WESO 2026

Geology Rocks! Study Guide

Online Websites that We Recommend:

General geoscience: National Park Service - https://www.nps.gov/subjects/geology/geology-concepts.htm

General geoscience: Ducksters Science - https://www.ducksters.com/science/earth_science/

Rock and Minerals: Minerals for Kids - https://min4kids.org/

Volcano World - http://volcano.oregonstate.edu/

Earthquakes - https://earthquake.usgs.gov/learn/kids/

Google Earth - https://www.google.com/earth/

***This study guide is intended to help coaches understand the topics the event will cover so that you are better equipped to coach your team*.**

We do not expect that teams will master all of this material. Focus on the major concepts outlined in the Detailed Event Description. It is recommended and expected that additional materials, websites, and activities be used to help prepare the teams for this event.

Plate Tectonic information can be found at: https://www.nps.gov/subjects/geology/plate-tectonics.htm

General composition terms

1. Broad classification of igneous rocks and layers of the Earth are given by percent silicon dioxide compared to percentages of magnesium and iron oxides
    a. Silicic > 65% silicon dioxide (SiO_2)
    b. Intermediate is between 55-65% silicon dioxide
    c. Mafic is between 45-55% silicon dioxide
    d. Ultramafic < 45% silicon dioxide
2. Because iron is a heavier element than silicon (atomic weights from a periodic table), the more mafic (or ultramafic) the rock is, the denser it is

Composition and physical properties of layers

1. Crust (0.2 – 0.6 % of Earth's radius)
    a. Base of crust is defined by a seismic velocity discontinuity first recognized by Andrija Mohorovicic (Croatian) referred to as the *Mohorovic discontinuity* or *Moho*
    b. Oceanic
        i. 6-7 km thick
        ii. Mafic, so denser than continental

c. Continental
    i. 35 – 40 km thick, thinner at rifts, thicker in mountains
    ii. Overall, less mafic than oceanic (silicic to intermediate), so less dense
2. Mantle (2885 km thick layer)
    a. Consists of ultramafic rock (peridotite); denser than crust
    b. Almost all mantle is solid rock, but so hot it's soft enough to flow (extremely slowly, few cms/yr; imagine thick taffy)
3. Core
    a. Iron alloys (iron with oxygen, nickel, silicon, sulfur); densest layer
    b. 2 parts
        i. Outer core (2900-5155 km deep) liquid
        ii. Inner core (5155 km to center which is 6371 km depth) solid

Lithosphere and Asthenosphere

1. Can also divide outer portion of the Earth based on mechanical properties
    a. Lithosphere (relatively rigid, nonflowable layer): surface to ~100-150 km
    b. Asthenosphere (relatively soft, flowable layer; like taffy)
2. Lithosphere consists of the crust and the uppermost mantle
    a. Ocean: surface to depths of ~100km
    b. Continents: surface to depth of ~150km
3. Asthenosphere is mostly solid, but small amounts of melt do occur
    a. Can't really define a base to asthenosphere
4. Boundary of lithosphere/asthenosphere is actually temperature dependent (1280°C), because this affects the strength of rock (warmer is softer)

Plate tectonics

1. Lithospheric plates consists of the crust plus the top (cooler) part of the upper mantle
2. Asthenosphere is a relatively soft layer composed of mantle that can flow (SLOWLY!) when acted upon by a force
3. Oceanic lithosphere lies lower than continental (denser), this is why it is covered with water (oceans)
4. Plates are broken up into 8 – 12 major plates and numerous microplates
    1. Some plate boundaries follow continental margins (coasts) and others do not
    2. Active *vs.* passive margins
    3. Some plates are all continent, some all ocean, some both
5. Basic premise of plate tectonics (restated)
    1. Earth's lithosphere is divided into plates that move relative to one another and to the underlying asthenosphere
    2. Plate movement occurs at rates of 1-15 cm /year
    3. As a plate moves, its internal area remains largely rigid and intact
    4. Rock along the plate boundaries undergoes deformation as it grinds or scrapes past the neighboring plates

5. As the plate move, so do the continents that form part of the plates, accounting for continental drift

Plate boundaries

1. Three types of plate boundaries
    a. Divergent
    b. Convergent
    c. Transform
2. Divergent boundaries and sea-floor spreading
    a. Mid-ocean ridges
    b. Ridges rise above the rest of the ocean floor
    c. Formation of new crust in a narrow zone in center of this ridge (the axis or rift)
    d. Ridge consists of short segments offset by fractures
    e. Formation
        i. Youngest seafloor occurs on either side of the ridge, and gets progressively older away from the axis
    f. Shallow earthquakes and volcanoes
3. Convergent boundaries and subduction
    a. When two plates move toward each other, an oceanic plate bends and begins to sink down into the asthenosphere
    b. Downgoing plate (slab) must be oceanic; overriding plate can be oceanic or continental
        i. Continental plates will not subduct because they are too light
    c. Deep-ocean trenches
    d. Shallow to deep earthquakes and volcanoes
4. Transform boundaries
    a. Plates slide past each other (fracture zones)
    b. Actively slipping segment of a fracture zone between two ridge segments (or trenches)
    c. Shallow earthquakes

Other plate features

1. Hot spots
    a. Volcanoes that occur in the middle of a plate (away from a boundary, e.g. Hawaii)
    b. Chain of extinct volcanoes often leads away from active volcanoes
    c. Form over a fixed mantle heat source under the moving plate
    d. Mantle plumes are thought to originate at outer core – mantle boundary
2. Continental rifting
    a. Linear belt where continental lithosphere pulls apart
    b. If rifting continues long enough, sea-floor spreading begins (incipient divergent boundary)
3. Continent – continent collision
    a. Continental lithosphere is too buoyant to subduct; the attached oceanic plate will break off and sink into the mantle

b. After collision, the convergent boundary that once existed between the plates has ceased to exist

Minerals

Mineral Information can be found at Minerals for Kids - https://min4kids.org/ and https://www.nps.gov/subjects/geology/rocks-and-minerals.htm

Introduction

1. Homogeneous, naturally-occurring, inorganic solid with a definable chemical composition and a fixed internal structure
    a. Naturally occurring: must be able to be found in nature, even if we can also make it artificially
    b. Inorganic: Not based on carbon-hydrogen chains. Minerals CAN contain carbon, and they CAN form by biological processes, but they are INORGANIC chemicals
    c. Chemical Composition: every mineral has a defined chemical formula (e.g. NaCl is halite, table salt)
    d. Internal Structure: the arrangement of atoms within a mineral are in a defined lattice
2. Crystal forms are characteristic of the individual mineral, directly related to their crystal structure (e.g. halite forms cubes, snowflakes form hexagons)
3. Mineral identification
    a. Characteristic physical properties including color, streak, hardness, luster, cleavage, reaction with acid (not used for WESO), magnetism, etc.
4. Mineral classification
    a. Based on chemistry
    b. Silicates are the most common group of minerals on Earth
        i. Contain $(SiO_4)^{4-}$ *tetrahedral* groups
        ii. Examples include quartz, feldspars, micas, clays, amphiboles, pyroxenes, and olivine
    3. Other important mineral groups
        i. Native metals, sulfides, oxides (ore minerals)
        ii. Phosphates, carbonates, sulfates and halides
5. Mineral or not a mineral?
    a. Ice - is a mineral
    b. Sugar - is NOT a mineral (organic hydrocarbon solid)
    c. Glass - is NOT a mineral (lacks fixed crystal structure)
    d. Copper - is a mineral
    e. Mercury - is NOT a mineral (liquid, not a solid)
    f. Diamond - is a mineral (even if it's made in a lab, because it CAN be found in nature, it's a mineral)

Rocks

Rock Information can be found at Minerals for Kids - https://min4kids.org/ and https://www.nps.gov/subjects/geology/rocks-and-minerals.htm

Introduction

1. Coherent, naturally-occurring solid consisting of an aggregate of minerals or a mass of glass
2. Either bonded together by cement (mineral material) or interlock like puzzle pieces
    a. Clastic
    b. Non-clastic (crystalline)
3. Rock classification
    a. Genetic (how they form)
    b. 3 Basic groups
        i. Igneous
        ii. Sedimentary
        iii. Metamorphic
    c. Distinguished by physical characteristics
        i. Grain size, shape and sorting
        ii. Composition
        iii. Texture
        iv. Layering

Igneous Rocks and Environments

Introduction

1. Most common rock on/in Earth; formed from the solidification of a melt
2. Magma *vs.* lava
3. Intrusive, extrusive, pyroclastics

Magma composition

1. All contain silicon (Si) and oxygen (O) with varying proportions of other elements (including aluminum, calcium, sodium, potassium, iron, magnesium, etc.)
2. Major types (see top of outline for definition)
    a. Silicic (felsic)
    b. Intermediate
    c. Mafic (an abbreviation of <u>ma</u>gnesium and <u>fe</u>rrum, which is Latin for iron)
    d. Ultramafic

Classifying Igneous Rocks

1. Based on composition and texture
    a. Silicic – intermediate – mafic – ultramafic
    b. Coarse (larger crystals) – fine (small crystals) – glassy

2. Silicic: Granite (coarse), rhyolite (fine)
3. Intermediate: Diorite (coarse), andesite (fine)
4. Mafic: Gabbro (coarse), basalt (fine)
5. Others include obsidian (glassy) and pumice (glassy with air bubbles)

Settings of igneous rock formation

1. Volcanic arcs bordering deep-ocean trenches (subduction)
2. Isolated hot spots (mantle plumes)
3. Continental rifting (thinning crust)
4. Mid-ocean ridges (divergent boundary)

VOLCANOES

Volcano Information can be found at: Volcano World - http://volcano.oregonstate.edu/

Definition of volcano

Products of volcanic eruptions

1. Three forms: lava flows, pyroclastic debris, and volcanic gas
    a. Influence the shape of the volcano and landscape around it
2. Lava and lava flows
    a. Variety of compositions
        i. High in silica are silicic (or rhyolitic)
        ii. Intermediate silica content are called intermediate (or andesitic)
        iii. Low in silica are mafic (or basaltic)
    b. Viscosity (resistance to flow) of lava depends on its composition and temperature

Architecture and shape of volcanoes

1. Chimney *vs*. fissure
2. Crater
    a. Summit eruptions
    b. Flank eruptions
3. Caldera
4. Resurgent dome
5. Shield volcanoes
6. Cinder cones
    a. Angle of repose
7. Stratovolcanoes (composite volcanoes)

Eruptive Style

1. Effusive eruptions
2. Explosive (pyroclastic) eruptions

3. Type of volcano depends on eruptive style

Settings of Volcanoes

1. Hot-spot eruptions
    a. Oceanic hot-spot (Hawaii)
    b. Continental hot-spot (Yellowstone)
    c. Flood-basalt eruptions
2. Eruptions along mid-ocean ridge (MOR)
    a. Iceland is one of the few places where MOR volcanism reaches above sea level
3. Eruptions along convergent boundaries
    a. Many different types of lava can be erupted, depending on whether it comes directly from the mantle, or if it has been altered after it formed
    b. Volcanic island arcs (Aleutians, Japan)
    c. Continental volcanic arcs (Cascades, Andes)
4. Eruptions in continental rifts
    a. Rifting of a continent produces a range of volcano types, because the magma comes from both partial melting of the mantle (basalt) and partial melting of the crust (rhyolite)
    b. Examples are the East African Rift Zone and the failed rift in the Keweenaw Peninsula of Michigan

Sedimentary Rocks

1. Sedimentary rocks form from the weathering of other rocks and then deposition of those weathered materials, either directly as grains or through precipitation from water
2. Found in the crust only at or relatively near the earth's surface
3. Clastic rocks consists of individual minerals or fragments of rock
    a. Classification is based on grain size
        i. Conglomerate (pebble-sized or larger; greater than 2 mm grains)
        ii. Sandstone (sand-sized; between 1/16 - 2 mm grains)
        iii. Siltstone (silt-sized; between 1/256 - 1/16 mm grains)
        iv. Shale or mudstone (clay-sized grains, less than 1/256 mm)
4. Non-clastic rocks consist of material that was dissolved and then precipitated out of water or material deposited by organisms
    a. Classification is based on composition
        i. Limestones (calcite); may or may not have fossils
        ii. Dolostone (dolomite)
        iii. Chert (quartz)
        iv. Bituminous Coal (carbon)

METAMORPHIC ROCKS

Introduction: What is a metamorphic rock?

1. Rock that changed from its original form into a new one, without first becoming melt or sediment (solid-state change)
2. Protolith
3. Metamorphic mineral assemblage
4. Metamorphic foliation

Types of Metamorphic rocks

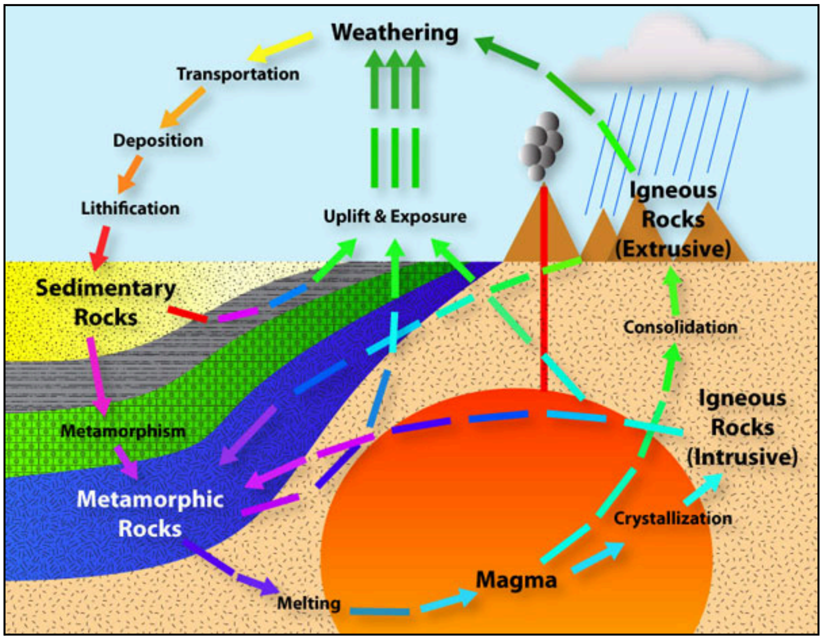
1. Foliated (leaf) - layered rocks
    a. Slate
    b. Schist
    c. Gneiss
    d. Amphibolite
2. Non-foliated
    a. Quartzite
    b. Marble
    c. Coal (anthracite)
    d. Soapstone

Grades of metamorphism

1. Conditions for metamorphism lie between lithification (very low pressures and temps) and where melting takes place (very high temps)
    a. Low-grade: relatively low temps (under 320 °C or around 600 °F)
    b. High-grade: relatively high temps (over 500 °C or around 930 °F)
    c. Intermediate is range in between

ROCK CYCLE

1. This describes the process of how one rock can be transformed into another through geologic processes
2. There is no <u>one</u> path through the rock cycle and not all rocks share the same <u>journey</u>
3. The diagram below shows some of the possible paths



EARTHQUAKES

Earthquake Information can be found at: Earthquakes - https://earthquake.usgs.gov/learn/kids/

Introduction

1. Scientific study suggests these possible causes:
    a. Sudden formation of a new fault
    b. Sudden movement on an existing fault
    c. Cracking of a volcano when it fills with lava
    d. Explosion of a volcano
    e. Giant landslides
2. Focus *vs.* epicenter

Seismic Waves

1. Distinguish between different types of waves based on where and how the wave moves
    a. Body waves
    b. Surface waves
    c. Compressional waves
    d. Shear waves
2. 4 basic types of seismic waves
    a. P-waves: (Primary)
    b. S-waves: (Secondary)
    c. R-waves: (Rayleigh)
    d. L-waves: (Love)
3. Speed of waves

Measuring and location

1. Seismographs record the arriving seismic waves as “wiggles”
2. Calculate distance to epicenter based on differences in arrival times of P- and S-waves
    a. Travel-time curve
    b. Triangulation
3. Settings
    a. Plate boundary earthquakes
    b. Intraplate earthquakes

<u>Physical Properties for Identifying Minerals and Rocks</u>

*****THESE WILL BE EXPLAINED AND DEMONSTRATED IN FULL AT THE APRIL WORKSHOP*****

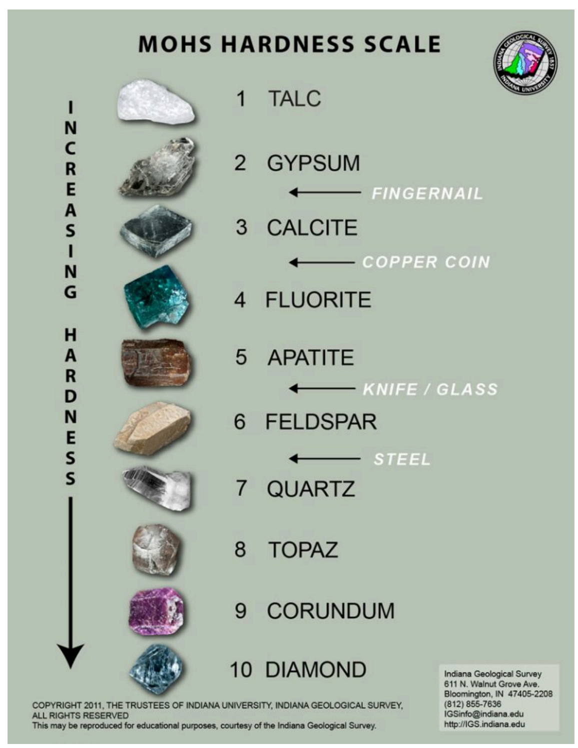
Mineral Identification

1. Many physical properties used for mineral identification can also be used with rocks
2. The best way to identify any sample is to use several properties, not just one
3. More information can be found on Minerals for Kids - https://min4kids.org/

4. <u>Morphology</u>
    a. This is the crystal form, which is tied to the internal structure of the mineral
    b. Examples include cube (halite/table salt), hexagonal (snowflake, quartz), rhombus (calcite)
    c. Not always obvious, but can be really helpful when it is

5. <u>Color and Streak</u>
    a. Color is not always helpful, but it can be when used with other properties
    b. Streak is slightly more useful; it is the color of the powdered mineral
        i. Obtained by rubbing the mineral across a piece of unglazed porcelain (streak plate, provided in your kits)

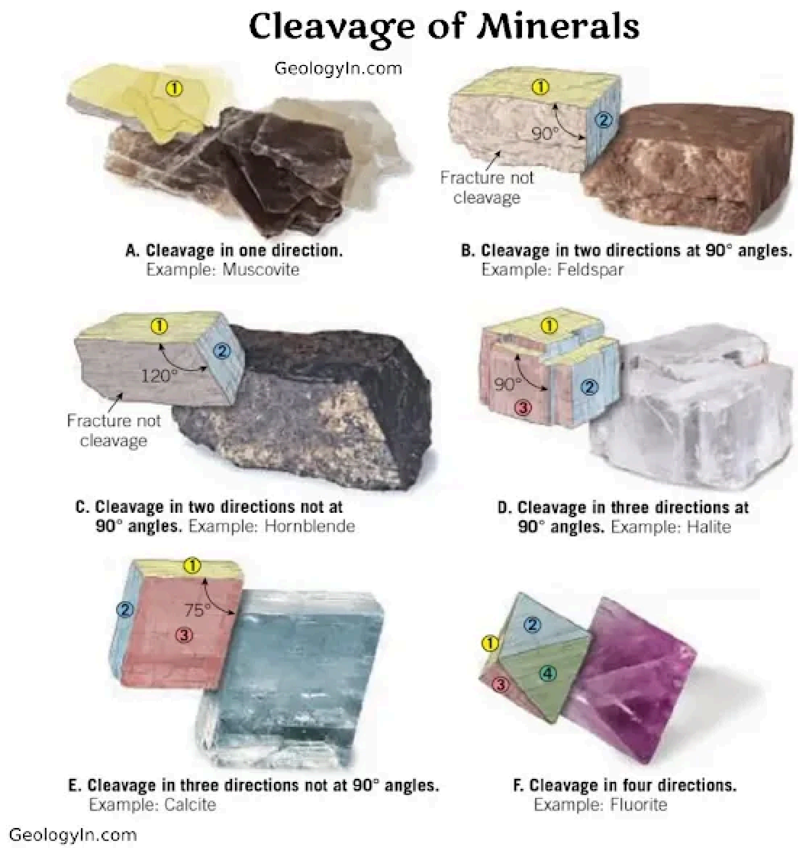
6. <u>Luster</u>
    a. Luster is the way the surface scatters light
    b. Metallic vs. non-metallic is the first division
    c. Non-metallic can be further categorized with terms such as glassy, dull, silky, etc.



7. <u>Hardness</u>
    a. Hardness is a measure of how resistant a material is to scratching (not breaking; that's a different property); we used a scale from 1-10 to designate hardness (Mohs Scale)
    b. Test by trying to either scratch the sample or the tester (e.g. copper, glass, provided in your kits); a scratch will be left in the softer material.
    c. Samples are usually identified as having a hardness in a range, such as less than 2.5 (softer than a fingernail), between 2.5-3.5 (softer than copper but harder than a fingernail), etc.

d. Use caution when testing hardness on a glass plate; the glass should be flat on the table, not in your hand
e. Some samples may break when testing; this isn't the hardness

8. Cleavage and fracture
    a. This is describing how a mineral breaks
    b. If the mineral breaks on flat, parallel planes, it is said to have cleavage
    c. If the mineral breaks in uneven and random ways, it is said to have fracture
    d. Cleavage:
        i. A mineral may have cleavage in one orientation, but fractures in any other direction
        ii. We define cleavage based on the number of directions, the angles of intersection, and how well-pronounced they are (excellent, good, poor)
        iii. Cleavage is obvious in some materials (e.g. muscovite, halite/table salt), but less obvious in others
    e. Fracture:
        i. Fracture describes breakage not defined by cleavage
        ii. Quartz and glass both break on smooth, shell-shaped curved surfaces known as conchoidal fracture
        iii. Other fracture terms include irregular, fibrous, splintery, etc.



9. Specific gravity
    a. Density of a sample
    b. We use general terms of light, average, or heavy compared to other materials the same size

10. Magnetism
    a. Some iron-bearing minerals are magnetic (a magnet will stick to them, provided in your kits)

b. These will also vary in how strongly they react to the magnet; magnetite will react strongly, while hematite will react weakly. These are both iron oxide minerals, but behave differently

11. <u>Striations</u>
    a. A series of parallel lines seen on crystal or cleavage faces (pictured, vertical striations on tourmaline)

12. <u>Reaction to acid</u>
    a. Some minerals (mostly carbonates) react with acid
    b. Some react more vigorously than others
    c. We will be demonstrating how to safely use acid during the event workshop. Coaches can show their students this with vinegar during practice (with vinegar you may need to test on a fresh scratch or on the streak (powder) of the sample

13. For each mineral, 3 or 4 properties should be enough to identify the mineral, however, *which* 3 or 4 will vary from mineral to mineral

Rock Identification

1. The Study Guide that comes with the rock kit has a very good description of how to differentiate the different samples; coaches should read the booklet to help their students