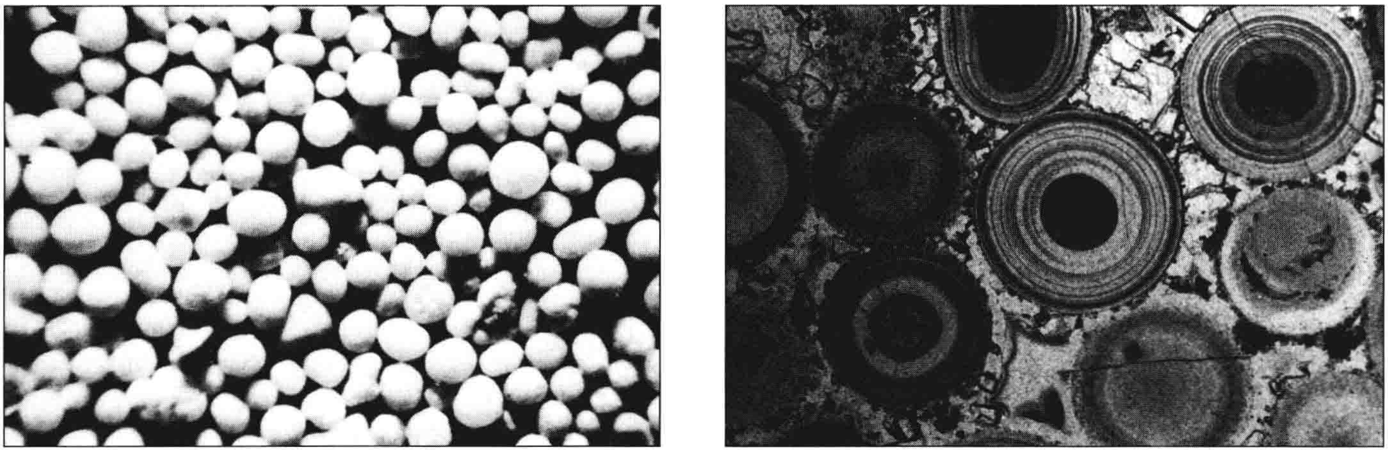
If you are undecided as to whether a sedimentary rock is of medium or fine grain size, use the following "rule of thumb." If most of the grains are easily visible (you can distinguish the shape and size of the grain), consider it to have a medium-grain size. However, if the grains are too small to be distinguished with the unaided eye, consider it to be fine-grained. With a 10X hand lens you will be able to see the fine-grained constituents in this rock. Many sedimentary

Figure 1.1 Examples of clast materials that become compacted or cemented together to form clastic or bioclastic sedimentary rocks. Sandstone would be formed from the clasts in A and B, oölitic limestones from C and D, clastic limestone from E, and fossiliferous limestone or coquina from F.



A Immature sand, artificially crushed granite. Magnification 40X.

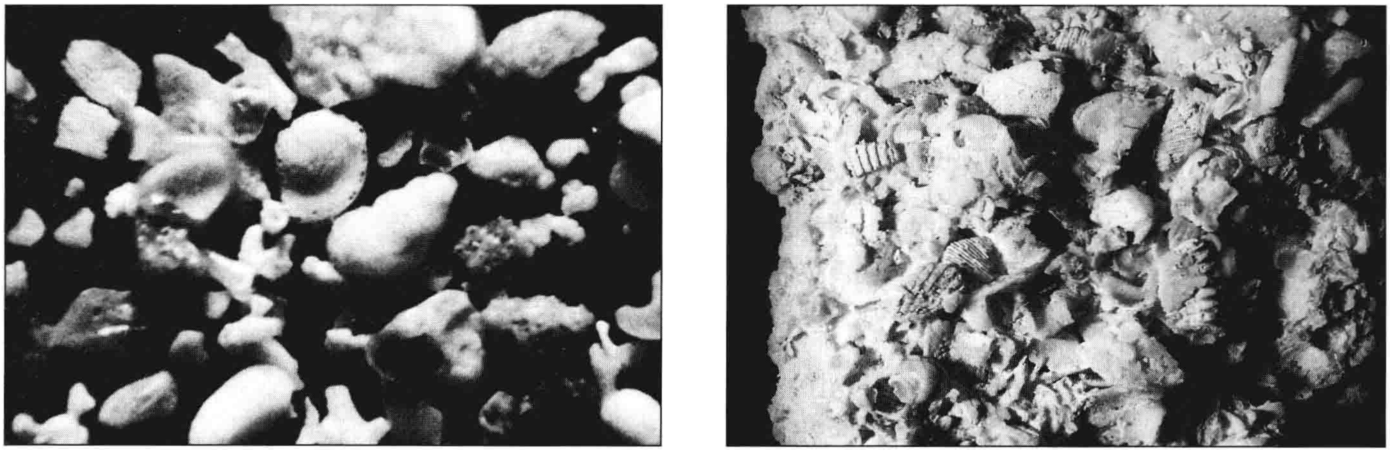
B Mature quartz sand from the St. Peter sandstone (Ordovician). Magnification 50X.



C Oöid sand. Magnification 15X.

D Replacement of oöids by microcrystalline silica preserves the fine concentric laminae. Field of view about 4 mm.

Photo: G. Ross.



E Carbonate beach sand from the Bahamas, composed of bioclasts. Magnification 15X.

F Coquina. This rock is composed almost entirely of broken bivalve (mollusk) shells cemented together by a calcite ($CaCO_3$) cement. The cement was either derived from the dissolution of the shell material or precipitated from seawater.

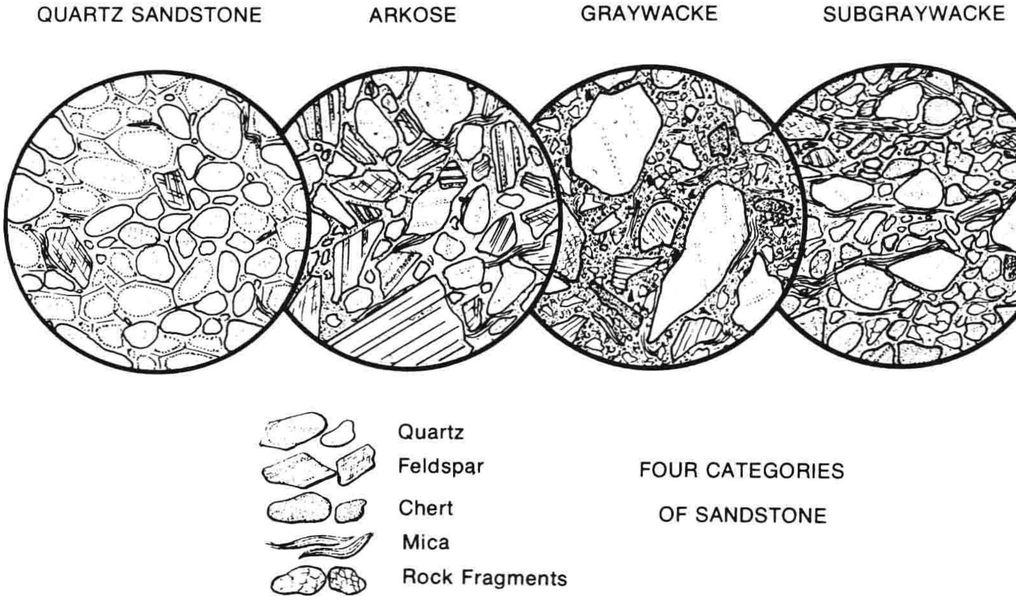


Figure 1.2 Four categories of sandstone as seen in thin section under the microscope. Note that although the quartz sandstone is texturally mature, its compositional maturity is only moderate because of small amounts of feldspar. Subgraywackes show characters that are transitional between quartz sandstones and graywackes. Rounding and sorting in subgraywackes are better than in graywackes, but poorer than in quartz sandstones. Subgraywackes also contain less feldspar than graywackes and may exhibit mineral cements. Diameter of field about 4 mm.

From Levin, H. L., *The Earth Through Time*, 5th ed. Philadelphia: Saunders College Publishing, 1996.

rocks have clastic texture, but because of the wide range of particles that can form sedimentary rocks, a variety of descriptive terms are used (see Table 1.1 and Chapters 2 and 3 for further discussion of textural features).

The shape(s), size distribution, and identity of the sediment grains are additional attributes used to classify the sedimentary rock as well as to evaluate the sedimentary rock's origin and its depositional history. These attributes define the maturity of the rock (Fig. 1.2). **Maturity** evalutes the shape of the particles **(rounding),** the overall sizes of the sediment grains (**sorting**), and the composition of the components. **Roundness** is a measure of the shape of the grains and refers to the degree to which sharp corners and edges of pieces of rock or mineral have been worn away. The shapes of clastic grains are described in terms of degree of roundness and how closely a particle approaches a perfectly spherical shape (see Chapter 2 for further details). Because the sediment particles are transported by gravity, running water, or the wind, the particles often are variably rounded depending upon the amount of time they have been transported as well as the chemical and mechanical resistivity of the particle. For example, a **conglomerate** and a **breccia** have coarse-grain-size clasts, but the rock or mineral fragments of a conglomerate are rounded while those of a breccia are angular.

Sorting refers to the uniformity of the particle sizes in a clastic sedimentary rock. Poorly sorted sediments differ from well-sorted sediments in the method of transport and the distance traveled from their source region. Angular fragments in a sedimentary rock generally imply transportation over relatively short distances. Thus, an **immature** sandstone has more angular fragments and associated detrital material that gives it an overall "dirty" appearance (Fig. 1.1A), whereas a **mature** sandstone is composed mainly of rounded quartz grains with very little detrital material between the larger grains (Fig. 1.1B). These observations allow the geologist to describe a rock according to its textural and compositional maturity. The **textural maturity** of a rock is described by the shapes and sizes of the rock's constituents, whereas **compositional maturity** is evaluated by the variety and types of mineral constituents (Fig. 1.2).

Chemical Sedimentary Rocks

Another type of texture in sedimentary rocks occurs when rocks form by either the growth of developing crystals **precipitated** from solution or as a change in the form of the grains that have already been deposited. The most common minerals precipitated from solution are calcium carbonate ($CaCO_3$; calcite), iron oxide (hematite (Fe_2O_3) or limonite ($FeO \cdot OH \cdot n\ H_2O$)) and opaline silica ($SiO_2 \cdot nH_2O$; opal, chalcedony, or **chert**). The grain size of the minerals formed by chemical precipitation is fine to very fine and is the result of the nucleation and growth processes. Since these minerals grow together in an interlocking pattern (much like a tile mosaic), chemical sedimentary rocks have a **crystalline rock texture.** Many types of limestone (or dolostone) as well as rocks formed by the evaporation of seawater (such as rock gypsum or rock salt) and rocks formed from hot springs deposits (such as travertine or **sinter,** found around the geysers of Yellowstone National Park) have this type of texture.

Table 1.1A Key to Identification of Some Common Sedimentary Rocks

Texture	General Appearance	Diagnostic Features	Sedimentary Rock Name	
CLASTIC	Boulders, cobbles, pebbles or coarse (2–4 mm size) particles embedded in a matrix of sand grains.	Angular rock/mineral fragments.	Breccia	
		Rounded rock/mineral fragments.	Conglomerate	
	Coarse sand and rock/mineral fragments.	Angular feldspar fragments mixed with coarse sand. Color: pink, reddish-brown, buff.	SANDSTONE	Arkose
	Sand-size particles.	With < 25% rock/mineral fragments and sand-size matrix.		Coarse sandstone
		With few to no rock/mineral fragments - mainly quartz grains. Color: buff, white, pink, brown.		Sandstone
	Coarse to fine sand-size particles with clay-size matrix.	Fine to coarse, angular to subangular rock fragments, poorly sorted. Color: dark gray to gray-green.		Graywacke
	Fine-grained clay and silt-sized particles.	Show fissile nature, soft enough to be scratched with fingernail. Color: varies - mostly dark colored.	Shale	
		Not fissile, look like hardened mud, silt or clay. Color: varies - dark to light colored.	Siltstone, mudstone or claystone (Siltstones are grittier than mudstone, claystones are very smooth).	
	Very fine-grained silt-sized particles.	Have a silty feel between fingers, yellowish appearance, softer than a fingernail but some particles will scratch glass.	Loess	
CRYSTALLINE	Very fine-grained, interlocked crystals. Grains are uniform in size.	Effervesce strongly with dilute HCl. Hardness greater than fingernail, will not scratch glass.	Limestone	
		Sample effervesces only when the rock is powdered. Hardness greater than fingernail, will not scratch glass.	Dolostone	
		Scratches glass, conchoidal fracture (looks like a broken glass bottle). Does not effervesce with dilute HCl. Color: white to gray to black (black variety called flint).	Chert	
		Same hardness as a fingernail, salty taste, greasy to waxy luster. Color: white to gray.	Rock salt	
		Hardness greater than fingernail, less than calcite. Crystals often platy to tabular in appearance. Color: varies - usually pink, buff, white.	Rock gypsum	
	Grains uniform in size and very spherical. Grains appear to have crystalline material or cement holding them together.	Spherical grains effervesce readily in dilute HCl. Color: very light (white to cream).	Oölitic limestone	
	Fossils of various sizes are present, yet most of the rock is either fine-grained matrix or cement.	Matrix/cement effervesce readily in dilute HCl.	Fossiliferous limestone	
		Matrix/cement requires powdering prior to weakly reacting to dilute HCl.	Fossiliferous dolostone	
BIOCLASTIC	Composed mainly (>90%) of fragments of fossils (invertebrate skeletal remains, shells or other hard parts of organisms).	Whole or nearly whole shells, show abrasion on surfaces, weakly held together by matrix.	Coquina	
		Effervesce with dilute HCl, powder easily rubbed off with fingers. Minor fossils may be present. Color: white to off-white to buff.	Chalk	
		Soft, crumbles easily, but particles scratch glass. Does not react with dilute HCl. Color: gray-white (composed of microscopic siliceous algal remains).	Diatomite	
	Composed mainly of plant material.	Fibrous, brown plant fibers, soft, very porous.	Peat	
		Sooty feel, may contain wood fragments or plant impressions, from dull, dark brown to a shiny black in appearance.	Coal (Lignite - brown; Bituminous - sooty black, blocky fracture; Anthracite - shiny, dense metallic black, conchoidal fracture)	

Table 1.1B Sedimentary Rock Identification Form: Use in Conjunction with Table 1.1

Sample Number	Texture	Grain/Particle Size (from Table 2.1)	Composition	Other Distinguishing Features	Rock Name

Student Name ______________________ Class/Section Number ______________________

Crystalline texture can also occur by the *recrystallization* of sediment grains during the process or series of processes of lithification or burial. For example, the opaline silica *tests* (skeletons) of microorganisms such as radiolarian or diatoms (major components of the siliceous oozes of the deep sea floor) may chemically react during deposition and burial on the seafloor with pore waters and recrystallize into a fine-grained crystalline texture sedimentary rock called **chert.**

Chemical sedimentary rocks may have fossil remains, primarily because many of these rock types are formed in the marine environment. If fossils are present, attempt to describe the fossils and use this in your description and identification of the rock.

Lastly, the chemical precipitation processes that produce these types of rock can also produce a specific type of chemical precipitate called the **oöid** (Fig. 1.1C, D). In certain shallow water environments calcium carbonate precipitates from the water and accumulates around a tiny shell fragment or grain of silt. Agitated by wave action, the tiny particle forms small, concentrically layered spheres of calcium carbonate called **oöids.** These individual ooids could be considered clasts and are often cemented together by minerals with a crystalline texture. What this often produces is a limestone composed of these spheres that has an **oölitic texture** (which is both clastic and crystalline).

Bioclastic Sedimentary Rocks

A third type of texture in sedimentary rocks occurs when rocks are composed *mainly* of fragments of organic origin. This type of texture is described as **bioclastic.** The fragments of organic origin are called **bioclasts** and represent a variety of materials, such as broken (or whole) skeletal parts (Fig. 1.1 E), plant material or fecal pellets.

The presence of fossils in a sedimentary rock often confuses students when they attempt to classify the rock as clastic, chemical, or bioclastic. A "rule of thumb" is that if the rock is composed almost completely of fossil (or plant) material, and the fossil materials are weakly held together, you should call it a bioclastic sedimentary rock (such as a **coquina** or **peat**). If fossils are present, but not in great amounts, the sedimentary rock is fossiliferous (bears or contains fossil remains). To determine if it is a clastic or chemical sedimentary rock, look at how the fossils are held together and at the type of material surrounding the fossils. If the surrounding material is individual clasts, it is a fossiliferous clastic sedimentary rock. If the surrounding material is very fine grained and has a crystalline texture, it is a fossiliferous chemical sedimentary rock such as a fossiliferous limestone (Fig. 1.1F).

To help you identify the common sedimentary rocks in this laboratory (and later), Table 1.1 divides sedimentary rocks into three main categories according to an *overall* major texture. These are **clastic,** mainly collections of broken, inorganic material, such as mineral or lithic (rock) fragments; **crystalline,** formed mainly by chemical or biochemical precipitation; and **bioclastic,** mainly composed of the remains of plants and/or animals (skeletal material, plant material or shell). It is important to recognize that there are many gradational types of sedimentary rocks with a range of textural and compositional maturity. For example, both a conglomerate and a sandstone have a clastic texture, but they differ in their composition and textural maturity. A fossiliferous limestone and a coquina both contain skeletal fragments; however, a coquina is composed mainly of mechanically abraded fossil debris that is poorly lithified, while the fossiliferous limestone contains some fossil fragments but also has a crystalline texture.

Figure 1.3 Thin section of sandstone composed of poorly sorted, angular grains of quartz (clear), feldspars (thin stripes), and rock fragments. Note that this sandstone lacks cement. Spaces between grains are filled with a matrix of clay and silt, which holds the rock together.

From Levin, H. L., *The Earth Through Time*, 5th ed. Philadelphia: Saunders College Publishing, 1996.

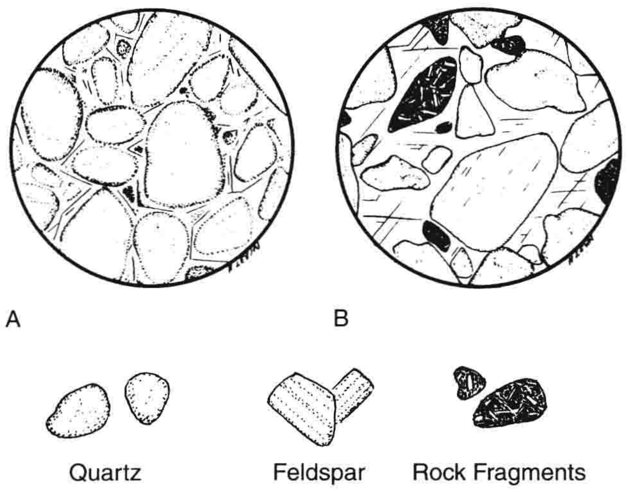
MATRIX AND CEMENTS

A sedimentary rock may be composed of several different sizes of particulate matter. When sedimentary rock is formed, the sediments can be bound together by compaction or cementation. **Compaction** occurs when the sediments are buried and the overlying pressure (from the material piled on top of the underlying sediments) causes the sediment grains to pack closely together, reducing the size of the **pore spaces** between the grains. The relatively fine-grained detrital material in which the larger fragments are embedded is called the **matrix** (Fig. 1.3), and is the binding material in compacted sediments.

Cementation occurs when minerals, such as quartz (SiO_2), iron oxide (hematite (Fe_2O_3) or limonite ($FeO \cdot OH \cdot nH_2O$)), or calcium carbonate ($CaCO_3$), are precipitated in the pore spaces between the particles of sediment (Fig. 1.4). These cements bind the rock together (generally more strongly than a rock with matrix) and may not be readily evident when examining a hand specimen. To determine if the cement is calcium carbonate, geologists often use the "acid test." A drop of *dilute* hydrochloric acid (HCl) will cause the

Figure 1.4 Two common types of cement in sandstones. (A) Quartz sandstone composed of well-sorted, rounded quartz grains tightly cemented by quartz (SiO_2) overgrowths. (B) Sandstone composed of quartz, feldspar, and rock fragments cemented by coarse, sparry calcite. Both are drawings of thin sections as viewed under the microscope. Diameter of areas each 1.0 mm.

From Levin, H. L., *The Earth Through Time,* 5th ed. Philadelphia: Saunders College Publishing, 1996.



calcium carbonate to effervesce. This test can also be used to distinguish limestone from dolostone. **Caution:** It is important to observe this reaction carefully to see if it is the cement that is effervescing rather than calcium carbonate mineral grains that may be in the rock (or chalk dust on your hands that has rubbed off onto the rock).

As a "rule of thumb," a sedimentary rock bound together by a fine-grained matrix is generally less indurated (and less hard) than one that has been bound together by a cement. In general, a sedimentary rock bound by a silica cement is generally more strongly indurated (and much harder) than one with a calcium carbonate cement.

HARDNESS

Table 1.2 Mohs Scale of Hardness

Mineral	Scale #	Common Object
Talc ____	1	(SOFTEST)
Gypsum ____	2	Fingernail
Calcite ____	3	Copper wire/penny
Fluorite ____	4	
Apatite ____	5	Pocket knife
Orthoclase ____	6	Window glass
Quartz ____	7	
Topaz ____	8	
Corundum ____	9	
Diamond ____	10	(HARDEST)

The particles that compose a sedimentary rock may be of varying hardness or *durability* (resistance to abrasion). If the particles of a rock have low hardness or durability, they are likely to undergo a higher degree of rounding over a given distance and duration of transportation.

The hardness test is used to aid in the identification of sedimentary rocks and their constituents and to help distinguish carbonate rocks (limestone and dolostone) from sandstones. A scale of relative hardness, based on common identifiable minerals and developed by Frederich Mohs in 1822, is outlined in Table 1.2. The *Mohs hardness scale* tests the ability of one mineral to scratch another mineral; the numbers from one to ten do not portray actual hardness. On the Mohs hardness scale, quartz, which is almost always present in sandstone, has a Mohs hardness of 7, and hence will scratch glass or steel. Neither calcite (major mineral of limestone with a Mohs hardness of 3) nor dolomite (major mineral of dolostone with a Mohs hardness of 4) will scratch glass or steel, but both are distinctly harder than the fingernail (hardness between that of talc and calcite). Rock types that are fine grained and/or loosely consolidated, such as gypsum, halite (rock salt), most chalk, and some **shale,** are easily scratched with the fingernail. Additionally, compacted sediments such as **loess** can also be easily scratched, yet the quartz grains of the loess will scratch the glass plate because their individual hardness is 7 on the Mohs scale.

If Mohs hardness is tested by scratching a rock against glass, as recommended here, *the glass is placed flat on a table* and the rock is held firmly against it. More than one corner or edge of the rock must be tested, because some rocks that are otherwise soft contain a few scattered quartz grains. If the rock is really scratching the glass, you will feel it "bite" into the surface; if not, it will merely slide across the surface.

COLOR

Because color is one of the most conspicuous features of sedimentary rocks and is useful in environmental interpretations, it should be described as accurately as possible. However, it is possible that the original color of a sediment (or sedimentary rock) may have changed since the time that it was buried, or that the color has changed as a result of weathering after it was exposed at the earth's surface. The color of unweathered sedimentary rocks is mainly influenced by amount of iron (generally in the form of an iron oxide mineral such as hematite (Fe_2O_3) or limonite ($FeO \cdot OH \cdot nH_2O$)). The oxidation of iron results in colors such as red, yellow, or brown. Furthermore, oxygen is likely to be more abundant in the nonmarine than in the marine environment, and the presence of red (Fe_2O_3) coloration is used as an indicator of terrestrial sedimentation. Figure 1.5 is a greatly simplified version of the Munsell color system, adapted for the

Figure 1.5 Scheme for the description of rock color adapted from the Munsell color chart. The hues at bottom are combined with values of gray to give 12 color names. The values of gray are also used as color names.

WHITE				
LIGHT GRAY	Light grayish pink	Light grayish orange	Light grayish yellow	Light grayish green
MEDIUM GRAY	Medium red	Medium brown	Olive gray	Greenish gray
DARK GRAY	Dark red	Dark brown	Dark olive gray	Dark greenish gray
BLACK				
	RED	YELLOW RED	YELLOW	GREEN

description of rock colors, which are generally restricted to four of the ten major hues. The color description of a rock should apply to a fresh (unweathered) specimen and the color should be observed using natural sunlight. Commonly, gray and green rocks are likely to turn brown on weathering, but rocks that are originally red or brown retain their color. For example, the color of a shale or a siltstone is more diagnostic than the color of a sandstone or a limestone. Gray or greenish-gray immature sandstones are very likely to turn brown at the weathered surface.

BEDDING

Bedding (or *stratification,* which is another term for bedding) is the most obvious feature of sedimentary rocks in outcrop. It results from a change in grain size, color, or rock type from one bed to the next, and it is usually more obvious on a weathered outcrop than on a fresh one. This layering is a result of processes that occurred during the deposition of the sediment and the formation of the sedimentary rock.

Bedding, if it is greater than 1 cm in thickness (see Chapter 4), is not usually seen in hand specimens unless the beds are very thin. However, beds less than 1 cm in thickness, called **laminae,** can be observed in some hand samples. Bedding should not be confused with another property that is commonly found in some sedimentary rocks. This property is called **fissility** and is present when a rock easily separates into thin, flat pieces. In your laboratory hand samples of shale and very fine-grained and laminated mudstones, you will find that it is sometimes very easy to separate the rock into very thin, flat pieces. The fissility of a rock is mainly controlled by the abundance and orientation of platy clay mineral such as biotite or muscovite mica. In fact, most shale is so fissile and poorly consolidated such that hand specimens of sufficient size are difficult to collect for laboratory study.

Exercise

Using Table 1.1, along with the study set of demonstration minerals and sedimentary rocks and the set of Mohs hardness minerals (Table 1.2), examine the unknown samples given to you by your instructor and determine their texture and identity. Use the Sedimentary Rock Identification Form that accompanies Table 1.1 to record your observations.

TERMS

arkose	A feldspar-rich sandstone, typically coarse-grained and pink or reddish in color. It is composed of angular to subangular grains, either poorly or moderately sorted. Arkoses generally reflect a terrestrial depositional environment where an uplifted granitic rock body undergoes rapid erosion, transportation deposition, and burial.
bed	One of the layers of rock in a stratified sequence of rocks, having well-defined boundaries with the overlying and underlying layers. A bed is generally greater than 1 cm in thickness.
bioclastic texture	A texture composed mainly of organic remains that are weakly cemented together. The bioclasts may range from shell fragments (see **coquina**) to plant fragments (see **peat** or **coal**).
bioclasts	Fragmental organic remains usually consisting of shell or skeletal material of marine invertebrates or calcareous algae.
breccia	A coarse-grained clastic rock, composed of angular broken rock and mineral fragments held together either by a mineral cement or in a fine-grained matrix.

cementation The precipitation of minerals (such as calcite, silica, or iron oxides) in pore spaces between particles of sediment. Cement is added to a sediment *after* deposition.

chert A hard, dense sedimentary rock composed of microcrystalline silica (silicon dioxide; SiO_2) and characterized by conchoidal fracture.

clast An individual grain of a detrital sedimentary rock or sediment produced by the disintegration of a larger rock mass through the processes of erosion and weathering.

clastic texture A texture consisting of the broken fragments of rock, minerals, or skeletal remains held together by either a cement or a matrix. The individual clasts are described based on identity, grain size, degree of rounding, and sorting.

coal A rock formed from the compaction and induration of variously altered plant remains similar to those in peat. Formed as a result of the compaction of peat over long periods of time.

compaction Reduction in the pore spaces between sediment grains as a result of burial or overlying pressure. In compaction, the sediment grains are bound together by finer-grained sediment particles, called the **matrix.**

compositional maturity A measure of the amount of weathering, erosion, and transport experienced by a sediment as indicated by the variety of mineral constituents ultimately deposited to form the sedimentary rock. Examples: Feldspars weathered to clay; ferromagnesian minerals (olivine or pyroxene) weathered into iron oxides such as the minerals limonite or hematite.

conglomerate A coarse-grained clastic sedimentary rock, composed of rounded to subangular rock and/or mineral fragments greater than 4 mm in diameter. These components are either set together in a fine-grained matrix or held together by a mineral cement.

coquina A bioclastic sedimentary rock composed largely of shells of marine invertebrates, usually mollusks, that are held weakly together with little to no matrix present and have high porosity.

crystalline texture A term that describes a sedimentary rock composed of crystals (rather than clasts) precipitated from a saturated solution. The mineral crystals are fine to very fine in grain size and form an interlocking mosaic. Rocks formed by chemical precipitation are called **chemical sedimentary rocks.**

detrital A term applied to *any* particles of minerals or rocks (clasts) that have been derived from preexisting rocks by processes of weathering or erosion.

fissile A property of some sedimentary rocks that separate into thin, flat layers, usually along bedding planes.

graywacke A general term for a dark gray, firmly indurated, coarse-grained sandstone that consists of poorly-sorted, angular to subangular grains of quartz and feldspar along with a variety of dark-colored rock fragments embedded in a fine-grained matrix.

immature sand A poorly sorted sand that contains abundant, relatively unstable (to weathering), often angular grains. An immature sandstone would be similarly composed.

lamina A thin layer of sediment or sedimentary rock in which the planes of stratification are 1 cm or less apart.

lithification The process (or processes) that convert(s) unconsolidated rock-forming materials into a coherent rock mass.

loess A soft, crumbly clastic sediment formed from accumulations of wind-blown silt.

matrix Clastic, fine-grained particles (often clay) that are deposited at the same time as larger grains and help to hold (or bind) the grains together. Also called the *groundmass.*

mature sand A well-sorted sand consisting primarily of subrounded to rounded grains of very stable minerals, usually quartz. Most quartz sandstones are derived from mature sands.

oöids Spherical particles of sand size that are mostly composed of concentric laminae of calcium carbonate. A limestone made up of cemented oöids has an **oölitic texture.**

peat An unconsolidated deposit of semicarbonized plant remains in a water-saturated environment, such as a bog or fen. It is considered an early stage in the development of coal.

pore space The open spaces (or voids) between sediment grains.

precipitation Process whereby materials that are carried in solution (dissolved) are deposited as a crystalline solid.

roundness (of sedimentary particles) The degree to which sharp corners or edges of a particle are worn away. Roundness is commonly expressed as the ratio of the average radius of the corners to the radius of the maximum inscribed circle for the particle.

shale A fine-grained clastic (detrital) sedimentary rock, formed by the compaction and consolidation of clay, silt, or mud that is characterized by finely laminated structures (very thin layers).

sinter A chemical sedimentary rock formed from the precipitation of calcite- (or silica-) saturated hot water from hot springs or geysers. Calcareous sinter is also called *travertine.* Siliceous sinter is often called *sinter.*

sorting A measure of the uniformity of particle sizes in a sediment or a sedimentary rock.

subgraywacke A "dirty" sandstone with more quartz and less feldspar than a graywacke and more rock fragments. The quartz and feldspar grains are more rounded than those in a graywacke, indicating more textural maturity.

textural maturity A measure of size and shape variation of the constituents of a sedimentary rock. Increased textural maturity is characterized by greater rounding of the grains and decreased grainsize variation.

2

Textural Clues to the History of Sediment

MATERIALS

1. Demonstration specimens of sediment grains showing various degrees of rounding and angularity.
2. Tray containing eleven (or more) pebbles ranging in size (diameter) from 8 to 64 mm.
3. Vials of coarse sand and fine gravel ranging in size from 1 to 8 mm.
4. Millimeter scale, graph paper and Table 2.1 (this chapter).
5. 10X magnification hand lens or binocular microscope.
6. Hand calculator.

PARTICLE SIZE AND SORTING

The textural attributes of sediment, such as the size and shape of **clastic** particles, can often be used to infer the manner in which sediment was transported and deposited. We are all aware that a stronger current of water is required to move a large pebble than to move a tiny grain of sand. Thus, the size of the particles in a clastic sedimentary rock may serve as an indicator of the approximate strength of the medium (such as running water or wind) that transported those particles. In addition, the size of the particles may also reflect the density and other properties of the transporting medium. For example, glacial ice can transport much larger pieces of rock than the strongest desert winds can move.

Not only the sizes of the individual particles but also the distribution of those sizes can yield information about a sediment's history. One term that applies to the distribution of particle sizes is *sorting*. **Sorting** is a measure of the uniformity of particle sizes. It is more specifically defined as the range of particle sizes that deviate from the average size. Rocks composed of grains that are all about the same size are said to be well sorted. Poorly sorted sediments have a wide range of particle sizes, as depicted in the sandstone of Figure 2.1A. Currents of wind or water may **winnow** out the finer particles in an originally poorly sorted sediment, leaving behind a coarser and better-sorted sediment. The winnowed material (which is generally of a small particle size) is then transported to another region of deposition. Poor sorting is characteristic of sediment that has been deposited rapidly and has not been subjected to the sorting action of waves and currents. Such deposition may occur at the foot of mountain ranges or along the margins of glaciers.

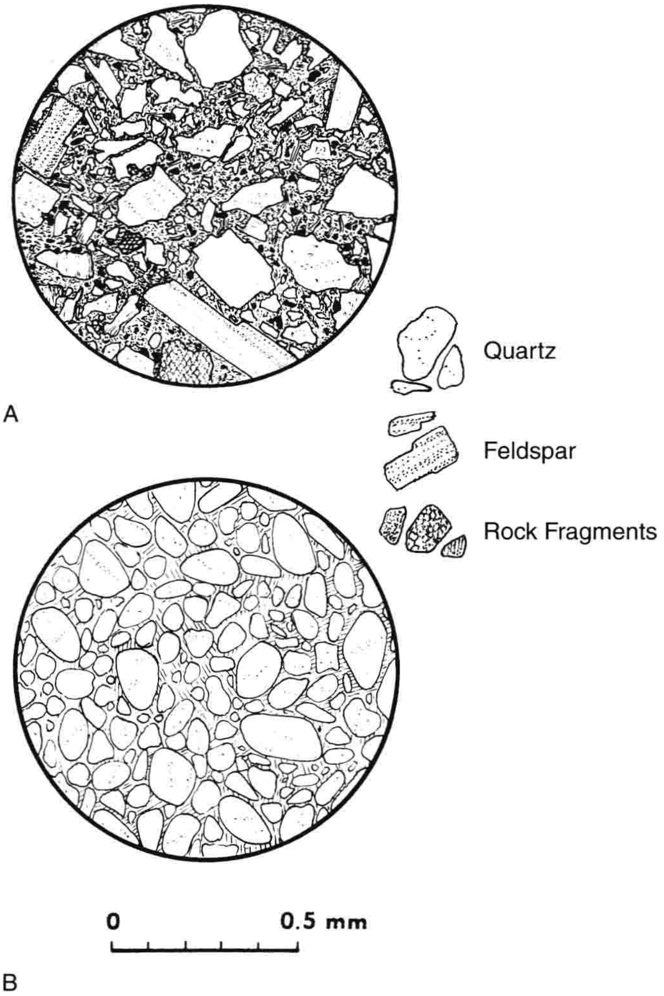
To ensure uniformity in the use of such terms as *pebble, silt,* and *sand,* geologists employ a table of particle size known as the Wentworth grain-size scale (Table 2.1). Note that the size groups in the Wentworth grain-size scale increase geometrically by a factor of 2 rather than arithmetically. This is desirable because a given arithmetic increment of increase, for example one millimeter, makes no difference in the behavior of large grains, but makes a large difference in the behavior of small grains. This is important when examining the concept of grain settling in a column of water (which models deposition of sediment in any nonturbulent body of water). A grain having a diameter of 2 mm falls about twice as fast as one having a diameter of 1 mm, but a difference of 1 mm makes no appreciable difference in the settling velocities for pebbles with diameters from 50 to 60 mm.

The millimeter-based Wentworth grain-size scale can be transformed into a logarithmic scale, which can then be plotted on ordinary graph paper. This technique evolved into the **Phi (Ø) grain-size scale** (Table 2.1) where $Ø = -\log_2 (D)$, with Ø as the Phi number and D as the particle diameter in mm. Phi units are used to take into account the large range of grain diameters that exist in clastic sedimentary rocks. The more negative the Phi number, the coarser grained are the particles; the more positive the Phi number, the finer grained are the particles.

ROUNDNESS OF GRAINS

The roundness of particles is another textural attribute that provides evidence of the history of a clastic rock or sediment (Fig. 2.1). **Roundness** refers to the degree to which sharp corners and edges of pieces of rock or mineral have been worn away. The term should not be confused with **sphericity,** which is a measure of how closely a particle approaches a perfectly spherical shape. For example, an elongate pebble may be well rounded but have poor sphericity. The roundness of a particle may provide an approximation of the length of time a particle has been subjected to transport by waves, water currents, or wind. For example, pebbles in the downstream portion of streams like the Colorado River are

Figure 2.1 Two sandstones as seen in thin section under the microscope. (A) is a poorly sorted, immature sandstone composed of angular to subangular grains of quartz, feldspar, and rock in a matrix of clay and micaceous minerals. (B) is a well-sorted, mature quartz sandstone with chemical cement.



more rounded than their upstream counterparts as a result of the greater number of impacts they have been subjected to over the longer span of transport.

Roundness may be expressed either as an approximation based on comparison with grains of known roundness (as in Figure 2.2), or it may be measured and expressed quantitatively as *the average radius of the corners of a grain (or pebble) divided by the radius of the maximum inscribed circle* (Fig. 2.3).

1. In qualitative terms (using Fig. 2.2), what is the roundness of pebbles A and B (Fig. 2.3)?

   Pebble A __________

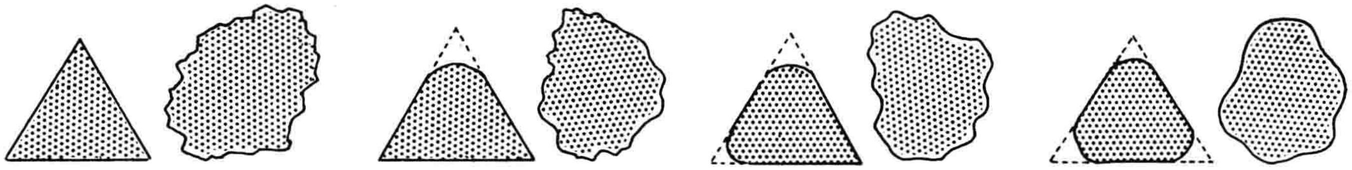
   Pebble B __________

2. Determine the numerical value of roundness of pebbles A and B in Figure 2.3. Assume all edges and corners are shown. Measure the radii of edges (r_1, r_2, r_3, etc.) and the radius of the maximum inscribed circle with a millimeter scale.

Table 2.1 The Wentworth and Phi (Ø) Grain-Size Classification for Sediment Grains

Size (m)	Class Boundary (mm)	Size Classes			Phi (Φ) Units
		Gravel	Boulders	very large	
	2048				−11
				large	
1	1024				−10
				medium	
	512				−9
				small	
	256				−8
			Cobbles	large	
10^{-1}	128				−7
				small	
	64				−6
			Pebbles	very coarse	
	32				−5
				coarse	
	16				−4
10^{-2}				medium	
	8				−3
				fine	
	4				−2
				very fine	
	2				−1
		Sand		very coarse	
10^{-3}	1				0
				coarse	
	500μm				1
				medium	
	250μm				2
				fine	
10^{-4}	125μm				3
				very fine	
	63μm				4
	31μm	Mud	Silt		
	16μm				5
10^{-5}					
	8μm				6
					7
	4μm				8
			Clay		
	2μm				9
10^{-6}					

Figure 2.2 Profiles for estimating approximate roundness of sand and gravel particles.



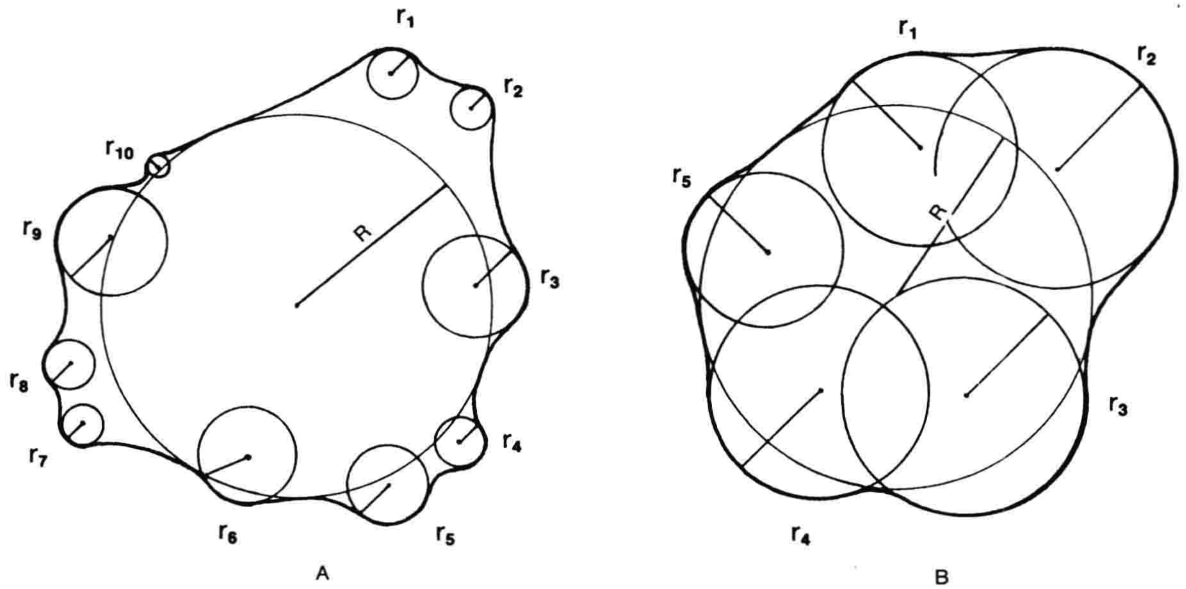
Angular (A)
All edges sharp
Roundness 0.10–0.20

Subangular (SA)
⅓ edges rounded
Roundness 0.30

Subrounded (SR)
⅔ edges rounded
Roundness 0.40

Rounded (R)
All edges rounded
Roundness 0.60–0.85

Figure 2.3 Grain profiles to be used in calculating the numerical value of roundness.



Pebble A

r_1. __________

r_2. __________

r_3. __________

r_4. __________

r_5. __________

r_6. __________

r_7. __________

r_8. __________

r_9. __________

r_{10}. __________

Sum of radii. __________

Average radius (sum of radii/number of radii). __________

Radius of maximum inscribed circle (R). __________

Roundness. __________

Pebble B

r_1. __________

r_2. __________

r_3. __________

r_4. __________

r_5. __________

Sum of radii. __________

Average radius (sum of radii/number of radii). __________

Radius of maximum inscribed circle (R). __________

Roundness. __________