

# ENGINEERING GEOLOGY

## Lecture #4 Surface Processes and Sedimentary Rocks

CE1301



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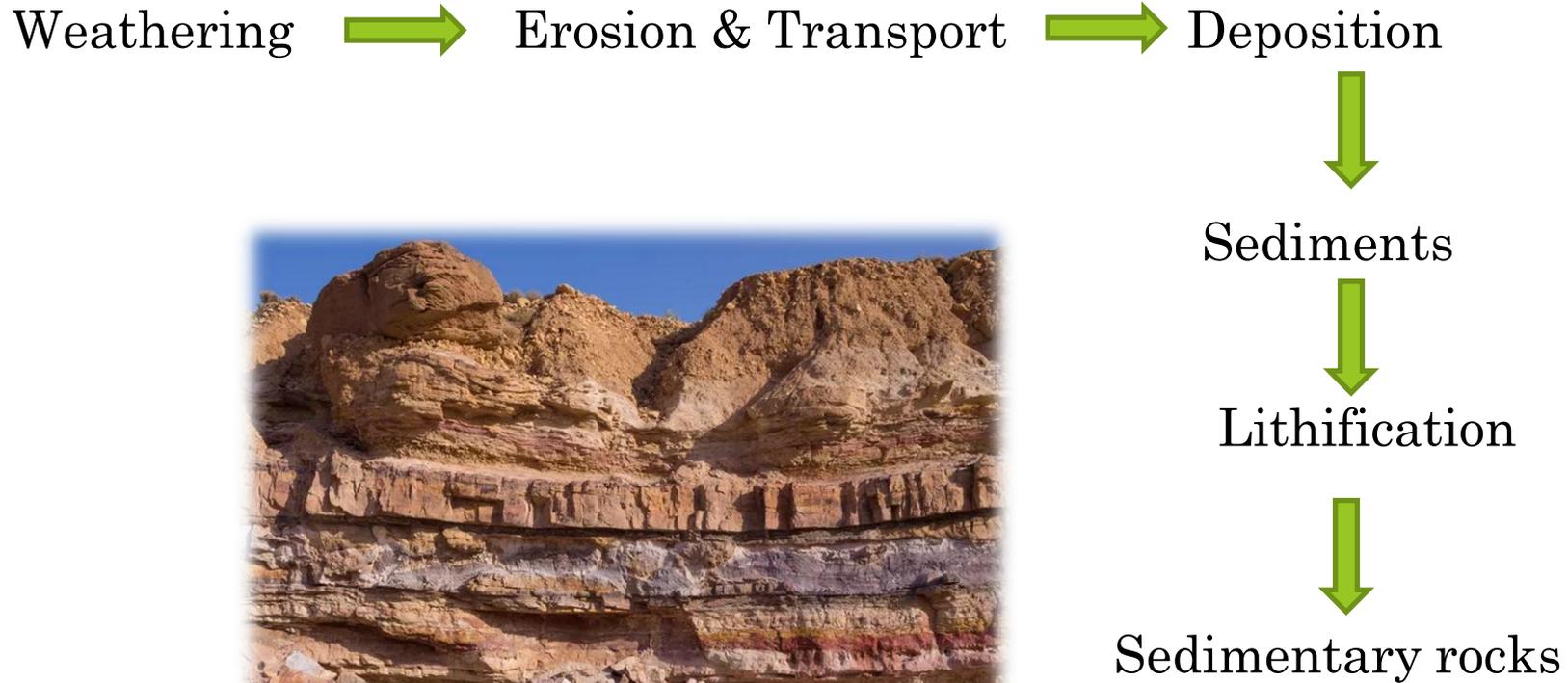
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# SEDIMENTARY ROCKS FORMATION STAGES



Source: <https://www.thoughtco.com/sedimentary-rock-classification-diagrams-4123127>

# SURFACE PROCESSES

**Weathering** is the gradual breakdown of rock under atmospheric conditions. It takes place in surface rocks (directly exposed to atmosphere) as well as in the fractured subsurface rocks.

**Erosion** is the process by which rock particles are grinded and moved to another place by action of gravity, wind, water (main agent) or ice.

- Land areas are continually being reduced and their shape modified by weathering and erosion, and the general term for this is **denudation**.
- Weathering leads to a decrease in density and strength, and to increasing deformability.
- By these processes a covering layer of weathered rock is formed on a land surface. Normally the upper layers of this cover are continually removed, exposing the fresher material beneath it to the influence of the weathering agents; in this way the work of denudation continues.

## CHEMICAL WEATHERING

Chemical weathering leads to mineral alteration and the solution of rocks.

### Natural factors

- Presence of water
- Climate: wet climates cause more weathering than dry climates.

<u>Process</u>	<u>Description</u>
Dissolution	Dissociation of minerals into ions, greatly aided by the presence of CO <sub>2</sub> in the soil profile, which forms carbonic acid (H <sub>2</sub> CO <sub>3</sub> ) with percolating rainwater.
Oxidation	The combination of oxygen with a mineral to form oxides and hydroxides or any other reaction in which the oxidation number of the oxidized elements is increased.  Think of rocks containing iron or sulphur!
Hydration	Absorption of water molecules into the mineral structure. This normally results in expansion, some clays expand as much as 60%.
Hydrolysis	Hydrogen ions in percolating water replace mineral cations: no oxidation occurs.
Leaching	The migration of ions produced by the above processes. Note: the mobility of ions depends upon their ionic potential: Ca, Mg, Na, K are easily leached by moving water, Fe is more resistant, Si is difficult to leach and Al is almost immobile.
Cation Exchange	Absorption onto the surface of negatively charged clay of positively charged cations in solution, especially Ca, H, K, Mg.

## CHEMICAL WEATHERING

- Chemical weathering is seen most readily in its solvent action on some rocks, notably limestones and those rocks containing the minerals Halite (NaCl), Anhydrite (CaSO<sub>4</sub>) and Gypsum (CaSO<sub>4</sub>·2H<sub>2</sub>O).
- **Common hydration reaction:**  $\text{CaSO}_4 + 2\text{H}_2\text{O} \rightarrow \text{CaSO}_4 \cdot 2\text{H}_2\text{O}$
- This reaction produces an increase in volume of approximately 6% and, accordingly, causes the enclosing rocks to be wedged further apart.
- **Common dissolution reaction:** the calcium carbonate of the limestone is slowly dissolved by rainwater containing carbon dioxide, and is held in solution as calcium bicarbonate, thus:  
$$\text{CaCO}_3 + \text{H}_2\text{O} + \text{CO}_2 \leftrightarrow \text{Ca}(\text{HCO}_3)_2 \quad (\text{Calcium bicarbonate})$$
- The ground surface of a limestone area commonly shows solution hollows, depressions that may continue downwards as tapering or irregular channels. These may be filled with sediment such as sand or clay.
- Vertical joints in the rock are widened by solution as rain passes down over their walls, and are then known as **grikes**.
- Continued solution may lead to the formation of **swallow holes** (also known as sinkholes) at the intersection of vertical joints.
- **Karst topography** is an area formed by the dissolution (chemically weathering) of soluble rocks such as limestone, dolomite, and gypsum. It is characterized by underground drainage systems with sinkholes and caverns.
- The most easily weathered rocks are limestones; of greater resistance are sandstones and shales.

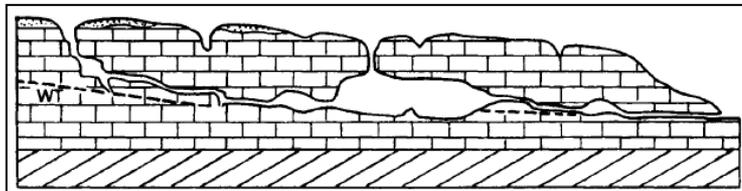


Fig. 3.2 Section through a limestone plateau to show solution features. WT=water table.



Source: [brennanjordan.org](http://brennanjordan.org)



Source: [www.curriculumvisions.com](http://www.curriculumvisions.com)

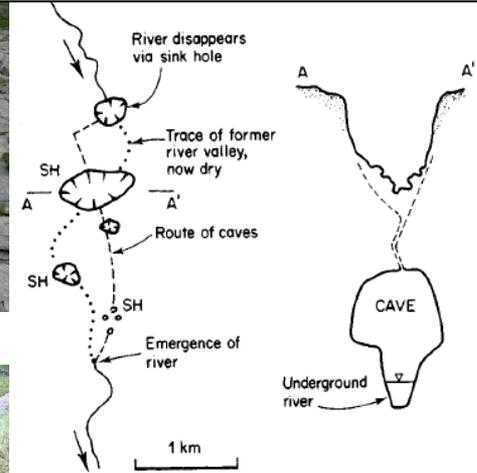
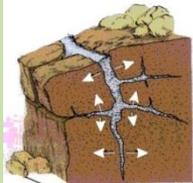


Fig. 3.3 Map showing a river that disappears from the surface to continue its course below ground (SH=sink hole), and a vertical section illustrating the nature of an underground river in Karstic regions.

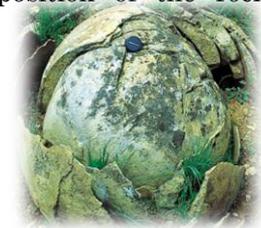
# MECHANICAL WEATHERING

The processes most commonly involved in mechanical weathering are listed in the table.

<u>Process</u>	<u>Description</u>
Mechanical Unloading	Vertical expansion due to the reduction of vertical load by erosion. This will open existing fractures and may permit the creation of new fractures.
Mechanical Loading	Causes impact on rock, and abrasion, by sand and silt size particles in deserts. Impact on soil and weak rocks by rain drops during intense rainfall.
Thermal Loading	Expansion by the freezing of water in pores and fractures in cold regions, or by the heating of rocks in hot regions. Contraction by the cooling of rocks and soils in cold regions.
Wetting and Drying	Expansion and contraction associated with the repeated absorption and loss of water molecules from mineral surfaces and structures: (see hydration in the previous table).
Crystallization	Expansion of pores and fissures by crystallization of minerals that were originally in solution. Note: expansion is only severe when crystallization occurs within a confined space.



- Mechanical weathering is particularly effective in climatic regions that experience significant diurnal changes of temperature.
- In hot climates, when a rock surface is exposed to a considerable daily range of temperature, as in arid and semi-arid regions, the expansion that occurs during the day and the contraction at night, constantly repeated, weaken the structure of the rock. The outer heated layers tend to pull away from the cooler rock underneath and flakes and slabs split off (**exfoliation**). The effects of exfoliation are concentrated at the corners and edges of rocks so that their shape gradually become rounded.
- A large range of temperature occurs daily in deserts, commonly 30°C and sometimes as high as 50°C; the daily range for rock surfaces is often higher than for air. Strain is set up in a rock by the unequal expansion and contraction of its different mineral constituents and its texture is thereby loosened.
- Under natural conditions, insolation of rock faces may result in the opening of many small cracks - some of hair-like fineness - into which water and dissolved salts enter; and thus both the decomposition of the rock and its disintegration are promoted.



## The grade of weathering

- ❖ The grade of weathering of a given rock is assessed in terms of its macroscopic and microscopic petrography.
- ❖ The macroscopic factors included an evaluation of the amount of discoloration, decomposition and disintegration shown by the rock.
- ❖ The microscopic analysis involved assessment of mineral composition and degree of alteration by modal analysis and micro-fracture analysis.
- ❖ Changes in chemical and physical properties in rock also have been used to assess the grade of weathering such as bulk density and index tests like the absorption.
- ❖ Example of the use of physical tests for the recognition of weathering grades: Coefficient of weathering,  $K$ , for granitic rock, based upon the ultrasonic velocities of the rock material according to the expression:

$$K = (V_u - V_w) / V_u$$

where  $V_u$  and  $V_w$  are the ultrasonic velocities of the fresh and weathered rocks, respectively, see the table below.

Table 3.1. Ultrasonic velocity and grade of weathering

Grade of weathering	Ultrasonic velocity (m s <sup>-1</sup> )	Coefficient of weathering
Fresh	Over 5000	0
Slightly weathered	4000–5000	0–0.2
Moderately weathered	3000–4000	0.2–0.4
Strong weathered	2000–3000	0.4–0.6
Very strongly weathered	Under 2000	0.6–1.0

- **Sediments** are inorganic or organic material derived from the weathering and erosion of rocks on the Earth's surface.
  - 95% of the outer 16 km of the earth crust is composed of igneous and metamorphic rocks. However 75% of all rocks at the surface are sedimentary rocks.
  - Of the sedimentary rocks on the surface, 46% are shales, 32% are sandstones and 22% are limestones.

Sedimentary rocks	Mineral grains/ substance
Sandstone 	<ul style="list-style-type: none"> <li>- mostly quartz, also muscovite</li> <li>- Rock fragments and volcanic debris</li> </ul>
Clays	clay minerals
Limestone 	<ul style="list-style-type: none"> <li>- <b>Organic debris:</b> dominated by calcite from marine shell debris</li> <li>- <b>Solutes:</b> dominantly calcite precipitated from sea water largely due to biological activity</li> </ul>
Minor rocks	Organic debris: plant material to form peat and coal
Minor rocks	Solutes: including gypsum and salt, and other less abundant soluble compounds

## SEDIMENT TRANSPORT

- Water is far the most important agent of sediment transport.
  - Sediment is also moved in the sea, mainly in coastal waters where wave action reaches the shallow sea bed.
- Other transport processes have only limited scope:
- gravity, wind, ice, volcanoes



Source: <http://geology.com/rocks/limestone.shtml>

**“A Limestone-Forming Environment:** Here the entire seafloor is covered by a wide variety of corals which produce calcium carbonate skeletons. A United States Geological Survey image by Curt Storlazzi.”

**Deposition:** is the process of laying down of sediments transported by wind, water, or ice.

# LITHIFICATION

- **Lithification:** The processes by which a weak loose sediment is turned into a stronger sedimentary rock.

- Induced by burial pressure and slightly increased temperature beneath a kilometre or more of overlying sediment.

Three main processes of lithification:

- **Compaction:** Restructuring and change of grain packing, with decrease in volume, due to burial pressure, with consequent reduction of porosity as air and water is squeezed out.

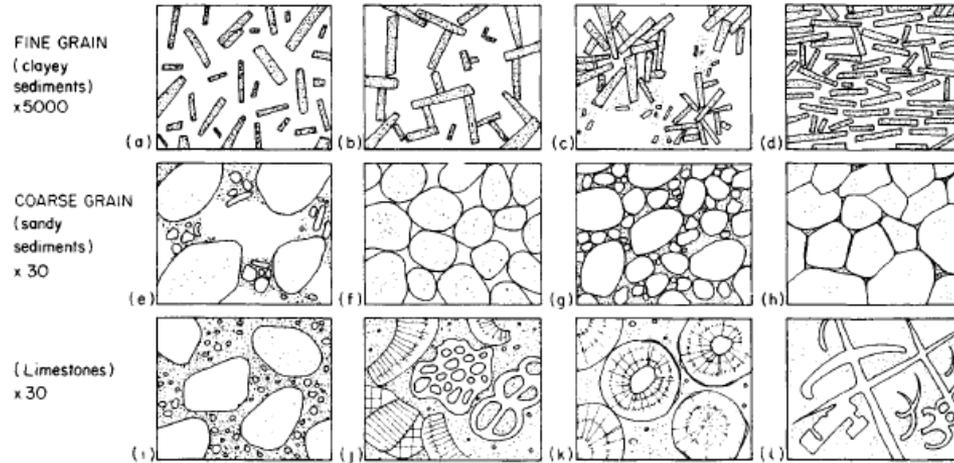
- Increase in strength occurs due to more grain to grain contact. This process is dominant in clays.

- **Cementation:** The filling of the pore spaces between individual particles by cementing material brought in by circulating groundwater. These cementing materials then precipitate in the pores and crystallize to give the binding effect.

- Rock strength is largely dependant on the type of cement, which may be silica (strongest), iron oxides, calcite or clay (weakest). This process is dominant in sandstones.

- **Recrystallization:** Minerals within solution crystallize and crystals of existing minerals increase in size.

- Result may be similar to cementation, but may produce stronger mosaic texture. This process is dominant in limestones.



**Fig. 6.3** Microscopic texture of some common sediments. Clays, (a) dispersed as a colloidal suspension prior to sedimentation; (b) aggregated edge to face as often deposited in fresh water; (c) flocculated, the form of many newly deposited marine clays; (d) compacted with parallel packing, the eventual form of many clays after burial. Sands, (e) grains separated by finer matrix; (f) grains in contact; (g) dense and closely packed grains; (h) grain boundaries in contact (*sutured*), as when severely compressed by deep burial. Limestones, (i) grains separated by matrix of lime mud; (j) shelly limestone; (k) oolitic limestone. (l) shelly limestone broken by fractures with both shells and fractures enlarged by dissolution to create voids.

# SEDIMENTARY ROCKS CLASSIFICATION

## Based on texture

- **Clastic;**
- **Coarsely crystalline;**
- **Fine grained or cryptocrystalline;**
- **Whole fossils or their products.**

## 1- Clastic sedimentary rocks:

Composed of pre-existing mineral grains or rock pieces that settled out of water and were subsequently cemented or compressed together.

The classification below is based on Wentworth scale used by geologists. The rock name is decided by the size of the most prevalent grains

Sediment	Size (mm)	Sedimentary rock
Gravel	>2	Conglomerate (if particles rounded), Breccia (if angular)
Sand	2 - 1/16	Sandstone
silt	1/16 - 1/256	Siltstone (commonly called shale)
Clay	<1/256	Claystone (commonly called shale)
Silt and clay		Shale

## ○ Conglomerate

Erosion process involves transport some distance by stream. This causes rock pieces to become round before reaching the sedimentation basin.



## ○ Breccia

Angular pieces denote a short transport distance with quick burial



## ○ Sandstone

- When the grains of the rock are all composed of quartz, the rock is called quartz sandstone.

Source: <https://marlimillerphoto.com/Sed-44.html>



- When the grains of the rock are all composed of feldspar, the rock is called arkosic sandstone.

Source: <https://www.sandatlas.org/arkose/>



# SEDIMENTARY ROCKS CLASSIFICATION

- Dark rock particles from basalt comprise sandstones are called **graywackes**. They are more strongly cemented (due to the existence of clay minerals) than quartz sandstones.

The sandstone that is mostly quartz with some calcite perhaps as a cement is commonly called **calcareous sandstone**.



## ○ Shales

- Shale are composed of silt and clay. They show fissility (closely spaced bedding planes along which the rock will break).



Shales

## 2- Coarsely crystalline sedimentary rocks

- These rocks composed mostly of carbonate, sulfate and chloride minerals.
- Formed by precipitation from water or by recrystallization of a finer material during and after lithification.
- Precipitation occurs when solutions becomes saturated or oversaturated with certain compound (either by temperature decrease—pH will change, or by reduction in liquid volume by evaporation).

## ○ Carbonates

- The two most common carbonate rocks are limestone (composed of mostly of calcite ( $\text{CaCO}_3$ ) and dolomite which is composed primarily of the mineral dolomite [ $\text{CaMg}(\text{CO}_3)_2$ ] plus varying amount of ( $\text{CaCO}_3$ ).
- A considerable amount of  $\text{CaCO}_3$  is known to participate directly from solution in the open and warm oceans.
- Dolomites are formed commonly by the substitution of  $\text{Mg}^{++}$  for some of the  $\text{Ca}^{++}$  in the limestone long after the lithification.



Limestone



Dolomite

# SEDIMENTARY ROCKS CLASSIFICATION

## ○ Evaporates

- Evaporates are sedimentary rocks derived when sea water is evaporated in an isolated portion of the ocean.
- Minerals precipitate sequentially with decreasing water volume and the order of crystallization is dictated by the relative solubilities of the mineral constituents.
- Seawater contains about 3.5% dissolved solids. 78% of the solids are  $\text{Na}^+$  and  $\text{Cl}^-$ .
- If seawater volume is reduced to about 1/2, calcium and some iron oxide are precipitated.
- With additional reduction in water volume to about 1/5, gypsum  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$  is precipitated from seawater in an evaporate deposit.
- Gypsum is altered to anhydrite ( $\text{CaSO}_4$ ) at depth under the heat and pressure of a growing rock column in a sedimentary basin.
- Gypsum is formed again when erosion brings the evaporate deposit close enough to the surface that ground water comes in contact with it.
- Salt solution rise by capillary could also lead to deposit gypsum and anhydrite at the surface when water evaporates



Gypsum



Anhydrite

- With 10% remaining seawater volume,  $\text{NaCl}$  begins to crystallize (rock salt) and Magnesium salts ( $\text{MgSO}_4$  and  $\text{MgCl}_2$ ) are formed on further evaporation.

## 3- Fine grained or cryptocrystalline sedimentary rocks;

- Are those rocks with textures that are too fine to distinguish with naked eye.

### ○ Chert

- In its unweathered condition, it has many properties of quartz such as hardness (7) and high resistance to chemical weathering.
- Formed through primary deposition of silica in the ocean or a secondary replacement in carbonate rocks after deposition.



## 4- Whole fossils or their products.

- Are those rocks with textures formed from calcite fossils or materials with a high organic content, including coal.

### ○ Fossiliferous limestones

- Consist of calcite fossils of sand size or bigger, cemented together by minor amount of calcite.
- Rocks of this type are too weak to be used for aggregates in concrete or bituminous mixes or for base course.



### ○ Rocks rich with organic matter

- Organic matter is present in nearly all sedimentary rocks, especially in fine-grained rocks. (0.5% to 10%) by weight.
- Important group: coal (peat, brown coal, bituminous coal).
- Organic debris comprises the petroleum-rich rocks.

# FEATURES OF SEDIMENTARY ROCKS

## o Bedding

A bed is the smallest division of a geologic formation or stratigraphic rock series marked by well-defined divisional planes (bedding planes) separating it from layers above and below. Each layer is characterized by its color, mineral content or texture.

Bedding provides important information on directional properties of sedimentary rocks such as permeability, compressibility and strength.



Image source:

[http://geologycafe.com/images/cross\\_bedding.jpg](http://geologycafe.com/images/cross_bedding.jpg)

**Cross bedding:** inclined formations meet at acute angle in some sedimentary rocks related to ripples and dunes caused by fluid movements (water or wind).



**Graded bedding**— refers to the systematic change in gradation properties (i.e. particle size) with depth. The coarse particles precipitate (faster) at the bottom while the fine grains precipitate (slower) at the top.



**Desiccation cracks (mudcracks):** cracks developed in the fine grained cohesive material (silt and clay) caused by shrinkage under water loss conditions.



*All of the above features are preserved in the cross section of a sedimentary rock!*

# ENGINEERING CONSIDERATIONS OF SEDIMENTARY ROCKS

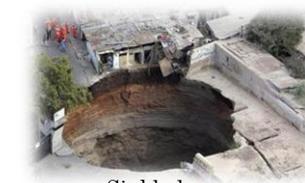
- 1- Limestone and dolomite provide the best sedimentary aggregates for construction materials. Siltstone, shale, quartz are generally not accepted, while graywacke is marginal.
- 2- Stream and terrace gravels commonly contain weak pieces that yield nondurable aggregates in concrete.
- 3- Weathered siltstone, clay carbonate or chert can cause pop-outs at the concrete surface after a number of freeze-thaw cycles.
- 4- Coarse-grained limestones abrade (particles reduce in size) too severely to be used for aggregates for construction.
- 5 - Sedimentary rocks used as dimension stone for the facing should be resistant to weathering effects, such as clastic limestones. Quartz sandstones are used for flagstone wall.
- 6- Shales and siltstones can provide a suitable foundation for buildings, dams and bridges. However, there are few concerns related to the effect of weathering and slabbing loose of rock due to stress release after excavation.
- 7- Limestones, dolomite and evaporates deposits can show an irregular soil-rock interface in their weathering profiles. Therefore care must be taken to place heavy structures on solid rocks.
- 8- Sinkholes and underground conduits in limestone and dolomite must be recognised and properly dealt with before construction.
- 9- For dams constructed on rocks involving limestone, presence of solution channels in dams reservoir will lead to leakage unless the channels are grouted.
- 10- Some shales used as rock fills in highway embankments suffer from softening when exposed to water, thus causing certain problems such as subsidence and slope instability. These shales must be broken then compacted into solid mass.
- 11- Special treatment should be considered when conglomerates are encountered in dam works. These sedimentary rocks are poorly cemented and can be highly permeable to water.
- 12- Sedimentary rocks containing anhydrite are troublesome to engineering structures such as dams, highways because of alteration of anhydrite to gypsum upon wetting which is accompanied by volume increase.
- 13- Sedimentary rocks containing gypsum are also troublesome to engineering structures due to salt dissolution in water leading to severe collapsing in the superstructures.



dimension stone



Flagstone wall



Sinkhole



solution channel

# GYPSEOUS SOILS IN IRAQ

## Collapsibility

Collapse potential of soil is calculated from the results of a lab test called double oedometer test on two identical samples; one on them are compressed in its natural water content while the other one is soaked with water. The collapse potential C.P. is identified as

$$C.P. = \Delta e / 1 + e_0$$

where  $\Delta e$  is the difference in void ratio of the two samples at a given stress and  $e_0$  is the natural void ratio. The collapse severity in relation to the collapse potential is as shown in table below.

Severity	No problem	Moderate	Trouble	Severe	Very Severe
C.P. %	0-1	1-5	5-10	10-20	> 20

## Uses of Gypsum

Gypsum has variety of industrial uses, including:

- Manufacturing of wallboard and ceiling boards,
- Plaster of Paris, cement,
- Soil conditioner,
- A hardening retarder in Portland cement.

