Sedimentology and Stratigraphy, 2020-2021

Carbonate rocks.
How do we look at them and what may we see in them?

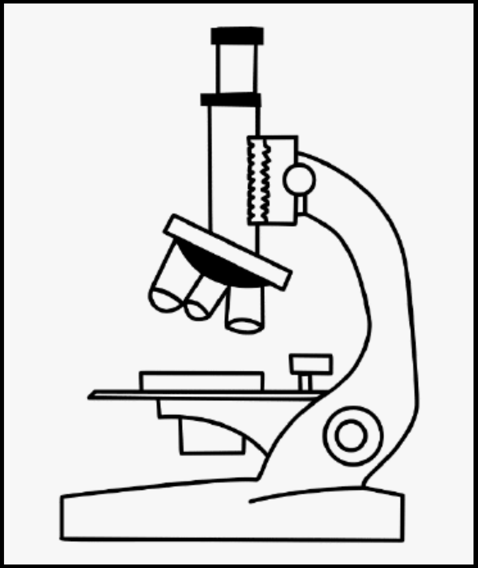
Observation and classification of carbonate rocks

Classification is a fundamental step in understanding the origin of carbonate rocks and is performed evaluating both quantitatively and qualitatively their features.

Carbonate rocks should be observed at different scales:

Outcrop observation

hand lens



microscope

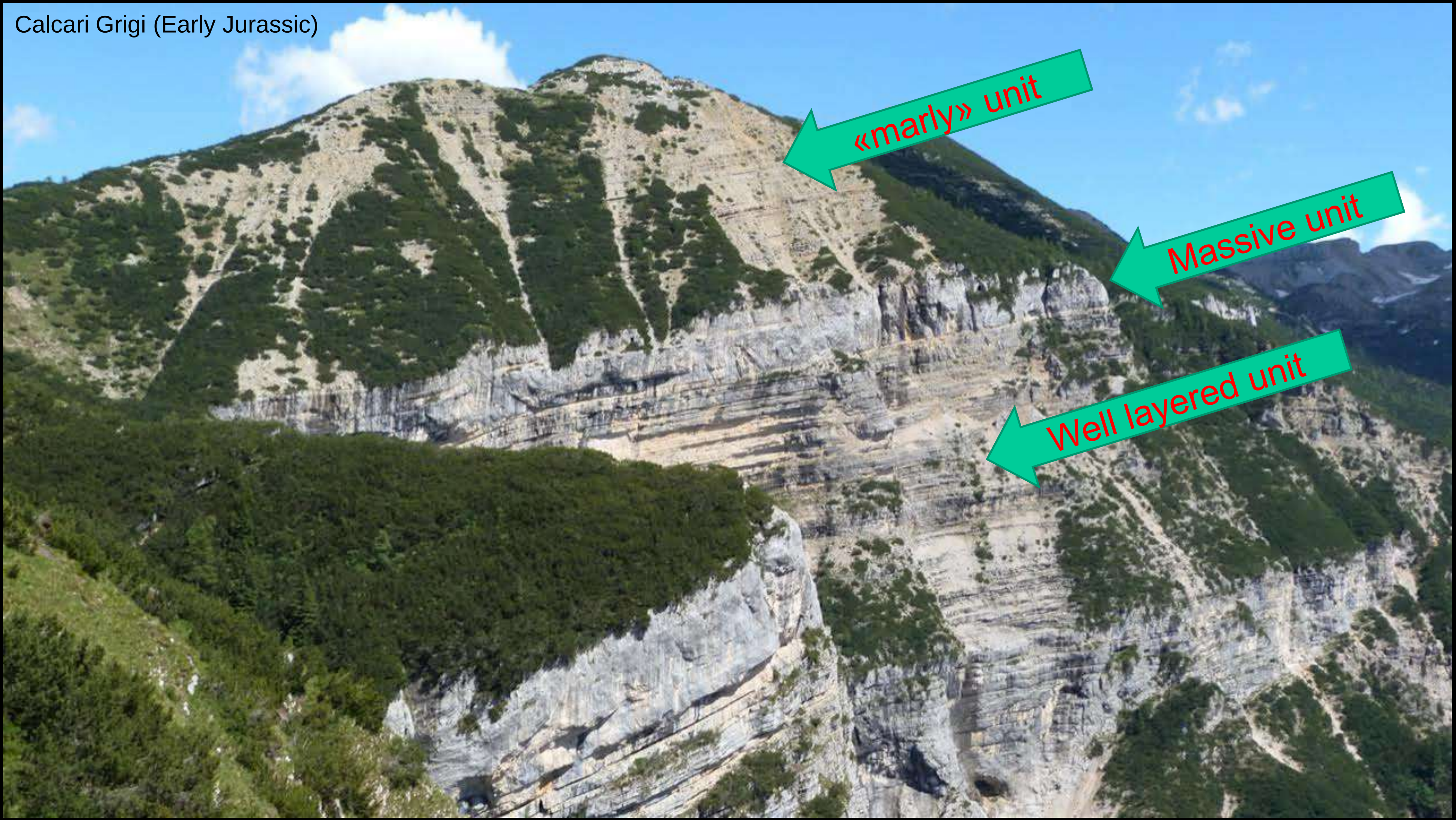
Carbonate rocks in outcrop

Observation of carbonate rock outcrops can provide key information for their interpretation. Some of the features that can be appreciated are:

- Bedding (is the rock layered? Is it massive?)
- Bedding style (planar, ondulated, nodular…?)
- Sedimentary structures (lamination? What type of lamination?)
- Large scale geometries (e.g. lateral closure of carbonate bodies…)
- …

Carbonate rocks in outcrop

Carbonate rocks in outcrop

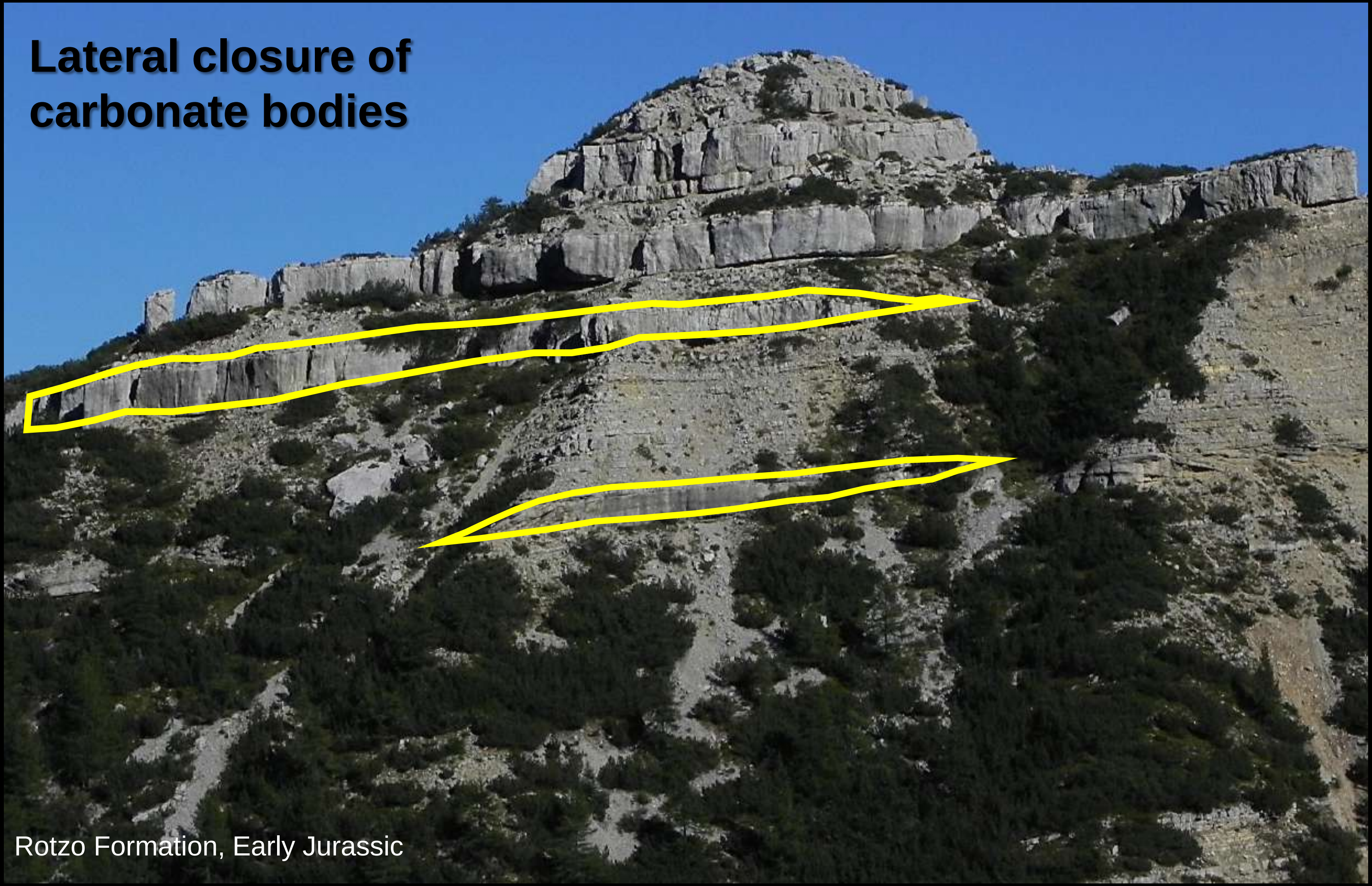


This outcrop exposes carbonate rocks that have very different characteristics. A well layered carbonate unit at the bottom is followed by a massive carbonate bed of constant thickness. This latter is overlain by a well-layered unit with a more recessive erosional profile that is suggestive of a higher content terrigenous material.

Carbonate rocks in outcrop

This outcrop features carbonate bodies that display a lens-shaped geometry

Carbonate rocks in outcrop

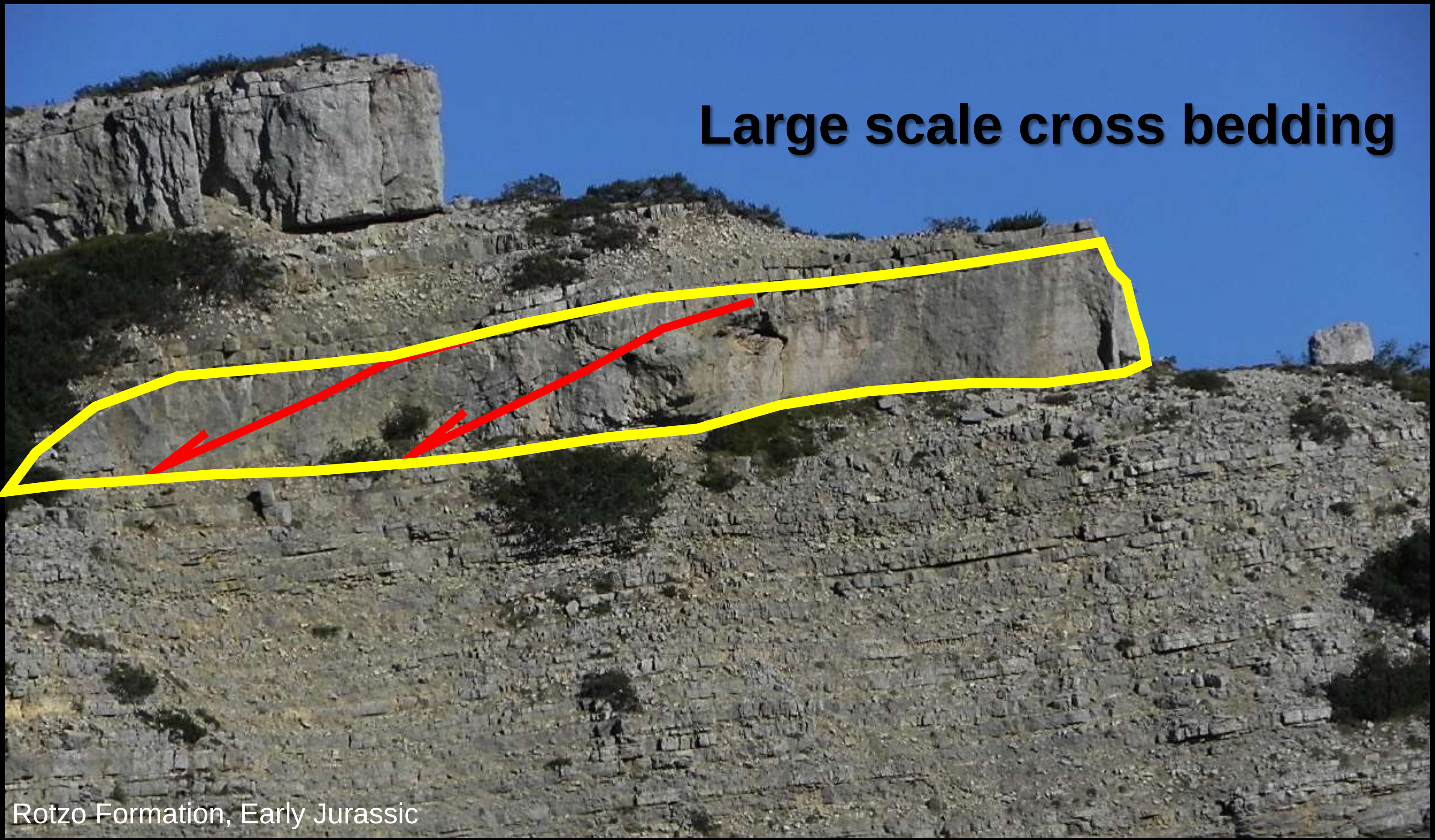


This outcrop features carbonate bodies that display a lens-shaped geometry

Carbonate rocks in outcrop

Zooming-in on one of those lens-shaped carbonate bodies, large scale cross bedding is clearly visible.

Carbonate rocks in outcrop



Zooming-in on one of those lens-shaped carbonate bodies, large scale cross bedding is clearly visible.

Carbonate rocks in outcrop

A thick succession of carbonate rocks

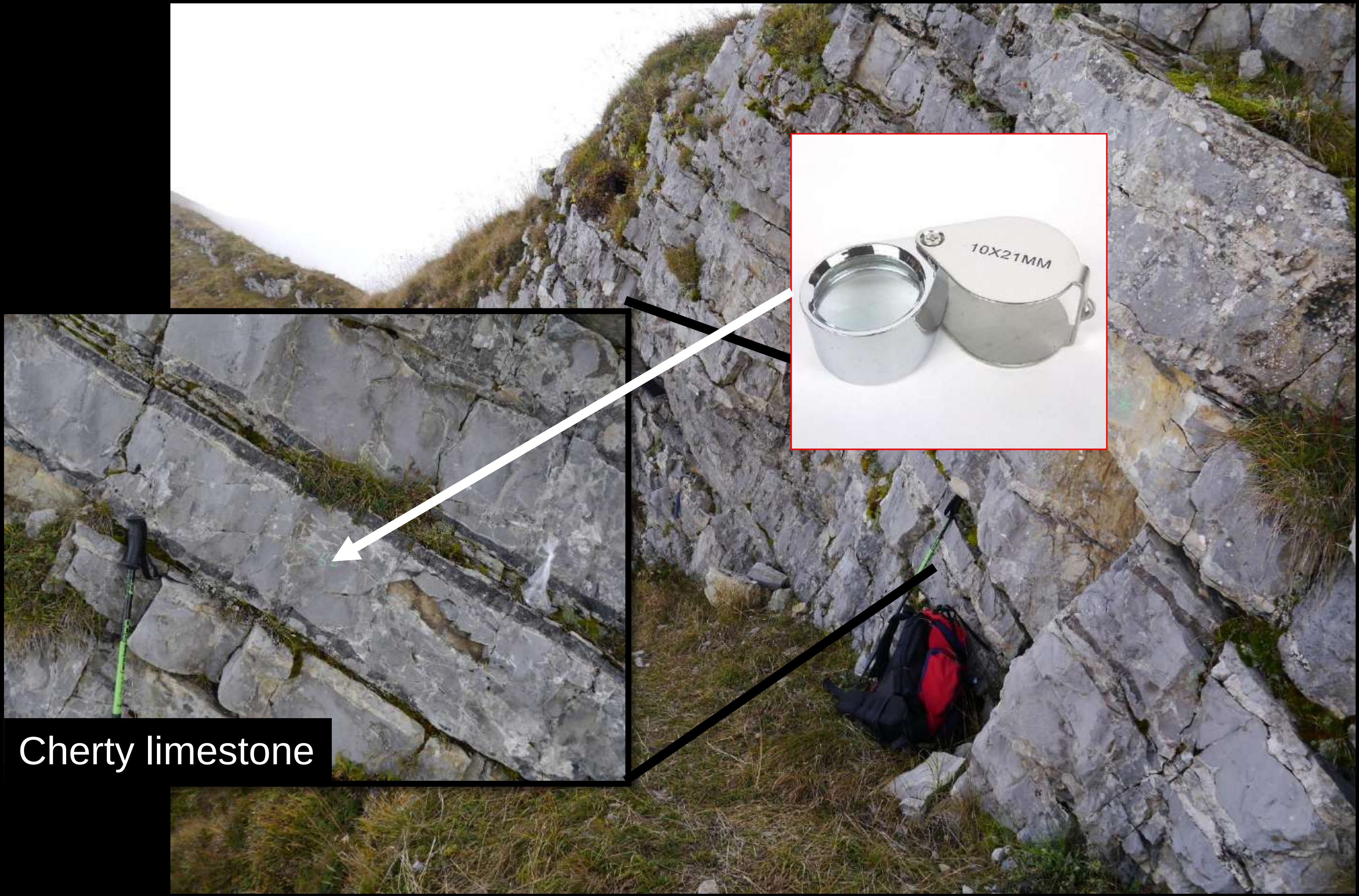
Carbonate rocks in outcrop

Observation are made at various scales

Carbonate rocks in outcrop

Observation are made at various scales

Carbonate rocks in outcrop

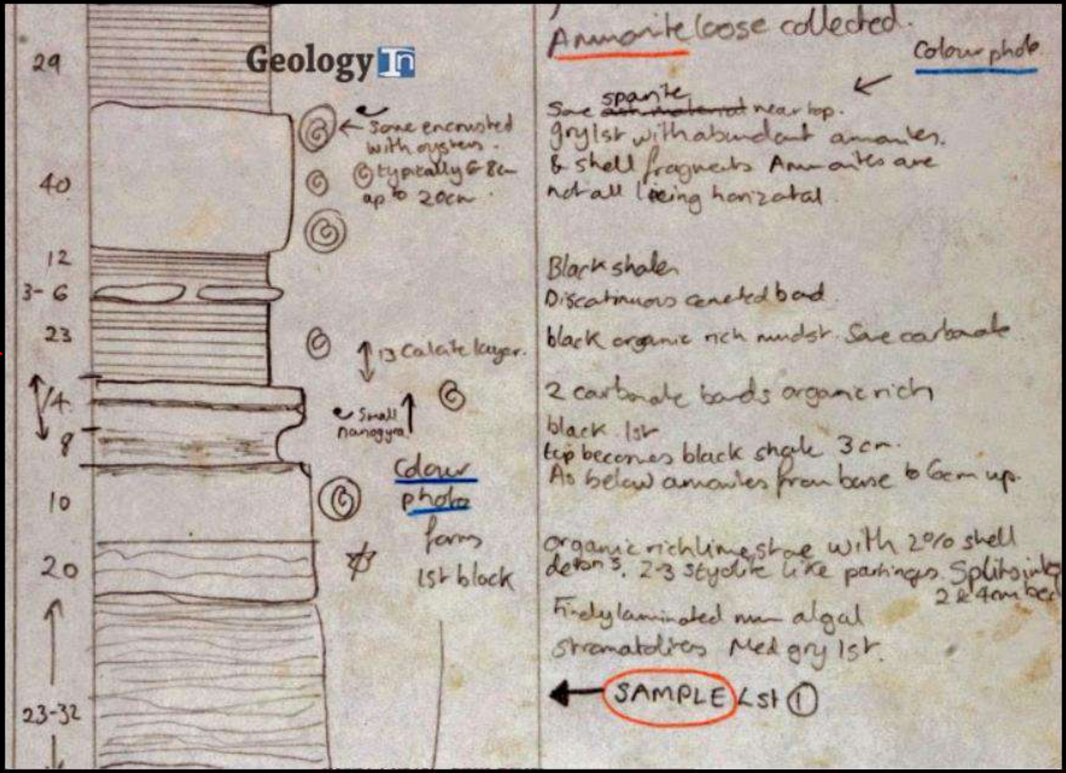


Observation are made at various scales

Carbonate rocks in outcrop

Write down oservations on your field notebook.
Write them **accurately** and **clearly** (You may go back to them after a long while. Do not trust your memory).
It is better to spend some more time taking accurate notes than have them incomplete or messy.

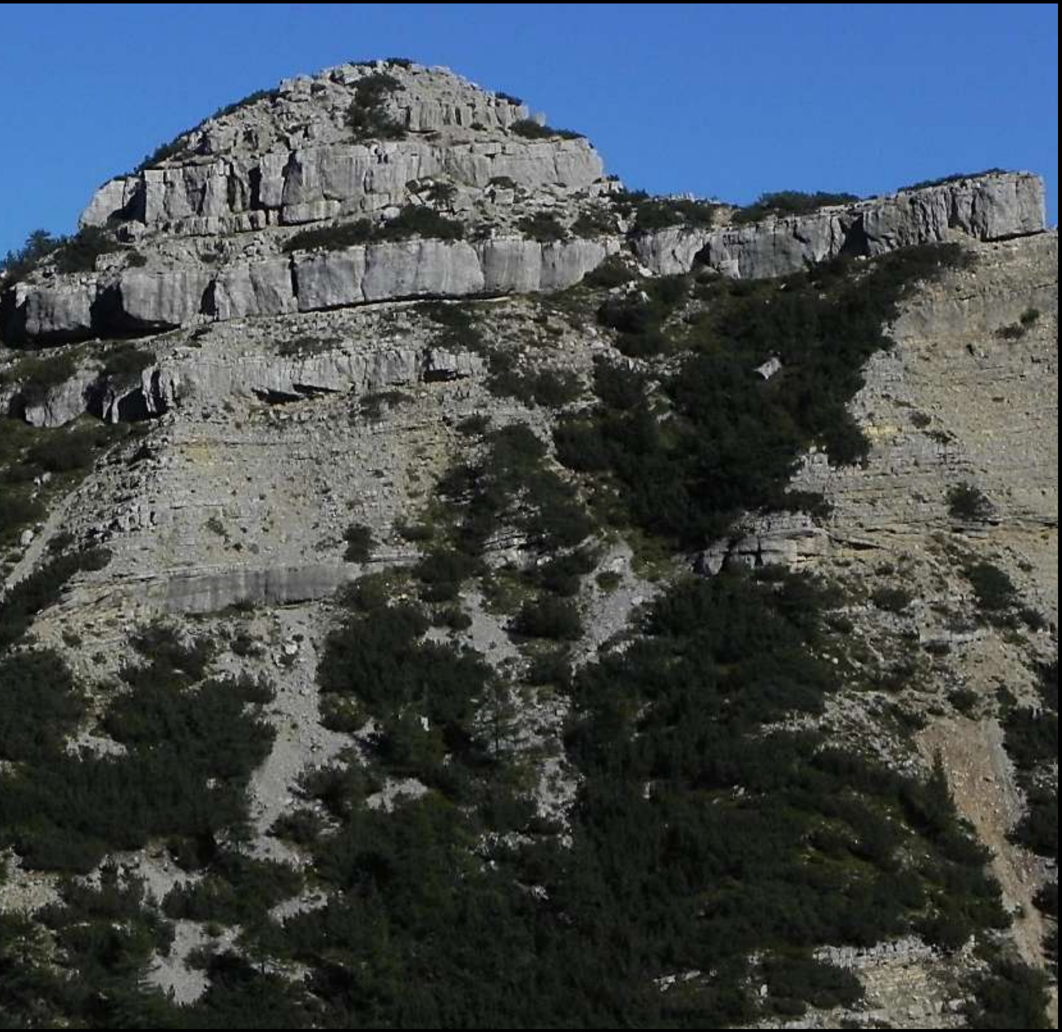
Graphic log

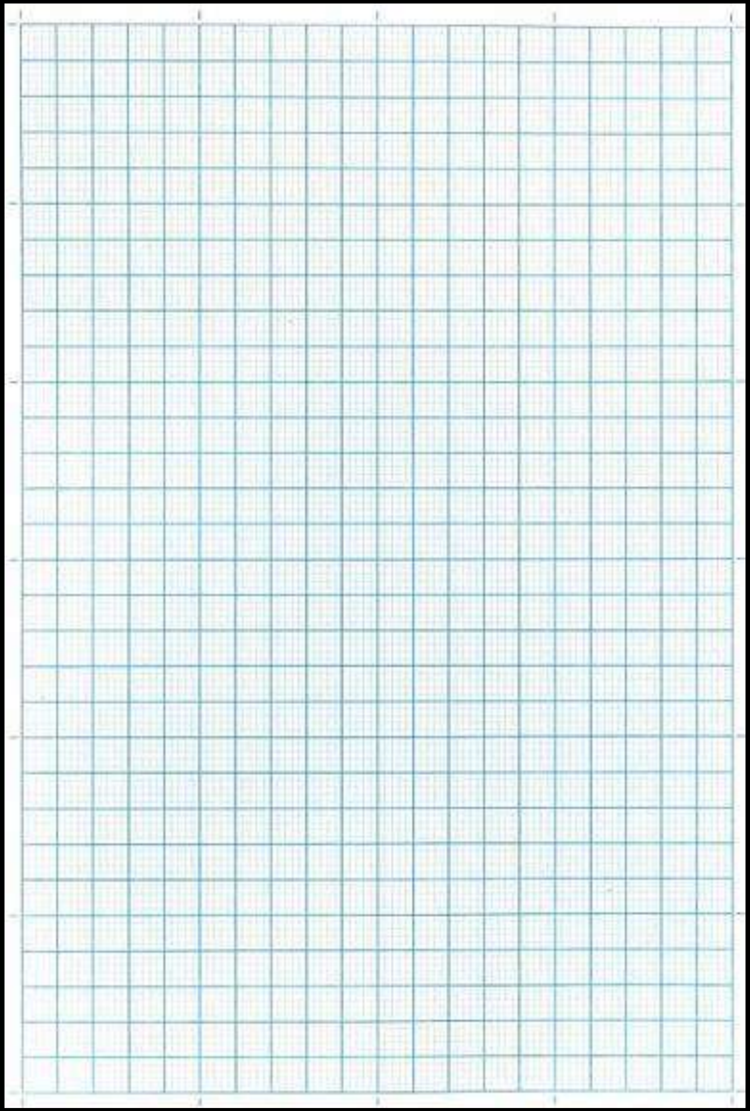


Example of field notebook page

Graphic log
a graphic log is the standard method for collecting field data of sedimentary rocks. There is no set format for a graphic log. Its main purpose is emphasizing the vertical changes in a succession of rocks.

A practical example…





Observing carbonate rocks with hand lens

Observing carbonate rocks with hand lens

This is how you **DO NOT** use the hand lens

Observing carbonate rocks with hand lens

This is how you **DO** use the hand lens

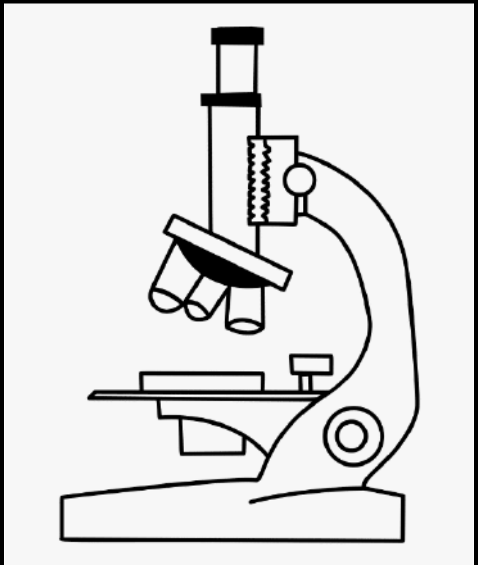
Observing carbonate rocks with hand lens

Lick* and look!

Carbonate rocks should be always observed on fresh cut and the obsrved surface should be wet before looking with the hand lens. This procedure enhances the visibility of the grains.

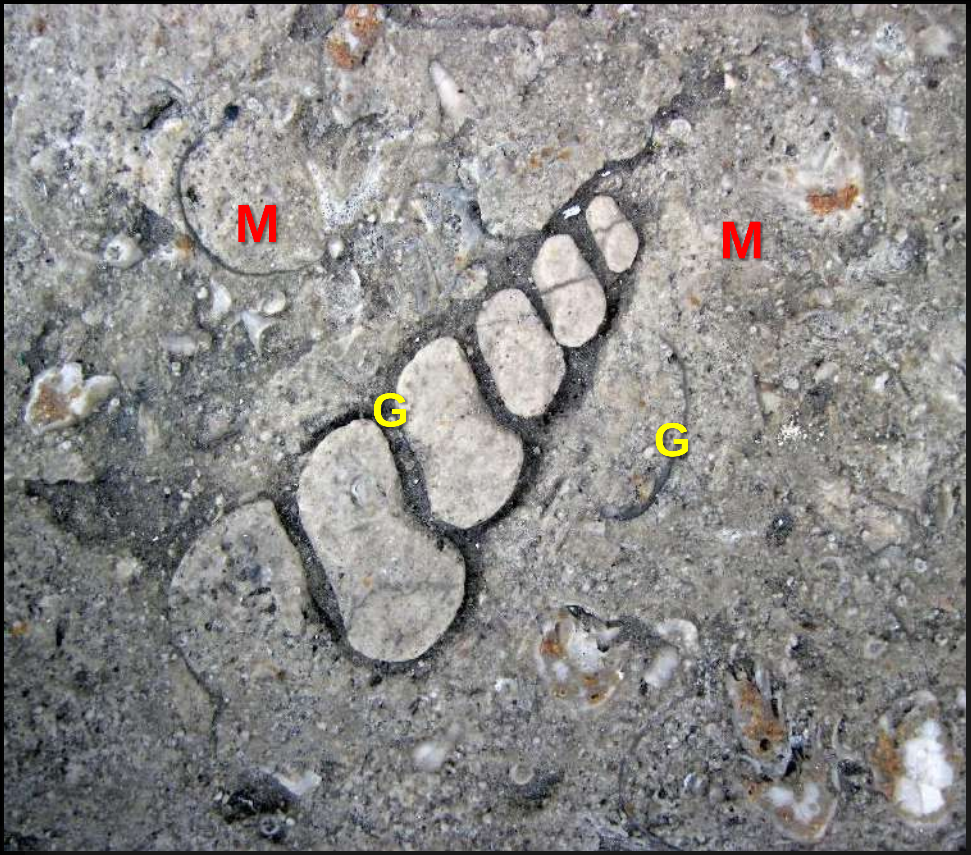
*) You do not necessarily have to lick the rock, you can also pour some water on it.

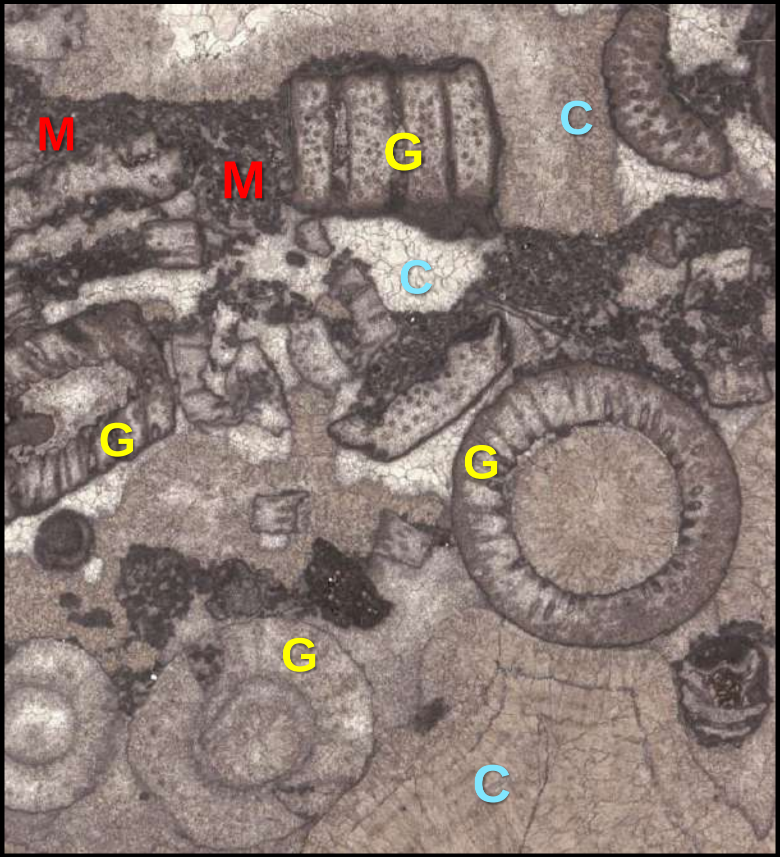
Observing carbonate rocks with optical microscope



Thin section of a carbonate rock

Main elements that can be observed in a carbonate rock





Grains (**G**) – all recognizable grains in the rock (e.g., fossils)

Matrix/Micrite (**M**) – fine grained carbonate particles up to few microns in size

Cement (**C**) – carbonate mineral filling what was originally open pores and voids

Observations of the nature and the proportion of elements that make a carbonate rocks allow defining their facies

- **Facies**:
  the observable characteristics of a rock

- **Microfacies**:
  the characteristics of a rock that can be observed at the optical microscope (thin sections, peels, polished surfaces).

“Field geology, including mapping and profiling, is a prerequisite for successful microfacies analysis”

Erik Flügel, 2004

“If you are a bad petrographer, you are a bad geologist”

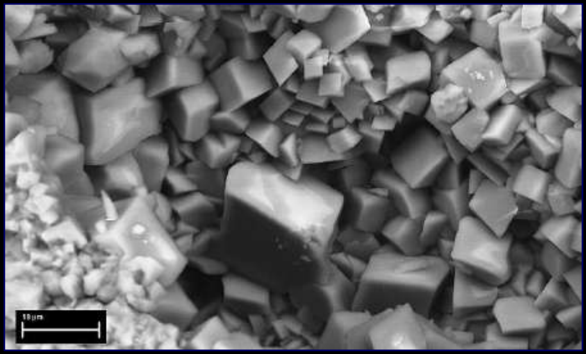
Hans Machel
Potsdam, 25th of March, 2010

Classifications for carbonate rocks

- **Rocks with allochems** are rocks made of mobile carbonate grains. Use:
  - → Dunham (1962)
  - → Folk (1959)

- **Boundstones** are rocks built by carbonate-secreting, in-situ sessile organisms. Use:
  - → Embry and Klovan (1971)
  - → Insalaco (1998)

- **Crystalline carbonate rocks** are either produced by replacement or precipitation: dolomites, speleothems, marbles...
  - → Randazzo and Zachos (1983)
  - → Friedman (1965)

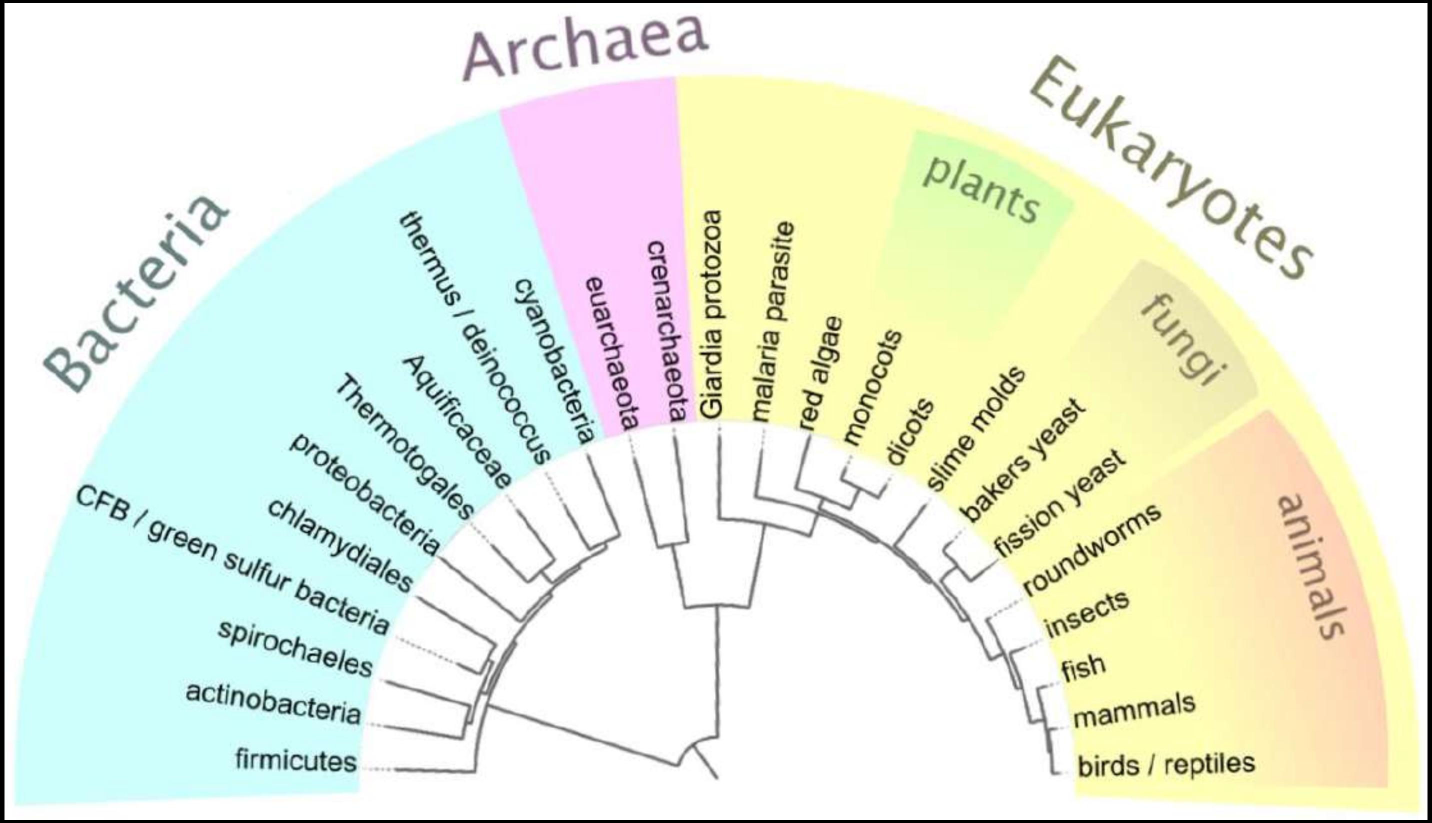


Skeletal grains

Skeletal grains are microfossils or microscopic fragments of fossils.

Thus, when determining the skeletal grains, we are browsing the tree of life... this means that there are many, many types of skeletal grains. It is beyond the scope of this module to provide a complete list.

We will mention some main types you may come across.



Echinoderms

Echinoderm spines in thin section

Payne Limestone, Carboniferous, USA

Some diagnostic features

Microscope:
plain extinction.
Echinoid spines may have doisy shape.

Hand sample:
A carbonate rock rich in echinoderm bioclasts can appear particularly shiny (be careful, however, because crystalline dolostone can be shiny as well).
It is often possible to see that clasts are broken along perfect cleavage (rhomboedral).

Significance:
Strictly stenohaline. They are consdiered indicators of normal marine water conditions

Dasycladacean algae

Dasycladacean algae in thin section

Latemar limestone, Triassic, Italy

Some diagnostic features

Microscope:
Each element of the stem is a ring, perforated by pores. Typical sections are round, elliptic or double square. Elements can be found in anatomical connection.

Hand sample:
In some instance dasycladacean algae can be seen with naked eye. They may appear like a stick of «polo» candies.

Significance:
They are typical of the euphotic zone

Bivalves

Thin shelled bivalves under microscope

Early Jurassic, Italy

Some diagnostic features

Microscope:
They can be large. Depending on the original mineralogy of the shell (aragonitic or calcitic) thay can be completely recristallyzed (and therefore the internal structure of the shell appers made of blocky calcite) or preserve their original structure. For instace, Inoceramids display prismatic shell structure. In some cases shells are bimineralic and shell fragments can display two layers.

Hand sample:
They are often well recognizable in section or by the ornamentation of the shells.
With the hand lens it is sometimes possible to see also thin shelled bivalves, that appear as thin curved eylashes.

Significance:
Thin shelled bivalves can be indicative of deep water environments. Aragonitic bivalves are generally found in shallow waters.

Gastropods

Gastropod in thin section

Columbus Limestone, Devonian, USA

Some diagnostic features

Microscope:
They can be large (several cm). The shell (originally aragonitic) is nearly always dissolved or replaced by mosaic calcite

Hand sample:
They are normally pretty easy to recognize because of their typical sections.
When in small fragments is almost impossible to distinguish a gastropod from a bivalve.

Significance:
Typically indicative of shallow water environments.

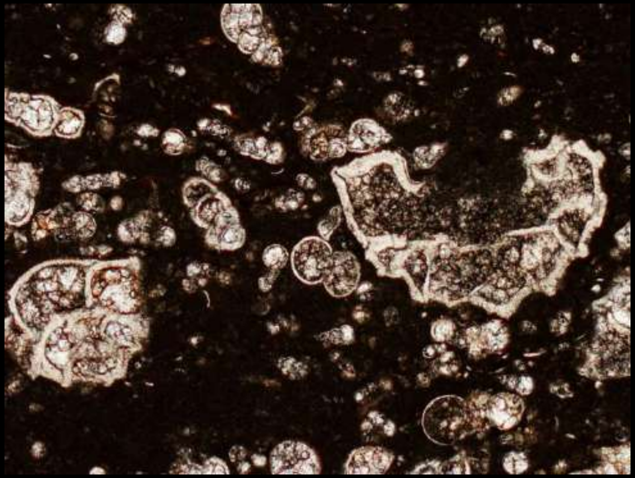
Foraminifera

There are many forms of foraminifera. Planktic foraminifera are generally of the size of few hundreds of microns, while benthic forms can be larger, up to several centimeters.

They identification is normally performed under microscope, in function of the structure of the shell and morphological features.
We will not discuss their identification here.

With some experience it is possible to identify many genera with the hand lens. They may appear as tiny «gastropod like» bioclasts

Foraminifera provide paleoenvironmental indications and, especially planktic foraminifera, are an inportant biostratigraphic tool. Planktic foraminifera, however, are common only since the Cretaceous.



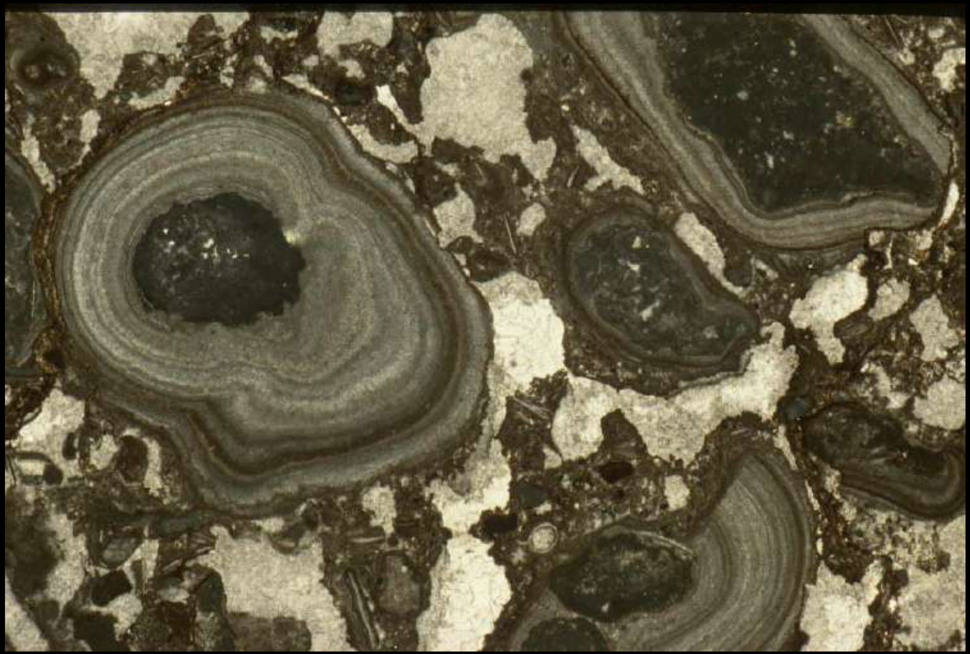
Planktic foraminifera

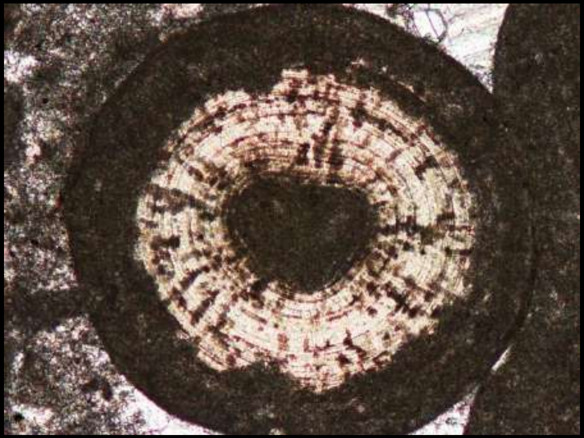
Porcelanous foraminifera

Agglutinated foraminifera

Hyaline foraminifera

Inorganic grains

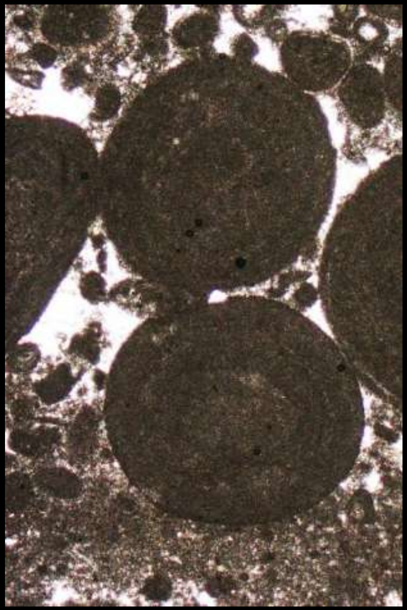




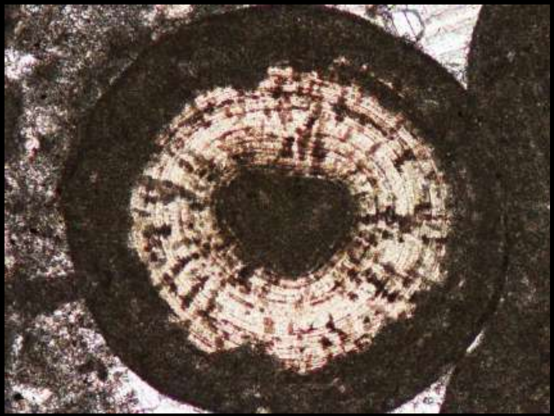
Ooids

Loppio oolitic Limestone,
Early Jurassic, Italy

tangential ooid



micritic ooid



radial ooid

Some diagnostic features

Microscope:
Ooids are recognized under the miscroscope because of their typical laminated concentric structure. Three main types of ultrastructures can be observed under the miscroscope: laminated, radial or micritic.

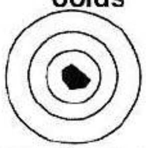
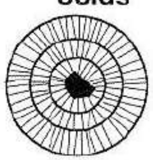
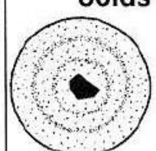
Hand sample:
Under hand lens they appear as sections of nearly perfect spheres. In some cases it is possible to distinguish the tangential or radial ultrastructure.

Significance:
They are indicative of high-energy shallow water marine environments.

Ooids

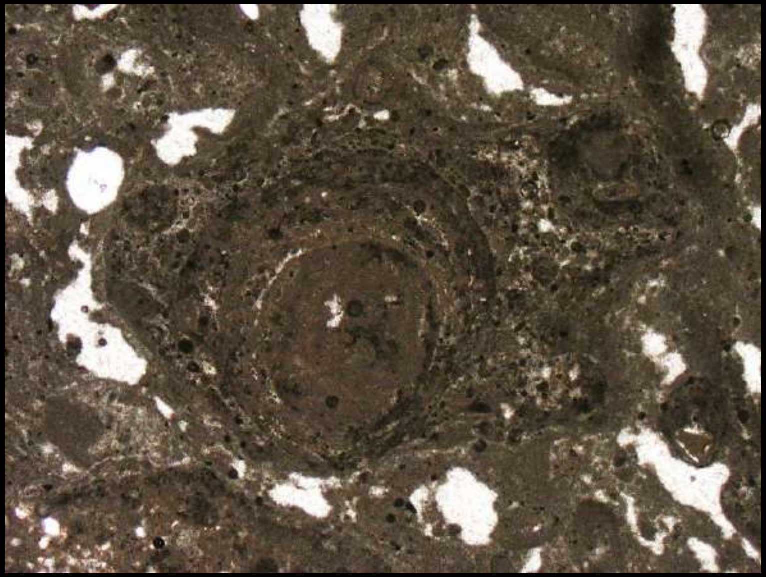
They have a nucleus and three main ultrastructures:

- Tangential ooids have crystals elongated parallel to laminae
- Radial ooids have crystals perpendicular to the laminae
- Micritic ooids are made of micrite (fine carbonate, < 4 μm)

	Microfabric of the cortex	Mineralogy, modern examples		Environment
Concentric (tangential) **ooids** 	Concentric laminae consisting of tangentially arranged crystals whose long axes are aligned to the surface of the laminae. High microporosity	Aragonite:	Bahamas, Yucatan, Abu Dhabi, Persian Gulf	Very shallow, warm low-latitudinal seas; *common in high-energy settings*
			(Great Salt Lake/Utah)	Lacustrine-hypersaline
		Low-Mg calcite: Caliche ooids*		Terrestrial
Radial (radial-fibrous) **ooids** 	Laminae consisting of radially arranged crystals; long crystal axes perpendicular to the laminae surface	Aragonite:	Persian Gulf, Great Barrier Reef, (Yucatan, Shark Bay, Mediterranean)	Shallow marine, *common in low-energy settings*
			Gulf of Aqaba	Sea-marginal hypersaline pool
			Great Salt Lake/Utah	Lacustrine-hypersaline
		Mg-calcite:	(Baffin Bay/Texas)	Marine-hypersaline
		Calcite and Low-Mg calcite:	e.g. Cave pearls*	Non-marine
Micritic (random) **ooids** 	Laminae composed of randomly arranged microcrystalline crystals or Laminae obliterated or absent, due to a pervasive micritization of the cortex	Aragonite:	Bahamas	Shallow-marine

Flügel, 2004

Oncoids



Oncoids in thin section

Latemar limestone, Triassic, Italy

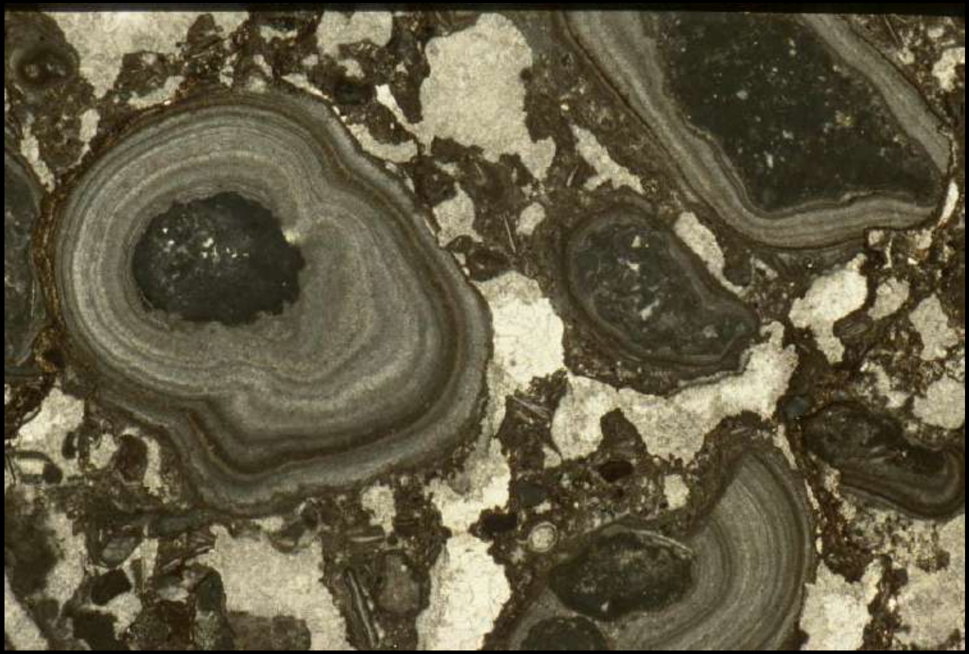
Some diagnostic features

Microscope:
They can be large (up to cm size). Coatings are made of micrite or microsparite and often enbed microfossils

Hand sample:
They can be visible by naked eye when they are quite large. The laminae are always irregular (in ooids are instead regular). The shape can be rather regular, but in most cases is irregular.

Significance:
They can be found in rocks anterior to the Cenozoic.

Pisoids



Marine pisoids, Latemar platform, Triassic

https://upload.wikimedia.org/wikipedia/commons/8/8b/Calcario2EZ.jpg

Some diagnostic features

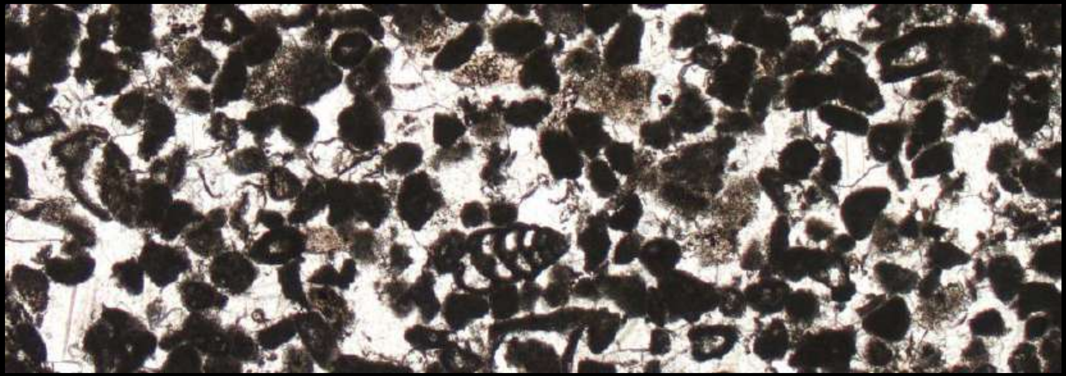
Microscope:
Smaller than oncoids. The coatings are crystalline, can be radial, but never tangetial. The shape is irregular.

Hand sample:
They can be regognized as irregularly clasts with rounded, but irregular shape, larger than ooids, but smaller than oncoidsSmaller

Significance:
Normally indicate low-energy restricted marine environments, but continental pisoids also exist (for instance in caves).

Peloids

Peloids in thin section



Peloids in thin section

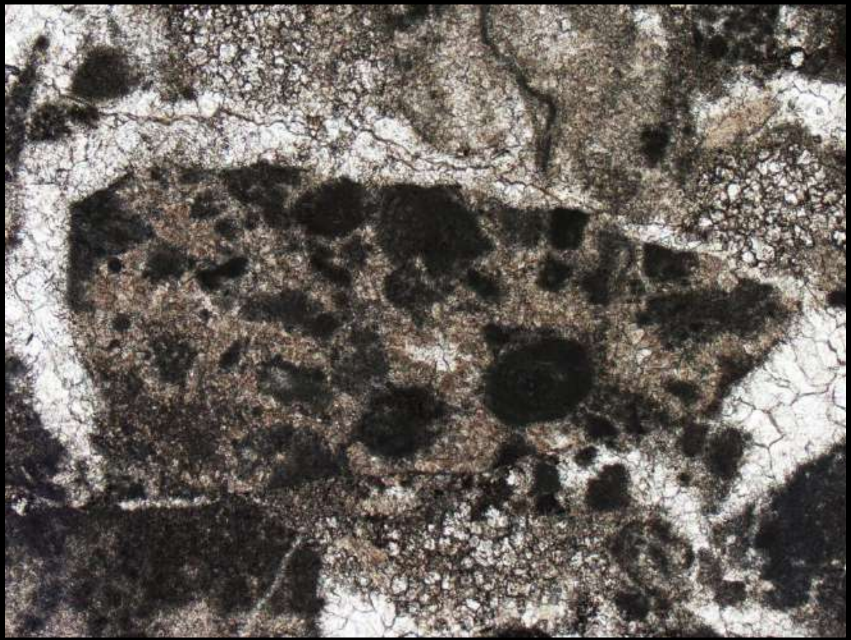
Some diagnostic features

Microscope:
Grains made of micrite (or microsparite) that cannot fit in the cathegories decribed above are normally classified as peloids

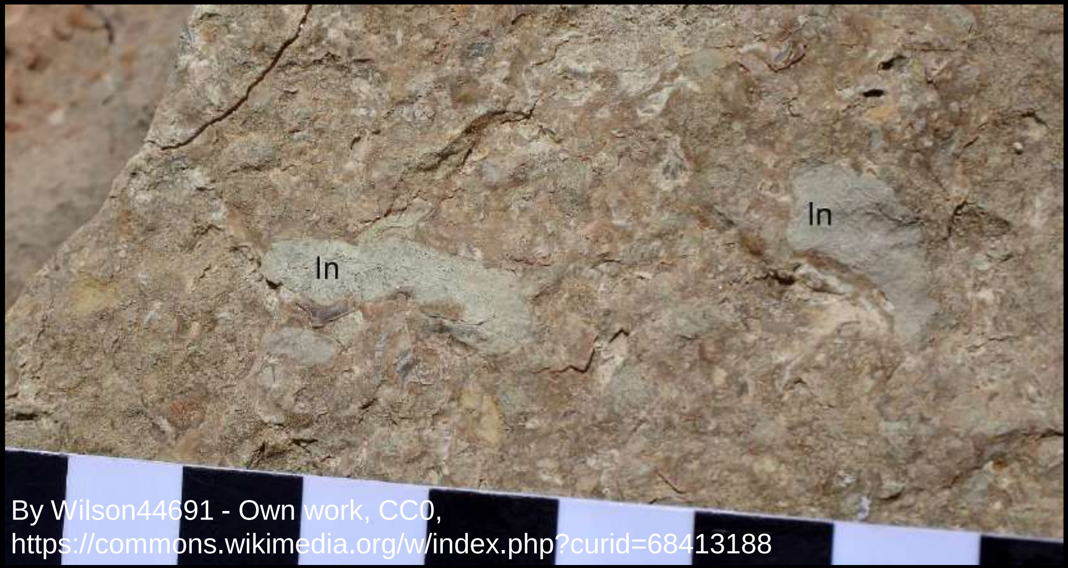
Hand sample:
Peloids canno be seen on hand samples

Significance:
None

Intraclasts



Intraclasts in thin section



Carmel Formation, Middle Jurassic, USA

Some diagnostic features

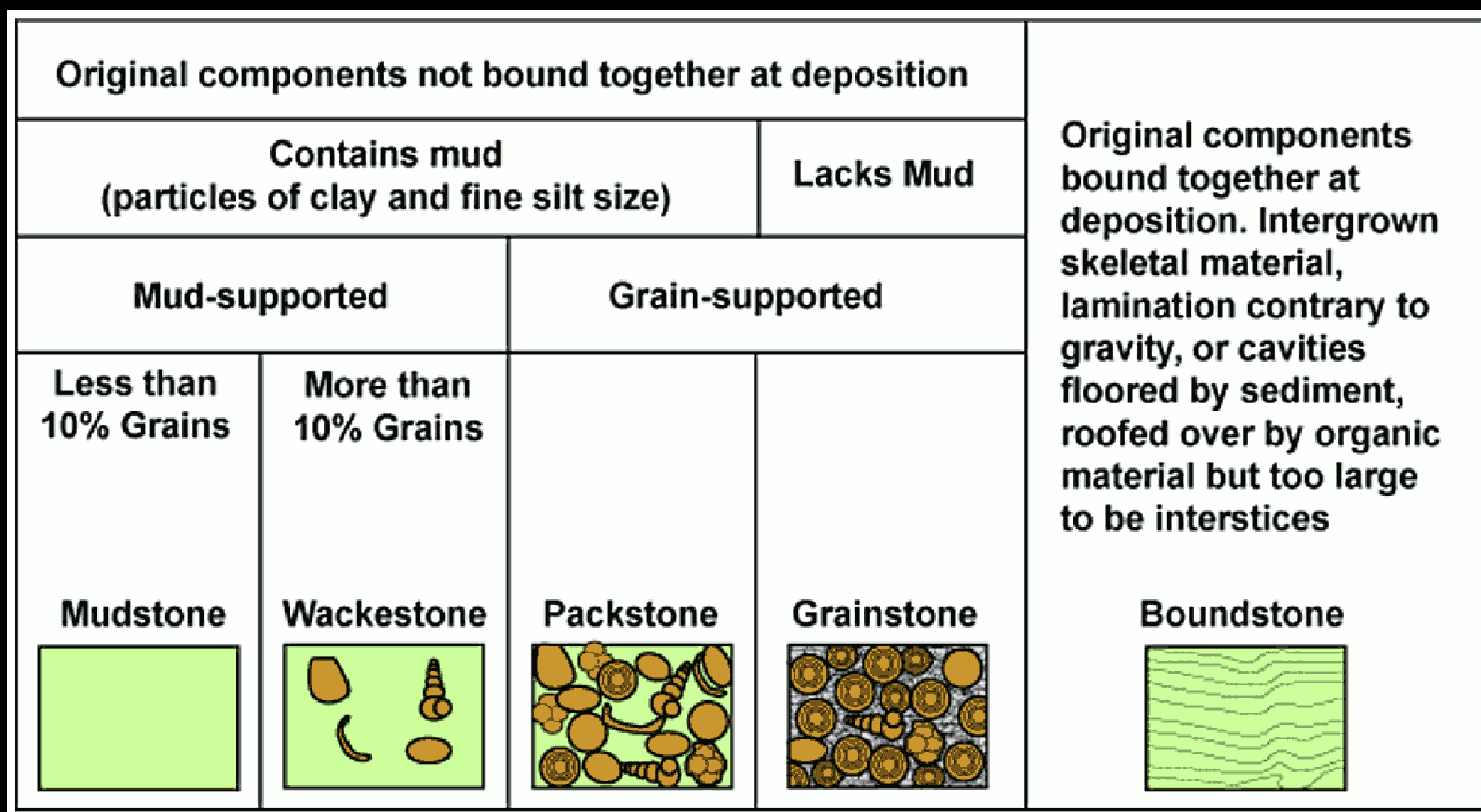
Intraclasts are early cemented carbonate aggregates or grains that are remobilized within the depositional system, so they were not transported much.
They may appear deformed, testifying for partial cementation at the time they were remobilized .

They are common in most shallow water sedimentary environments.

Dunham Classification

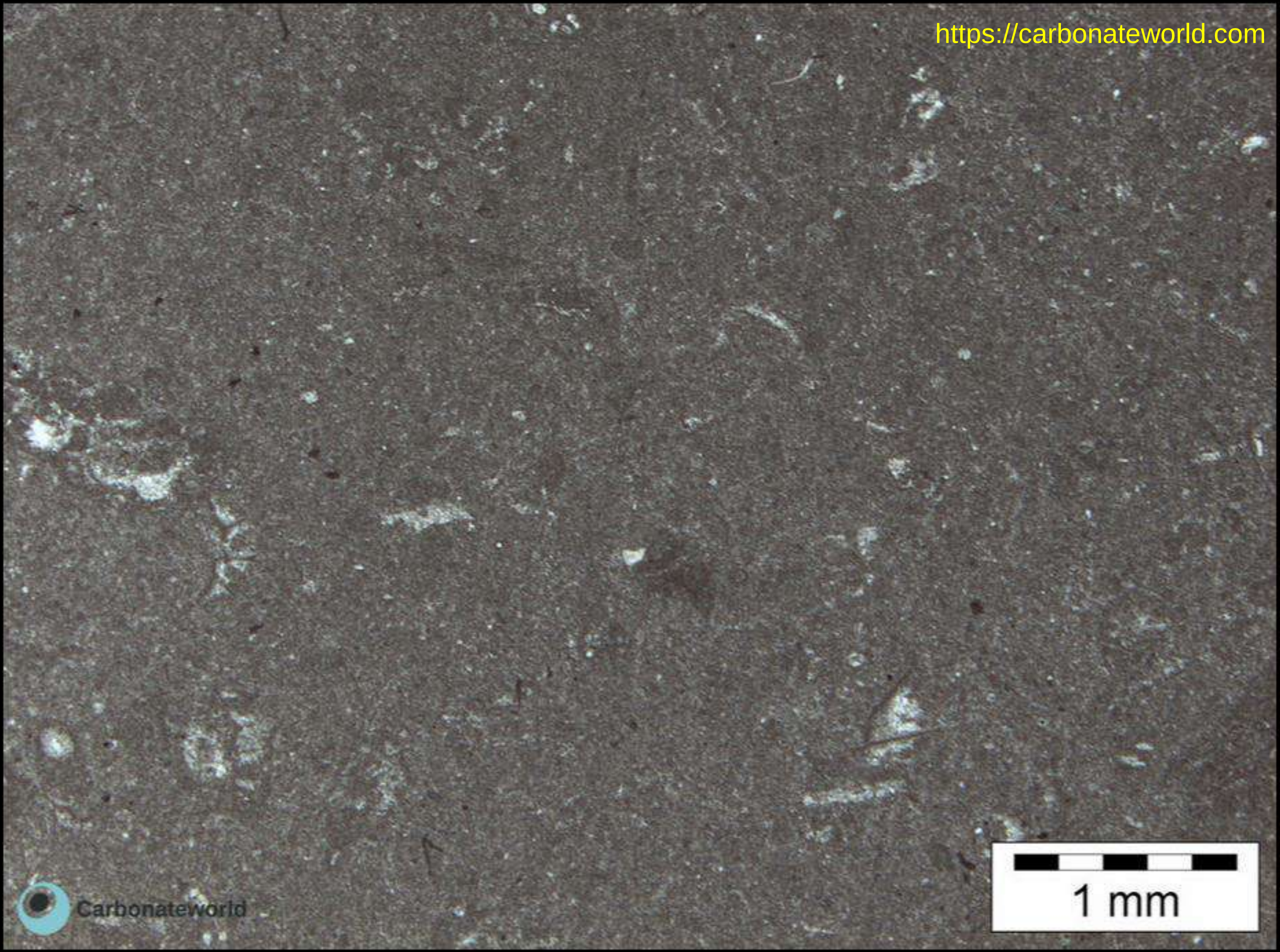
• **Rocks with allochems** are rocks with chemical grains (allochems) which are free to be transported and deposited by physical processes as waves and currents.

→ Dunham (1962)



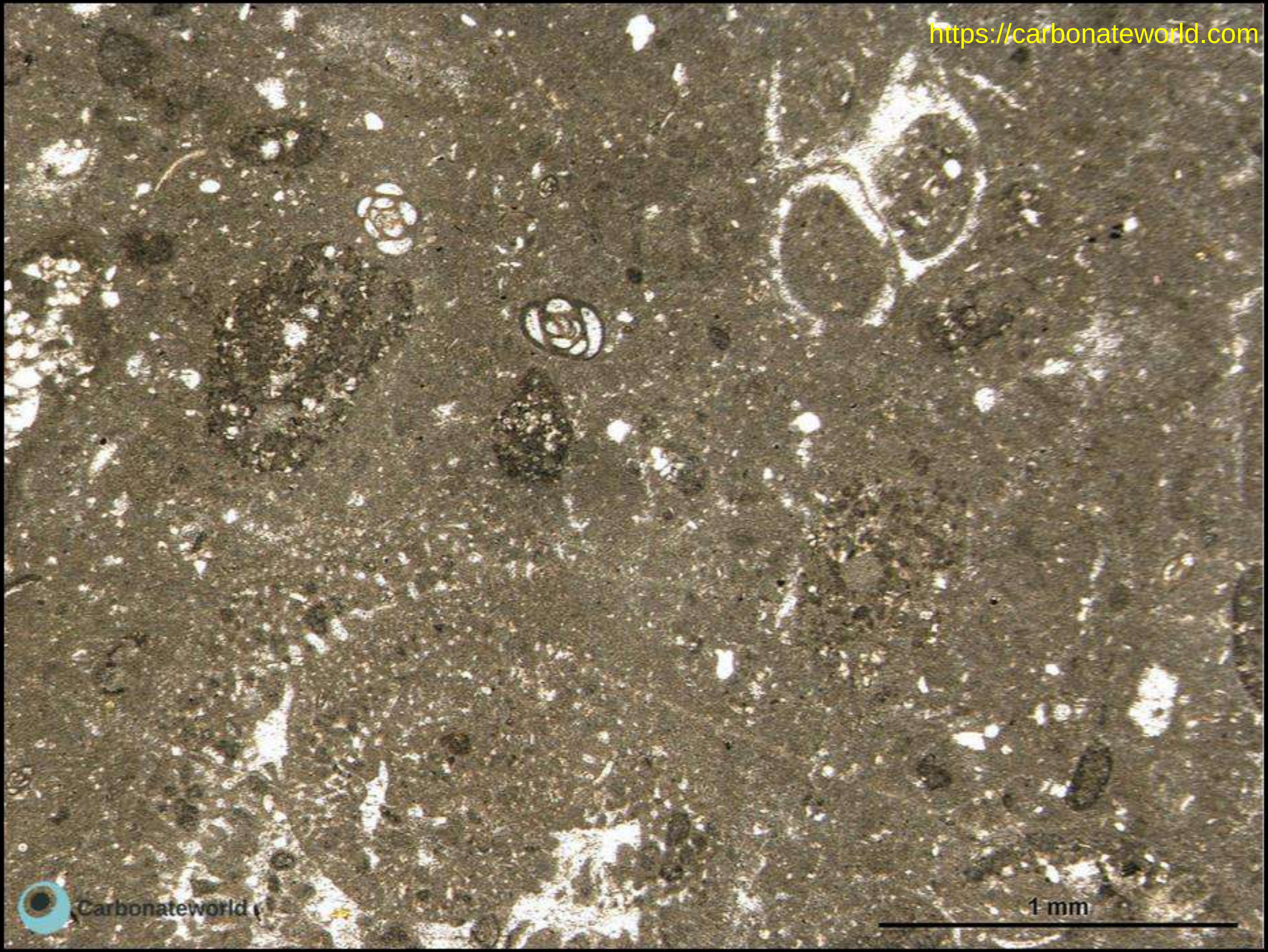
C. G. St. C. Kendall, 2005 (after Dunham, 1962, AAPG Memoir 1)

MUDSTONE



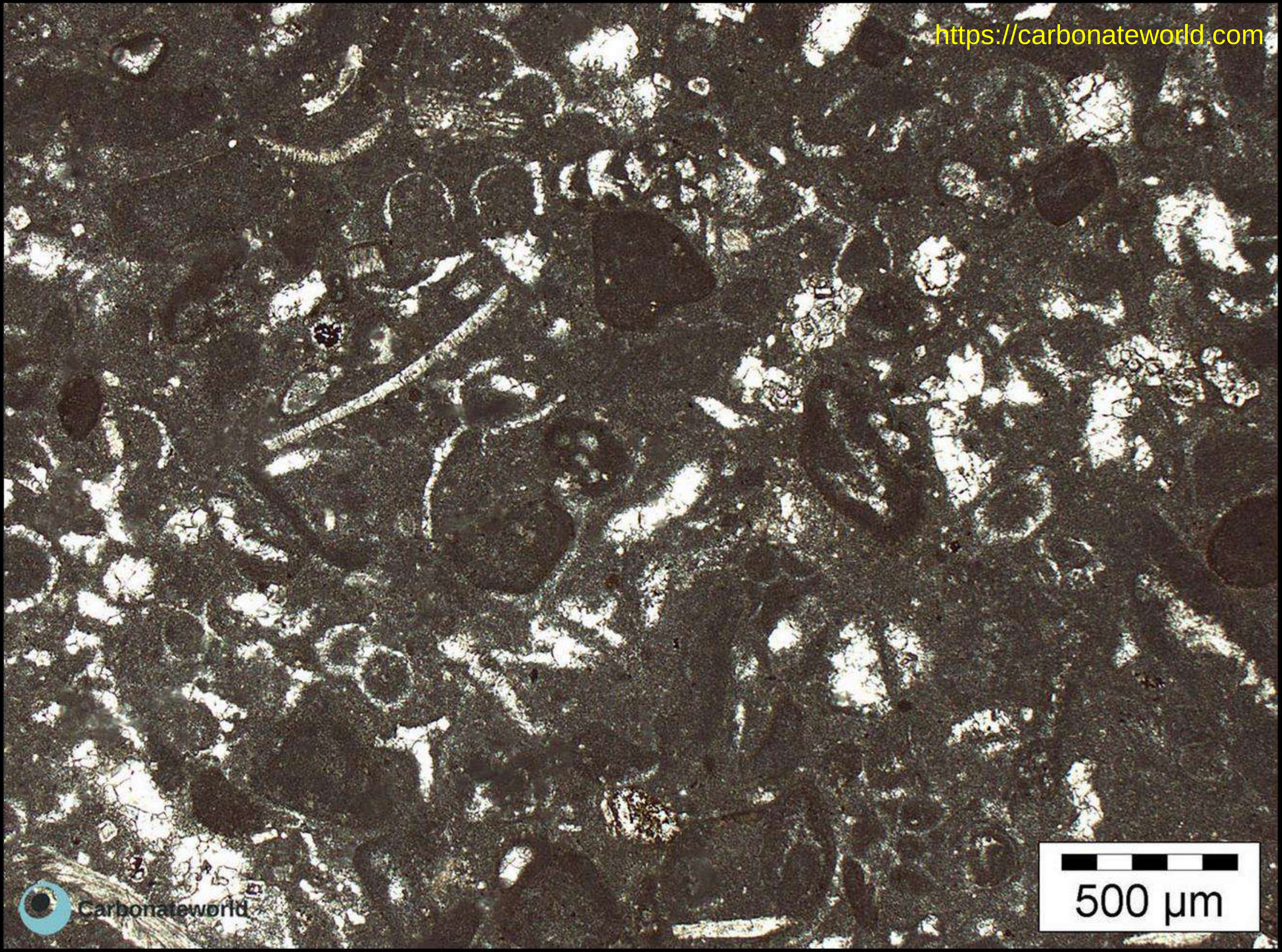
Micrite matrix-supported. Grains <10%

WAKESTONE



Matrix-supported (micrite or fine carbonate). Grains >10%

PACKSTONE



Grain-supported. Carbonate matrix between grains. Grains >10%

GRAINSTONE

Grain-supported. Cement in interparticle pore space

Take home messages for today

- The observation of carbonate rocks is done at various scales, ranging from the macro- (outcrop) to the micro- (thin section, SEM) scale
- The identification of the grain types and textural features of a carbonate rock allows their classification
- Several classifications of carbonate rocks exist, and we have focused on the Dunham classification
- There are many types of carbonate grains. The main cathegories are skeletal (bioclasts) and inorganic grains.
- The main classes of the Dunham classification are mudstone, wakestone, packstone and grainstone