International degree on

**Geosciences and Georesources**

# Course of
# Applied Stratigraphy and Sedimentology

**3. Sedimentology**

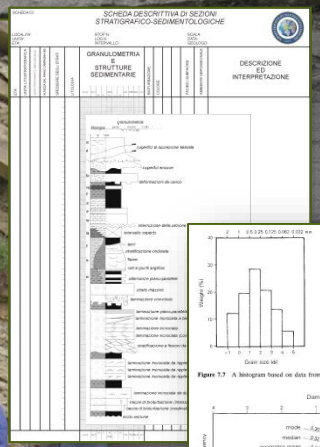
**3a.** Origin of sediments; **3b.** Clastic and non-clastic sediments; **3c.** Main processes of erosion, transport and sedimentation; **3d.** Main sedimentary processes (tractive, mass, etc …); **3e.** Facies, facies associations, depositional environments and systems. **3f**. Georisources of sedimentary origin.

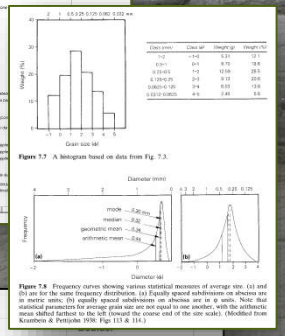
## S E D I M E N T O L O G Y

It includes the observation, description and interpretation of the sedimentary rocks and deposits (facies), in order to understand their genetic processes, the depositional environments and the depositional systems, boh from surface and subsurface data.

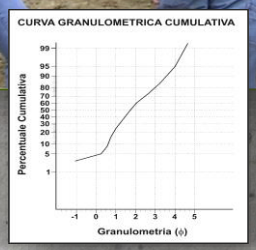
### CLASSIC SEDIMENTOLOGY

Facies Analysis



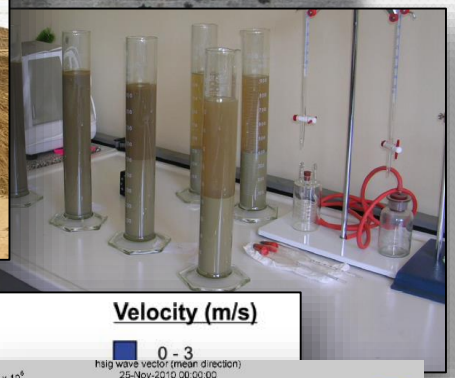


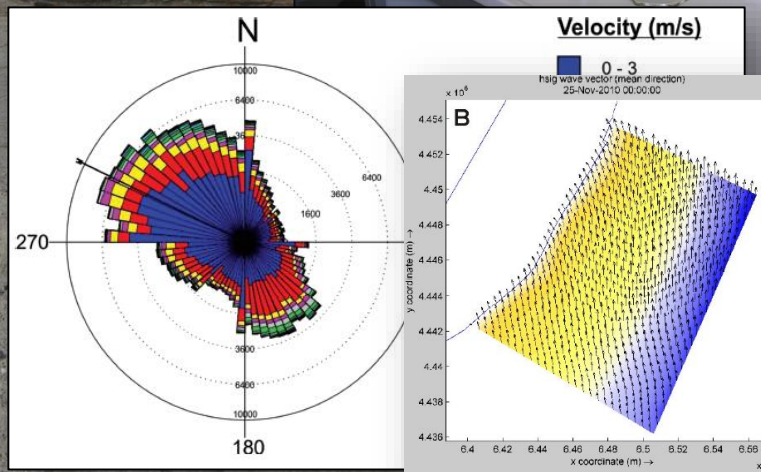



| | | | |
|---|---|---|---|
| | | ottolo molto grossolano | Cobble |
| | | ottolo grossolano | Cobble |
| | | ottolo medio-grossolano | Pebble |
| | | ottolo medio | Pebble |
| | | ottolo medio-fine | Pebble |
| | | ottolo fine | Pebble |
| | | anulo | Granule |
| | | abbia molto grossolana | Very coarse sand |
| | | Sabbia grossolana | Coarse sand |
| ½- | ¼ | Sabbia media | Medium sand |
| ¼- | 1/8 | Sabbia fine | Fine sand |
| 1/8- | 1/16 | Sabbia molto fine | Very fine sand |
| 1/16- | 1/32 | Silt grossolano | Coarse silt |
| 1/32- | 1/64 | Silt medio | Medium silt |
| 1/64- | 1/128 | Silt fine | Fine silt |
| 1/128- | 1/256 | Silt molto fine | Very fine silt |
| | <1/256 | Argilla | Clay |

Rudite | Arenite | Pelite

### MODERN SEDIMENTOLOGY





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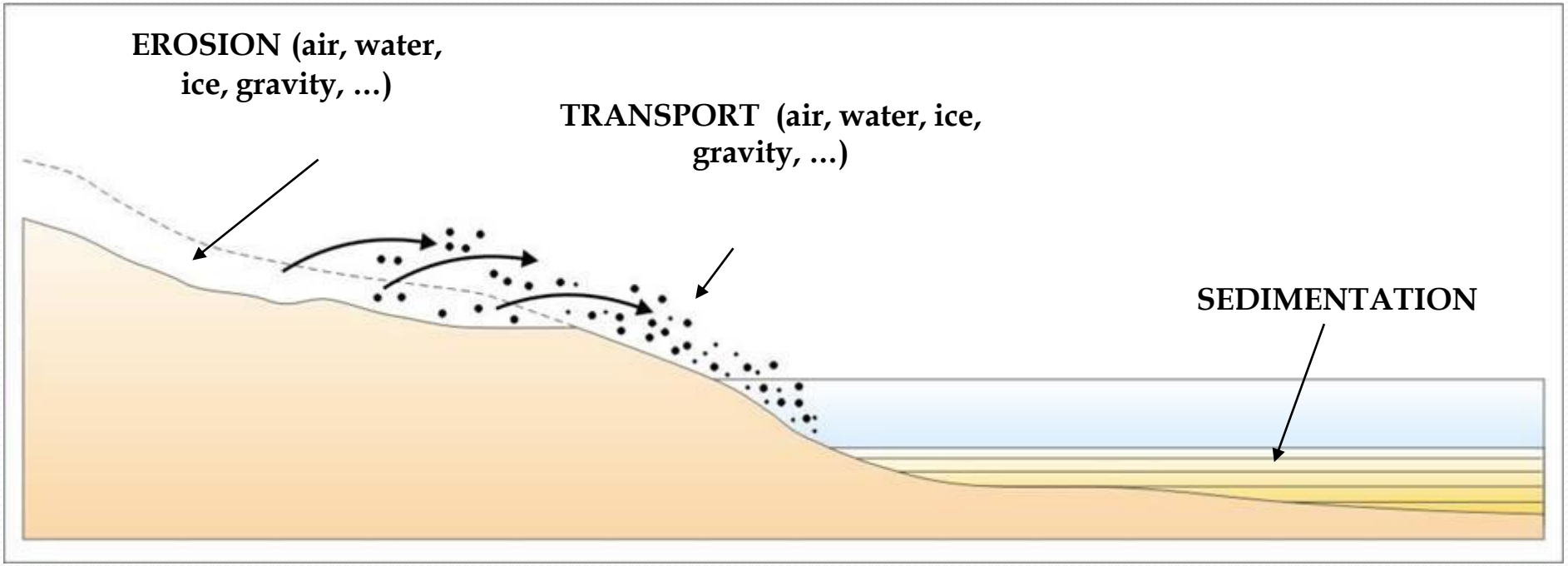
**Clastic sediments originate due to the fragmentation of pre-existent rocks (EROSION).**

Sediments can undergo a TRANSPORT, whose time duration indicates SELECTION.

Sediments can be accumulated or deposited (SEDIMENTATION).




EROSION, TRANSPORTO and SEDIMENTATION represent the three phases of a SEDIMENTARY CYCLE

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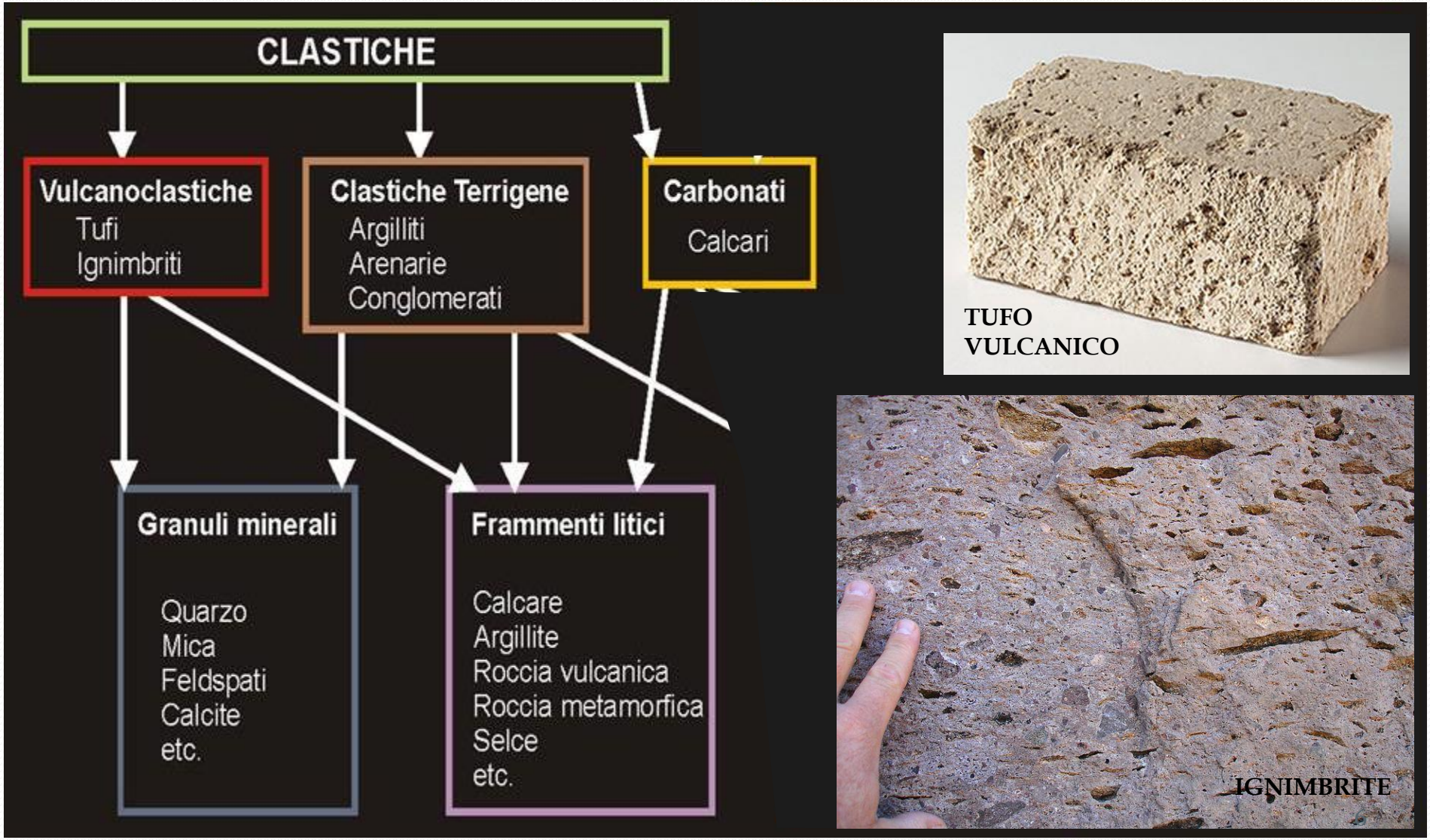
**SEDIMENTS and SEDIMENTARY ROCKS can be divided into CLASTIC and NON-CLASTIC**



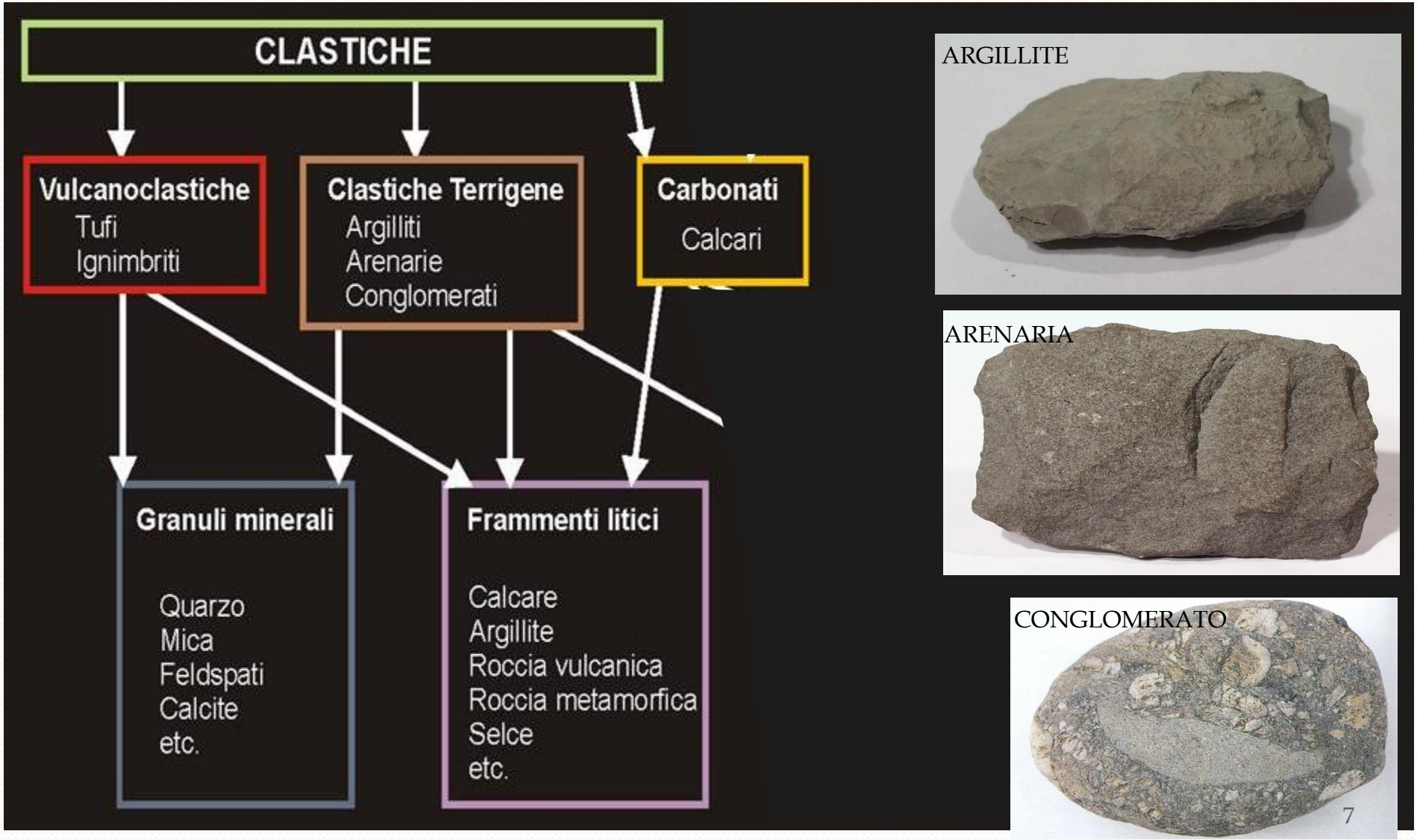



TUFO VULCANICO



IGNIMBRITE

**SEDIMENTS and SEDIMENTARY ROCKS can be divided into CLASTIC and NON-CLASTIC**



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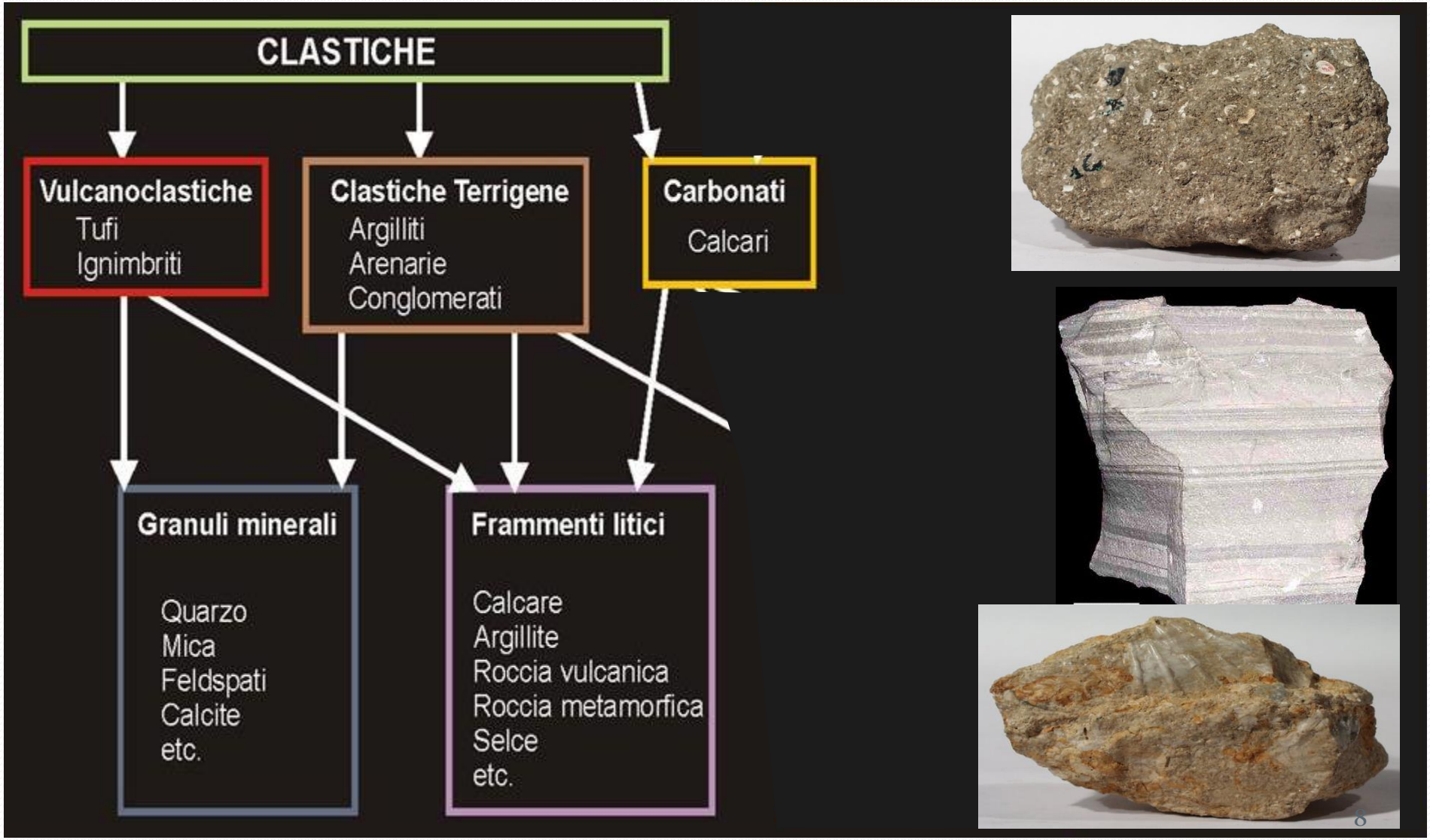


**SEDIMENTS and SEDIMENTARY ROCKS can be divided into CLASTIC and NON-CLASTIC**

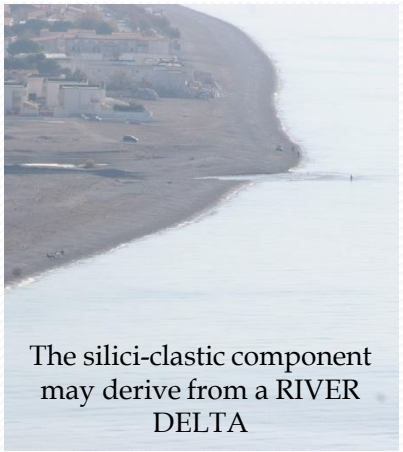

CLASTIC SEDIMENTS and SEDIMENTARY ROCKS can be distinguished based on the dominant composition of the composing elements.

Therefore, we can identify:

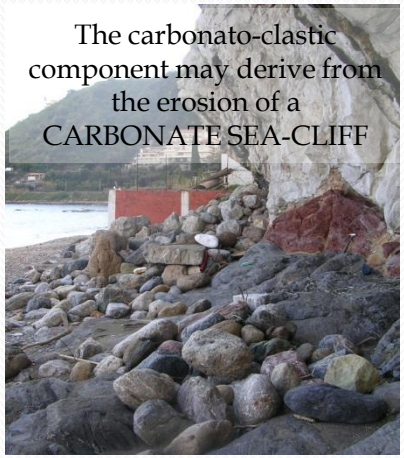
1) **terrigenous** (siliciclastic or calcilcastic),
2) **carbonatic** (or bioclastic)
3) **mixed** (siliciclastic/bioclastic).

A TERRIGENOUS ROCK contains more than the 80% of clastic components deriving from fragments of pre-existing rocks.

These components can be dominantly Quartz-rich (silici-clastics) or carbonatic (carbonato-clastics).



The silici-clastic component may derive from a RIVER DELTA



The carbonato-clastic component may derive from the erosion of a CARBONATE SEA-CLIFF

siliciclastic rock (conglomerate)

carbonato-clastic rock (micro-conglomerate)

CLASTIC SEDIMENTS and SEDIMENTARY ROCKS can be distinguished based on the dominant composition of the composing elements.

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3) **mixed** (siliciclastic/bioclastic).

A CARBONATE ROCK contains more than the 80% of bio-clastic components, deriving from carbonate or aragonitic shells or skeletal parts of living orgnisms.

These components can be **oligotypic** (consisting of rests of one type of organism) or **multitypic**, formed by different species occurring together in the same fossil assemblage).

Bioclastic rock (*grainstone* o *biosparite*)

Bioclastic rock (*grainstone* o *biosparite*)

CLASTIC SEDIMENTS and SEDIMENTARY ROCKS can be distinguished based on the dominant composition of the composing elements.

Therefore, we can identify:

1) **terrigenous (siliciclastic or calcilcastic),**
2) **carbonatic (or bioclastic),**
3) **mixed** (siliciclastic/bioclastic).

A MIXED ROCK contains more than the 20% both of bio-clastic and silici-clastic components.

The silico-clastic component may derive from pre-existent volcanic, metamorphic or sedimentary rocks.

The bio-clastic component may derive from the consumption of calcareous shells of different phaunal associations.

A mixed rock (silici-clastic/bio-clastic)

A mixed sediment (silici-clastic/bio-clastic)

# TERRIGENOUS SEDIMENTS and ROCKS

(SILICICLASTIC and CALCICLASTIC)

The **TEXTURE** of a sediment or a sedimentary rock is the ensemble of physical features that can be observed both in a macro- and a microscopic view.
The TEXTURE includes:

- The **GRAIN SIZE**
- The **MORPHOMETRY** (roundness, elongation & sphericity)
- The **SORTING**

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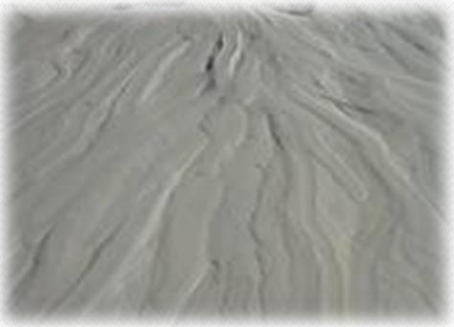
**The GRAIN SIZE (*GRANULOMETRIA in Italian*) is the quantitative estimation of the average size of the clasts composing a sediment or a sedimentary rock.**



Generally, it can be referred to the energy, modality and amount of sedimentary transport that a sediment undergoes (e.g.,: high-energy transport can move coarse-grained sediments).

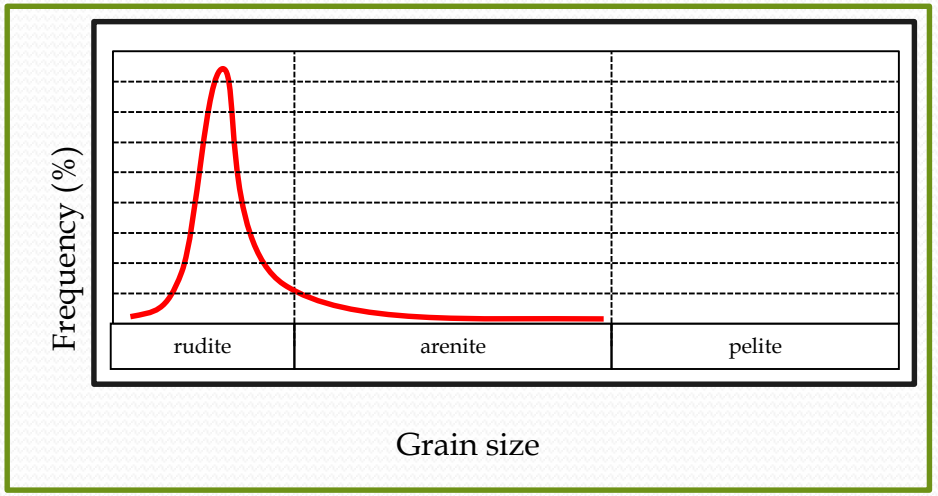
HOW TO MEASURE SEDIMENT GRAIN SIZE?

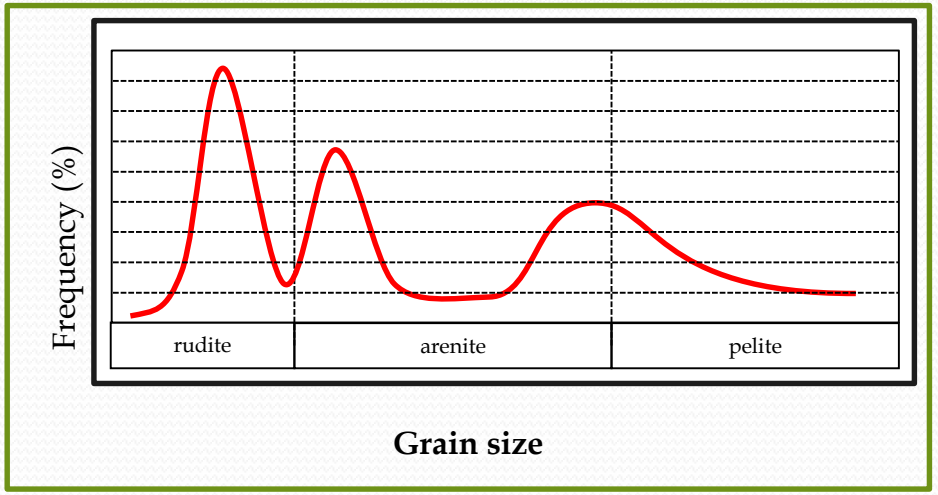
## The Udden-Wentworth scale

| Diameter of the particles in ϕ | Diameter of the particles in mm | Definition | | |
|---|---|---|---|---|
| | > 256 | Masso | Boulder | Rudite |
| 256- | 128 | Ciottolo molto grossolano | Cobble | |
| 128- | 64 | Ciottolo grossolano | Cobble | |
| 64- | 32 | Ciottolo medio-grossolano | Pebble | |
| 32- | 16 | Ciottolo medio | Pebble | |
| 16- | 8 | Ciottolo medio-fine | Pebble | |
| 8- | 4 | Ciottolo fine | Pebble | |
| 4- | 2 | Granulo | Granule | Arenite |
| 2- | 1 | Sabbia molto grossolana | Very coarse sand | |
| 1- | ½ | Sabbia grossolana | Coarse sand | |
| ½- | ¼ | Sabbia media | Medium sand | |
| ¼- | 1/8 | Sabbia fine | Fine sand | |
| 1/8- | 1/16 | Sabbia molto fine | Very fine sand | |
| 1/16- | 1/32 | Silt grossolano | Coarse silt | Pelite |
| 1/32- | 1/64 | Silt medio | Medium silt | |
| 1/64- | 1/128 | Silt fine | Fine silt | |
| 1/128- | 1/256 | Silt molto fine | Very fine silt | |
| | <1/256 | Argilla | Clay | |

HOW TO MEASURE SEDIMENT GRAIN SIZE?

## Frequency plots



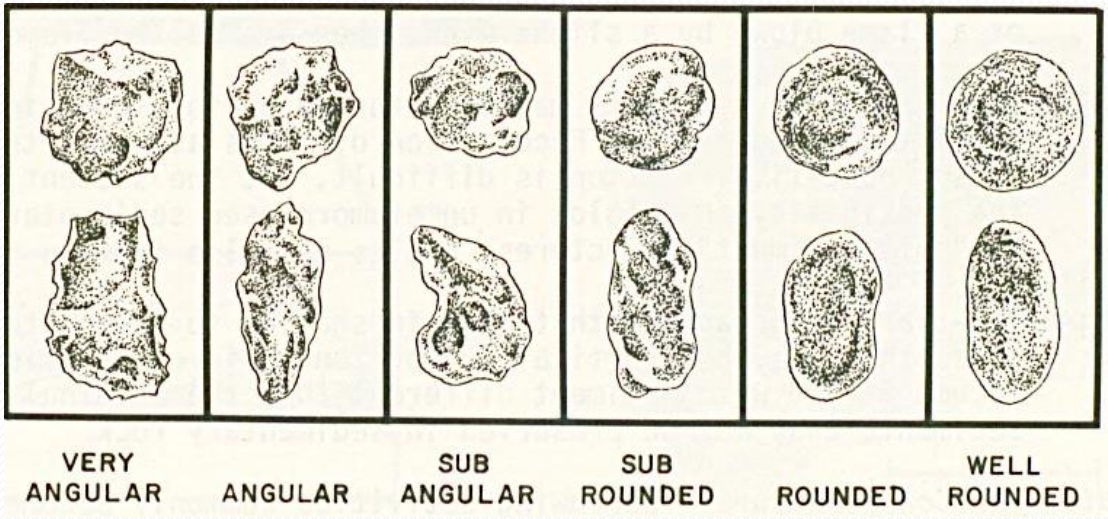
The **TEXTURE** of a sediment or a sedimentary rock is the ensemble of physical features that can be observed both in a macro- and a microscopic view.
The TEXTURE includes:

- The **GRAIN SIZE**
- The **MORPHOMETRY** (roundness, elongation & sphericity)
- The **SORTING**

**La MORPHOMETRY is the estimation of the shape of the clasts contained in a sediment or a sedimentary rock**

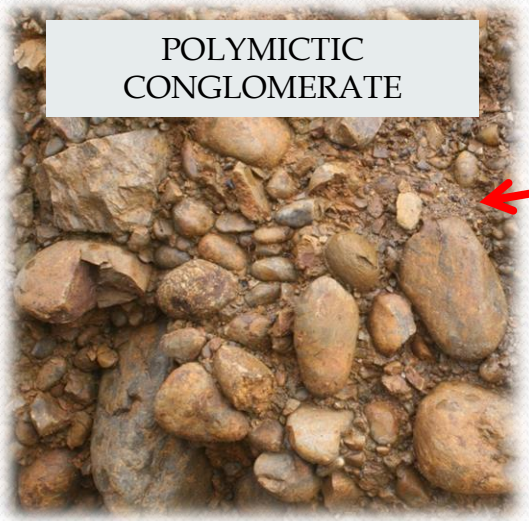
**i. Degree of roundness degree:** it defines the degree of consumption or angulosity of a group of clasts

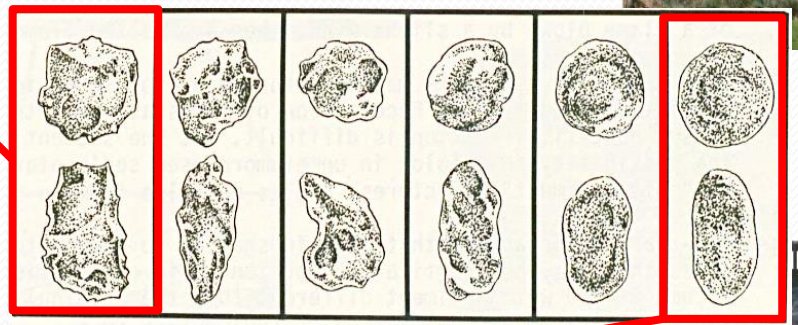
Generally, it correlates with the amount of transportof a sediment (e.g., the more longer the transport, the better rounded the clasts).



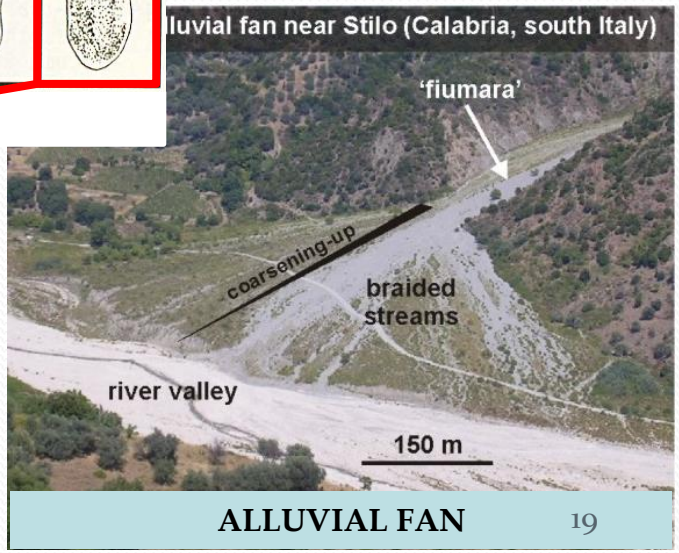
MONOMICTIC BRECCIA

POLYMICTIC CONGLOMERATE





**COLLUVIAL FAN**


**ALLUVIAL FAN**

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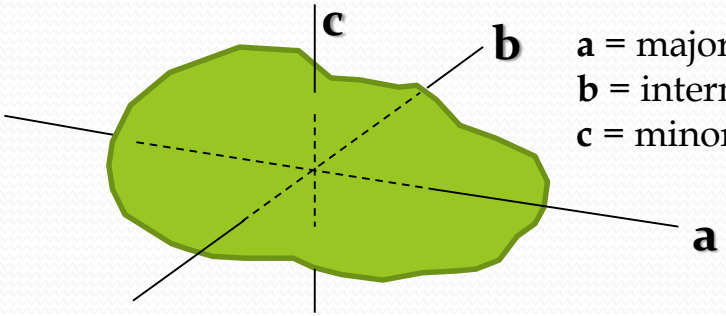
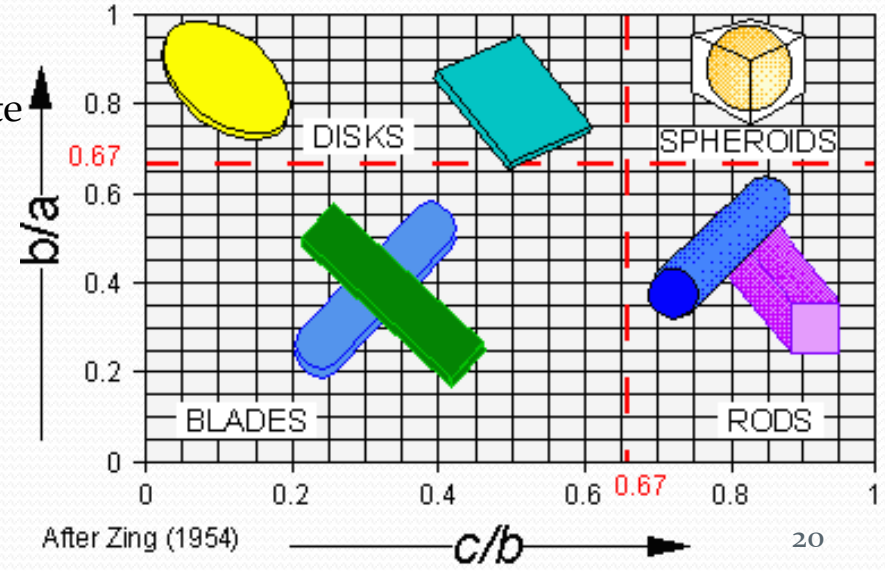
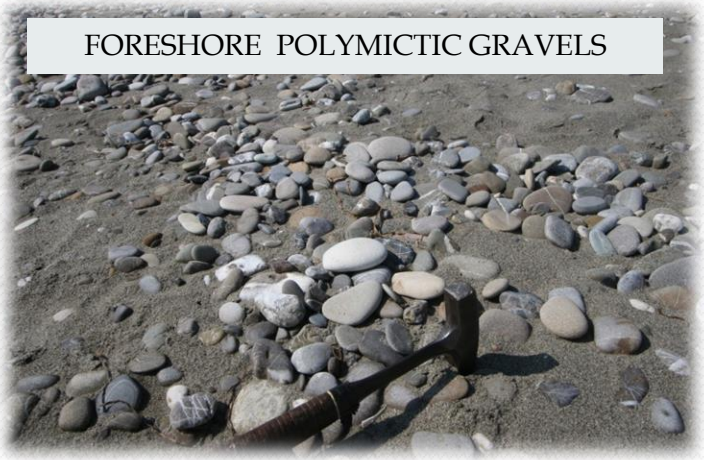
**ii. Degree of Elongation: it** defines the reciprocal dimensions of the three main axes which individuate each single clast



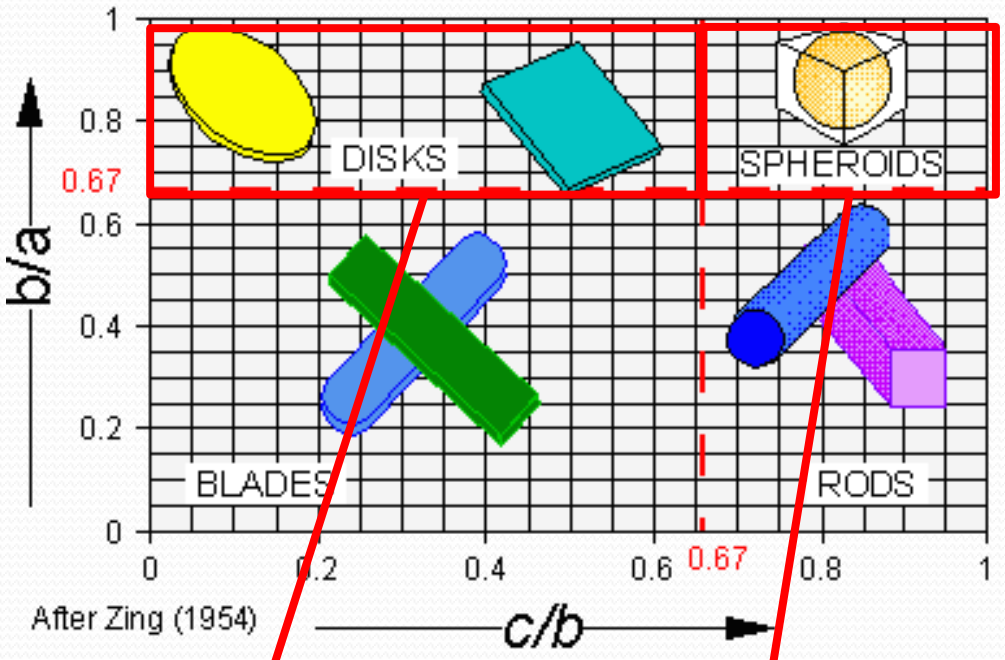

**a** = major axis;
**b** = intermediate axis;
**c** = minor axis.

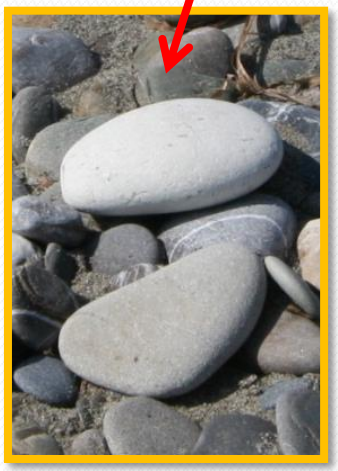


FORESHORE POLYMICTIC GRAVELS



ALLUVIAL POLYMICTIC CONGLOMERATES



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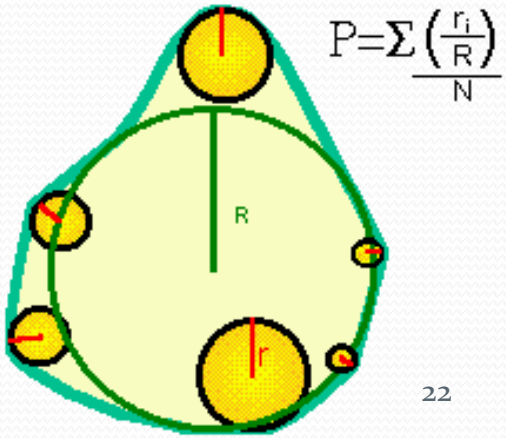
**iii. Degree of Sphericity:** defines the degree of approximation of the clast profile to a spheric contour

Es.: also in this case, the more spherical, the longer the transport.

Well-rounded clasts indicate a better degree of textural maturity, compared to angular clasts.



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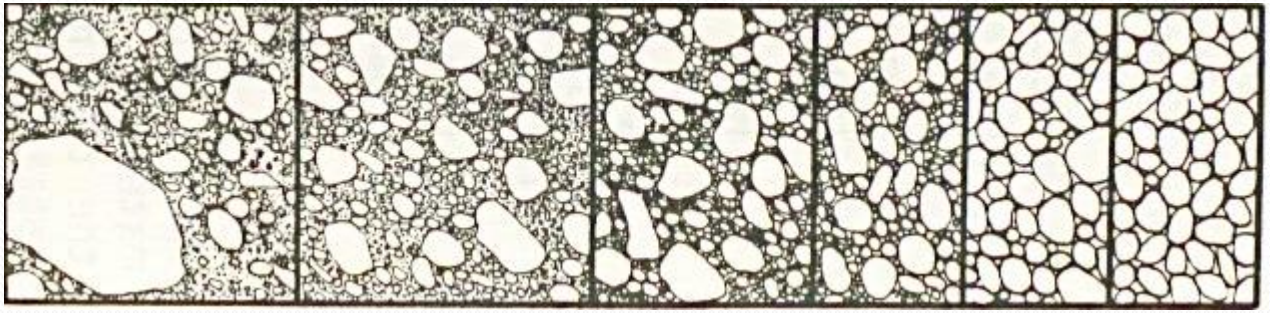
**The SORTING** (*cernita, in Italian*) **is the degree of variability in the average grain size of the clasts.**

e.g., a scarce sorting indicates a very rapd deposition. On the contrary, a good sorting indicates a longer transport and a consequent selection. In order of effectiveness: wind > waves > rivers > glaciers.
A well-sorted sediment is texturally more mature than a poorly-sorted sediment.



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## Main type of sediments and sedimentary rocks

Terrigenous sediments and sedimentary rocks can be classified based on their dominant grain size. Therefore, we can distinguish:

| | SEDIMENT | ROCK |
|---|---|---|
| • GRAVEL or CONGLOMERATE |  |  |
| • SAND or SANDSTONE |  |  |
| • CLAY or CLAYSTONE |  |  |

## i. GRAVELS and CONGLOMERATES

Gravels and conglomerates are sediments and rocks dominantly formed by ruditic clasts. They can be divided into:

- MONOMICTIC
  with one dominant lithology

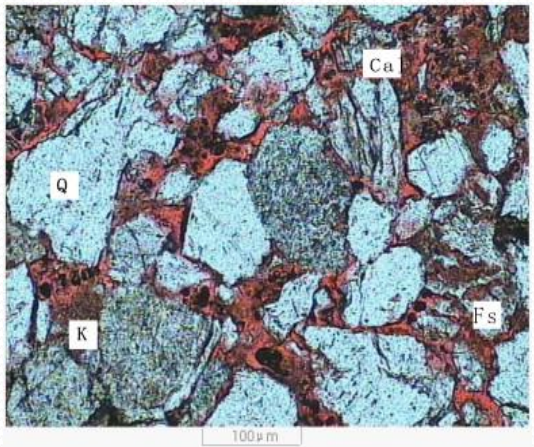
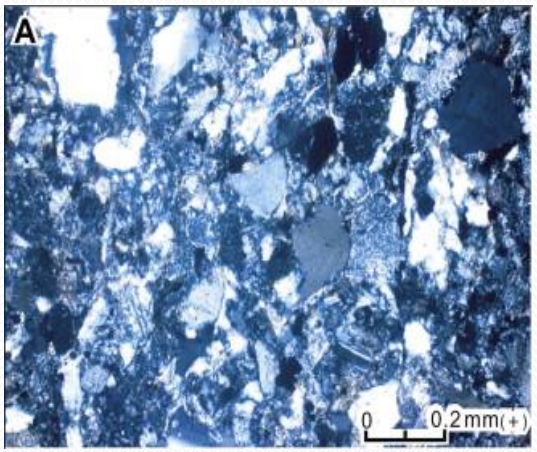
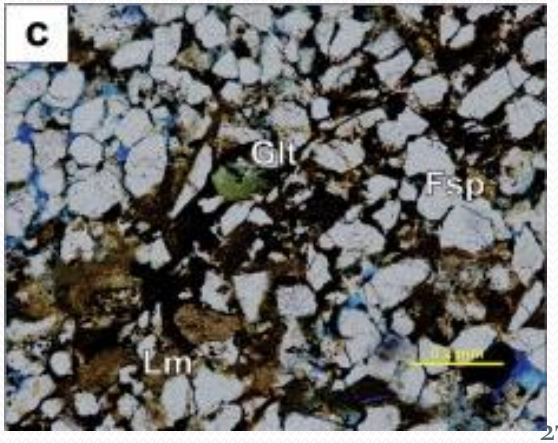
POLYMICTIC
with more lithologies

- CLAST-SUPPORTED
  Clasts are self-sustained as they are at direct contact each other (matrix is scarce or absent)

MATRIX-SUPPORTED
Clasts float into a finer matrix

## ii. SANDS and SANDSTONES

SANDSTONES are sedimentary rocks dominantly consisting of arenitic clasts. Based on their mineralogic composition e.g., % of Quartz, Feldspar (Sodium, Potassium, Calcium allumosilicates: Ortoclasium, Albite, Anortite, Celsian) and lithic fragments, sandstones can assume different names.

| | **QUARTZ (*Q*)** | **FELDSPAR (*F*)** | **LITHIC FRAGMENTS (*R*)** |
|---|---|---|---|
| Macroscopic aspect |  |  |  |
| Microscopic aspect |  |  |  |

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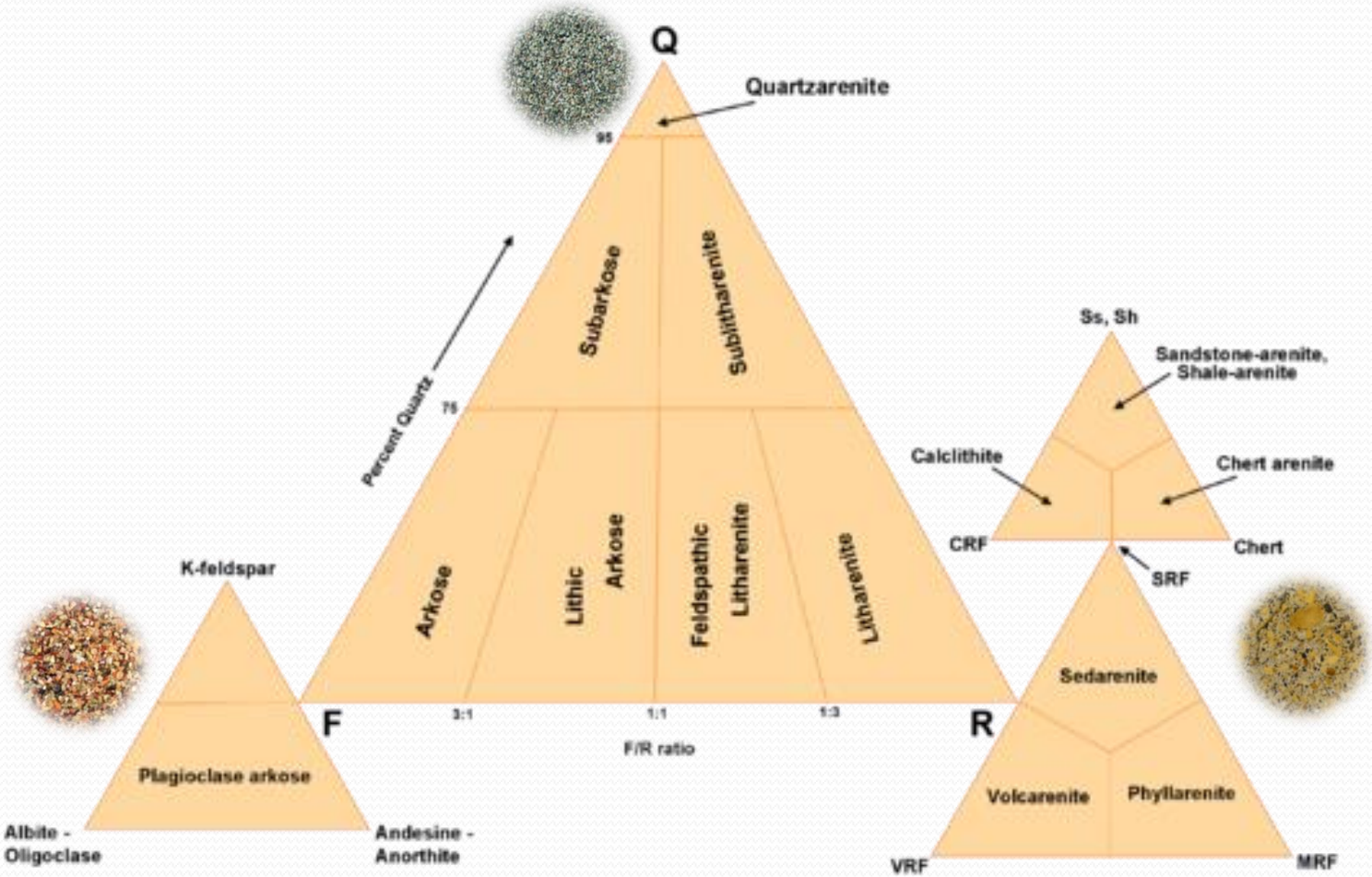
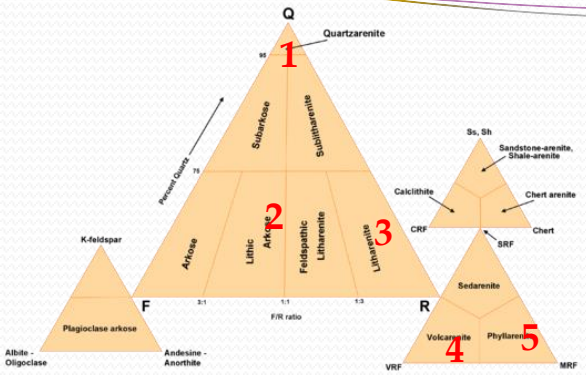
**CLASSIFICATION OF SANDSTONES**



## ii. SANDS and SANDSTONES




Some common example …

**QUARZARENITE**


**LITHIC ARCOSE**

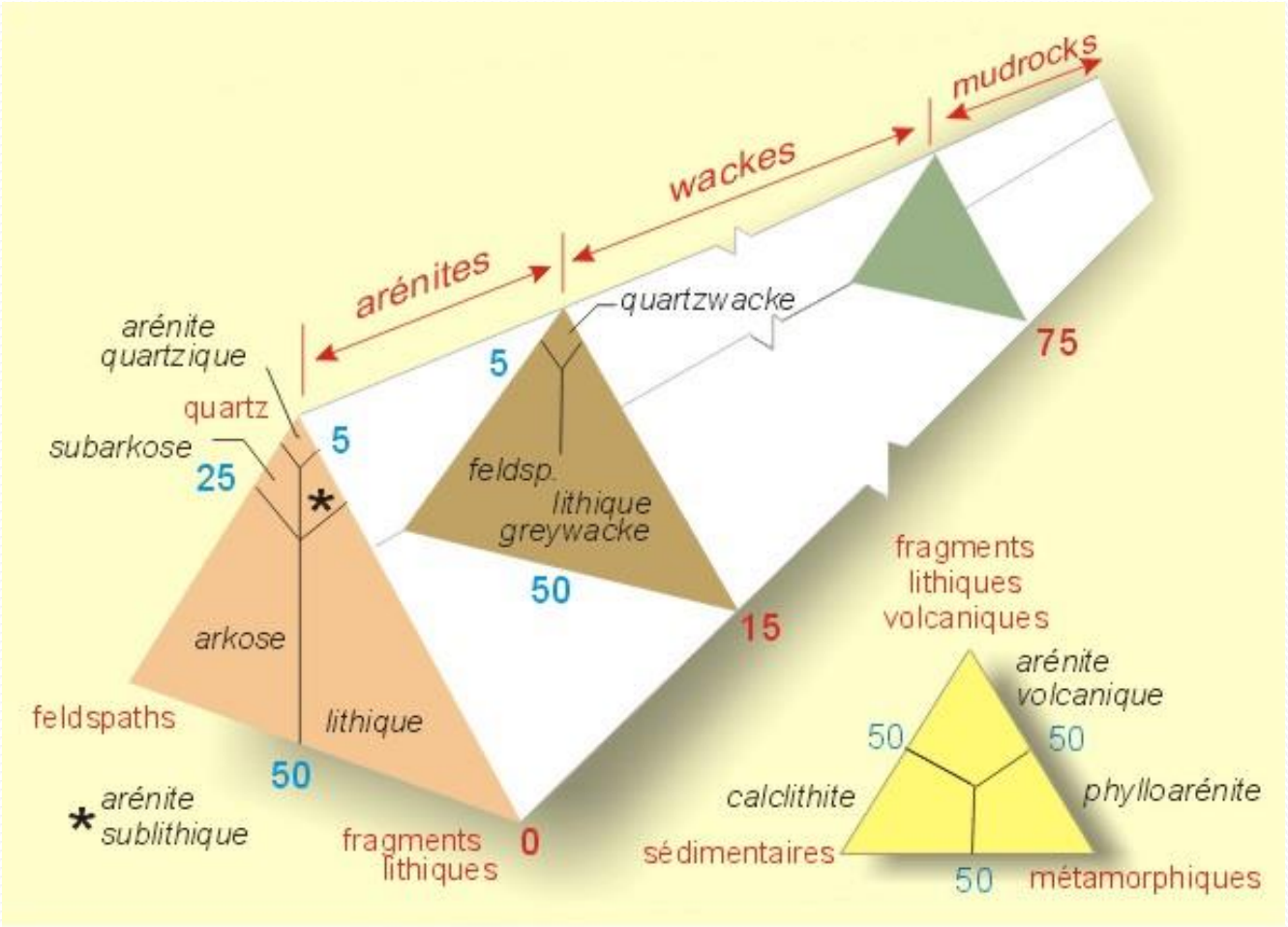

**LITHARENITE**


**VOLCANIC SANDSTONE**


**FILLARENITE**

**ii. SANDS and SANDSTONES**

SANDSTONES are sedimentary rocks dominantly consisting of arenitic clasts. Based on their mineralogic composition e.g., % of Quartz, Feldspar (Sodium, Potassium, Calcium allumosilicates: Ortoclasium, Albite, Anortite, Celsian) and lithic fragments, sandstones can assume different names.



**iii. CLAYS and CLAYSTONES**

CLAYS are fine-grained sediments consisting of particles with grain size less than 2 μm (pelite) . Once lithified, and depending on their mineralogic composition (e.g., % di fillosilicates), CLAYSTONES can assue different names. Amog the most common, we can list the fillosilicate-based ones:

***Kaolinite***

$[Si_4]Al_4O_{10}(OH)_8.nH_2O$

***Illite***

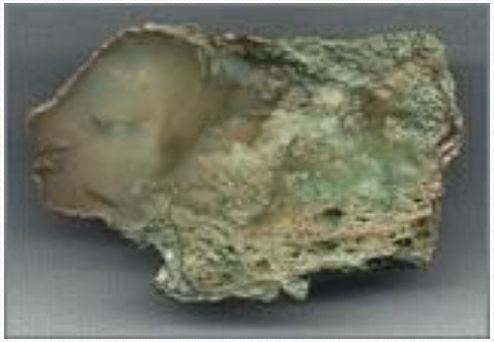
$[Si_{6.8}Al_{1.2}]Al_3Fe.025Mg_{0.7}5O20(OH)_4$

***Vermiculite***

$[Si_7Al]AlFe.05Mg0.5O_20(OH)_4$

***Smectite***

$[Si_8]Al_{3.2}Fe_{0.2}Mg_{0.6}O_20(OH)_4)$



***Clorite***

$(Al(OH)_{2.55})4[Si_{6.8}Al0_{1.2}\}Al_{3.4}Mg_{0.6})20(OH)_4$

### iii. CLAYS and CLAYSTONES

Depositional systems (consisting of a numbero of environments) that can provide clays:

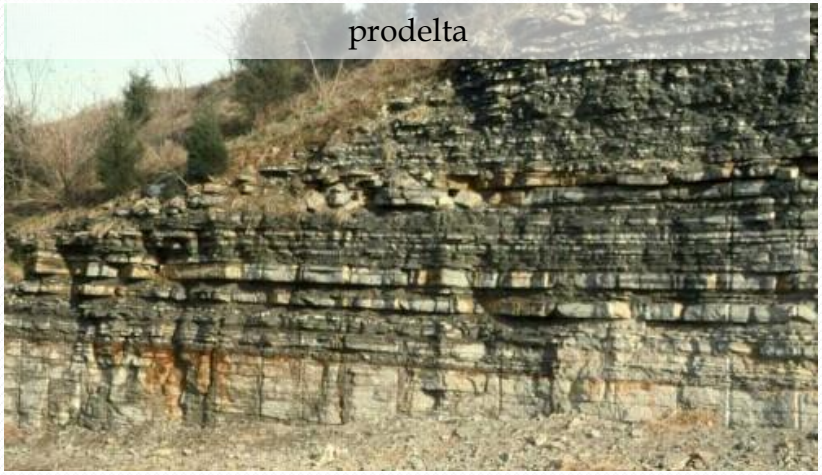
MODERN

Tidal flat

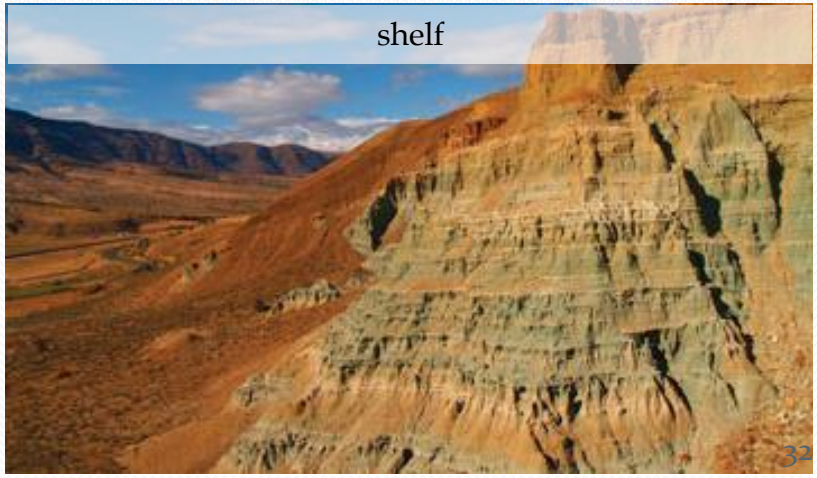
rivers

ANCIENT

prodelta



shelf



# CARBONATE SEDIMENTS and ROCKS

## CARBONATE ROCKS

CARBONATES are CaCo3-rich rocks, mostly generated by biological and chemical processes.
Carbonates record a number of relevant information on the primary sedimentary environment, including:

1. Temperature of the waters during the sedimentation.
2. Salinity of the waters.
3. Depth.

These three factors change the nature of carbonate rocks. This is due to organisms living within the sediment and to the Carbonate Compensation Depth (CCD).

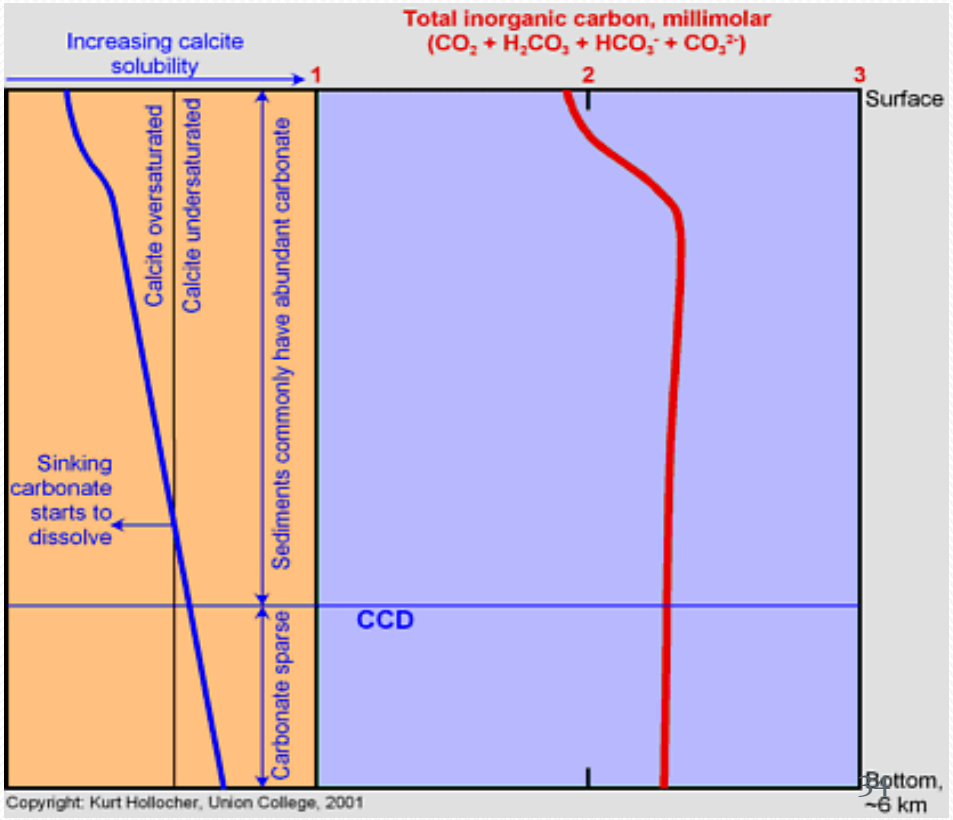
Som shell remains (after the deth of the organisms) fall out from the surface of the water downwards;

Shells reach a depth where waters are significantly sub-sature of $CaCO_3$

At that depth, shells begin to dissolve.

In modern environments (e.g., oceans) there is a depth beneath which $CaCO_3$ is chemically unstable.

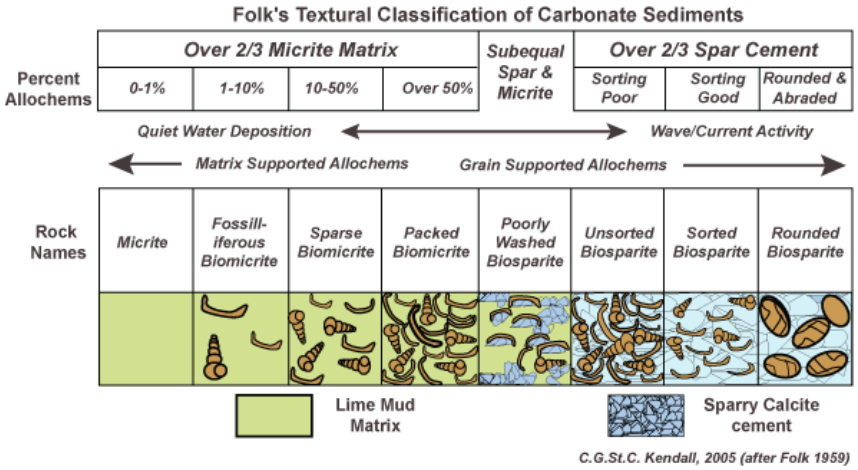
Such a depth is known as CARBONATE COMPENSATION DEPTH (CCD).



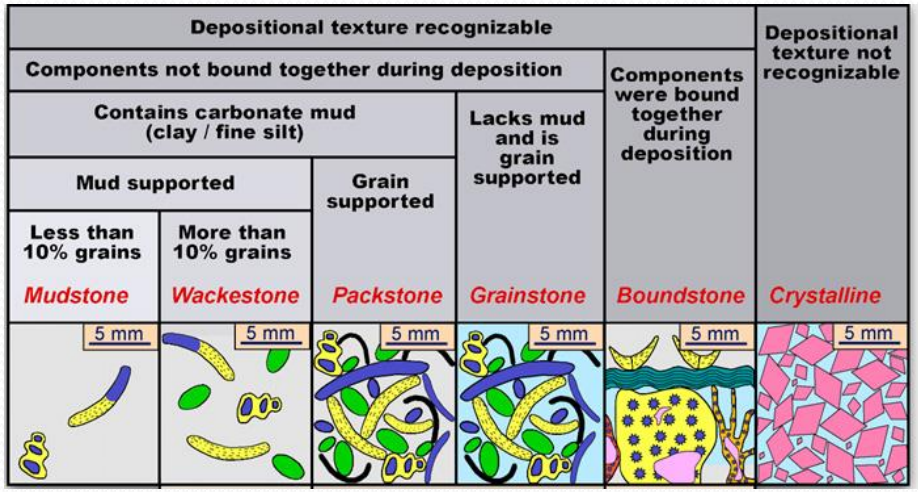
## CARBONATE ROCKS

There are two main classifications for carbonate rocks:

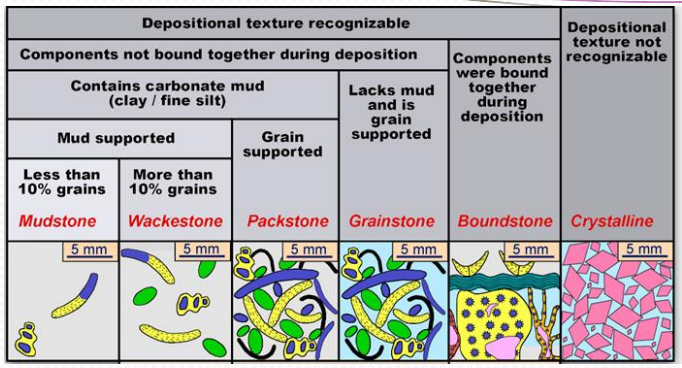
The most common and widely used classification is after **Folk** (1962), which is based on the carbonate rock textures.




A second, more used approach is after **Dunham** (1962), which is based on the composition of carbonate rocks and their average grain size.

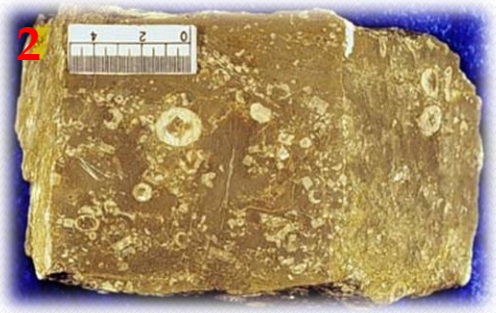


## CARBONATE ROCKS




MUDSTONE


WACKESTONE



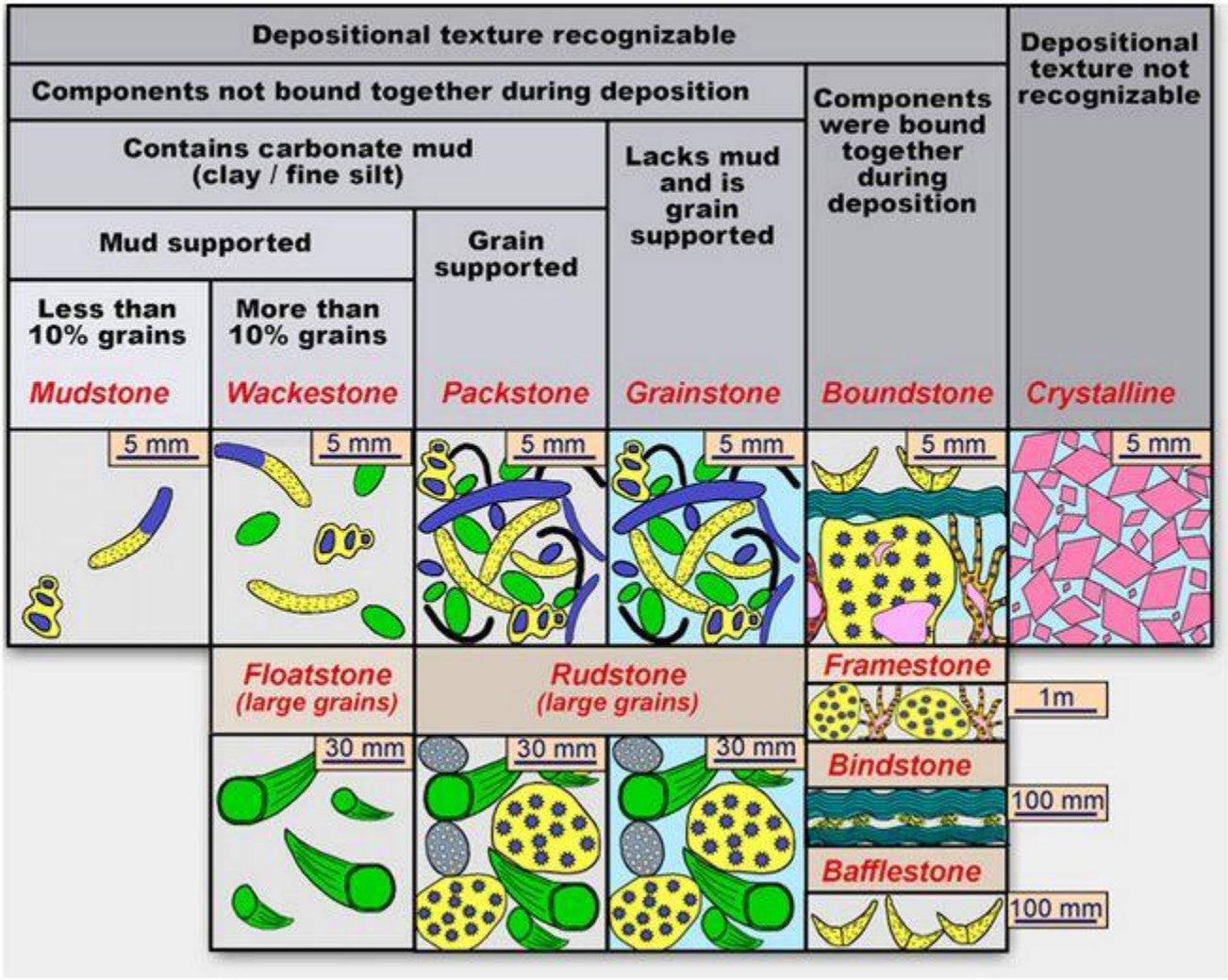

PACKSTONE


GRAINSTONE


BOUNDSTONE


CRYSTALLINE CARBONATE

**CARBONATE ROCKS**



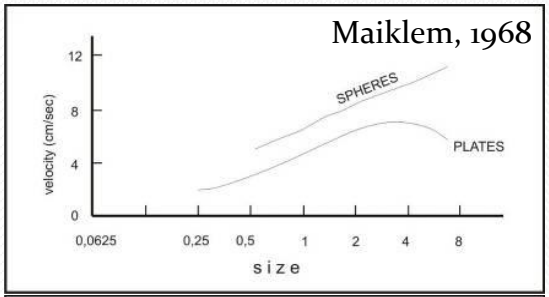
# MIXED
# SEDIMENTS and ROCKS

Often in nature, it is possible recognize rocks in which the **carbonate** and **siliciclastic** fractions occur together, although with different proportions or percentages.

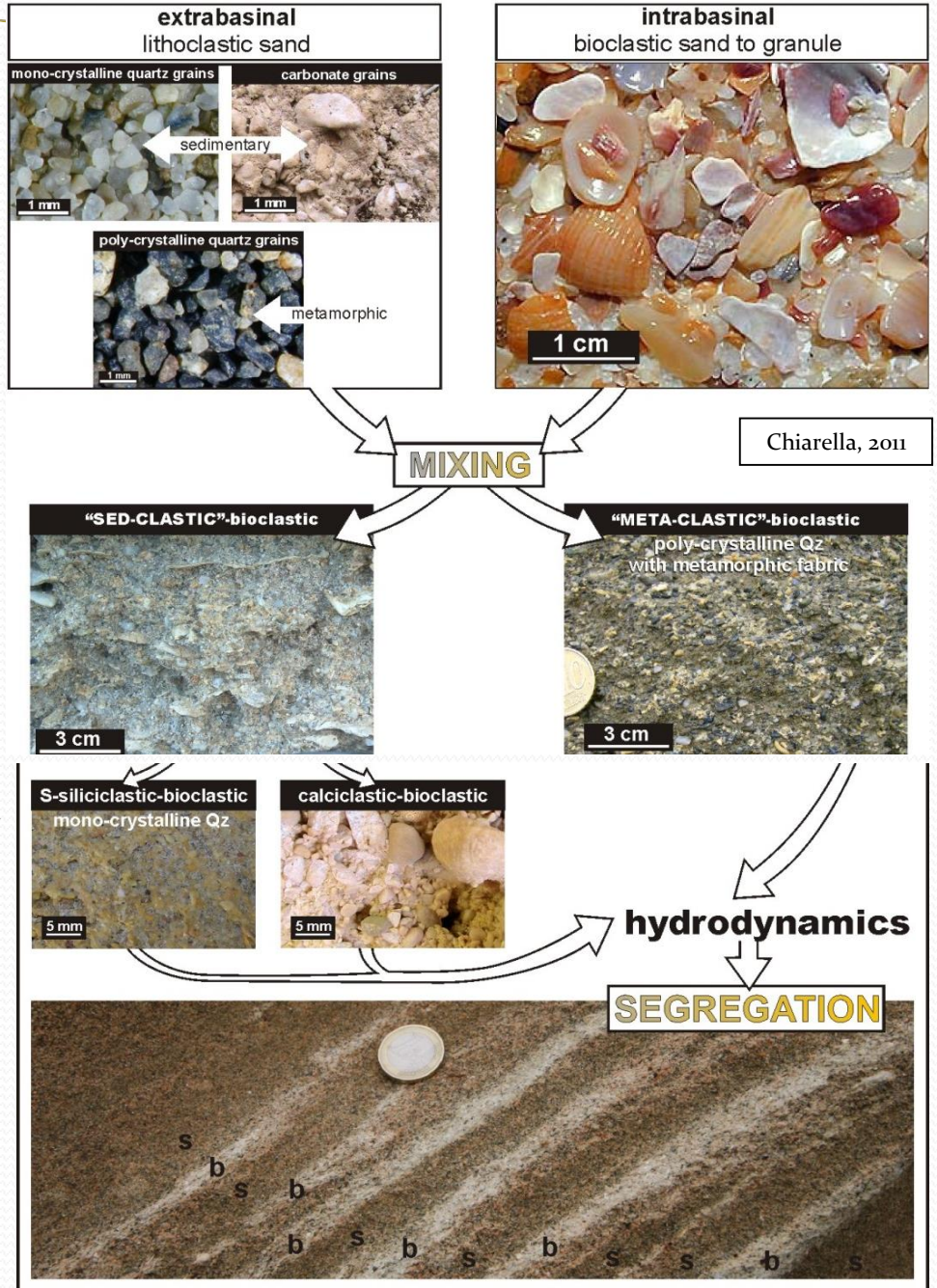
When we are able to estimate such percentages with precision (e.g., with mineralogical quantitative analysis) an indicative nomenclature can be adopted on these rocks which are of MIXED COMPOSITION.

A MIXED SEDIMENT or ROCK consists of:

1) an EXTRA-BACINAL fraction, and
2) An INTRA-BACINAL fraction (Mount, 1984).



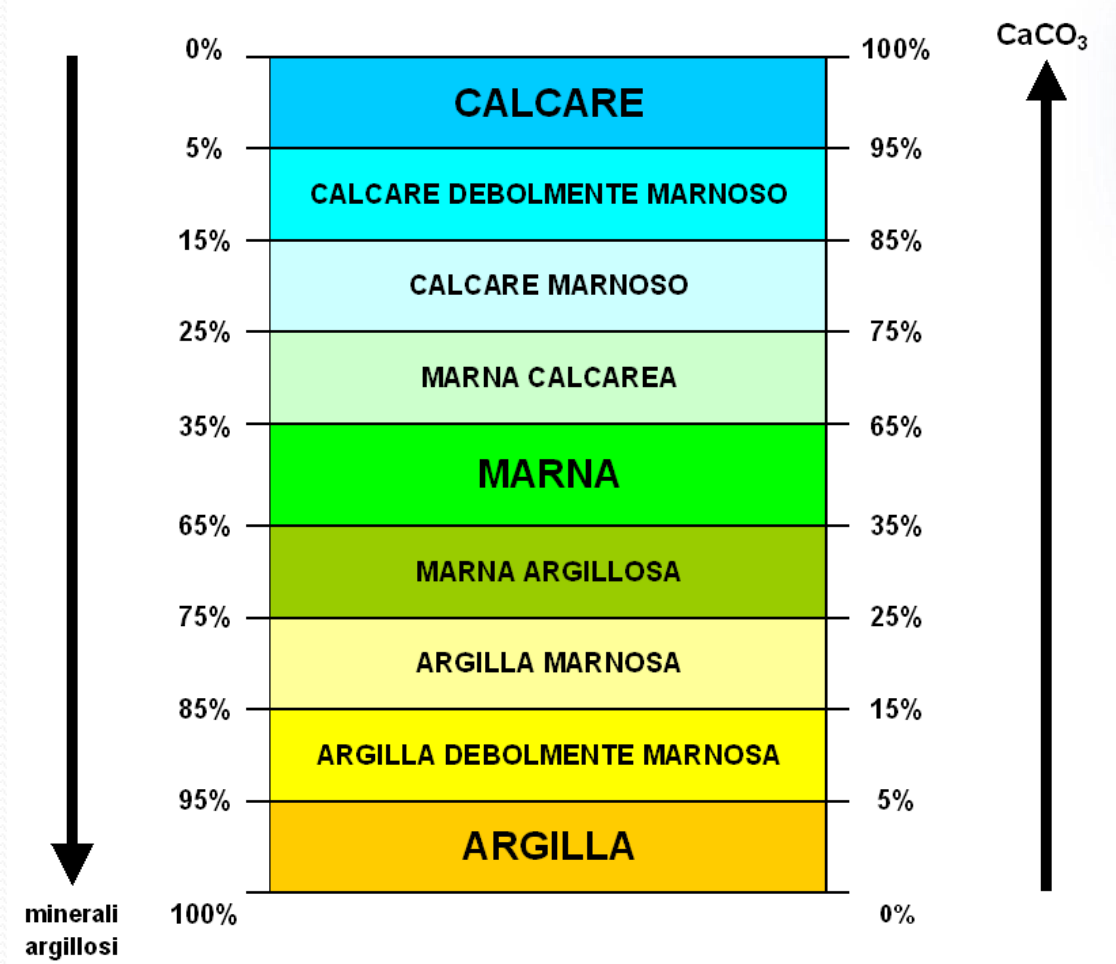

The two heterolithic components can be subject to a different hydraulic behavior if incepted in a moving (e.g., waves, currents, ...). Consequently, they can be organized into different ways or structures, allowing to a HETEROLITHIC SEGREGATION.



Often in nature, it is possible recognize rocks in which the **carbonate** and **siliciclastic** fractions occur together, although with different proportions or percentages.

When we are able to estimate such percentages with precision (e.g., with mineralogical quantitative analysis) an indicative nomenclature can be adopted on these rocks which are of MIXED COMPOSITION.

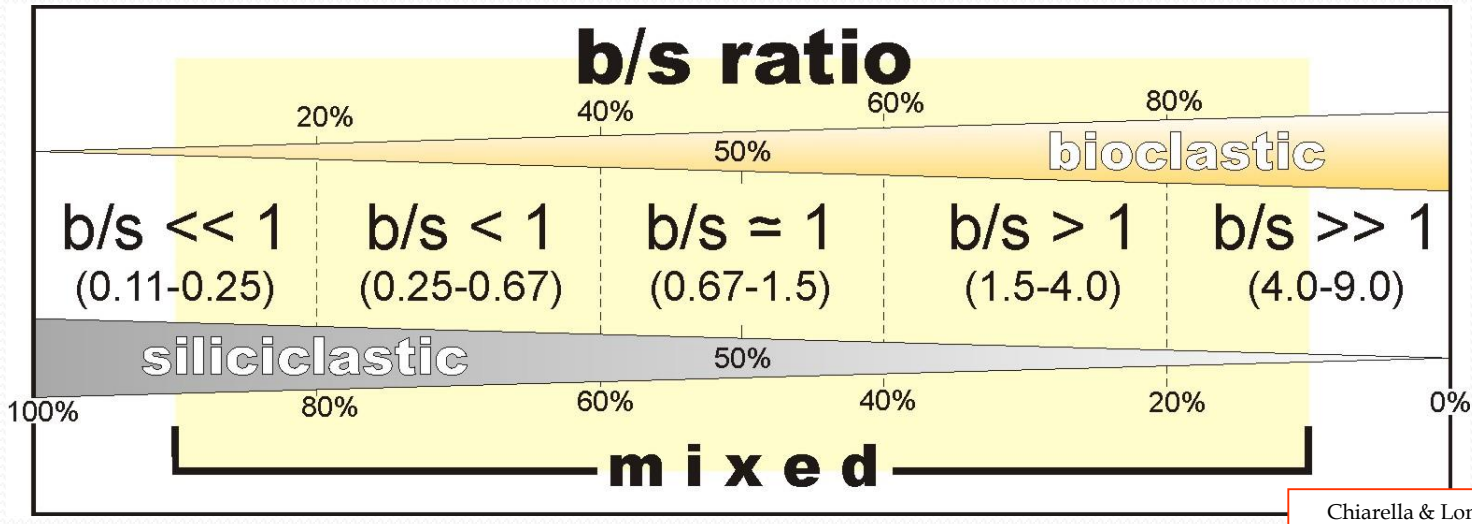
## FINE-GRAINED MIXED ROCKS




**MIXED ROCKS**. A method to classify them [*bioclastic/siliciclastic ratio* (*b/s*)]

The *bioclastic/siliciclastic ratio* (*b/s*) misures the quantitative proportion of the two heterolithic components of a mixed sediment or rock (Chiarella & Longhitano, 2012)

Such feature is a pre-condition to consider or define a sediment as MIXED: «a mixed sediment can be considered as such, when both of their component are more than the 10%» (Mount, 1985).




Chiarella & Longhitano, JSR (2012)

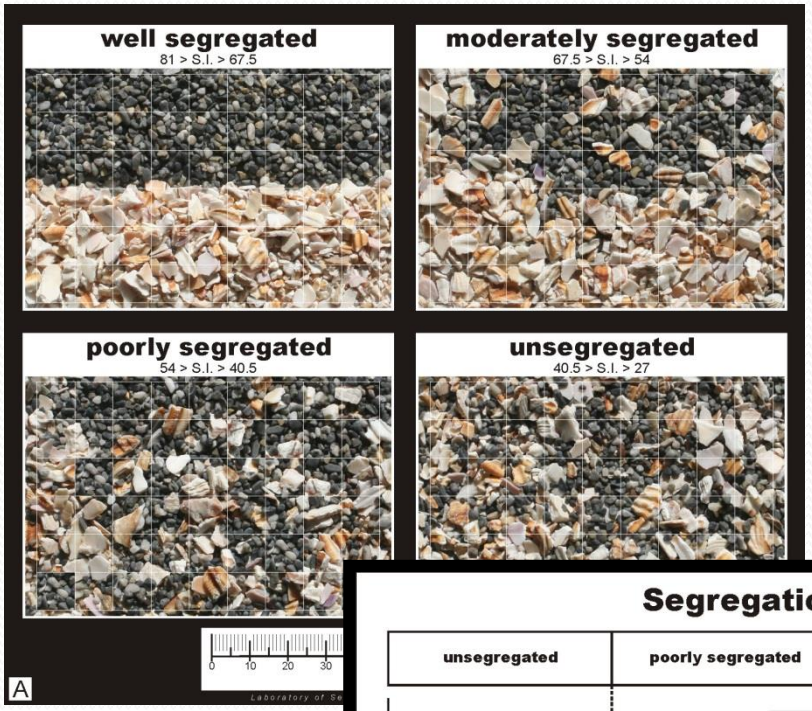
The *b/s* ratio includes 5 classes, in which the numerical interval corresponds to the reciprocal relationship between the two components, according to a progression of the 20%.

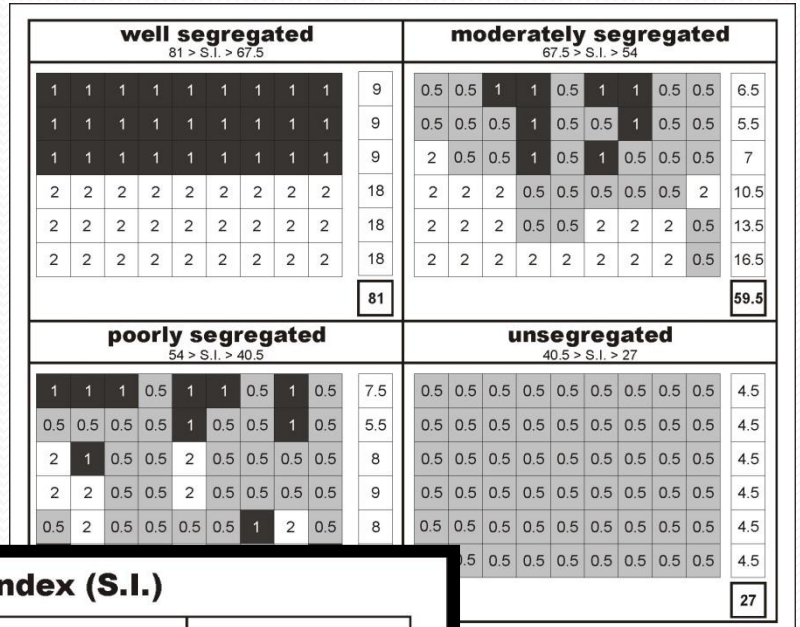
**MIXED ROCKS**. A method to classify them [*segregation index* (*S.I.*)]

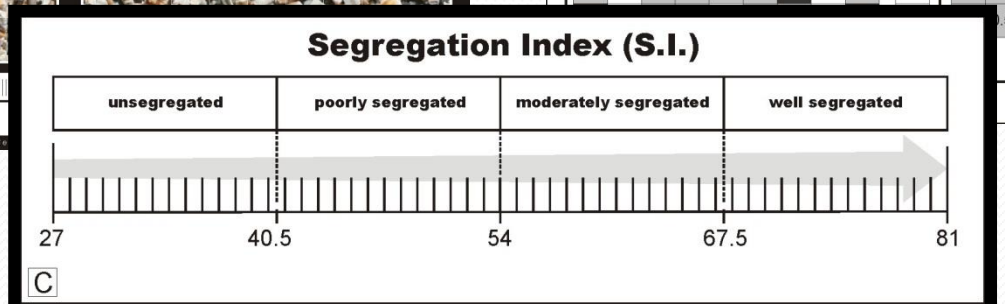
The *Segregation Index* (*S.I.*) represents an adimensional parameter whch quantifies the degree of heterolithic segregation in a mixed sediment or rock.

For HETEROLITHIC SEGREGATION we intend the spatial distribution that clastic particles assume within a rock.

The numerical estimation of such feature can be applied through the use of a visual comparator.




Chiarella & Longhitano, JSR (2012)

Evaluation of the *Segregation Index* (*S.I.*). Use of a matrix (9 x 6) and arithmetic sum of the indexes.

EXAMPLE # 1

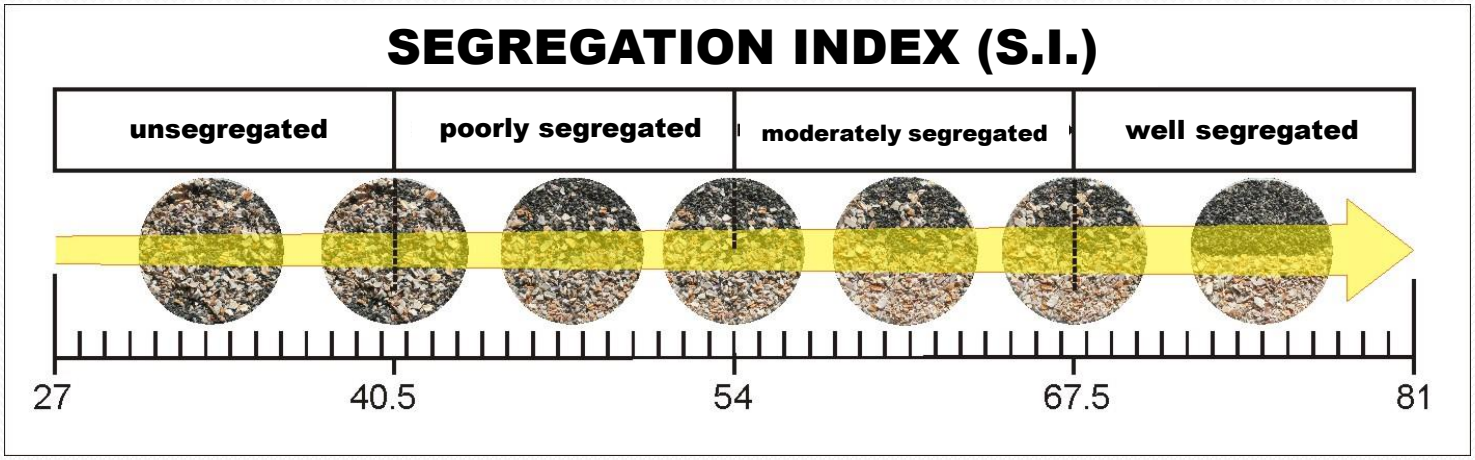
USED INDEXES:

SilicIclastic= **1**

Bioclastic= **2**

Mixed = **0,5**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 2 | 2 | 0.5 | 2 | 2 | 12.5 |
| 1 | 1 | 1 | 0.5 | 2 | 2 | 2 | 2 | 2 | 13.5 |
| 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 13 |
| 1 | 1 | 1 | 1 | 1 | 0.5 | 0.5 | 2 | 2 | 10 |
| 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 17 |
| 0.5 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 16.5 |




82.5

Evaluation of the *Segregation Index* (*S.I.*). Use of a matrix (9 x 6) and arithmetic sum of the indexes.

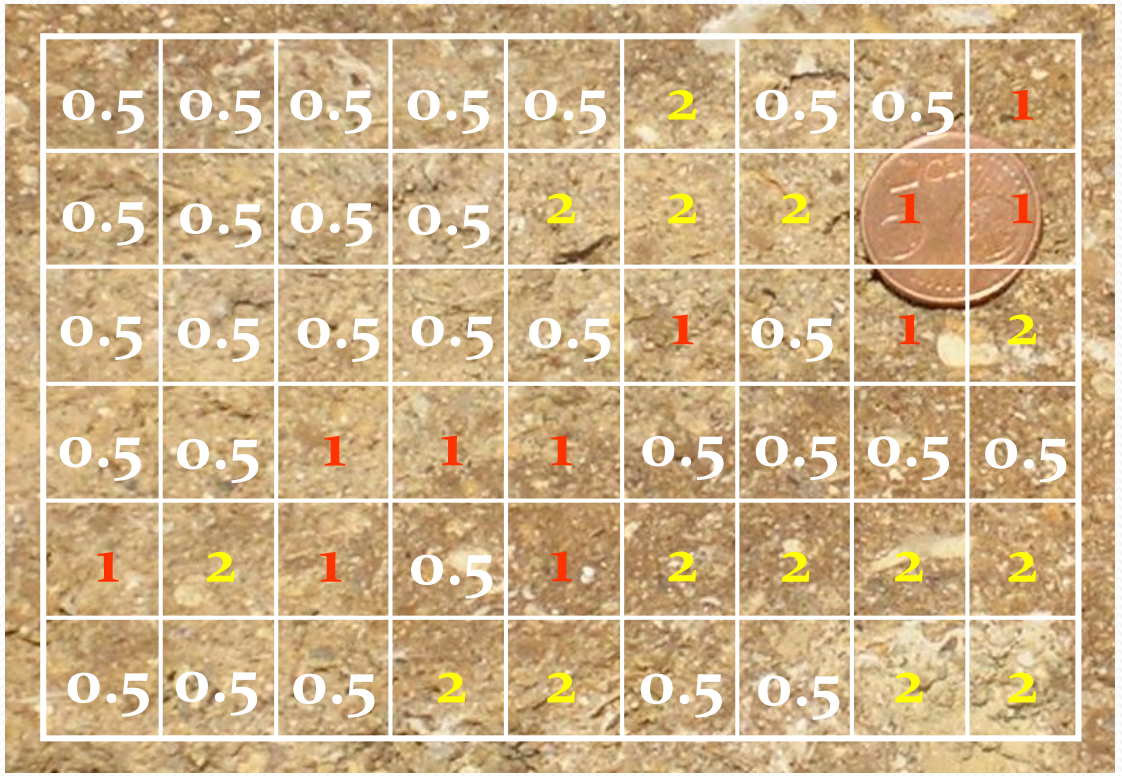
EXAMPLE # 2

USED INDEXES:

SilicIclastic= **1**

Bioclastic= **2**

Mixed = **0,5**




| |
|---|
| 6.5 |
| 10 |
| 7 |
| 6 |
| 13.5 |
| 10.5 |

53.5