IDC 203: INTRODUCTION TO EARTH SCIENCES

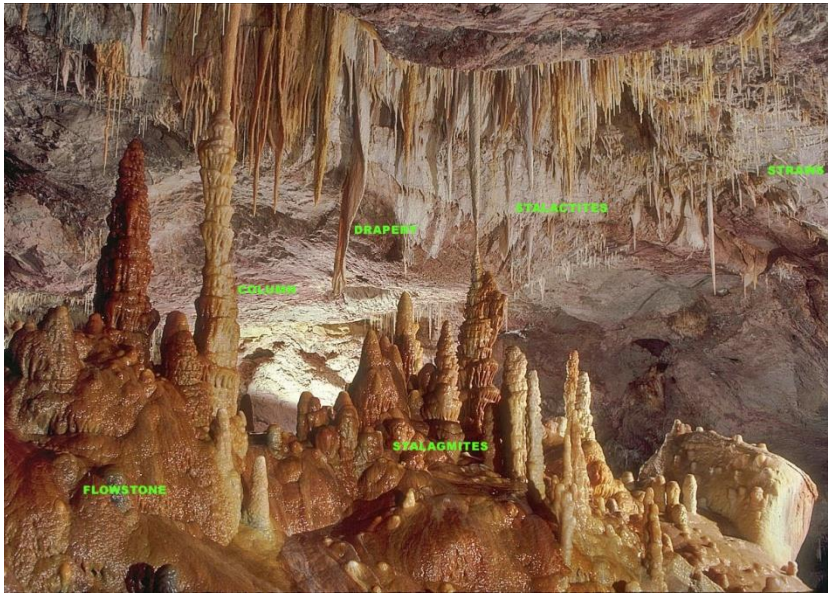


Table 2.4 Physical Properties of Minerals

Property	Relation to Composition and Crystal Structure
Hardness	Strong chemical bonds give high hardness. Covalently bonded minerals are generally harder than ionically bonded minerals.
Cleavage	Cleavage is poor if bond strength in crystal structure is high and is good if bond strength is low. Covalent bonds generally give poor or no cleavage; ionic bonds are weak and so give excellent cleavage.
Fracture	Type is related to distribution of bond strengths across irregular surfaces other than cleavage planes.
Luster	Tends to be glassy for ionically bonded crystals, more variable for covalently bonded crystals.
Color	Determined by kinds of atoms and trace impurities. Many ionically bonded crystals are colorless. Iron tends to color strongly.
Streak	Color of fine powder is more characteristic than that of massive mineral because of uniformly small size of grains.
Density	Depends on atomic weight of atoms and their closeness of packing in crystal structure. Iron minerals and metals have high density; covalently bonded minerals have more open packing and so have lower density.

Outline

- Rocks
- Igneous rock- types and forms
- Tectonic settings of Igneous rock formation
- Sedimentary rock formation

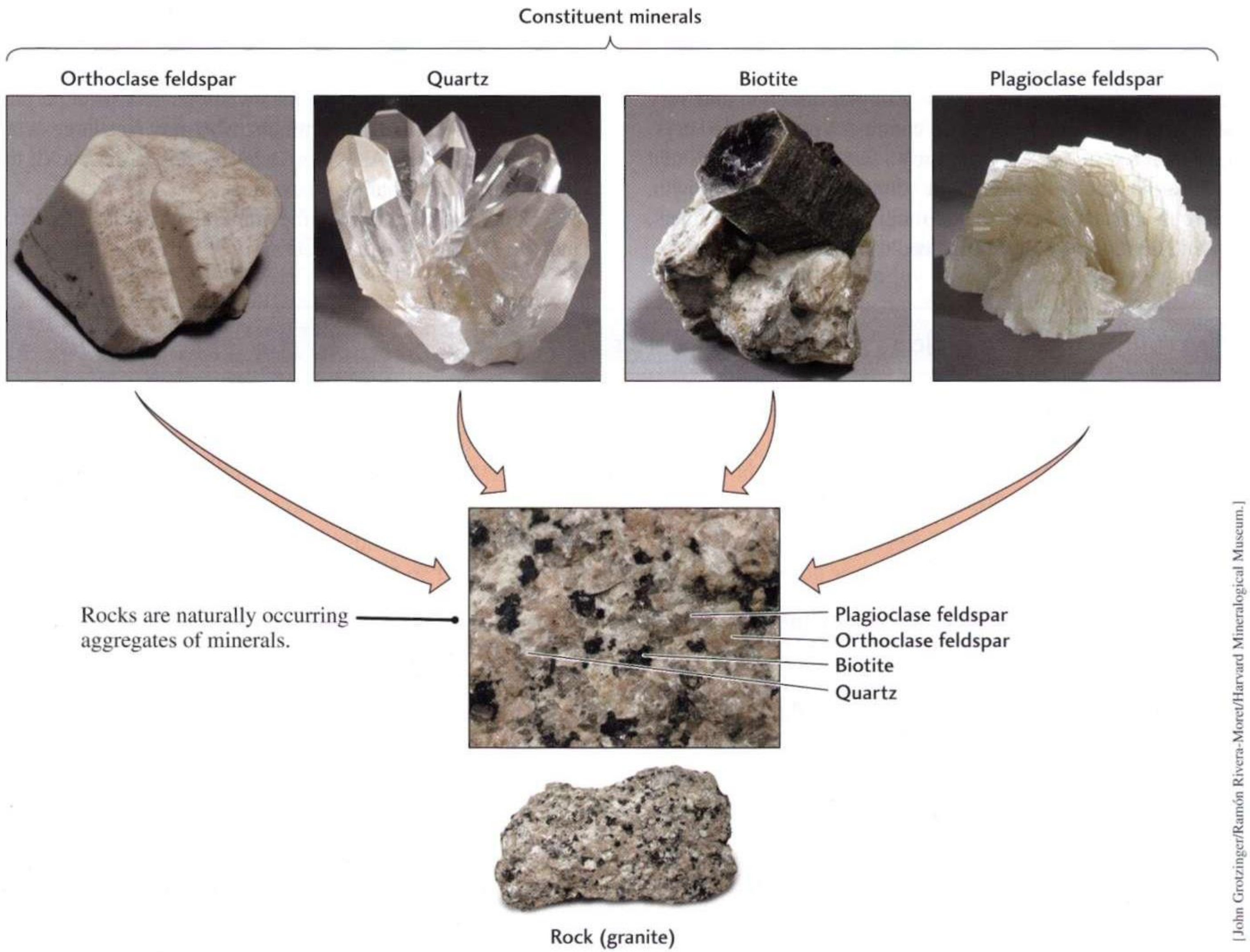
Rocks

- A naturally occurring consolidated mixture of minerals or mineral-like substances

- Rocks can be also made up of non mineral matter (e.g., obsidian and coal)

- The identity of rock is determined partly by its mineral and partly by its texture.

Rocks


Constituent minerals
Orthoclase feldspar
Quartz
Biotite
Plagioclase feldspar
Rocks are naturally occurring aggregates of minerals.
Plagioclase feldspar
Orthoclase feldspar
Biotite
Quartz
Rock (granite)
[John Grotzinger/Ramón Rivera-Moret/Harvard Mineralogical Museum.]

Texture

- Texture describes size and shapes of a rocks mineral crystals or grains.

- The grain large enough to be seen the rock is classified as coarse grained.
- The grain not large enough to be seen the rock is classified as fine grained.

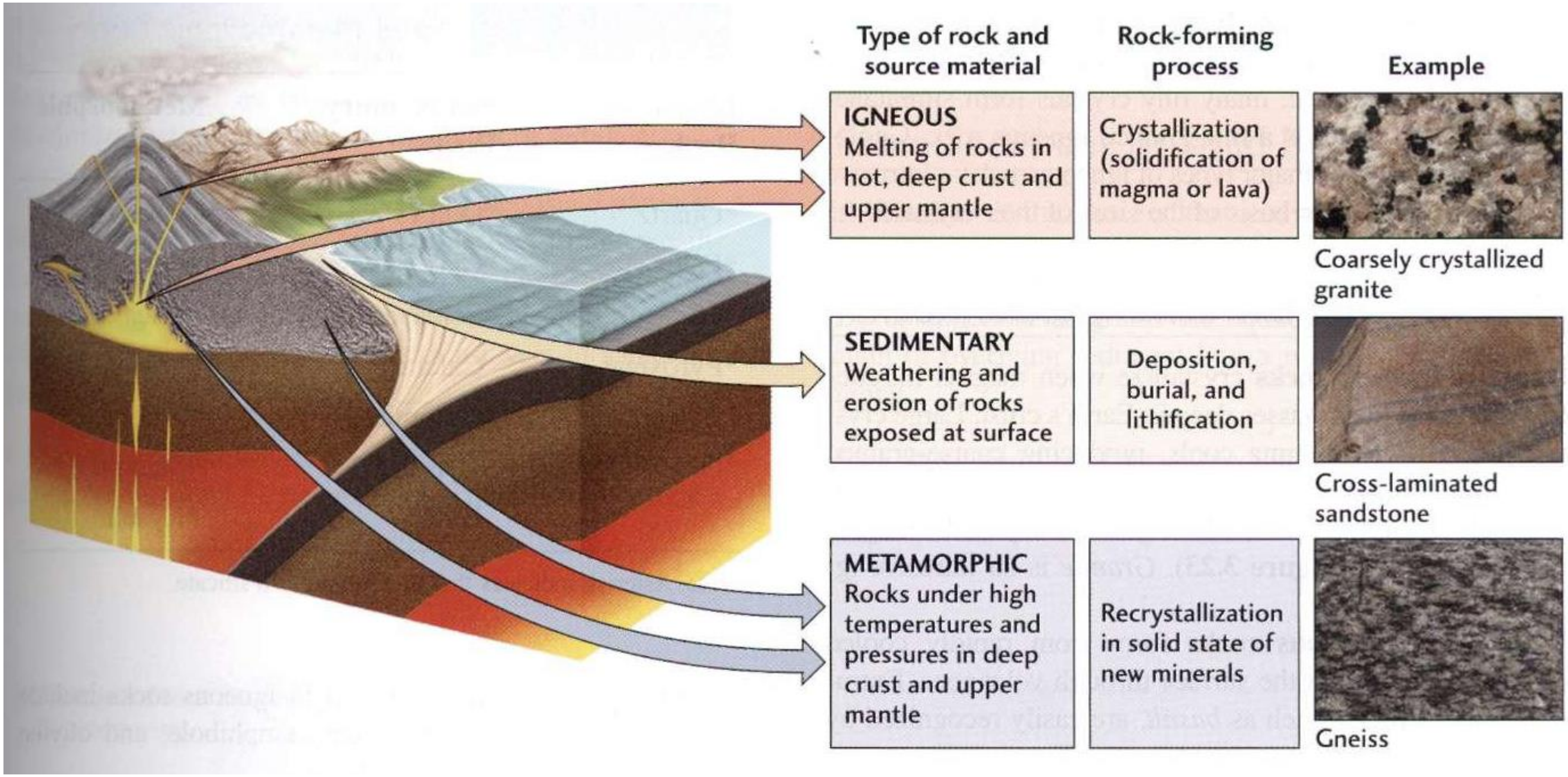
Rocks

- Rocks formed by solidification of molten rock are called igneous rock

- Weathering and erosion of rocks exposed at the surface – sedimentary rocks

- Rocks formed under high pressure and temperature in deep crust and upper mantle is metamorphic rocks

Rocks



Type of rock and source material
Rock-forming process
Example
IGNEOUS
Melting of rocks in hot, deep crust and upper mantle
Crystallization (solidification of magma or lava)
Coarsely crystallized granite
SEDIMENTARY
Weathering and erosion of rocks exposed at surface
Deposition, burial, and lithification
Cross-laminated sandstone
METAMORPHIC
Rocks under high temperatures and pressures in deep crust and upper mantle
Recrystallization in solid state of new minerals
Gneiss

Rocks

Table 3.5 Some Common Minerals of Igneous, Sedimentary, and Metamorphic Rocks

Igneous Rocks	Sedimentary Rocks	Metamorphic Rocks
*Quartz	*Quartz	*Quartz
*Feldspar	*Clay minerals	*Feldspar
*Mica	*Feldspar	*Mica
*Pyroxene	Calcite	*Garnet
*Amphibole	Dolomite	*Pyroxene
*Olivine	Gypsum	*Staurolite
	Halite	*Kyanite

Note: Asterisk indicates that the mineral is a silicate.

Igneous rocks

- **Formed from the cooling and consolidation of magma**
- **The first division of igneous rocks were made based on the evidences of texture**

Clues for early division of igneous rocks

-Volcanic rocks

-Laboratory studies of crystallization

-Granite as evidence of slow cooling

Texture of igneous rocks

- **Controlled by cooling rate**
- **Grain size**
- **Degree of crystallinity**
- **Vesicularity**

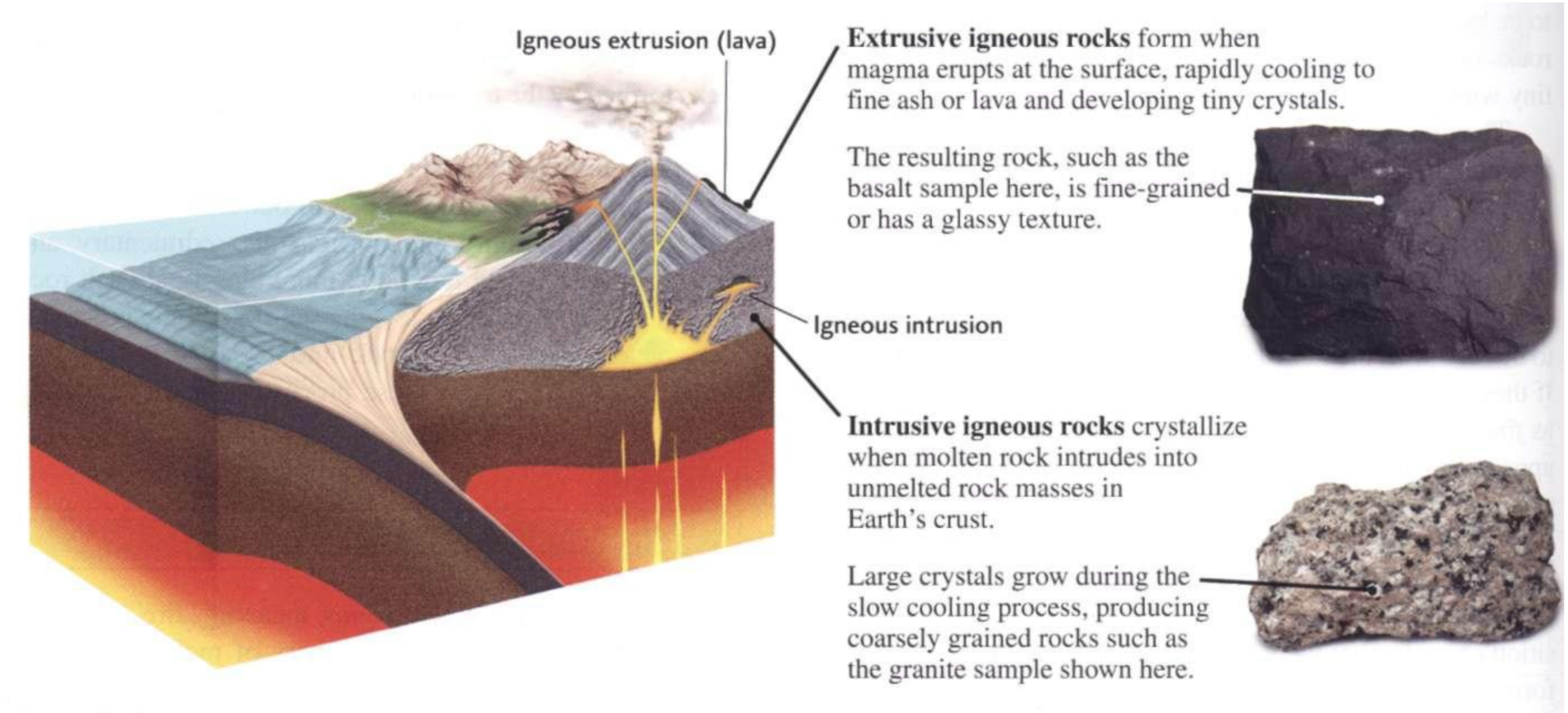
Classification of igneous rocks

Defined by texture:

Fine-grained: extrusive or volcanic

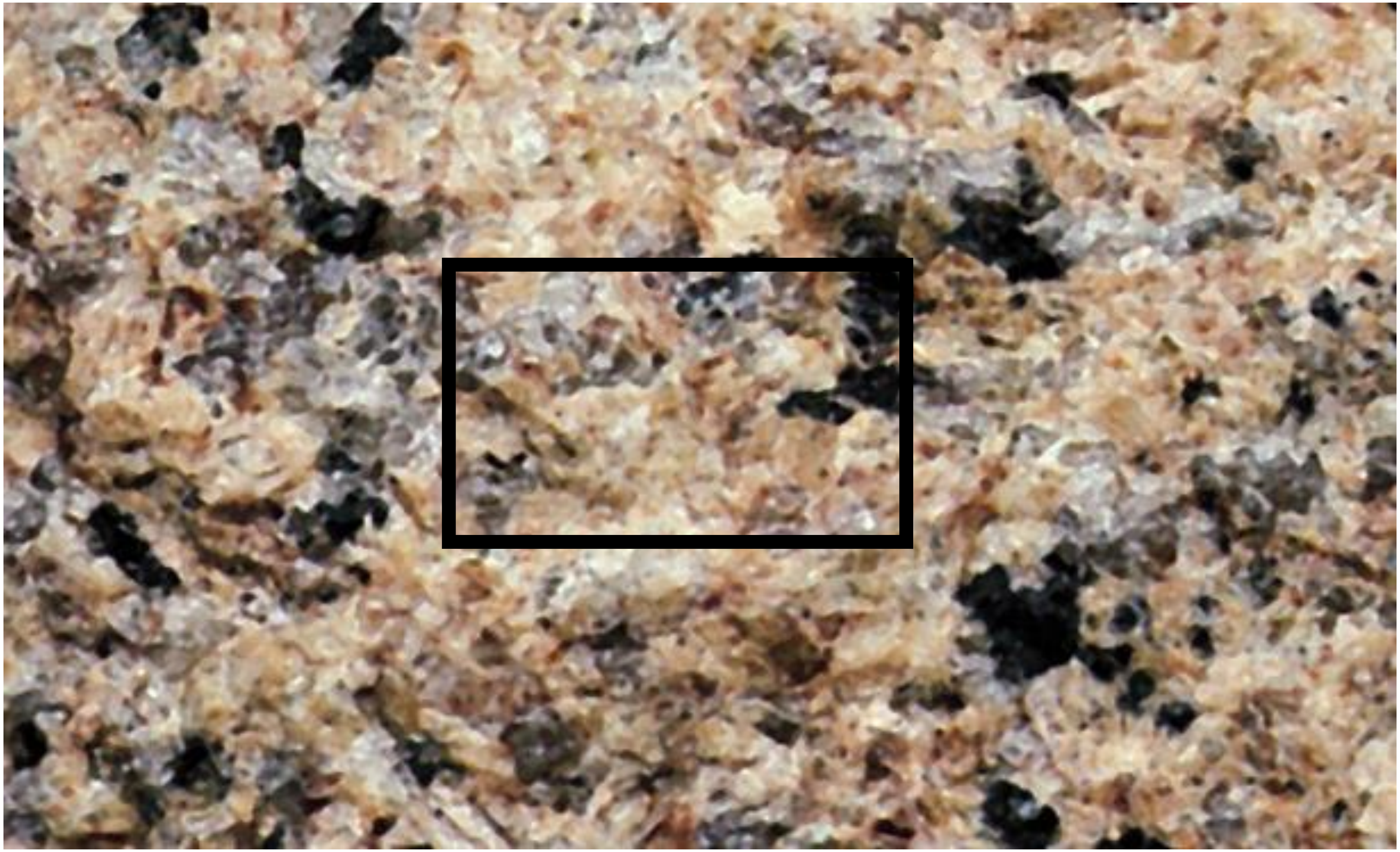
Coarse-grained: intrusive or plutonic

Igneous Rocks



- Plutonic (intrusive) — cooled below the surface
- volcanic (extrusive) — cooled on the surface

Coarsely crystalline granite



Photomicrograph of granite

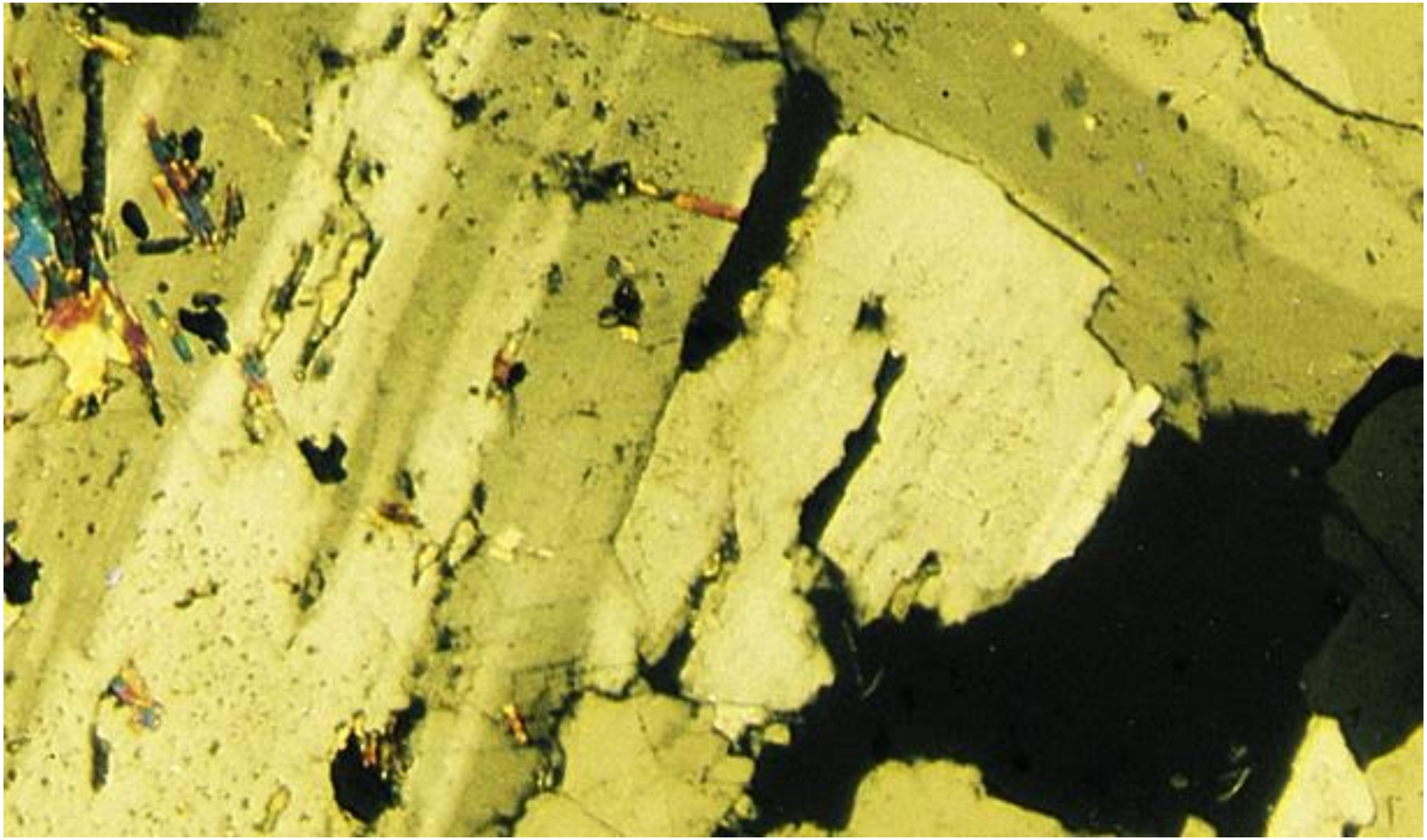


Fig. 4.1

Finely crystalline basalt

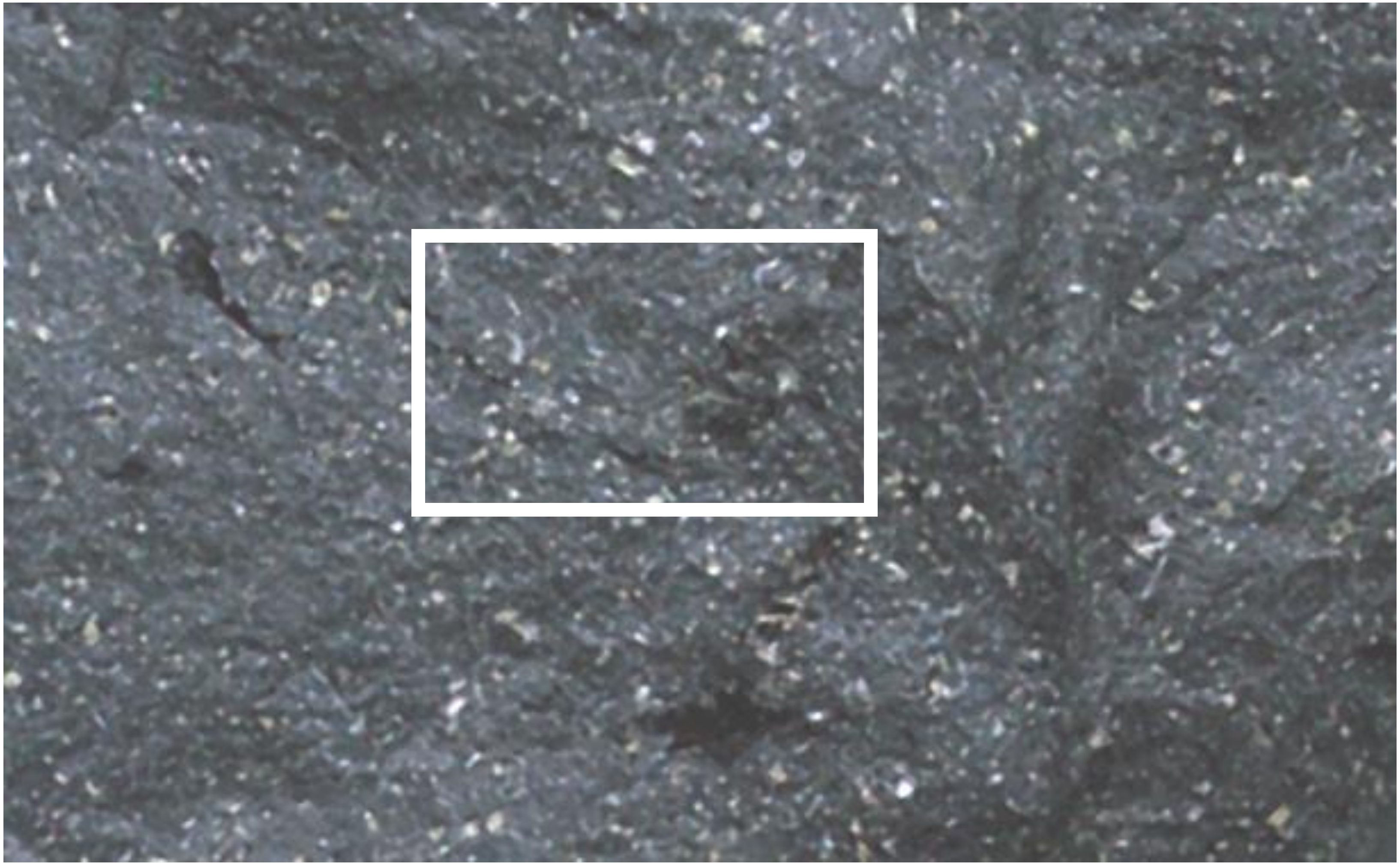


Fig. 4.1

Photomicrograph of basalt

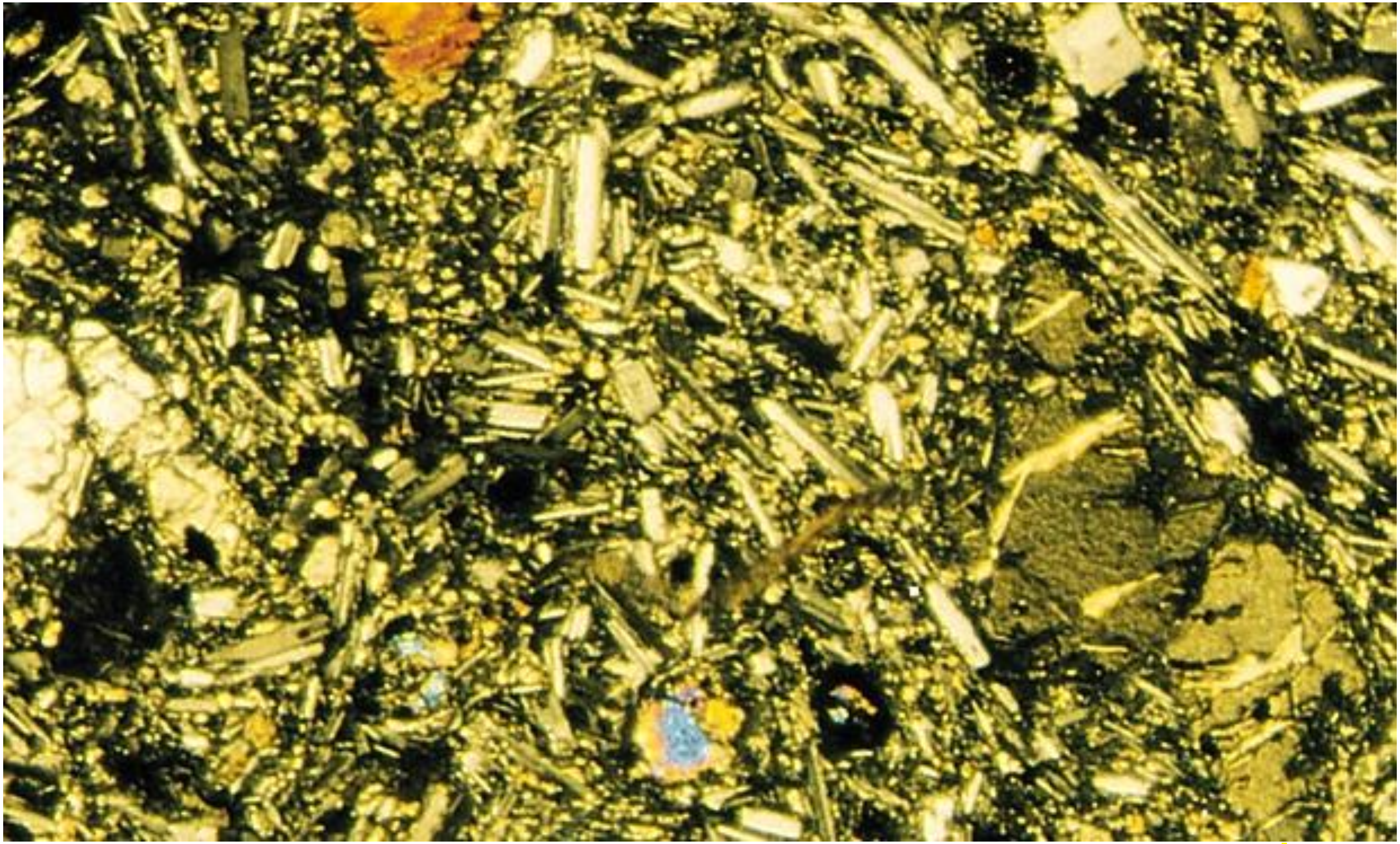


Fig. 4.1

Igneous Classification by texture

Extrusive	*Intrusive*
Basalt	**Gabbro**
Andesite	**Diorite**
Rhyolite	**Granite**

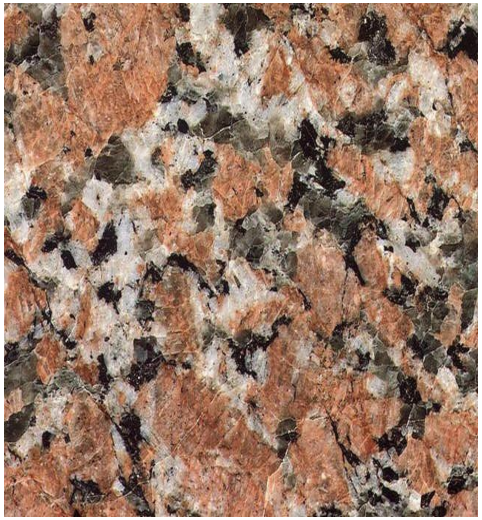
Extrusive Intrusive

Igneous textures

Glassy	**no minerals present**
Crystalline	**rocks made of mineral grains**
Porphyritic	**mixture of coarse and fine**
Vesicular	**with bubble holes**

Igneous textures

Glassy



Crystalline

Porphyritic

Vesicular

Classification of igneous rocks

- **Determined by composition (both chemical and mineralogical)**
- **Magnesium (Mg) + iron (Fe) = Mafic**
- **Feldspar + quartz (Si) = Felsic**

Classification of igneous rocks

Table 4.1 Common Minerals of Igneous Rocks

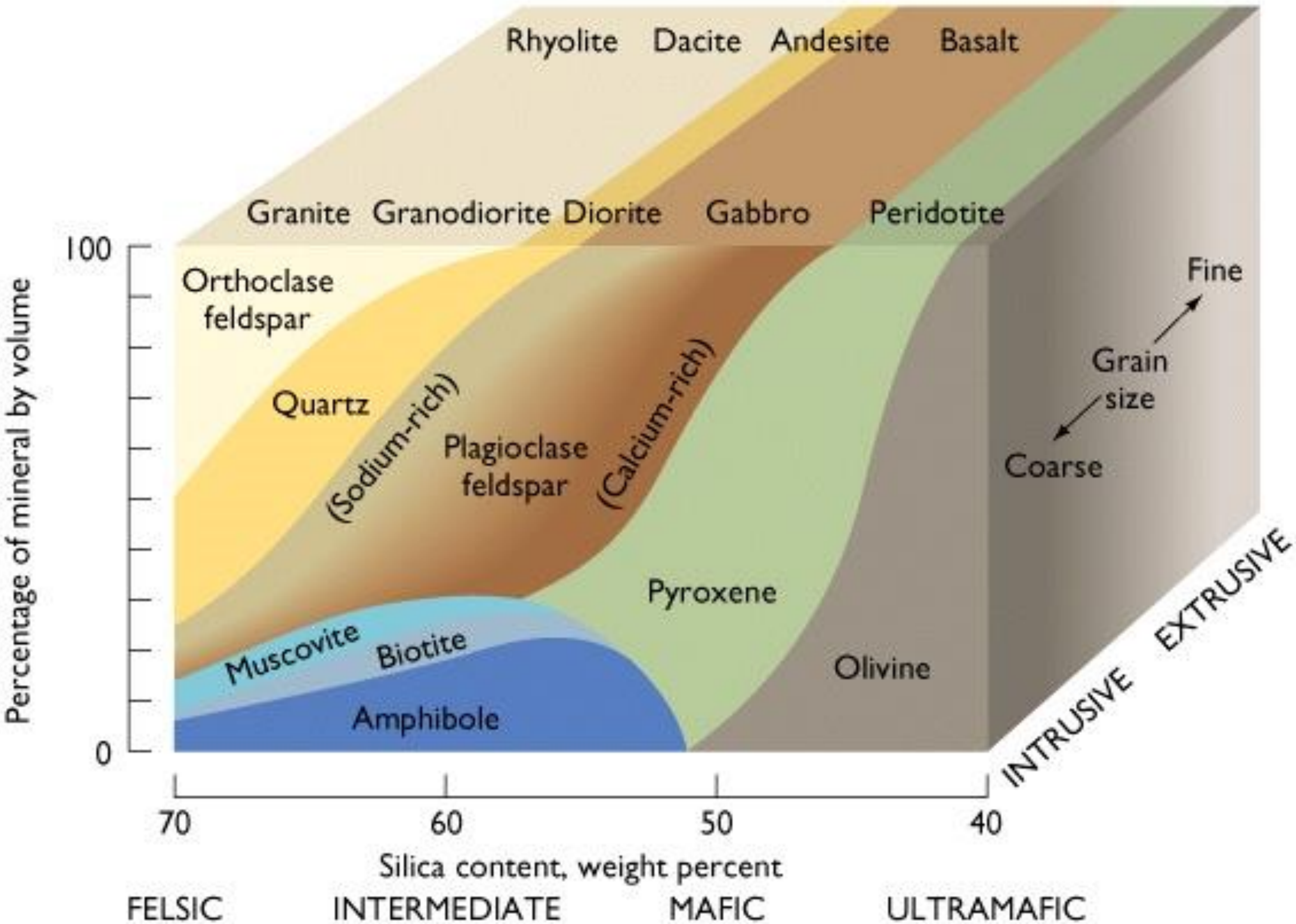
Compositional Group	Mineral	Chemical Composition	Silicate Structure
FELSIC	Quartz	SiO_2	Frameworks
	Potassium feldspar	$KAlSi_3O_8$	
	Plagioclase feldspar	$\begin{cases} NaAlSi_3O_8 \\ CaAl_2Si_2O_8 \end{cases}$	
	Muscovite (mica)	$KAl_3Si_3O_{10}(OH)_2$	Sheets
MAFIC	Biotite (mica)	$\left.\begin{matrix} K \\ Mg \\ Fe \\ Al \end{matrix}\right\} Si_3O_{10}(OH)_2$	
	Amphibole group	$\left.\begin{matrix} Mg \\ Fe \\ Ca \\ Na \end{matrix}\right\} Si_8O_{22}(OH)_2$	Double chains
	Pyroxene group	$\left.\begin{matrix} Mg \\ Fe \\ Ca \\ Al \end{matrix}\right\} SiO_3$	Single chains
	Olivine	$(Mg,Fe)_2SiO_4$	Isolated tetrahedra

Classification of igneous rocks

When we talk about the chemical composition of a rock we usually speak in terms of the oxides, *e.g.*,

	Typical basalt	Typical granite
SiO_2	50%	70%
Al_2O_3	15%	12%
FeO+MgO	15%	3%
CaO	8%	2%
K_2O+Na_2O	5%	8%

Classification of igneous rocks



Classification of igneous rocks

Table 4.2 Changes in Some Major Chemical Elements from Felsic to Mafic Rocks

	Felsic	Intermediate		Mafic
Coarse-Grained (intrusive)	Granite	Granodiorite	Diorite	Gabbro
Fine-Grained (extrusive)	Rhyolite	Dacite	Andesite	Basalt

← Silica increasing

← Sodium increasing

← Potassium increasing

Calcium increasing →

Magnesium increasing →

Iron increasing →

← (Viscosity increasing)

(Melting temperature increasing) →

How do rocks melt?

Partial melting : the fracture of rock that has melted at given temperature

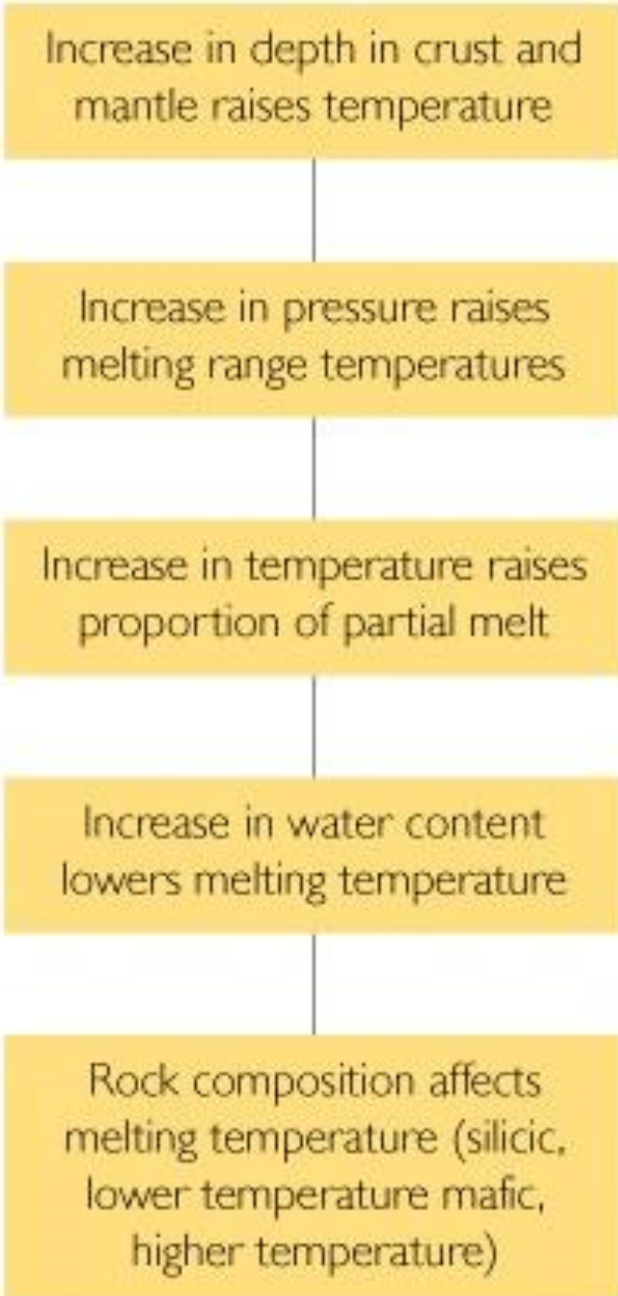
- **The temperature at the depth of crust and mantle**

- **Last minerals to form will melt at lowest temperature**

- **Biggest changes will be for small degrees of melting**

How do rocks melt?

- **The pressure due to overburden rocks also affect partial melting**
- **The melting temperature increases with high pressure**
- **Decompression melting: sudden decrease in pressure**



Factors affecting melting temperatures

The formation of magma chamber

- The large pools of molten rock form magma chamber
- The rise of magmas at rate from 0.3 m/year to almost 50 m/year

Magmatic differentiation

- The process by which rocks of varying chemical composition can arise from a uniform parent magma.

- This segregation happens in several way following a sequence described as **Bowen reaction series**

Fractional crystallization

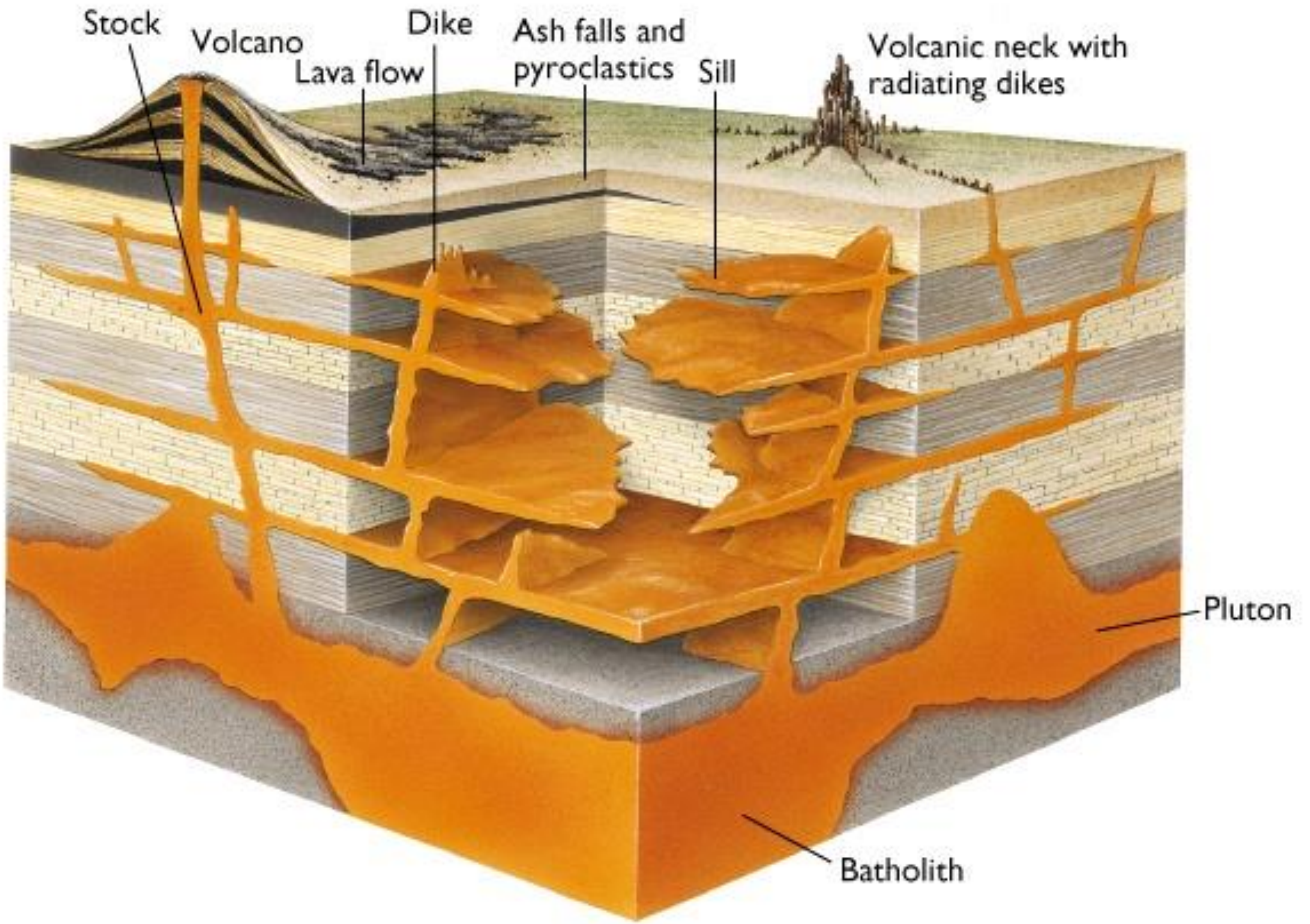
- The modification of magma by crystallization and removal of mineral phases.

- Because only certain elements will go into a given mineral, this will tend to change the composition of the remaining liquid.

Bowen’s reaction series

- **Series of chemical reactions that take place in silicate magmas as they cool**
- **First investigated in the 1920s and 1930s by N. L. Bowen**
- **Important experiments that help us understand the evolution of magmas**

Types of igneous structures



Forms of intrusive igneous masses

Plutons: large igneous bodies formed in deep earth crust

Plutons can be divided into two groups:

1) Concordant

2) Discordant

Forms of intrusive igneous masses

Concordant:

Sills

Discordant:

Dikes

Batholiths

Forms of intrusive igneous masses

***Batholith*: Any deep-seated pluton of coarse-grained rocks that has a surface exposure of over 100 sq. km that is mostly granitic. Examples include Sierra Nevada, Coast Range, Idaho batholiths.**

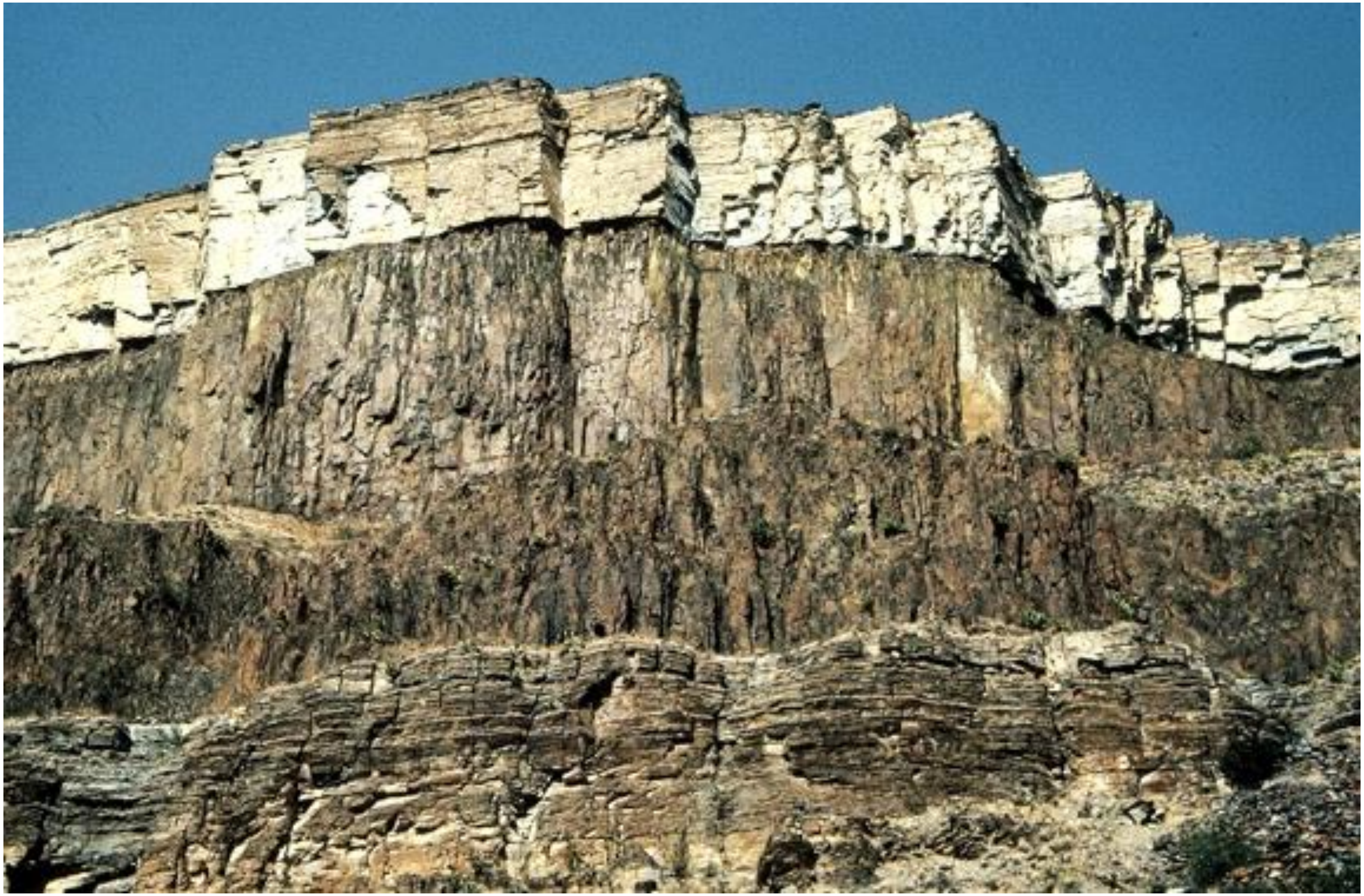
***Stock*: Same as a batholith, only smaller**

Forms of intrusive igneous masses

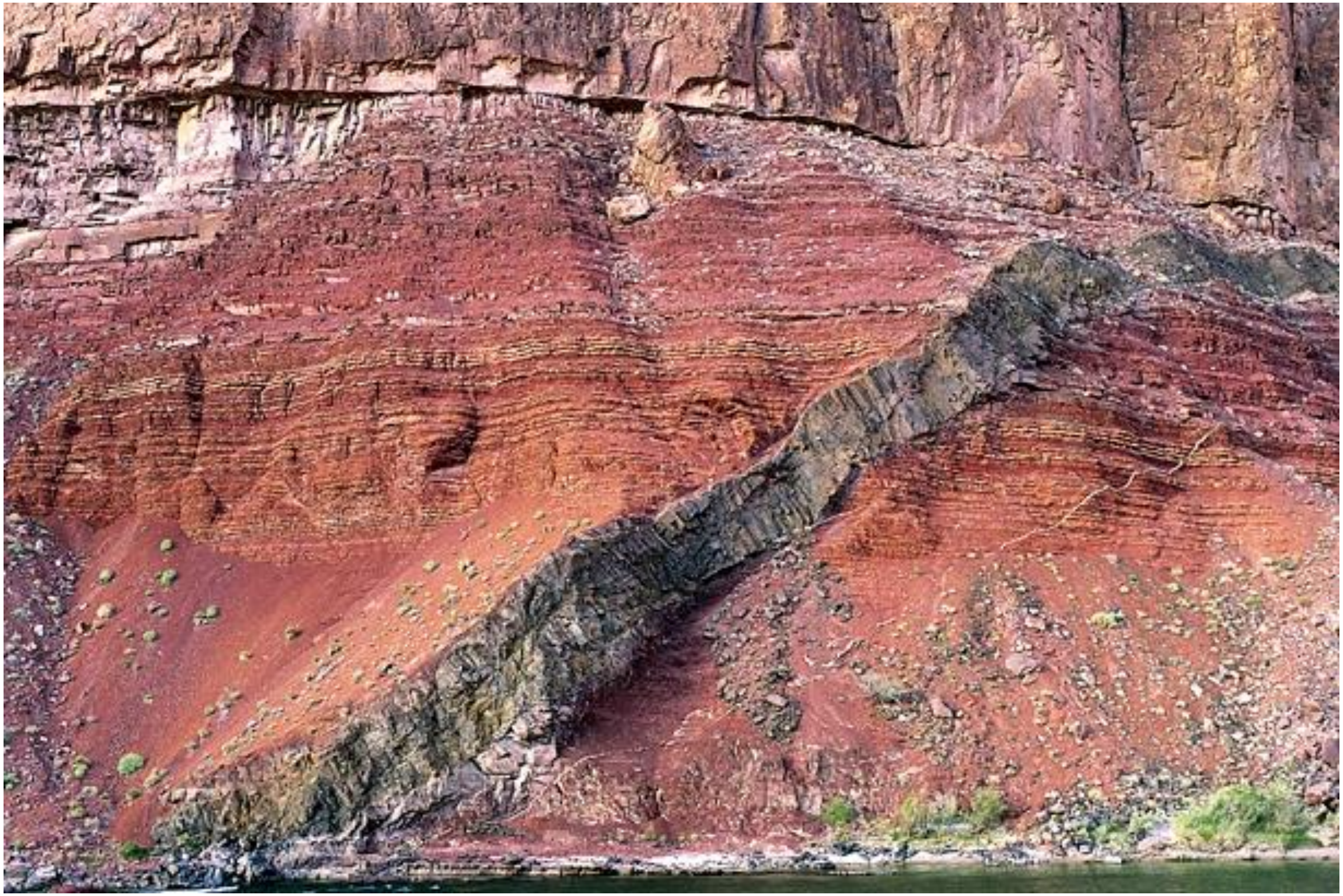
Sills**: sheetlike body formed by the injection of magma between parallel layers of bedded country rock.**

Dyke**: sheetlike body formed by the injection of magma cut across the layers in bedded country rock.**

Sill



Dike



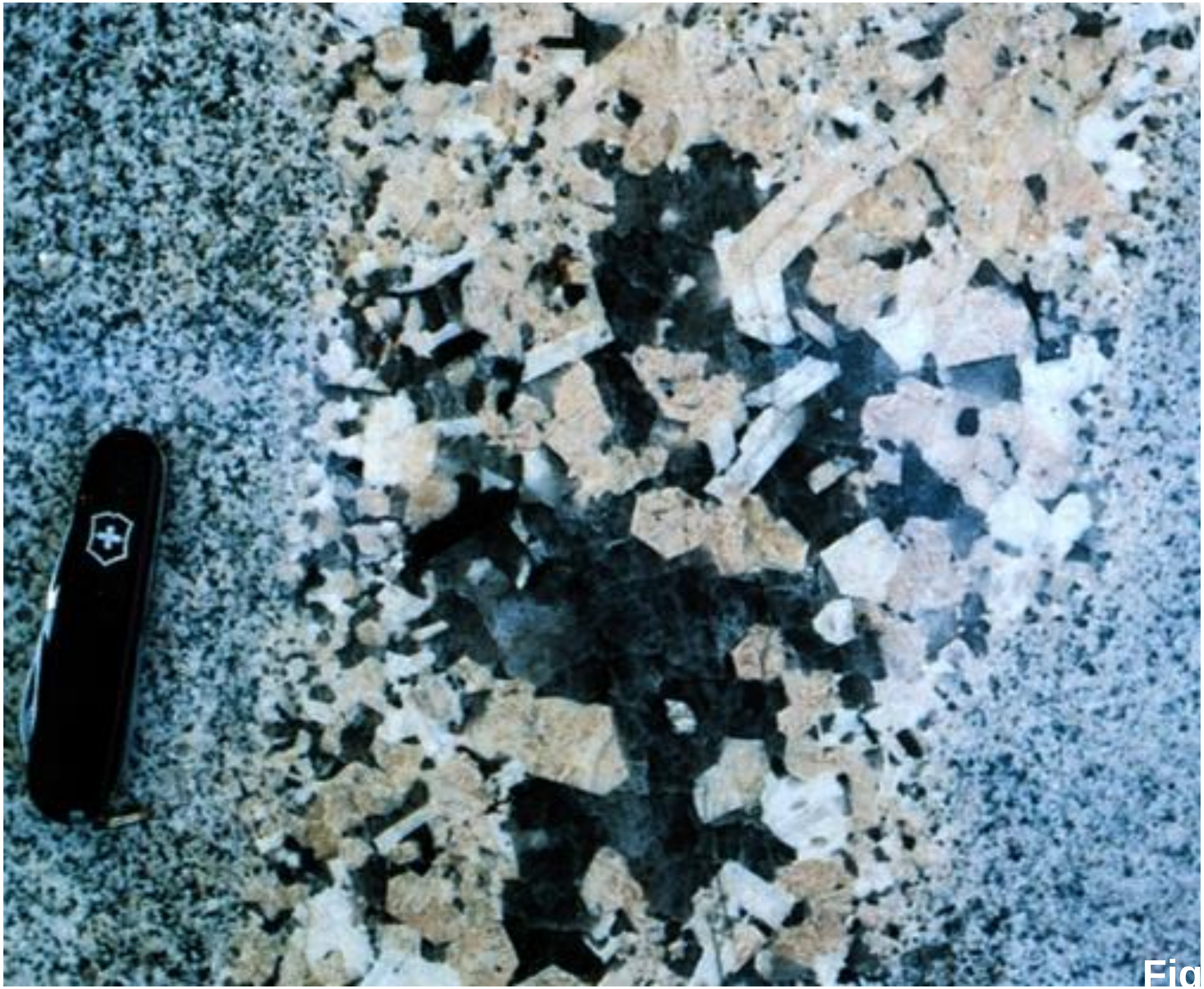
Forms of intrusive igneous masses

***Veins*: deposits of minerals found within a rock fracture that are foreign to the country rock.**

Veins

Monochromatic chert cut by quartz veins

Pegmatite veins



Igneous processes and plate tectonics

Sedimentary rocks

Weathering –Decomposition and disintegration of pre-existing rock into small fragments or new minerals

Transportation of the sediments to a sedimentary basin

Deposition of the sediment

Burial and Lithification to make sedimentary rock

Sedimentary stages in the rock cycle

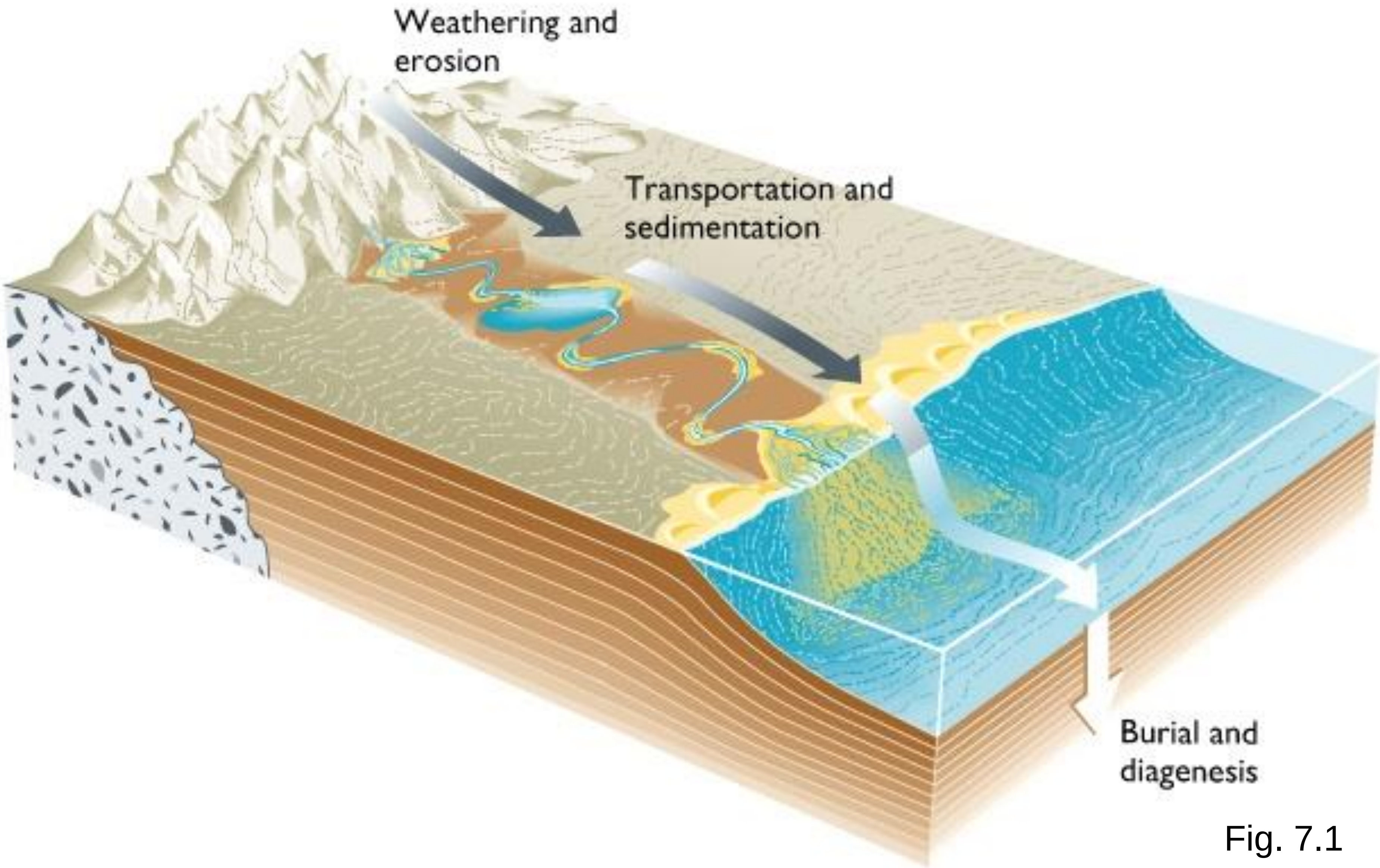


Fig. 7.1

Sedimentary rocks

Weathering process

Types of sedimentary rocks

Depositional environments

Weathering process

1. Physical (Mechanical): Large rocks broken into smaller fragments with no change in composition

2. Chemical: Rocks dissolved –
chemical and mineralogical composition can be altered
   - new minerals may form

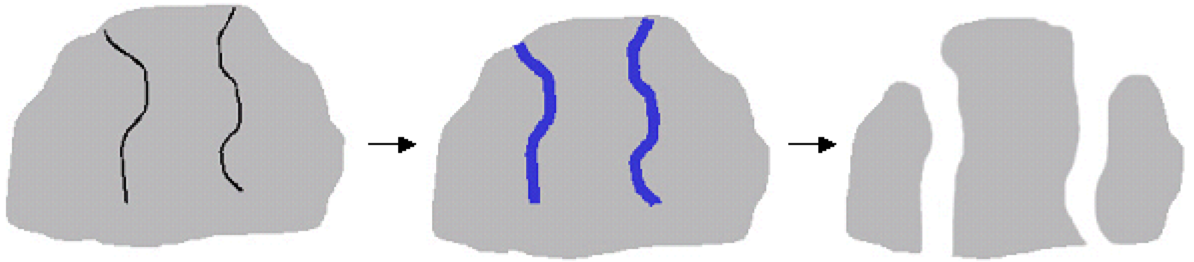
3. Biological : plants & animals

Physical weathering

1. **Joints** (also termed extensional fractures) are planes of separation on which no shear displacement has taken place

Physical Weathering

2. Frost wedging



The black lines in the rock represent fractures that are occurring in the rock.

The blue lines in the rock represent water soaking into the fractures.

The water freezes and expands. If this cycle of freezing, expansion, and thawing continues, the rock will gradually disintegrate.

Physical Weathering

3. Salt precipitation

Physical Weathering

4. Abrasion

Physical grinding of rock fragments

Chemical Weathering

Chemical weathering is the weakening and subsequent disintegration of rock by chemical reactions.

These reactions include

i) Hydration

ii) Hydrolysis

iii) Carbonation

Chemical Weathering

Carbonation is the process of rock minerals reacting with carbonic acid. Carbonic acid is formed when water combines with carbon dioxide. Carbonic acid dissolves or breaks down minerals in the rock.

$CO_2 + H_2O \rightarrow H_2CO_3$

(carbon dioxide + water → carbonic acid)

$CaCO_3 + H_2CO_3 \rightarrow Ca^{2+} + 2HCO_{3-}$

(calcite + carbonic acid → calcium + bicarbonate)

Chemical Weathering

Hydrolysis is a chemical reaction caused by water.

Water changes the chemical composition and size of minerals in rock, making them less resistant to weathering.

$$2KAlSi_3O_8 + 2H^+ + 9H_20 \rightarrow H_4Al_2Si_2O_9 + 4H_4SiO_4 + 2K^+$$

Chemical Weathering

Hydration is the absorption of water into the mineral structure.

A good example of hydration is the absorption of water by anhydrite, resulting in the formation of gypsum. Hydration expands volume and also results in rock deformation.

Biological Weathering

- This form of weathering is caused by activities of living organism

Factors affect the rates of weathering process

- **Climate**
- **Structural weakness**
- **Topography**
- **Time**
- **Nature of rocks and minerals**

Weathering process

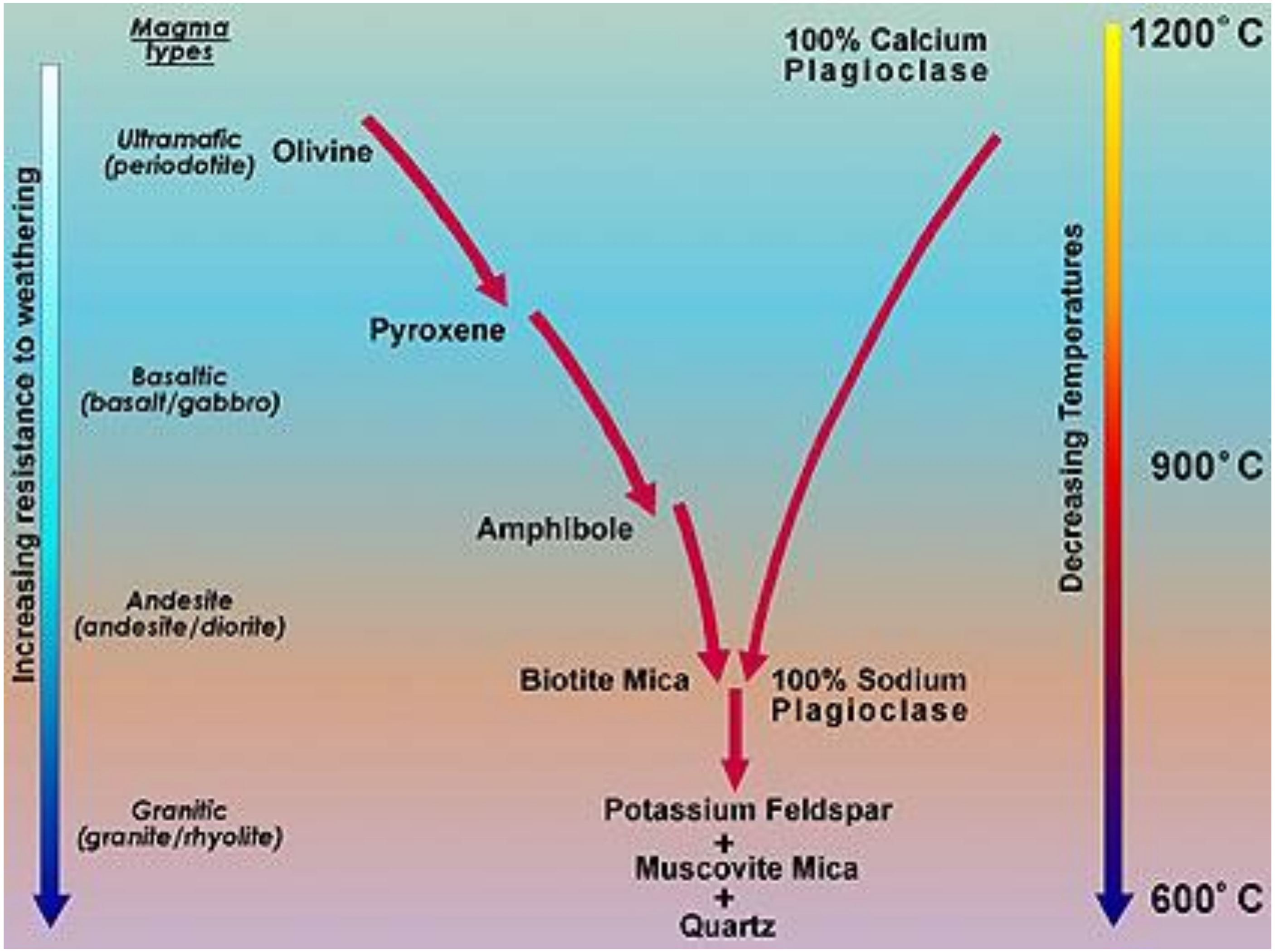
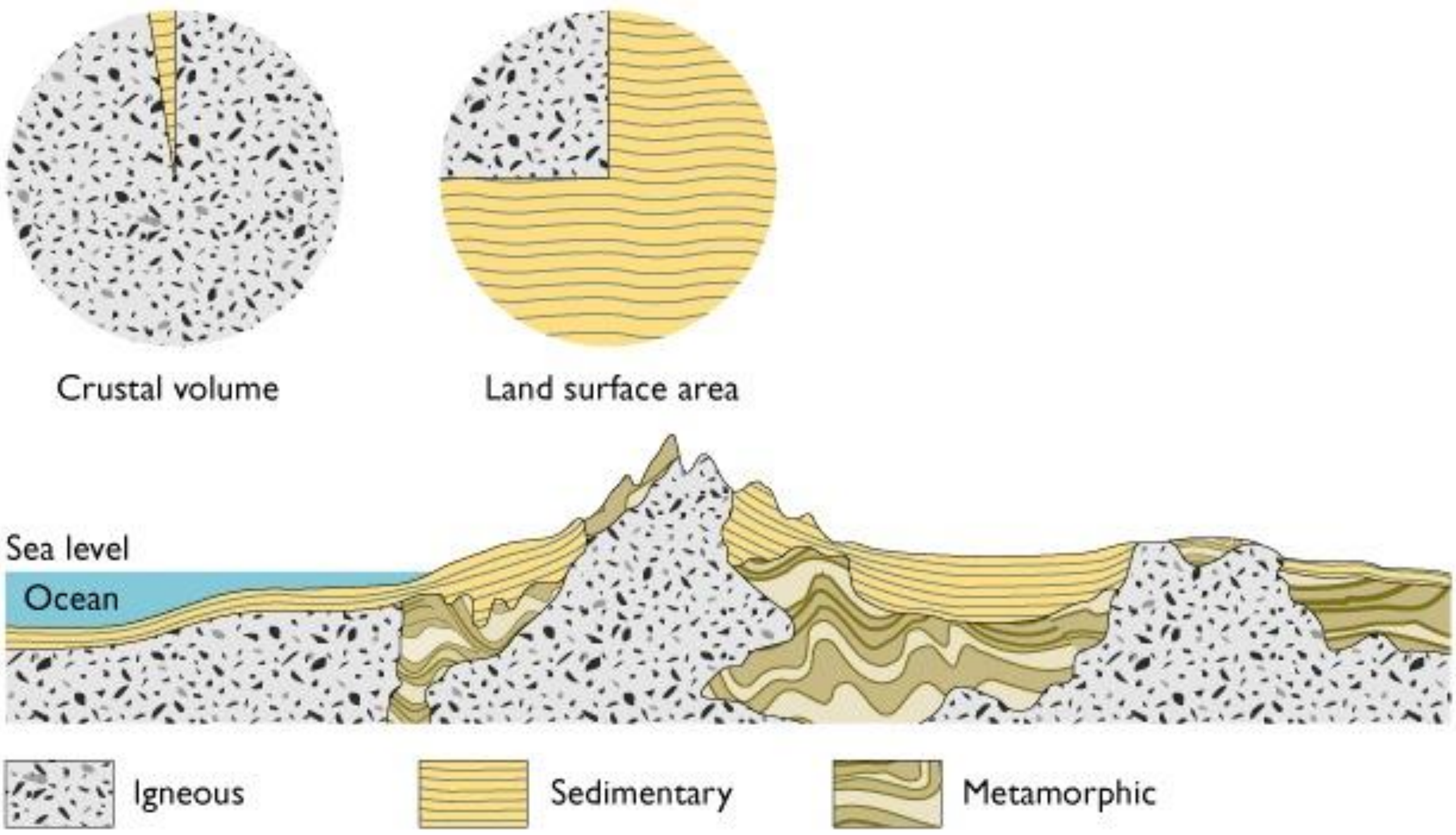


Table 7.1

Minerals Remaining in Clastic Sediments Derived from an Average Granite Outcrop Under Varying Intensities of Weathering

Intensity of Weathering		
Low	**Medium**	**High**
Quartz	Quartz	Quartz
Feldspar	Feldspar	Clay minerals
Mica	Mica	
Pyroxene	Clay minerals	
Amphibole		

HOW COMMON ARE SEDIMENTARY ROCKS?



Sedimentary Rocks

- *Detrital* (clastic) rocks produced from rock fragments
- *Chemical* rocks produced by precipitation of dissolved ions in water
- *Organic* rocks produced by accumulation of biological debris, such as in swamps or bogs

Sedimentary rock types and *sedimentary structures* within the rocks give clues to *past environments*

Transport and deposition of Clastic sediments

- **Movement of sediment by wind, ice or water.**

- **Mode of transport produces distinctive deposits.**

Transport affects the sediment in several ways

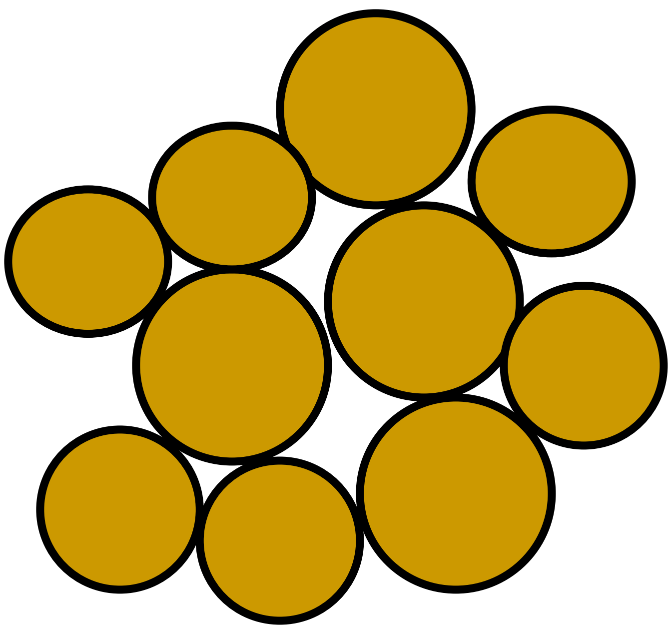
Sorting: **measure of the variation in the range of grain sizes in a clastic rock or sediment**

- **Well-sorted sediments indicate that they have been subjected to prolonged water or wind action.**

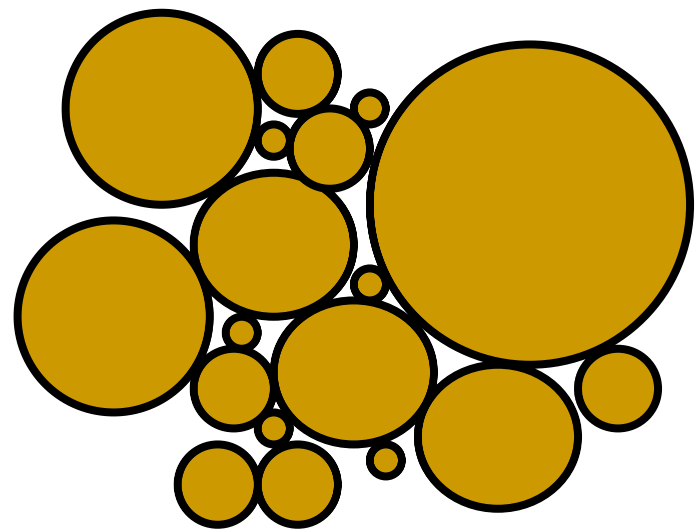
- **Poorly-sorted sediments are either not far-removed from their source or deposited by glaciers.**

Sorting

Well-sorted



Poorly-sorted



Well-sorted sand **Poorly-sorted sand**

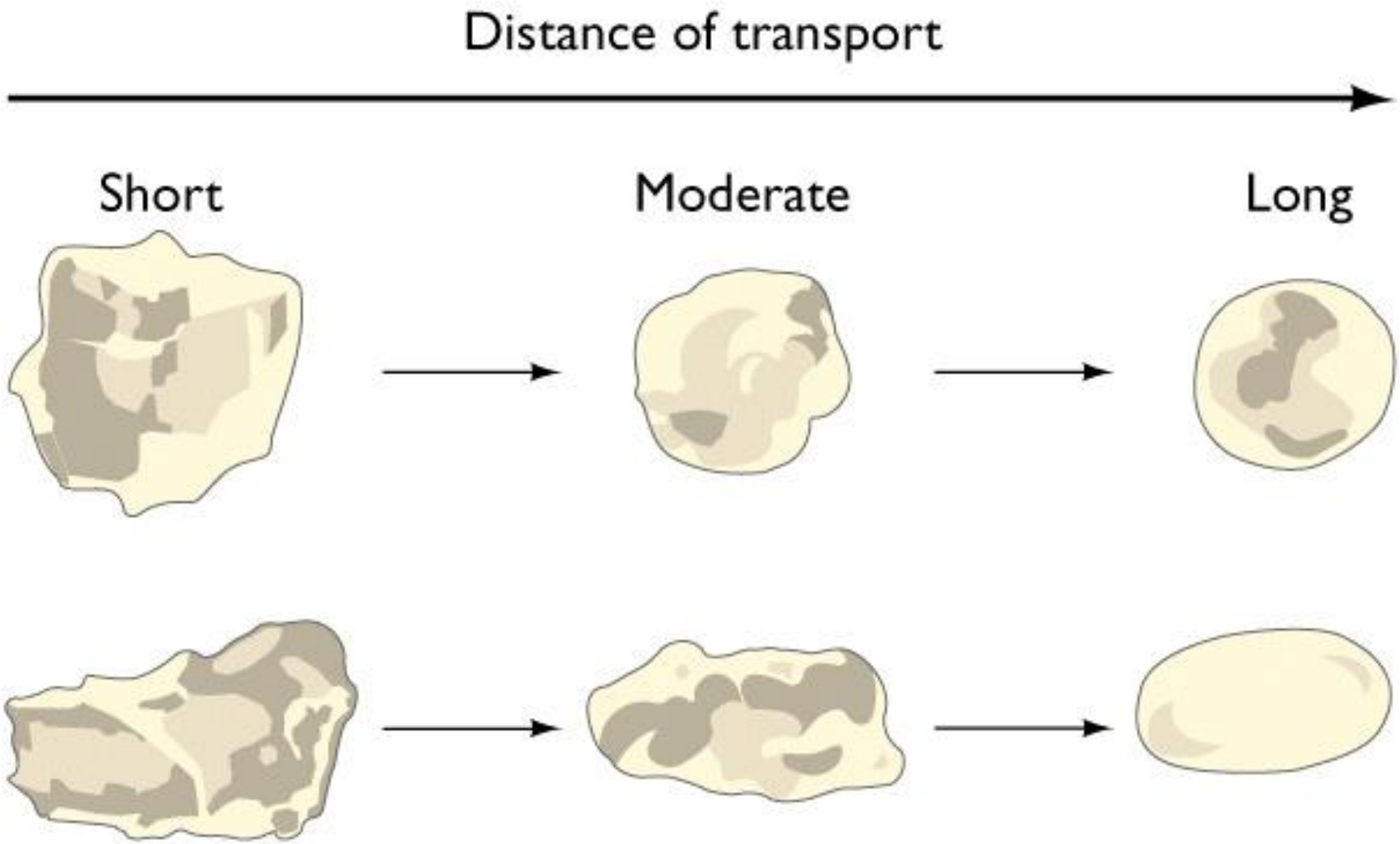
Transport affects the sediment in several ways

Roundness: measure of how rounded the corners are

Sphericity: measure of how much it is like a sphere

Sorting, roundness, and sphericity all increase with amount of transport.

Roundness and sphericity



Types of detrital rocks

Largely based on the size of the particles, which may be anything.

- *Sediment* -classified by *particle size*
  - Boulder - >256 mm
  - Cobble - 64 to 256 mm
  - Pebble - 2 to 64 mm ---- Gravel
  - Sand - 1/16 to 2 mm
  - Silt - 1/256 to 1/16 mm
  - Clay - <1/256 mm

Types of detrital rocks

Conglomerate

Breccia

Sandstone (quartzite, arkose, greywacke)

Shale

Mudstone

Siltstone

Clastic sedimentary rocks

- ***Breccia and Conglomerate***
  - *Coarse-grained clastic* sedimentary rocks
  - Sedimentary breccia composed of coarse, *angular rock fragments* cemented together
  - Conglomerate composed of *rounded gravel* cemented together

Conglomerate

Breccia

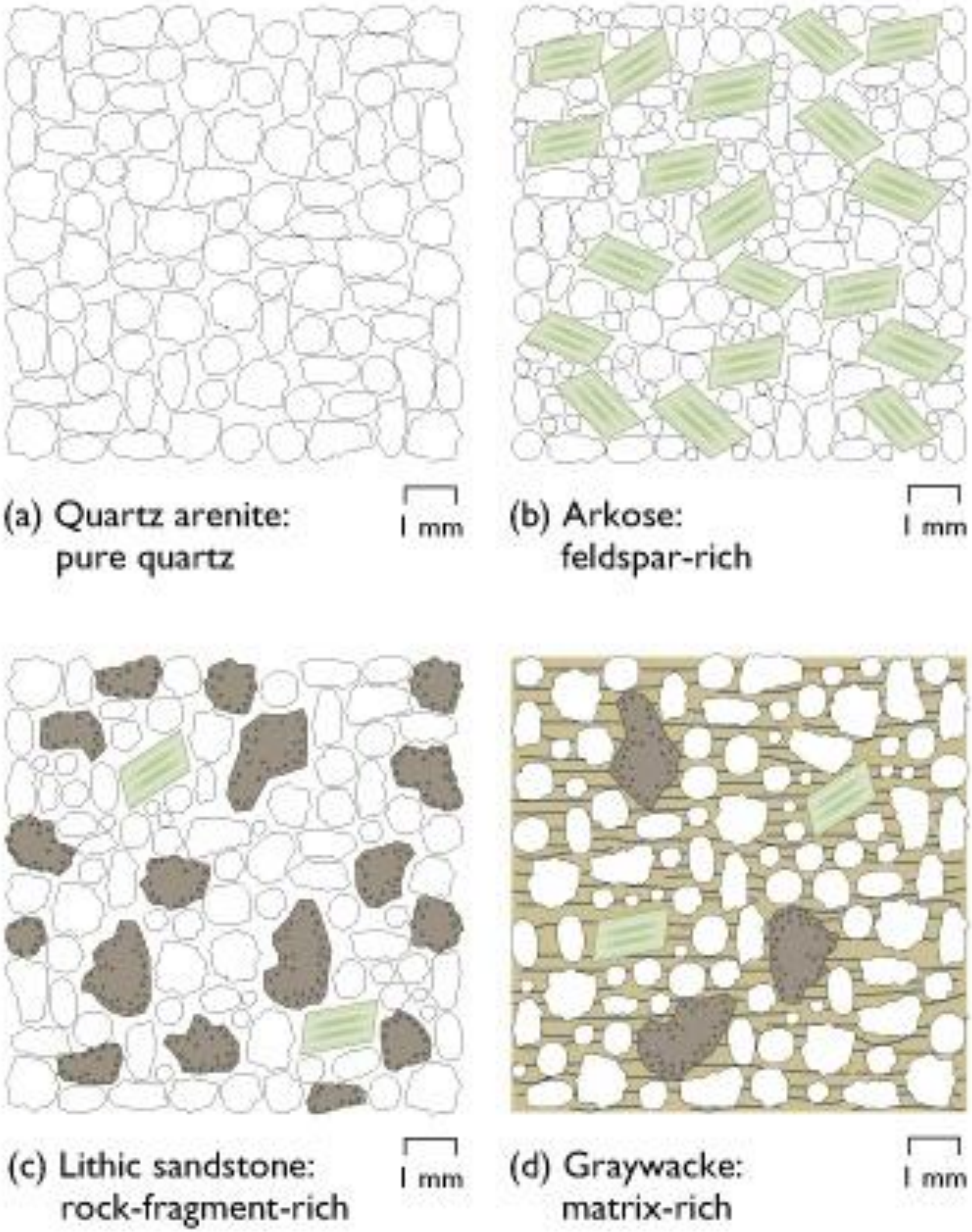
Breck Kent

Clastic sedimentary rocks

- ***Sandstone***
  - *Medium-grained clastic* sedimentary rock
  - Types determined by composition
    - *Quartz sandstone* - >90% quartz grains
    - *Arkose* - mostly feldspar and quartz grains
    - *Graywacke* - sand grains surrounded by dark, fine-grained matrix, often clay-rich

Sandstone

Breck Kent



Four major groups of sandstones

Shale

Shales are clastic rocks, made up mainly fine silt/clay

They are most abundant sedimentary rocks, accounts for about 80% of them

Often contain fossils

Mostly hydrous aluminum silicate in composition = from weathered feldspars

Deposition takes place under low fluvial regime or under weak water current. Eg. Offshore or in Lagoon

- Shales are made of fine well sorted silt and clayey sediments, where normally one can expect high porosity and permeability.

Shale

Types of chemical sedimentary rocks

Limestone	$CaCO_3$
Chert	SiO_2
Salt	$NaCl$, KCl, K_2SO_4
Gypsum	$CaSO_4 \cdot 2H_2O$
Coal	**altered organic debris**

Chemical sedimentary rocks

- *Carbonates*
  - Contain CO_3 as part of their chemical composition
  - *Limestone* is composed mainly of *calcite*
    - Most are *biochemical*, but can be *inorganic*
    - Often contain easily recognizable fossils

Chemical sedimentary rocks

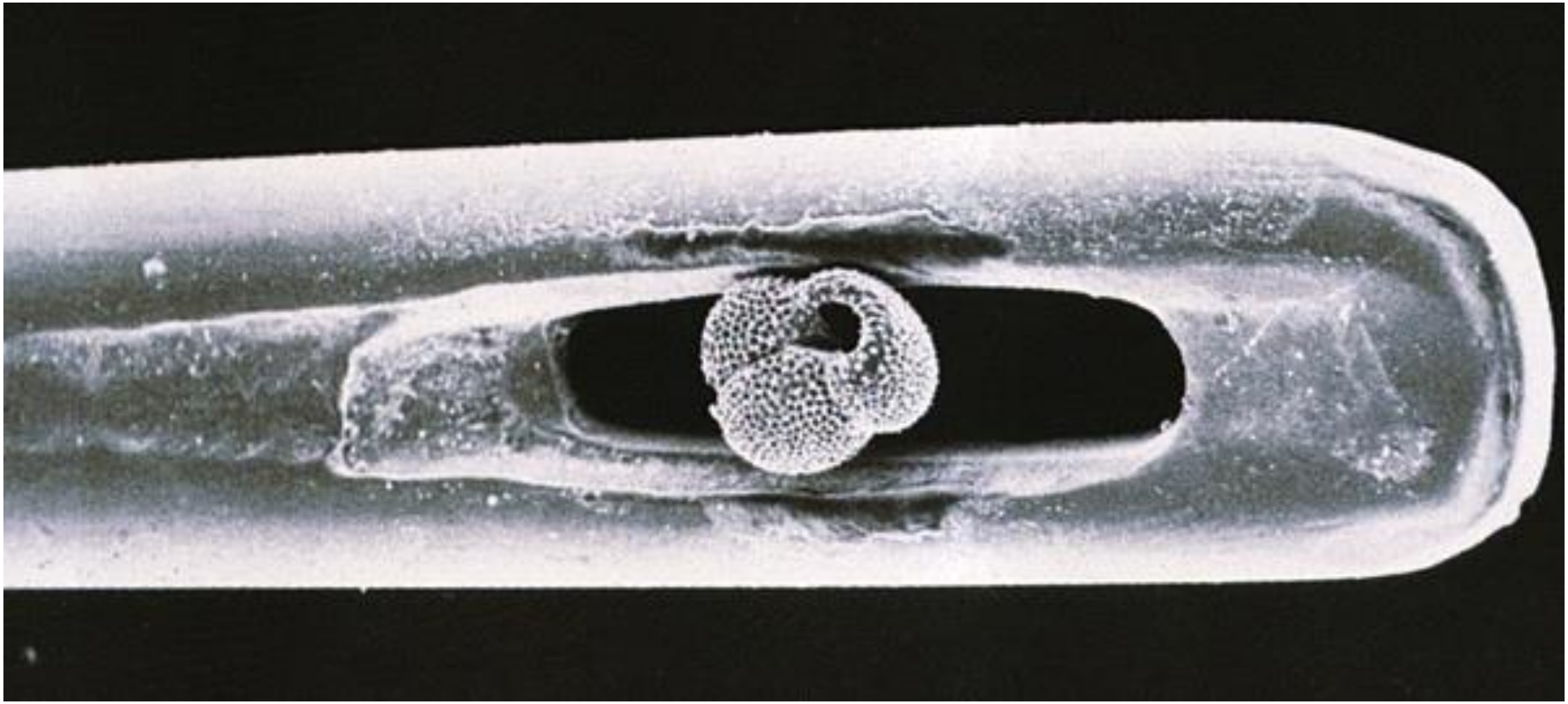
Limestone: It is a non-clastic rock formed either chemically or due to precipitation of calcite ($CaCO_3$) from organisms usually shell. These remains will result in formation of a limestone.

Limestones formed by chemical precipitation are usually fine grained, whereas, in case of organic limestone the grain size vary depending upon the type of organism responsible for the formation

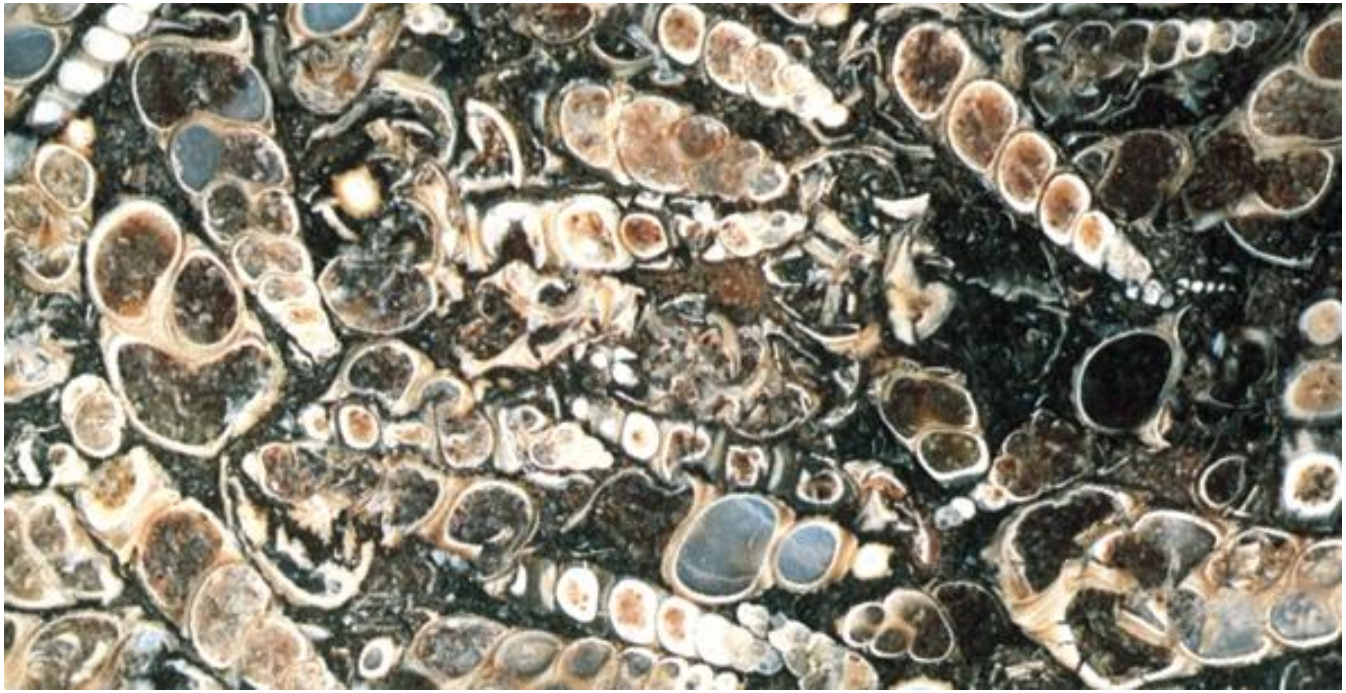
Fossiliferous Limestone: which medium to coarse grained, as it is formed out of cementation of Shells.

Limestone

Foraminifera in the eye of a needle



Fossiliferous limestone



Chemical sedimentary rocks

Chert

- Hard, compact, fine-grained, formed almost entirely of silica
- Can occur as layers or as lumpy nodules within other sedimentary rocks, especially limestones

Evaporites

- These rocks are formed within the a depositional basin from chemical substances dissolved in the seawater or lake water

- Characteristic of arid conditions

Evaporites

Minerals precipitate according to solubility.

Gypsum

50%

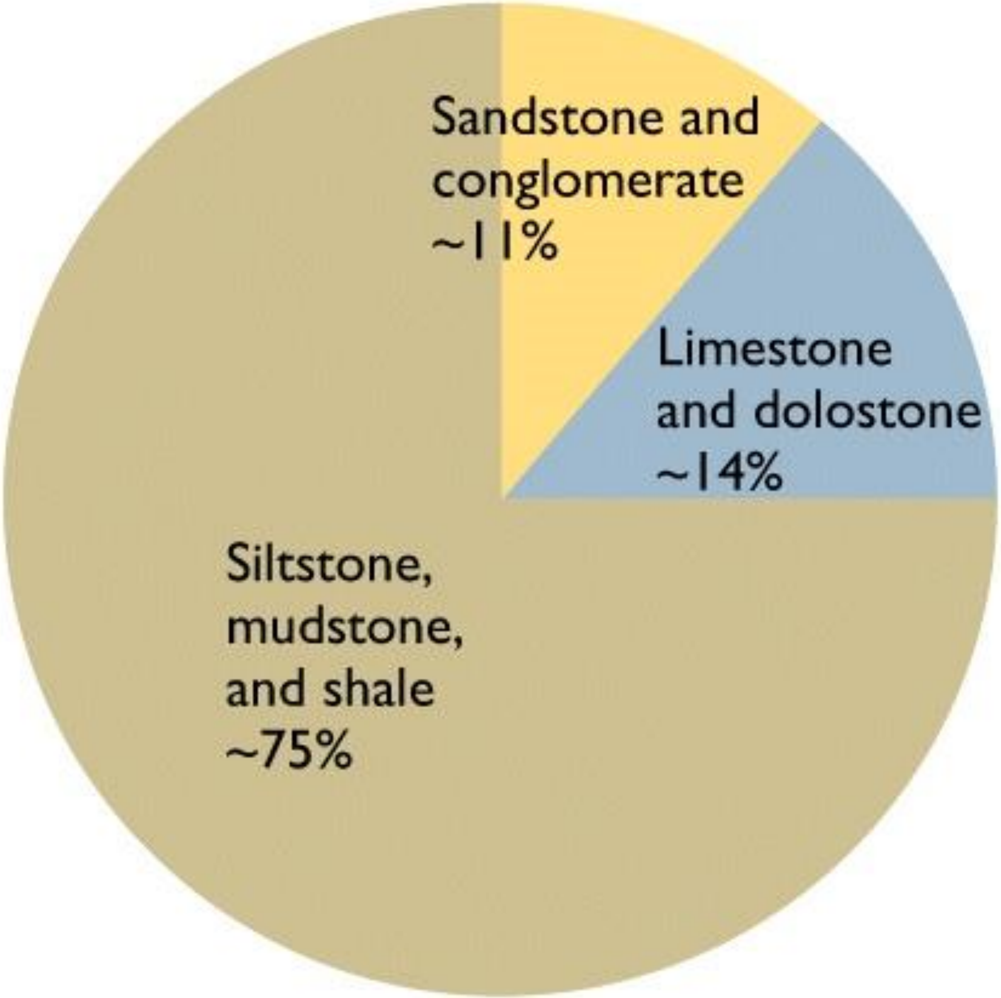
$CaSO_4.2H_20$

Halite

90%

NaCl

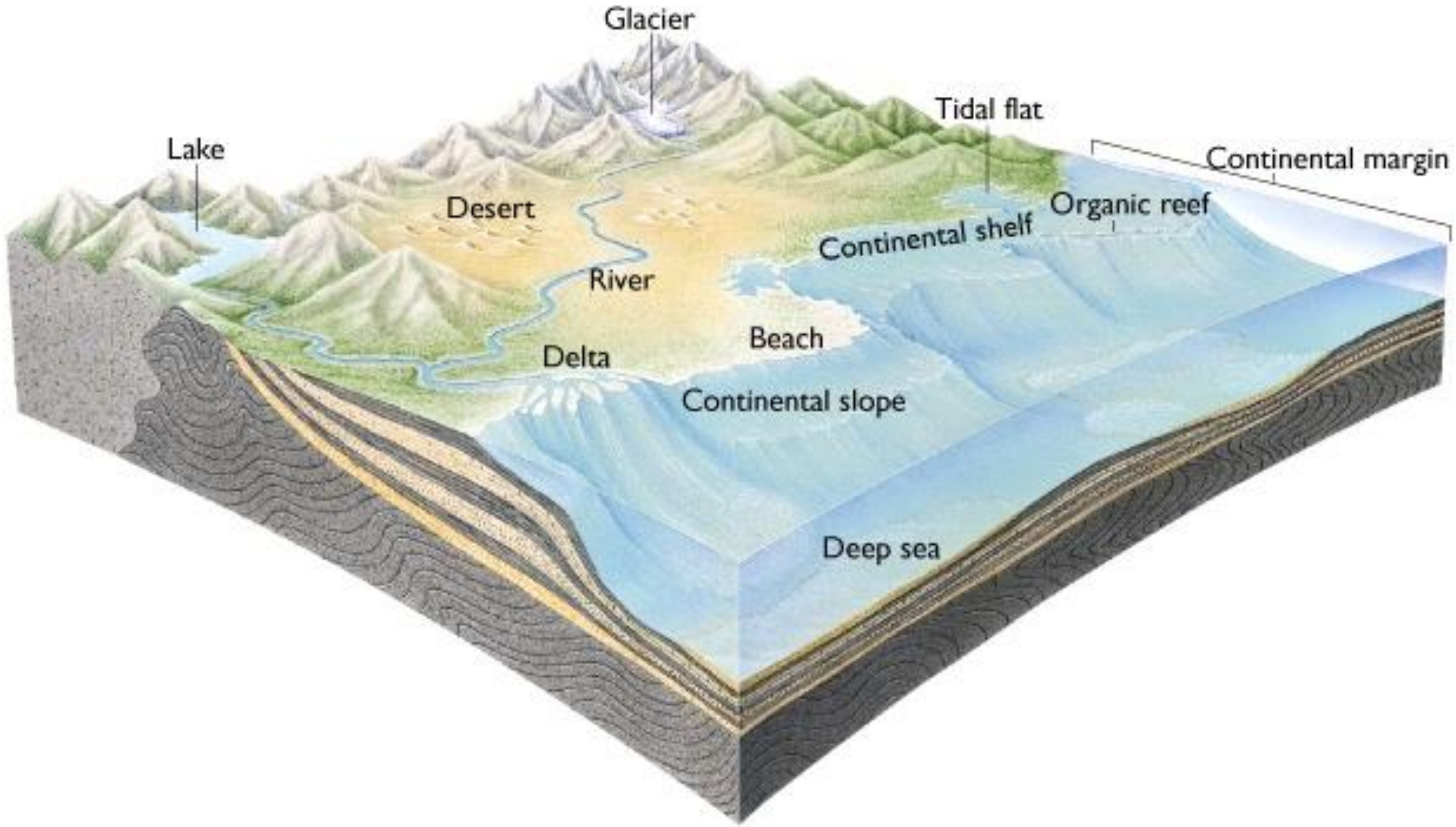
Relative abundance of sedimentary rock types

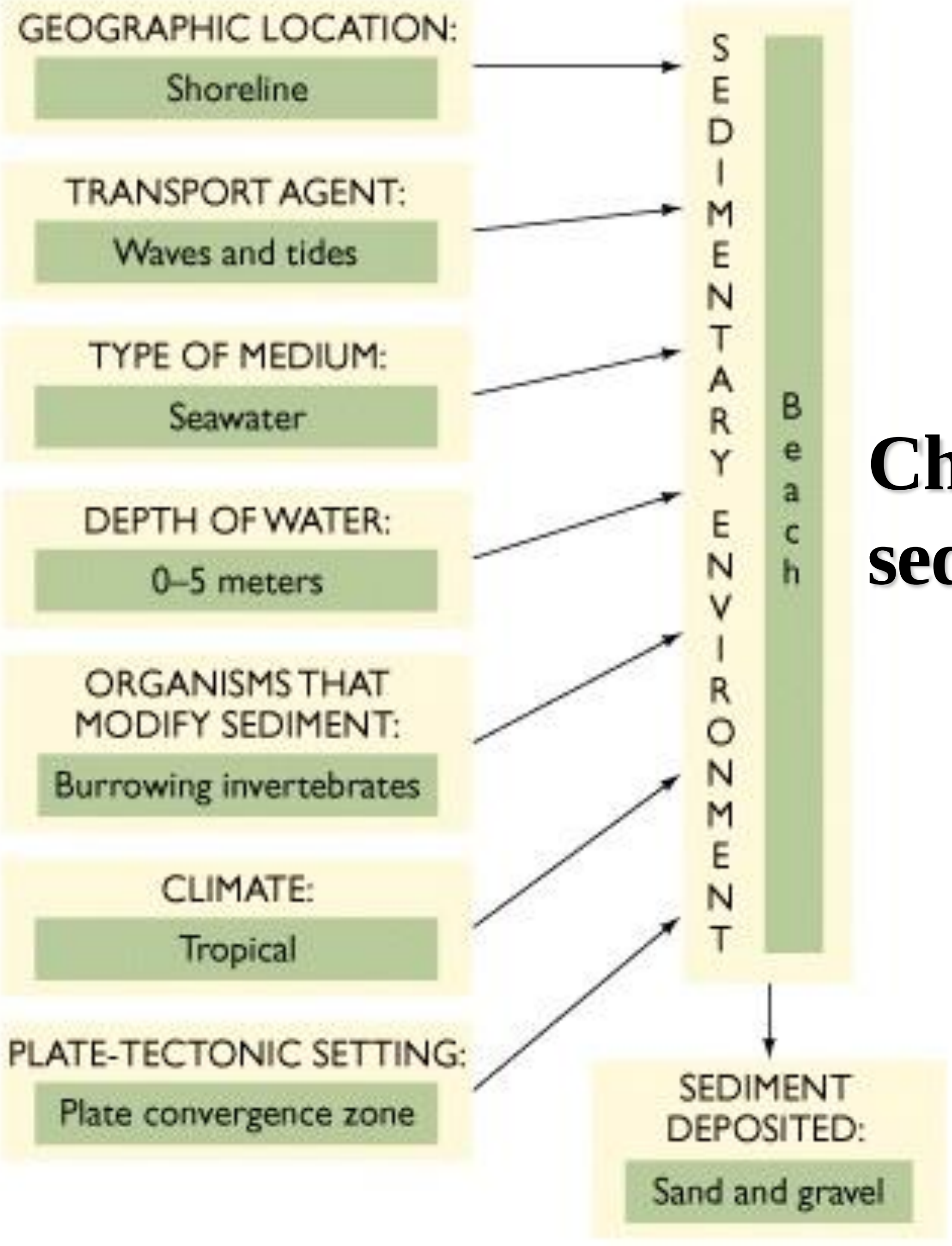


Sedimentary environment

- Sediments accumulate in some environment of deposition or **depositional environments**
- These areas receive net deposition
- Erosion may occur, but deposition dominates
- Features of these depositional environments are preserved in the rock record
- Examples:
  - Sediment texture
  - Fossils of organisms that lived in the environment
- **Ancient environments can be reconstructed from the clues that are preserved in the sedimentary rocks**

Common sedimentary environments





Characteristics of a sedimentary environment

Table 7.2 Clastic Sedimentary Environments

Environment	Agent of Transportation, Deposition	Sediments
CONTINENTAL		
Alluvial	Rivers	Sand, gravel, mud
Desert	Wind	Sand, dust
Lake	Lake currents, waves	Sand, mud
Glacial	Ice	Sand, gravel, mud
SHORELINE		
Delta	River + waves, tides	Sand, mud
Beach	Waves, tides	Sand, gravel
Tidal flats	Currents	Sand, mud
MARINE		
Continental shelf	Waves, tides	Sand, mud
Continental margin	Ocean currents	Mud, sand
Deep sea	Ocean currents, settling	Mud

Table 7.3

Major Chemical and Biochemical Sedimentary Environments

Environment	Agent of Precipitation	Sediments
SHORELINE AND MARINE		
Carbonate (includes reef, bank, deep sea, etc.)	Shelled organisms, some algae; inorganic precipitation from seawater	Carbonate sands and muds, reefs
Evaporite	Evaporation of seawater	Gypsum, halite, other salts
Siliceous: deep sea	Shelled organisms	Silica
CONTINENTAL		
Evaporite	Evaporation of lake water	Halite, borates, nitrates, other salts
Swamp	Vegetation	Peat