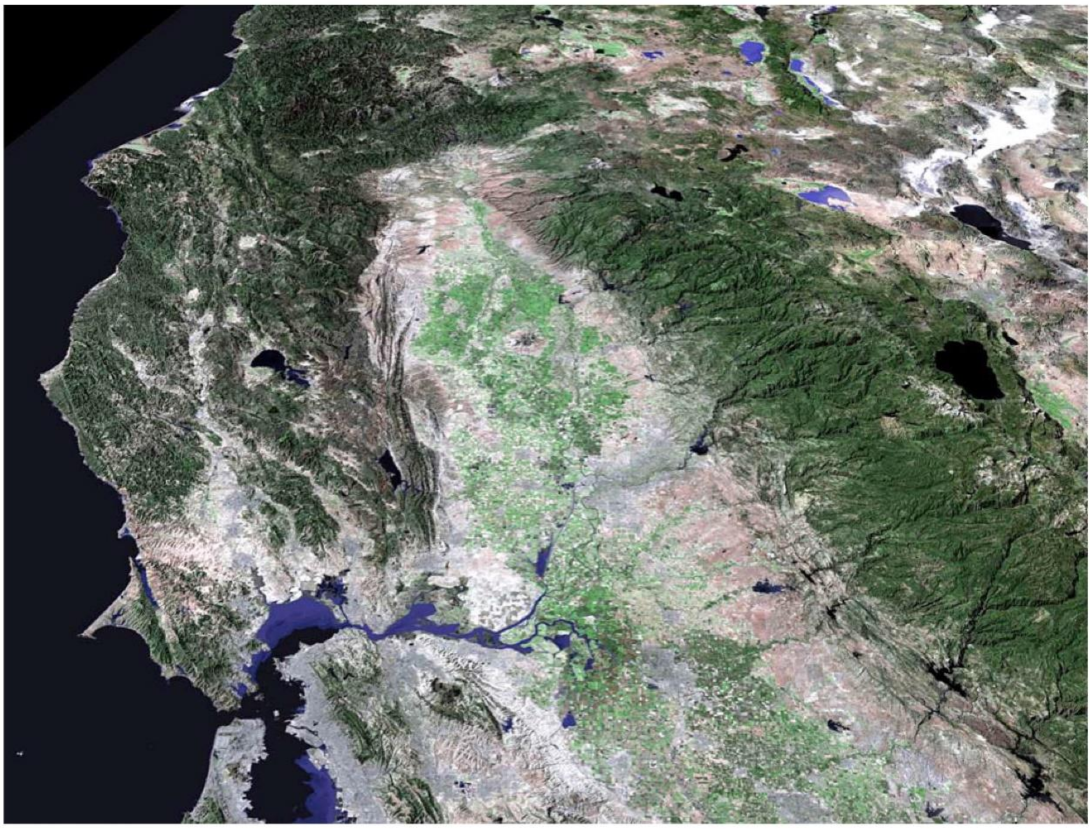
Komar University of Science and Technology

General Geology and Lab

Laboratory Manual



Lecturer**:**

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1. Introduction

The first lecture in this manual deals with how to identify and describe the minerals through their properties like hardness, chemical reaction with acid, streak and so on (see also Appendix A). In line with the first lesson, the second lecture explains about the type of rocks and their classification. The third lab lesson in this manual deals with how to read and use topographic and geologic maps. This lesson follows a sequence that progresses through the basics of plate tectonics, seismology, and geologic time and concludes with such overarching topics as Earth's major geologic features (e.g., the deformation of Earth's surface like folds and faults) and economic geology resources.

Each lesson includes specific learning objectives that the students should use to prepare for the lab. The lab manual includes the procedures that illuminate the central principles of physical geology and lab course. The procedures can help the students to review, analyze, and apply their knowledge of the materials covered in the lab course. Reading this lab manual, completing the activities and exercises, and doing the field trip at the end of lab course will provide the pupils with useful information that they would receive in the classroom if you were taking this lab course on campus.

2. Minerals

According to geologists, **minerals** are inorganic, naturally occurring solids that have a definite chemical composition, distinctive physical properties, and crystalline structure. In other words, each mineral:

- ✓ occurs in the solid, rocky body of Earth, where it formed by processes that are inorganic (not involving life),
- ✓ has a definite chemical composition of one or more chemical elements that can be represented as a chemical formula (like $NaCl$ for halite),
- ✓ has physical properties (like hardness, how it breaks, and color) that can be used to identify it,
- ✓ has crystalline structure—an internal patterned arrangement or geometric framework of atoms that can be revealed by external crystal faces, the way a

mineral breaks, and in atomic- resolution images

2.1.Classification of Minerals

Geologists have identified and named thousands of different kinds of minerals, but they are often classified into smaller groups according to their importance, use, or chemistry. For example, a group of only about twenty are known as **rock-forming minerals,** because they are the minerals that make up most of Earth's crust. Another group is called the **industrial minerals**, because they are the main non-fuel raw materials used to sustain industrialized societies like ours. Some industrial minerals are used in their raw form, such as quartz (quartz sand), muscovite (used in computer chips), and gemstones. Most are refined to obtain specific elements such as iron, copper, and sulfur. All minerals are also classified into the following chemical classes (Table 1):

Table 1

Class	Silicate	Oxide	Hydroxide	Sulfide	Carbonate	Phosphate	Halide	Sulfate
Chemical Composition	SiO_2 $(SiO_4)^{4-}$	O^{2-}	$(OH)^-$	S^{2-}	$(CO_3)^{2-}$	$(PO_4)^{3-}$	F^-, Cl^- Br^-, I^-	$(SO_4)^{2-}$
Example	Quartz Olivine	Hematite Magnetite	Limonite	Pyrite Galena	Calcite Dolomite	Apatite	Halite Fluorite	Gypsum

2.2.Minerals and rocks

Most **rocks** are aggregates of one or more mineral crystals. For example, mineral crystals comprise all of the rocks in Fig. 1. Notice that you can easily detect the mineral crystals in Fig. 1 by their flat **faces**, which are an external feature of the internal geometric framework of their atoms. However, the crystals in many rocks have grown together in such a crowded way that few faces are visible. Some rocks are also **cryptocrystalline**, made of crystals that are only visible under a microscope. Earth is sometimes called the "third rock" (rocky planet) from the Sun, because it is mostly made of rocks. But rocks are generally made of one or more minerals, which are the natural materials from which every inorganic item in our industrialized society has been manufactured. Therefore, minerals are the physical foundation of both our rocky planet and our human societies.

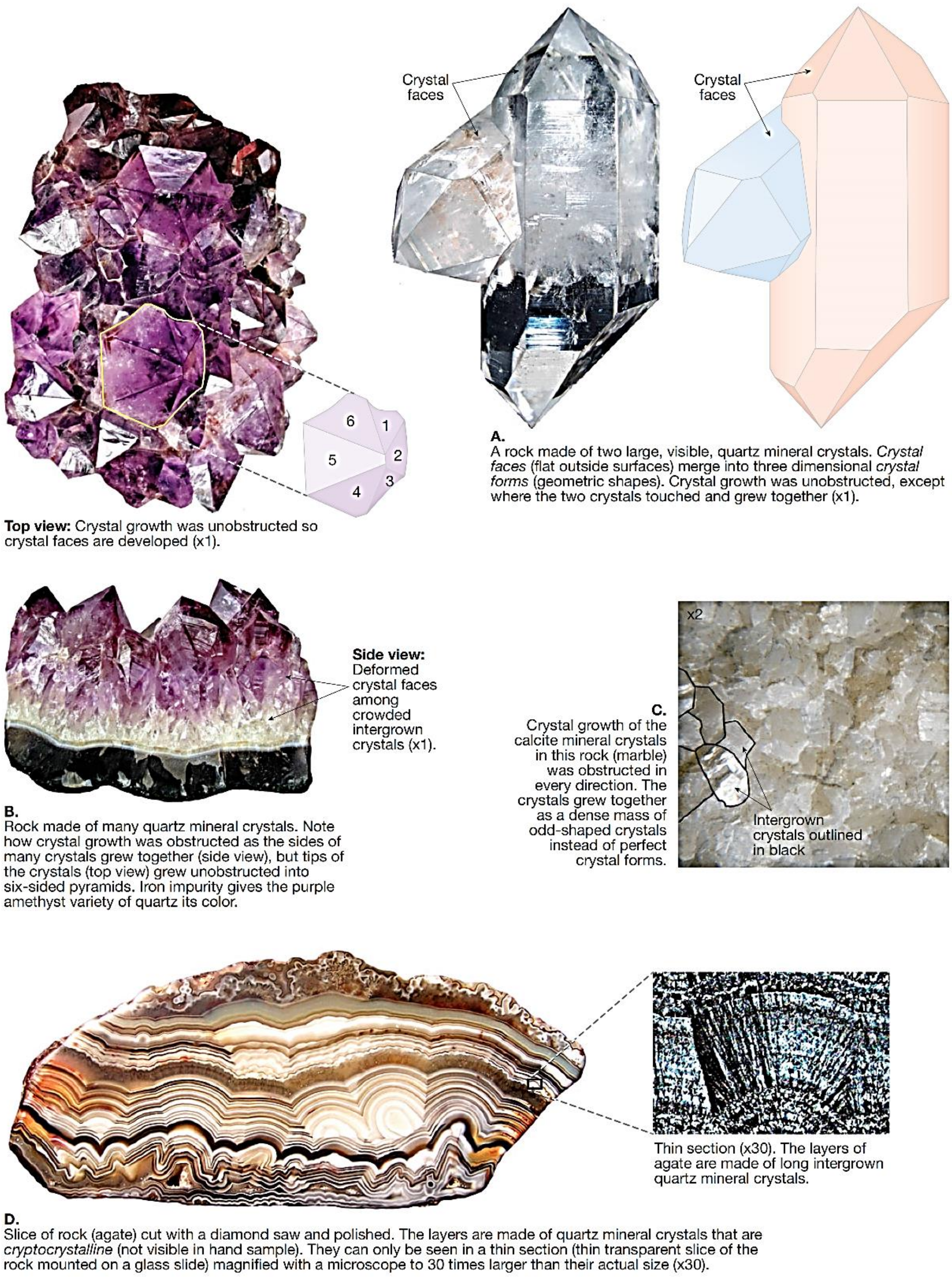


Fig. 1

2.3.Chemical and Physical Properties

The **chemical properties** of a mineral are its characteristics that can only be observed and measured when or after it undergoes a chemical change due to reaction with another material. This includes things like if or how it tarnishes (reacts with air or water) and whether or not it reacts with acid. For example, calcite and other carbonate (CO_3- containing) minerals react with acid, and native copper tarnishes to a dull brown or green color when it reacts with air or water.

The **physical properties** of a mineral are its characteristics that can be observed (and sometimes measured) without changing its composition. This includes things like how it looks (color, luster, and clarity) before it tarnishes or weathers by reacting with air or water, how well it resists scratching (hardness), how it breaks or deforms under stress (cleavage, fracture, tenacity), and the shapes of its crystals. For example, quartz crystals are hard to scratch, glassy, and transparent, while talc is easily scratched, opaque, and feels greasy.

In this activity, you will use the properties of color and clarity (before and after tarnishing), crystal form, luster (before and after tarnishing), streak, hardness, cleavage, and fracture to describe mineral samples. Additional properties— such as tenacity, reaction with acid, magnetic attraction, specific gravity, striations, and ex-solution lamellae - can also be helpful in analyzing particular minerals.

***Color and Clarity*.** A mineral's **color** is usually its most noticeable property and may be a clue to its identity. Minerals normally have a typical color, like gold. A rock made up of one color of mineral crystals is usually made up of one kind of mineral, and a rock made of more than one color of mineral crystals is usually made up of more than one kind of mineral. However, there are exceptions, like the agate in Fig. 3. It has many colors, but they are simply *varieties* (var.)—different colors—of the mineral quartz. This means that a mineral cannot be identified solely on the basis of its color. The mineral's other properties must also be observed, recorded, and used collectively to identify it. Most minerals also tend to exhibit one color on freshly broken surfaces and a different color on tarnished or weathered surfaces. Be sure to note this difference, if present, to aid your identification.

Mineral crystals may vary in their **clarity**: degree of transparency or their ability to transmit light. They may be *transparent* (clear and see-through, like window glass), *translucent* (foggy, like looking through a steamed- up shower door), or *opaque* (impervious to light, like concrete and metals). It is good practice to record not only a mineral's color, but also its clarity. For example, the crystals in Fig. 3 are purple in color and have transparent to translucent clarity.

***Crystal Forms and Mineral Habits*.** The geometric shape of a crystal is its **crystal form**. Each form is bounded by flat **crystal faces** that intersect at specific angles and in symmetrical relationships (Fig. 1). The crystal faces are the outward reflection of the way that atoms or groups of atoms bonded together in a three-dimensional pattern as the crystal grew under specific environmental conditions. There are many named crystal forms (Fig. 2). Combinations of two or more crystals can also form named patterns, shapes, or twins (botryoidal, dendritic, radial, and fibrous: Fig. 2). A mass of mineral crystals lacking a distinctive pattern of crystal growth is called *massive*.

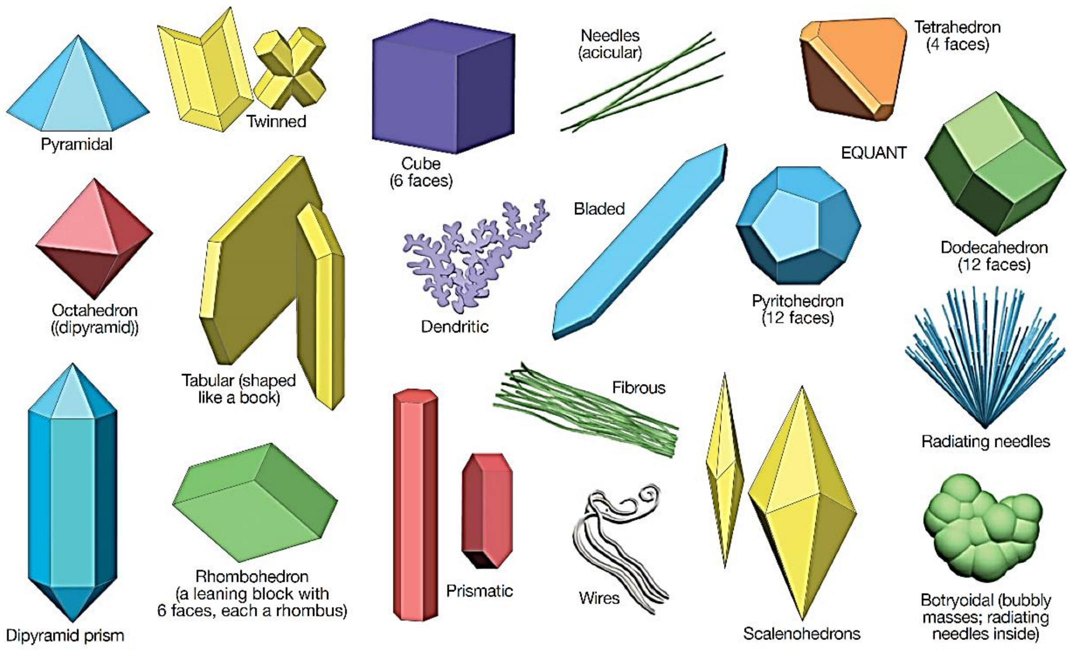


Fig. 2

***Crystal Systems*.** Each specific crystal form can be classified into one of six *crystal systems* (Fig. 3) according to the number, lengths, and angular relation- ships of imaginary geometric axes along which its crystal faces grew. The crystal systems comprise 32 classes of crystal forms, but only the common crystal forms are illustrated in Fig. 3.

***Luster*.** A mineral's **luster** is a description of how light reflects light from its surfaces. Luster is of two main types— metallic and nonmetallic—that vary in intensity from bright (very reflective, shiny, polished) to dull (not very reflective, not very shiny, not polished). For example, if you make a list of objects in your home that are made of metal (e.g., coins, knives, keys, jewelry, door hinges, aluminum foil), then you are already familiar with metallic luster. Yet the metallic objects can vary from bright (very reflective—like polished jewelry, the polished side of aluminum foil, or new coins) to dull (non-reflective—like unpolished jewelry or the unpolished side of aluminum foil).

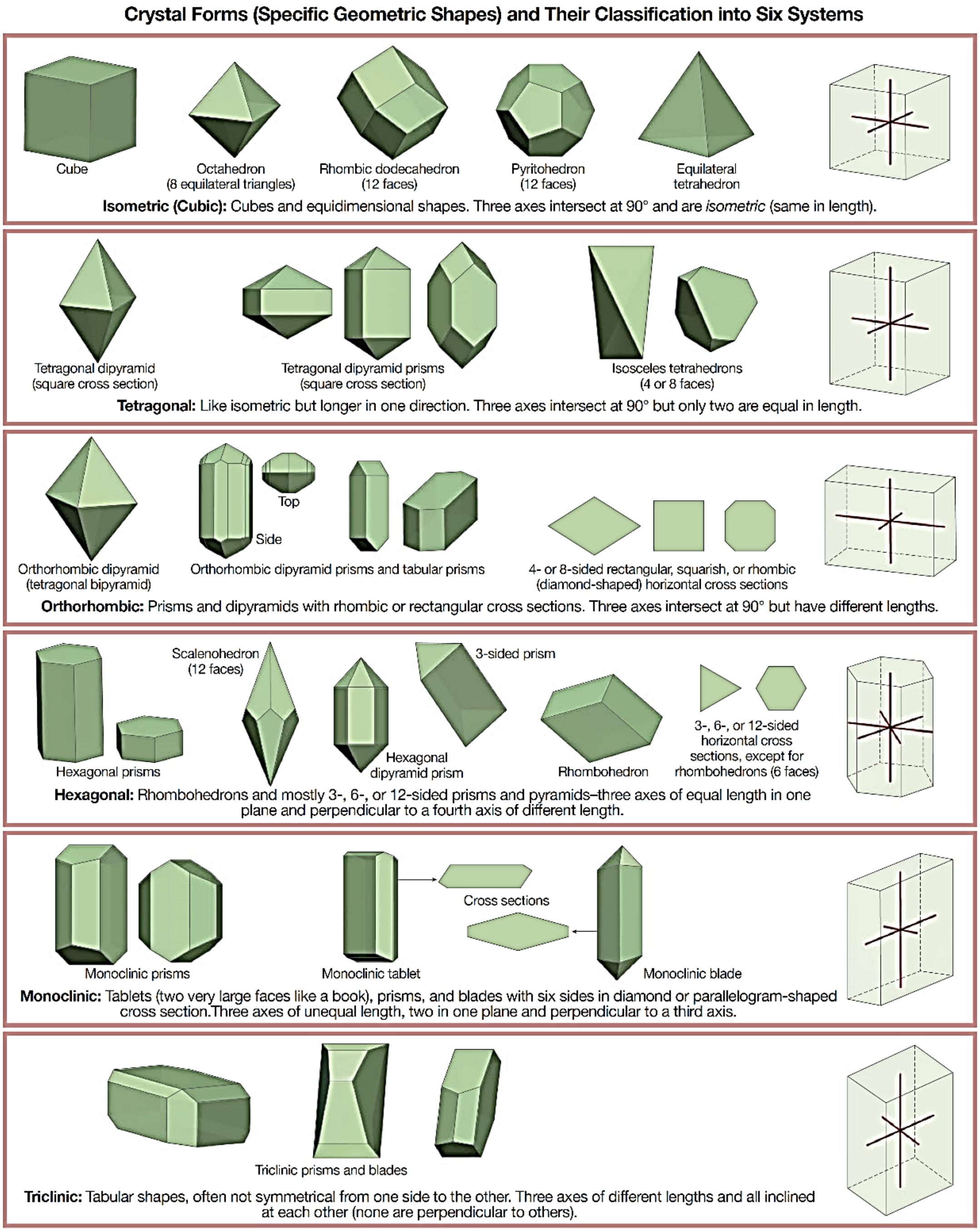


Fig. 3

***Streak*.** **Streak** is the color of a mineral or other substance after it has been ground to a fine powder (so fine that you cannot see the grains of powder). The easiest way to do this is simply by scratching the mineral back and forth across a hard surface such as concrete, or a square of unglazed porcelain (called a *streak plate*). The color of the mineral's fine powder is its streak. Note that the brassy mineral in Fig. 4 has a dark gray streak, but the reddish silver mineral has a red-brown streak. A mineral's streak is usually similar even among all of that mineral’s varieties.

If you encounter a mineral that is harder than the streak plate, it will scratch the streak plate and make a white streak of powder from the streak plate. The streak of such hard minerals can be determined by crushing a tiny piece of them with a hammer (if available). Otherwise, record the streak as unknown.

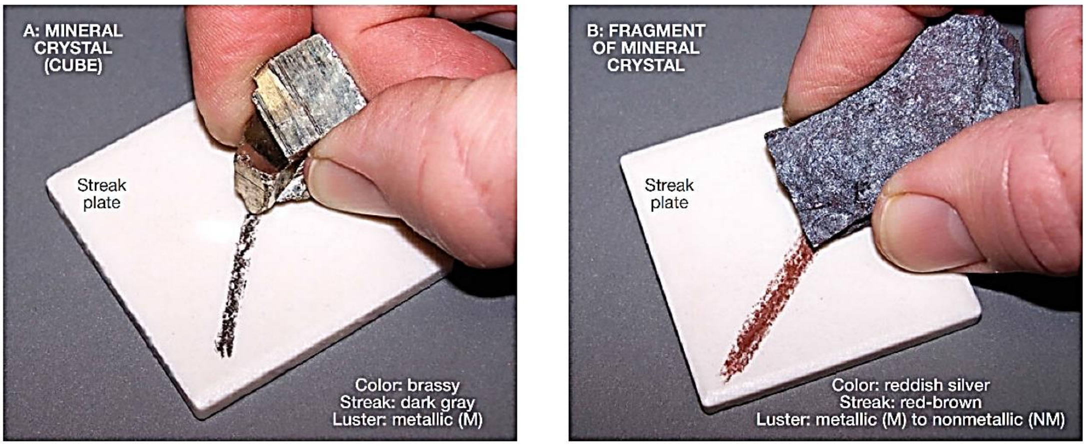


Fig. 4

<u>Hardness (H)</u>**.** A mineral’s **hardness** is a measure of its resistance to scratching. A harder substance will scratch a softer one. German mineralogist Friedrich Mohs (1773–1839) developed a quantitative scale of relative mineral hardness on which the softest mineral (talc) has an arbitrary hardness of 1 and the hardest mineral (diamond) has an arbitrary hardness of 10. Higher- numbered minerals will scratch lower-numbered minerals (e.g., diamond will scratch talc, but talc cannot scratch diamond). **Mohs scale of Hardness** (Fig. 5) is widely used by geologists and engineers. When identifying a mineral, you should mainly be able to distinguish minerals that are relatively hard (6.0 or higher on Mohs scale) from minerals that are relatively soft (less than or equal to 5.5 on Mohs scale). You can use common objects such as a glass plate (Fig. 6), pocket knife, or steel masonry nail to make this distinction as follows.

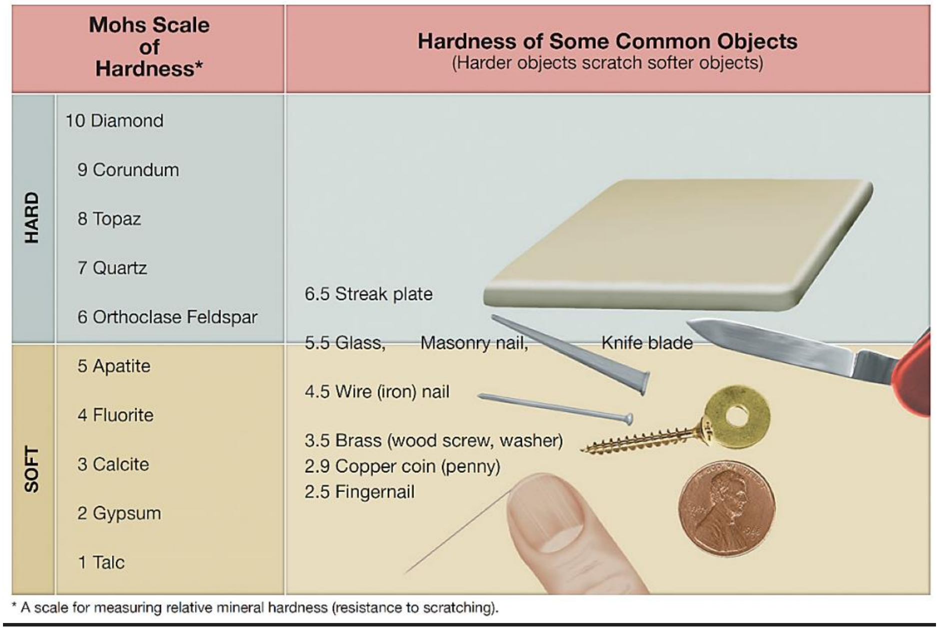


Fig. 5

- ✓ **Hard minerals:** Will scratch glass; cannot be scratched with a knife blade or masonry nail.
- ✓ **Soft minerals:** Will not scratch glass; can be scratched with a knife blade or masonry nail.

You can determine a mineral's hardness number on Mohs scale by comparing the mineral to common objects shown in Fig. 5 or pieces of the minerals in Mohs scale. When using such kits to make hardness comparisons, remember that the harder mineral/object is the one that scratches, and the softer mineral/object is the one that is scratched.

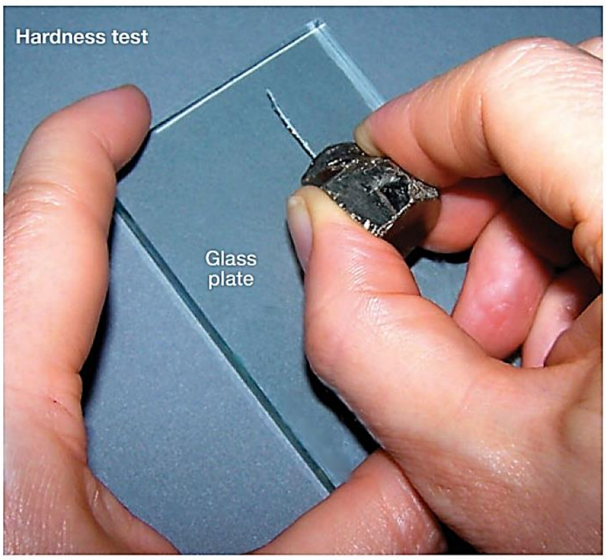


Fig. 6

Cleavage and Fracture**.** **Cleavage** is the tendency of some minerals to break (*cleave*) along flat, parallel surfaces (**cleavage planes**) like the flat surfaces on broken pieces of galena. Cleavage planes are surfaces of weak chemical bonding (attraction) between repeating, parallel layers of atoms in a crystal. Each different set of parallel cleavage planes is referred to as a *cleavage direction*. Cleavage can be described as excellent, good, or poor (Fig. 7). An *excellent cleavage* direction reflects light in one direction from a set of obvious, large, flat, parallel surfaces. A *good cleavage* direction reflects light in one direction from a set of many small, obvious, flat, parallel surfaces. A *poor cleavage* direction reflects light from a set of small, flat, parallel surfaces that are difficult to detect. Some of the light is reflected in one direction from the small cleavage surfaces, but most of the light is scattered randomly by fracture surfaces separating the cleavage surfaces.

Fracture refers to any break in a mineral that does not occur along a cleavage plane. Therefore, fracture surfaces are normally not flat and they never occur in parallel sets. Fracture can be described as *uneven* (rough and irregular, like the milky quartz in, *splintery* (like splintered wood), or *hackly* (having jagged edges, like broken metal).

Other Properties**.** There are additional mineral proper- ties, too numerous to review here. However, the following other properties are typical of specific minerals or mineral groups:

Reaction to acid. Reaction to acid differs among minerals. Cool, dilute hydrochloric acid (1–3% HCl) applied from a dropper bottle is a common “acid test.” All of the so-called *carbonate* minerals (minerals with a chemical composition including carbonate, CO_3) will effervesce (“fizz”) when a drop of such dilute HCl is applied to one of their freshly exposed surfaces (Fig. 8). Calcite ($CaCO_3$) is the most commonly encountered carbonate mineral and effervesces in the acid test.

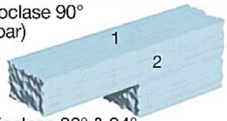
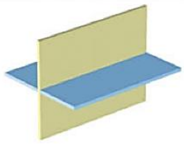
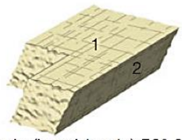
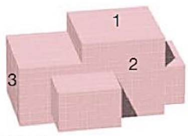
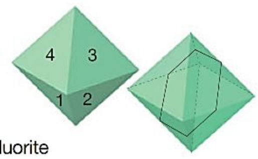
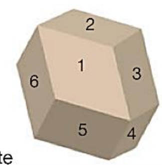
Number of Cleavages and Their Directions	Name and Description of How the Mineral Breaks	Shape of Broken Pieces (cleavage directions are numbered)	Illustration of Cleavage Directions
No cleavage (fractures only)	No parallel broken surfaces; may have conchoidal fracture (like glass)	 Quartz	None (no cleavage)
1 cleavage	**Basal (book) cleavage** "Books" that split apart along flat sheets	 Muscovite, biotite, chlorite (micas)	
2 cleavages intersect at or near 90°	**Prismatic cleavage** Elongated forms that fracture along short *rectangular* cross sections	Orthoclase 90° (K-spar)  Plagioclase 86° & 94°, pyroxene (augite) 87° & 93°	
2 cleavages do not intersect at 90°	**Prismatic cleavage** Elongated forms that fracture along short *parallelogram* cross sections	 Amphibole (hornblende) 56° & 124°	
3 cleavages intersect at 90°	**Cubic cleavage** Shapes made of cubes and parts of cubes	 Halite, galena	
3 cleavages do not intersect at 90°	**Rhombohedral cleavage** Shapes made of rhombohedrons and parts of rhombohedrons	 Calcite and dolomite 75° & 105°	
4 main cleavages intersect at 71° and 109° to form octahedrons, which split along hexagon-shaped surfaces; may have secondary cleavages at 60° and 120°	**Octahedral cleavage** Shapes made of octahedrons and parts of octahedrons	 Fluorite	
6 cleavages intersect at 60° and 120°	**Dodecahedral cleavage** Shapes made of dodecahedrons and parts of dodecahedrons	 Sphalerite	

Fig. 7

Specific Gravity (SG)**.** Density is a measure of an object's mass (weighed in grams, g) divided by its volume (in cubic centimeters, cm^3). **Specific gravity** is the ratio of the density of a substance divided by the density of water. Since water has a density of 1 g >cm^3 and the units cancel out, specific gravity is the same number as density but without any units. For example, the mineral quartz has a density of 2.65 g>cm^3 so its specific gravity is 2.65 (i.e., SG = 2.65).

Fig. 8

2.4.The Importance of SG and Density

Have you ever considered buying silver coins as an investment? If so, then you should be wary of deceptive sales. For example, there have been reports of less valuable silver-plated copper coins marketed as pure silver coins. Copper has a specific gravity of 8.94, which is very close to silver's specific gravity of 9.32. So, even experienced buyers cannot tell a solid silver coin from a silver-plated copper coin just by hefting it to approximate its specific gravity. They must deter- mine the coin's exact specific gravity as one method of ensuring its authenticity. Mineral identification is also aided by knowledge of specific gravity. If you heft same-sized pieces of the minerals galena (lead sulfide, an ore of lead) and quartz, you can easily tell that one has a much higher specific gravity than the other. But the difference in specific gravities of different minerals is not always so obvious. In this activity you will learn how to measure the volume and mass of mineral samples, calculate their specific gravities, and use the results to identify them.

How to Determine Volume. Recall that **volume** is the amount of space that an object takes up. Most mineral samples have odd shapes, so their volumes cannot be calculated from linear measurements. Their volumes must be determined by measuring the volume of water they displace. This is done in the laboratory with a *graduated cylinder* (Fig. 9), an instrument used to measure volumes of fluid (fluid volume). Most graduated cylinders are graduated in metric units called milliliters (mL or ml), which are thousandths of a liter. *You should also note that 1 mL (1 ml) of fluid volume is exactly the same as 1 cm^3 of linear volume*.

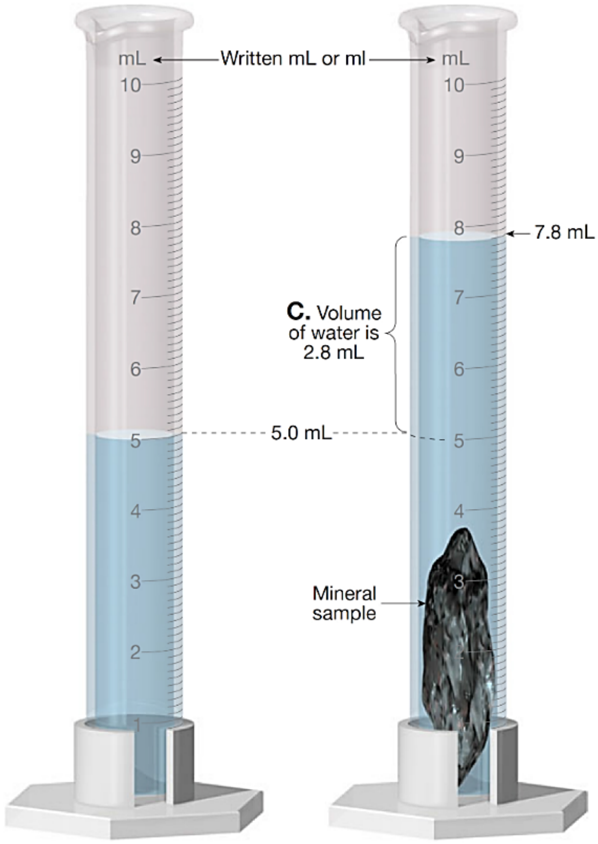
Procedures for determining the volume of a mineral sample are provided in Fig. 9. Note that when you pour water into a glass graduated cylinder, the surface of the liquid is usually a curved *meniscus*, and the volume is read at the bottom of its concave surface. In most plastic graduated cylinders, however, there is no meniscus. The water level is flat and easy to read.

If you slide a mineral sample into a graduated cylinder full of water (so no water splashes out), then it takes up space previously occupied by water at the bottom of the graduated cylinder. This displaced water has nowhere to go except higher into the graduated cylinder. Therefore, the volume of the mineral sample is exactly the same as the volume of fluid (water) that it displaces.

How to Determine Mass. Earth materials do not just take up space (volume). They also have a mass of atoms that can be weighed. You will use a gram balance to measure the **mass** of materials (by determining their weight under the pull of Earth's gravity). The gram (g) is the basic unit of mass in the metric system, but instruments used to measure grams vary from triple-beam balances to spring scales to digital balances (page viii). Consult with your laboratory instructor or other students to be sure that you understand how to read the gram balance provided in your laboratory.

How to Calculate Density and Specific Gravity. Every material has a *mass* that can be weighed and a *volume* of space that it occupies. However, the relationship between a material's mass and volume tends to vary from one kind of material to another. For example, a bucket of rocks has much greater mass than an equal-sized bucket of air. Therefore a useful way to describe an object is to determine its mass per unit of volume, called **density**. *Per* refers to division, as in miles *per* hour (distance divided by time). So density is the measure of an object's mass divided by its volume (density = mass ÷ volume). Scientists and mathematicians use the Greek character rho (**r**) to represent density. Also, the gram (g) is the basic metric unit of mass, and the cubic centimeter is the basic unit of metric volume (cm^3), so density (**r**) is usually expressed in grams per cubic centimeter (g/cm^3).

WATER DISPLACEMENT METHOD FOR DETERMINING VOLUME OF A MINERAL SAMPLE



A. Starting volume of water

B. Ending volume of water

PROCEDURES

A. Place water in the bottom of a graduated cylinder. Add enough water to be able to totally immerse the mineral sample. It is also helpful to use a dropper bottle or wash bottle and bring the volume of water (before adding the mineral sample) up to an exact graduation mark like the 5.0 mL mark above. Record this starting volume of water.

B. Carefully slide the mineral sample down into the same graduated cylinder, and record the ending volume of the water (7.8 mL in the above example).

C. Subtract the starting volume of water from the ending volume of water to obtain the displaced volume of water. In the above example: 7.8 mL – 5.0 mL = 2.8 mL (2.8 mL is the same as 2.8 cm^3). This volume of displaced water is the volume of the mineral sample.

Fig. 9

3. Rocks and the Rock Cycle

Most rocks are solid aggregates of mineral grains (particles), either mineral crystals or clasts (broken pieces) of mineral crystals and rocks (e.g., pebbles, gravel, sand, and silt). There are, however, a few notable rocks that are not made of mineral grains. For example, *obsidian* is a rock made of volcanic glass, and *coal* is a rock made of plant fragments.

Rock-forming materials come from Earth's mantle (as molten rock called *magma* while underground and *lava* when it erupts to the surface), space (meteorites), organisms (parts of plants and animals), or the fragmentation and chemical decay of mineral crystals and other rocks. Environmental changes and processes affect these materials and existing rocks in ways that produce three main rock groups:

1) **Igneous rocks** form when magma or lava cool to a solid form.
2) **Sedimentary rocks** form mostly when mineral crystals and clasts (broken pieces, fragments) of plants, animals, mineral crystals, or rocks are compressed or naturally cemented together.
3) **Metamorphic rocks** are rocks deformed or changed from one form to another (transformed) by intense heat, intense pressure, and/or the action of hot fluids.

3.1. The Rock Cycle

All rocks are part of a system of rock-forming processes, materials, and products that is often portrayed in a conceptual model called the **rock cycle** (Fig. 10). The rock cycle model explains how all rocks can be formed, deformed, transformed, melted, and reformed as a result of environmental factors and natural processes that affect them.

Of course, not all rocks undergo change along such an idealistic path. There are *at least* three changes that each rock could undergo. The arrows in Fig. 10 to either of the other two groups *or* recycled within its own group. Igneous rock can be (1) weathered and eroded to form sediment that is lithified to form sedimentary rock; (2) transformed to metamorphic rock by intense heat, intense pressure, and/or hot fluids; or (3) re-melted, cooled, and solidified back into another igneous rock. Sedimentary rock can be (1) melted, cooled, and solidified into an igneous rock; (2) transformed to metamorphic rock by intense heat, intense pressure, and/or hot fluids; or (3) weathered and eroded back to sediment that is lithified back into another sedimentary rock. Metamorphic rock can be (1) weathered and eroded to form sediment that is lithified into sedimentary rock; (2) melted, cooled, and solidified into igneous rock; or (3) re-metamorphosed into a different type of metamorphic rock by intense heat, intense pressure, or hot fluids.

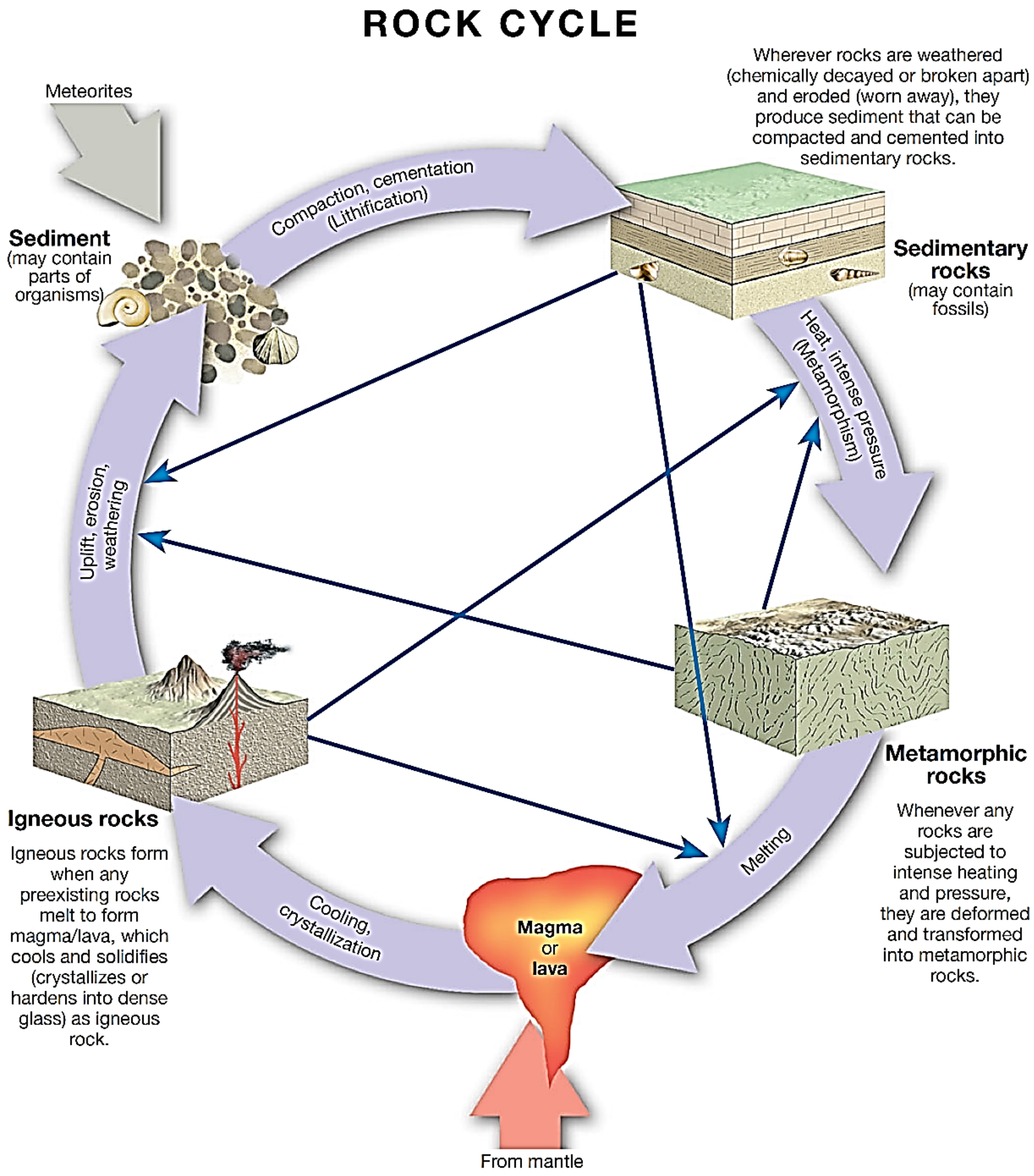


Fig. 10

3.2.Rock Classification

All rocks are classified as igneous, sedimentary, or metamorphic, based on their properties of composition and texture and how they formed. Some properties are characteristic of more than one rock type. For example, igneous, sedimentary, and metamorphic rocks all can be dark, light, or made of mineral particles. Therefore, it is essential to classify a rock based on more than one of its properties.

3.2.1. Igneous Composition and Texture

Recall that igneous rocks form when molten rock (rock liquefied by heat and pressure in the mantle) cools to a solid form (Fig. 11). Molten rock exists both below Earth's surface (where it is called *magma*) and at Earth's surface (where it is called *lava*). Igneous rocks can have various textures, including crystalline (hetro-granular), glassy, or vesicular (bubbly). They commonly contain mineral crystals of olivine, pyroxene, or feldspars. Igneous rocks from cooled lava flows may have ropy, streamlined shapes or layers (from repeated flows of lava). Igneous rocks usually lack fossils and organic grains.

3.2.2. Sedimentary Composition and Texture

Recall that sedimentary rocks form in two ways (Fig. 11). **Lithification** is the hardening of sediment—masses of loose Earth materials such as clasts (rock fragments, detrital mineral grains, pebbles, gravel, sand, silt, mud, shells, plant fragments) and products of chemical decay (clay, rust). **Precipitation** produces mineral crystals that collect as *in situ* aggregates, such as the rock salt that remains when ocean water evaporates. The lithification process occurs as layers of sediments are **compacted** (pressure-hardened) or **cemented** (glued together by tiny crystals precipitated from fluids in the pores of sediment).

Thus, most sedimentary rocks are layered and have a **clastic** texture (i.e., are made of grains called *clasts* —fragments of rocks, mineral crystals, shells, and plants—usually rounded into pebbles, gravel, sand, and mud). The sedimentary grains are arranged in layers due to sorting by wind or water. Sedimentary rocks may also include **fossils** — bones, impressions, tracks, or other evidence of ancient life.

The crystalline sedimentary rocks are layered aggregates of crystals precipitated from water. This includes the icicle-shaped stalactites that hang from the roofs of caves. Common minerals of these precipitated sedimentary rocks include calcite, dolomite, gypsum, or halite.

3.2.3. Metamorphic Composition and Textures

Recall that metamorphic rocks are rocks that have been deformed and transformed by intense heat, intense pressure, or the chemical action of hot fluids (Fig. 11). Therefore, metamorphic rocks have textures indicating significant deformation (folds, extensive fractures, faults, and foliation). Fossils, if present, also are deformed (stretched or compressed). Metamorphic rocks often contain garnet, tourmaline, or foliated layers of mica. Serpentine, epidote, graphite, galena, and sphalerite occur only in metamorphic rocks. Metamorphism can occur over large regions, or in thin "contact" zones (like burnt crust on a loaf of bread) where the rock was in contact with magma or other hot fluids.

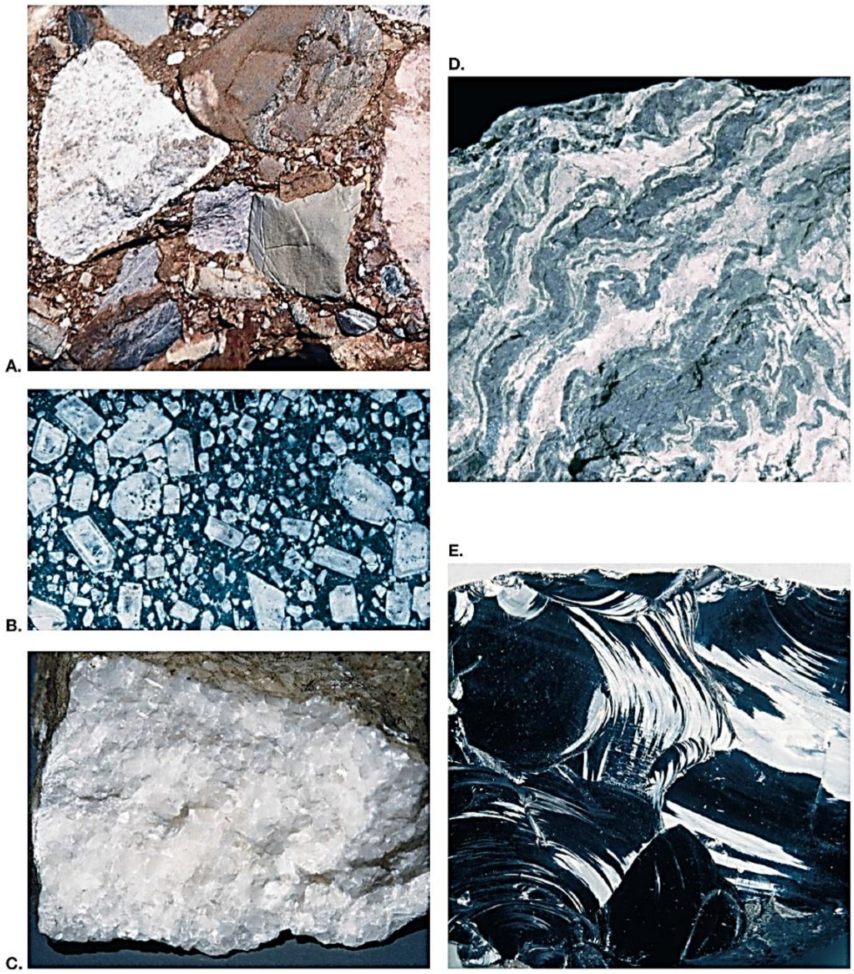


Fig. 11

3.3. Igneous Rocks

Right now, there are more than a hundred volcanoes erupting or threatening to erupt on continents and islands around the world. Some pose direct threats to humans. Others pose indirect threats, such as earthquakes and episodic melting of glaciers. In the oceans, deep under water and far from direct influence on humans, there are likely hundreds more volcanoes. The exact number is unknown, because they are erupting at places on the sea floor that humans rarely see. Most of the world's volcanoes occur along its 260,000 kilometers of linear boundaries between lithospheric plates. The rest are largely associated with hot spots. All of the volcanoes overlie bodies of molten (hot, partly or completely melted) rock called **magma**, which is referred to as **lava** when it reaches Earth's surface at the volcanoes. In addition to their liquid rock portion, or *melt,* magma and lava contain dissolved gases (e.g., water, carbon dioxide, sulfur dioxide) and solid particles. The solid particles may be pieces of rock that have not yet melted and/or mineral crystals that may grow in size or abundance as the magma cools. **Igneous rocks** form when magma or lava cool to a solid state. The bodies of igneous rock may be as large as those in Yosemite Park, where bodies of magma cooled underground to form batholiths of igneous rock, tens of kilometers in diameter. They may be as small as centimeter-thick layers of volcanic ash, which is composed of microscopic fragments of igneous rock (mostly volcanic glass pulverized by an explosive volcanic eruption).

There are eight silicate minerals that form most igneous rocks. This is because silicon and oxygen are the most common elements in magma and lava. The silicon and oxygen naturally forms silicon-oxygen tetrahedral, in which one silicon atom shares electrons with four oxygen atoms (Table 2). This creates a silicon-oxygen tetrahedron (four-pointed pyramid) with four electrons too many, so each oxygen atom also shares an electron with another adjacent silicon atom. The simplest ratio of silicon to oxygen is 1:2, written SiO_2 and called **silica.** The mineral quartz is a crystalline form of pure silica. However, with the abundance of other chemicals in magma and lava, silicon-oxygen tetrahedral often bond with other kinds of metal atoms to make the other silicate minerals commonly found in igneous rocks. Although each one has its own unique properties that can be used to identify it, the minerals are also categorized into two chemical groups.

Table 2

COMPOSITION OF IGNEOUS ROCKS		
Chemical Composition		**Physical Composition**
Compositional Group Name	Silica % (by weight) in the magma, lava, or rock	**Mafic Color Index (MCI):** Percent of mafic (green, dark gray, and black) mineral crystals in the rock
Felsic (acidic)	above 65%	below 15%
Intermediate	54 – 64%	16 – 45%
Mafic	45 – 53%	46 – 85%
Ultramafic	below 45%	above 85%

3.4. Textures of Igneous Rocks

Texture of an igneous rock is a description of its constituent parts and their sizes, shapes, and arrangement. You must be able to identify the common textures of igneous rocks described below and understand how they form. Notice the list of textures and their origins in Fig. 12. Igneous rocks are also classified into *two textural groups*: intrusive (plutonic) versus extrusive (volcanic).

Intrusive (plutonic) rocks form deep underground, where they are well insulated (take a long time to cool) and pressurized. The pressure prevents gases from expanding, just like carbonation in a sealed soft drink. The cap seals in the pressure— an intrusive process. If you remove the cap, then the carbon dioxide inside the bottle expands and bubbles— an extrusive process. Therefore, **extrusive (volcanic) rocks** form near and on Earth's surface, where the confining pressure is low and gases begin to bubble out of the magma. Cooler surface temperatures also rob thermal energy from magma, so it cools quickly. The size of mineral crystals in an igneous rock generally indicates the rate at which the lava or magma cooled to form a rock and the availability of the chemicals required to form the crystals. Large crystals require a long time to grow, so their presence generally means that a body of molten rock cooled slowly (an intrusive process) and contained ample atoms of the chemicals required to form the crystals. Tiny crystals generally indicate that the magma cooled more rapidly (an extrusive process).

Volcanic glass (no crystals) can indicate that a magma was quenched (cooled immediately), but most volcanic glass is the result of poor nucleation as described below.

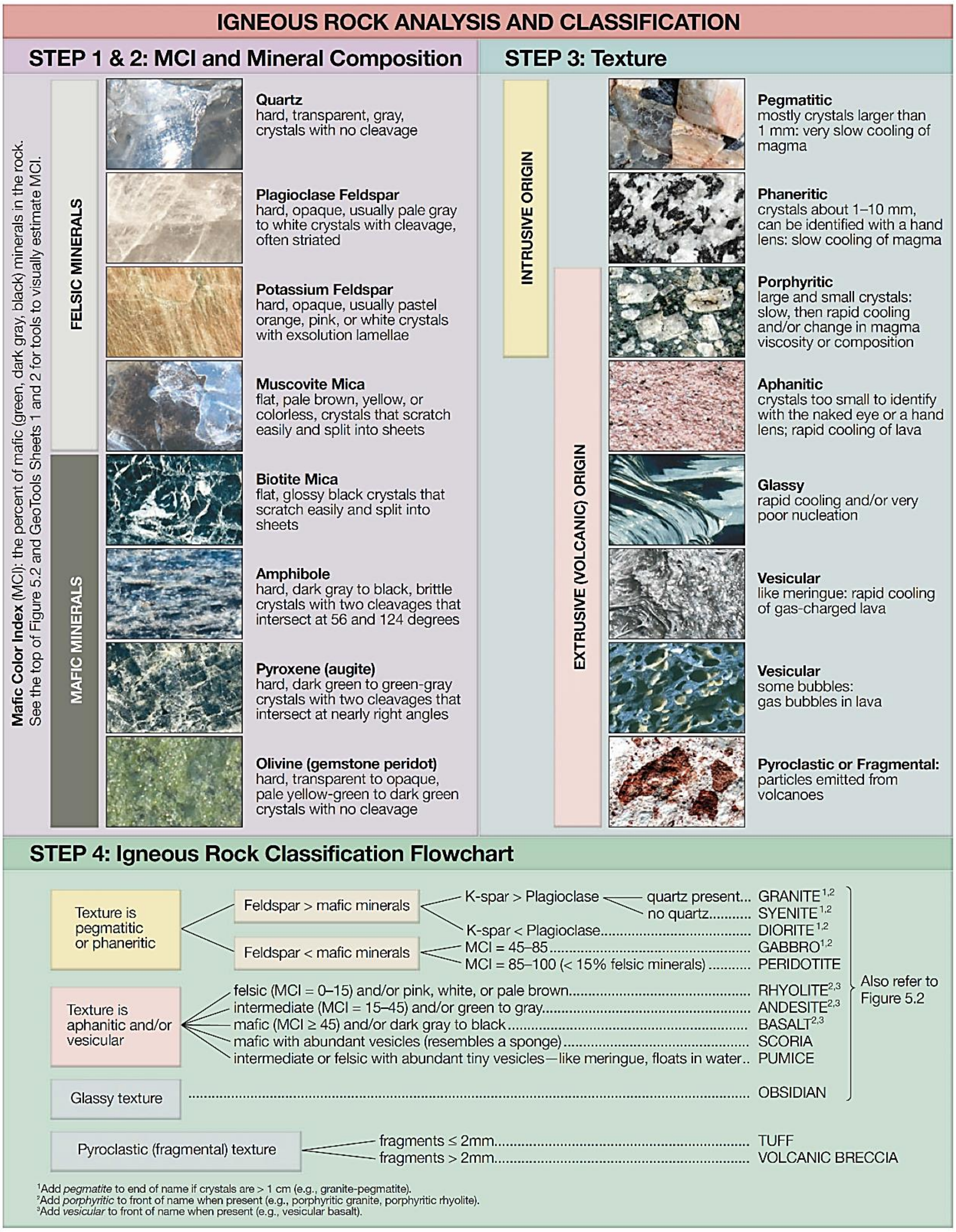


Fig. 12

3.5. How to Identify Igneous Rocks

The identification and interpretation of an igneous rock is based on its composition and texture. ***Follow these steps to classify and identify an igneous rock:***

Steps 1 and 2:

- ✓ Identify the rock's mafic color index (MCI).Then, if possible, identify the minerals that make up the rock and estimate the percentage of each.

- ✓ If the rock is very fine-grained (aphanitic or porphyritic-aphanitic), then you must estimate mineralogy based on the rock's mafic color index. *Felsic* fine-grained rocks tend to be pink, white, or pale gray/brown. *Intermediate* fine-grained rocks tend to be greenish gray to medium gray. *Mafic* and *ultramafic* fine-grained rocks tend to be green, dark gray, or black.
- ✓ If the rock is coarse-grained (phaneritic or pegmatitic), then estimate the mafic color index (MCI) and percentage abundance of each of the specific felsic and mafic minerals. With this information, you can also characterize the rock as felsic, intermediate, mafic, or ultramafic.

Step 3: Identify the rock's texture(s) using Fig. 12.

Step 4: Determine the name of the rock using the flowchart in Fig. 12.

- ✓ Use textural terms, such as porphyritic or vesicular, as adjectives. For example, you might identify a pink, aphanitic (fine-grained), igneous rock as a rhyolite. If it contains scattered phenocrysts, then you would call it a *porphyritic rhyolite*. Similarly, you should call a basalt with vesicles a *vesicular basalt.*
- ✓ The textural information can also be used to infer the origin of a rock. For example, vesicles (vesicular textures) imply that the rock formed by cooling of a gas-rich lava (vesicular and aphanitic). Pyroclastic texture implies violent volcanic eruption. Aphanitic texture implies more rapid cooling than phaneritic texture.

3.6.Sedimentary Rocks

Sedimentary rocks form when sediments are compressed, cemented, or otherwise hardened together. Some sedimentary rocks form by a process similar to mud hardening in the Sun to form *adobe.* Others form when masses of intergrown mineral crystals precipitate from aqueous (water-based) solutions and lock together to form crystalline rock, like rock salt that remains when ocean water is evaporated. **Sediments** are loose grains and chemical residues of Earth materials, including rock fragments, mineral grains, parts of plants or animals like seashells and twigs, and chemical residues like rust (hydrated iron oxide residue). Grains of sediment are affected by chemical and physical weathering processes until they are buried in a sedimentary deposit.

Sedimentary processes include everything from the time and place that sediment forms to the time and place where it is *lithified* (hardened into sedimentary rock).

3.7. Textures of Sediments and Sedimentary Rocks

Sediment and sedimentary rocks are described, classified, named, and interpreted on the basis of their composition and textures.

The **composition** of a sediment or sedimentary rock is a description of the kinds and abundances of grains that compose it (Fig. 13).

Fig. 13

Sediments and sedimentary rocks are classified as biochemical (bioclastic), chemical, or detrital (siliciclastic) based on their composition. **Biochemical** sediments and rocks consist of whole and broken **(bioclastic)** parts of organisms, such as shells and plant fragments. **Chemical** sediments and rocks consist of chemical residues and intergrown mineral crystals precipitated from aqueous solutions. The precipitated minerals commonly include gypsum, halite, hematite, limonite, calcite, dolomite, and chert (microcrystalline variety of quartz). **Detrital** sediments and rocks consist of **siliciclastic** grains (rock fragments, quartz, feldspar, clay minerals) that are also *detrital* grains—rock fragments and mineral grains that were worn and transported away from the landscape.

Processes of weathering, transportation, precipitation, and deposition that contribute to the formation of a sediment or sedimentary rock also contribute to forming its texture. The **texture** of a sediment or sedimentary rock is a description of its parts and their sizes, shapes, and arrangement (Fig. 14). **Grain Size.** The particles that make up sedimentary rocks are called **grains.** Size of the grains is commonly expressed in these *Wentworth classes,* named after C. K. Wentworth, an American geologist who devised the scale in 1922:

1) **Gravel** includes grains larger than 2 mm in diameter (granules, pebbles, cobbles, and boulders).
2) **Sand** includes grains from 1/16 mm to 2 mm in diameter (in decimal form, 0.0625 mm to 2.000 mm).This is the size range of grains in a sandbox. The grains are visible and feel very gritty when rubbed between your fingers.
3) **Silt** includes grains from 1/256 mm to 1/16 mm in diameter (in decimal form, 0.0039 mm to 0.0625 mm). Grains of silt are usually too small to see, but you can still feel them as very tiny gritty grains when you rub them between your fingers or teeth.
4) **Clay** includes grains less than 1/256 mm diameter (in decimal form, 0.0039 mm). Clay-sized grains are too small to see, and they feel smooth (like chalk dust) when rubbed between your fingers or teeth. Note that the word *clay* is used not only to denote a grain size, but also a clay mineral. However, clay mineral crystals are usually clay-sized.

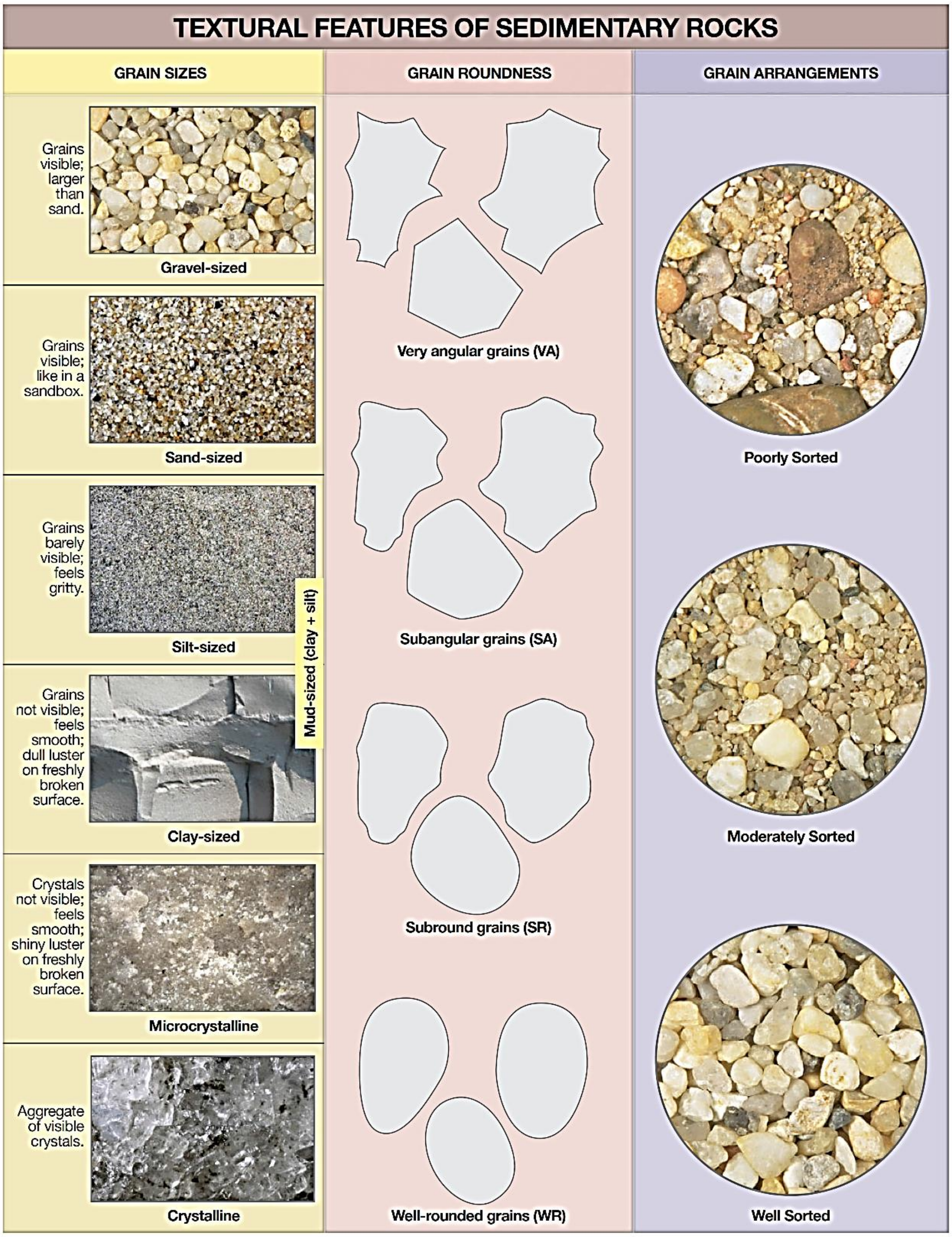


Fig. 14

Rounding of Sediment. Sediments deposited quickly at or near their source tend to lack abrasion. Sediments that have been moved about locally (as in waves on a beach) or transported away from their source are abraded (worn). **Roundness** is a description of the degree to which the sharp corners and points of a fragmented grain have been worn away and its profile has become round (Fig. 14). A newly formed clast is *very angular*. As itis transported and worn it will become *sub-angular*, then *sub-round*, and then *well rounded.* A freshly broken rock fragment, mineral grain, or seashell has sharp edges and is described as *angular*. The more rounded a grain becomes, the smaller it generally becomes. Gravel gets broken and abraded down into sand, and sand gets broken and abraded into silt and clay-sized grains. When combined, the silt plus clay mixture is called *mud.*

Sorting of Sediment. Different velocities of wind and water currents are capable of transporting and naturally separating different densities and sizes of sediments from one another. **Sorting** is a description of the degree to which one size class of sediment has been separated from the others (Fig. 14). *Poorly sorted* sediments consist of a mixture of many different sizes of grains. *Well-sorted* sediments consist of grains that are of similar size and/or density.

Crystalline and Microcrystalline Textures. Sedimentary rocks that form when crystals precipitate from aqueous solutions have a **crystalline texture** (clearly visible crystals; see Fig. 14) or **microcrystalline texture** (crystals too small to identify). As the crystals grow, they interfere with each other and form intergrown and interlocking texture that also holds the rock together.

3.8.Classifying Sedimentary Rocks

Geologists classify sedimentary rocks into three main groups (Fig. 13): biochemical, chemical (inorganic), and detrital (siliciclastic).

3.9.Hand Sample Analysis and Interpretation

Follow these steps to analyze and interpret a sedimentary rock:

- ✓ **Step 1:** Determine and record the rock's general composition as *biochemical (bioclastic), chemical,* or *detrital (siliciclastic)* and record a description of the specific kinds and abundances of grains that make up the rock.
- ✓ **Step 2:** Record a description of the rock's texture(s) with reference to Fig. 14.
- ✓ **Step 3:** Determine the name of the sedimentary rock. Use the compositional, textural, and special properties data from Steps 1 and 2 to deduce the rock name.
- ✓ **Step 4:** After you have named the rock, then you can use Fig. 15 and information from Steps 1and 2 to infer where and how the rock formed. See the example for sample X.

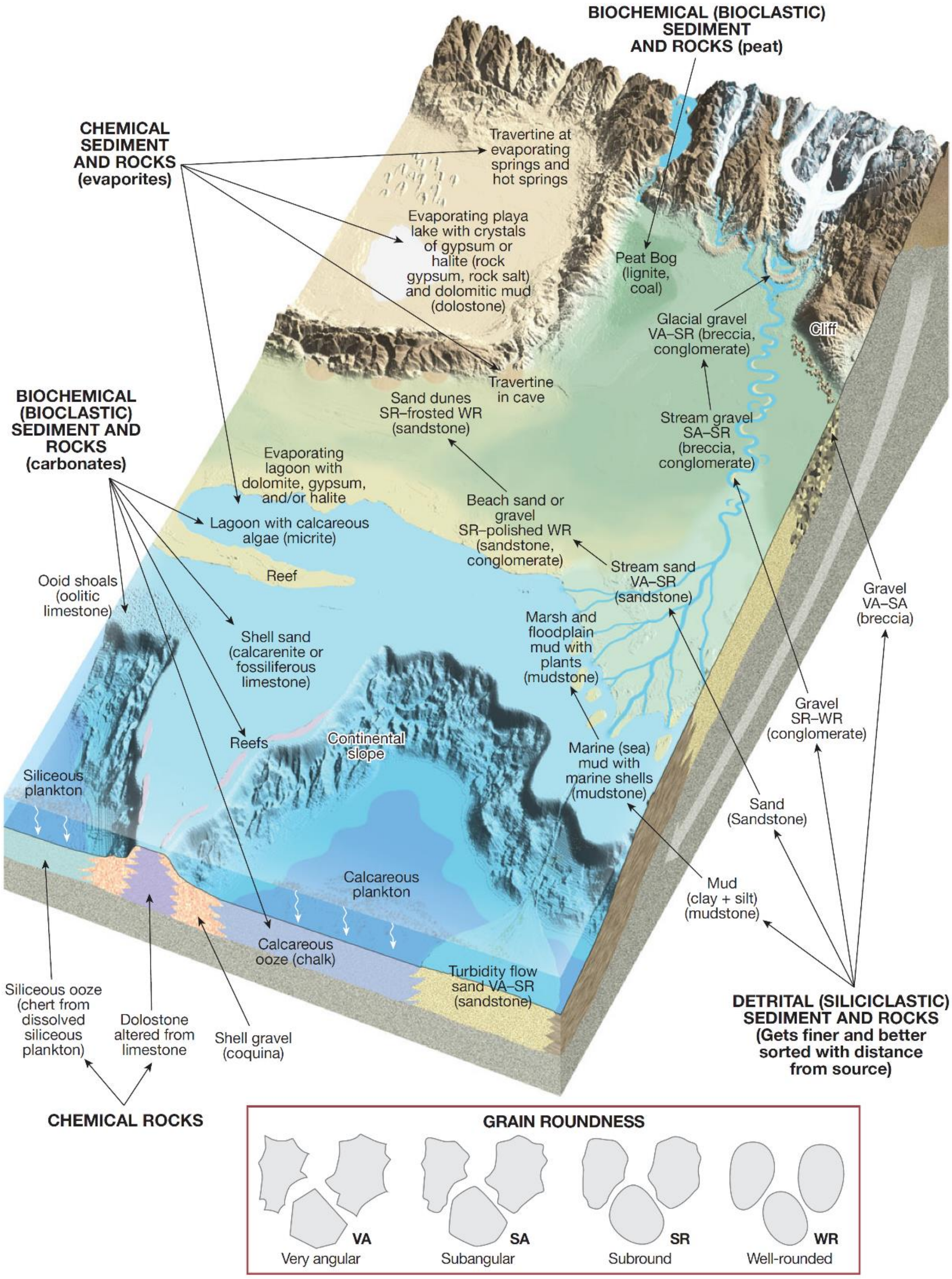

BIOCHEMICAL (BIOCLASTIC) SEDIMENT AND ROCKS (peat)
CHEMICAL SEDIMENT AND ROCKS (evaporites)
Travertine at evaporating springs and hot springs
Evaporating playa lake with crystals of gypsum or halite (rock gypsum, rock salt) and dolomitic mud (dolostone)
Peat Bog (lignite, coal)
Glacial gravel VA–SR (breccia, conglomerate)
Cliff
Travertine in cave
Sand dunes SR–frosted WR (sandstone)
Stream gravel SA–SR (breccia, conglomerate)
BIOCHEMICAL (BIOCLASTIC) SEDIMENT AND ROCKS (carbonates)
Evaporating lagoon with dolomite, gypsum, and/or halite
Beach sand or gravel SR–polished WR (sandstone, conglomerate)
Lagoon with calcareous algae (micrite)
Reef
Stream sand VA–SR (sandstone)
Ooid shoals (oolitic limestone)
Gravel VA–SA (breccia)
Marsh and floodplain mud with plants (mudstone)
Shell sand (calcarenite or fossiliferous limestone)
Gravel SR–WR (conglomerate)
Reefs
Continental slope
Marine (sea) mud with marine shells (mudstone)
Siliceous plankton
Sand (Sandstone)
Calcareous plankton
Mud (clay + silt) (mudstone)
Calcareous ooze (chalk)
Turbidity flow sand VA–SR (sandstone)
Siliceous ooze (chert from dissolved siliceous plankton)
Dolostone altered from limestone
Shell gravel (coquina)
DETRITAL (SILICICLASTIC) SEDIMENT AND ROCKS (Gets finer and better sorted with distance from source)
CHEMICAL ROCKS
GRAIN ROUNDNESS
VA
Very angular
SA
Subangular
SR
Subround
WR
Well-rounded

Fig. 15

3.10. Metamorphic Rocks

Metamorphic rocks are rocks changed from one form to another (metamorphosed) by intense heat, intense pressure, or the action of watery hot fluids. Think of metamorphism as it occurs in your home. *Heat* can be used to metamorphose bread into toast, *pressure* can be used to compact an aluminum can into a flatter and more compact form, and the chemical action of *watery hot fluids* (boiling water, steam) can be used to change raw vegetables into cooked forms. Inside Earth, all of these metamorphic processes are more intense and capable of changing a rock from one form to another. Thus metamorphism can change a rock's size, shape, texture, color, and/or mineralogy. Every metamorphic rock has a **parent rock**, the rock type that was metamorphosed. Parent rocks can be any of the three main rock types: igneous rock, sedimentary rock, or even metamorphic rock, and the degree that a parent rock is metamorphosed can vary. As temperature and pressure increases, so does the metamorphic grade. **Metamorphic grade** refers to the intensity of metamorphism, from low grade (least intense metamorphism) to high grade (most intense metamorphism).

3.11. Textures of Metamorphic Rocks

Texture of a metamorphic rock is a description of its constituent parts and their sizes, shapes, and arrangements. Two main groups of metamorphic rocks are distinguished on the basis of their characteristic textures, *foliated* and *non-foliated.*

Foliated metamorphic rocks (foliated textures) exhibit **foliations** — *layering* and parallel alignment of platy (flat) mineral crystals, such as micas. The foliations form when directed pressure causes the platy (flat) mineral crystals to slide parallel to and past one another (shear). This can happen as they recrystallize. Crystals of minerals such as tourmaline, hornblende, and kyanite can also be foliated because their crystalline growth occurred during metamorphism and had a preferred orientation in relation to the directed pressure. Specific kinds of foliated textures are described below:

- ✓ **Slaty rock cleavage** — *a very flat foliation* (resembling mineral cleavage) developed along flat, parallel, closely spaced shear planes (microscopic faults) in tightly folded clay- or mica-rich rocks (Fig. 16). Rocks with excellent slaty cleavage are called *slate*, which is used to make roofing shingles and classroom blackboards.

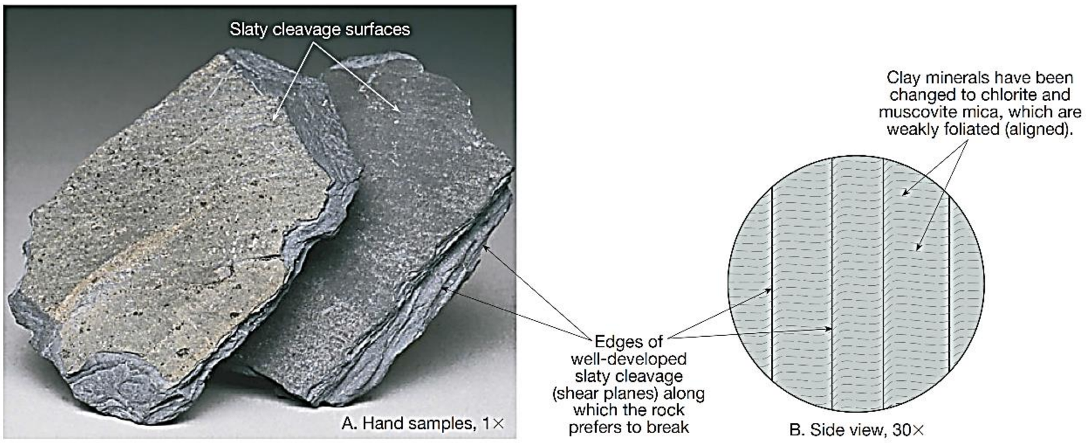


Fig. 16

- ✓ **Phyllitic texture** — *a wavy and/or wrinkled foliation* of fine-grained *platy minerals* (mainly muscovite or chlorite crystals) that gives the rock a satiny or metallic cluster. Rocks with phyllite texture are called *phyllite* (Fig. 17).

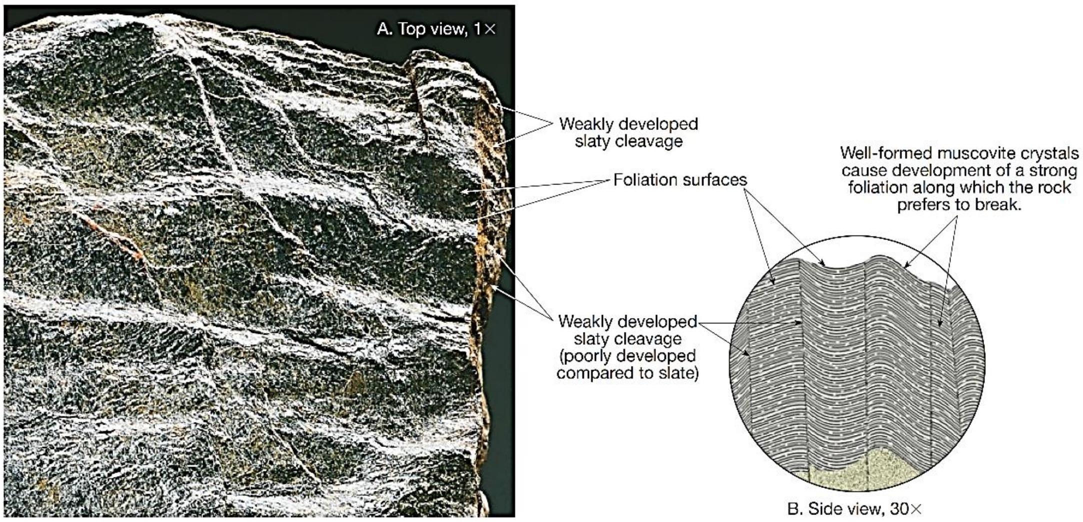


Fig. 17

- ✓ **Schistosity** — *a scaly glittery layering* of visible (medium- to coarse-grained) *platy minerals* (mainly micas and chlorite) *and/or linear alignment of long prismatic crystals* (tourmaline, hornblende, and kyanite). Rocks with schistosity break along scaly, glittery foliations and are called *schist* (Fig. 18). Schists are a product of intermediate-to-high grades of metamorphism.

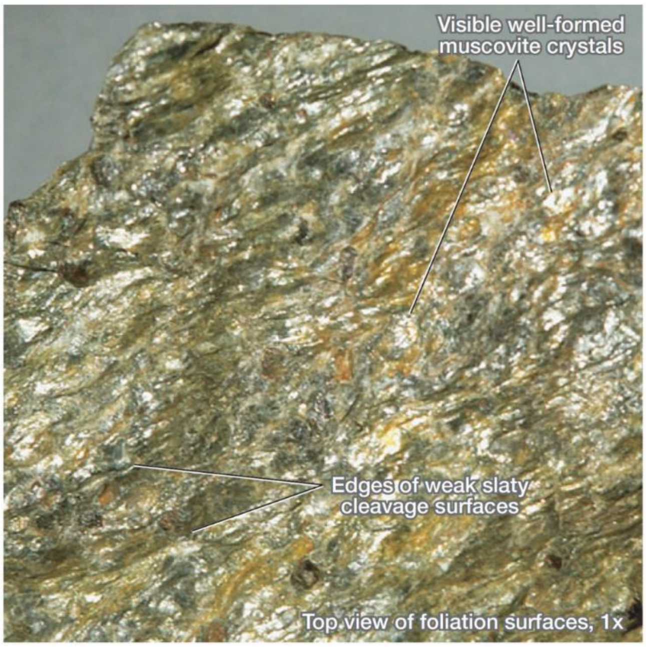


Fig. 18

- ✓ **Gneissic banding** — *alternating layers or lenses of light and dark medium- to coarse-grained minerals.* Rock with gneissic banding is called *gneiss* (Fig. 19). Ferromagnesian minerals usually form the dark bands. Quartz or feldspars usually form the light bands.

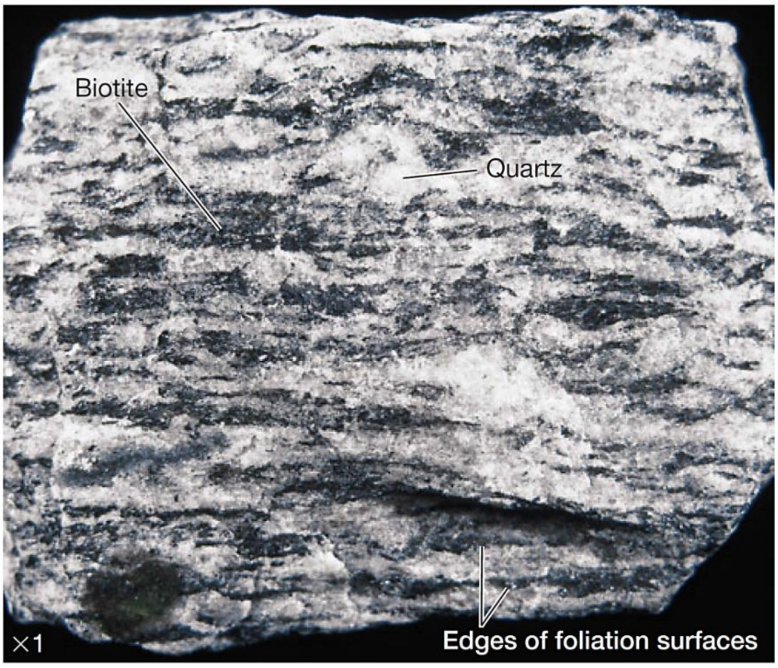


Fig. 19

Non-foliated metamorphic rocks have no obvious layering (i.e., no foliations), although they may exhibit stretched fossils or long, prismatic crystals (tourmaline, amphibole) that have grown parallel to the pressure field. Non-foliated metamorphic rocks are mainly characterized by the following textures: **Crystalline texture (non-foliated)** —a medium- to coarse-grained aggregate of intergrown, usually equal-sized (equi-granular), visible crystals. *Marble* is a non-foliated metamorphic rock that typically exhibits an equi-granular crystalline texture (Fig. 20).

- ✓ **Microcrystalline texture** —a fine-grained aggregate of intergrown microscopic crystals (as in a sugar cube). *Hornfels* is a non-foliated metamorphic rock that has a microcrystalline texture.

Fig. 20

- ✓ **Sandy texture** —a medium- to coarse-grained aggregate of fused, sand-sized grains that resembles sandstone. *Quartzite* is a non-foliated metamorphic rock with a sandy texture (Fig. 21) remaining from its sandstone parent rock, but the sand grains cannot be rubbed free of the rock because they are fused together.
- ✓ **Glassy texture** —a homogeneous texture with no visible grains or other structures and breaks along glossy surfaces; said of materials that resemble glass, such as *anthracite coal*.

Fig. 21

3.12. Classification of Metamorphic Rocks

Metamorphic rocks are mainly classified according to their texture and mineralogical composition. This information is valuable for naming the rock and determining how it formed from a parent rock. It is also useful for inferring how the metamorphic rock could be used as a commodity for domestic or industrial purposes.

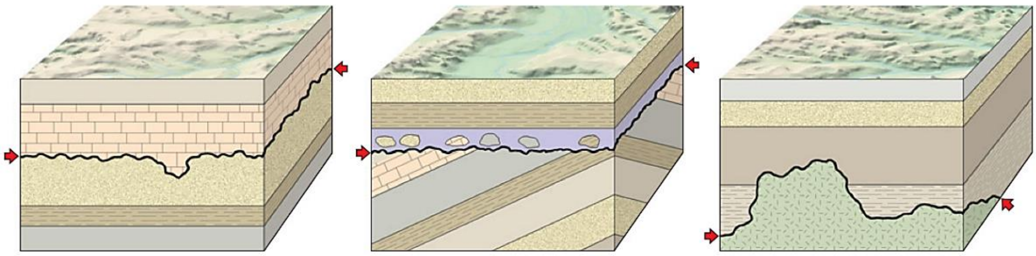
4. Unconformities

Surfaces called unconformities represent gaps in the geologic record that formed wherever layers were not deposited for a time or else layers were removed by erosion. Most contacts between adjacent strata or formations are conformities, meaning that rocks on both sides of them formed at about the same time. An unconformity is a rock surface that represents a gap in the geologic record. It is like the place where pages are missing from a book. An unconformity can be a buried surface where there was a pause in sedimentation, a time between two lava flows, or a surface that was eroded before more sediment was deposited on top of it. There are three kinds (Fig. 22). A disconformity is an unconformity between parallel strata or lava flows. Most disconformities are very irregular surfaces, and pieces of the underlying rock are often included in the strata above them. An angular unconformity is an unconformity between two sets of strata that are not parallel to one another. It forms when new horizontal layers cover up older layers folded by mountain-building processes and eroded down to a nearly level surface. A nonconformity is an unconformity between younger sedimentary rocks and subjacent metamorphic or igneous rocks. It forms when stratified sedimentary rocks or lava flows are deposited on eroded igneous or metamorphic rocks.

A geologist's initial challenge in the field is to subdivide the local sequence of sediments and bodies of rock into mappable units that can be correlated from one site to the next. Subdivision is based on color, texture, rock type, or other physical features of the rocks, and the mappable units are called **formations.** Formations can be subdivided into *members,* or even individual strata. Surfaces between any of these kinds of units are **contacts.**

Relative age dating (Figs. 23-25) is the process of determining when something formed or happened in relation to other events. For example, if you have a younger brother and an older sister, then you could describe your relative age by saying that you are younger than your sister and older than your brother.

Absolute age dating is the process of determining when something formed or happened in exact units of time such as days, months, or years. Using the example above, you could describe your absolute age just by saying how old you are in years.

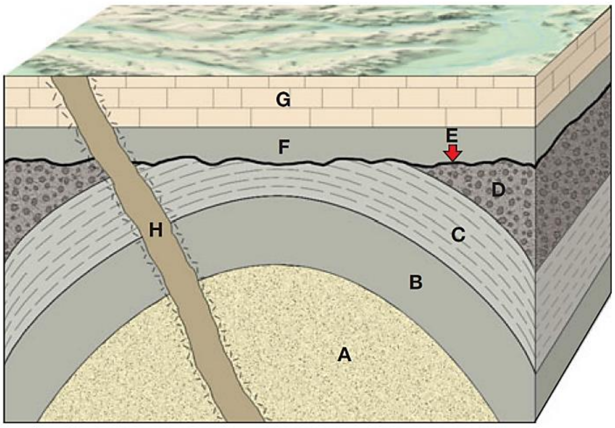


Disconformity
In a succession of rock layers (sedimentary strata or lava flows) parallel to one another, the disconformity surface is a gap in the layering. The gap may be a non-depositional surface where some layers never formed for a while, or the gap may be an erosional surface where some layers were removed before younger layers covered up the surface.

Angular unconformity
An angular unconformity is an erosional surface between two bodies of layered sedimentary strata or lava flows that are not parallel. The gap is because the older body of layered rock was tilted and partly eroded (rock was removed) before a younger body of horizontal rock layers covered the eroded surface.

Nonconformity
A nonconformity is an erosional surface between older igneous and/or metamorphic rocks and younger rock layers (sedimentary strata or lava flows). The gap is because some of the older igneous and/or metamorphic rocks were partly eroded (rock was removed) before the younger rock layers covered the eroded surface.

Fig. 22



Law of cross-cutting. The body of igneous rock **H** is the youngest rock unit, because it cuts across all of the others. (When a narrow body of igneous rock cuts across strata in this way, it is called a **dike**.) **A** is the oldest formation because it is at the bottom of the sedimentary rock sequence that is cut by **H.** Folding and erosion occurred after **D** was deposited, but before **F** was deposited. **E** is an angular unconformity.

The sequence of events began with deposition of formations **A** through **D** in alphabetical order and one atop the other. That sequence was folded, and the top of the fold was eroded. Formation **F** was deposited horizontally atop the folded sequence and the erosional surface, which became angular unconformity **E. G** was deposited atop **F.** Lastly, a magma intruded across all of the strata and cooled to form basalt dike **H.**

Fig. 23

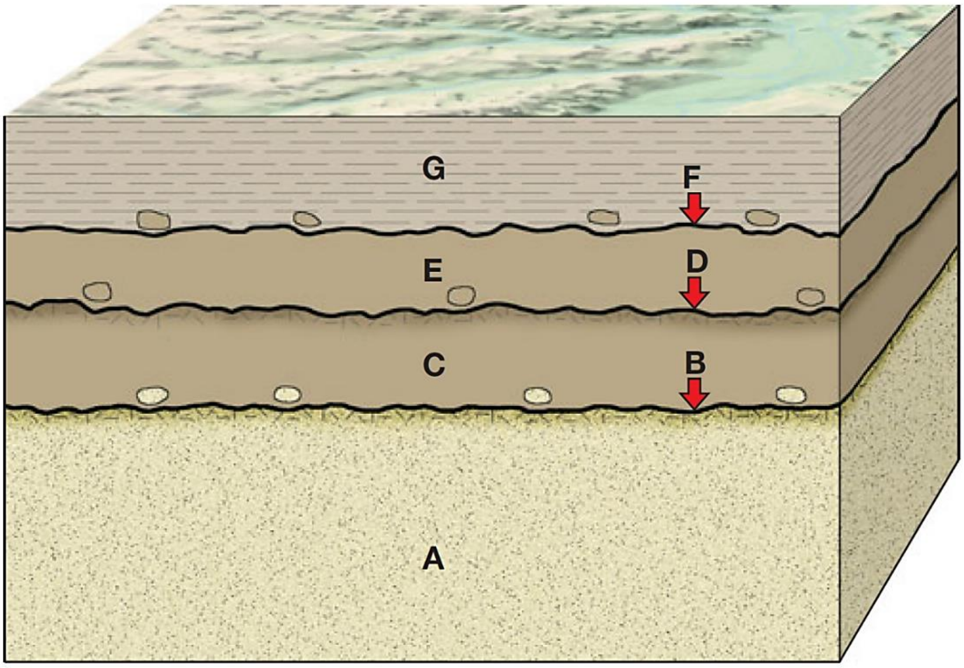


Fig. 24

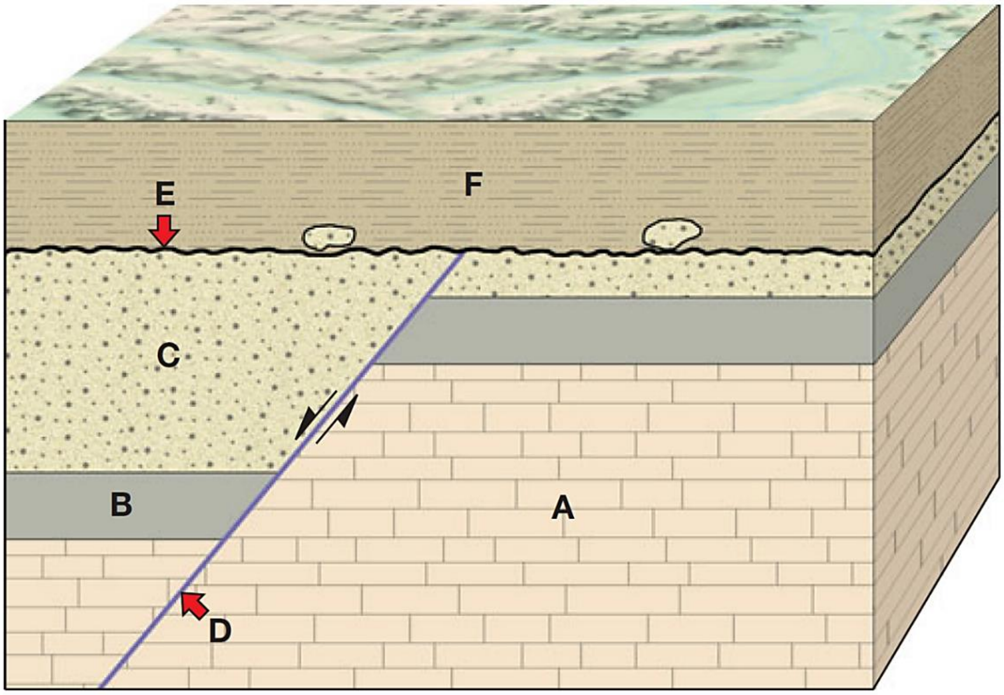


Fig. 25

5. Topographic Map

A **map** is a flat representation of part of Earth's surface as viewed from above and reduced in size to fit a sheet of paper or computer screen. A **plan metric map** (Fig. 26) is a flat representation of Earth's surface that shows horizontal (two-dimensional) positions of features like streams, landmarks, roads, and political boundaries. A **topographic map** shows the same horizontal information as a plan metric map but also includes *contour lines* to represent elevations of hills and valleys. The contour lines are the distinguishing features of a topographic map and make it appear three dimensional. Thus topographic maps show the shape of the landscape in addition to horizontal directions, distances, and a system for describing exact locations. Most United States topographic maps are published by the U.S. Geological Survey (USGS) and available at their US Topo website (http://store.usgs.gov). Canadian topographic maps are produced by the Centre for Topographic Information of Natural Resources Canada (NRCAN: http://maps.nrcan.gc.ca). State and provincial geological surveys, and the national geological surveys of other countries, also produce and/or distribute topographic maps.

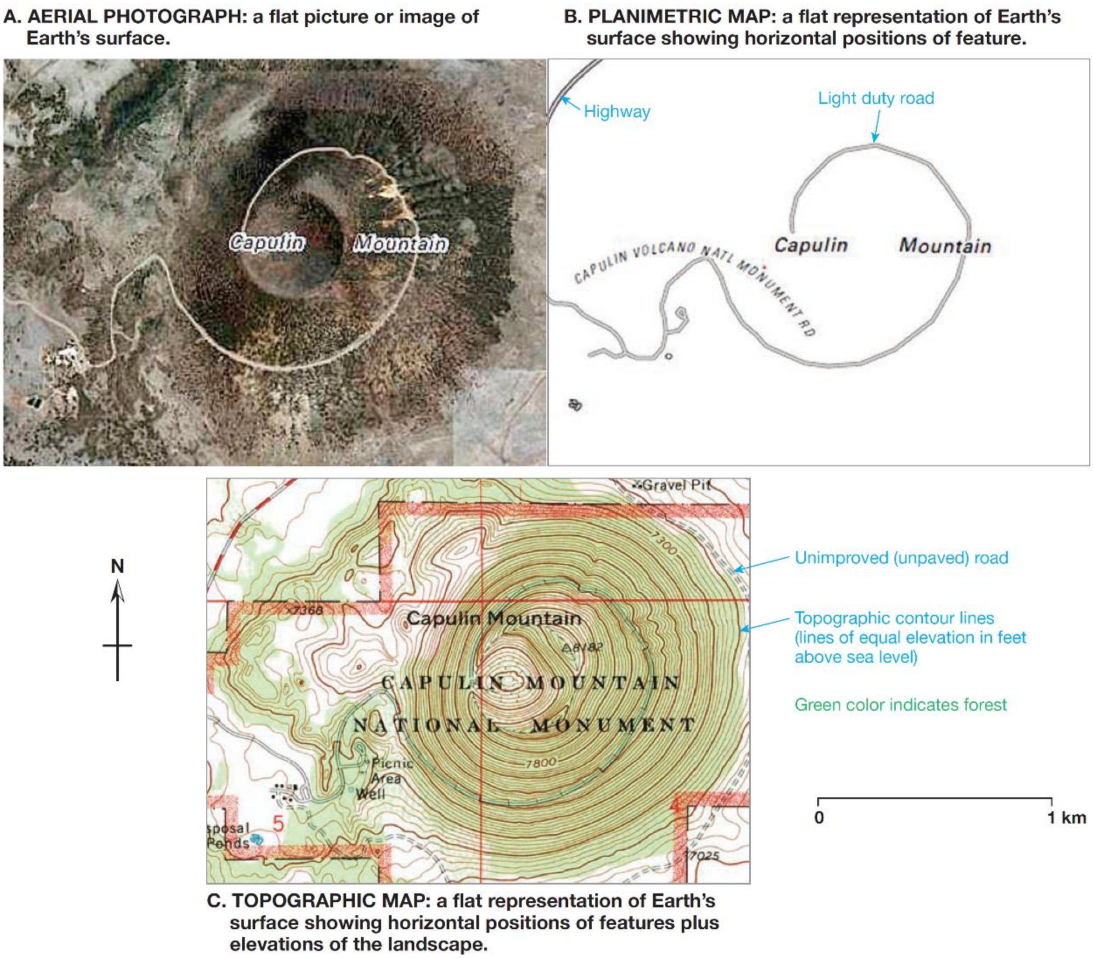


Fig. 26

5.1.Latitude-Longitude and Quadrangle Maps

Earth is a spherical body or globe, and specific points on the globe can be defined exactly using a geographic coordinate system in which points are defined by the intersection of imaginary reference lines. The most traditional geographic coordinate system consists of reference lines of geographic latitude and longitude.

Earth's spherical surface is divided into lines of latitude (*parallels)* that go around the world parallel to the Equator, and lines of longitude (*meridians)* that go around the world from pole to pole (Fig. 27). There are360 degrees (360°) around the entire Earth, so the distance from the Equator to a pole (one-fourth of the way around Earth) is 90° of latitude. The Equator is assigned value of zero degrees (0°) latitude, the North Pole is90 degrees north latitude (90°N), and the South Pole is 90 degrees south latitude (90°S). The *prime meridian* is zero degrees of longitude and runs from pole to pole through Greenwich, England. Locations in Earth's Eastern Hemisphere are located in degrees east of the prime meridian, and points in the Western Hemisphere are located in degrees west of the prime meridian. Therefore, any point on Earth (or a map) can be located by its latitude-longitude coordinates. The latitude coordinate of the point is its position in degrees north or south of the Equator. The longitude coordinate of the point is its position in degrees east or west of the prime meridian. For example, point **A** in Fig. 27 is located at coordinates of: 20° north latitude, 120° west longitude. For greater detail, each degree of latitude and longitude can also be subdivided into 60 minutes 60′, and each minute can be divided into 60 seconds (60″).

Quadrangle Maps. Most depict rectangular sections of Earth's surface, called quadrangles. A **quadrangle** is a relatively rectangular area of Earth's surface, bounded bylines of latitude at the top (north) and bottom (south) and by lines of longitude on the left (west) and right (east) (Fig. 27). A *quadrangle map* is the map of a quadrangle. Quadrangle maps are published in many different sizes but the most common USGS sizes are 15-minute and7.5-minute quadrangle maps. The numbers refer to the amount of area that the maps depict, in degrees of latitude and longitude. A 15-minute topographic map represents an area that measures 15 minutes of latitude by15 minutes of longitude. A 7.5-minute topographic map represents an area that measures 7.5 minutes of latitude by 7.5 minutes of longitude. Therefore, four 7.5-minutequadrangle maps comprise one 15-minutequadrangle map. Notice its name (Ritter Ridge, CA) and size (7.5 Minute Series, SW 1/4 of the Lancaster 15' Quadrangle) in the upper right and lower right corners of the map, respectively. Also notice that the map has colors, patterns, and symbols that are used to depict water bodies, vegetation, roads, buildings, political boundaries, place names, and other natural and cultural features of the landscape. The lower right corner of the map indicates that the map was originally published in 1958, but it was photo revised in 1974. *Photo revised* means that aerial photographs (from airplanes) were used to discover changes on the landscape, and the changes are overprinted on the maps in a standout color like purple, red, or gray. The main new features shown on this 1974photorevised map are the California Aqueduct (that carries water south, from the Sierra Nevada Mountains to the southern California desert) and several major highways.

5.2.Map Scales

Maps are representations of an area of Earth's surface. The real sizes of everything on a map have been reduced so they fit a sheet of paper or computer screen. So maps are scale models. To understand how the real world is depicted by the map, you must refer to the map scales. Topographic maps commonly have any or all of the following kinds of scales.

The most obvious scales on topographic maps are the **bar scales (graphic scales)** printed in their lower margins. Bar scales are rulers for measuring distances on the map. **Ratio scales** are commonly expressed above the bar scales in the bottom margins of topographic maps and express the ratio of a linear dimension on the map to the actual dimension of the same feature on the ground (in real life). For example, the ratio scale of the map is written as "SCALE 1:24,000." This indicates that any unit (inch, centimeter, foot, etc.) on the map is actually 24,000 of the same units (inches, centimeters, and feet) on the ground. So 1 cm on the map represents 24,000 cm on the ground, or your thumb width on the map represents 24,000 thumb widths on the ground. The ratio scale can also be interpreted as a **fractional scale,** which indicates how much smaller something is than its actual size on the ground. A map ratio scale of 1:24,000 equals a fractional scale of 1/24,000. This means that everything on the map is 1/24,000 of its actual size on the ground.

5.3.Declination and Compass Bearings

Because longitude lines form the left and right boundaries of a topographic map, north is always at the top of the quadrangle. This is called grid north (GN) and is usually very close to the same direction as *true north* on the actual Earth. Unfortunately, magnetic compasses are not attracted to grid north or true north (the geographic North Pole). Instead, they are attracted to the *magnetic north pole* (MN), currently located northwest of Hudson Bay in Northern Canada, about 700 km (450 mi)from the true North Pole.

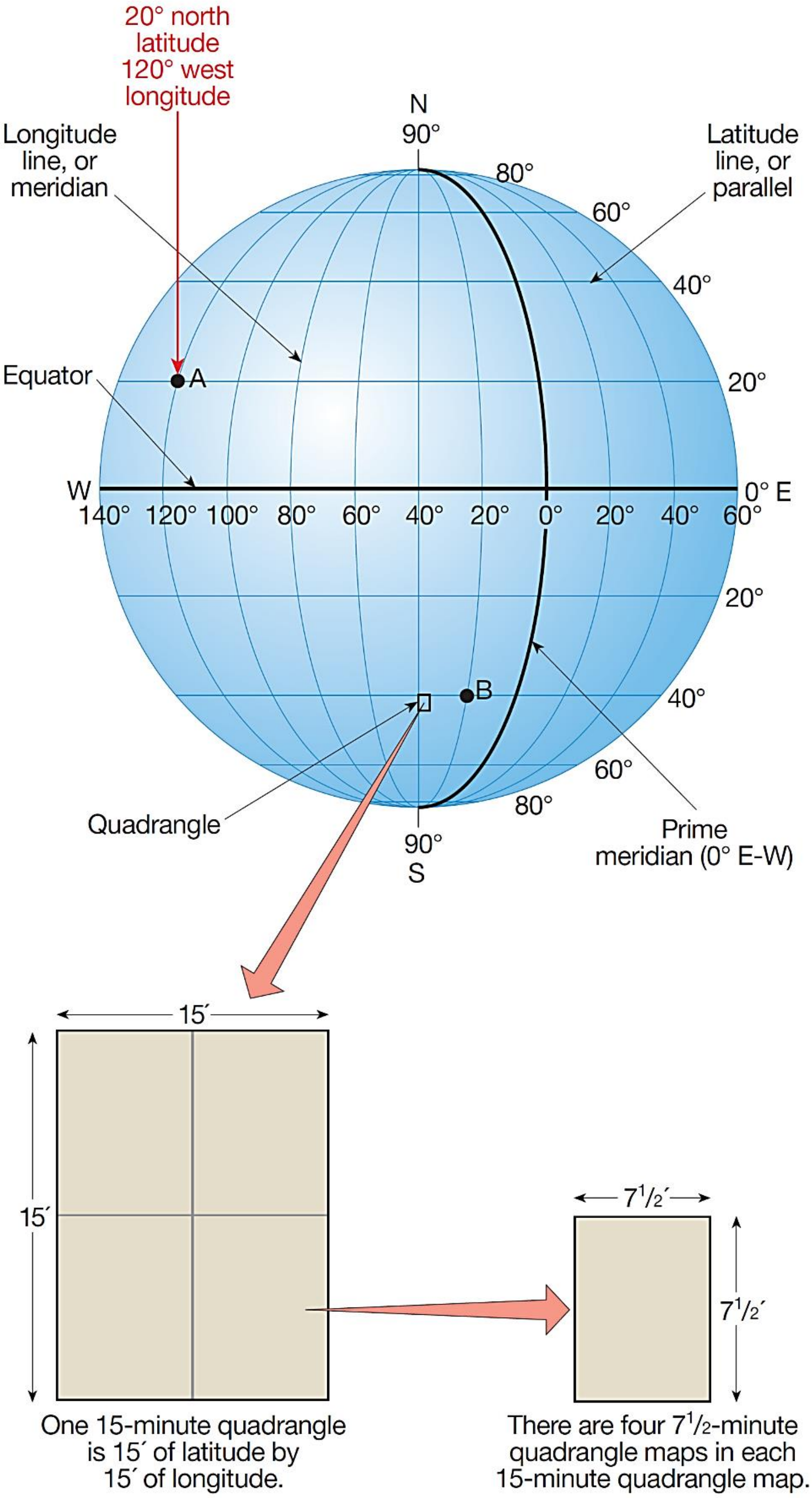

20° north latitude 120° west longitude
Longitude line, or meridian
N
90°
80°
Latitude line, or parallel
60°
40°
Equator
A
20°
W
0° E
140° 120° 100° 80° 60° 40° 20° 0° 20° 40° 60°
20°
B
40°
60°
80°
Quadrangle
90°
S
Prime meridian (0° E-W)
15′
15′
7 1/2′
7 1/2′
One 15-minute quadrangle is 15′ of latitude by 15′ of longitude.
There are four 7 1/2-minute quadrangle maps in each 15-minute quadrangle map.

Fig. 27

The trident-shaped symbol on the bottom margin of topographic maps shows the **declination** (difference in degrees) between compass north (MN) and true north (usually a *star* symbol). Also shown is the declination between true north (*star* symbol) and grid north (GN). The magnetic pole migrates very slowly, so the declination is exact only for the year listed on the map. You can obtain the most recent magnetic data for your location from the NOAA National Geophysical Data Center (http://www.ngdc.noaa.gov/geomag-web/#declination).

A **bearing** is the *compass direction* along a line from one point to another. If expressed in degrees east or west of true north or south, it is called a *quadrant bearing*. Or it may be expressed in degrees between 0 and 360, called an *azimuth bearing*, where north is 0° (or 360°), east is 90°,south is 180°, and west is 270°. Linear geologic features (faults, fractures, and dikes), lines of sight and travel, and linear property boundaries are all defined on the basis of their bearings. But because a compass points to Earth's *magnetic north* (MN) pole rather than the true North Pole, one must correct for this difference. If the MN arrow is to the east of true north (star symbol), then subtract the degrees of declination from your compass reading (imagine that you are rotating your compass counter-clockwise to compensate for declination). If the MN arrow is to the west of true north, then add the degrees of declination to your compass reading (imagine that you rotated your compass clockwise).These adjustments will mean that your compass readings are synchronized with the map (so long as you used the latest declination values obtained from NOAA).

Some compasses allow you to rotate their basal ring graduated in degrees to correct for the magnetic declination. If the MN arrow is 5° east (right) of true north, then you would rotate the graduated ring 5° east (clockwise, to subtract 5° from the reading). If the MN arrow is 5° west (left) of true north, then you would rotate the graduated ring 5° west (counter-clockwise, to add 5° to the reading).

To determine a compass bearing on a topographic map, follow the directions in (Fig. 28). Then imagine that you are buying a property for your dream home. The boundary of the property is marked by four metal rods driven into the ground, one at each corner of the property. The location of these rods is shown on the map in Fig. 28 (left side) as points ***A, B, C,*** and ***D.*** The property deed notes the distances between the points *and* bearings between the points. This defines the shape of the property. Notice that the northwest edge of your property lies between two metal rods located at points ***A*** and ***B.*** You can measure the distance between the points using a tape measure. How can you measure the bearing? First, draw a line (very lightly in pencil so that it can be erased) through the two points, ***A*** and ***B.*** Make sure the line also intersects an edge of the map. In both parts of Fig. 28, a line was drawn through points ***A*** and ***B*** so that it also intersects the east edge of the map. Next, orient a protractor so that its 0° and 180° marks are on the edge of the map, with the 0° end toward geographic north. Place the origin of the protractor at the point where your line–***B*** intersects the edge of the map. You can now read a bearing of 43° east of north. We express this as a quadrant bearing of "North 43° East" (written N43°E) or as an azimuth bearing of 43°. If you were to determine the opposite bearing, from ***B*** to ***A*** then the bearing would be pointing southwest and would be read as "South 43°, and West," or as an azimuth of 223°. Remember that a compass points to Earth's *magnetic north* pole (MN) rather than true north or grid north (GN). When comparing the bearing read directly from the map to a bearing read from a compass, you must adjust your compass reading to match true north or grid north (GN) of the map, as described above. You also can use a compass to read bearings, as shown in Fig. 28 (right). Ignore the compass needle and use the compass as if it were a circular protractor. Some compasses are graduated in degrees, from 0–360, in which case you read an azimuth bearing from 0–360°.Square azimuth protractors for this purpose are provided in Geo-Tools Sheets 3 and 4 at the back of this manual.

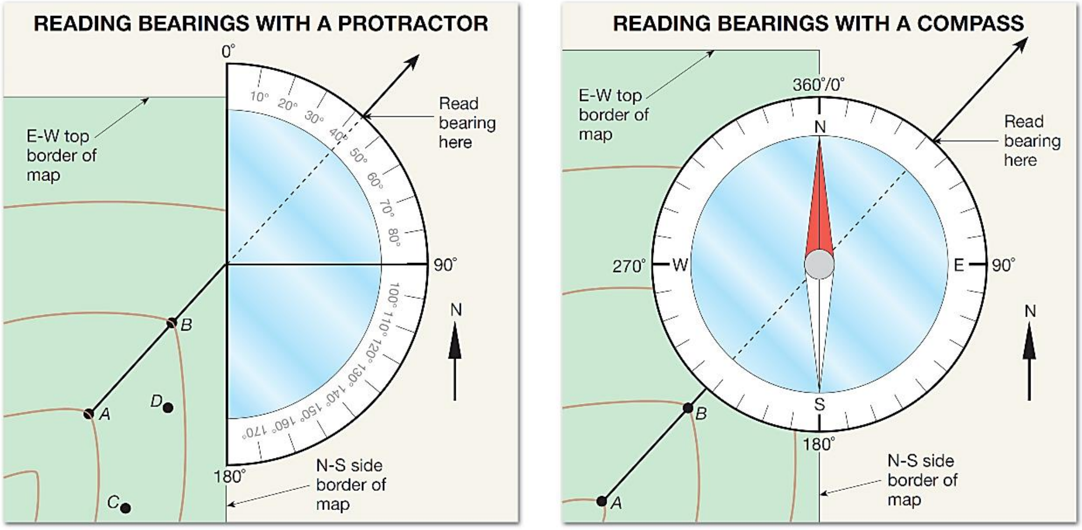


Fig. 28

5.4.Reading Elevations

If a point on the map lies on an index contour, you simply read its elevation from that line. If the point lies on an unnumbered contour line, then its elevation can be determined by counting up or down from the nearest index contour. For example, if the nearest index contour is 300 m., and your point of interest is on the fourth contour line *above* it, and the contour interval is 20 m., then you simply count up by 20s from the index contour: 320, 340, 360, and 380. The point is 380 m. above sea level. If a point lies between two contour lines, then you must estimate its elevation by interpolation. For example, on a map with a 20-m contour interval, a point might lie between the 340 and 360 m contours, so you know it is between 340 and 360 m. above sea level. If a point lies between a contour line and the margin of the map, then you must estimate its elevation by extrapolation (See Appendix B).

5.5.Depressions

Fig. 29 shows how to read topographic contour lines in and adjacent to a depression. *Hachure marks* (short line segments pointing downhill) on some of the contour lines in these maps indicate the presence of a closed depression (a depression from which water cannot drain). At the top of a hill, contour lines repeat on opposite sides of the rim of the depression. On the side of a hill, the contour lines repeat only on the downhill side of the depression.

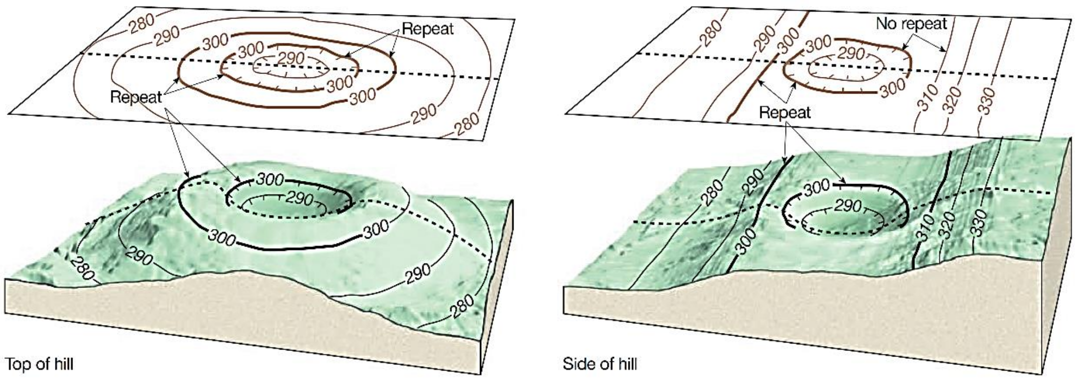


Fig. 29

5.6.Ridges and Valleys

Fig. 30 shows how topographic contour lines represent linear ridge crests and valley bottoms. Ridges and valleys are roughly symmetrical, so individual contour lines repeat on each side. To visualize this, picture yourself walking along an imaginary trail across the ridge or valley (dashed lines in Fig. 30). Every time you walk up the side of a hill or valley, you cross contour lines. Then, when you walk down the other side of the hill or valley, you re-cross contour lines of the same elevations as those crossed walking uphill.

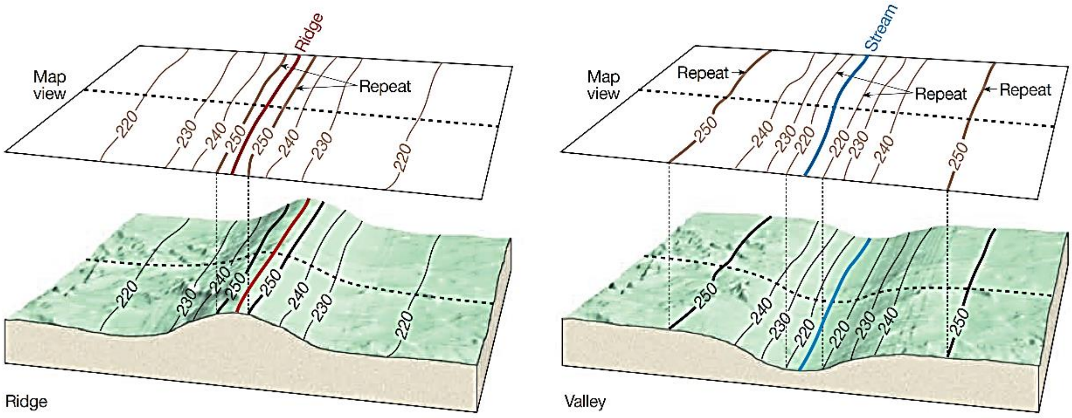


Fig. 30

6. Geologic Maps and Block Diagrams

Geologic maps are flat (two-dimensional, like a sheet of paper or computer display) models of Earth's surface, viewed from directly above, that use different colors and symbols to represent the locations of formations (Fig. 31). You can search for U.S. geologic maps and formation descriptions with the National Geologic Map Database and Geologic Names Lexicon (http://ngmdb.usgs.gov). This site also has links to state geologic maps.

The widths of formations vary in outcrops and on maps because of variations in formation thickness, angle of tilting, and the angle of the land surface at which they crop out. To visualize this, geologist's use block diagrams. A **block diagram** is an oblique sketch of a block of Earth's lithosphere, like a block of cake cut from a sheet cake and viewed from one corner, just above the level of the table on which the cake is sitting. It has a geologic map on top and a geologic cross section on each of its visible sides. Notice how the block diagram in Fig. 31 gives you a three-dimensional perspective of how the formations are oriented.

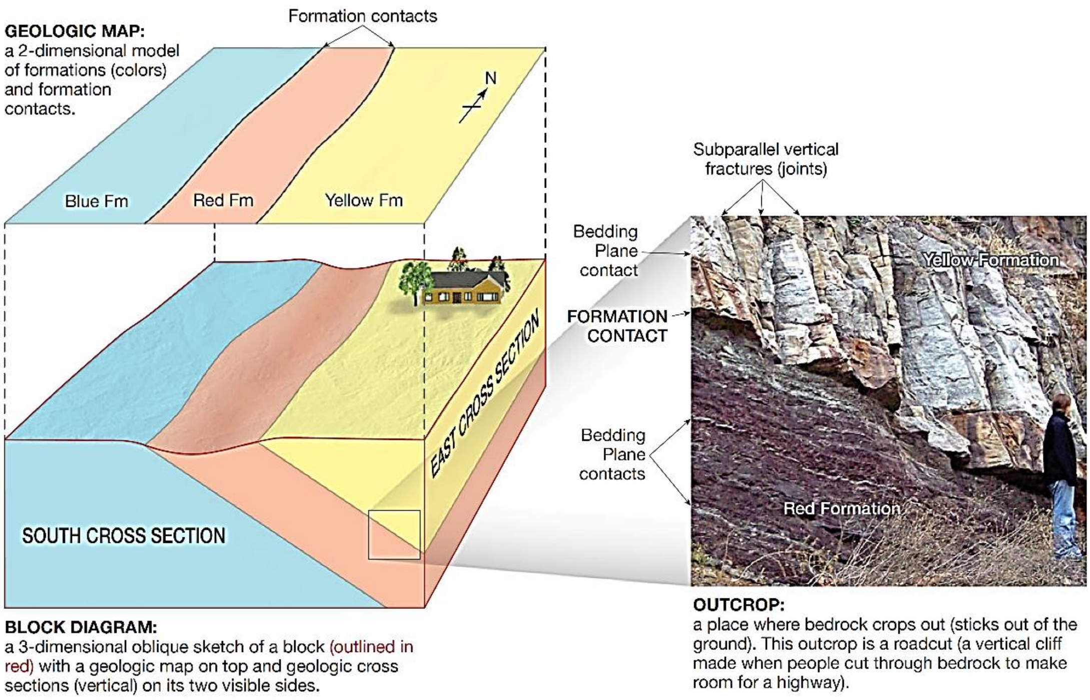


Fig. 31

Attitude is the orientation of a rock unit, surface (contact), or line relative to horizontal and/or a compass direction. Geologists have devised a system of strike and-dip for measuring and describing the attitude of tilted rock layers or surfaces, so they can visualize how they have been deformed from their original horizontality (Fig. 32).

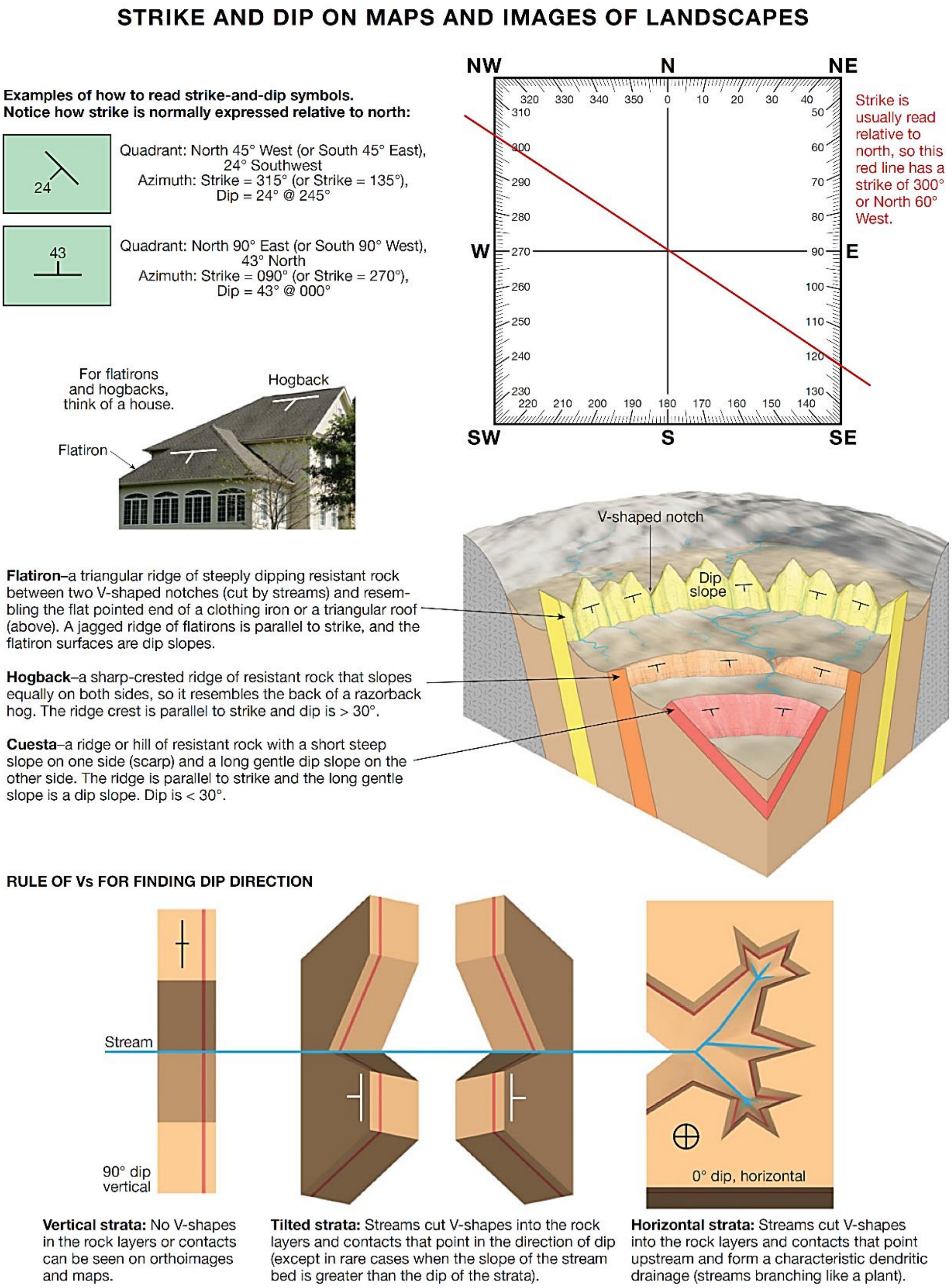


Fig. 32

Strike and dip are usually measured directly from an outcrop using a compass and clinometer (device for measuring the angle of inclined surfaces). However, they can be measured or estimated by the shapes of landforms observed from a distance or on aerial photographs, ortho-images, and satellite images (Fig. 33).

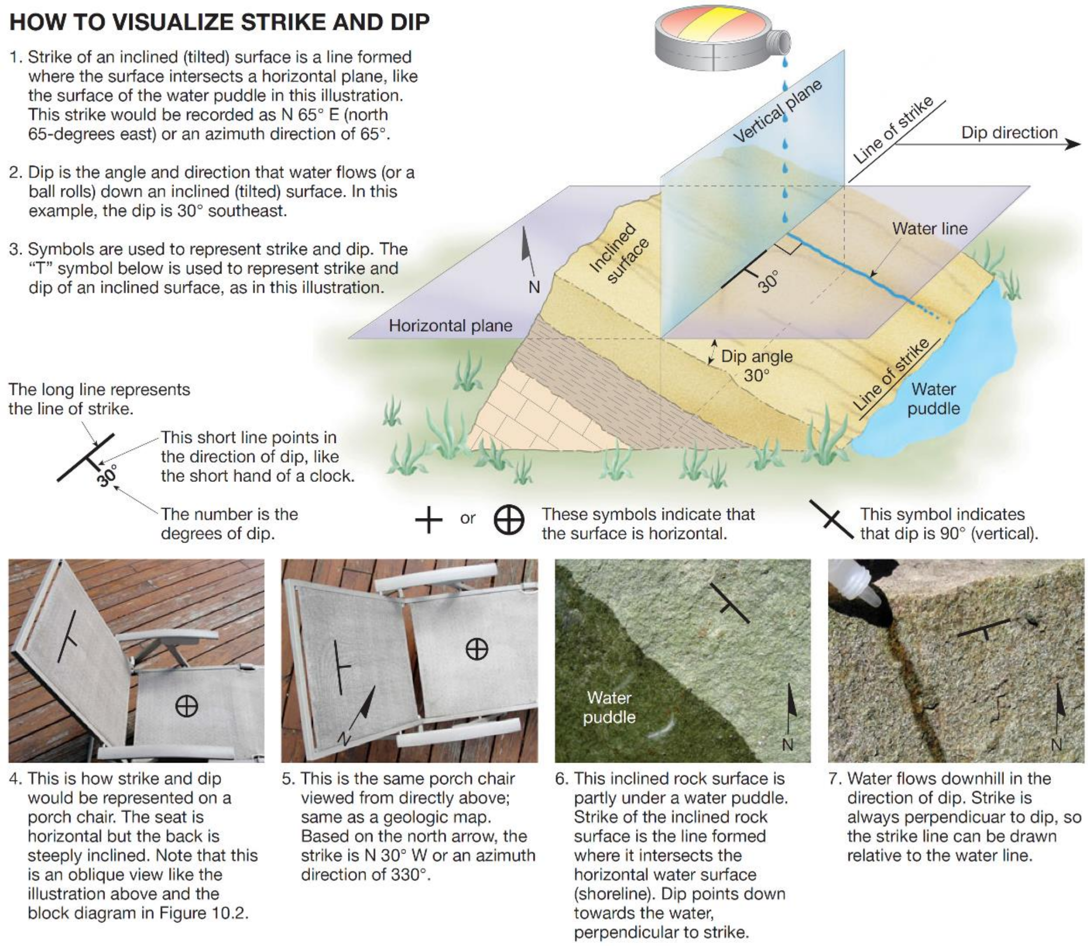


Fig. 33

Strike is the *compass bearing* (line of direction or trend) of a line formed by the intersection of a horizontal plane, such as the surface of a lake, and an inclined surface (contact) or rock layer such as a bed, stratum, or formation (Fig. 32).When the strike is expressed in degrees east or west of true north or true south, it is called a *quadrant bearing*. However, it is more common to express strike as a three-digit *azimuth bearing* in degrees between 000 and 360. In azimuth form, north is 000° (or 360°), east is 090°, south is 180°, and west is 270°. Because the azimuth data represents directions with a number, instead of letters and numbers, it is easier to enter it into spreadsheets for numerical analysis. Strike is usually expressed relative to north (Fig. 33).

Dip is the *angle* between a horizontal plane and an inclined (tilted) surface, measured perpendicular to strike. The surface may be a formation contact, bedding plane contact, fault, or fracture. As you can see in Fig. 32, a thin stream of water poured onto an inclined surface always runs downhill along the **dip direction,** which is always perpendicular to the line of strike. The inclination of the water line, compared to a horizontal plane, is the **dip angle.** Dip is always expressed in terms of its dip angle and dip direction. The dip angle is always expressed in degrees of angle from 0 (horizontal) to 90(vertical). The dip direction can be expressed as a three-digit azimuth direction or as a quadrant direction.

A strike-and-dip symbol consists of a long line showing the orientation of strike, plus a short line for the direction of dip. Note that the dip direction is always perpendicular to strike and points *down dip* —the direction that drops of water would flow or a ball would roll. Accompanying numerals indicate the dip angle in degrees. See Fig. 33 for examples of how to read and express strike and dip in quadrant or azimuth form. Also note that special symbols are used for horizontal strata (rock layers) and vertical strata (Fig. 34).

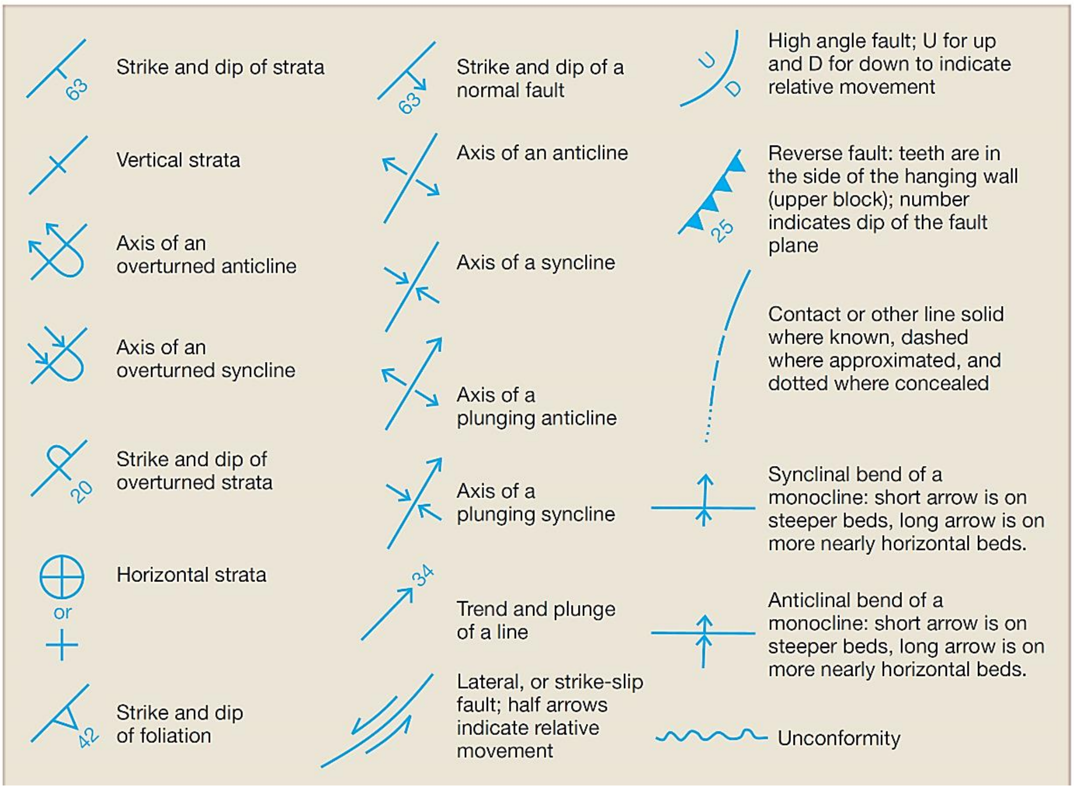


Fig. 34

7. Fractures and Faults

Brittle deformation is said to occur when rocks **fracture** (crack) or **fault** (slide in opposite directions along a crack in the rock). Motion and scraping of brittle rocks along the fault surfaces causes development of *slickensides*, polished surfaces with lineation and step-like linear ridges that indicate the direction of movement along the fault (Fig. 35). If you gently rub the palm of your handback and forth along the slickensides, then one direction will seem smoother (down the step like ridges) than the other. That is the relative direction of the side of the fault represented by your hand. Faults form when brittle rocks experience one of these three kinds of directed pressure (stress): *tension* (pulling apart or lengthening), *compression* (pushing together, compacting, and shortening), or *shear* (smearing or tearing). The three kinds of stress produce three different kinds of faults: normal, reverse/thrust, and strike-slip (Fig. 35). Normal and reverse/thrust faults both involve vertical motions of rocks. These faults are named by noting the *sense of motion* of the top surface of the fault (top block) relative to the bottom surface (bottom block), regardless of which one actually has moved. The top surface of the fault is called the **hanging wall** and is the base of the **hanging wall** (top) **block** of rock. The bottom surface of the fault is called the **footwall** and forms the top of the **footwall block.** Whenever you see a fault in a vertical cross section, just imagine yourself walking on the fault surface. The surface that your feet would touch is the footwall.

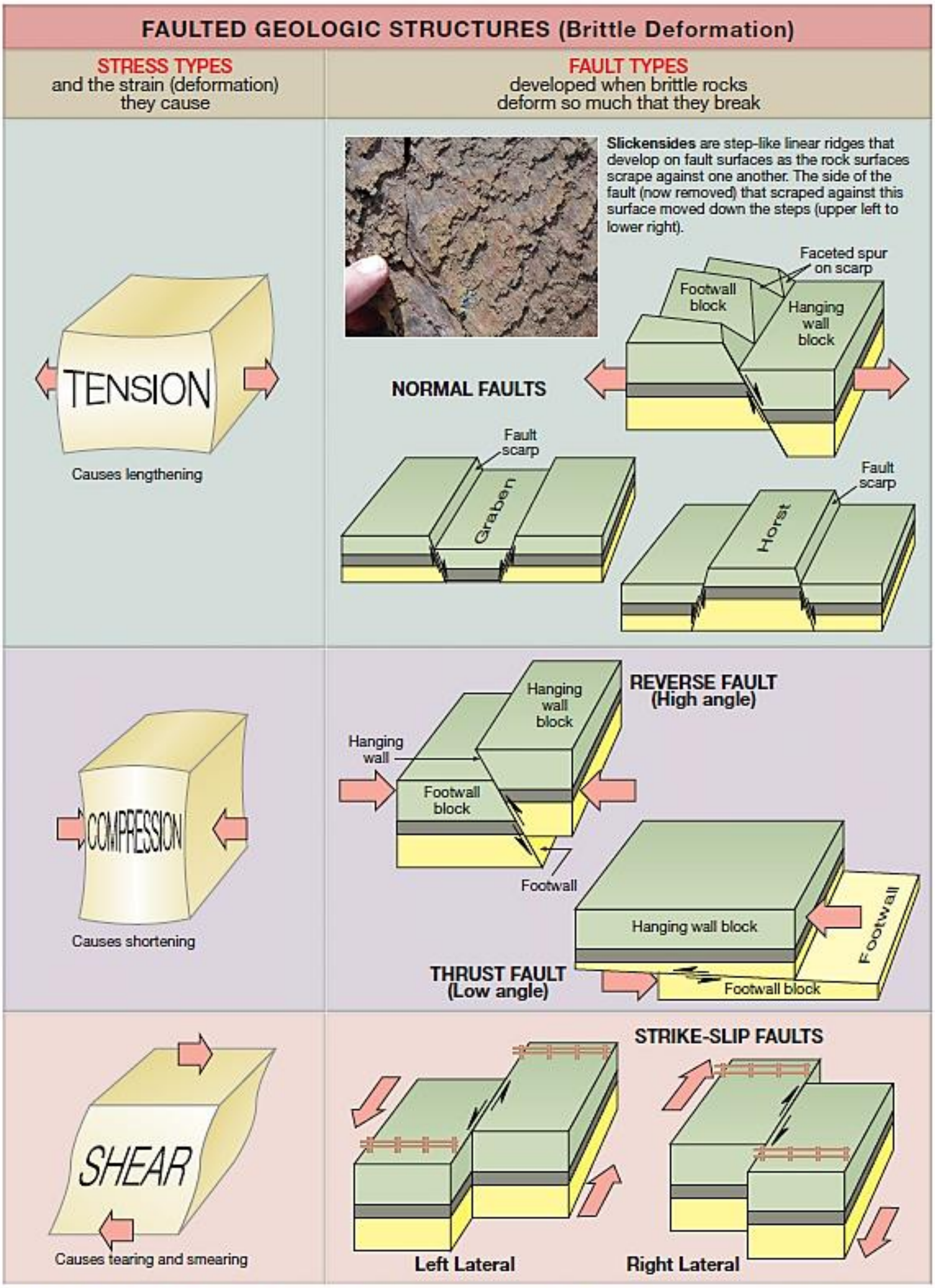
Normal faults are caused by tension (rock lengthening).As tensional stress pulls the rocks apart, gravity pulls down the hanging wall block. Therefore, normal faulting gets its name because it is a normal response to gravity. You can recognize normal faults by recognizing the motion of the hanging wall block relative to the footwall block. First, imagine that the footwall block is stable (has not moved).If the hanging wall block has moved downward in relation to the footwall block, then the fault is a normal fault.

Reverse faults are caused by compression (rock shortening). As compressional stress pushes the rocks together, one block of rock gets pushed atop another. You can recognize reverse faults by recognizing the motion of the hanging wall block relative to the footwall block. First, imagine that the footwall block is stable (has not moved).If the hanging wall block has moved upward in relation to the footwall block, then the fault is a reverse fault. **Thrust faults** are reverse faults that develop at a very low angle and may be very difficult to recognize (Fig. 35). Reverse faults and thrust faults generally place older strata on top of younger strata.

Strike–slip faults (lateral faults) are caused by shear and involve horizontal motions of rocks (Fig. 35). If you stand on one side of a strike–slip fault and look across it, then the rocks on the opposite side of the fault will appear to have slipped to the right or left. Along a *right-lateral (strike–slip) fault,* the rocks on the opposite side of the fault appear to have moved to the right. Along a *left-lateral (strike–slip) fault,* the rocks on the opposite side of the fault appear to have moved to the left.

8. Folded Structures

Folds are upward, downward, or sideways bends of rock layers. **Synclines** are "down folds" or "concave folds," with the *youngest* rocks in the middle (Fig. 36). **Anticlines** are "up folds" or "convex folds" with the *oldest* rocks in the middle. In a fold, each stratum (rock layer) is bent around an imaginary axis, like the crease in a piece of folded paper. This is the **fold axis** (or **hinge line)**. For all strata in a fold, the fold axes lie within the **axial plane** of the fold. The axial plane divides the fold into two **limbs**. For symmetric anticlines and synclines, the fold axis is vertical, but most anticlines and synclines are asymmetric. The axial plane of asymmetric folds is leaning to one side or the other, so one limb is steeper and shorter than the other. The fold axis may not be horizontal, but rather it may plunge into the ground. This is called a **plunging fold**. **Plunge** is the angle between the fold axis and horizontal. The **trend** of the plunge is the bearing (compass direction), measured in the direction that the axis is inclined downward. You can also think of the trend of a plunging fold as the direction a marble would roll if it were rolled down the plunging axis of the fold. If a fold is tilted so that one limb is upside down, then the entire fold is called an **overturned fold**. **Monoclines** have two axial planes that separate two nearly horizontal limbs from a single, more steeply inclined limb. **Domes** and **basins** are large, somewhat circular structures formed when strata are warped upward, like an upside-down bowl (dome) or downward, like a bowl (basin). Strata are oldest at the center of a dome, and youngest at the center of a basin (Fig. 37).



Faults (brittle deformation). Three classes of faults result from three kinds of directed pressure (stress: tension, compression, shear) applied to brittle rocks.

Fig. 35

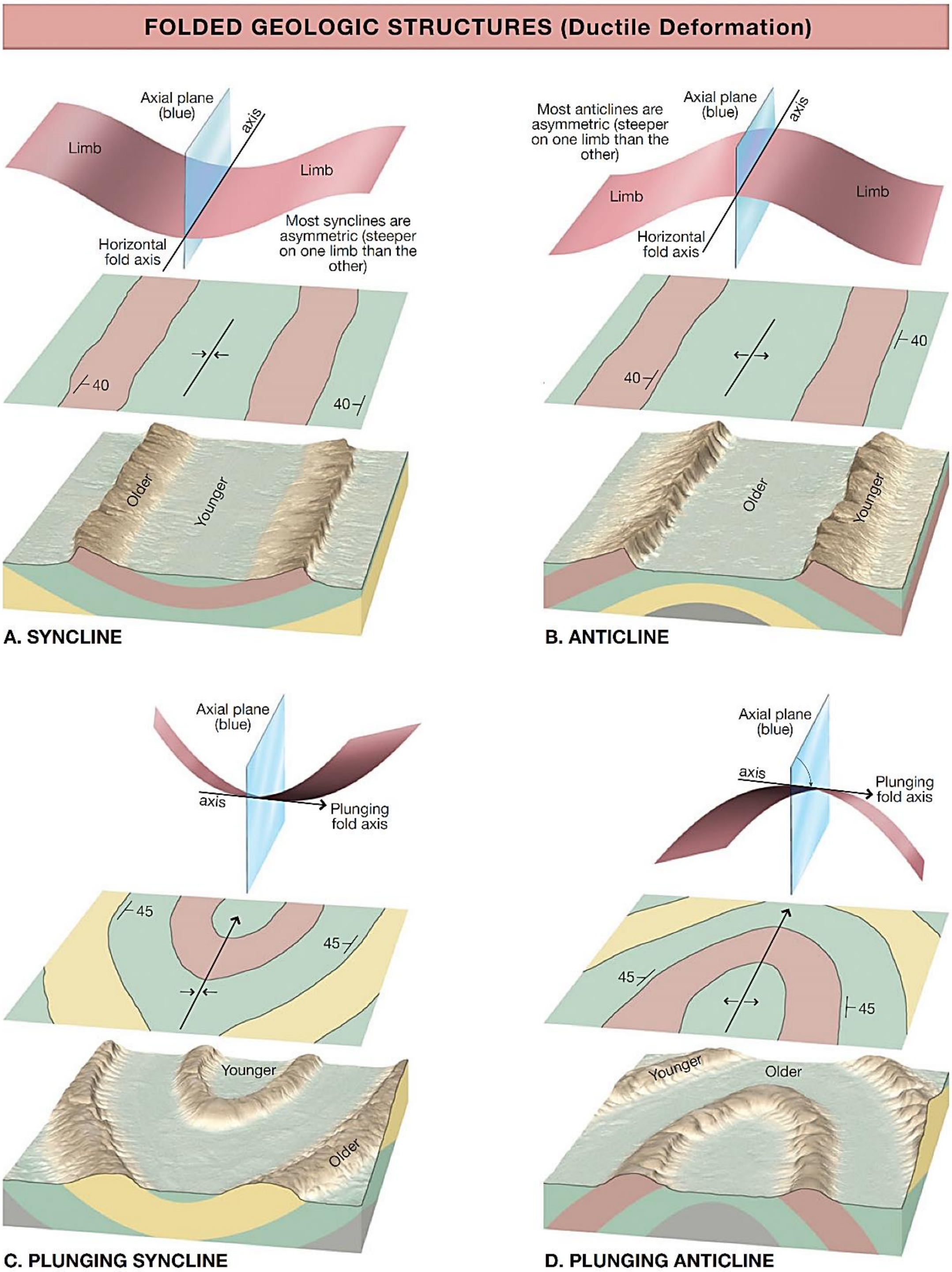

FOLDED GEOLOGIC STRUCTURES (Ductile Deformation)
Axial plane (blue)
axis
Limb
Limb
Horizontal fold axis
Most synclines are asymmetric (steeper on one limb than the other)
40
40
Older
Younger
A. SYNCLINE
Most anticlines are asymmetric (steeper on one limb than the other)
Axial plane (blue)
axis
Limb
Limb
Horizontal fold axis
40
40
Older
Younger
B. ANTICLINE
Axial plane (blue)
axis
Plunging fold axis
45
45
Younger
Older
C. PLUNGING SYNCLINE
Axial plane (blue)
axis
Plunging fold axis
45
45
Younger
Older
D. PLUNGING ANTICLINE

Fig. 36

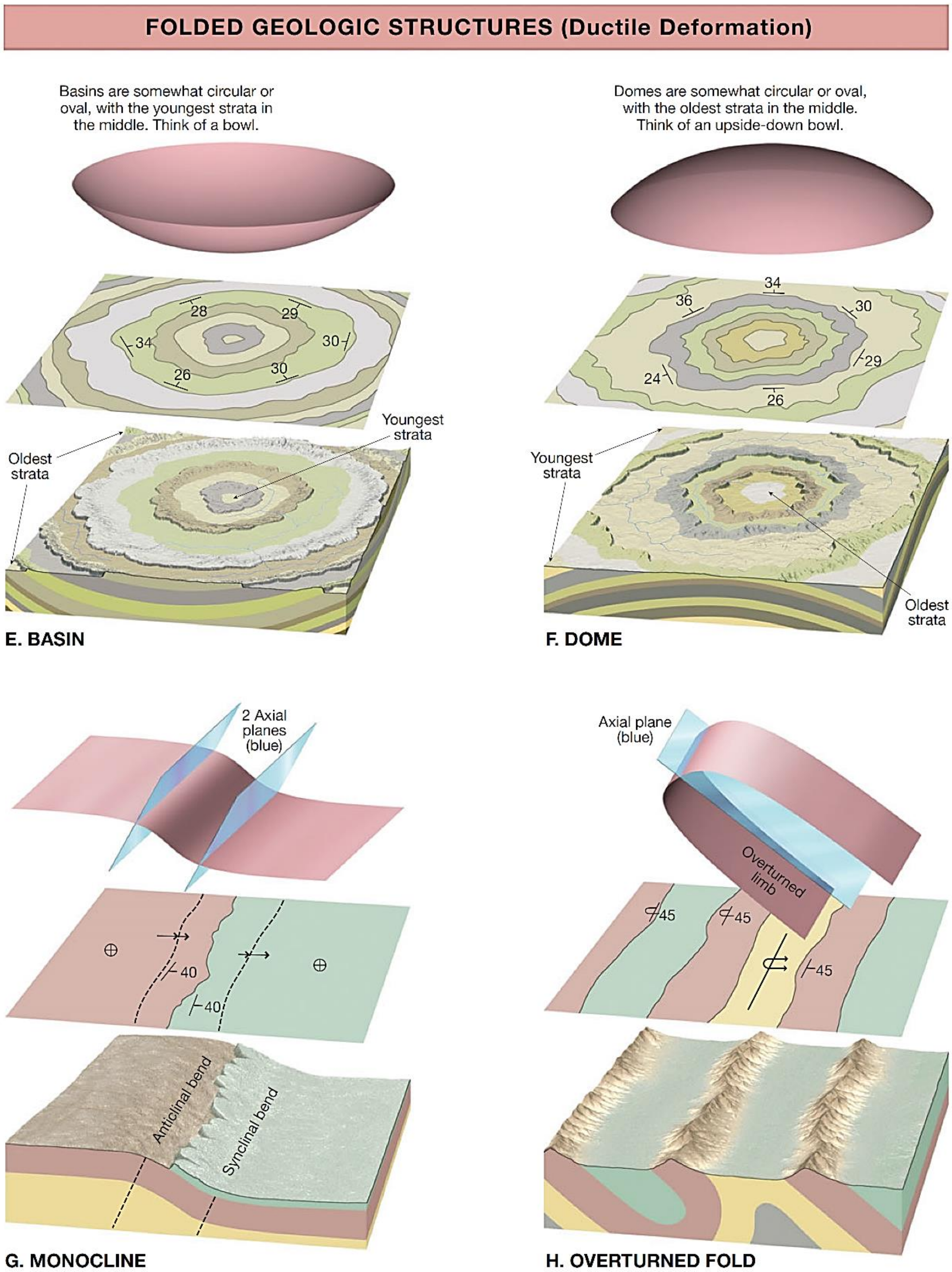

FOLDED GEOLOGIC STRUCTURES (Ductile Deformation)
Basins are somewhat circular or oval, with the youngest strata in the middle. Think of a bowl.
Domes are somewhat circular or oval, with the oldest strata in the middle. Think of an upside-down bowl.
28
29
34
30
26
30
34
36
30
29
24
26
Oldest strata
Youngest strata
Youngest strata
Oldest strata
E. BASIN
F. DOME
2 Axial planes (blue)
Axial plane (blue)
Overturned limb
40
40
45
45
45
Anticlinal bend
Synclinal bend
G. MONOCLINE
H. OVERTURNED FOLD

Fig. 37

9. References

(1) The American Geological Institute & the National Association of Geoscience Teachers. (2015). *Laboratory manual in physical geology*. 10th edition, Edited by: Richard M. Busch, (editor: West Chester University of Pennsylvania); illustrated by Dennis Tasa, Tasa Graphic Arts, Inc.

(2) Charles Merguerian and J Bret Bennington. (2006). *Physical Geology Laboratory Manual*. 9th edition, Geology Department, Hofstra University, New York, USA.

(3) Greg P. Gardiner. (2011). *Introductory Physical Geology: Laboratory Manual for Distance Learning*. Coastline Community College, Coast Learning Systems. Kendall/Hunt Publishing Company. USA.
ISBN-13: 978-0-7575-6320-1

Measurement Units

People in different parts of the world have historically used different systems of measurement. For example, people in the United States have historically used the English system of measurement based on units such as inches, feet, miles, acres, pounds, gallons, and degrees Fahrenheit. However, for more than a century, most other nations of the world have used the metric system of measurement. In 1975, the U.S. Congress recognized that global communication, science, technology, and commerce were aided by use of a common system of measurement, and they made the metric system the official measurement system of the United States. This conversion is not yet complete, so most Americans currently use both English and metric systems of measurement.

The International System (SI)

The International System of Units (SI) is a modern version of the metric system adopted by most nations of the world, including the United States. Each kind of metric unit can be divided or multiplied by 10 and its powers to form the smaller or larger units of the metric system. Therefore, the metric system is also known as a “base-10” or “decimal” system. The International System of Units (SI) is the official system of symbols, numbers, base-10 numerals, powers of 10, and prefixes in the modern metric system.

SYMBOL	NUMBER	NUMERAL	POWER OF 10	PREFIX
T	one trillion	1,000,000,000,000	10^{12}	tera-
G	one billion	1,000,000,000	10^{9}	giga-
M	one million	1,000,000	10^{6}	mega-
k	one thousand	1000	10^{3}	kilo-
h	one hundred	100	10^{2}	hecto-
da	ten	10	10^{1}	deka-
	one	1	10^{0}	
d	one-tenth	0.1	10^{-1}	deci-
c	one-hundredth	0.01	10^{-2}	centi-
m	one-thousandth	0.001	10^{-3}	milli-
μ	one-millionth	0.000001	10^{-6}	micro-
n	one-billionth	0.000000001	10^{-9}	nano-
p	one-trillionth	0.000000000001	10^{-12}	pico-

Examples

1 meter (1 m) = 0.001 kilometers (0.001 km), 10 decimeters (10 dm), 100 centimeters (100 cm), or 1000 millimeters (1000 mm)
1 kilometer (1 km) = 1000 meters (1000 m)
1 micrometer (1μm) = 0.000,001 meter (.000001 m) or 0.001 millimeters (0.001 mm)
1 kilogram (kg) = 1000 grams (1000 g)
1 gram (1 g) = 0.001 kilograms (0.001 kg)
1 metric ton (1 t) = 1000 kilograms (1000 kg)
1 liter (1 L) = 1000 milliliters (1000 mL)
1 milliliter (1 mL or 1 ml) = 0.001 liter (0.001 L)

Abbreviations for Measures of Time

A number of abbreviations are used in the geological literature to refer to time. Abbreviations for “years old” or “years ago” generally use SI prefixes and “a” (Latin for *year*). Abbreviations for intervals or durations of time generally combine SI symbols with “y” or “yr” (*years*). For example, the boundaries of the Paleozoic Erathem are 542 Ma and 251 Ma, so the Paleozoic Era lasted 291 m.y.

ka = kiloannum—thousand years old, ago, or before present
Ma = megannum—million years old, ago, or before present
Ga = gigannum—billion years old, ago, or before present
yr (or y) = year or years
Kyr or k.a. = thousand years
Myr or m.y. = million years
Gyr (or Byr or b.y) = gigayear—billion years

Mathematical Conversions

To convert:	To:	Multiply by:	
kilometers (km)	meters (m)	1000 m/km	**LENGTHS AND DISTANCES**
	centimeters (cm)	100,000 cm/km	
	miles (mi)	0.6214 mi/km	
	feet (ft)	3280.83 ft/km	
meters (m)	centimeters (cm)	100 cm/m	
	millimeters (mm)	1000 mm/m	
	feet (ft)	3.2808 ft/m	
	yards (yd)	1.0936 yd/m	
	inches (in.)	39.37 in./m	
	kilometers (km)	0.001 km/m	
	miles (mi)	0.0006214 mi/m	
centimeters (cm)	meters (m)	0.01 m/cm	
	millimeters (mm)	10 mm/cm	
	feet (ft)	0.0328 ft/cm	
	inches (in.)	0.3937 in./cm	
	micrometers (μm)*	10,000 μm/cm	
millimeters (mm)	meters (m)	0.001 m/mm	
	centimeters (cm)	0.1 cm/mm	
	inches (in.)	0.03937 in./mm	
	micrometers (μm)*	1000 μm/mm	
	nanometers (nm)	1,000,000 nm/mm	
micrometers (μm)*	millimeters (mm)	0.001 mm/μm	
nanometers (nm)	millimeters (mm)	0.000001 mm/nm	
miles (mi)	kilometers (km)	1.609 km/mi	
	feet (ft)	5280 ft/mi	
	meters (m)	1609.34 m/mi	
feet (ft)	centimeters (cm)	30.48 cm/ft	
	meters (m)	0.3048 m/ft	
	inches (in.)	12 in./ft	
	miles (mi)	0.000189 mi/ft	
inches (in.)	centimeters (cm)	2.54 cm/in.	
	millimeters (mm)	25.4 mm/in.	
	micrometers (μm)*	25,400 μm/in.	
square miles (mi2)	acres (a)	640 acres/mi^2	**AREAS**
	square km (km^2)	2.589988 km^2/m	
square km (km2)	square miles (mi^2)	0.3861 mi^2/km^2	
acres	square miles (mi^2)	0.001563 mi^2/acr	
	square km (km^2)	0.00405 km^2/acr	
gallons (gal)	liters (L)	3.78 L/gal	**VOLUMES**
fluid ounces (oz)	milliliters (mL)	30 mL/fluid oz	
milliliters (mL)	liters (L)	0.001 L/mL	
	cubic centimeters (cm^3)	1.000 cm^3/mL	
liters (L)	milliliters (mL)	1000 mL/L	
	cubic centimeters (cm^3)	1000 cm^3/mL	
	gallons (gal)	0.2646 gal/L	
	quarts (qt)	1.0582 qt/L	
	pints (pt)	2.1164 pt/L	
grams (g)	kilograms (kg)	0.001 kg/g	**WEIGHTS AND MASSES**
	pounds avdp. (lb)	0.002205 lb/g	
ounces avdp (oz)	grams (g)	28.35 g/oz	
ounces troy (ozt)	grams (g)	31.10 g/ozt	
pounds avdp. (lb)	kilograms (kg)	0.4536 kg/lb	
kilograms (kg)	pounds avdp. (lb)	2.2046 lb/kg	

To convert from degrees Fahrenheit (°F) to degrees Celsius (°C), subtract 32 degrees and then divide by 1.8 To convert from degrees Celsius (°C) to degrees Fahrenheit (°F), multiply by 1.8 and then add 32 degrees.

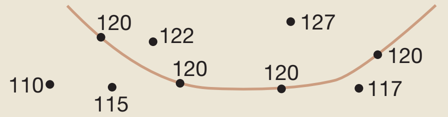
*Formerly called microns (μ)

LABORATORY EQUIPMENT

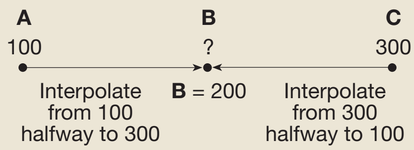
NORTH AMERICA
Political & Physical Map
ELEVATION IN METERS
4000+
2000–4000
500–1,999
200–499
0–199
Below sea level
Sea Level
Metropolitan areas more than 20 million
Metropolitan areas 10–20 million
Metropolitan areas 5–9.9 million
Metropolitan areas 1–4.9 million
Selected smaller metropolitan areas
Plate boundaries
ARCTIC OCEAN
PACIFIC OCEAN
ATLANTIC OCEAN
Gulf of Mexico
Gulf of Alaska
Hudson Bay
Baffin Bay
Bering Strait
Bering Sea
Aleutian Islands
Anchorage
Greenland
Baffin Island
Brooks Range
Alaska Range
Prudhoe Bay
YUKON TERRITORY
Whitehorse
NORTHWEST TERRITORIES
NUNAVUT
Great Slave Lake
Mackenzie R.
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
MANITOBA
ONTARIO
QUÉBEC
NEWFOUNDLAND AND LABRADOR
Newfoundland
Prince Edward Island
P.E.I.
NEW BRUNSWICK
NOVA SCOTIA
C A N A D A
UNITED STATES
MEXICO
Edmonton
Calgary
Saskatoon
Regina
Winnipeg
Lake Winnipeg
Vancouver Island
Vancouver
Puget Sound
Columbia R.
Seattle
Portland
Coast Mountains
ROCKY MOUNTAINS
GREAT PLAINS
Cascade Range
Coast Ranges
Central Valley
Sierra Nevada
Great Basin
Teton Range
Great Salt Lake
Salt Lake City
Boise
Sacramento
San Francisco
San Jose
Los Angeles
Riverside
San Diego
Las Vegas
Salton Sea
Grand Canyon
Colorado Plateau
Colorado R.
Phoenix
Tucson
Albuquerque
El Paso
Denver
Rio Grande
Austin
San Antonio
Houston
Dallas-Fort Worth
Oklahoma City
Red R.
Arkansas R.
Kansas City
Platte R.
Missouri R.
Minneapolis-St. Paul
Ozark Mtns.
Ouachita Plateau
St. Louis
Memphis
Nashville
Mississippi R.
New Orleans
Chicago
Milwaukee
L. Superior
L. Michigan
L. Huron
L. Erie
L. Ontario
Detroit
Indianapolis
Cincinnati
Ohio R.
Louisville
Columbus
Cleveland
Pittsburgh
Buffalo
Toronto
Hamilton
Ottawa
Montréal
Quebec City
St. Lawrence R.
Saint John
Halifax
Adirondack Mtns.
Boston
Providence
Bridgeport
New York City
Philadelphia
Baltimore
Washington, D.C.
Chesapeake Bay
Virginia Beach
APPALACHIAN HIGHLANDS
Piedmont
Charlotte
Atlanta
Jacksonville
Orlando
Tampa-St. Petersburg
Miami
Florida Keys
NORTH AMERICAN PLATE
PACIFIC PLATE
JUAN DE FUCA PLATE
EURASIAN PLATE
Arctic Circle
HAWAII
Kauai
Oahu
Honolulu
Maui
Hawaii
100 Miles
100 Kilometers
300 Miles
300 Kilometers
250
500 Miles
500 Kilometers

RULES FOR CONTOUR LINES

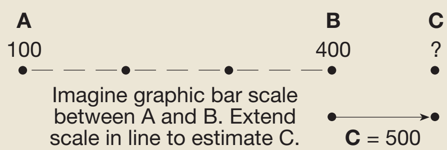
1. Every point on a contour line is of the exact same elevation; that is, contour lines connect points of equal elevation. The contour lines are constructed by surveying the elevation of points, then connecting points of equal elevation.



2. Interpolation is used to estimate the elevation of a point B located in line between points A and C of known elevation. To estimate the elevation of point B:



3. Extrapolation is used to estimate the elevations of a point C located in line beyond points A and B of known elevation. To estimate the elevation of point C, use the distance between A and B as a ruler or graphic bar scale to estimate in line to elevation C.

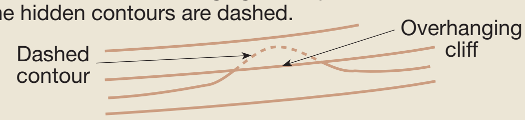


4. Contour lines always separate points of higher elevation (uphill) from points of lower elevation (downhill). You must determine which direction on the map is higher and which is lower, relative to the contour line in question, by checking adjacent elevations.

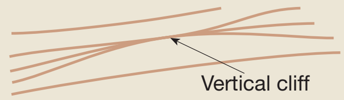
5. Contour lines always close to form an irregular circle. But sometimes part of a contour line extends beyond the mapped area so that you cannot see the entire circle formed.

6. The elevation between any two adjacent contour lines of different elevation on a topographic map is the *contour interval*. Often every fifth contour line is heavier so that you can count by five times the contour interval. These heavier contour lines are known as *index contours*, because they generally have elevations printed on them.

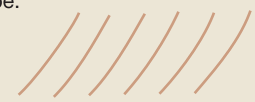
7. Contour lines never cross each other except for one rare case: where an overhanging cliff is present. In such a case, the hidden contours are dashed.



8. Contour lines can merge to form a single contour line only where there is a vertical cliff or wall.



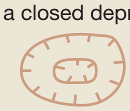
9. Evenly spaced contour lines of different elevation represent a uniform slope.



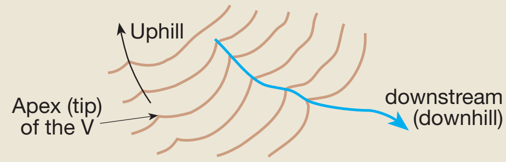
10. The closer the contour lines are to each other the steeper the slope. In other words, the steeper the slope the closer the contour lines.

11. A concentric series of closed contours represents a hill:

12. *Depression contours* have hachure marks on the downhill side and represent a closed depression:



13. Contour lines form a V pattern when crossing streams. The apex of the V always points upstream (uphill):



14. Contour lines that occur on opposite sides of a valley or ridge always occur in pairs. See Figure 9.13.

Rules for constructing and interpreting contour lines on topographic maps.

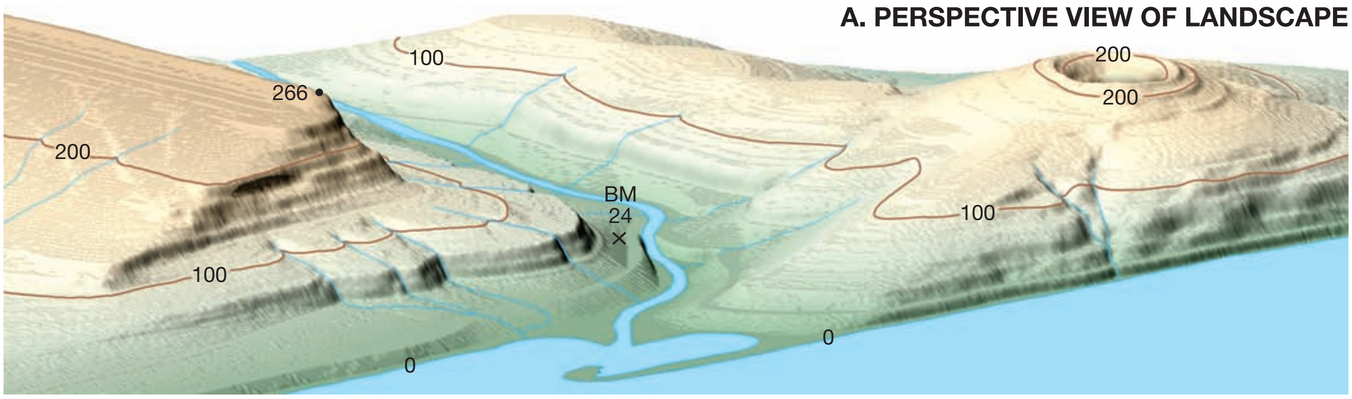
Relief and Gradient (Slope)

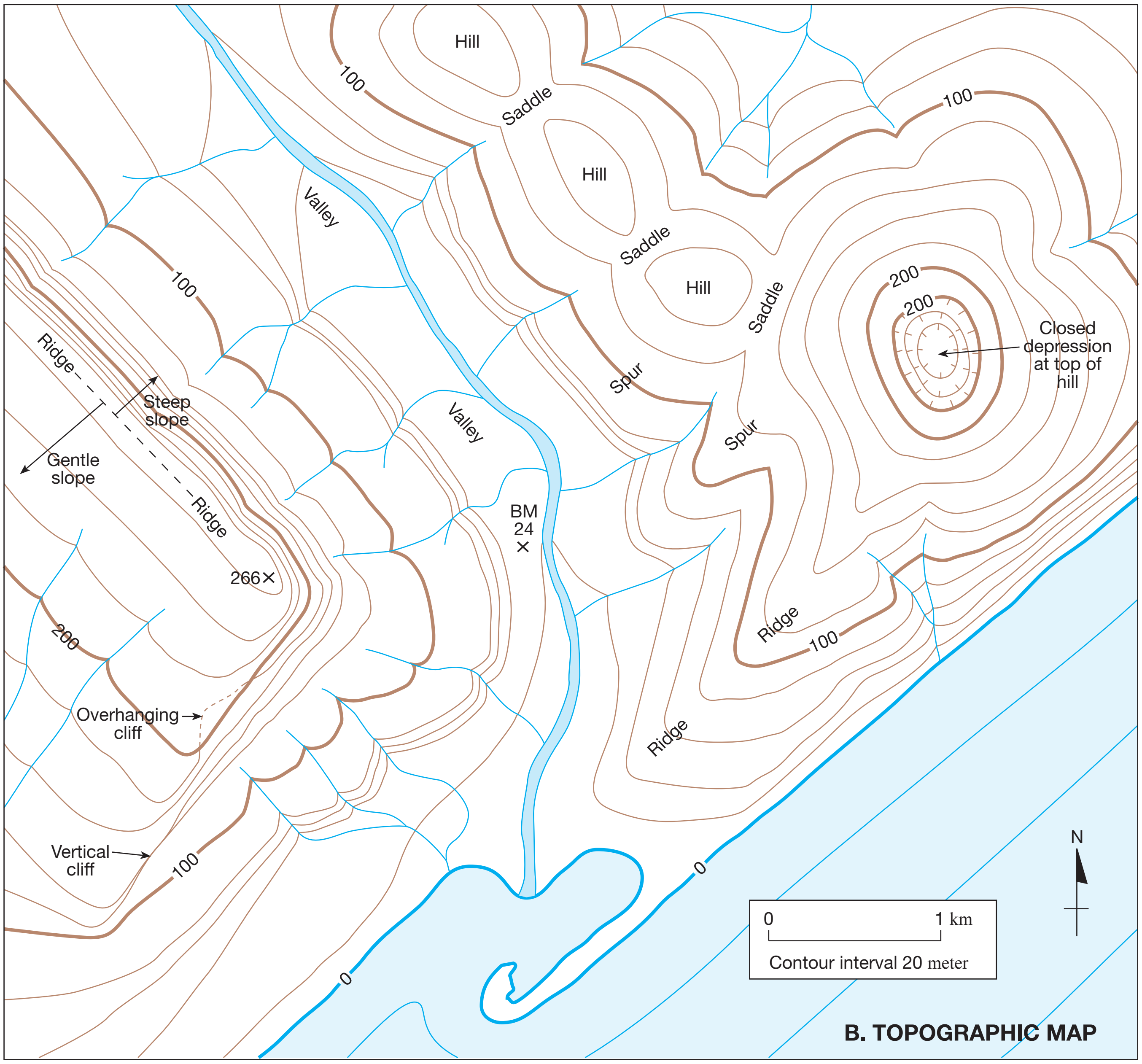
Recall that **relief** is the difference in elevation between landforms, specific points, or other features on a landscape or map. *Regional relief* (total relief) is the difference in elevation between the highest and lowest points on a topographic map. The highest point is the top of the highest hill or mountain; the lowest point is generally where the major stream of the area leaves the map, or a coastline. **Gradient** is a measure of the steepness of a slope. One way to determine and express the gradient of a slope is by measuring its steepness as an angle of ascent or descent (expressed in degrees). On a topographic map, gradient is usually determined by dividing the relief (rise or fall) between two points on the map by the distance (run) between them (expressed as a fraction in feet per mile or meters per kilometer). For example, if points **A** and **B** on a map have elevations of 200 m and 300 m, and the points are located 2 km apart, then:

$$\text{gradient} = \frac{\text{relief (amount of rise or fall between } \mathbf{A} \text{ and } \mathbf{B}\text{)}}{\text{distance between } \mathbf{A} \text{ and } \mathbf{B}}$$

$$= \frac{100 \text{ m}}{2 \text{ km}}$$

$$= 50 \text{ m/km}$$

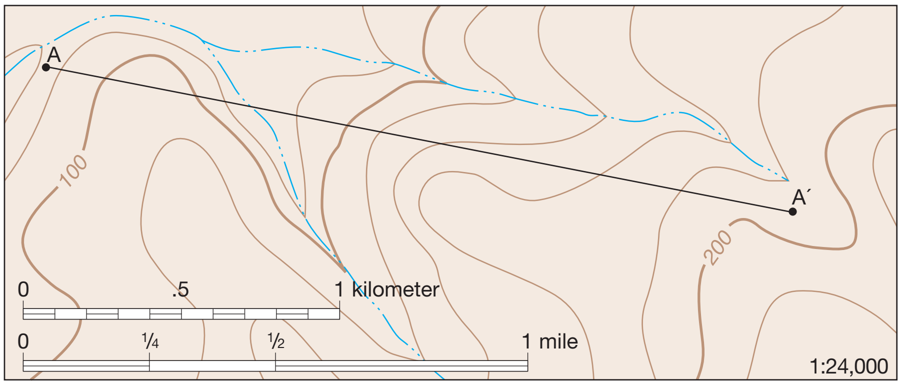




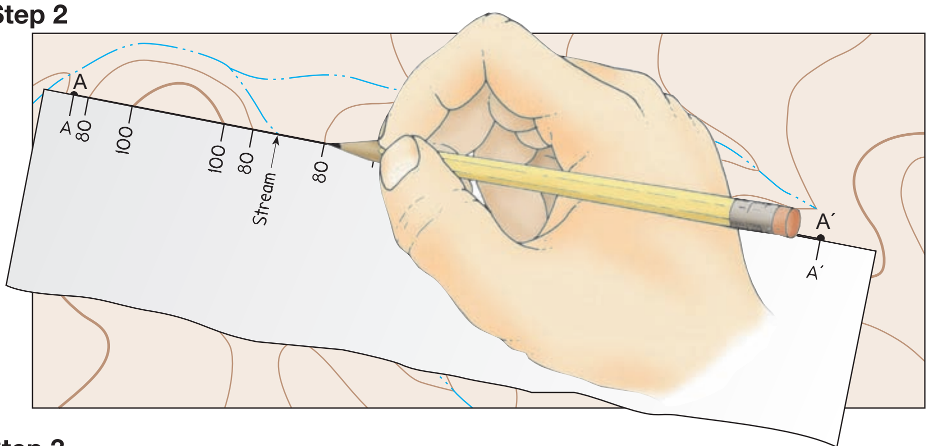
Names of landscape features observed on topographic maps.

Note perspective view (A) and topographic map (B) features: valley (low-lying land bordered by higher ground), hill (rounded elevation of land; mound), ridge (linear or elongate elevation or crest of land), spur (short ridge or branch of a main ridge), saddle (low point in a ridge or line of hills; it resembles a horse saddle), closed depression (low point/area in a landscape from which surface water cannot drain; contour lines with hachure marks), steep slope (closely spaced contour lines), gentle slope (widely spaced contour lines), vertical cliff (merged contour lines), overhanging cliff (dashed contour line that crosses a solid one; the dashed line indicates what is under the overhanging cliff).

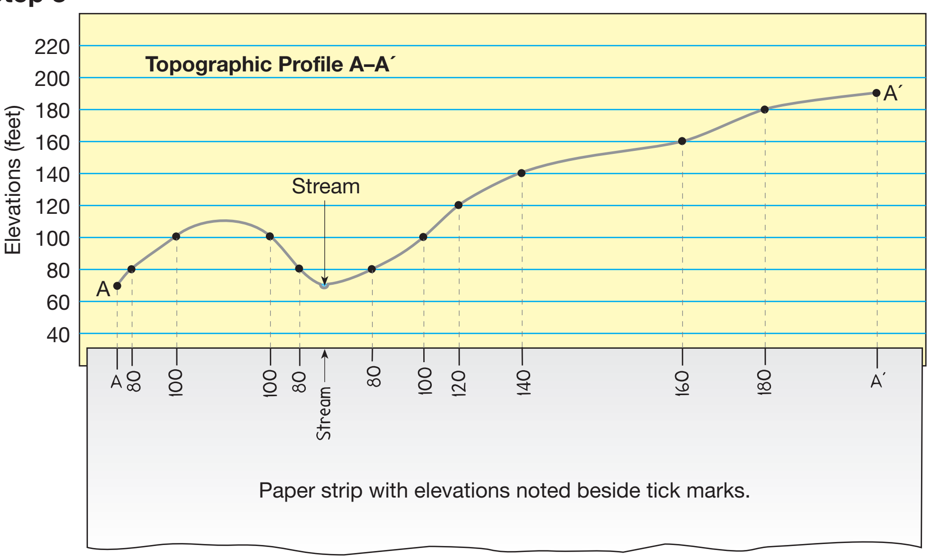
Step 1



Step 2



Step 3



Step 4 Vertical Exaggeration

On most topographic profiles, the vertical scale is exaggerated (stretched) to make landscape features more obvious. One must calculate how much the vertical scale (V) has been exaggerated in comparison to the horizontal scale (H).

The horizontal scale is the map's scale. This map has an H ratio scale of 1:24,000, which means that 1 inch on the map equals 24,000 inches of real elevation. It is the same as an H fractional scale of 1/24,000.

On the vertical scale of this topographic profile, one inch equals 120 feet or 1440 inches (120 feet x 12 inches/foot). Since one inch on the vertical scale equals 1440 inches of real elevation, the topographic profile has a V ratio scale of 1:1440 and a V fractional scale of 1/1440.

The vertical exaggeration of this topographic profile is calculated by either method below:

Method 1: Divide the horizontal ratio scale by the vertical ratio scale.

$$\frac{\text{H ratio scale}}{\text{V ratio scale}} = \frac{1{:}24{,}000}{1{:}1440} = \frac{24{,}000}{1440} = 16.7\times$$

Method 2: Divide the vertical fractional scale by the horizontal fractional scale.

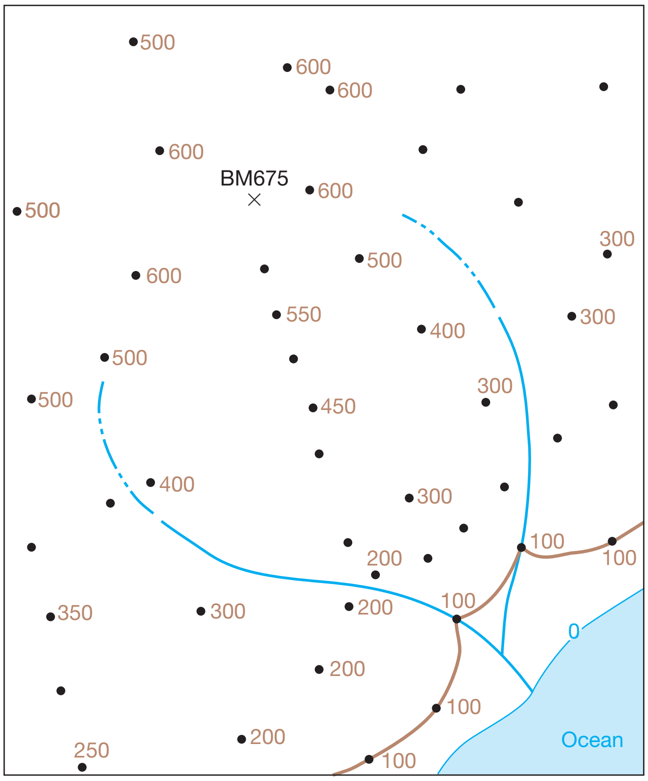
$$\frac{\text{V fractional scale}}{\text{H fractional scale}} = \frac{1/1440}{1/24{,}000} = \frac{24{,}000}{1440} = 16.7\times$$

Topographic profile construction and vertical exaggeration.
Shown are a topographic map (Step1), topographic profile constructed along line **A–A′** (Steps 2 and 3), and calculation of vertical exaggeration (Step 4). **Step 1**—Select two points (**A, A′**), and the line between them (line **A–A′**), along which you want to construct a topographic profile. **Step 2**—To construct the profile, the edge of a strip of paper was placed along line **A–A′** on the topographic map. A tick mark was then placed on the edge of the paper at each point where a contour line and stream intersected the edge of the paper. The elevation represented by each contour line was noted on its corresponding tick mark. **Step 3**—The edge of the strip of paper (with tick marks and elevations) was placed along the bottom line of a piece of lined paper, and the lined paper was graduated for elevations (along its right margin). A black dot was placed on the profile above each tick mark at the elevation noted on the tick mark. The black dots were then connected with a smooth line to complete the topographic profile. **Step 4**—*Vertical exaggeration* of the profile was calculated using either of two methods. Thus, the vertical dimension of this profile is exaggerated (stretched) to 16.7 times greater than it actually appears in nature compared to the horizontal/map dimension.

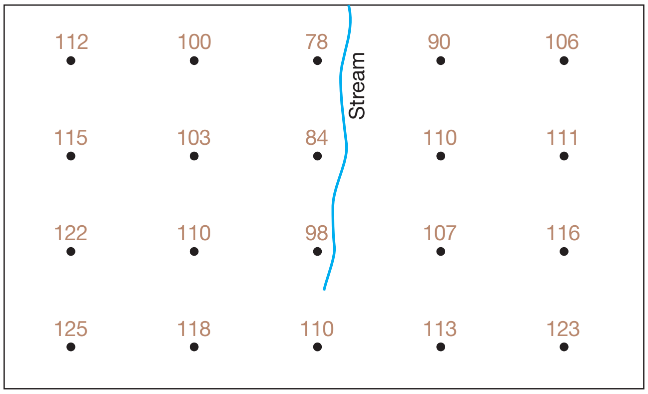
Topographic Map Construction

Name: ______________________ **Course/Section:** ______________________ **Date:** ____________

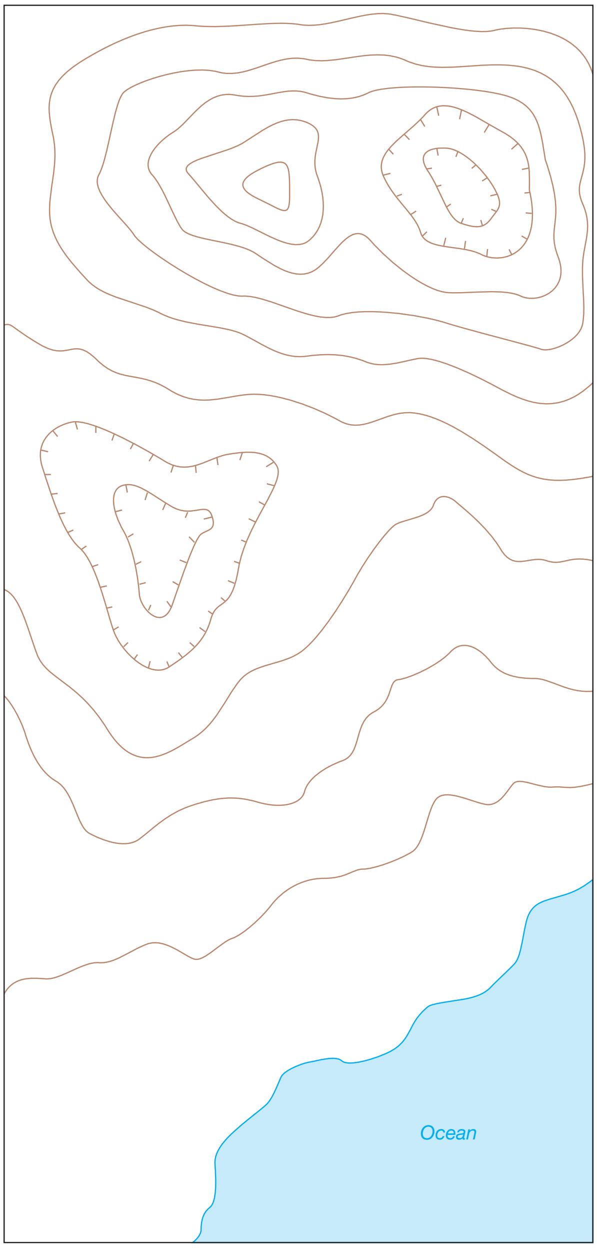
A. Use interpolation and extrapolation to estimate and label elevations of all points below that are not labeled
Then add contour lines using a contour interval of 100 feet. Notice how the 0-meter and 100-meter contour lines have already been drawn.



B. Contour the elevations on the map below using a contour interval of 10 meter.



C. Using a contour interval of 10 meter, label the elevation of every contour line on the map below.



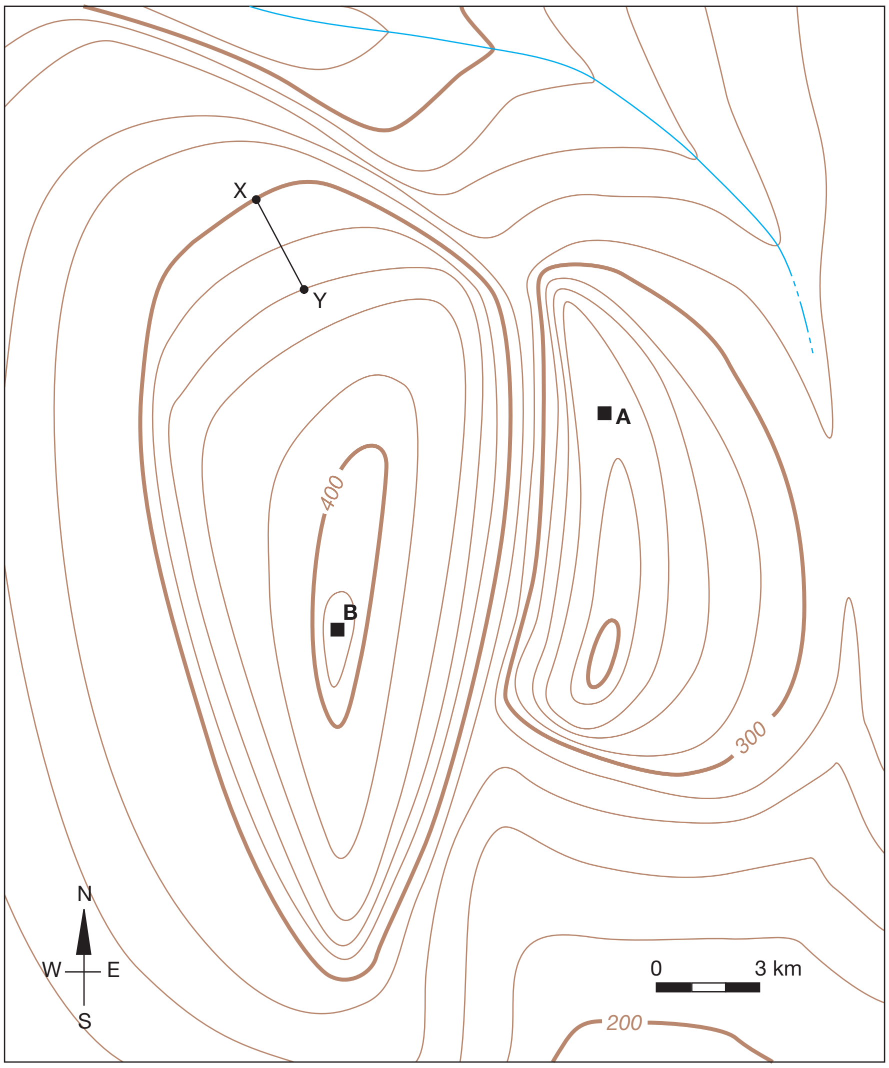
ACTIVITY

Relief and Gradient (Slope) Analysis

Analyze the topographic map below.

1. The contour lines on this map are labeled in meters.
   What is the contour interval of this map in meters? ____________________
2. What is the regional (total) relief of the land represented in this map in meters? ____________________
3. What is the gradient (steepness of slope) from **Y** to **X**? Show your work.

4. Apply your thinking from A4. Imagine that you need to drive a truck from point **A** to point **B** in this mapped area and that your truck cannot travel up any slopes having a gradient over 20 m/km. Trace a route that you could drive to get from point **A** to point **B** (More than one solution is possible).

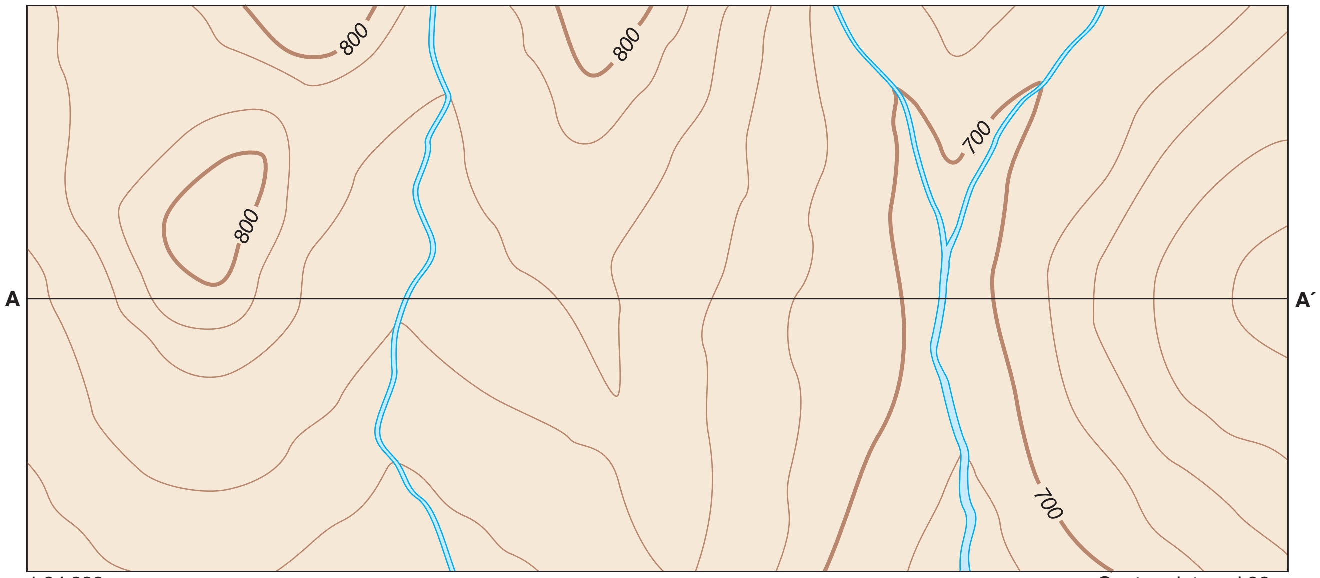


Elevations are in meters.

ACTIVIT

Topographic Profile Construction

A Construct a topographic profile for **A–A’** on the graph paper provided.



1:24,000

Contour interval 20 meter

B. What is the vertical exaggeration of the topographic profile that you constructed above? Show your work.