Outline Talk of Lec.1

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Sedimentary Petrography

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1.Historical Introduction: The petrographic analysis of sediments, in sandstones and carbonate rocks , became an organized discipline with development of thin-section techniques and the polarizing microscope a development attributed to Henry Clifton Sorby, Sorbys was making thin-section in 1849, published a paper on the microscopical structure of calcareous. Folk(1965) has ably summarized Sorbys petrographic contributions as has sumerson(1978). The prime objective of the study of a thin section is , or should be, the reading of *rock history*. The microscope is the most useful, general method for close study of the mineral composition, fabric, porosity ……etc.

2 .Rock description and Analysis in Field: Rock description and analysis are mainly based on study of outcrops, cores hand specimen, and thin section. Thin section can be easily prepared for unconsolidated sands (Middleton and Kaurus, 1980). The main point about field work is being able to observe and record accurately what you see. With a little experience and some background knowledge you will soon know what to expect and what to look for in certain type of sedimentary rocks or particular facies. The study of sedimentary rocks in field requires the initial identification of the lithology (often by using lens) in terms of *compositions, grain size, texture and fossils content*. The attributes can be confirmed and quantified later in the laboratory. Sedimentary structures are usually described and measured in the field because of their size. Many sedimentary structures can be used for paleocurrent analysis and these and others reflect the processes operating in the environment . Finally it is necessary to collecting a sufficient samples from field (Green Smith 1980).

3. In the Laboratory: A great deal can done with Sedimentary rocks in the laboratory and there are several books concerned with laboratory procedures (Muller, 1967; Bouma 1969; Carver, 1971; Hutchison,1974). Starting with hand specimen cutting and polishing a surface may reveal sedimentary structures poorly displayed or invisible in the field. With the limestone's etching with acid and staining a surface may further enhance the structures. Although the *Alizerin red solution* is a good method for distinguishing between calcite and dolomite minerals and *Cobalt nitrate* also another staining is using to distinguish between types of feldspar. With unconsolidated sediments which are readily disaggregated, sediment grain size can be measured through use of sieves and sedimentation chambers(Folk, 1974, Blatt *et al.,*1980). The heavy minerals are extracted from loose sediments by using liquid called *bromoform* to separate heavy from light minerals.

In recent years, much sedimentological work has been carried out on the scanning electron microscope (SEM). The instrument allows examination of specimens at very high magnification, features down to 0.1μm can been seen. The SEM is especially useful for fine-grained sedimentary rocks and for observing clay minerals and the cements of sandstones and limestone's.

(Gartner et al., 2013) studied the morphology and surface characteristics of detrital zircon grains in different sediments and subdivided into five categorizes (*cracks, fracturing, collision marks, striations and impact pits) and all resulting from transport processes.* This investigations was mainly based on SEM-BSE method.

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Surface characteristics of zircon by Gartner et al., 2013)

Fracturing

1-No fracture
2- fracture are parallel to c axes.
3-fracture perpendicular to c axes.

Cracks

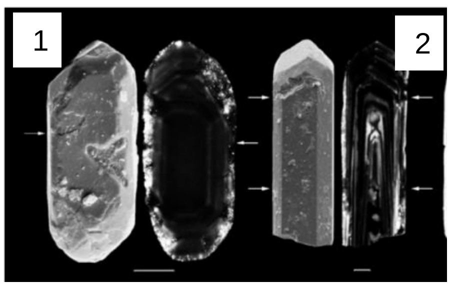
1-Grains without cracks on their surface.
2-Grains with cracks on their surface

Collision marks

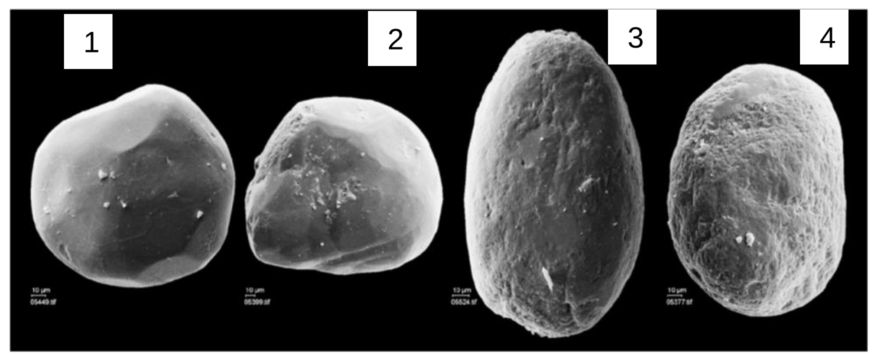
1-Grains without or only very few collision on surface.
2-Grains with some collision marks.
3-Grains with medium amount of collision on surface.
4-Grains with numerous collision marks on the surface.

Striations

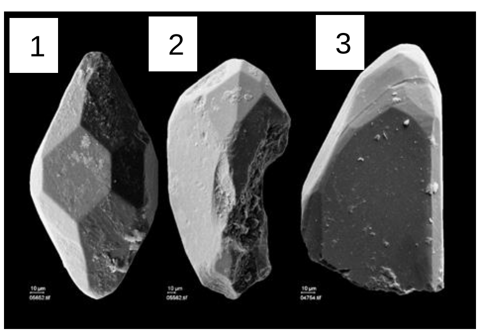
Impact pits



Typical zircon gains and two types of cracks.



Typical zircon grains of the four classes of collision marks



Typical zircon gains three types of fractures.

For *mineral identification in finer-grained and sedimentary rocks X-ray diffraction (XRD) is widely used*. *Major and trace elements are mostly determined by atomic absorption spectrophotometry (A.A.)* and X-ray *fluorescence (X.R.F.)*. On the scale of individual grains and crystals, in limestone cements for example, the electron microprobe analysis (EMPA) is used to determine trace elements on areas only a few microns across. Finally use *of Cathodoluminescence (CL) facility*, which bombards a rock slide with electron and causes luminescence, can reveal details cements *overgrowths and zonation in sandstone*
(Friis et al., 2010; Götte et al., 2013; Omer and Friis 2014) (Figures 1b and 6 B) and dolomite.

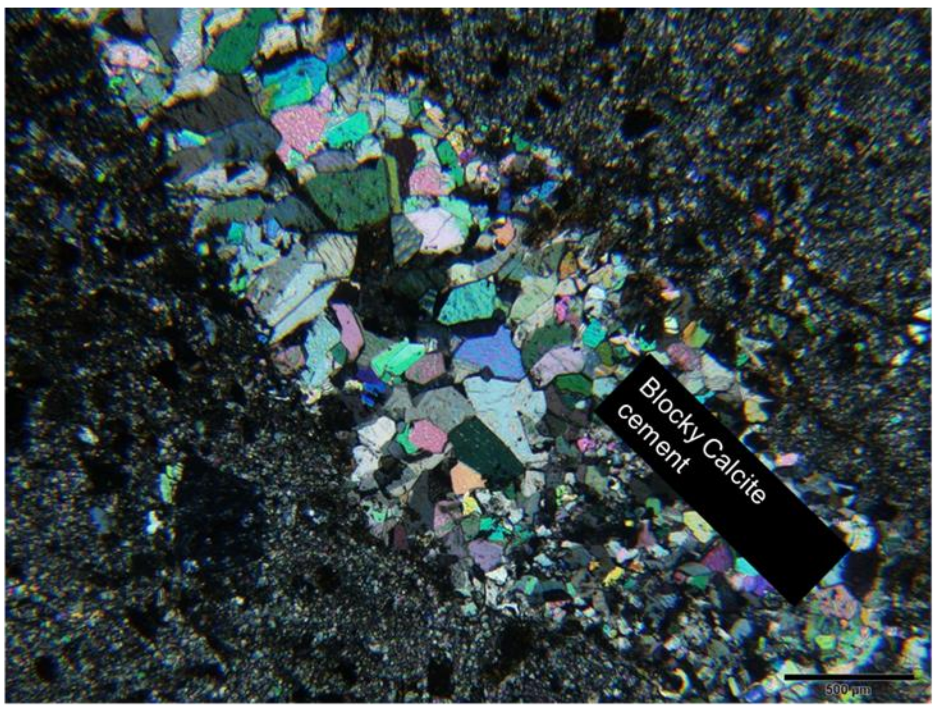


Figure 1a: Microphotograph of optical microscope showing thin section of blocky calcite cement (XPL) filling pores Khurmala Formation- Duhok section. by Dr. Muhamed F. Omer

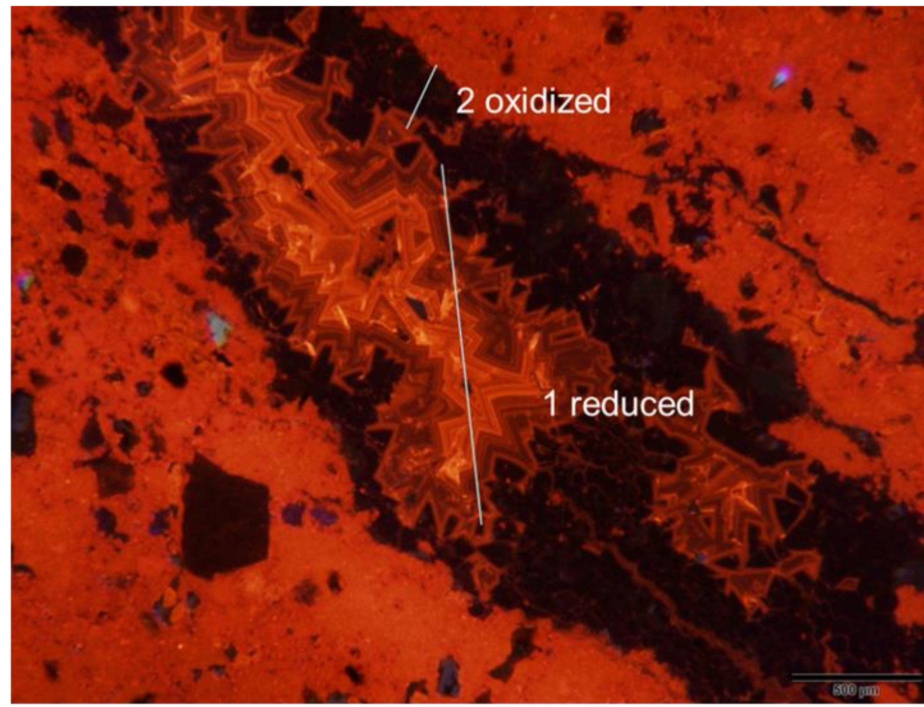


Figure 1b: Cathodoluminescence (Hot-CL) showing vugs that filled by blocky calcite with different zonation sector and two generations (1 and 2) Khurmala Formation-Duhok section (Same figure in 1a). by Dr. Muhamed F.Omer

- **4. Sedimentary Petrography**: is the analysis of both depositional and diagentic fabrics from thin sections and includes minerologic composition, grain size, grain fabrics, sediment provenance and determination of the sequence of diagenetic events. The techniques used in sedimentary petrography are quantitative and /or qualitative (descriptive).

Sedimentary Petrography

- Depositional fabrics
  - Grain identification
  - Grain size
  - Grain Orientation
  - Modal composition
  - Provenance
  - → Depos.Envi.
- Diagenetic fabrics
  - Mechanical compaction
  - Chemical compaction
  - Cementation
  - Replacement
  - Dissolution
  - → Depos. Regime

- **Petrography** it’s a powerful technique of recognition different types of minerals and textures in sedimentary rocks which provide much basic information on the nature, origin and history of a sedimentary rocks (Green smith, 1980; Pettijohn *et al*.,1987;Blatt *et al*.,2006).

- 5. Detailed petrographic report from (Modified from Folk,1974) :

1- Samples identification: Formation name, age, and precise geographic location of outcrop and full well name, location, and depth of a core sample.

2-Field relations or subsurface data: Outcrop or core thickness and position of outcrop ore core with respect to formational boundaries, associated lithologies, bedding characteristics, sedimentary structures, fossils, deformation, and mineralization .

3-Handspecime description: Concise simple description including a field name consistent with petrographic analysis, include color, grain size, sorting, roundness, mineral compositions, bedding, tectonic deformation, and weathering.

4- Thin –section description:

A- Abstract : Brief comments, perhaps 50 words . Prepare only after all other aspects of the report are complete. Include rock name, summarized modal analysis using point counts, interpretation, possible economic significance , and relevance to scientific problems.

B- Texture:

1-Fabric: Grain to grain relations, grain orientation, cementation, and porosity.

2-Grain size: Specify mean, median, and range of sorting, and percent of gravel,sand, silt, and clay . Plot cumulative curve on log probability.

3-Angular and Sphericity: Describe and comments on how they vary with size.

4-Textural maturity.

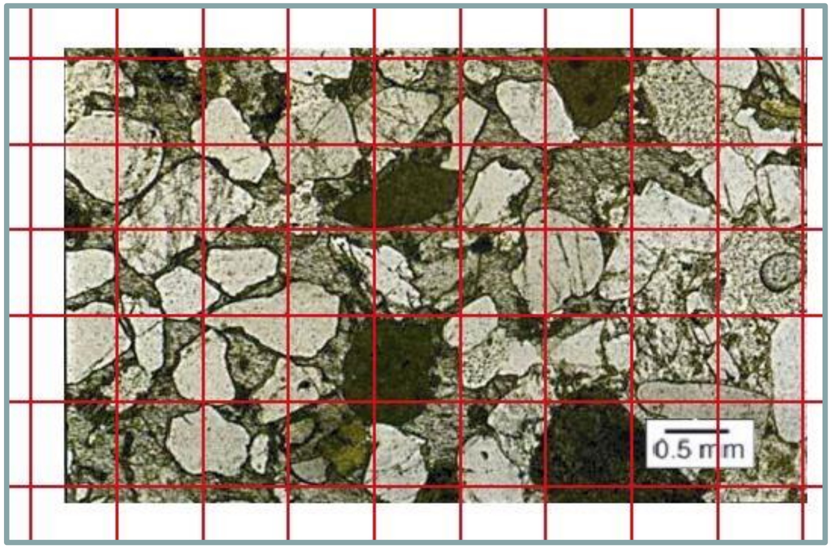
C-Porosity and Permeability.

To classify sandstones using Dott's scheme the first step is to determine composition of the rock.

Point counting (Modal Analysis):- is a method where by a thin section on a petrographic microscope is examined by stepping across the thin section at equal intervals and identifying the material (quartz, feldspars, rock fragments or matrix) that lies immediately beneath the cross hairs. Normal point counting is 250 to 300 grains will accurately yield the proportion of each component.

Why Geology use point count?

Is a best method to determine type of the sandstone e.g. Quarzarenite, Arkosic sandstone or lithiarenite sandstone. In a carbonate rocks can be calculated different skeletal grains (fossils) and type of non-skeletal grains.



Example Point Count Data (Modal Analysis):

Component	Number of Grains counted	Proportion (%)
Quartz	73	26
Feldspar	56	20
Rock fragments	34	12
Matrix	118	42
Total:	**281**	**100**

A first order classification is based on the proportion of matrix that is present:

% matrix	Rock Name
< 15	Arenite
15 - 75	Wacke or Graywacke
>75	Mudstone

To classify Arenites and Graywacke's on the basis of their specific compositions the data must be "normalized" to 100% quartz, feldspars and rock fragments

D-Mineralogy: Separate into terrigenous, allochemical, and orthochemical constituents and give percent of each reproduce modal analysis in a compact table.

5- Interpretation: Here one integrates the data from the thin section with all other evidence. Field or subsurface observations, chemical or microprobe analysis, and the literature. Remember that the best interpretation is one that uses all the relevant facts

A- Source area : Estimate lithologic composition and maturity of sandstones in source plus tectonic state and weathering, location, and distance from depositional site . Plot QFR. Or other diagram.

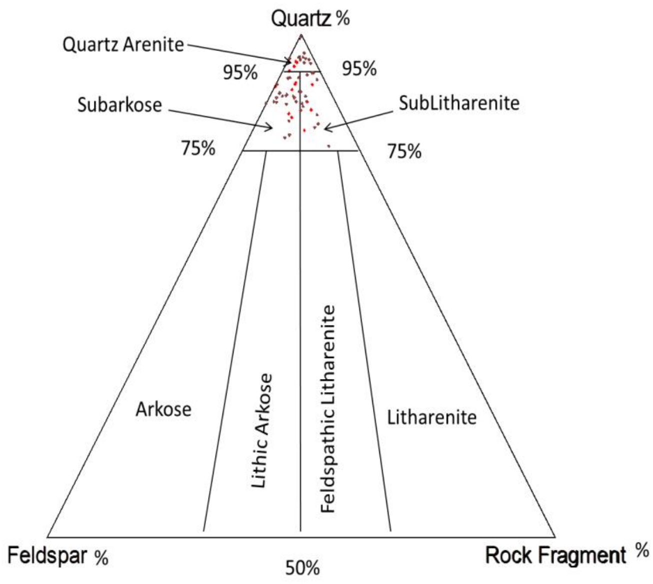


Figure 2: Classification of sandstone according to Folk (1974).

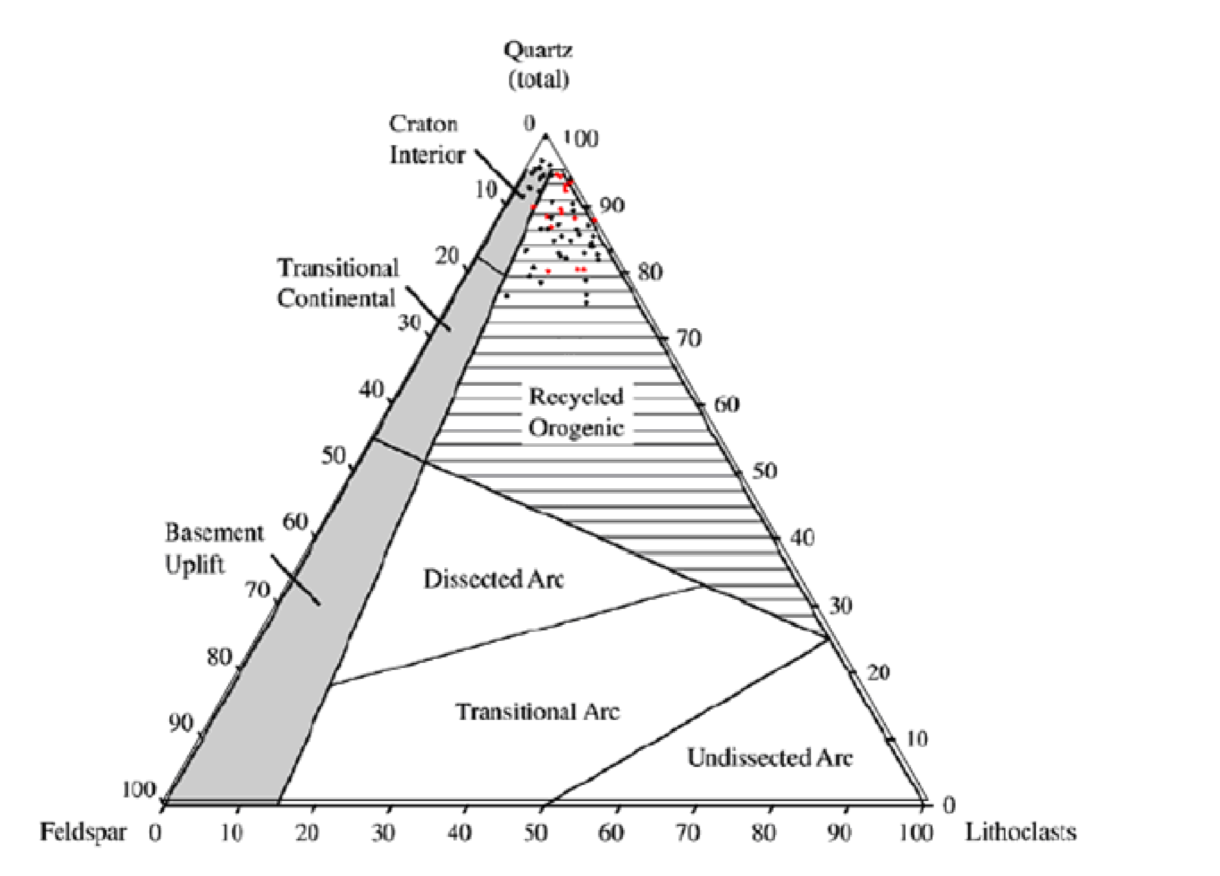


Figure 3:Sandstone provenance after Dickinson (1985) total quartz includes polycrystalline quartz.

B-Depositional basin: Estimate nature and strength of currents and water depth. Identify environment of deposition as fully as evidence permits. If marine how far from shore? And identify trace fossils. Tectonic setting of basin.

C-Diagenesis: State and interpret diagenetic processes history (paragenetic). So are diagenetic effects is major or minor in your thin section study? How are they related to porosity and permeability Ration of primary to secondary porosity?

6- Economic Importance: Discuss economic importance and give industrial name. Comment on possible market value and problems of development.

7-Bearing on scientific problems: how does the interpretation of this sample relate to the historical development of the sandstone body or limestone of the sedimentary basin? To paleotectonics? To thermal history of basin ?.

6. Scheme for petrographic description of sandstone by Tucker (2001)

1-Hand specimen color, grain size, bedding, lamination and any other sedimentary structures. Any fossils content? Determine composition/ mineralogy of grains and cements if possible.

2-Thin-section

Check the macroscopic features of the thin section by holding up to light and noting any lamination, large fossils or grains.

-*Texture:* determine the grain size, sorting, roundness of grains, grain shape, fabric (any preferred orientation of grains?) and nature of grain-grain contacts.

-*Grains*: identify grain types, determine relative proportion of quartz, feldspar and lithic grains and matrix.

-*Matrix:* check whether it is detrital; it may have formed from alteration and compaction of labile grains.

-*Compaction*: look for concave-convex and sutured grain contacts, broken / bent mica flakes or bioclasts.

-*Cementation*: identify cements, e.g. quartz , calcite, dolomite clay, ..etc. pore filling and overgrowths.

-*Replacement/dissolution* of grains e.g. feldspar by calcite or clay, partial or complete dissolution and look oversized of grains.

-*Porosity*: of present determine origin and type –intergranular and intragranular porosity.

-Classification: from assessment of matrix content, is sandstones an arenite or wackes? If arenite, asses type (quartz, arenite, arkose or litharenite) from grain composition. From texture assess the maturity.

3-Interpretation:

Depositional environment: suggest from texture and composition, and any other information available, such as sedimentary structures from hand specimen and field data.

Diagenesis: determine nature and order of diagenetic events and whether near-surface (pre-compaction) or burial (post compaction) on basis of textural evidence; suggest evolution of pore-fluids and destruction or creation of porosity in content burial history.

- **7. Classification of Sedimentary Rocks**: Sedimentary rocks are formed through physical, chemical and biological. On the basis of the dominant process operating, the common sediment lithologies can be grouped into four broad categories (Table 1). The terrigenous clastic sediments also refereed to siliclastic sedimentary rocks are those consisting fragments (Clasts) of pre-existing rocks, which have been transported and deposited by physical processes. The Conglomerate, breccias ,sandstone and mudrocks are belongs to this group. Sediments largely of biogenic, biochemical and organic origin are limestone, dolomite phosphates, coal and oil shale. Sedimentary rocks largely of chemical origin principally direct precipitation are those evaporites and ironstones. Finally volcanoclastics is another group consist of lava and rock fragments derived from contemporaneous volcanic activity

Table 1 Principal groups of sedimentary rocks

Terrigenous	Biogenic, biochemical	Chemical	Volcanoclastic sediments
Conglomerate	Limestone's, dolomite	Evaporites	Ignimbrite tuffs
sandstone	phosphates, coal,	ironstones	
mudrocks	oil shale		

(A) Terrigenous components

1-Derived from erosion of areas outside the depositional basin.

2-Brought to the basin as solids.

3-Examples: quartz and feldspar sand, heavy minerals, clay minerals, and chert and limestone clasts.

(B) Allochemical components

Greek: “allo” meaning different from normal.

1-Precipitated directly from solution within the depositional basin.

2-Termed “allo” because they have been moved as solids within the basin.

3-Examples: broken or intact shells, oolites, calcareous pellets, or fragments of carbonate sediments.

(C) Orthochemical l components

Greek: “ortho” meaning true.

1-Termed “ortho” because they are produced chemically within the basin.

2-Examples: microcrystalline calcite or dolomite ooze, some evaporites, and cements in sandstones.

The Classification of Clastic Sedimentary Rocks

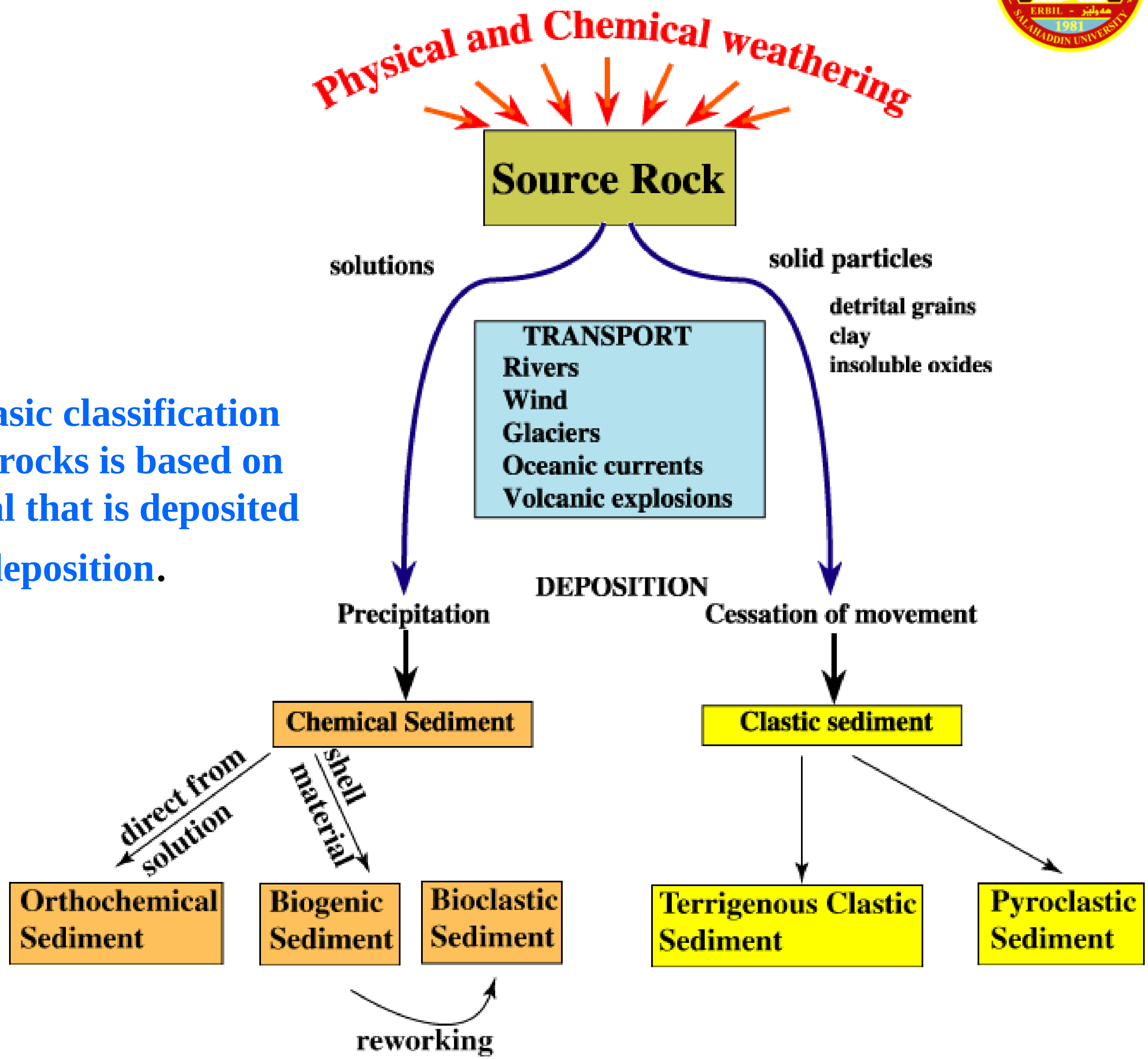
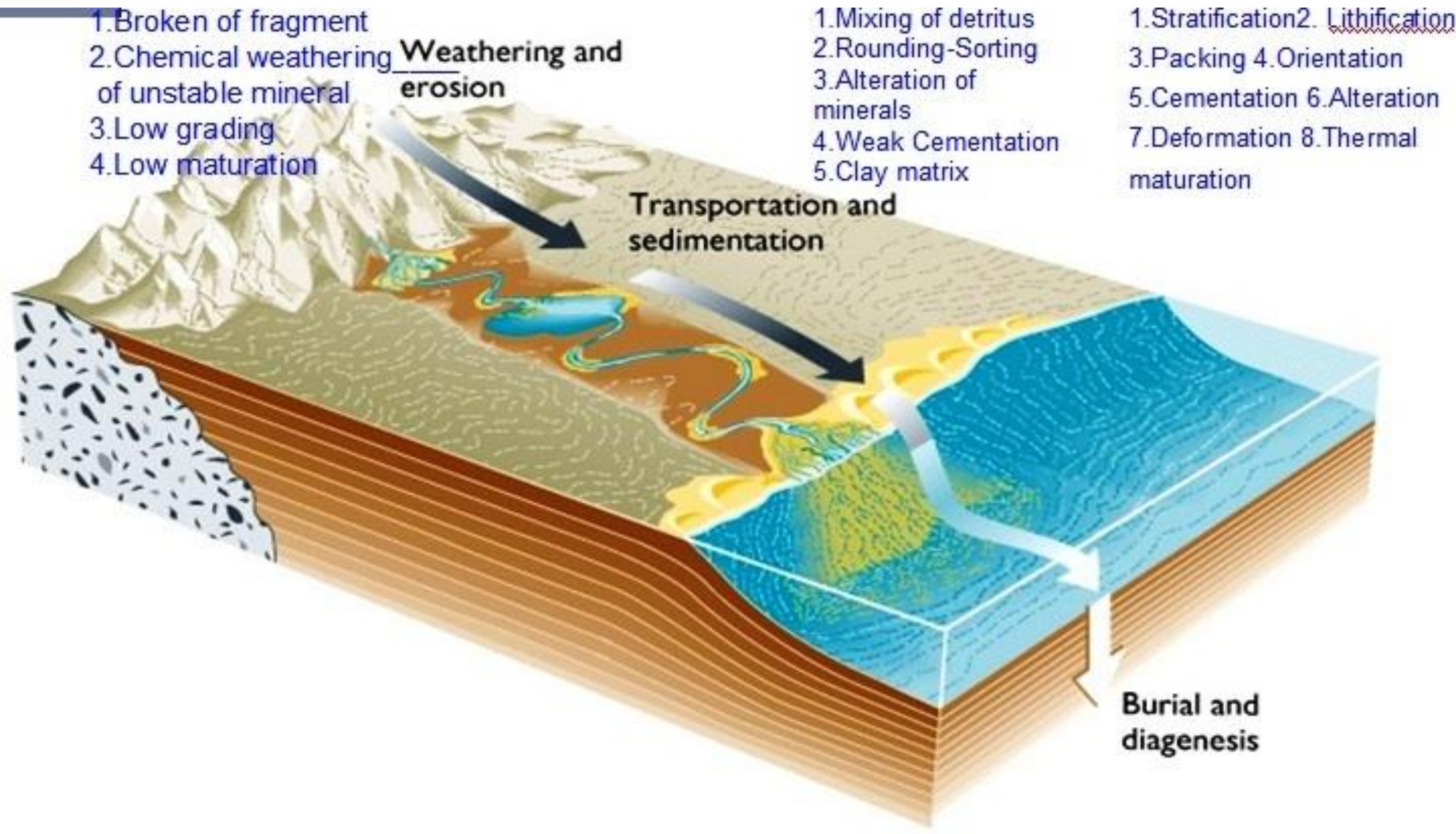


Figure 3: A very basic classification of all sedimentary rocks is based on the type of material that is deposited and the modes of deposition.

{Sedimentary Petrography}

Clastic rock - Conglomerate



Terrigenous clastic sediments: Terrigenous clastic sediments are diverse group of rocks, ranging from the fine-grained mudrocks, through the coarser grained sandstones to conglomerates and breccias. The sediments are largely composed of fragments or clasts, derived from pre-existing igneous, metamorphic and sedimentary rocks. The clastic grains are released through mechanical and chemical weathering processes, and then transported to the depositional site. Mechanisms involved in the transportation include the wind, glaciers, river currents, waves , tidal currents and turbidity currents. The detrital grains may be *rock fragments* but the majority are individual crystals chiefly of *quartz* and *feldspar* abraded to various degree. In a broad sense, the composition of clastic sediments is a reflection of weathering processes, largely determined by the *climate* and *geology of the source area* . Sediment composition is also affected by distance transport and by diagenetic process.

8. **Detrital component of siliclastic sediments**:

1- Sandstone, conglomerate and breccias consist of *detrital grains*, which is form the framework of the sediments,

2-Fine-grained *matrix* located between grains.

3-Authigenic minerals and *cements* precipitated after deposition of the sediment, during diagenesis. The abundance of terrigenous mineral in a sedimentary rock is dependent on its variability for e.g. source area geology, mechanical and chemical weathering. With regards to chemical stability, minerals can be arranged into series from the most to the least stable. With decreasing stability, the order :

Quartz, zircon, tourmaline

Chert

Muscovite

Microcline

Orthoclase

Plagioclase

Hornblende, biotite

Pyroxene

Olivine.

The mechanical stability of a mineral depends on the presence of cleavage planes and the mineral hardness. The detrital particles in terrigenous clastic rocks can be divided into six categories :

1- Quartz: Also chert which is the most abundant of stable minerals.

2- Feldspar: The most abundant unstable mineral grains.

3- Rock fragments: includes igneous, metamorphic and sedimentary rock fragments.

4-Micas and clays: These minerals can be considered together because they are closely related in chemical composition (hydro aluminumsilicates) and crystal structures .

5- Heavy minerals: This group include various silicates and oxides that found in a small quantities in sandstone, the total quantity of such constituents rarely making up more than once percent of the rock. But in other hand it is very useful to study provenance of sandstone.

6- Other constituents.

9.1- Matrix :The smaller or fine-grained, constituents material enclosing or filling the interstices between the larger grains or particles of the sediments. They often consist of argillaceous material or calcareous mud (micrite).

9.2- Cement: The cement of the terrigenous sediments comprises the post-depositional (diagenetic) precipitated mineral material that occur in the spaces among the individual grains, there by binding the grains together as a rigid, coherent mass(ex.. lithification of the rocks) .The most common cements are silica (quartz, chalcedony, opal), carbonates ,Calcite, dolomite and siderite) and various iron oxides, other include gypsum, anhydrate, barite and pyrite.

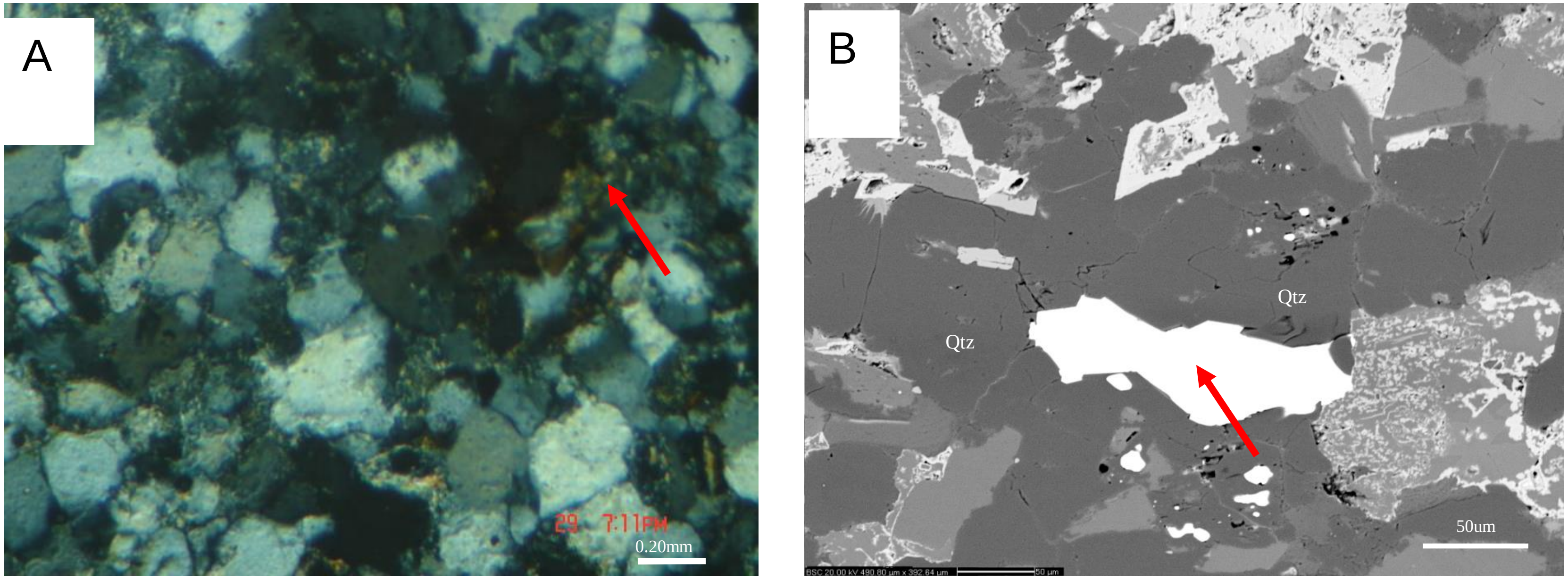


Figure 4: Microphotograph showing micaceous matrix are squeezed between quartz grains from Khabour Formation XPL.(A). BSE Image showing poikilotopic barite cement enclose quartz from Khabour Formation .

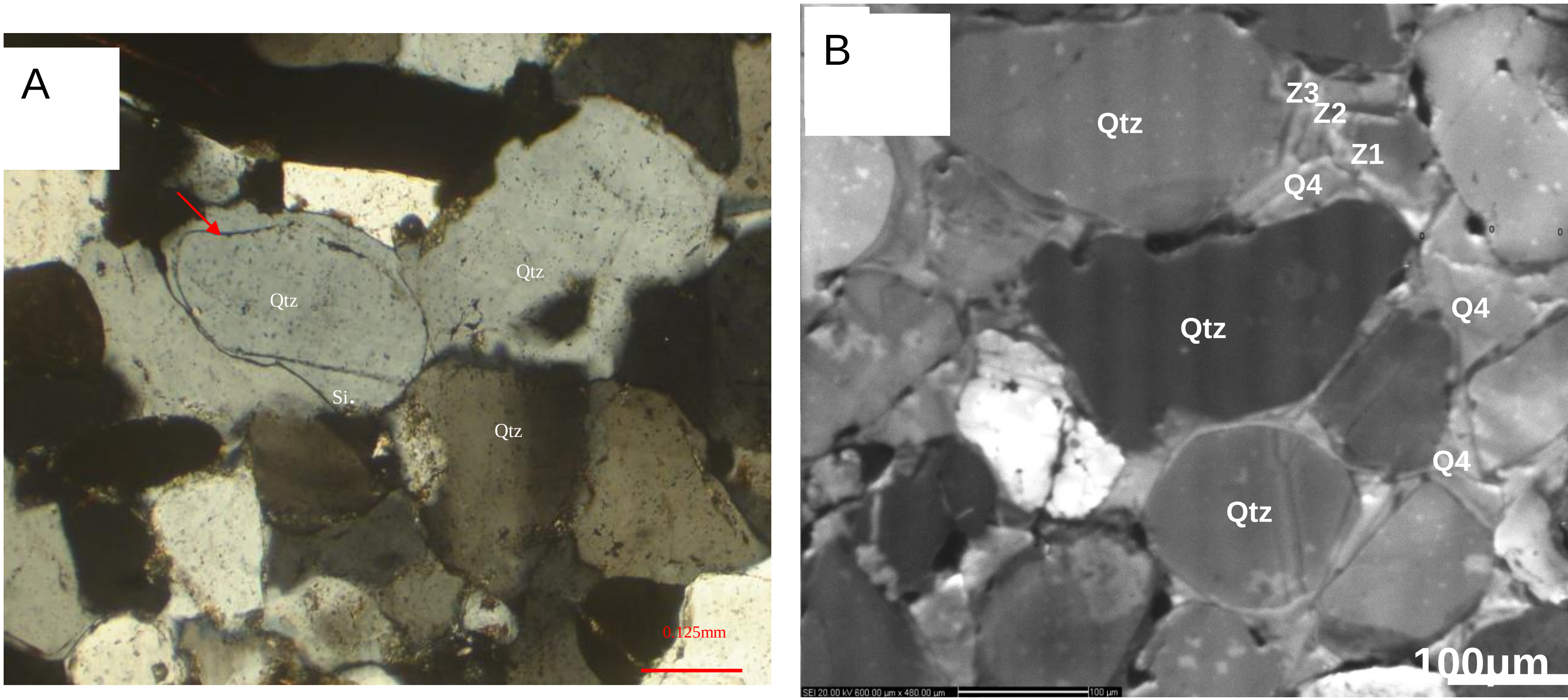


Figure 5: Microphotograph showing syntaxial quartz overgrowth by presence thin rims of iron oxide around quartz by optical microscope XPL (A). Cathodoluminesence image (CL) showing outgrowth zonation sector Z1, Z2, Z3 occlude primary porosity from Khabour Formation (B). Image edited by Dr.muhamed F.Omer

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