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## Sedimentary rocks

### **Origin, classification, and occurrence of sedimentary rocks:**

Sedimentary rocks form at low temperatures and pressures at the surface of Earth owing to deposition by water, wind, or ice.

Sedimentary rocks are characterized particularly by the presence of layers, although layers are also present in some volcanic and metamorphic rocks, and by distinctive textures and structures. Many sedimentary rocks are also distinguished from igneous and metamorphic rocks by their mineral and chemical compositions and fossil content.

After deposition of particulate sediment or chemical/biochemical precipitates, burial takes place as this sediment is covered by successive layers of younger sediment. The increased temperatures and pressures encountered during burial bring about diagenesis of the sediment, leading to solution and destruction of some constituents, generation of some new minerals in the sediment, and eventually consolidation and lithification of the sediment into sedimentary rock.

### **Diagenesis**

collectively refers to the physical, chemical, and biological changes which may occur during the formation of sedimentary rocks. Recrystallization, compaction, cementation, and lithification, are all examples of diagenetic changes.

1- **Recrystallization** occurs when unstable minerals recrystallize to form more stable minerals. Recrystallization most often occurs during the formation of chemical sedimentary limestone rocks that previously contained aragonite a chemically unstable form of calcium carbonate ( $\text{CaCO}_3$ ).

2- **Compaction** occurs when sediments are progressively deposited on top of one another, and over time the weight of the accumulated sediments increases and compresses the buried sediments. Continued compression of buried sediments reduces pore-spaces and removes excess water, as a result the closely packed individual grains begin to slowly compact into a solid rock.

3- **Cementation** involves a chemical change whereby individual grains are cemented together as minerals are precipitated out of saturated

solution that is percolating as a matrix between individual sediments. The accumulation of the precipitated minerals causes the grains to cement together. Cementation can occur in combination with the presence of other minerals, rock fragments, or organic constituents such as fossilized organisms.

4- **Lithification** occurs when unconsolidated sediments are cohesively bound to form a solid sedimentary rock. Compaction and/or cementation are generally the precursor to the lithification process.

Classification of Sedimentary Rocks

Group	Class
I. Autochthonous sediments	<ul style="list-style-type: none"> <li>(a) <i>Chemical precipitates</i> – the evaporites: gypsum, rock salt, etc.</li> <li>(b) <i>Organic deposits</i> – coal, limestones, etc.</li> <li>(c) <i>Residual deposits</i> – laterites, bauxites, etc.</li> </ul>
II. Allochthonous sediments	<ul style="list-style-type: none"> <li>(d) <i>Terrigenous deposits</i> – clays, siliciclastic sands, and conglomerates</li> <li>(e) <i>Pyroclastic deposits</i> – ashes, tuffs, volcaniclastic sands, and agglomerates.</li> </ul>

Like most classifications of geologic data this one has several inconsistencies. Note particularly that many limestones, though organic in origin, are detrital in texture. Cannel, drift, or boghead coals are not truly autochthonous. Many evaporites are diagenetic in origin.

In general sedimentary processes leads to generation of four fundamental kinds of constituents – **terrigenous siliciclastic particles, chemical/biochemical constituents, carbonaceous constituents, and authigenic constituents** – which, in various proportions, make up all sedimentary rock.

**1. Terrigenous siliciclastic particles:**

The processes of terrestrial explosive volcanism and rock decomposition owing to weathering generate gravel- to mud-size particles that are either individual mineral grains or aggregates of minerals (rock fragments or clasts). The minerals are mainly silicates such as quartz, feldspars, and micas. The rock fragments are clasts of igneous, metamorphic, or older sedimentary rock that are also composed dominantly of silicate minerals. Further, fine-grained secondary minerals, particularly iron oxides and clay minerals, are generated at weathering sites by recombination and crystallization of chemical elements released from parent rocks during weathering. These land-derived minerals and rock fragments are subsequently transported as solids to depositional basins. Because of their largely extrabasinal origin and the fact that most of the particles are silicates, we commonly refer to them as terrigenous siliciclastic grains, although some pyroclastic particles may originate within depositional

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basins. These siliciclastic grains are the constituents that make up common sandstones, conglomerates, and shales.

## **2. Chemical/biochemical constituents:**

Chemical and biochemical processes operating within depositional basins may lead to extraction from basin water of soluble constituents to form minerals such as calcite, gypsum, and apatite, as well as formation of calcareous and siliceous tests or shells of organisms.

Some precipitated minerals may become aggregated into silt- or sand-size grains that are moved about by currents and waves within the depositional basin. Carbonate ooids and pellets are familiar examples of such aggregate grains. There is no commonly accepted group name for precipitated minerals and mineral aggregates, analogous to the term siliciclastic; they are referred to here simply as chemical/biochemical constituents. These constituents are the materials that make up intrabasinal sedimentary rocks such as limestones, cherts, evaporites, and phosphorites.

## **3. Carbonaceous constituents:**

The preserved, carbonized residues of terrestrial plants and marine plants and animals, together with the petroleum bitumens, make up a third category of sedimentary constituents. Humic carbonaceous materials are the woody residues of plant tissue and are the chief components of most coals. Sapropelic residues are the remains of spores, pollen, phyto- and zooplankton, and macerated plant debris that accumulate in water. They are the chief constituents of cannel coals and oil shales. Bitumens are solid asphaltic residues that form from petroleum through loss of volatiles, oxidation, and polymerization.

## **4. Authigenic constituents:**

Minerals precipitated from pore waters within the sedimentary pile during burial diagenesis constitute a fourth category of constituents. These secondary, or authigenic, constituents may include silicate minerals such as quartz, feldspars, clay minerals, and glauconite and nonsilicate minerals such as calcite, gypsum, barite, and hematite. They may be added during burial to any type of sedimentary rock but are never the dominant constituents of sedimentary rocks.

Depending upon the relative abundance of siliciclastic, chemical/biochemical, and carbonaceous constituents, we recognize **three fundamental types of sedimentary rocks** (Fig. 1): **1- siliciclastic (terrigenous) sedimentary rocks, 2- chemical/biochemical sedimentary rocks, and 3- carbonaceous sedimentary rocks.**

Composition		Group name	Particle size	Principal constituents	Main rock types
<~15% Carbonaceous residues	<50% Terrigenous siliciclastic grains	or siliciclastic rocks	>2 mm	Rock fragments	Conglomerates and breccias
			1/16–2 mm	Silicate minerals and rock fragments	Sandstones
			<1/16 mm	Silicate minerals	Shales (mudrocks)
	>50% Chemical/biochemical constituents	Chemical/biochemical rocks	Variable	Carbonate minerals, grains; skeletal fragments	Carbonate rocks (limestones and dolomites)
				Evaporite minerals (sulfates, chlorides)	Evaporites (rock salt, gypsum, anhydrite)
				Chalcedony, opal, siliceous skeletal remains	Siliceous rocks (cherts and related rocks)
				Ferruginous minerals	Ironstones and iron-formations
				Phosphate minerals	Phosphorites
	>~15% Carbonaceous residues	Carbonaceous rocks	Variable	Siliciclastic or chemical–biochemical constituents: carbonaceous residues	Oil shales Impure coals
Carbonaceous residues				Humic coals Cannel coals Solid hydrocarbons (bitumens)	

Figure (1) Classification of sedimentary rocks.

As shown in Fig. 1, each of these major groups of sedimentary rocks can be further subdivided on the basis of grain size and/or mineral composition. Thus, the siliciclastic sedimentary rocks are divided by grain size into conglomerates/breccias, sandstones, and mudrocks (shales), each of which can be classified on a still finer scale on the basis of composition. The chemical/biochemical sedimentary rocks are divided by composition into carbonates, evaporites, cherts, ironstones and iron-formations, and phosphorites. Carbonaceous sedimentary rocks may be separated by composition into oil shales, impure coals, coals, and bitumens.

## **Siliciclastic sedimentary rocks:**

### **Sandstones:**

Particle composition:

Detrital constituents: Sandstones are composed of a very restricted suite of major detrital minerals and rock fragments, plus a variety of minerals that may be present in accessory amounts (Table 1).

Detrital constituents are defined as those derived by mechanical-chemical disintegration of a parent rock. Most detrital constituents in sandstones are terrigenous siliciclastic particles that are generated through the process of weathering, explosive volcanism, and sediment transport from parent rocks located outside the depositional basin.

Some volcanoclastic particles may, however, originate from volcanic centers located within basins. A few detrital constituents in sandstones may be nonsiliciclastic particles, such as skeletal fragments or carbonate clasts, formed within the depositional basin by mechanical disruption of reef masses or other consolidated or semiconsolidated carbonate bodies. Sandstones may also contain intrabasinal biogenic remains that accumulated at the depositional site, as organisms died, along with detrital sediment.

Owing to the wide variety of igneous, metamorphic, and sedimentary rocks that may constitute source materials for detrital sediment, sandstones could theoretically contain an extensive suite of major minerals. The fact that they do not can be attributed to the processes of chemical weathering and physical and chemical attack during transport, deposition, and burial that tend to destroy or degrade chemically unstable and mechanically weak sand-size grains. Thus, the framework grains of most sandstones are composed predominantly (commonly > 90 percent) of quartz, feldspars, and rock fragments.

Clay minerals may be abundant in some sandstones as matrix constituents; however, the detrital origin of such clay minerals is often difficult to establish. Coarse micas, especially muscovite, make up a few percent of the framework grains of many sandstones. Finally, heavy minerals may constitute a small percentage of the detrital constituents of sandstones, particularly the chemically stable heavy minerals such as zircon, tourmaline, and rutile.

Table 1 Common minerals and rock fragments in siliciclastic sedimentary rocks

**Major minerals (abundance > ~ 1–2%)****Stable minerals (greatest resistance to chemical decomposition)**

**Quartz** – makes up approximately 65% of average sandstone, 30% of average shale; 5% of average carbonate rock

**Less stable minerals**

**Feldspars** – include **K-feldspars** (orthoclase, microcline, sanidine, anorthoclase) and plagioclase **feldspars** (albite, oligoclase, andesine, labradorite, bytownite, anorthite); make up about 10–15% of average sandstone, 5% of average shale, < 1% of average carbonate rock

**Clay minerals and fine micas** – clay minerals include the kaolinite group, illite group, smectite group (montmorillonite a principal variety), and chlorite group; fine micas are principally muscovite (sericite) and biotite; make up approximately 25–35% of total siliciclastic minerals, but may comprise > 60% of the minerals in shales

**Accessory minerals (abundances < ~ 1–2%)**

**Coarse micas** – principally muscovite and biotite

**Heavy minerals (specific gravity > ~ 2.9)**

**Stable nonopaque minerals** – zircon, tourmaline, rutile, anatase

**Metastable nonopaque minerals** – amphiboles, pyroxenes, chlorite, garnet, apatite, staurolite, epidote, olivine, sphene, zoisite, clinozoisite, topaz, monazite, plus about 100 others of minor importance volumetrically

Stable opaque minerals – hematite, limonite

Metastable opaque minerals – magnetite, ilmenite, leucoxene

Rock fragments (make up about 10–15% of the siliciclastic grains in average sandstone and most of the gravel-size particles in conglomerates; shales contain few rock fragments)

Igneous rock fragments – may include clasts of any igneous rock, but fragments of fine-crystalline volcanic rock and volcanic glass are most common in sandstones

Metamorphic rock fragments – include metaquartzite, schist, phyllite, slate, argillite, and less commonly gneiss clasts

Sedimentary rock fragments – any type of sedimentary rock possible in conglomerates; clasts of fine sandstone, siltstone, shale, and chert are most common in sandstones; limestone clasts are comparatively rare in sandstones

Chemical cements (abundance variable)

Silicate minerals – predominantly quartz; others may include chalcedony, opal, feldspars, and zeolites

Carbonate minerals – principally calcite; less commonly aragonite, dolomite, siderite

Iron oxide minerals – hematite, limonite, goethite

Sulfate minerals – anhydrite, gypsum, barite

**Classification of sandstones:**

sandstones can be separated into two groups: **epiclastic and volcanoclastic**. Epiclastic deposits are formed from fragments of pre-existing rocks derived by weathering and erosion. Thus, they are composed mainly of silicate minerals and various kinds of igneous, metamorphic, and sedimentary rock fragments. Volcanoclastic deposits are those especially rich in volcanic debris, including glass. Many volcanoclastic deposits consist principally of pyroclastic materials such as ash or lapilli, derived directly through explosive volcanism. On the other hand, some material in volcanoclastic deposits may be epiclastic debris derived by weathering of older volcanic rock. Epiclastic and

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volcaniclastic deposits can be further classified on the basis of their composition.

Two common sandstone names that do not appear in many formal classifications require some additional explanation. The term **arkose** is used in some sandstone classifications and is in general use by many geologists. It has been applied to any sandstone containing conspicuous amounts of feldspars, as seen in hand specimens, to sandstones containing more than 20 percent, more than 25 percent, or more than 30 percent feldspars, and to sandstones derived from granitic source rocks. Probably the most widely accepted definition for an arkose is a feldspathic sandstone containing more than 25 percent feldspars. The term **graywacke** is applied to dark-gray, greenish-gray, or black, matrix-rich, well indurated sandstones.

### **epiclastic sandstones:**

1- Quartz arenites: Quartz arenites are composed of > 90–95 percent siliceous grains (quartz, chert, quartzose rock fragments). They are commonly white or light gray, but may be stained red, pink, yellow, or brown by iron oxides. They are generally well lithified and well cemented with silica or carbonate cement; however, some are porous and friable. Quartz arenites typically occur in association with assemblages of rocks deposited in stable cratonic environments such as eolian, beach, and shelf environments. Thus, they tend to be interbedded with shallow-water carbonates and, in some cases, feldspathic sandstones.

2- Feldspathic arenites: Feldspathic arenites contain less than 90 percent quartz grains, more feldspar than unstable rock fragments, and minor amounts of other minerals such as micas and heavy minerals. They may contain as little as 10 percent feldspar grains, but most feldspathic arenites show greater feldspar enrichment. Feldspathic arenites originate mainly by weathering of feldspar-rich crystalline rocks, either plutonic igneous rocks or feldspar-rich metamorphic rocks.

### **Volcaniclastic sandstones:**

The term volcaniclastic is applied to all siliciclastic sedimentary rocks enriched in volcanic fragments regardless of the mechanism that produced the fragments. Volcaniclastic deposits can be emplaced or deposited in any environment, on land, under water, or under ice, and may be mixed in any significant proportion with nonvolcanic fragments. They are classified on the basis of particle composition into **lithic arenites** or **feldspathic arenites**.

**Conglomerates:**

Siliciclastic sedimentary rocks that consist predominantly of gravel-size ( $> 2$  mm) clasts are called conglomerates. Conglomerates are common rocks in stratigraphic sequences of all ages, but make up less than about one percent by weight of the total sedimentary rock mass.

The framework grains of conglomerates are composed mainly of rock fragments (clasts) rather than individual mineral grains. These clasts may consist of any kind of rock. Some conglomerates are composed almost entirely of highly durable clasts of quartzite, chert, or vein quartz. Others are composed of a variety of clasts, some of which, limestone and shale clasts for example, may be unstable or weakly durable. Conglomerates may contain various amounts of matrix, which commonly consists of clay- or sand-size particles or a mixture of clay and sand.

There are two types of conglomerates:

- 1- If mud or sand matrix is so abundant that the clasts in a rudite or gravelly sediment do not form a supporting framework, the fabric is commonly referred to as **matrix-supported** (Fig. 2).
- 2- Rudites or gravelly sediments that contain so little matrix that the gravel-size framework grains touch and thus form a supporting framework are called **clast-supported** (Fig. 3).



Figure (2)



Figure (3)



**Mudstones and shales:**

Fine-grained, siliciclastic sedimentary rocks, composed mainly of particles smaller than ~ 62 microns (coarse silt and finer), make up approximately 50 percent of all sedimentary rocks in the stratigraphic record.

The term shale has been used in two ways: (1) in a restricted sense to mean a laminated clayey rock (Fig. 4) and (2) as a broad, group name for all fine-grained siliciclastic rocks.



Figure (4) shale in Gulneri Formation, NE Iraq  
(photo by Maher)



mudstone in Fatha Formation, NE Iraq  
(Photo by Salah)

Mudstones and shales may have a variety of colors ranging through red, brown, yellow, green, light gray, and dark gray to black. The colors of shales appear to be a function mainly of the carbon content and the oxidation state of iron in the shales. The progression of colors from light gray through dark gray to black correlates with increasing carbon content of shales.

**Carbonate sedimentary rocks****Limestones**

carbonate rocks make up about one-fifth to one-quarter of all sedimentary rocks in the stratigraphic record. They occur in many Precambrian assemblages and in all geologic systems from the Cambrian to the Quaternary. Both limestone and dolomite are well represented in the stratigraphic record. Dolomite is the dominant carbonate rock in Precambrian and Paleozoic sequences, whereas limestone is dominant in carbonate units of Mesozoic and Cenozoic age.

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Carbonate rocks are obviously an important group of rocks. They contain much of the fossil record of past life forms, and they are replete with structures and textures that provide invaluable insight into environmental conditions of the past. Aside from their intrinsic value as indicators of Earth history, they also have considerable economic significance. They are used for a variety of agricultural and industrial purposes, they make good building stone, they serve as reservoir rocks for more than one-third of the world's petroleum reserves, and they are hosts to certain kinds of ore deposits such as epigenetic lead and zinc deposits.

### **Mineralogy of carbonate:**

Carbonate rocks are so called because they are composed primarily of carbonate minerals. These minerals, in turn, derive their identity from the carbonate anion ( $\text{CO}_3^{2-}$ ), which is a fundamental part of their structure. The  $\text{CO}_3^{2-}$  carbonate anion combines with cations such as  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Fe}^{2+}$ ,  $\text{Mn}^{2+}$ , and  $\text{Zn}^{2+}$  to form the common carbonate minerals. The common carbonate minerals fall into three main groups: the calcite group, the dolomite group, and the aragonite group.

### **Mineralogy of carbonate-secreting organisms:**

The skeletal remains of calcium carbonate-secreting organisms are volumetrically important components of many limestones. These skeletal remains may consist of aragonite, calcite, or high-magnesian calcite containing as much as 30 mole percent  $\text{MgCO}_3$ . For example, most molluscs are composed of aragonite, although some (e.g. some gastropods) are composed of low-magnesian calcite. Echinoderms are composed of high-magnesian calcite, and foraminifers are composed of low- or high-magnesian calcite. Some groups of organisms may build skeleton of both aragonite and calcite. A few organisms, e.g. diatoms and radiolarians, secrete skeletons composed of silica.

Note that the mineral composition of calcareous organisms may change with burial diagenesis. Aragonite in skeletal grains transforms to calcite with time and, as indicated, high-magnesian calcite may either lose Mg and alter to low-magnesian calcite or gain Mg to form dolomite.

### **Noncarbonate components:**

Carbonate rocks commonly contain various amounts of noncarbonate minerals, but generally less than about 5 percent. Noncarbonate minerals may include common silicate minerals such as quartz, chalcedony or microquartz, feldspars, micas, clay minerals, and heavy minerals. Clay

minerals are particularly abundant constituents of some carbonates. Other minerals reported in carbonate rocks include fluorite, celestite, zeolites, iron oxides, barite, gypsum, anhydrite, and pyrite. Most noncarbonate minerals in limestones and dolomites are probably of detrital origin; however, some minerals such as chalcedony, pyrite, iron oxides, and anhydrite may form during carbonate diagenesis.

### **Major components of limestones:**

The mineralogy of carbonate rocks is almost totally different from that of sandstones, but many limestones resemble sandstones texturally in that they consist of various kinds of sand- and silt-size carbonate grains and various amounts of fine lime mud matrix and carbonate cements.

Although limestones commonly contain only one or two dominant minerals, in contrast to sandstones, several distinct kinds of carbonate grains are recognized. Most of these grains are not single crystals but are composite grains made up of large numbers of small calcite or aragonite crystals. Folk (1962) proposed the term allochem to cover all of these organized carbonate aggregates that make up the bulk of many limestones. The principal kinds of carbonate grains are illustrated and briefly described in Fig. 5. They include both non-skeletal grains (e.g. lithoclasts, ooids) and skeletal grains (fossil and fossil fragments).


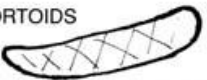

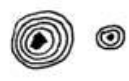




PELOIDS			Small micritic grains, commonly without internal structure. Subrounded, spherical, ovoid or irregular in shape. Size between <math><0.02</math> and about 1 mm, commonly 0.10 to 0.50 mm.
COATED GRAINS	CORTOIDS		Rounded skeletal grains and other grains covered by a thin micrite envelope. Boundary between the central grain and the envelope indistinct. Size between <math><1</math> mm to a few centimeters.
	ONCOIDS		Large and small grains consisting of a more or less distinct nucleus (e.g. a fossil) and a thick cortex formed by irregular, non-concentric, partially overlapping micritic laminae. Laminae may exhibit biogenic structures. No tendency to increase sphericity during growth. Size from <math><1</math> mm to a few decimeters.
	OIDS		Spherical or ovoid grains, consisting of smooth and regular laminae formed as successive concentric coatings around a nucleus. Laminae may exhibit tangential and radial microfabrics. Size between 0.20 and about 2 mm, commonly between 0.5 and 1 mm.
	PISOIDS		Large subspherical and irregularly shaped grains, consisting of a mostly non-biogenic nucleus and a thick cortex formed by conspicuously, often densely spaced laminae exhibiting tangential and radial microfabrics. PISOIDS occur as isolated grains or are incorporated in crusts. Size generally >2 mm, up to >1 cm.
GRAIN AGGREGATES			Compound grains consisting of two or more originally separated particles (e.g. ooids, skeletal grains) that have been bound and cemented together, forming grape-like or rounded lumps. Intergrain spaces filled with micrite or spar. Outline irregular lobular or rounded. Size 0.5 to more than 2 mm.
CLASTS			Synsedimentary or postsedimentary lime clasts, reworked partly consolidated carbonate sediment or already lithified material. Shape and size are highly variable: angular to rounded. Size ranges between <math><0.2</math> mm and several decimeters. Very small clasts are hardly distinguishable from peloids.
SKELETAL GRAINS			Fragmented or complete skeletons of organisms. Size from 0.05 mm to many centimeters.

Figure (5) Descriptive terminology of the major kinds of carbonate grains.

### Carbonate grains

1- Peloids: Peloids are spherical, ovoid, or rod-shaped, mainly silt-sized carbonate grains that commonly lack definite internal structure (Fig. 6). They are generally dark gray to black owing to contained organic material and may or may not have a thin, dark outer rim. The most common size of peloids ranges from about 0.05 to 0.20 mm, although some are much larger. Peloids are composed mainly of fine micrite 2 to 5 microns in size, but larger crystals may be present. They are commonly well sorted and they may occur in clusters. They are produced by a variety of organisms that ingest fine carbonate mud while feeding on organic-rich sediments.

2- Coated grains: ooids, oncoids, and cortoids

Definition:

Coated grain is a general term used for all carbonate grains composed of a nucleus surrounded by an enclosing layer or layers commonly called the cortex. Various kinds of coated grains are recognized, largely on the basis

of the structure of the cortex. Coated grains are divided into four broad groups: ooids, oncoids, cortoids, and pisoids.

**A- Ooids**

Calcareous ooids are small, more or less spherical to oval carbonate particles, which are characterized by the presence of concentric laminae that coat a nucleus. The nucleus may be a skeletal fragment, peloid, smaller ooid, or even a siliciclastic grain such as a quartz grain. Most ooids are sand- to silt-size particles (Fig. 6).

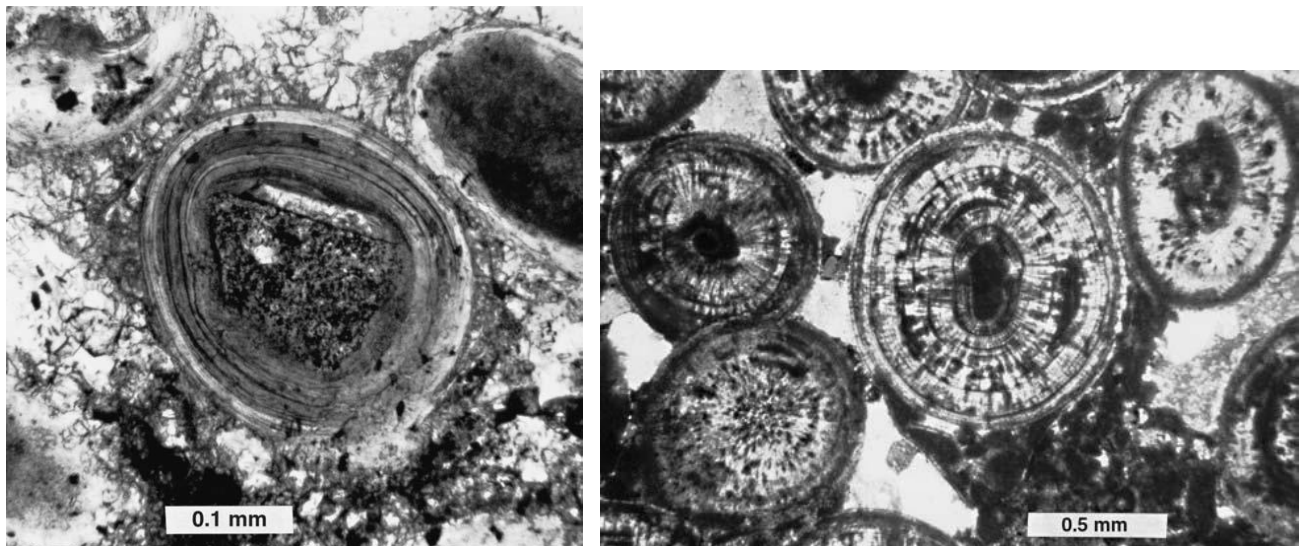


Figure (6) showing ooids

**B-Oncoids**

Coated grains more irregular in shape than ooids, and with more irregular laminae, are called oncoids (Fig. 7). Oncoids are also generally larger than ooids, commonly ranging from < 2 mm to > 10 mm. They form in both nonmarine and marine environments. Many authors restrict the term oncoid to grains of cyanobacterial and bacterial origin. Others include also as oncoids carbonate grains encrusted by red algae and bryozoans.



Figure (7) Large oncoids exposed on a weathered limestone of Qamchuqa Formation, NE Iraq. (Photo by Salah)

### C- Cortoids

Some coated grains consist of fossils, ooids, or peloids coated with a thin envelope of generally dark colored micrite (Fig. 8), commonly consisting of crystals 2 to 5 microns in size. The micrite envelopes may originate by several processes, which can include destructive micritization related to the activities of microboring organisms.

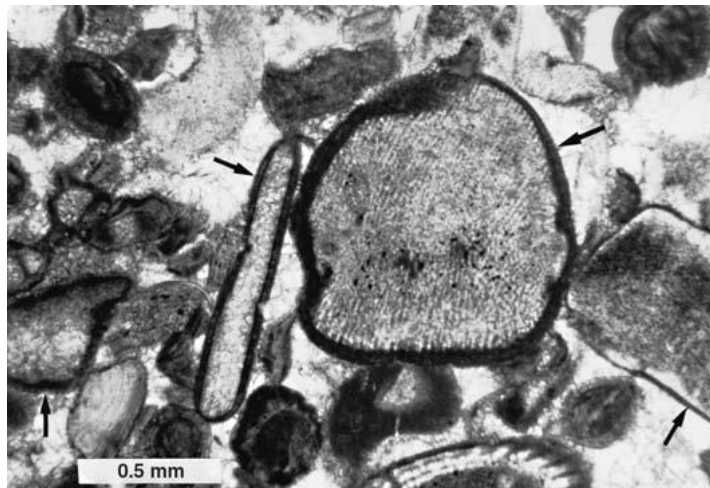


Figure (8) Micrite envelopes (arrows) developed around echinoderms and other fossil fragments.

### Lithoclasts

Carbonate lithoclasts are detrital fragments of carbonate rock produced by disintegration of pre-existing carbonate rock or sediment, either within or outside a depositional basin. They are also sometimes called limeclasts. Lithoclasts may range in size from very fine sand to pebbles or even boulders. They tend to be well rounded, but may also be subrounded, subangular, or angular. Very small lithoclasts may be confused with large peloids. Two kinds of lithoclasts are recognized on the basis of origin: intraclasts and extraclasts.

#### Intraclasts

Some lithoclasts originate within a depositional basin by fragmentation of commonly weakly cemented, carbonate sediment. Small pieces of this sediment are eroded from the seafloor and redeposited at or near the original area of deposition. Lithoclasts having this origin are called intraclasts.

Although most intraclasts are probably produced by physical disruption of sediment by normal waves, storm waves, or currents, some intraclasts

may form by other mechanisms. These mechanisms could include organic activity on the surface of sediment, burrowing or boring activity within sediment, and local sliding of weakly consolidated sediment (Fig. 9).

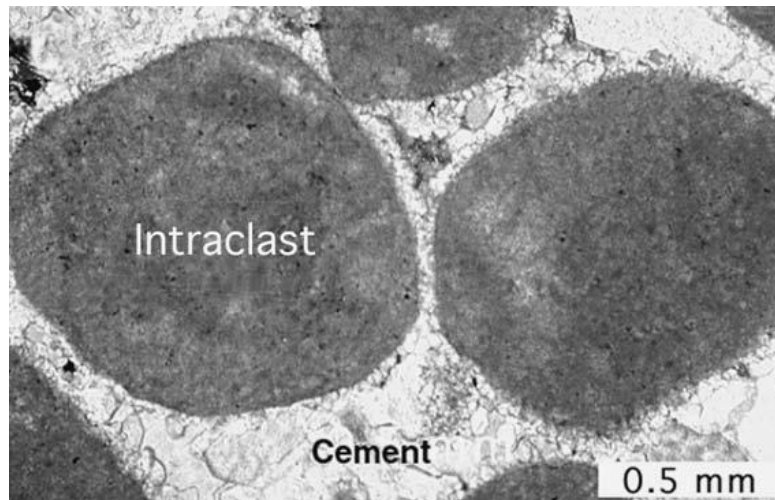


Figure (10) Well-rounded intraclasts (produced in a high-energy environment), cemented with sparry calcite cement.

#### Extraclasts

Lithoclasts generated by erosion of much older, lithified carbonate rock exposed on land (outside the depositional basin in which the clasts accumulate) are called extraclasts. They are simply carbonate rock fragments (Fig. 11).

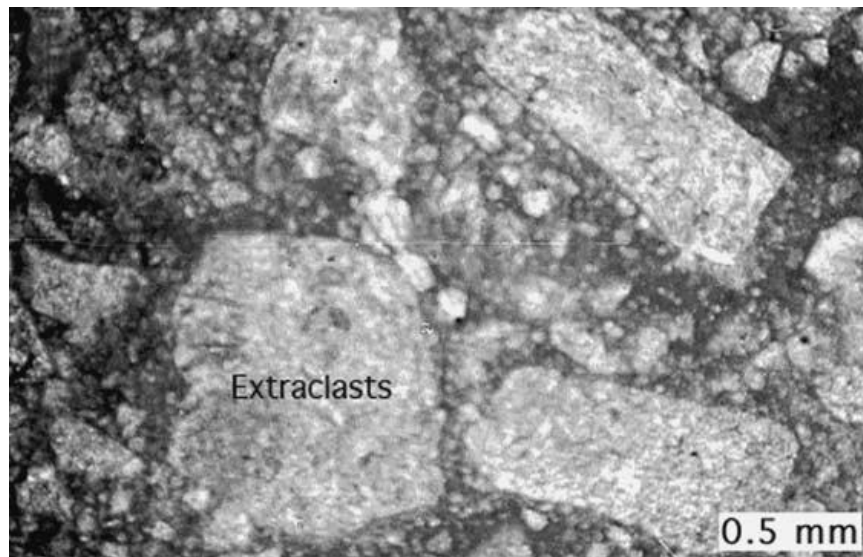


Figure (11) Angular to subrounded lithoclasts in a lime-mud (dark) matrix.



**Skeletal grains (bioclasts)**

Skeletal grains are among the most abundant and important kinds of grains that occur in limestones of Phanerozoic age. Skeletal grains may consist of whole fossil organisms, angular fragments of fossils, or fragments rounded to various degrees by abrasion. Skeletal grains may occur with other kinds of carbonate grains or they may constitute the only kind of carbonate grains in a particular limestone. Some limestones are composed almost entirely of skeletal remains, which are cemented together with a small amount of micrite or sparry calcite cement.

The kinds of skeletal grains that occur in limestones encompass essentially the entire spectrum of organisms that secrete hard parts; however, the relative abundance of various kinds of skeletal remains has varied through time.

most skeletal grains are composed of aragonite, calcite, or magnesian calcite. Vertebrate remains, fish scales, conodonts, and the remains of a few invertebrate organisms such as inarticulate brachiopods are composed of calcium phosphate. Also, a few, e.g. diatoms and radiolarians, are composed of silica. The original composition of skeletal grains may be altered during diagenesis. Aragonite skeletons transform to calcite, and high-magnesian calcite grains may alter to calcite or become dolomitized. Carbonate skeletal grains may also undergo replacement by silica. Each kind of organism that lived in the past was adapted to a particular set of ecological conditions. Because this was so, fossils yield vital information about environmental conditions such as water depth, salinity, turbidity, and energy levels. Therefore, it is extremely important in petrologic studies of carbonate rocks to identify each skeletal grain (Fig. 12).

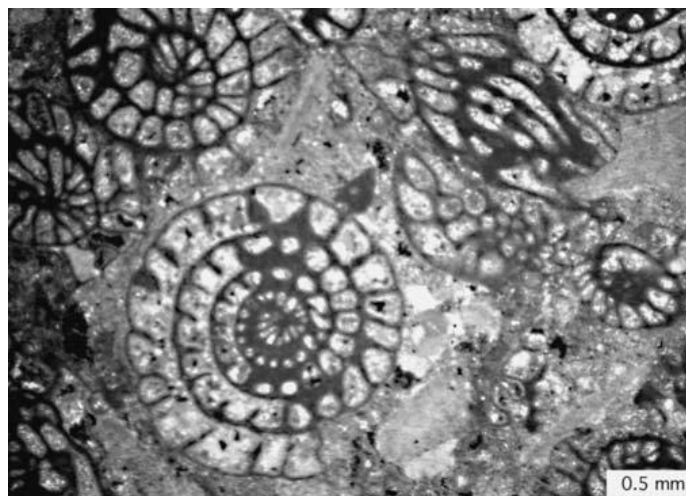


Figure (12) Fusulinid foraminifers as they appear in thin section.

**Classification of carbonate rocks**

Dunham’s classification (1962)

Dunham classification is focusing upon depositional limestone textures rather than upon the identity of specific kinds of carbonate grains. He considers two aspects of texture: (1) grain packing and the relative abundance of grains and micrite and (2) depositional binding of grains. To use this classification the user must first determine if the original constituents of the limestone were or were not bound together at the time of deposition.

For rocks composed of components not bound together during deposition (i.e. components deposited as discrete grains or crystals), the rocks are further divided into those that contain lime mud (micrite) and those that lack mud. Rocks that contain lime mud are either mud-supported or grain-supported (Fig 13).






Carbonates					
Dunham (1962)					
Groundmass:					
Fine carbonate matrix		+ spar		sparry cement	
Matrix-supported		Grain-supported			
Grains: < 10%		Grains: > 10%			
MUDSTONE	WACKESTONE	PACKSTONE		GRAINSTONE	BOUNDSTONE
					

Figure (13) Dunham classification of carbonate rocks

Mud-supported limestones are **mudstone** (i.e. lime mudstones) if they contain less than 10 percent carbonate grains and **wackestone** if they contain more than 10 percent grains. Grainsupported limestones that contain some micrite mud matrix are **packstone**. Grain-supported limestones that lack mud matrix are **grainstone**. Dunham uses the term **boundstone** for limestones composed of components bound together at the time of deposition.

## Nonmarine carbonates

Carbonate rocks also form in a variety of nonmarine settings, including lakes, streams, marshes, springs, caves, soils, and dune environments. The volume of these nonmarine or terrestrial carbonates is small, but they are an interesting addition to the overall carbonate record. Also, when they can be identified in ancient deposits, they make useful paleoenvironmental indicators.

### 1- Lacustrine carbonates:

Carbonate sediments occur in some freshwater lakes. The principal carbonate mineral formed in freshwater lakes is low-Mg calcite. The deposits of saline lakes may include low-Mg calcite, high-Mg calcite.

Lacustrine carbonate sediments may include abiotic precipitates, algal carbonates, and carbonate shell accumulations. These carbonate materials may be mixed to various degrees with organic matter; biogenic silica (mainly diatom frustules); fine, detrital siliciclastics; and evaporite minerals. Abiotic precipitation is probably important mainly in saline lakes in areas where evaporation rates are high. Under these conditions, both loss of water and loss of CO<sub>2</sub> can trigger precipitation of calcite and Mg-calcite.

### 2- Carbonates in rivers, streams, and springs:

Only a very small volume of carbonate sediment forms in the flowing water of rivers, streams, and springs. Commonly, such water is too undersaturated with calcium carbonate to precipitate carbonate minerals; however, saturation may occur in waters that drain regions underlain by carbonate rocks. Carbonate precipitated from streams and cold-water springs commonly consists of low-Mg calcite, whereas precipitates from hot springs may also include aragonite. The terminology of carbonate sediments formed in these freshwater environments is **travertine**.

On the other hand, some authors apply the name travertine only to the more massive, dense, finely crystalline varieties of these deposits. These carbonates range in color from tan to white or cream (Fig. 14). The more porous, spongy, or cellular varieties of these freshwater carbonates (Fig. 15), which commonly form as encrustations on plant remains, are called **tufa**.

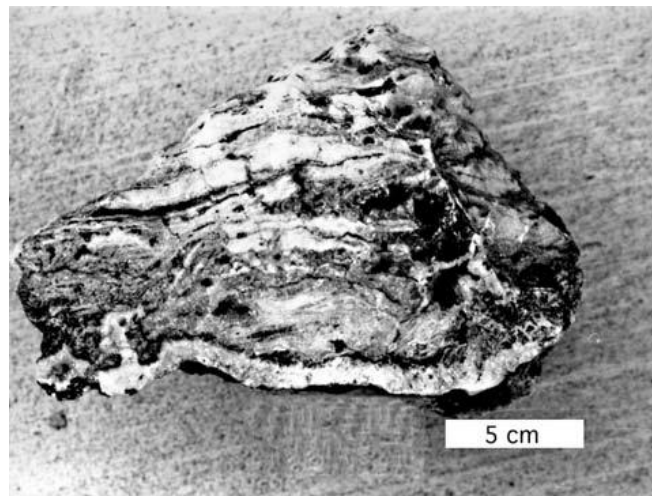


Figure (14) travertine

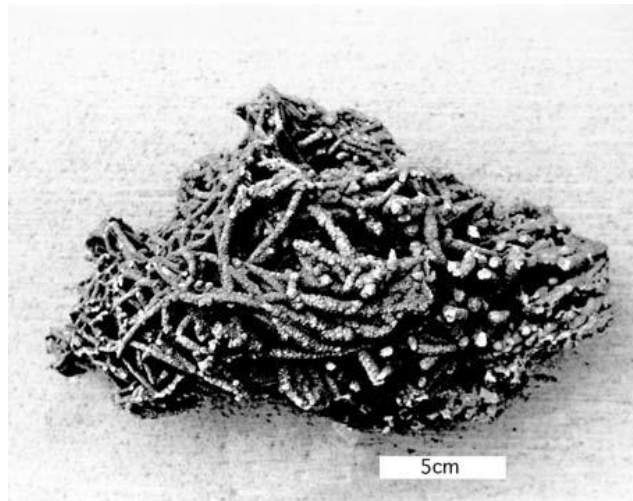


Figure (15) tufa

Precipitation of travertine occurs predominantly in springs and spring-fed lakes and at waterfalls or cascades. Chafetz and Folk (1984) suggest that, morphologically, travertines can occur as (1) waterfall or cascade deposits, (2) lake-fill accumulations, (3) sloping mounds, fans, or cones, (4) terraced mounds, and (5) fissure ridges. Precipitation of travertine requires that ground waters or streams be supersaturated with calcium carbonate with respect to calcite and supersaturated in  $\text{CO}_2$  with respect to air. Precipitation can occur in cold-water springs owing to loss of  $\text{CO}_2$  resulting from higher temperatures at the mouth of the spring and exposure of spring water to the atmosphere (decrease in pressure).

Tufas apparently form as a result of precipitation of calcite onto plants such as mosses and algae. Chafetz and Folk (1984) conclude that bacteria are also important agents in precipitation of travertines.

## 3- Speleothem (cave) carbonates:

Carbon dioxide-rich groundwaters that migrate through carbonate formations dissolve away parts of the formations and create solution pipes, sinks, and caves. The geomorphological features resulting from such solution activity are referred to as karst features (Fig. 16).

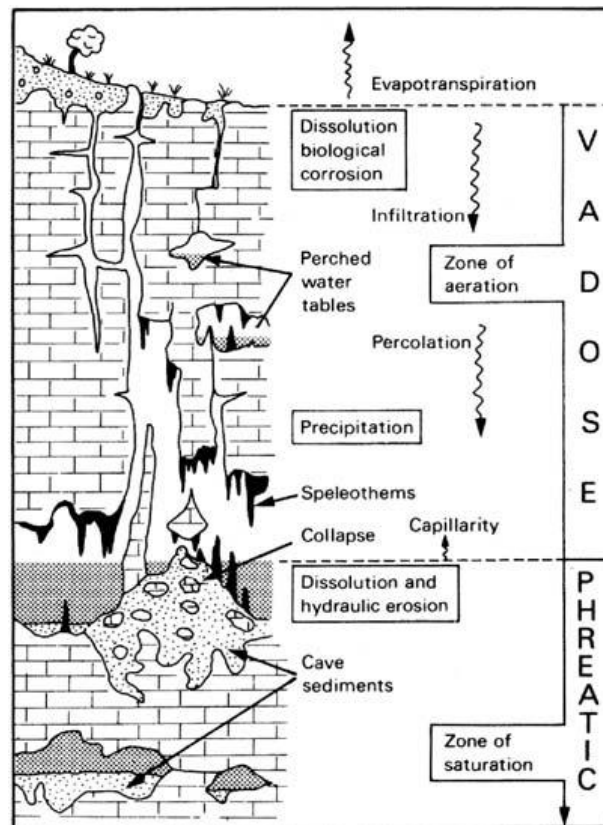


Figure (16) Features of a mature karst profile. The vadose zone is the groundwater zone of aeration, and the phreatic zone is the zone of saturation where pore space is filled with water. Note that speleothems occur especially in the vadose zone, whereas collapse breccias and other cave sediments are common in the phreatic zone.

When carbonate- and CO<sub>2</sub>-saturated groundwater enters air-filled caves, carbonate precipitation occurs on a massive scale owing to loss of CO<sub>2</sub>, probably as a result of decreased pressure and evaporation. Therefore, caves in carbonate terrains are the sites of extensive carbonate deposits, which are referred to collectively as **speleothems**. These deposits may take the form of **stalactites** (conical projection hanging from the roof, formed by dripping water), **stalagmites** (conical dripstone projecting upward from the floor), laminated **flowstones** (formed by flowing water), and **globoids** (cave pearls or cave pisolites formed by precipitation of carbonate as concentric layers around a nucleus).

## chemical/biochemical sedimentary rocks

Evaporites, cherts, iron-rich sedimentary rocks, and phosphorites:

These rocks are far less abundant than siliciclastic sedimentary rocks and carbonate rocks, but have considerable economic significance. Evaporite deposits such as gypsum, halite (rock salt), and trona are mined for a variety of industrial and agricultural purposes, iron-rich sedimentary rocks are the source of most of our iron ores, phosphorites are extremely important sources of fertilizers and other chemicals, and the siliceous sedimentary rocks have some economic value, e.g. in the semiconductor industry.

### 1- Evaporites:

We use the term evaporites to include all those sedimentary rocks formed by evaporation of saline waters. Sedimentary rocks containing evaporite minerals are common in the geologic record. Evaporite salts have been mined and used by humans for more than 5000 years. Halite, gypsum, trona, and other salts are currently used for a variety of industrial and agricultural purposes. In addition to their commercial value, evaporites are associated with carbonate rocks in many major oil fields of the world. Squeezing and remobilization of salt deposits creates petroleum traps in association with salt domes; subsurface solution of evaporite cements in carbonate and siliciclastic rocks can create important amounts of secondary porosity in these rocks; and evaporite caprocks form seals over many petroleum traps that prevent the petroleum from escaping. Evaporite deposits are composed dominantly of varying proportions of halite (NaCl), anhydrite (CaSO<sub>4</sub>) and gypsum (CaSO<sub>4</sub>·2H<sub>2</sub>O).

### Marine evaporite minerals:

Because marine evaporites are precipitated from seawater, the mineral composition of marine evaporites in various deposits tends to be relatively constant. Seawater has an average salinity of about 35 parts per thousand (‰). Although 12 elements are present in seawater in amounts greater than 1 ppm (0.001 parts per thousand) (Braitsch, 1971), Cl<sup>-</sup> (18.98‰), Na<sup>+</sup> (10.56‰), SO<sub>4</sub><sup>2-</sup> (2.65‰), Mg<sup>2+</sup> (1.27‰), Ca<sup>2+</sup> (0.40‰), K<sup>+</sup> (0.38‰), and HCO<sub>3</sub><sup>-</sup> (0.14‰) make up the bulk of the dissolved solids in seawater.

Nonmarine evaporates:

Nonmarine evaporites form from waters that were originally river water or groundwater. The chemistries of these original waters can be highly variable, depending upon the lithology of the rocks with which they interact. For example, rivers that flow across limestones are commonly enriched in  $\text{Ca}^{2+}$  and  $\text{HCO}_3^-$ , whereas those that flow across igneous and metamorphic rocks tend to be enriched in silica,  $\text{Ca}^{2+}$ , and  $\text{Na}^+$ .

Classification of evaporates:

Evaporites can be classified into marine and nonmarine types on the basis of origin, and They can be further classified as chlorides, sulfates, and carbonates on the basis of mineralogy.

Rocks composed mainly of halite are called halite or rock salt. Rocks made up dominantly of gypsum or anhydrite are simply called gypsum or anhydrite, although some geologists use the names rock gypsum or rock anhydrite.

Deposition of evaporates:

Ocean water has an average salinity of about 35‰. When ocean water is evaporated in the laboratory, evaporite minerals are precipitated in a definite sequence that was first demonstrated by Usiglio in 1848 (reported in Clarke, 1924). Minor quantities of carbonate minerals begin to form when the original volume of seawater is reduced by evaporation to about one-half, and brine concentration is about twice that of seawater. Gypsum appears when the original volume has been reduced to about 20 percent. At this point, the brine has a concentration of about four to five times that of normal seawater (130–160‰). Halite begins to form when the water volume reaches approximately 10 percent of the original volume, or 11 to 12 times the brine concentration of seawater (340–360‰). Magnesium and potassium salts are deposited when less than about 5 percent of the original volume of water remains; at that point, brine concentration may be more than 60 times that of seawater.

Many marine evaporite deposits are quite thick, some exceeding 2 km, yet it has long been recognized that evaporation of a column of seawater 1000m thick will produce only about 14 to 15m of evaporites. Evaporation of all the water of the Mediterranean Sea, for example, would yield a mean thickness of evaporites of only about 60 m.

Physical processes in deposition of evaporates:

Evaporite deposits as simply the products of chemical precipitation owing to evaporation, many evaporite deposits are not just passive chemical precipitates. The evaporite minerals have, in fact, been transported and reworked in the same way as the constituents of siliciclastic deposits and carbonate deposits. Transport can occur by normal fluid-flow processes or by mass-transport processes such as slumps and turbidity currents.

### **Siliceous sedimentary rocks (cherts):**

Siliceous sedimentary rocks are fine-grained, dense, commonly very hard rocks composed dominantly of the SiO<sub>2</sub> minerals quartz, chalcedony, and opal. Most siliceous rocks also contain minor amounts of impurities such as clay minerals, hematite, calcite, dolomite, and organic matter. Chert is the general group name used for siliceous sedimentary rocks. Cherts are common but not abundant rocks in the geologic record. Overall, they probably make up less than 1 percent of all sedimentary rocks, but they are represented in stratigraphic sequences ranging in age from Precambrian to Quaternary. Also, they are forming today as siliceous oozes in some parts of the modern ocean.

Mineralogy and texture:

Quartz is the primary mineral of siliceous deposits; however, other SiO<sub>2</sub> minerals in these deposits can include chalcedonic quartz, amorphous silica (opal-A), and disordered cristobalite and tridymite (opal-CT). Opal-CT is low-temperature cristobalite disordered by interlayered tridymite lattices.

We commonly use the group name chert to cover all rocks formed of these minerals. Opal-A is primarily of biogenic origin and forms the tests of siliceous plankton and the spines of some sponges.

Principal kinds of cherts:

Although chert is the general group name for siliceous sedimentary rocks composed dominantly of SiO<sub>2</sub> minerals, several names are applied to various varieties of chert. Flint is used both as a synonym for chert and as a varietal name for chert, particularly chert that occurs as nodules in Cretaceous chalks. Jasper is a variety of chert colored red by impurities of disseminated hematite. Jasper that is interbedded with hematite in Precambrian iron formations is called jaspilite. Novaculite is a very



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dense, fine-grained, even-textured chert that occurs mainly in mid-Paleozoic rocks of the Arkansas, Oklahoma, Texas region of south central United States.

#### A- Bedded chert:

Bedded cherts can be subdivided on the basis of type and abundance of siliceous organic constituents into three principal types:

1- Diatomaceous deposits include both diatomites and diatomaceous cherts. Diatomites are light-colored, soft, friable siliceous rocks composed chiefly of the opaline frustules of diatoms, a unicellular aquatic plant related to the algae. Thus, they are fossil diatomaceous oozes.

2- Radiolarian deposits consist dominantly of the remains of radiolarians, which are marine Planktonic protozoans with a latticelike skeletal framework.

3- Siliceous spicule deposits include spicularite (spiculite), a siliceous rock composed principally of the siliceous spicules of invertebrate organisms, particularly sponges. Spicularite is loosely cemented in contrast to spicular chert, which is hard and dense.

#### B- Nodular cherts:

Nodular cherts are subspheroidal masses, lenses, or irregular layers or bodies that range in size from a few centimeters to several tens of centimeters (Fig. 17). They commonly lack internal structures, but some nodular cherts contain silicified fossils or relict structures such as bedding. Colors of these cherts range from green to tan and black. They typically occur in shelf-type carbonate rocks where they tend to be concentrated along certain horizons parallel to bedding.

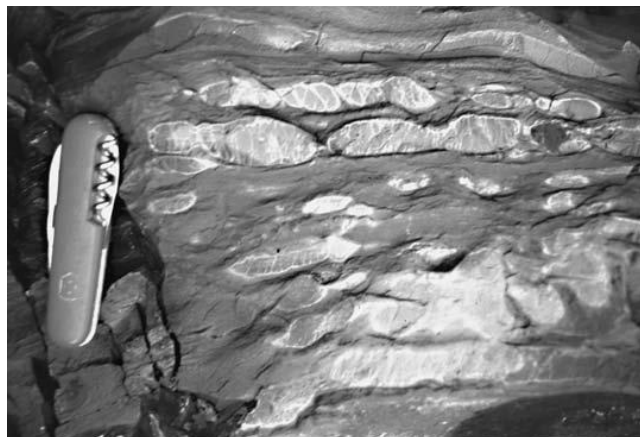


Figure (17) Nodular chert in limestones

## Iron-rich sedimentary rocks

Small amounts of iron occur in nearly all sedimentary rocks – about 4.8 percent in the average shale, 2.4 percent in the average sandstones, and 0.4 percent in the average limestone. Sedimentary rocks that contain more than about 15 percent iron, corresponding to 21.3 percent  $\text{Fe}_2\text{O}_3$  or 19.4 percent  $\text{FeO}$ , are considered to be iron rich. Although iron-bearing minerals occur in sedimentary rocks of all ages, true iron-rich rocks are very unevenly distributed by age in the geologic record. Most iron-rich sedimentary rocks were deposited during three major time periods: the Precambrian, the early Paleozoic, and the Jurassic and Cretaceous.

Principal kinds of iron-rich sedimentary rocks

### I. Detrital chemical iron-rich sediments

**A. Cherty iron-formation** Texture: analogous to limestone texture

Composition: iron-rich chert containing hematite, magnetite, siderite, ankerite, or (predominantly alumina-poor) silicates as predominating iron minerals; relatively poor in Al and P

**B. Minette-type ironstone (aluminous iron-formation)** Texture: analogous to limestone texture

Composition: aluminous iron silicates (chamosite, chlorite, stilpnomelane), iron oxides, and carbonates; relatively rich in Al and P

### II. Iron-rich shales

#### C. Pyritic shales

Bituminous shales containing nodules or laminae of pyrite; grade into massive pyrite bodies by coalescence of pyrite laminae and nodules

#### D. Siderite-rich shales

Bituminous shales with siderite concretions; grade into massive siderite bodies by coalescence of concretions

### III. Miscellaneous iron-rich deposits

#### E. Iron-rich laterites

#### F. Bog iron ores

#### G. Manganese nodules and oceanic iron crusts

H. Iron-rich muds precipitated from hydrothermal brines, Lahn-Dill-type iron oxide ores, and stratiform, volcanogenic sulfide deposits

#### I. Placers of magnetite, hematite, or ilmenite sand

Mineralogy and geochemistry:

On the basis of relative abundance of major iron-bearing minerals, James (1966, 1992) defined four principal kinds of iron-rich sedimentary rocks, which he referred to as facies:

**1) oxides, (2) silicates, (3) carbonates, and (4) sulfides.**

The chemistry of iron-formations is dominated by  $\text{SiO}_2$  and Fe which can be expressed as  $\text{Fe}_2\text{O}_3$ , FeO, and  $\text{FeS}_2$ . Gole and Klein (1981) show that the average chemical composition of iron-formations is about 45–50 percent  $\text{SiO}_2$ , 13–27 percent  $\text{Fe}_2\text{O}_3$ , 17–25 percent FeO (29–32 percent total Fe), 3–6 percent MgO, 2–7 percent CaO, 1–2 percent  $\text{Al}_2\text{O}_3$ , and less than 1 percent each of TiO<sub>2</sub>, MnO, Na<sub>2</sub>O, K<sub>2</sub>O, P<sub>2</sub>O<sub>5</sub>, S, and C.

Principal kinds of iron-formations:

Various attempts have been made to classify iron-formations into a few specific, representative types. For example, Gross (1965) divided iron-formations into **Algoma-type** and **Superior-type**. According to him, **Algoma-type** iron-formations are intimately associated with various volcanic rocks. They are thinly banded or laminated, lack oolitic or granular textures, and commonly extend laterally for only a few kilometers. By contrast, Gross suggested that **Superior-type** iron-formations are not associated with volcanic rocks but commonly occur with quartzite, black carbonaceous shale, conglomerate, dolomite, massive chert, chert breccia, and argillite.

### **Sedimentary phosphorites**

Phosphorites are sedimentary deposits containing more than about 15–20 percent  $\text{P}_2\text{O}_5$ . Thus, they are significantly enriched in phosphorus over most other types of sedimentary rocks. The phosphorus content of average shales is about 0.11–0.17 percent  $\text{P}_2\text{O}_5$ , the average sandstone contains about 0.08–0.16 percent  $\text{P}_2\text{O}_5$ , and the average limestone about 0.03–0.7 percent  $\text{P}_2\text{O}_5$  (McKelvey, 1973). Shales, sandstones, or limestones that contain less than 20 percent  $\text{P}_2\text{O}_5$  but which are enriched in phosphorus over that found in average sediments are referred to as phosphatic, e.g. phosphatic shale. Phosphorus-rich sedimentary rocks are called by a variety of names – phosphate rock, rock phosphate, phosphates, phosphatites, and phosphorites.

Stratigraphic characteristics:

In ancient phosphorite deposits, phosphate-rich layers typically occur interbedded with carbonate rocks, mudrocks, or chert. A characteristic feature of many major phosphorite accumulations is the triple association of phosphate, chert, and sediments containing abundant organic carbon.

Composition of phosphorites

Sedimentary phosphates are composed of phosphate minerals, all of which are varieties of apatite. The principal varieties are fluorapatite  $[\text{Ca}_5(\text{PO}_4)_3\text{F}]$ , chlorapatite  $[\text{Ca}_5(\text{PO}_4)_3\text{Cl}]$ , and hydroxyapatite  $[\text{Ca}_5(\text{PO}_4)_3\text{OH}]$ . Most sedimentary phosphates are carbonate hydroxyl fluorapatites in which up to 10 percent carbonate ions can be substituted for phosphate ions to yield the general formula  $\text{Ca}_{10}(\text{PO}_4, \text{CO}_3)_6\text{F}_{2-3}$ .

Principal kinds of phosphate deposits:

Five principal groups have been identified:

1. Bedded phosphorites form distinct beds of variable thickness, commonly interbedded and interfingering with carbonaceous mudrocks, cherts, and carbonate rocks. The phosphorite occurs as peloids, ooids, pisoids, phosphatized fossils and skeletal fragments, and cements.
2. Bioclastic phosphorites are a special type of bedded phosphate deposit composed largely of vertebrate skeletal fragments such as fish bones, shark teeth, fish scales, coprolites, etc.
3. Nodular phosphates are brownish to black, spherical to irregular-shaped nodules ranging in size from a few centimeters to a meter or more.
4. Pebble-bed phosphorites are composed of phosphatic nodules, phosphatized limestone fragments, or phosphatic fossils that have been mechanically concentrated by reworking of earlier-formed phosphate deposits.
5. Guano deposits are composed of the excrement of birds and possibly bats that has been leached to form an insoluble residue of calcium phosphate.

### Deposition of phosphorites:

The conditions that favor precipitation of calcium carbonate also favor formation of carbonate-apatite, although carbonate-apatite can precipitate at values of pH possibly as low as 7.0 whereas calcium carbonates generally do not precipitate below a pH of about 7.5.

The average concentration of phosphorus in the ocean is 70 ppb (parts per billion) compared to 20 ppb in average river water. The concentration of phosphorus in ocean water ranges from only a few ppb in surface waters, which are strongly depleted by biologic uptake, to values of 50–100 ppb at depths greater than about 200–400 m.

Phosphorus is removed from seawater in several ways. Some phosphorus is precipitated along with calcium carbonate minerals during deposition of limestones; however, the average limestone contains only about 0.04 percent P<sub>2</sub>O<sub>5</sub>. Phosphorus is also removed from ocean water by concentration in the tissues of organisms, but this phosphorus is returned to the ocean when organisms die unless they are quickly buried by sediment before decay of the organic tissue is complete.

Early ideas on upwelling and phosphorite deposition assumed that inorganic precipitation of apatite occurred as cold, deep, phosphate-rich waters welled up onto a shallow shelf. Under these postulated conditions, carbon dioxide would be lost from the upwelling waters owing to pressure decrease, warming, or photosynthesis, causing pH to increase and carbonate-apatite precipitation to occur.

### Carbonaceous sedimentary rocks

Most sedimentary rocks, including rocks of Precambrian age, contain at least a small amount of organic matter consisting of the preserved residue of plant or animal tissue. The average sedimentary rock contains about 1 percent organic carbon. A few special types of sedimentary rocks have significantly more organic material than these average rocks. Black shales and other organic-rich and bituminous mudrocks typically contain 3 to 10 or more percent by weight of organic matter.

### Principal kinds of organic matter:

Organic content of carbonaceous sedimentary rocks is the characteristic that particularly distinguishes them from other sedimentary rocks. **Three basic kinds** of organic matter accumulate in subaerial and subaqueous environments: **humus, peat, and sapropel**. **Soil humus** is plant organic matter that accumulates in soils to form a number of decay products such

as humic and fulvic acids. **Peat** is also humic organic matter, but peat accumulates in freshwater or brackish-water swamps and bogs, where stagnant, anaerobic conditions prevent total oxidation and bacterial decay. Therefore, some peat that accumulates under these conditions can be preserved in sediments, e.g. in coals and shales. **Sapropel** is fine organic matter that accumulates subaqueously in lakes, lagoons, and marine basins where oxygen levels are moderately low. It consists largely of the remains of phytoplankton and zooplankton and of spores, pollen, and macerated fragments of higher plants.

The organic matter in shales is not the same as the original organic material deposited in the parent mud. The original organic material has been changed by a complex diagenetic process involving chemical and biochemical degradation, yielding an insoluble organic substance called **kerogen**. Among other things, kerogen is believed to be the precursor material of petroleum, which is derived from kerogen by natural thermal or thermocatalytic cracking.

Kerogen is insoluble in both aqueous alkaline solvents and common organic solvents. Some organic material in sediments is soluble in and extractable by organic solvents. This material is called bitumen. In ancient shales, kerogen makes up 80 to 99 percent of the organic matter; the rest is **bitumen**.

### **Classification of kerogen:**

**1- Type I kerogen** has high initial H/C and low O/C ratios. It is rich in aliphatic structures and thus in hydrogen. Algal kerogens belong in this group.

**2- Type II kerogen** has relatively high H/C and low O/C ratios, and derived from phytoplankton, zooplankton, bacteria, etc. deposited in marine environments under reducing conditions.

**3- Type III kerogen** has relatively low initial H/C and high initial O/C ratios. It is believed to be derived mainly from terrestrial plants and contains much identifiable vegetal debris.

### Major kinds of carbonaceous sedimentary rocks

The dominant organic constituents of carbonaceous sediment s are humic and sapropelic organic matter. The nonorganic constituents are either siliciclastic grains or carbonate materials. Carbonaceous sediments can be classified, on the basis of relative abundance of these constituents and the kinds of organic matter that compose the constituents (humic vs. sapropelic), into **three basic types of organic-rich rocks: coal, oil shale , and asphaltic substances.**