GEOLOGY FOR CIVIL ENGINEERING

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Today: Course Overview

- A few ground rules…
- Stuff about me.
- Why are we here?
- Course exams & grading.
- Prelude: What is Geology?
● **Read the textbook**

Ketin İ., Genel Jeoloji Yerbilimlerine Giriş, İTÜ Vakfı Yayınları, 2016.


Alan E. Kehew, Geology for Engineers and Environmental Scientists, Prentice Hall, 3rd ed., 2006

● **Attend lectures**

  - Hear topical overviews & ask questions
  - Do in-class assignments & turn in & pick up HW
  - Exams, quizzes & extra credit opportunities

● **In-class exercises and homework assignments (depend on your status!!!)**

  - Exercises weekly & homework every other week
Required by all students:

While in lecture, please DO NOT:

- Forget to turn off cell phones
- read different documents instead of course notes
- Talk and have conversations
- Sleep uncontrollably, endangering yourself and others
Required by all students:

While in the lecture, please DO:

- Ask questions when anything is not clear
- Engage in the discussions
- Fully participate in in-class exercises
- Geology is great! Have fun with it!
Since you will be Civil Engineer, you should learn basics of geology

You need a science credit to graduate

Just curious, it seemed like it might be cool

You have absolutely no idea
Graduate from Department of Geological Engineering (2003)
Research assistant (2006-2011)
Geological Engineer (2011-2012) DSI
Geological Engineer (2012-...) The Ministry of Forestry and Water Affairs
Phd and section manager of Modelling department
Research Areas
Geology
Petroleum reservoir geology
GIS and remote sensing
Hydrology
Groundwater
Water resources modelling
Geology Exams:

1. There will be two Exams.
   - In class, 1-hour, 100 points each
   - One midterm, one final

2. Review outline
   - Will be handed out before exams
   - Will provide a list of topics that will be covered

3. Final Exam
   - Covers last section of course, but all exams may call on basic concepts presented earlier.
MAKE-UP EXAMS

- There are none! Exceptions include a health problem.

TERM PAPER OPTION

- It is optional, not decided yet
Basic principles of geology, geochemistry, and geophysics. Rocks, minerals, weathering, earthquakes, mountain building, volcanoes, water, and glaciers.
But also, we have these goals:

- To develop critical thinking skills & a basic understanding of how the science works.
- Become familiar with some of the observational methods, reasoning processes and analytical tools used by geologists to understand the Earth and its history.
- Learn the basic scientific concepts and principles of Earth sciences.
You will be learning a new language!

Geology is a broad, interdisciplinary science with a rich vocabulary. The terminology we will use throughout this course will require that you learn a new language.
Geology: The study of the Earth and its systems
A Prelude:

- Geology; Physics, chemistry, mathematics, zoology, botany, construction, mining and other engineering.

- Geology «The history of the earth, its combination of rock, soil and water, and the science of studying evolution»

- Geological Engineering: Provides the use of geological data for practical engineering purposes.

And just what is Geology?
The relationship between Geological Engineering and other engineering sciences

- **Civil Engineering** (safe and economical construction of buildings)
- **Mining Engineering** (safety and economical factors in mining deposition operating and development)
- **Petroleum Engineering** (Economic design for extracting petroleum and obtaining petroleum products)
- **Geophysical Engineering** (earth physical properties and its engineering applications)
- **Architecture** (project designing)
- **City and Regional Planners**
Geology Branches

- General geology
  - Structural geology
  - Sedimentology-Sedimentary petrography
  - Stratigraphy
- Mineralogy-Petrography
  - Mineralogy
  - Petrography
- Ore deposits-Geochemistry
  - Mineral deposits
  - Geochemistry
  - Petroleum Geology
- Applied Geology
  - Engineering Geology
  - Hidrogeology
  - Mathematical Geology
The world's origin and geological processes

Mineral types, rocks and rock formations, distribution and characteristics

Internal and external geological processes that affect the properties of earth materials

Geological structures

Surface and groundwater movements and related properties

Deformation types and structural properties, geological time concept

Use of topographical-geological maps

The basic concepts of engineering geology
How old is the world and how did it?
Layers of the earth
How continents are formed?
How the mountains are formed and eroded?
Geology and Civil Engineering Relationship

Civil engineering works are carried out either on site or within the site.

For this reason, erosional and geological process which cause the stability of the rocks and ground and their changes are important for civil engineering.
Geology and Civil Engineering Relationship
Geology and Civil Engineering Relationship

- Where is a geologically safe and economical engineering structure built?
- How to choose the communication and transport infrastructure route where geological conditions are convenient?
- How are the building bases constructed safely and economically in terms of geological and geotechnical aspects?
- How to create a slope both safely and economically?
- How is a safe tunnel and underground facility excavation done?
- How is location geological materials required for construction of dams and road construction determined?
- What are the measurements and application methods for improvements of ground conditions and controlling instability, infiltration etc.?
- What are required geological and geotechnical conditions store urban, toxic and radioactive waste?
- How are to identify, prevent or reduce geological hazards identified, prevented anf reduced?
Geology deals with complex historical systems that have evolved and changed over time.

Time is thus a fundamental variable in geology.

Coupled processes, operating over time produce all that we see.
Various Projects
Various Projects
2. Week
Nature of scientific inquiry

Basic Concepts:
- Scientific method
- Observation
- Hypothesis
- Test
- Scientific “certainty”
- Paradigms and the nature of scientific revolutions
- Theory
Science is based on:

- assumption that the natural world behaves in a consistent & predictable manner

Goals of science:

- understand underlying patterns in nature (from careful observations/measurements form hypotheses that lead to predictions
Nature of scientific inquiry

Four basic steps:

1) **collect the facts** (observation/measurement)
2) **develop hypothesis** (one or more)
3) **test hypothesis**
4) **accept/modify/reject**
Process begins with Observation!

Formulation of Hypotheses:
  Construction of a tentative (untested) explanation for something observed
  Value of multiple working hypotheses

Testing hypotheses
  Evaluate explanatory power.
  Certainty in science and the nature of scientific proof
  Science has been described as the orderly accumulation of rejected hypotheses.
Theory

- well-tested/widely accepted hypothesis that “acceptably” predicts observed facts.
- also: explains additional observations not used originally to form theory
  - predictive power
  - still testable and subject to disproof!
THE BIG BANG THEORY

1. The cosmos goes through a superfast "inflation," expanding from the size of an atom to that of a grapefruit in a tiny fraction of a second.

2. Post-inflation, the universe is a seething hot soup of electrons, quarks and other particles.

3. A rapidly cooling cosmos permits quarks to clump into protons and neutrons.

4. Still too hot to form into atoms, charged electrons and protons prevent light from shining; the universe is a superhot fog.

5. Electrons combine with protons and neutrons to form atoms, mostly hydrogen and helium. Light can finally shine.

6. Gravity makes hydrogen and helium gas coalesce to form the giant clouds that will become galaxies; smaller clumps of gas collapse to form the first stars.

7. As galaxies cluster together under gravity, the first stars die and spew heavy elements into space; these will eventually form into new stars and planets.

NOTE: The numbers in cosmology are so large and the numbers in subatomic physics are so small that it is often necessary to express them in exponential form. Ten multiplied by itself, or 10^2, is written as 10^2.
Geology: The study of the Earth and its systems
Layers of EARTH
Prelude: Earth Systems

- Atmosphere
- Hydrosphere
- Cryosphere
- Solid Earth
- Biosphere
Atmosphere
Blanket of gases surrounding the Earth

- Protection from Sun’s heat & UV rays
- Weather: due to exchange of energy
  - between Earth’s surface & atmosphere
  - between atmosphere & outer space
- Strongly interacts water/surface
Hydrosphere

Water portion of Earth

- Oceans (most prominent)
  71% of surface of Earth

- Streams, lakes, glaciers, underground water

- Atmosphere
Cryosphere

Icy portion of Earth’s crust

- Glaciers
- Permafrost and ground ice
- Polar ice caps
- Frozen polar seas
Biosphere

Earth’s Ecosystems

- Earth’s surface and subsurface to depths of a few kilometers
- Life occupies an extreme range of environments
- Life strongly interacts with the atmosphere, the hydrosphere and the solid earth (these interactions are called ecology!)
Prelude: Earth’s internal structure

3 distinct divisions:

- **crust**
  - Oceanic 0-6 km ("young", < 180 m.y.)
  - Continental 0-34 km (older, up to 3.8 b.y.)

- **mantle**
  - Upper 34-670 km
  - Lower 670-2900 km

- **core**
  - Outer – Liquid
  - Inner – Solid
Earth’s internal structure

Continental crust – Underlies the continents.

- Avg. rock density about 2.7 g/cm³.
- Avg. thickness 35-40 km.
- Felsic composition. Avg. rock type = Granite

Oceanic crust – Underlies the ocean basins.

- Density about 3.0 g/cm³.
- Avg. thickness 7-10 km.
- Mafic composition
- Avg. rock type = Basalt/Gabbro
Crust vs Earth’s internal structure

The Outer Layers of the Earth

- Ocean Crust
- Oceanic Crust
- Continental Crust
- Upper Mantle
- Lower Mantle
- Asthenosphere
- Lithosphere
- Outer Core
- Inner Core
- Transition Zone
- Thinned continental crust
- Thickened continental crust
- Normal continental crust
- Moho
- Sea Level

Earth’s internal structure:
- Crust
- Upper mantle
- Lower mantle
- Asthenospheric mantle
- Plastic Asthenosphere
- Lithosphere
- 10 km
- 100 km
- 200 km
- 400 km
- 660 km
- 2,900 km
- 5,155 km
- 6,371 km

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Plate tectonics

- Plate tectonics, theory dealing with the dynamics of Earth’s outer shell, the lithosphere, that revolutionized Earth sciences by providing a uniform context for understanding mountain-building processes, volcanoes, and earthquakes, as well as understanding the evolution of Earth’s surface and reconstructing its past continental and oceanic configurations.

- *Describing in detail the processes that make up the Earth's fundamental surface features, «The definition of lithospheric separation of rigid plates moving on the asthenosphere» (Alfred Wegener 1915) forms the basis of the plate tectonics theory.*
Plate tectonics
Plate tectonics

[Diagram showing the movement of tectonic plates over time, including images of Pangaea 200 million years ago, 130 million years ago, and 65 million years ago, and the present configuration.]
Plate tectonics

Data indicates that Plates separate from each other

- Coastal forms and continents match each other
- Similarity of sediment deposits; The continuation of the vegetation and geological structure of Africa, India, Australia, Madagascar, South America which make up Gondwana,
- Similarity of mountain ranges; When the continents are brought side by side, the mountain lines form a single continuous mountain line in the same age and deformation style.
- The glaciation that began in Gondwana was also experienced at the same time (carboniferous) by parts separated from Gondwana
- The remains of the reptile family which is impossible to swim the ocean were found only in South West Africa and Brazil
- Palaeomagnetism
- Propagation of the sea floor
Plate tectonics

Lithosphere thickens away from the axis.

Mid-ocean ridge

(a) At a divergent boundary, two plates move away from the axis of a mid-ocean ridge. New oceanic lithosphere forms.

(b) At a convergent boundary, two plates move toward each other; the downgoing plate sinks beneath the overriding plate.

(c) At a transform boundary, two plates slide past each other on a vertical fault surface.

The process of consuming a plate is called subduction.

Overriding plate

Volcanic arc

Trench

Lithosphere

Asthenosphere

No new plate forms, and no old plate is consumed.

Transform fault
Plate tectonics
Plate tectonics
Plate tectonics

Convergent plate boundaries

- Subduction event occurs
- Colliding with Oceanic/oceanic or oceanic/continental plate generated a deep ocean trenches
- Crust melting and magma generation occur
- Volcanism and volcanic island arcs occur, volcanic island arcs arranged like a barrier can form inner seas between continents and the oceans
- Events of metamorphism occur
- Two continental or continental and an oceanic plate collides to form a curved mountain line
Plate tectonics
Plate tectonics
Plate tectonics

Events happening in places where plates are moving away from each other:

- Mid-ocean ridge (2500 m high ridge in the Atlantic Ocean)
- Volcanic islands
- New crust formation
- Basaltic lavas are solidified and added to the continental margins, the ocean floor expands and the continents move away from each other
- Magma is emerged from the fractures generated by divergent event and volcanic events occur
- Best example of that is Atlas Ocean
Plate tectonics

- Transform Plate Boundaries are locations where two plates slide past one another.
- The fracture zone that forms a transform plate boundary is known as a transform fault.
- Most transform faults are found in the ocean basin and connect offsets in the mid-ocean ridges.
- A smaller number connect mid-ocean ridges and subduction zones.
- The most famous example of this is the San Andreas Fault Zone of western North America.
- Another example of a transform boundary on land is the Alpine Fault of New Zealand.
Plate tectonics

The most common areas of tectonic earthquakes in the world are:

- Great Oceanic boulders (Pacific waters): Kamchatka in the east of Asia, Japan, the Philippines, Indonesia, the Aleut Islands in the west of America, California, Mexico, Chile, Peru.

- Mediterranean Himalayan Belts: Spain, Italy, North Africa, Yugoslavia, Greece, Turkey, Iran, India, Pakistan, Afghanistan, East Indian islands.

- Central part of Atlantic Ocean: Asor Islands and Iceland Island
Plate tectonics

• The least common areas of tectonic earthquakes in the world are:

  ➢ The Western of Australian,
  ➢ The Eastern of USA and Canada
  ➢ Iceland of N.West European-Grönland, İskandinav peninsula,
  ➢ Eastern Europe • Northern of Asia
  ➢ Sourthern and Middles of Africa
Geologic Time...

Millions years

A few seconds.
Geologic Time...

Washington May 17, 1980

September 10, 1980
3. WEEK
MINERALS AND ROCKS GROUPS WHICH GENERATES EARTH CRUST
EARTH CRUST

- Average depth of the earth crust thickness is 8-10 km.
- There are two different rocks which have different chemical and biological content.
  - Sial; average density: 2.7 gr/cm² (granite, sandstone and limestone)
  - Sima; 2.8-3 gr/cm³ (bazalt type rocks)
- The sial layer in the ocean floor is almost absent.
- Sima reaches 8-10 km thickness.
MATERIALS WHICH GENERATES THE CRUST

• Eight of the 108 elements found on the Earth's surface are very common.
• The 8 most common elements in the crust form 98.59% by weight of the ground shell.
• The remaining 98 elements constitute 1.4% by weight of the earth's crust.

<table>
<thead>
<tr>
<th>Element</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>46.6</td>
</tr>
<tr>
<td>Silisium</td>
<td>27.72</td>
</tr>
<tr>
<td>Aluminum</td>
<td>8.13</td>
</tr>
<tr>
<td>Iron</td>
<td>5</td>
</tr>
<tr>
<td>Calcium</td>
<td>3.63</td>
</tr>
<tr>
<td>Sodium</td>
<td>2.83</td>
</tr>
<tr>
<td>Potassium</td>
<td>2.59</td>
</tr>
<tr>
<td>Magnesium</td>
<td>2.09</td>
</tr>
</tbody>
</table>
MINERALS

More than 2000 minerals on Earth generates rocks, rocks constitutes the crust.

- It is found naturally
- Has chemical composition (element or compound form).
- It can be expressed by a specific crystal system.
- It is mostly solid, liquid (mercury and water)
- Generally inorganic, at least organic compounds.
The Importance of Minerals

- Minerals and mines are part of the legacy that remains to us from the geological past. These are the basic building blocks of the solid part of the earth and are very important for construction geology;
- The minerals and rocks are the main sources for the production of automobiles, computers and many other things we use,
- Minerals and rocks play an important role in many earth processes such as landslides, coastal erosion and volcanic activity,
- Studies on minerals and rocks provide important information on earth history,
- Knowing process properties of the minerals and rocks provides to how the mechanisms in the earth and to understand how we can best manage the our earth resources.
# CRYSTAL SHAPES OF MINERALS

## Crystal Systems and Examples / Kristallsysteme und Beispiele

<table>
<thead>
<tr>
<th>System</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>cubic</td>
<td></td>
</tr>
<tr>
<td>tetragonal</td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td>hexagonal</td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>rhombic</td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td>monoclinic</td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>triclinic</td>
<td><img src="image5.png" alt="Image" /></td>
</tr>
</tbody>
</table>
## CRYSTAL SHAPES OF MINERALS

<table>
<thead>
<tr>
<th></th>
<th>cubic</th>
<th>tetragonal</th>
<th>hexagonal</th>
<th>orthorhombic</th>
<th>monoclinic</th>
<th>triclinic</th>
</tr>
</thead>
<tbody>
<tr>
<td>examples:</td>
<td>halite</td>
<td>zircon</td>
<td>quartz</td>
<td>sulfur</td>
<td>mica</td>
<td>feldspar</td>
</tr>
<tr>
<td></td>
<td>galena</td>
<td>chalcopyrite</td>
<td>calcite</td>
<td>staurolite</td>
<td>gypsum</td>
<td>rhodonite</td>
</tr>
</tbody>
</table>
PHYSICAL PROPERTIES OF MINERALS

The main physical properties of minerals;

- Tenacity,
- Hardness,
- Fracture,
- Cleavage,
- Streak,
- Luster,
- Density
Tenacity

- The property of tenacity describes the behavior of a mineral under deformation. It describes the physical reaction of a mineral to externally applied stresses such as crushing, cutting, bending, and striking forces. Adjectives used to characterize various types of mineral tenacity include 'brittle,' 'flexible,' 'elastic,' 'malleable,' 'ductile,' and 'sectile.'

  Mica (turns back to its original state when twisted), Chlorite (remains twisted)

- When the hammer hit some minerals can become extended or plate.

  Gold, silver, copper.
Tenacity

• *Brittle* - Breaks or powders easily.

• *Malleable* - can be hammered into thin sheets.

• *Sectile* - can be cut into thin shavings with a knife.

• *Ductile* - bends easily and does not return to its original shape.

• *Flexible* - bends somewhat and does not return to its original shape.

• *Elastic* - bends but does return to its original shape.
Tenacity

Most mineral species are brittle, and will crumble or fracture under pressure or upon the application of a blow. Such materials break or powder easily.

Antimony and quartz etc.
Hardness

**Hardness** has traditionally been defined as the level of difficulty with which a smooth surface of a mineral specimen may be scratched.

The hardness of a mineral species is dependent upon the strength of the bonds which compose its crystal structure.

Hardness is a property characteristic to each mineral species and can be very useful in identification.
Hardness

• Hardness minerals are resistance to scratching.
• It is the result of the cohesion between these molecules.
• It is determined with the aid Mohs hardness scale formed by mineral hardness.
# Mohs Hardness Scale

<table>
<thead>
<tr>
<th>Mineral Name</th>
<th>Scale Number</th>
<th>Common Object</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diamond</td>
<td>10</td>
<td>Masonry Drill Bit (8.5)</td>
</tr>
<tr>
<td>Corundum</td>
<td>9</td>
<td>Steel Nail (6.5)</td>
</tr>
<tr>
<td>Topaz</td>
<td>8</td>
<td>Knife/Glass Plate (5.5)</td>
</tr>
<tr>
<td>Quartz</td>
<td>7</td>
<td>Copper Penny (3.5)</td>
</tr>
<tr>
<td>Orthoclase</td>
<td>6</td>
<td>Fingernail (2.5)</td>
</tr>
<tr>
<td>Apatite</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Fluorite</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Calcite</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Gypsum</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Talc</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>RATING</td>
<td>DESCRIPTION</td>
<td>MINERAL EXAMPLE</td>
</tr>
<tr>
<td>---------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>1: VERY SOFT</td>
<td>EASILY CRUMBLES. CAN BE SCRATCHED WITH A FINGERNAIL (2.2)</td>
<td>TALC</td>
</tr>
<tr>
<td>2: SOFT</td>
<td>CAN BE SCRATCHED WITH A FINGERNAIL (2.2)</td>
<td>GYPSUM</td>
</tr>
<tr>
<td>3: SOFT</td>
<td>CAN BE SCRATCHED WITH A COPPER PENNY (3.5)</td>
<td>CALCITE</td>
</tr>
<tr>
<td>4: SEMI-HARD</td>
<td>CAN BE SCRATCHED WITH A NAIL (5.2)</td>
<td>FLUORITE</td>
</tr>
<tr>
<td>5: HARD</td>
<td>CAN BE SCRATCHED WITH A NAIL (5.2)</td>
<td>APATITE</td>
</tr>
<tr>
<td>6: HARD</td>
<td>MINERAL WITH HARDNESS OF 6 OR MORE CAN SCRATCH GLASS</td>
<td>FELDSPAR</td>
</tr>
<tr>
<td>7: VERY HARD</td>
<td>CAN BE SCRATCHED WITH A CONCRETE NAIL (7.5)</td>
<td>QUARTZ</td>
</tr>
<tr>
<td>8: VERY HARD</td>
<td></td>
<td>TOPAZ</td>
</tr>
<tr>
<td>9: EXTREMELY HARD</td>
<td>USED IN INDUSTRIAL TOOLS FOR CUTTING AND GRINDING</td>
<td>CORUNDUM</td>
</tr>
<tr>
<td>10: THE HARDEST</td>
<td>DIAMOND IS USED TO CUT ALL MINERALS</td>
<td>DIAMOND</td>
</tr>
</tbody>
</table>
Cleavaga

- A cleavage plane is a plane of structural weakness along which a mineral is likely to split smoothly.
- Cleavage thus refers to the splitting of a crystal between two parallel atomic planes.
- Despite the fact that every mineral belongs to a specified crystal system, not every mineral exhibits cleavage.
- Cleavage planes, if they exist, are always parallel to a potential crystal face. However, such planes are not necessarily parallel to the faces which the crystal actually displays. Fluorite, for example, has octahedral cleavage yet forms cubic crystals.
- Nonetheless, the property of cleavage, if it is present, can offer important information about the symmetry and inner structure of a crystal.
Fracture

If the mineral contains no planes of weakness, it will break along random directions called fracture. Several different kinds of fracture patterns are observed.

- Conchoidal fracture - breaks along smooth curved surfaces.
- Fibrous and splintery - similar to the way wood breaks.
- Hackly - jagged fractures with sharp edges.
- Uneven or Irregular - rough irregular surfaces.
Colour

- Color is sometimes an extremely diagnostic property of a mineral, for example olivine and epidote are almost always green in color.
- But, for some minerals it is not at all diagnostic because minerals can take on a variety of colors. These minerals are said to be allochromatic. For example quartz can be clear, white, black, pink, blue, or purple.
Streak

Streak is the color produced by a fine powder of the mineral when scratched on a streak plate. Often it is different than the color of the mineral in non-powdered form.

Hematite: red; Limonite: brown; Magnetite: dark gray; Chromite: brown; Magnetite: dark gray; Chromite: brown
Luster

Luster refers to the general appearance of a mineral surface to reflected light. Two general types of luster are designated as follows:

- **Metallic** - looks shiny like a metal. Usually opaque and gives black or dark colored streak.
- **Non-metallic** - Non metallic lusters are referred to as
  
  - **vitreous** - looks glassy - examples: clear quartz, tourmaline
  - **resinous** - looks resinous - examples: sphalerite, sulfur.
  - **pearly** - iridescent pearl-like - example: apophyllite.
  - **greasy** - appears to be covered with a thin layer of oil - example: nepheline.
  - **silky** - looks fibrous. - examples - some gypsum, serpentine, malachite.
  - **adamantine** - brilliant luster like diamond.
Structure

Kidney, chordal, chordal radial, concussion, lump and concentric.

• Kidney: Chalcedon, hematite
• Chordal: Asbestos, gypsum, calcite,
• Radial: Antimuan,
• Chordal radial: Pyrite, barite
• Concussion: Calcite, agate, pyrite, agate
• Lump: Flintstone
• Concentric: Agat, Calcedon
Specific Gravity

• Density refers to the mass per unit volume.

• Specific Gravity is the relative density, (weight of substance divided by the weight of an equal volume of water).

• In cgs units density is grams per cm$^3$, and since water has a density of 1 g/cm$^3$, specific gravity would have the same numerical value has density, but no units (units would cancel).

• Specific gravity is often a very diagnostic property for those minerals that have high specific gravities.

• In general, if a mineral has higher atomic number cations it has a higher specific gravity.
## Specific Gravity

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Composition</th>
<th>Atomic # of Cation</th>
<th>Specific Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aragonite</td>
<td>CaCO₃</td>
<td>40.08</td>
<td>2.94</td>
</tr>
<tr>
<td>Strontianite</td>
<td>SrCO₃</td>
<td>87.82</td>
<td>3.78</td>
</tr>
<tr>
<td>Witherite</td>
<td>BaCO₃</td>
<td>137.34</td>
<td>4.31</td>
</tr>
<tr>
<td>Cerussite</td>
<td>PbCO₃</td>
<td>207.19</td>
<td>6.58</td>
</tr>
</tbody>
</table>
Specific Gravity

Specific gravity can usually be qualitatively measured by the heft of a mineral, in other words those with high specific gravities usually feel heavier.

Most common silicate minerals have a specific gravity between about 2.5 and 3.0. These would feel light compared to minerals with high specific gravities.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Composition</th>
<th>Specific Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graphite</td>
<td>C</td>
<td>2.23</td>
</tr>
<tr>
<td>Quartz</td>
<td>SiO$_2$</td>
<td>2.65</td>
</tr>
<tr>
<td>Feldspars</td>
<td>(K,Na)AlSi$_3$O$_8$</td>
<td>2.6 - 2.75</td>
</tr>
<tr>
<td>Fluorite</td>
<td>CaF$_2$</td>
<td>3.18</td>
</tr>
<tr>
<td>Topaz</td>
<td>Al$_2$SiO$_4$(F,OH)$_2$</td>
<td>3.53</td>
</tr>
<tr>
<td>Corundum</td>
<td>Al$_2$O$_3$</td>
<td>4.02</td>
</tr>
<tr>
<td>Barite</td>
<td>BaSO$_4$</td>
<td>4.45</td>
</tr>
<tr>
<td>Pyrite</td>
<td>FeS$_2$</td>
<td>5.02</td>
</tr>
<tr>
<td>Galena</td>
<td>PbS</td>
<td>7.5</td>
</tr>
<tr>
<td>Cinnabar</td>
<td>HgS</td>
<td>8.1</td>
</tr>
<tr>
<td>Copper</td>
<td>Cu</td>
<td>8.9</td>
</tr>
<tr>
<td>Silver</td>
<td>Ag</td>
<td>10.5</td>
</tr>
</tbody>
</table>
Radioactivity

The radioactivity in the minerals comes from the uranium (U) and thorium (Th) found in them. Some elements such as potassium (K) and rubidium (Rb) also have a small amount of radioactivity.

It is aimed to determine the geological age by making use of the radioactivity feature in minerals.
Chemical properties of the minerals

• Minerals have a special composition
  • It is determined by qualitative and quantitative analyzes and indicated by related formulas.
  • The same chemical composition, a different crystal system polymorphism (multidimensionality) is used.
    • Calcite with aragonite and diamond with graphite are polymorph minerals.
  • If minerals have the same shape but they have different chemical composition, isomorphism (coordination) is used.
    • Calcite (CaCO3) dolomite (CaCO3.MgCO3) and siderite (FeCO3) are isomorphic minerals.

<table>
<thead>
<tr>
<th>Bileşim</th>
<th>İsim</th>
<th>Sistem</th>
<th>Özgül Ağırlık (gr/cm³)</th>
<th>Sertlik (Mohs)</th>
<th>Optik Özellik</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaCO₃</td>
<td>Kalsit</td>
<td>Romboedrik</td>
<td>2,7</td>
<td>3,0</td>
<td>Tek eksenli</td>
</tr>
<tr>
<td></td>
<td>Aragonit</td>
<td>Ortorombik</td>
<td>2,9-3,0</td>
<td>3,5-4,0</td>
<td>Çift eksenli</td>
</tr>
</tbody>
</table>
Optical properties of the minerals

• The light-related properties of the minerals make up the optical properties of minerals. Optical properties of the minerals provide colours, fracture properties, single and double breaking properties, and the shapes they show under a polarizing microscope.

• Apart from these properties of minerals, some minerals have their own unique characteristics. Some minerals are magnetic, some minerals are radioactive, some minerals are good conductors, and some minerals are poor conductors. Some minerals have piezoelectric properties. Industry benefits from these properties of the minerals.
THE IMPORTANCE OF MINERALS FOR CIVIL ENGINEERING

• Many minerals are used as building materials in the construction industry.
• The concrete is generally obtained with a mixture of gravel, sand, cement and water
• Aggregate (aggregate): sand, gravel, crushed stone (blasted rock), slag (slag) as concrete (concrete) course used for the construction or artificial or both types often broken in various sizes up to 10cm or broken granular material stack (sand + gravel + natural rock material consisting of crushed stone).
• Gypsum (gypsum); (CaSO4.2H2O-Mohs hardness 2); colorless or white color is converted into plaster losing some of the water at 120 ° C. Plaster is used in indoor and outdoor applications.
• Various clay minerals have been used in mud bricks, bricks, tiles since ancient times.
THE IMPORTANCE OF MINERALS FOR CIVIL ENGINEERING

• Pale limestone which is white or black without include silisium and clay is used for making lime
  • Lime is used as a binder in mortar and also in stabilization of roads.
  • Limes which are found various colour and pattern and well polished are used as coating materials in the buildings

• Apart from this, the mechanical behavior of the clays directly reflects on the structures and causes the forces to deform the structures.
THE IMPORTANCE OF MINERALS FOR CIVIL ENGINEERING

• Feldspar and feldspathoids, which are found in the composition of many masses, can be very dangerous for engineering because they are decomposed by environmental factors.
  • The behaviors of fully matured clay minerals vary with increasing water uptake rate and progressive dissociation time.
  • Therefore, if feldspars are encountered in the basement, applications are carried out, ranging from project changes to new measures to extend the construction time.
  • In such cases, a series of precautions are taken, such as removal of the dissimilar part, placement of the foundation in a firm-to-undeformed section, selection of the concrete quality with the appropriate foundation system and construction of a good drainage network.
THE IMPORTANCE OF MINERALS FOR CIVIL ENGINEERING

• The concrete is generally obtained with a mixture of gravel, sand, cement and water depending on the importance and size of the engineering structure to be built, the chemistry of each of these components forming concrete may be primary importance.

• Especially aggregate (sand-gravel) which is added to concrete and constitutes 75-85% by weight of concrete is either naturally extracted from the earth's crust or artificially broken by rock masses.

• If quartz sand and pebbles are to be used as aggregates in a dam body concrete, they must be well studied.

• The high alkaline cement in the concrete is affected by the hydration caused by the hardening of the concrete and the alkali such as sodium-potassium in the cement are released.

• Quartz, opal, chalcedony, agate, tridimite sand and gravel composed of siliceous minerals and silicates interact with the alkalis released in the concrete, cause expansion, cracking and fracturing of the concrete.

• This results in concrete can be easily damaged by being non-resistant against external influences. The volume percentages of the silica minerals constituting the aggregate component in the concrete are as follows; Opal 0,20%; Calcinedon 5%; Acid volcanic mass% 3
The main minerals found in the rocks

The rocks are mineral assemblages; either by the combination of various minerals or pieces of stone, or by the accumulation of a large number of single minerals.

**Main minerals:** Mass forming and called minerals play a role in their nomenclature. A number of them are 20 to 30.

Quartz, feldspar, nepheline, olivine etc. They play a role in the name of this rock minerals.

**Accessory minerals:** tourmaline, magnetite, zircon, etc. There are also minerals that rarely enter into the masses and have no effect on their naming.

**Secondary minerals:** New minerals that have formed as a result of various environmental factors of the existing main minerals, mostly due to the effects of decomposition, metamorphism and melt, and their composition.

Kaolin, serpentine, chlorite, zeolite etc.
The main minerals found in the rocks

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Kimyasal Bileşimi</th>
<th>Kristal Sistemi</th>
<th>Dilinimi</th>
<th>Sertliği (Mohs)</th>
<th>Yoğunluğu (gr/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kuvars</td>
<td>SiO₂</td>
<td>Heksagonal</td>
<td>± Yok</td>
<td>7</td>
<td>2,65</td>
</tr>
<tr>
<td>Ortoz-Sanidin</td>
<td>K₂Al₂Si₃O₈</td>
<td>Monoklinal</td>
<td>İyi, çok iyi</td>
<td>6</td>
<td>2,56</td>
</tr>
<tr>
<td>Albit</td>
<td>NaAlSi₃O₈</td>
<td>Triklinal</td>
<td>Çok iyi</td>
<td>6</td>
<td>2,62</td>
</tr>
<tr>
<td>Anortit</td>
<td>CaAl₂Si₂O₈</td>
<td>Triklinal</td>
<td>İyi</td>
<td>6</td>
<td>2,72</td>
</tr>
<tr>
<td>Nefelin</td>
<td>NaAlSiO₄</td>
<td>Heksagonal</td>
<td>Zayıf</td>
<td>6</td>
<td>2,60</td>
</tr>
<tr>
<td>Lösit</td>
<td>KAl₂SiO₄</td>
<td>Kübik</td>
<td>Zayıf</td>
<td>6</td>
<td>2,47</td>
</tr>
<tr>
<td>Biyotit</td>
<td>K(Mg,Fe)₃(Al₃O₁₀)(OH)₂</td>
<td>Monoklinal</td>
<td>Çok iyi</td>
<td>2,5</td>
<td>2,80</td>
</tr>
<tr>
<td>Muskovit</td>
<td>KAl₃(Al₂Si₃O₁₀)(OH)₂</td>
<td>Monoklinal</td>
<td>Çok iyi</td>
<td>2,5</td>
<td>2,90</td>
</tr>
<tr>
<td>Klorit</td>
<td>(Mg,Fe,Al₆)(Al,Fe₂O₃OH)₆</td>
<td>Monoklinal</td>
<td>Çok iyi</td>
<td>2,5</td>
<td>2,60-3,30</td>
</tr>
<tr>
<td>Ojit</td>
<td>Ca(Mg,Fe,Al)(Al₂SiO₃O₆)</td>
<td>Monoklinal</td>
<td>İyi</td>
<td>6</td>
<td>3,25-3,55</td>
</tr>
<tr>
<td>Enstatit</td>
<td>MgSiO₃</td>
<td>Ortorombik</td>
<td>İyi</td>
<td>6</td>
<td>3,20-3,90</td>
</tr>
<tr>
<td>Hornblend</td>
<td>NaCa₃(Mg,Fe,Al₆)(Al₂Si₃O₁₂)OH₂</td>
<td>Monoklinal</td>
<td>İyi</td>
<td>6</td>
<td>3,0-3,4</td>
</tr>
<tr>
<td>Piro</td>
<td>Mg₃Al₂(SiO₄)₃</td>
<td>Kübik</td>
<td>Yok</td>
<td>7-7,5</td>
<td>3,56</td>
</tr>
<tr>
<td>Almandin</td>
<td>Fe₃Al₂(SiO₄)₃</td>
<td>Kübik</td>
<td>Yok</td>
<td>7-7,5</td>
<td>4,32</td>
</tr>
<tr>
<td>Olivin</td>
<td>(Mg,Fe)₂SiO₄</td>
<td>Ortorombik</td>
<td>Belirsiz</td>
<td>6,5</td>
<td>3,22</td>
</tr>
<tr>
<td>Apatit</td>
<td>Ca₅(PO₄)₃(F,Cl,OH)</td>
<td>Heksagonal</td>
<td>Belirsiz</td>
<td>5</td>
<td>3,20</td>
</tr>
<tr>
<td>Zirkon</td>
<td>ZrSiO₄</td>
<td>Tetragonal</td>
<td>Belirsiz</td>
<td>7,5</td>
<td>4,60-4,70</td>
</tr>
<tr>
<td>Andalusit</td>
<td>Al₂SiO₃</td>
<td>Ortorombik</td>
<td>Orta</td>
<td>7,5</td>
<td>3,15</td>
</tr>
<tr>
<td>Kalsit</td>
<td>CaCO₃</td>
<td>Trigonal</td>
<td>Çok iyi</td>
<td>2,7 (3)</td>
<td>2,71</td>
</tr>
<tr>
<td>Jips</td>
<td>CaSO₄·2H₂O</td>
<td>Monoklinal</td>
<td>Çok iyi</td>
<td>2</td>
<td>2,50-2,80</td>
</tr>
</tbody>
</table>
Main minerals in Magmatic rocks:

- Quartz
- Feldspar: Orthoclase, Plagioclase
- Feldspathoid: leucite, nepheline; Sodalite
- Pyroxene: Bronzeite, Enstatite, Hipersten, Augite, Diyalage, Deiodopsite
- Amphibole: Hornblend
- Mica: Biotite, Muscovite
- Perido: Olivin
Main minerals in sedimentary rocks

- Magmatic rock fragments (especially quartz and feldspar)
- Clay minerals
- Calcite, Dolomite
- Siderite
- Limonite
Main minerals in metamorphic rocks

- Quartz
- Feldspar
- Biotite, Muscovite
- Hornblend
- Epidote
- Garnet
- Silimanite
- Andalusite
- Calcite
- Serpentine
- Talc
- Chlorite
Secondary minerals

- The most important ones are Tourmaline, Magnetite, Ilmenite, Rutile, Apatite, Zircon and Topaz.
Quartz Group

- It is found in Magmatic, metamorphic and sedimentary masses.
- Crystal system Hexagonal,
- Density is 2.65 and hardness is 7.
- Usually colorless and transparent.
- Other elements that come into crystal structure can offer different colors. In this case, it gets different names. Some contain liquid or gaseous inclusions.
- Quartz has not cleavage.
- It offers its own unique twinning.
- The face of the fracture is concoidal, glassy and oily.
- It is not affected from acids apart from florur.
- Quartz which is pure and clean is used in optical and chemical industry and ceramic industry
- Bright and colorful varieties (Necefaşı, Amethist, Sitrin, Agat, etc.) are used in making ornaments.
Quartz Group

- There are many types of quartz. The most important ones are; Chalcedony; chrysoprase; Heliotrop; Agate; Flintstone; Jasper; Silicified Tree; Opal;
- If quartz sand and gravel are to be used as building material, it is necessary to carry out the analyzes thoroughly.
- When the quartz and its species used as aggregates in cement start to harden with high alkali cement, hydro treatment occurs and Na, K etc. The alkalies are released.
- All silicates, especially opal, chalcedony and agate, and siliceous minerals act with alkalis, causing the concrete material to expand, crack, break down and eventually reduce its strength.
- Therefore, cement-aggregate reactions become important according to the size and importance of the structure to be constructed.
Quartz Group

Yüksek alkali çimento+agrega
   └ Sertleşikten hidratasyon olayları
       └ Alkaliler (Na, K vs.) açıkça çıkar
           └ Silikat ve silisli mineraallere etkir
               └ Betonda genişleme, çatlama, dağıılma gelişir. Mukavemet azalır.
Feldspars

• They form 40-50% of the earth's crust, their composition is potassium-sodium-calcium aluminum silicate.
• The crystal system is Monoclinal or Triclinal.
• There are cleavages in two directions and by the angle between the cleavage planes;
  1. orthoclases
  2. Plagioclase
Feldspars

Ortoklas Group; Cleavage angles are 90 feldspar. They are crystallized in the monoclinal system. Orthotic mineral is important in this group.

Plajioklas Group; the angles of cleavage of feldspar is 86,80.

This group of minerals;

Albite and Anorthite consist of a mixture of different proportions. They are crystallized in the triclinal system. Colors are variable. The fracture faces are glassy.

• Their hardness is 6-6,5 and their specific weights are 2,60-2,76. They are found in different proportions in the composition of Magmatic stones and play an important role in naming these rocks.

• It is also found in metamorphic and sedimentary rocks.
Feldspars

• Nomenclature is based on the percentage of Na and Ca in the compositions. The main minerals of this group are;
  1. Albite (NaOAl2O3), (90-100% Albite + 0-10% Anorthite)
     Oligoclase
  3. Andesine (50% Albite + 50% Anorthite)
  4. Labrador
  5. Bitovnit
  6. Anorthite (CaOAl2O32SiO2), (90-100 Anorthite + 0-10% Albite)
Decomposition of feldspar;

- As a result of the decomposition events, quartz occurs with clay minerals that are soluble in water.
- Factors affecting decomposition: Climate, temperature, humidity, the effect of superficial acid waters and fumerols or hydrothermal processes which are deeply magic.
- The shape and depth of the variable increase in volume is the result of decomposition of 5-30%.
- The carrying capacity of the decomposition mass and pressure resistance are reduced. When building on such masses, it is necessary to pay attention to disintegration events.

\[
\begin{align*}
\text{H}_2\text{O} + \text{CO}_2 & \rightarrow \text{H}_2\text{CO}_3 \\
2\text{KAlSi}_3\text{O}_8 + n\text{H}_2\text{O} & \rightarrow \text{K}_2\text{CO}_3 + 2\text{SiO}_2 + \text{Al}_2(\text{OH})_2\text{Si}_4\text{O}_{10}.\text{H}_2\text{O} \quad \text{Ortoz} \\
2\text{NaAlSi}_3\text{O}_8 + \text{CaAl}_2\text{Si}_2\text{O}_8 + 4\text{H}_2\text{CO}_3 + 2\text{H}_2\text{O} & \rightarrow \text{Ca}(\text{HCO}_3)_2 + 2\text{NaHCO}_3 + 2\text{Al}_2(\text{OH})_2\text{Si}_4\text{O}_{10}.\text{H}_2\text{O} + \text{SiO}_2 \quad \text{Albit + Anortit}
\end{align*}
\]
Kaolenization-argillisation

Feldispot + (CO2 + H2O) + iklim (sıcaklık-nem) + yüzeysel asidik sular

Kil mineralleri (kaolen) + kuvars ± zeolit + %5-30 hacim artışı

Taşıma gücü ve basınç dayanımında düşme
4. WEEK
Rock forming minerals

- Rocks is assemblies of minerals, it is formed by various minerals or rock fragments come together or consists of a large number of accumulations of a single mineral.
- It is found in the majority of 8 element minerals as rock builder, representing more than 98% of the weight of the continental crust.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>%46.6</td>
</tr>
<tr>
<td>Silisium</td>
<td>%27.72</td>
</tr>
<tr>
<td>Aluminum</td>
<td>%8.13</td>
</tr>
<tr>
<td>Iron</td>
<td>%5</td>
</tr>
<tr>
<td>Calcium</td>
<td>%3.63</td>
</tr>
<tr>
<td>Sodium</td>
<td>%2.83</td>
</tr>
<tr>
<td>Potassium</td>
<td>%2.59</td>
</tr>
<tr>
<td>Magnesium</td>
<td>%2.09</td>
</tr>
</tbody>
</table>

Most common elements in the crust:
- Oxygen (46.4%)
- Silicon (28.2%)
- Magnesium (2.33%)
- Calcium (4.15%)
- Sodium (2.36%)
- Aluminum (8.32%)
- Iron (5.63%)
- Titanium (0.57%)
- Potassium (2.09%)
- Magnesium (2.09%)
- Hydrogen (0.14%)
The rocks that make up the Earth's crust are the various minerals or single minerals, rock fragments, or both mineral and rock fragments.

For example, Magmatic rocks such as granite, gabbro, syenite are formed by minerals; marble, quartzite is formed by a single mineral; various types of sandstones and conglomerates are formed by rocks and minerals.

The rocks are studied according to their formation conditions and their origins;

• Magmatic rocks;
• Sedimentary rocks;
• Metamorphic rocks;
Rock forming minerals

- Kaya Oluşturan Mineraller
  - Silikat Mineralleri
    - Olivin Grubu
    - Prokoen Grubu
    - Antibol Grubu
    - Mikeler: Biotit-Muskovit
    - Feldspatlar: Ortoklas-Fraflyoklas
    - Kuvart
  - Silikat Olmayan Mineraller
    - Karbonatlar
    - Haltlier
    - Oksitler
    - Sulfiter
    - Sulfatlar
    - Değeri Elementler (Tek ailesi elementler)
Rock Cycle

CLASSIFICATION OF ROCKS

Sedimentary
- Chemical
  - Limestone
  - Dolomite
  - Evaporites
- Biologic
  - Coal
  - Chert
- Clastic
  - Conglomerate
  - Breccia
  - Sandstone
  - Siltstone
  - Mudstone
  - Shale

Igneous
- Intrusive
  - Gabbro
  - Diorite
  - Granodiorite
  - Granite
- Extrusive
  - Basalt
  - Andesite
  - Dacite
  - Rhyolite

Metamorphic
- Foliated
  - Slate
  - Schist
  - Gneiss
- Non-foliated
  - Quartzite
  - Marble

Sediments & Sedimentary Rocks

Magma

Melting

Crystallization

Metamorphic Rocks

Metamorphism

Erosion

Igneous Rocks

Sedimentation
Magmatic Rocks

• If the hot and fluid melt "magma" found in the depths of the earth is cooled or crystallized, it is called as "Magmatic rocks"

• Magma contains O, Si, Al, Fe, Ca, Mg, Na, K together with water, other rare earth elements as well as CO2, SO2 in vapor form.
Magmatic Rock Forming Minerals

• Main minerals; Quartz, feldspar (orthoclase, plagioclase), nepheline, sodalite, leucite, mica, muscovite, biotite, pyroxene, amphibole olivine.

• Accessory minerals; Zircon, sifen, magnetite, ilmenite, hematite, apatite, pyrite, rutile, corundum, garnet.
Acidic (felsic) if it contains 65% silica and a large amount of aluminum, sodium, potassium and a small amount of calcium, iron and magnesium;

Neutral (intermediate) if it contains 52-65% silica;

It is possible to call it basic (mafic) component magma if it contains more than 45-52% of silica, calcium, iron and magnesium.
• The basic magma often reflects the composition of the mantle source area.

• The oceanic crust is a basic compound and richer in Fe and Mg elements. Therefore oceanic crust is more intense than the continental crust and the asthenosphere directly owned properties hosting site.

• The continental crust, on the other hand, consists of minerals rich in silicon and aluminum. While the magma that passes through the continental crust, it takes the material from the crust in its place. As a result of this, its composition returns from basic to neutral and acidic composition. Therefore, magmatic rock in the continental crust is richer and less intensive in terms of SiO2 mineral.
Magmatic rocks

The change in the amount of SiO2 in the bodies of magmatic rocks causes significant changes in the color of the rocks. The minerals and rocks rich in basic iron and nickel elements are darker, while minerals and rock which is acidic in nature and the richer in SiO2 are lighter.
Magmatic rocks

• The composition of the magmatic rock develops depending on the composition of the last melt crystallized the rock.
  - If the melt is poorly silicic, the rocks consist poorly siliceous and richly dark ferromagnesite minerals, they are formed by dark colored rocks in the melt. For example, Gabro
  - If the ratio of silica is high, quartz crystals are formed because the rocks are rich in silica and they have so less dark colored minerals
  - All of the magmatic rocks such as peridotite can be composed of ferromagnesian (dark colored) minerals. The composition of these rocks is not the same as the composition of the melt.
Magmatic rocks

• The magma, which is hot and fluid, moves in different depths under different composition and pressure.

• Plutonic rocks are formed underground. They involve the "intrusion" or insertion of magma between other rocks, which then cools below the surface.

• Volcanic rocks are formed above ground. They involve the "extrusion" or eruption of magma, which then is called "lava." The lava cools upon or very close to the surface. Volcanic rocks can also form from "ash," which is simply pulverized rock blown into the air (not like the "ash" that results from burning wood) -- larger rocks are "bombs."
Extrusive igneous rocks cool quickly and as a result these rocks are fine grained or has lack of crystal growth.

Intrusive igneous rocks are formed from magma that cools slowly and as a result these rocks are coarse grained.

Magmatik kayaçlar

Şekil 3.4. Derinlik, yarı derinlik ve yüzey kayaçlarının yer kabuğunda oluşturdukları bölgeler ile asidik ve bazık karakterli kayaçlara ait örnekler (Press vd., 2004).
Magmatic rocks

- Intrusive rocks;
  - They are sturdy and durable (because they are made of crystal only)
    Granite, syenite

- Extrusive rocks;
  - It is semi-crystalline and the crystals are floating in a dough
    Andesite, rhyolite, basalt

- Semi-deep rocks;
  - They form a transition between the depth rocks and the surface rocks.
  - The slurry is not glassy, and other rocks are composed of small crystals in cracks and crevices are located.
    Granitporphyr, quartosporphyr, syenitporphyr
Magmatic rocks

• **Plutonic rocks;** crystallize below Earth's surface, and the slow cooling that occurs there allows large crystals to form. Examples of intrusive igneous rocks are diorite, gabbro, granite, pegmatite, and peridotite.

• After occurring solidifies dozens or even hundreds over the years up to millions continental uplift as a result of erosion of sediments that can reach several kilometers thick on them as a result of wear of such rocks are seen today on the ground surface in the current topography.

  • Çavuşbaşi granodiorite pluton on the Anatolian side of Istanbul and granite pluton of Gebze-Sancaktepe.
Magmatic rocks

• **Semi-deep rocks;** Magmatic rocks are called semi-deep rocks as the magmatic rocks which eventually solidify on the earth in the course of upward movement following the discontinuities such as cracks and cracks in the upper part of the lithosphere.

• Intrusive rocks consist of coarse, very coarse grains of crystals that develop due to slow cooling and less pressure in spaces and cracks at depths near the earth. Granite pegmatite, gabbro pegmatite, etc. named.
Magmatic rocks

Commonly observed forms of intrusive rocks observed in the field are: dykes, sills, laccoliths, bysmaliths, phacoliths, lopolith, volcanic necks, batholiths and chonoliths.
Magmatic rocks

Dikes cut across layers of country rock...

but sills run parallel to them.

Batholiths are the largest forms of plutons, covering at least 100 km².
DYKES: Dykes and sills are the most common forms of the intrusive Magmatic bodies.

- They are discordant
- Cut across the bedding of the rocks in which they intrude
- Vertical to steeply inclined and sheet like body (extensive in lateral dimension)
- Thickness vary widely from an inch up to hundred of feet
- Injected through fractures, joints, and weak planes
Quartz-Dolerite dykes of Midland valley of Scotland are about 50-60 km long and up to 30m thick. Few places some dykes are very short up to few meters and as thin as few cm.
SILLS: Sills are relatively thin tabular sheet like body that penetrates parallel to the bedding planes.

- Laterally it may extends for 100s of km and up to 10 km in width.
- Lateral extend mainly depends on the hydrostatic force, temperature, degree of fluidity or viscosity, weight of overlying sediment column.
- Since basic magma are more fluid then acidic magma- mostly sills are made up of gabros, dolorites and basalts
Spreads parallel to the bedding planes of the rocks, hence concordant in nature.
**LACCOLITHS**: It is a concordant body, with flat bottom and convex upward. It is dome shaped.

- When viscous magma is injected rapidly along the bedding, as it cannot spread, it pushes up the overlying layers and keep on piling up.
- It causes folding of the overlying rock layers.
BATHOLITHS: are the largest kind of plutons, irregular in shape and occupies large area.

- Their side sloping away from each other which makes them larger and large downwards extending to greater depth

- Their occurrence is commonly associated with the mountain-building process

- These are either granites or granodiorites in composition
**Stocks:** Are smaller irregular bodies with 10 km in maximum dimension, and are associated with batholiths.
**PHACOLITHS:** These are concordant bodies that occurs along the crests and troughs of the folded sedimentary strata.

**LOPOLITHS:** These are basin or saucer-shaped concordant bodies with top nearly flat and convex bottom. They are very huge body with diameter up to 150 miles (app. 240 km)
Magmatic rocks

• Extrusive Magmatic rocks are rocks formed by cooling magma lavas near a surface with a chimney or by moving to the surface. The crystals are small because they cool quickly. They usually form a small crystalline matrix (porphyric texture) surrounding large crystals. In general, except for special conditions, the crystals are coarse grained rocks and the differences are fine-grained or glassy. For example when granite rocks from the depths to the surface through cracks reaches, rhyolites, diorites: andesite-dacite; Syenite: trachyte; Gabbro: basalt; Peridotite is called picrite. When the lavas cool very rapidly on the surface, there is no crystallization and the resulting texture is glassy.
Magmatic rocks

• Melt state magma can rise to the surface of the earth's crust cracks and crevices. Volcanic rocks form from magma emerging from the earth. The magma, which is fluid when it reaches the earth, solidifies after a while. Solidified magma is called "lava". Because the lava suddenly cool down, they show glassy texture. The volcanic material can sometimes rise to the earth as a solid. The grain size of the solid material changes. Classification according to grain size;

  • Block or volcano bomb larger than 32 mm,
  • lapilli those between 4-32 mm,
  • volcano ash in between 0.25-4 mm
  • Those larger than 0.25 mm are also called dust.
Classification of the pyroclastic rocks. 


Structure and texture of igneous rocks

• Structure: The natural architectural features of a rock mass seen on the ground in large scale. Here, the physical appearance of the rock mass determines character of the rock-forming mineral assemblages and plays an important role in shaping the rock mass structure. Faults are taken into account in the concept of platoon structure in joints, folds, flow or sedimentary rocks.
Structure and texture of igneous rocks

• Texture; The geometry and appearance of the minerals of the rocks, including the appearance, size, shape and arrangement of the rocks forming the rock, including their size, shape and sequence under a hand sample or microscope.

• The texture of Magmatic rocks depends on the conditions of the environment, such as magma or lava cooling rate, pressure and temperature, and slow cooling usually causes deep crystals to form at depths of the earth, and this texture is called fanaritic texture. The texture of minerals is visible in all plutonic rocks. In surface rocks, very fine grained texture, which is formed by rapid cooling on the surface and near the surface, can be seen only by magnification. Large grain crystals and the texture formed by the small crystals surrounding them are also called porphyryic texture.
Structure and texture of igneous rocks

• In Magmatic rocks, they are classified according to their crystallization grades (whole or semi-crystalline, all glass), crystal sizes (phaneretic, afanatic), grain sizes in relation to each other (granular and porphyric texture) and their relations with each other (panidiomorphic and hidiomorphic).

• The textures of Magmatic rocks play a major role in determining the physical and mechanical properties of Magmatic rocks, mineral species, mineral sizes, dissociation states. These qualities play an important role in the use of Magmatic rocks as construction or building materials.
• Textures by crystallization degree
  • Holocristalline (all crystalline) texture
  • Hypocrystalline texture (semicrystalline)
  • Holohyalin (crystalline / vitreous) texture

• Textures according to the crystal size
  • Afaneritic(<1 mm)
  • Faneritic (distinguishable by 5mm-1mm)
  • Pegmatitic (very coarse> 5 mm)
  • Porfiric (two-phase)

• Textures according to the crystal forms
  • Diamorph (self-shaping)
  • Hypidiomorph (partially self-shaped)
  • Csnomorph (self-formed)
Textures by crystallization degree:

Holocrystalline (all crystalline) texture
Hypocrystalline tissue (semicrystalline)
Holohyalin (crystalline / vitreous) tissue
Textures according to the crystal size

Afanitic (The particles are invisible <1 mm)
Faneritic (distinguishable by 5mm-1mm)
Pegmatitic (very coarse> 5 mm)
Porifric (two-phase)
Textures according to the crystal forms

diamorph (self-shaping)
Hypidiomorph (partially self-shaped)
Csnomorph (self-formed)
Magmatik Kayaçların yapı ve dokuları

<table>
<thead>
<tr>
<th>Texture</th>
<th>Composition</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phaneritic</td>
<td>Felsic (Granič)</td>
<td>Intermediate (Andesit)</td>
</tr>
<tr>
<td>Aphanitic</td>
<td>Rhyolite</td>
<td>Andesite</td>
</tr>
<tr>
<td>Porphyritic</td>
<td>Granite porphyry</td>
<td>Andesite porphyry</td>
</tr>
</tbody>
</table>

Fast cooling at surface

- A. Fine-grained
- C. Glassy (pumice)

Slow cooling below surface

- B. Coarse-grained
- D. Porphyritic
<table>
<thead>
<tr>
<th>Chemical Composition</th>
<th>Dominant Minerals</th>
<th>Texture</th>
<th>Rock Color</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Granitic</strong> (Felsic)</td>
<td>Quartz, Potassium feldspar, Sodium-rich plagioclase feldspar</td>
<td>Coarse-grained</td>
<td>(based on % of dark minerals)</td>
</tr>
<tr>
<td><strong>Andesitic</strong> (Intermediate)</td>
<td>Amphibole, Sodium- and calcium-rich plagioclase feldspar</td>
<td>Fine-grained</td>
<td>0% to 25%</td>
</tr>
<tr>
<td><strong>Basaltic</strong> (Mafic)</td>
<td>Pyroxene, Calcium-rich plagioclase feldspar</td>
<td>Porphyritic</td>
<td>25% to 45%</td>
</tr>
<tr>
<td><strong>Ultramafic</strong></td>
<td>Olivine, Pyroxene</td>
<td>Glassy</td>
<td>45% to 85%</td>
</tr>
</tbody>
</table>

*Porphyritic* precedes any of the above names whenever there are appreciable phenocrysts.

- Obsidian (compact glass)
- Pumice (frothy glass)
The Importance of Magmatic Rocks in Engineering

• Plutonic rocks often become resistant to breakage and pressure when they are fresh and although the rock is fractured. Therefore they show high resistance.

• They can be used in material engineering services when their resistance is between 1500-2000 kg / cm2.
The Importance of Magmatic Rocks in Engineering

• The resistance of the rock depends on weathering and hence degradation degree will vary inversely with the degree of weathering.

• Since the volcanic masses have different physical properties, it is necessary to thoroughly inspect them before construction starts.

• Some lavas, agglomerates and volcanic rocks protect their freshness, so their resistance may be as high as deep rocks such as basalt. But volcanic tuffs and breccias are hollow and decayed, so they show a drossy structure. At the same time they lose credibility because they show clay mineralization.
Metamorphic Rocks

✓ Any rock (igneous, sedimentary, or metamorphic) can become a metamorphic rock. If rocks are buried deep in the Earth at high temperatures and pressures, they form new minerals and textures all without melting. If melting occurs, magma is formed, starting the rock cycle all over again.

✓ Rocks that form when a pre-existing rock (protolith) changes due to temperature or pressure, and/or as a result of squashing or shearing.

✓ Metamorphism doesn’t include weathering, diagenesis, and melting. It is a solid-state process.
Metamorphic Rocks

- Metamorphism progresses incrementally from low grade to high-grade
- During metamorphism (transformation) the rock remains essentially solid
- Metamorphism characterized by
  - Growth of new minerals from pre-existing minerals through recrystallization
  - Deformation of existing minerals
  - Change in shape
  - Change in orientation
  - Metamorphic settings
Metamorphic Rocks

• Metamorphic rocks occur because of changes that are caused by high temperatures (above 600°C) and high pressures (500 Mpa) (20 km deep).
• Metamorphic rock type is depended on parent rocks (pre-existing rocks), the process through which a rock’s structure is changed by heat and pressure
  • Parent rocks can be Igneous, sedimentary, or other metamorphic rocks.
• Most of the metamorphic changes begin at depths of a few miles of the earth, continuing up to the upper mantle depths with rising temperature and pressure.
metamorphic rocks: controlling factors

• parent rock composition (also called protolith)
• temperature and pressure during metamorphism
• tectonic forces
• fluids
Figure 6.4 Metamorphic changes can occur as the result of changes in temperature, pressure, and in the composition of pore fluids, as the rocks attempt to reach equilibrium with the new conditions. These cross sections illustrate some of the changes.
parent rock composition

no new material is added to rock during metamorphism

*metamorphic rock will have similar composition to parent rock*

if parent material contains only one mineral

resultant metamorphic rock will only have one mineral

--mineral will be recrystallized (texture changes)--

```
Limestone    -->    Marble
```
if parent material contains many minerals…

...old minerals will recombine to form new minerals

clay, quartz, mica, and volcanic fragments in a sandstone will combine to form new metamorphic minerals

example is garnet: which grows during metamorphism

garnet growing
garnet schist (metamorphic rock)
heat is essential

temperature during metamorphism

• heat from Earth’s deep interior

• all minerals stable over finite temperature range

• higher temperatures than range cause melting (and therefore generates *igneous* rocks)

heat is essential

think about mixing flour, yeast, water, salt….

….nothing happens until they have a heat source and then they make bread
pressure during metamorphism

*pressure in the Earth acts the same in all directions*

**pressure is proportional to depth in the Earth**

- increases at \(~1\) kilobar per \(3.3\) km

*look at example with deep water*

*consequence on cube is squeezing into smaller cube --grains pack together--*

*high pressure minerals: more compact and dense*
tectonic forces - driven by plate motion!

lead to forces that are not equal in all directions (differential stress)

compressive stress (hands squeeze together)
causes flattening at 90° to stress

shearing (hands rubbing together)
causes flattening parallel to stress
flattened pebbles in metamorphic rock
fluids

- hot water (water vapor) most important
- heat causes unstable minerals to release water
- water reacts with surrounding rocks and transports dissolved material and ions

time

- metamorphism may take millions of years
- longer times allow new minerals to grow larger --coarser grained rocks
types of metamorphism

• Contact or thermal metamorphism
  Driven by a rise in temperature within the host rock
• Regional metamorphism
  Occurs during mountain building
  Produces the greatest volume of metamorphic rock
• Burial metamorphism
  Occurs at bottom of thick sedimentary rock piles
• Hydrothermal metamorphism
  chemical alterations from hot, ion-rich water
• Others
Contact metamorphism

- Occurs due to a rise in temperature when magma invades a host rock
- A zone of metamorphism forms in the rock surrounding the magma
- Most easily recognized when it occurs at the surface, or in a near-surface environment
types of metamorphism

contact metamorphism

- occurs adjacent to magma bodies intruding cooler country rock -- “contact”
- produces non-foliated metamorphic rocks
- happens in a narrow zone of contact (~1 to 100 m wide) known as aureole
- forms fine-grained (e.g. hornfels) or coarse-grained (e.g. marble) rocks
types of metamorphism

regional metamorphism

• occurs over wide region and mostly in deformed mountain ranges
• produces *foliated* metamorphic rocks
• happens at high pressures and over a range of temperature
• increases in pressures and temperatures forms rocks of higher metamorphic grade
(A) Contact metamorphism occurs around hot igneous intrusions. Changes in temperature and composition of pore fluids cause preexisting minerals to change and reach equilibrium in the new environment. Narrow zones of altered rock extending from a few meters to a few hundred meters from the contact are produced.

(B) Regional metamorphism develops deep in the crust, usually as the result of subduction or continental collision. Wide areas are deformed, subjected to higher pressures, and intruded by igneous rocks. Hot fluids may also cause metamorphic recrystallization.

FIGURE 6.6 Metamorphic environments are many and varied. Two major examples are shown here.
Burial metamorphism

• Associated with very thick sedimentary strata
• Required depth varies from one location to another
• Depending on the prevailing geothermal gradient
Other types of metamorphism

- Hydrothermal metamorphism

Chemical alteration caused when hot, ion-rich fluids, called hydrothermal solutions, circulate through fissures and cracks that develop in rock. Most widespread along the axis of the mid-ocean ridge system.

cold sea water encounters hot basalt, forms steam, alters minerals
other types of metamorphism (less common)

partial melting during metamorphism

• produces migmatites, which have both intrusive and metamorphic textures

shock metamorphism

• occurs during impact events
• yields very high pressures
• forms “shocked” rocks around impact craters
plate tectonics and metamorphism

regional metamorphism associated with *convergent* boundaries

- pressure increases with depth
- temperature varies laterally
- different P, T conditions yield different degrees of metamorphism

*temperatures cooler in down-going (subducting) plate*  
(dashed purple line is *isotherm* -- line of equal T)
Metamorphic rocks are classified on the basis of:
- **texture** and
- **composition** (either mineralogical or chemical)

<table>
<thead>
<tr>
<th>Rock Name</th>
<th>Texture</th>
<th>Grain Size</th>
<th>Comments</th>
<th>Parent Rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slate</td>
<td>Foliated</td>
<td>Very fine</td>
<td>Excellent rock cleavage, smooth dull surfaces</td>
<td>Shale, mudstone, or siltstone</td>
</tr>
<tr>
<td>Phyllite</td>
<td>Fine</td>
<td>Coarse</td>
<td>Breaks along wavy surfaces, glossy sheen</td>
<td>Slate</td>
</tr>
<tr>
<td>Schist</td>
<td>Medium to Coarse</td>
<td></td>
<td>Micaceous minerals dominate, scaly foliation</td>
<td>Phyllite</td>
</tr>
<tr>
<td>Gneiss</td>
<td>Medium to Coarse</td>
<td></td>
<td>Compositional banding due to segregation of minerals</td>
<td>Schist, granite, or volcanic rocks</td>
</tr>
<tr>
<td>Migmatite</td>
<td>Medium to Coarse</td>
<td></td>
<td>Banded rock with zones of light-colored crystalline minerals</td>
<td>Gneiss</td>
</tr>
<tr>
<td>Mylonite</td>
<td>Fine</td>
<td>Coarse</td>
<td>When very fine-grained, resembles chert, often breaks into slabs</td>
<td>Any rock type</td>
</tr>
<tr>
<td>Metaconglomerate</td>
<td>Coarse-grained</td>
<td></td>
<td>Stretched pebbles with preferred orientation</td>
<td>Quartz-rich conglomerate</td>
</tr>
<tr>
<td>Marble</td>
<td>Medium to coarse</td>
<td></td>
<td>Interlocking calcite or dolomite grains</td>
<td>Limestone, dolostone</td>
</tr>
<tr>
<td>Quartzite</td>
<td>Medium to coarse</td>
<td></td>
<td>Fused quartz grains, massive, very hard</td>
<td>Quartz sandstone</td>
</tr>
<tr>
<td>Hornfels</td>
<td>Fine</td>
<td></td>
<td>Usually, dark massive rock with dull luster</td>
<td>Any rock type</td>
</tr>
<tr>
<td>Anthracite</td>
<td>Fine</td>
<td></td>
<td>Shiny black rock that may exhibit conchoidal fracture</td>
<td>Bituminous coal</td>
</tr>
<tr>
<td>Fault breccia</td>
<td>Medium to very coarse</td>
<td></td>
<td>Broken fragments in a haphazard arrangement</td>
<td>Any rock type</td>
</tr>
</tbody>
</table>
Granite
igneous

Sandstone
sedimentary

Shale
sedimentary

Heat and pressure

Gneiss
metamorphic, foliated

Quartzite
metamorphic, nonfoliated

Slate
metamorphic, foliated
With increasing temperature and pressure, metamorphic grade also increases. The higher the metamorphic grade, the more changed the rock will be from its original form. The rocks shown here are (left to right) slate, phyllite, schist and gneiss.

(Photographs by Parvinder Sethi)
<table>
<thead>
<tr>
<th>Texture</th>
<th>Composition</th>
<th>Type of Metamorphism</th>
<th>Comment</th>
<th>Rock Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOLIATED</td>
<td>Mica</td>
<td>Regional</td>
<td>Low-Grade metamorphism of SHALE</td>
<td>Slate</td>
</tr>
<tr>
<td>MINERAL ALIGNMENT</td>
<td>Mica, Quartz, Feldspar, Amphiboles, Garnet</td>
<td>(Heat and Pressure increase w/ depth)</td>
<td>Foliation surfaces shiny from microscopic mica crystals</td>
<td>Phyllite</td>
</tr>
<tr>
<td></td>
<td>Mica, Quartz, Feldspar, Amphiboles, Garnet, Pyroxene</td>
<td></td>
<td>Platy mica crystals visible</td>
<td>Schist</td>
</tr>
<tr>
<td>BANDING</td>
<td>Mica, Quartz, Feldspar, Amphiboles, Garnet, Pyroxene</td>
<td></td>
<td>Compact, may split easily</td>
<td>Gneiss</td>
</tr>
</tbody>
</table>
# Scheme for Metamorphic Rock Identification

<table>
<thead>
<tr>
<th>Texture</th>
<th>Composition</th>
<th>Type of Metamorphism</th>
<th>Comment</th>
<th>Rock Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>NONFOLIATED</td>
<td>Variable</td>
<td>Contact (Heat)</td>
<td>Various rocks changed by nearby magma/lava</td>
<td>Hornfels</td>
</tr>
<tr>
<td>NONFOLIATED</td>
<td>Quartz</td>
<td>Regional (Heat &amp; Pressure)</td>
<td>Metamorphism of Quartz Sandstone</td>
<td>Quartzite</td>
</tr>
<tr>
<td>NONFOLIATED</td>
<td>Calcite and/or Dolomite</td>
<td>Regional (Heat &amp; Pressure)</td>
<td>Metamorphism of Limestone or Dolostone</td>
<td>Marble</td>
</tr>
<tr>
<td>NONFOLIATED</td>
<td>Various minerals in particles and matrix</td>
<td>Regional (Heat &amp; Pressure)</td>
<td>Pebbles may be distorted or stretched</td>
<td>Metaconglomerate</td>
</tr>
</tbody>
</table>
## Progression of Metamorphism

Start with a shale and then hit it with heat and pressure!

<table>
<thead>
<tr>
<th>Rock Name</th>
<th>Rock Type</th>
<th>Grade of Metamorphism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shale</td>
<td>Sedimentary</td>
<td>----</td>
</tr>
<tr>
<td>Slate</td>
<td>Metamorphic</td>
<td>Low</td>
</tr>
<tr>
<td>Phyllite</td>
<td>Metamorphic</td>
<td>Low/Intermediate</td>
</tr>
<tr>
<td>Schist</td>
<td>Metamorphic</td>
<td>Intermediate/High</td>
</tr>
<tr>
<td>Gneiss</td>
<td>Metamorphic</td>
<td>High</td>
</tr>
<tr>
<td>Molten Rock</td>
<td>Cools into Igneous Rock</td>
<td>----</td>
</tr>
</tbody>
</table>

More Heat & Pressure
Shale  
(Sedimentary Rock)

Heat & Pressure

Slate  
(Metamorphic Rock)
Slate (Metamorphic Rock)

Heat & Pressure

Phyllite (Metamorphic Rock)
Phyllite (Metamorphic Rock)

Schist (Metamorphic Rock)

Heat & Pressure
With even more heat & pressure (High-Grade Metamorphism)

... you end up with something that is really Gneiss!
<table>
<thead>
<tr>
<th>Texture</th>
<th>Grain Size</th>
<th>Composition</th>
<th>Type of Metamorphism</th>
<th>Comments</th>
<th>Rock Name</th>
<th>Map Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foliated</td>
<td>Fine</td>
<td>Mica, Quartz, Feldspar, Amphibole, Garnet, Pyroxene</td>
<td>Regional (Heat and pressure increases)</td>
<td>Regional metamorphism of shale</td>
<td>Slate</td>
<td><img src="image" alt="Slate" /></td>
</tr>
<tr>
<td></td>
<td>Fine to medium</td>
<td></td>
<td></td>
<td>Foliation surfaces shiny from microscopic mica crystals</td>
<td>Phyllite</td>
<td><img src="image" alt="Phyllite" /></td>
</tr>
<tr>
<td></td>
<td>Medium to coarse</td>
<td></td>
<td></td>
<td>Platy mica crystals visible from metamorphism of clay or feldspars</td>
<td>Schist</td>
<td><img src="image" alt="Schist" /></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>High-grade metamorphism; mineral types segregated into bands</td>
<td>Gneiss</td>
<td><img src="image" alt="Gneiss" /></td>
</tr>
<tr>
<td>Non-Foliated</td>
<td>Fine</td>
<td>Carbon</td>
<td>Regional</td>
<td>Metamorphism of bituminous coal</td>
<td>Anthracite coal</td>
<td><img src="image" alt="Anthracite coal" /></td>
</tr>
<tr>
<td></td>
<td>Fine</td>
<td>Various minerals</td>
<td>Contact (heat)</td>
<td>Various rocks changed by heat from nearby magma/lava</td>
<td>Hornfels</td>
<td><img src="image" alt="Hornfels" /></td>
</tr>
<tr>
<td></td>
<td>Fine to coarse</td>
<td>Quartz</td>
<td>Regional or contact</td>
<td>Metamorphism of quartz sandstone</td>
<td>Quartzite</td>
<td><img src="image" alt="Quartzite" /></td>
</tr>
<tr>
<td></td>
<td>Coarse</td>
<td>Calcite and/or dolomite</td>
<td>Regional or contact</td>
<td>Metamorphism of limestone or dolostone</td>
<td>Marble</td>
<td><img src="image" alt="Marble" /></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Various minerals</td>
<td></td>
<td>Pebbles may be distorted or stretched</td>
<td>Metaconglomerate</td>
<td><img src="image" alt="Metaconglomerate" /></td>
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<td></td>
</tr>
<tr>
<td><strong>Marble</strong></td>
<td><strong>Slate</strong></td>
<td><strong>Gneiss</strong></td>
<td><strong>Quartzite</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><img src="image1" alt="Marble" /></td>
<td><img src="image2" alt="Slate" /></td>
<td><img src="image3" alt="Gneiss" /></td>
<td><img src="image4" alt="Quartzite" /></td>
<td></td>
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</tbody>
</table>

Marble is a strong and beautiful rock. It is most commonly used for countertops because nothing will melt it if you set something on it and it will not be stained.

Slate is a rock that is very similar to shale. Slate is what you would see by lake erie. They are good for skipping stones. This rock is most commonly used for chalkboards.

Gneiss is a foliated rock. It is used for building and paving. You can see the crystals in this rock with the naked eye.

Quartzite can also be used for countertops because of its hardness. Quartzite can come in a variety of colors. The one in the picture above is pink.

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Slate</strong></td>
<td><strong>Serpentine</strong></td>
<td><strong>Quartzite</strong></td>
<td><strong>Gneiss</strong></td>
</tr>
<tr>
<td><img src="image5" alt="Slate" /></td>
<td><img src="image6" alt="Serpentine" /></td>
<td><img src="image7" alt="Quartzite" /></td>
<td><img src="image8" alt="Gneiss" /></td>
</tr>
</tbody>
</table>

Slate is a fine-grained gray, green, or bluish metamorphic rock easily split into smooth, flat pieces.

Serpentine is greenish, brownish, or spotted minerals commonly found in serpentinite rocks. They are used as a source of magnesium and asbestos, and as a decorative stone. The name is thought to come from the greenish color being that of a serpent. ...

Quartzite is an extremely compact, hard, granular rock consisting essentially of quartz. It often occurs as silicified sandstone, as in sarsen stones.

Gneiss is a metamorphic rock with a banded or foliated structure, typically coarse-grained and consisting mainly of feldspar, quartz, and mica.
Metamorphic Textures

Texture refers to the size, shape, and arrangement of grains within a rock.

1. **Foliated Rock**: Bands of minerals in parallel layers

Foliation – any planar arrangement of mineral grains or structural features within a rock.

Parallel alignment of platy and/or elongated minerals.

Foliation can form through:

- Rotation of platy and/or elongated minerals
- Recrystallization of minerals in the direction of preferred orientation
- Changing the shape of equidimensional grains into elongated shapes that are aligned

2. **Non-foliated Rock**: Without bands

Metamorphic rocks that lack foliation are referred to as nonfoliated.

Develop in environments where stress (deformation) is minimal.

Typically composed of minerals that exhibit equidimensional crystals.
Metamorphic Textures

**Foliation**: The structure is called as foliation when it is ranged as parallel planes of minerals forming metamorphic rocks to each other, collecting in the form of lenses or bands, it develops planar structures that occur with both planar and elongated flattened mineral grains, and it are repeatedly layered and dyed from a rock under high pressure and heat.

**Schistosity**: Platy minerals are discernible with the unaided eye and exhibit a planar or layered structure under high pressure and heat.

**Lineation**: passing there through regardless of their origin rock, repeated, visible linear eye structures of all kinds.

**Gneissic texture**: Segregation of minerals leads to distinctive banded appearance
Metamorphic Textures

• Cleavage: It is called cleavage of wrinkled planes connected by directional pressures, deformed by layering planes, which develops at a certain angle and develops in close proximity to each other, in parallel and in more than one direction. Cleavage is a secondary texture that allows a rock to separate into planes.

• Mylonite: Rock in the deep portions of faults undergoes dynamic metamorphism and creates a fine-grained metamorphic rock called a mylonite. Rock in the deep portions of faults undergoes dynamic metamorphism and creates a fine-grained metamorphic rock called a mylonite. During the deformation occurring in the fault zone, the primary grains of the rock are broken and crushed to form the milonitic zone, which forms again smaller rocks, smaller than 0.5 mm, forming the milonitis.
metamorphic rocks: basic classification

based on *rock texture*

*foliated* (layered)

*type of foliation* -- e.g. *slaty*

*non-foliated* (non-layered)

*composition* -- e.g. *marble*
**foliated (layered) metamorphic rocks**

results from differential stress (not equal in all directions)
appearance under microscope

non-foliated

foliated
Metamorphic rock series
Engineering Properties of Metamorphic Rocks

• Rocks showing foliation should not be preferred as construction materials in terms of strength.

• The strengths of the foliated metamorphic rocks, along with the leavening and foliations that develop as a result of the metamorphism, are decreasing along the foliage planes due to clay minerals that swell in water like chlorite and epidote.

• Marbles from metamorphic rocks are preferred as a good building material. It is the building material that is required in the building coverings.

• The metamorphic masses provide a solid structure for the foundation of the building, if it is not separated. Some slip planes can be used without any support if the slip gaps are not full with clays.
Engineering Properties of Metamorphic Rocks

- Metamorphics can be exposed to change immediately under favorable climatic conditions. Due to the changing construction, volume increases and pressure increases. Such features should be observed in tunnels and dam constructions and other constructions.

- Schist rocks along the schistosity plane cause shifts in the excavations. This is especially the case for the dissociated regions where the schistose and cleavage are opened and weakened and the rock resistance is greatly reduced.

- Schists and similar rocks create landslide hazards in road constructions, dam abrasions and reservoir slopes.

- Massive gneisses provide very good conditions for large underground openings. Facilities for swimming pools, theaters, skating rinks, industrial warehouses, production plants and many other activities have been created economically and safely in large openings to such rocks.

- Schistosized and competing gneisses can create stability problems in underground openings. Even in the ravaged schist and the small tunnels opened in the phyllite, the ceiling may collapse. As the metamorphic rocks are cracked and contested on the surface, excavations cause the rock blocks to move.
Sedimentary Rocks

- Materials which are derived by all kinds of rocks (magmatic, metamorphic, sedimentary) are subject to physical chemical and biological disruption and dispersion under all kinds of conditions, then they stay in place or are transported in different ways and settled in a certain place. It is called as «sedimen»

- Sedimentary rocks are formed by the accumulation of inorganic and organic sediments which undergo compaction and cementation to form rock.
Any rock fragment (size is > 4 mm = Pebble)

Matrix: is the finer grains or material that surrounds the larger clasts. It consists of either clay, silt and sand.

Cement: dissolved substance that bounds the sediments.
1. Calcareous
2. Siliceous

Fine-gravel/Granule (size < 4 mm)
Sediment
loose, solid particles originating from:
• Weathering and erosion of preexisting rocks
• Chemical precipitation from solution, including secretion by organisms in water
Sedimentary Rocks

• There are at least four phases in the generation of sedimentary rocks; These phases;
  1. Weathering and erosion
  2. Transportation: Movement of the material coming from the decay of the rocks in various ways
  3. Deposition: Storage or sedimentation of transported material in certain places,
  4. Lithification: Compaction and consolidation of stored or deposited sediments after diagenesis
Transportation

• Movement of sediment away from its source, typically by water, wind, or ice
• Rounding of particles occurs due to abrasion during transport
• Sorting occurs as sediment is separated according to grain size by transport agents, especially running water
• Sediment size decreases with increased transport distance
Deposition

- Settling and coming to rest of transported material
- Accumulation of chemical or organic sediments, typically in water
- Environment of deposition is the location in which deposition occurs
  - Deep sea floor
  - Beach
  - Desert dunes
  - River channel
  - Lake bottom
**Preservation**

- Sediment must be preserved, as by burial with additional sediments, in order to become a sedimentary rock

**Lithification**

- General term for processes converting loose sediment into sedimentary rock
- Combination of *compaction* and *cementation*
Sedimentary Rocks

• Diagenesis is the term used for all of the changes that a sediment undergoes after deposition and before the transition to metamorphism. The multifarious processes that come under the term diagenesis are chemical, physical, and biological.
Diagenesis

Compaction

Cementing
• Quartz
• Calcite
• Iron Oxide
• Clay
• Glauconite
• Feldspar

Alteration
• Limestone - Dolomite
• Plagioclase – Albite

Recrystallization
• Limestone
Sedimentary Rocks

Some of the criteria that distinguish sediment from sedimentary rocks are:

Sediments are loose because they do not bond to one another and do not undergo diagenesis. In Sedimentary rocks, granules are connected to each other by an intermediate material, namely cement. They are also diagenetic and petrified. Contrary to sedimans, they are consolidated and hardened.

Sedimentary rocks show stratification and provide different shapes when stratified (Graded stratification, cross stratification, etc.) Sediments are usually found in mass. They do not show stratification.

Sedimentary rocks contain organic residues. Organisms leave behind organic and inorganic materials after their deaths. Inorganic wastes become fossilized and organic materials leave their places to organic minerals such as petroleum and coal.

Sedimentary rocks may undergo some changes after their formation. This is called deformation. As a result of deformation are folded, bent, broken, or even are displaced.
IMPORTANCE OF SEDIMENTARY ROCK

“Present is the key to the past”

• Helps in knowing depositional environment viz. marine (ocean deposits), fluvial (river deposits), aeolian (wind deposits), glacial, estuarine, Lacustrine (lake deposits) etc.

• Helps in knowing the provenance (i.e. source area of the sediments); change in climatic conditions i.e. in knowing and understanding old climate= *paleoclimate*. 
## TYPES OF SEDIMENTARY ROCKS

### Clastic rocks
- Sandstones
- Conglomerates
- Breccia
- Shale/mudstones

### Chemical
- **Carbonate rocks**
  - Form basically from \( \text{CaCO}_3 \) – both by chemical leaching and by organic source (biochemical) eg. Limestone; dolomite

### Organic rocks
- **Organic rocks**
  - Form due to decomposition of organic remains under temperature and pressure eg. Coal/Lignite etc.

### Evaporitic rocks
- These rocks are formed due to evaporation of saline water (sea water) eg. Gypsum, Halit (rock salt)
Sedimentary Rocks are classified based on their components.

**Clastic**
1. Conglomerate
2. Sandstone
3. Shale

**Organic**
1. Coal
2. Fossiliferous Limestone

**Chemical**
1. Limestone
2. Salt
Environments affect the type of sediment.
Environments change throughout geologic time.

Where do you think these rocks are from? GRAND CANYON!!!
Different environments produce different sedimentary rocks.
Different environments produce different sedimentary rocks.
Different environments produce different sedimentary rocks.
Different environments produce different sedimentary rocks.
Clastic Sedimentary Rocks; formed from broken rock fragments weathered and eroded by river, glacier, wind and sea waves. These clastic sediments are found deposited on floodplains, beaches, in desert and on the sea floors.

These rocks usually form in water environments such as, rivers, lakes, oceans, but can also form in deserts.

Consist of solid particles from weathered rocks. These rock fragments include pebbles, sand, silt and clay.
<table>
<thead>
<tr>
<th>Diameter (mm)</th>
<th>Sediment</th>
<th>Sedimentary Rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>256</td>
<td>Boulder</td>
<td>Gravel</td>
</tr>
<tr>
<td>64</td>
<td>Cobble</td>
<td>Breccia (angular particles) or Conglomerate (rounded particles)</td>
</tr>
<tr>
<td>2</td>
<td>Pebble</td>
<td>Sandstone</td>
</tr>
<tr>
<td>1/16</td>
<td>Sand</td>
<td>Siltstone (mostly silt)</td>
</tr>
<tr>
<td>1/256</td>
<td>Silt</td>
<td>Shale or mudstone (mostly clay)</td>
</tr>
<tr>
<td></td>
<td>Clay</td>
<td></td>
</tr>
</tbody>
</table>

Sandstone and shale are quite common; the others are relatively rare.
This figure shows how clastic sediment of various sizes will, after compaction and cementation, form different types of detrital sedimentary rocks.

The process of sediment turning into rock is called lithification.
sediments

- gravel
- sand
- silt
- clay

sedimentary rocks

- conglomerate
- sandstone
- siltstone
- shale
<table>
<thead>
<tr>
<th>Particle Size</th>
<th>Sediment</th>
<th>Rock</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>COARSE</strong></td>
<td><strong>GRAVEL</strong></td>
<td></td>
</tr>
<tr>
<td>Larger than 256 mm</td>
<td>Boulder</td>
<td>Conglomerate</td>
</tr>
<tr>
<td>256–64 mm</td>
<td>Cobble</td>
<td></td>
</tr>
<tr>
<td>64–2 mm</td>
<td>Pebble</td>
<td></td>
</tr>
<tr>
<td><strong>MEDIUM</strong></td>
<td><strong>SAND</strong></td>
<td>Sandstone</td>
</tr>
<tr>
<td>2–0.062 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>FINE</strong></td>
<td><strong>MUD</strong></td>
<td>Siltstone</td>
</tr>
<tr>
<td>0.062–0.0039 mm</td>
<td>Silt</td>
<td></td>
</tr>
<tr>
<td>Finer than 0.0039 mm</td>
<td>Clay</td>
<td>Mudstone (blocky fracture)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shale (breaks along bedding)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Claystone</td>
</tr>
</tbody>
</table>
Chemical Sedimentary Rocks

These rocks form as a result of chemical weathering dissolving chemicals and transporting it in solution. When conditions are right, these dissolved chemicals change back into a solid through the processes of precipitation and evaporation.

Precipitation: Process where chemicals dissolved on solution, fall out of solution and forms a solid material. Most common in shallow water environments.

Evaporation: Process where there is a change in state from a liquid to a gas. Chemicals dissolved in the liquid (water) are left behind as a solid material.
Chemical Sedimentary Rocks

These rocks usually form in water environments such as lakes and shallow seas or oceans. Some examples of chemical sedimentary rocks include:

1) Limestone (Calcite) - (form by precipitation)
2) Rock Gypsum - (form by precipitation and evaporation)
3) Rock salt (Halite) – (from by evaporation)
4) Coquina - (form by biochemical processes)
Organic Sedimentary Rocks

These rocks form as a result of once living material accumulating to form solid rock.

The most common organic rock is coal, which forms when plant material in water saturated environments (swamps) die and accumulate to form peat. As peat is buried it compresses and eventually changes to form coal.
Textures of Sedimentary Rocks

• Most sedimentary rocks are derived by processes of weathering, transportation, deposition, and diagenesis. The final texture (grain size, shape, sorting, mineralogy, etc.) in a sediment or sedimentary rocks is dependent on process that occur during each stage. The points below summarize the basic factors affecting rock texture.
  – The nature of the source rocks (the rocks that were eroded to create the sediments). This determines the original shape of the grains and the mineralogical composition of the original sediment.
  – The strength of the wind or water currents that carry and deposit the sediment. This determines whether or not grains are transported or deposited. The deposition process also controls structures (see sedimentary structures below) that could be preserved in the sediment and thus give clues to the environment of deposition.
  – The distance transported or time in the transportation process. The longer grains are in the transportation process the more likely they are to change shape and become sorted on the basis of size and mineralogy. This also controls extent to which they break down to stable minerals during the transportation process.
  – Biological activity with the sediment prior to diagenesis. Burrowing organisms can redistribute sediment after it has been deposited, thus erasing some of the clues to the original environment of deposition.
  – The chemical environment under which diagenesis occurs. During diagenesis grains are compacted, new minerals precipitate in the pore spaces, some minerals continue to react to produce new minerals, and some minerals recrystallize. What happens depends on the composition of fluids moving through the rock, the composition of the mineral grains, and the pressure and temperature conditions attained during diagenesis.
Textures of Sedimentary Rocks

*Grain sorting:* Sorting refers to the uniformity of grain size in a sediment or sedimentary rock.

![Poorly Sorted Sediment](image1) ![Well Sorted Sediment](image2)

*Rounding:* During the transportation process, grains may be reduced in size due to abrasion. Random abrasion results in the eventual rounding off of the sharp corners and edges of grains. Thus, the degree of rounding of grains gives us clues to the amount of time a sediment has been in the transportation cycle.
Textures of Sedimentary Rocks

• Sphericity is controlled by the original shape of the grain. The longer the sediment is transported, the more time is available for grains to lose their rough edges and corners by abrasion
Layering (bedding)

One of the most obvious features of sedimentary rocks and sediment is the layered structure which they exhibit. The layers are evident because of differences in mineralogy, clast size, degree of sorting, or color of the different layers. In rocks, these differences may be made more prominent by the differences in resistance to weathering or color changes brought out by weathering.

Cross Bedding

Consists of sets of beds that are inclined relative to one another. The beds are inclined in the direction that the wind or water was moving at the time of deposition. Boundaries between sets of cross beds usually represent an erosional surface. Cross bedding is very common in beach deposits, sand dunes, and river deposited sediment. Individual beds within cross-bedded strata are useful indicators of current direction and tops and bottoms. Note how the beds become asymptotic to the lower boundary on which they were deposited.

Graded Bedding

As current velocity decreases, the larger or more dense particles are deposited first, followed by smaller particles. This results in bedding showing a decrease in grain size from the bottom of the bed to the top of the bed. This gives us a method for determining tops and bottoms of beds, since reverse grading will not be expected unless deposition occurs under unusual circumstances. Note that reverse graded bedding cannot occur as current velocity increases, because each layer will simply be removed as the current achieves a velocity high enough to carry sediment of a particular size.
Engineering Properties of Sedimentary Rocks

Physical and especially mechanical properties of the existing rocks should be determined by laboratory tests and tests. The results should be numbered and used in basic and static calculations.

The rocks have a certain carrying power. Rocks that are overloaded by forces change structure and shape, so the upper structures can be damaged.

The ground that is overloaded on the surface shows different physical and chemical properties.

The factors affecting the cost and safety of the construction which are known as the engineering properties of the rocks are the specific gravity, porosity, water absorption, unit volume weight, resistance corresponding to the press, resistance to atmosphere effect, wear, fragmentation,
Engineering Properties of Sedimentary Rocks

With laboratory experiments;
It should be determined whether they are essential or not according to various rock and soil conditions. Stability and resistance to depression should be determined.

The properties of storage (S) or permeability (K) and transmissibility T of groundwater of various rocks and soils should be determined.

Whether or not the rocks are suitable for building materials should be determined.
Engineering Properties of Sedimentary Rocks

• The resistance of the sedimentary rocks to breakage and pressures varies depending on the hardness grades and the susceptibility of the minerals to water. For example; Clay, marl, gypsum and limestone cemented sandstones and conglomerates show little resistance to water pressures. Silica cemented ones are more resistant, like granite and basalt. Good cemented rocks have high porosity and permeability ratings, so their water storage capacities are high, while their resistance is low.

• Sedimentary rocks containing clay minerals such as clay and shale contain water in a small or large amount depending on the type of minerals they contain. Their indentations loosen or degrade according to the water content. As a result, resistance and handling power are reduced.

• Limestones are used as building material for producing lime, aggregate, gravel and building stone. The resistance of the limestones to be used in this area must be at least 200 kg/cm² with respect to water absorption, less abrasion, and pore and porosity

• The resistance of the limestones is low and high, so the stratification of the limestones is effective.

• Cracking systems and melting gaps should be avoided or minimized in limestones if they are used in foundation and dam construction.

• Limestones must be cracked and melting space at groundwater investigations. Limestones which have high porosity and cracked provides to generate high discharges karstic springs.
Flatirons, Boulder, Colorado
Garden of the Gods, Colorado
Fig. 2.9 MAGMA
IGNEOUS

Plutonic

Solidification

MAGMA
Volcanic

IGNEOUS

Plutonic

Solidification

MAGMA
MAGMA

Volcanic

IGNEOUS

Plutonic

Weathering & Erosion

Uplift

Solidification

MAGMA
MAGMA

Volcanic

IGNEOUS

Plutonic

SEDIMENT

Weathering & Erosion

Erosion

Transport

Deposition

Solidification
MAGMA

Volcanic

IGNEOUS

Plutonic

SEDIMENT

Deposition

Burial/Compaction

Cementation

Increased P&T

Melting

Solidification

Weathering & Erosion

Deposition

SEDIMENTARY

Burial/Compaction

Cementation

Increased P&T

Melting

Solidification

Weathering & Erosion

SEDIMENT

Melting

Cementation

Increased P&T

Deposition

Weathering & Erosion

Volcanic

IGNEOUS

Plutonic

MAGMA
Weathering

A. Mechanical Weathering
B. Chemical Weathering
C. Soil
Weathering

- Mechanical Weathering
  - Physical disintegration of rock (with no chemical alteration)

- Chemical Weathering
  - Chemical alteration of minerals within the rock
  - Usually softening or dissolving the minerals
  - Forming clays, oxides and solutes
1. **Frost Action** - The freezing and thawing causes alternate expansion and contraction of rocks eventually breaking them apart.

- Dominate in mountain or polar regions.
- More likely to occur in winter.
The result of
Mechanical weathering
Rock falls and slides
Crushing and abrasion (more mechanical weathering)

Rock Avalanches
Slopes of rock fragments may let go and careen downhill as a very fast flow
Talus Slopes

- The result of
  - Mechanical weathering
  - Rock falls and slides
  - Crushing and abrasion (more mechanical weathering)

- Rock Avalanches
  - Slopes of rock fragments may let go and careen downhill as a very fast flow
MECHANICAL WEATHERING

Ice

Water in the ground below paved roads freezes and expands, lifting the pavement unevenly and allowing sections to collapse after the ice melts.
Salt crystal growth
As salt crystals gradually grow larger, they weaken the rock by pushing apart surrounding grains or enlarging tiny cracks.

Unloading
Pressure release forms sheet joints and exfoliation. Sheeting is caused by the expansion of crystalline rock as erosion removes the overlying material, a process termed unloading.
Mechanical Weathering

An exfoliation dome in Yosemite, CA (Half Dome)
2. Biological Action - With plant growth the root system will increase in volume and cause cracks in the rock to expand.

- Lichens are primary soil producers creating conditions for larger plant growth.
Chemical Weathering - when agents of weathering chemically change the composition of a rock.

II. AGENTS OF CHEMICAL WEATHERING

1. Oxidation - Oxygen combines with minerals to form oxides.
   (iron + oxygen = Rust)
Chemical Weathering

- Dissolving $\rightarrow$ Dissolved ions
- Oxidation $\rightarrow$ Iron in Ferromag. Minerals $\rightarrow$ Iron Oxides (e.g., Hematite)
- Formation of Clays from silicates (e.g., Feldspar)
2. *Hydration*—minerals absorb water and chemically change the composition of the material.

- Ex. granite contains mica.
- Mica has a weak chemical composition and absorb water.
- Turns into clay
3. **Carbonation** - When pollutants like Carbon Dioxide, Nitrogen & Sulfuric Oxides mix with rain water creating acid rain, which can dissolve limestone and harm the living environment.

- Coal Burning For Electricity
- Fossil Fuel Consumption for Cars
4. **Water** - Is unique and dissolves most minerals and metals in our environment. (universal solvent).
Chemical weathering:
ion exchange and the chemical breakdown of feldspar

1. Acidified water containing hydrogen ions (H⁺) enters feldspar crystal along existing fractures.

2. Where potassium has washed away, an insoluble residue of clay remains.
### Chemical Weathering

#### Chemical Equations Important to Weathering

#### A. Solution of Carbon Dioxide in Water to Form Acid

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide + water</td>
<td>$\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3$</td>
</tr>
<tr>
<td>Carbonic acid</td>
<td>$\text{H}_2\text{CO}_3$</td>
</tr>
<tr>
<td>Carbonic acid + water</td>
<td>$\text{H}_2\text{CO}_3 + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{O}^+ + \text{CO}_3^{2-}$</td>
</tr>
<tr>
<td>Hydrogen carbonate ion</td>
<td>$\text{H}_3\text{O}^+ + \text{HCO}_3^-$</td>
</tr>
</tbody>
</table>

#### B. Solution of Calcite

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcite + carbon dioxide</td>
<td>$\text{CaCO}_3 + \text{CO}_2$</td>
</tr>
<tr>
<td>Carbonic acid</td>
<td>$\text{CaCO}_3 + \text{H}_2\text{O} \rightleftharpoons \text{Ca}^{2+} + \text{HCO}_3^-$</td>
</tr>
<tr>
<td>Calcium ion</td>
<td>$\text{Ca}^{2+}$</td>
</tr>
</tbody>
</table>

#### C. Solution of Calcite

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcite + hydrogen ion</td>
<td>$\text{CaCO}_3 + \text{H}^+$</td>
</tr>
<tr>
<td>Hydrolysis</td>
<td>$\text{HCO}_3^- + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3 + \text{OH}^-$</td>
</tr>
<tr>
<td>Calcium ion</td>
<td>$\text{Ca}^{2+}$</td>
</tr>
</tbody>
</table>

#### D. Chemical Weathering of Feldspar to Form a Clay Mineral

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feldspar + water (from CO$_2$ and H$_2$O)</td>
<td>$2\text{KAlSi}_3\text{O}_8 + \text{H}_2\text{O} \rightarrow \text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4 + 4\text{SiO}_2$</td>
</tr>
<tr>
<td>Clay mineral</td>
<td>$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$</td>
</tr>
<tr>
<td>Silica in solution or as fine solid particles</td>
<td>$4\text{SiO}_2$</td>
</tr>
</tbody>
</table>

### Oxidation

$4\text{FeSiO}_3 + \text{O}_2 + \text{H}_2\text{O} \rightarrow \text{FeO(OH)} + 4\text{SiO}_2$

### Hydration

$\text{CaSO}_4 + 2\text{H}_2\text{O} \rightarrow \text{CaSO}_4\cdot2\text{H}_2\text{O}$
Factors affecting weathering

**Climate**
- Different climates and temperatures produce more favorable forms of weathering.
  - Chemical weathering is more prevalent in warm, wet tropical climates
  - Humid Climates are moist and the rate of weathering is fairly fast.
    - Mechanical weathering less important here
  - Mechanical weathering is more prevalent in cold, relatively dry regions
    - Arid Climates are very dry and the rate of weathering is slow
    - Chemical weathering occurs slowly here
  - Usually in the presence of heat weathering rates will also increase.
Factors affecting weathering:
color dots on map match colors on chart
**Cold and Humid** - Physical weathering is dominate at high latitudes, or in the winter.

- Frost Action and Glacial Abrasion

**Hot and Humid** - Chemical weathering is dominate near the equator and in the summer.

- Oxidation, Hydration
Humid climates also favor chemical weathering and increase the rate in which water will dissolve minerals.
Hot & humid climates can also increase the rate of physical weathering by biological action.
In the mountains and at the poles physical weathering like frost action and abrasion are more likely.
2. Particle Size and Shape  as particle size decreases the weathering rate increases

- When the surface area increase, more sides are able to react with the elements
Angular Sediments have more surface area.
- weather at a faster rate.

Round sediments have less surface area
- weathering rate decreases.
3. Mineral Composition - some rocks are resistant to weathering because of their composition

- **More Resistant**
  - Hard Rocks have Strong Chemical Compositions

- **Less Resistant**
  - Soft Rocks have Weak chemical compositions
Rocks will weather at different rates due to their chemical compositions.

- Granite w/ strong chemical composition (hard rock)
- Limestone w/ weak chemical composition (soft rock)
Rock composition
- Minerals weather at different rates
  - Calcite weathers quickly through dissolution
  - Quartz is very resistant to chemical and mechanical weathering
  - Mafic rocks with ferromagnesian minerals weather more easily

Resistant quartzite knob weathers slowly.
Rock structure
- Distribution of joints influence rate of weathering
  - Relatively close joints weather faster

Unjointed rock weathers slowly
Topography

- Weathering occurs faster on steeper slopes
  - Rockslides

Steep slope weathers quickly
Vegetation

- Contribute to mechanical and chemical weathering
- Promotes weathering due to increased water retention
- Vegetation removal increases soil loss

Deforestation accelerates weathering and erosion.

Vegetation can both hold water
And increase weathering. If removed
Rocks may also be vulnerable to abrasion
Rates of Weathering

- Stable at High Temperatures
- Quickly Weathered
- Slowly Weathered
- Stable at Atmos. Temperatures

Converted to clay, oxides, and ions by chemical weathering
IV. Products of Weathering - sediments and soils

1. Sediment Types

   a. **Solids** - Are clastic sediments such as pebbles, sand, silt, or clay

   b. **Colloids** - Are suspended clay size particles

   c. **Ionic Solutions** - Are dissolved compounds in water
Products of Weathering

- Clay
  - Tiny mineral particles of any kind that have physical properties like those of the clay minerals
  - Clays are hydrous alumino-silicate minerals
Products of Weathering

- **Sand**
  - A sediment made of relatively coarse mineral grains

- **Soil**
  - Mixture of minerals with different grain sizes, along with some materials of biologic origin
  - Humus
  - Partially decayed organic matter in soil
2. Soil Types

a. **Residual** - Soils formed from the weathering of the local bedrock and have the same mineral composition.

b. **Transported** - Soil that has been moved & the sediments are not of the same composition as the local rock

- **Soil Horizons**
  
  A. Top layer rich in organics & minerals from biologic activity.
  
  B. Sediments with minerals dissolved from above are found here.
  
  C. Mostly un-weathered bedrock.
Soil development from local bedrock.

- Stage 1 Mostly un-weathered bedrock
- Stage 2 Development of top soil by biologic activity
- Stage 3 Mature thick and well developed soil horizons

Soil is non-renewable resource

1 inch is made for every 100 years in New York
Different climates produce different soil types
- Form at different rates.
Differential Weathering

Ship Rock, New Mexico
Volcanic Neck

John Ford Point Monument, Arizona.
ENGINEERING PROPERTIES OF ROCKS

Engineering properties of rock determines geologic, chemical, mechanical, deformation and technological properties of rocks

1. Geological properties
   a) Generation time of rocks
   b) Generation environment of rocks
   c) Lithological properties of rocks
   d) Structural properties of rocks
   e) Hydrological properties of rocks
ENGINEERING PROPERTIES OF ROCKS

2. **Chemical properties;** include behavior of melting, weathering and against water with respect the compositon of rocks. It directly influences various engineering works and their projects.

3. **Physical Properties;** Unit volume weight, density, natural water content, porosity and void ratio, degree of saturation, permeability, weight water absorption and volumetric water absorption are physical properties of rocks.

4. **Mechanical Properties;** Are characteristics that determine the behavior of rocks under various stresses
   a) Compression strength (Uniaxial compressive strength, Schmidt Attractor Test, Point load resistance, Disc Shear Index Test)
   b) Tensile strength (Direct pull, Indirect pull (Brazilian test))
   c) Shear Strength (Triaxial compression test, Direct shear test)
   d) Buckling Strength
   e) Bending Strength

5. **Deformation Properties;** Elastic modulus and Poisson ratio, Rigidity module etc.

6. **Technological Properties;** Pierceable, breakable, excavable, interceptable, polishable, machinable, usable, tunnelable ...
**Intact rock material:** Rock mass is a matrix consisting of rock material and rock discontinuities. As discussed early, rock discontinuity that distributed extensively in a rock mass is predominantly joints. Faults, bedding planes and dyke intrusions are localised features and therefore are dealt individually. Properties of rock mass therefore are governed by the parameters of rock joints and rock material, as well as boundary conditions.

**Discontinuity:** A discontinuity is a plane or surface that marks a change in physical or chemical characteristics in a soil or rock mass. A discontinuity can be in the form of a bedding plane, schistosity, foliation, joint, cleavage, fracture, fissure, crack, or fault plane. This discontinuity controls the type of failure which may occur in a rock slope. The properties of discontinuities such as orientation, persistence, roughness and infilling are play important role in the stability of jointed rock slope. Discontinuities may occur multiple times with broadly the same mechanical characteristics in a discontinuity set, or may be a single discontinuity. It makes a soil or rock mass anisotropic.
In various engineering works and excavations; projects such as dams, tunnels, underground power plants, bridges, etc., calculation of the stability of foundation and materials which are used for them, the discontinuity properties that affect the engineering properties of the rocks in advance with the determined deformations in front of various forces must be well known.
Massive rock types: This rock types are found below the degradation zones and rock masses which do not include foliation such as massive sandstone and granites are in this group. Such masses are considered as continuous, homogeneous, isotropic rocks.

Partially jointed rock mass: rocks which have fewer than three and continous discontintuity can be obtained as individual blocks when excavated.

Partially Blocked Rock Mass: It is a rock mass which includes fewer than three discontinuous and whose discontiunity are filled by secondary material and which contain closed secondary discontinuity. If one of the closed joint sets is opened due to deformation, blockage in the rock mass develops.

Blocked Rock Mass: It is rock masses that contain well-developed, open or soft fillings, high continuity, and a set of discontinuities in excess of 3. It is easy to obtain blocks from such rock masses during excavation.

Hollow Rock Mass: The soluble limestones in this group are composed of dolomite, gypsum, rock salt and a soluble cement

Very porous rock mass: In such rock masses, significant amounts of pores influence the mechanical behavior of the rock.

Advanced fissured rock mass: Fissured rock substantially brittleness and anisotropy also contain small discontinuities frequent cause a deviation with respect to all mechanical properties.

Jammed and swollen rock mass: Such rock masses, when they come into contact with water, suddenly and intermittently crack and change volume and contain active clay minerals. The basic principles of ground mechanics can be applied to such rocks.
### Rock Mass Properties And Test Methods

#### Table 6.4.1a Geological Strength Index (GSI)

<table>
<thead>
<tr>
<th>GEOLOGICAL STRENGTH INDEX (GSI)</th>
<th>JOINT SURFACE CONDITION</th>
<th>ROCK MASS STRUCTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Good - very rough, fresh, unweathered joint surfaces</td>
<td>VERY GOOD - very rough, fresh, unweathered joint surfaces</td>
<td>BLOCKY - very well interlocked undisturbed rock mass consisting of cubical blocks formed by three orthogonal joint sets</td>
</tr>
<tr>
<td>Good - rough, slightly weathered joint surfaces</td>
<td>GOOD - rough, slightly weathered joint surfaces</td>
<td>VERY BLOCKY - interlocked, partially disturbed rock mass with multiple angular blocks formed by four or more joint sets.</td>
</tr>
<tr>
<td>Fair - moderately weathered joints, and altered surfaces</td>
<td>FAIR - moderately weathered joints, and altered surfaces</td>
<td>BLOCKY FOLDED - folded and faulted with many intersecting discontinuities forming angular blocks</td>
</tr>
<tr>
<td>Poor - slickensided, highly weathered surfaces with compact coating</td>
<td>POOR - slickensided, highly weathered surfaces with compact coating</td>
<td>CRUSHED - poorly interlocked, heavily broken rock mass with a mixture of angular and rounded blocks</td>
</tr>
<tr>
<td>Very Poor - slickensided highly weathered surfaces with soft clay coating or filling</td>
<td>VERY POOR - slickensided highly weathered surfaces with soft clay coating or filling</td>
<td></td>
</tr>
</tbody>
</table>

![Image showing geological strength index (GSI) chart](image-url)

- **Kaya malzemesi (A)**: Kirilin- elastik ve genellikle izotrop davranış.
- **Elastik-izotrop davranan, pek çok uygulama için yeteli derecede anlaşılabilir.**
- **Sürekli ve genellikle izotrop davranış.**
- **Çatıksız kaya malzemesi (B)**: Sürekli ve genellikle izotrop davranan, pek çok uygulama için yeteli derecede anlaşılabilir.
- **Yönetimsel ve makasal davranış**: Bu kaya sınıfı, oldukça yönetime sahip.
- **Çatıksız kaya malzemesi (C)**: Sürekli ve genellikle izotrop davranan, pek çok uygulama için yeteli derecede anlaşılabilir.
- **Elastik-izotrop davranan, pek çok uygulama için yeteli derecede anlaşılabilir.**

---

*Note: The table and image provide a detailed classification of rock mass properties based on their strength and behavior, suitable for engineering and geological applications.*
Rock Mass Behavior (Scale Effect) due to Increase in Excavation Dimensions
Discontinuity properties are defined for:
- Determination of geological structure,
- Engineering classification of rock mass
- Determination of rock stability

The rock masses are not continuous, homogeneous and isotropic materials, but are cut by various discontinuities. For this reason, the behavior of rock masses, which can be exposed to external loads, cannot be analyzed as close to reality without taking into account the characteristics of the discontinuities they contain.
Discontinuity properties of rock mass

The properties of discontinuities are determined and/or identified on the surface or in drilling cores by using different measurement techniques. Physical parameters of discontinuities:

- Type of discontinuity
- Discontinuity interval and frequency
- Continuity of discontinuity
- Roughness and fluctuation of discontinuity surface
- Properties of filling material
- The strength of discontinuity surface and the degree of degradation
- Water condition on discontinuity surface
- The number of discontinuity set and discontinuity orientation
- Block size
Discontinuity Properties / Discontinuity Types

Group 1: discontinuities as set or appears to be a system, which can be subjected to statistical analysis and surface along the layer in which the occurrence of any displacement, such as joint, cleavage (cleavage) Schistosity, foliation lamination.

Group 2: Located alone, not subjected to statistical analysis and a displacement is observed along its surface such as fault and shear zone.

1. Contact: It is boundary between two different lithological boundaries, it is either conformal or discorformal

2. Structure: It is developed depending on the grain size and orientation, the mineralogical composition, the color and hardness of the surface during the occurrence of sedimentary rocks.
Discontinuity Properties / Discontinuity Types

3. Fault surfaces exposed to shear failure where a relative displacement from a few centimeters to a kilometer long occurs.

4. Joint surfaces Fractures where it is not possible to change anywhere along the Joint Surface.

5. Foliation is the metamorphic origin weakness planes which are formed by preferential orientation of minerals under high pressure and/or temperature.

6. The veins are fractures filled by a different material from the perimeter of the rock. Since the surfaces are not discrete, they are not weak discontinuities.
Discontinuities Properties / discontinuity and Frequency Range

The discontinuity interval (or intermediate distance) is the distance between two discontinuities in a discontinuity set consisting of 2 adjacent discontinuities or parallel discontinuities in the rock masses. This value can be measured from the discontinuities intersecting the strip meter along the strip meter laid on a certain area on the outcrop surface as well as from the drilling cores.

<table>
<thead>
<tr>
<th>Width (mm)</th>
<th>Stratification</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 20</td>
<td>Very narrow</td>
</tr>
<tr>
<td>20-60</td>
<td>Narrow</td>
</tr>
<tr>
<td>60-200</td>
<td>Medium narrow</td>
</tr>
<tr>
<td>200-600</td>
<td>Medium</td>
</tr>
<tr>
<td>600-2000</td>
<td>Broad</td>
</tr>
<tr>
<td>&gt;2000</td>
<td>Very broad</td>
</tr>
</tbody>
</table>

Süreksizlik aralığı tanımlama ölçütleri (ISRM, 1981)
Discontinuities Properties / Discontinuity Continuity

The continuity of discontinuities is an important parameter affecting the stability of discontinuities. As the continuity increases, the slope durability increases. Continuous and uninterrupted joints out of the slope in figures are observed. Continuity is measured directly by the tape measure in the rock outcrop and is recorded as a three-dimensional concept.
Roughness and waviness are a measure of the deviation of a discontinuity surface from small and large scale planarity, respectively. Ripple characterizes a deviation in a large measure from planarity, while deviations in a small measure are defined as roughness.
The clearance is the perpendicular distance between two opposing surfaces of a discontinuity, which may be empty or filled with water or any filler material.

### Filling in discontinuities

Filler material is a material that fills between two opposing surfaces of discontinuity and is generally weaker than the parent rock material. The filler material reduces the roughness effect and reduces the shear strength of the discontinuities.
Discontinuities Properties / Degradation and Strength of Discontinuity Surfaces

The rock mass is often degraded in areas close to the surface, the deeper can be altered depending on the hydrothermal process. The impairment on the discontinuity surfaces is one of the factors affecting the strength of the discontinuities and should be defined by taking into consideration both the rock material and the impairment classifications recommended for the rock mass.

*Table 4.* Allocation of soils to aggressiveness classes (Jarvis and Hedges, 1994).
Discontinuities Properties / Degradation and Strength of Discontinuity Surfaces

The strength of the discontinuity surfaces is closely related to the degree of impairment of these surfaces and the rock material in the immediate vicinity. For this purpose, ISRM (1981) proposed a classification criterion of dislocation which can be used during field study. These categorizations lead to subjective evaluations in some cases since they are purely observational.

<table>
<thead>
<tr>
<th>Kaya kütülerinin bozunma derecesiyle ilgili sınıflama (ISRM, 1981).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tanım</strong></td>
</tr>
<tr>
<td>Bozunmanız (Taze)</td>
</tr>
<tr>
<td>Az bozunmuş</td>
</tr>
<tr>
<td>Orta derecede bozunmuş</td>
</tr>
<tr>
<td>Tamamen bozunmuş</td>
</tr>
</tbody>
</table>

Bozunma derecesi:
- W 1
- W 2
- W 3
- W 4
- W 5
Discontinuities Properties / Degradation and Strength of Discontinuity Surfaces

In order to estimate the compressive strength of the discontinuity surfaces, the application is usually determined indirectly by Schmidt attractive experiment, while utilizing the simple classification of the land with definitions (ISRM, 1981).

\[ W_c = \frac{Rf}{Rw} \]

(Rf); Taze kaya Schmidt geri sıçrama sertlik değerleri
(Rw); Bozunmaya uğramış sürekli yüzeyinin Schmidt geri sıçrama sertlik değerleri (Wc); bozunma katsayısı

<table>
<thead>
<tr>
<th>Simge</th>
<th>Tanım</th>
<th>Saha tanımlaması</th>
<th>Tek eksenli sıkışma dayanımı, ( c_{fr} ) (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R0</td>
<td>Aşırı derecede zayıf kayaç</td>
<td>Kayacın yüzeyinde tunak ile çentik olşutulabilir.</td>
<td>0.25-1.0</td>
</tr>
<tr>
<td>R1</td>
<td>Çok zayıf kayaç</td>
<td>Jeolog çekiciyle sert bir darbeyle uflatılan kayaç, çakı ile doğranabilir.</td>
<td>1.0-5.0</td>
</tr>
<tr>
<td>R2</td>
<td>Zayıf kayaç</td>
<td>Kayac, çakı ile güçlütke doğranır. Jeolog çekici ile yapılacak sert bir darbe kayacın yüzeyinde iz bırakır.</td>
<td>5.0-25</td>
</tr>
<tr>
<td>R3</td>
<td>Orta derecede sağlam kayaç</td>
<td>Kayac, çakı ile doğranamaz. Kayaç örneği, jeolog çekici ile yapılacak tek ve sert bir darbeyle kırılabilir.</td>
<td>25-50</td>
</tr>
<tr>
<td>R4</td>
<td>Sağlam kayaç</td>
<td>Kayacın örneğinin kırılabilmesi için, jeolog çekici ile birden fazla darbenin uygulanması gerekir.</td>
<td>50-100</td>
</tr>
<tr>
<td>R5</td>
<td>Çok sağlam kayaç</td>
<td>Kayacın örneğinin kırılabilmesi için jeolog çekici ile çok sayıda darbe gerekir.</td>
<td>100-250</td>
</tr>
<tr>
<td>R6</td>
<td>Aşırı derecede sağlam kayaç</td>
<td>Kayacın örneği, jeolog çekici ile sadece yontulabilir.</td>
<td>&gt;250</td>
</tr>
</tbody>
</table>
Discontinuities Properties / Degradation and Strength of Discontinuity Surfaces

Örnek çözüm:
Düşey bir sürekli yüzeyine uygulanan Schimdt deneyinde belirlenen geri sıkışma sayısı 48 ve birim hacim ağırlık 27 kN/m³ ise, yüzeyin sıkışma dayanımı yaklaşık 120 MPa'dır.
Discontinuity Properties / Water Conditions at Discontinuities

The infiltration of water in rock masses occurs through the flow of water through the discontinuities associated with each other (secondary permeability). The mechanical properties of the rock mass change, especially in the presence of a continuous stream of water along discontinuities. The water stress between the surfaces of discontinuity reduces normal shear stress.
Classification by discontinuities
The rocks in the earth are divided into the following classes according to their discontinuities.
Massive
Thick layered
Stratified
Laminated
Cracked and microcracked
Articulated
Fault
Schistosite and Foliated
Curved

Classification by Mechanical Properties

<table>
<thead>
<tr>
<th>Kaya dayanımı</th>
<th>Tek eksenli basınç dayanımı (MPa)</th>
<th>Nokta yük dayanımı (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Çok az dayanmılı</td>
<td>&lt; 25</td>
<td>1</td>
</tr>
<tr>
<td>Az dayanmılı</td>
<td>25-50</td>
<td>1-2</td>
</tr>
<tr>
<td>Orta dayanmılı</td>
<td>50-100</td>
<td>2-4</td>
</tr>
<tr>
<td>Çok dayanmılı</td>
<td>100-200</td>
<td>4-8</td>
</tr>
<tr>
<td>Çok fazla dayanmılı</td>
<td>&gt; 200</td>
<td>&gt; 8</td>
</tr>
</tbody>
</table>
Drilling parameters determined from drilling logs

**Toplam Karot Verimi:**

$$TKV = \frac{\sum \text{ilerlemede alınmış tüm karot ve kırıntı parçalarının uzunluğu}}{\text{ilerleme aralığının uzunluğu}}$$

**Sağlam Karot Verimi:**

$$SKV = \frac{\sum \text{ilerlemede silindirik şeklini koruyan karot parçalarının uzunluğu}}{\text{ilerleme aralığının uzunluğu}}$$

**Eklem Sıklığı (Ff):**

$$\lambda = \frac{\text{Bir ilerlemedeki doğal süreklişikliklerin sayısı}}{\text{ilerleme uzunluğu (m)}} (m^{-1})$$

<table>
<thead>
<tr>
<th>Sınıflama</th>
<th>Ortalama süreklişiklik aralığı, $\overline{x}$ (m)</th>
<th>Ortalama süreklişiklik sıklığı, $\lambda$ (m$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masif</td>
<td>$x &gt; 1$</td>
<td>$&lt; 1$</td>
</tr>
<tr>
<td>Az çatısal-kırdık</td>
<td>$0.3 \leq x &lt; 1$</td>
<td>$1-3$</td>
</tr>
<tr>
<td>Karıksal-çatısal</td>
<td>$0.1 \leq x &lt; 0.3$</td>
<td>$3-10$</td>
</tr>
<tr>
<td>Çak çatısal-kırdık</td>
<td>$0.02 \leq x &lt; 0.1$</td>
<td>$10-50$</td>
</tr>
<tr>
<td>Parçalılmış</td>
<td>$x &lt; 0.02$</td>
<td>$&gt;50$</td>
</tr>
</tbody>
</table>
Drilling parameters determined from drilling logs
Bir Örnek; RQD, TCR, SCR, FF

Kaya Kalite Göstergesi (RQD)
\[ RQD (%) = \frac{\Sigma \text{Karot parçalarının uzunluğu} \times 10 \text{ cm}}{\text{İlerleme aralığının uzunluğu}} \times 100 \]

\[ RQD (%) = \frac{38+17+20+35}{200} \times 100 = 55\% \]

Toplam Karot Verimi (TCR)
\[ TCR (%) = \frac{\text{Toplam karot uzunluğu} \times 100}{\text{İlerleme aralığının uzunluğu}} \]

\[ TCR (%) = \frac{38+17+9+20+35}{200} \times 100 = 60\% \]

Sağlam Karot Verimi (SCR)
\[ SCR (%) = \frac{\text{Silindir şekli koruyan toplam karot uzunluğu} \times 100}{\text{İlerleme aralığının uzunluğu}} \]

\[ SCR (%) = \frac{38+17+20+35}{200} \times 100 = 55\% \]

Süreksizlik Sikliği (FF)
\[ FF (m^{-1}) = \frac{\Sigma \text{Ayrıntı ve doğal süreksizliklerin sayısı}}{\text{İlerleme aralığının uzunluğu}} \times 100 \]

\[ FF = \frac{8}{2} = 4 \text{ m}^{-1} \]

RQD’nin hesaplanmasıyla ilgili bir örnek (Deere ve Deere, 1988)