CHAPTER 5

VOLCANISM, ROCK TYPES, GEOLOGIC DATING, WEATHERING AND EROSION, FAULTING, LANDSCAPE PATTERNS, AQUIFERS AND CAVES

5. 1. GEOLOGY

Because its scope is so broad, geology is traditionally divided into two general fields: **physical geology** and **historical geology**.

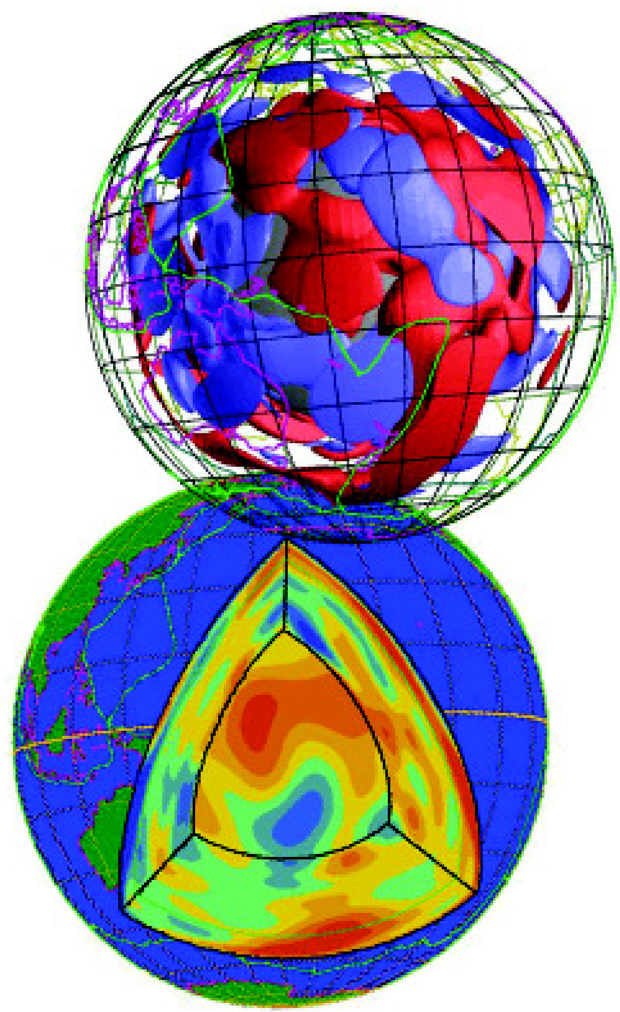
Physical geology deals with the structure and composition of the earth, and with the physical processes which affect it. Historical geology is concerned with the origin of the earth, the physical changes it has undergone, and the history of life as recorded in earth's rocky crust.

In their role as earth historians, historical geologists are detectives. Like astronomers who scan the heavens, searching for clues to solve riddles thousands of light years away, geologists probe the earth. They delve into its crust for evidence that will help unravel the mysteries of the geologic past.

These scientists trace the development of the earth from its cloudy beginnings, almost five billion years ago, through the frigid times of the Great Ice Age. They follow the slow march of life from the earliest known simple plants, more than two billion years ago, through the *Age of Dinosaurs*, to our ancestral humans—relative newcomers on the geologic scene.

Physical geologists help us to understand our rock types and their characteristics, and our various landscape forms.

To learn about the kinds of life we find in an area, we must also learn about the rocks and **topography** of the area. Each type of rock determines the type of formed soil and thereby the amount of water available to an area's plants and animals. The shape of the surface determines the effect of winds and water, the amount of shade in an area, and the depth of soil available for plant root growth. We will explore the nature of our soils in later chapters.



The geology of our planet is complex. This graphic illustrates high density (cold) and low density (warm) areas of upper mantle beneath the Pacific Ocean.

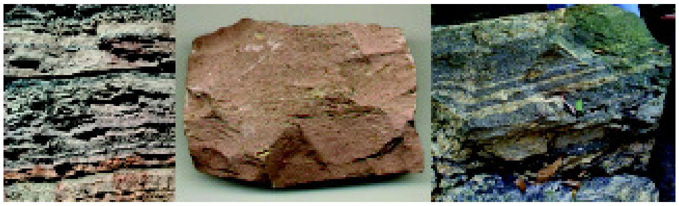
5. 2. ROCKS; THE RAW MATERIALS OF OUR LANDSCAPES

Many of the more spectacular features of a natural landscape are composed of, or have been carved into, solid rock.

Rocks are the raw materials of geology. They are the stuff from which landforms are shaped. It is helpful to know something about our rocks' general characteristics and their role in the development of our landscapes.

5. 2. 1. Defining a Rock

Rock is everywhere around us and one of the commonest things in the world. Yet few people can actually define a rock. So, at the outset, we should learn that a **rock** is a naturally formed physical mass of one or more minerals.



From left to right, Sedimentary, Igneous and Metamorphic rock

Because rocks are composed of minerals, we should also know that a **mineral** is a naturally-occurring substance which has a fairly definite chemical composition (such as gold), and which occurs in a definite shape, called a **crystal**.

5. 3. ROCK TYPES

It is generally believed that all the rocks of the earth's crust have originated in one of three general ways. They are classified accordingly. The three major classes of rocks are: sedimentary, igneous, and metamorphic rocks.

The most common type of rock in the southernmost Mariana Islands is called **sedimentary rock**. Sedimentary rock comes from rock parts that have been broken up or dissolved. These parts are deposited in a new place and made into new rock.

Another type of rock that is commonly found in our islands is called **igneous rock**. This rock comes from molten rock called **magma**.

The last group of rocks is called **metamorphic rock**. This is rock that heat and pressure have changed. We find metamorphic rocks rarely, if at all, in our islands. All these rocks relate to each other in a process called the **rock cycle**.

Another name for igneous rock is volcanic rock. Volcanic eruption of Mt. Pagan, 1981.

5. 4. THE ROCK CYCLE

The rock cycle is a process in which old rock is broken down, changed, melted, and made into new rock.

The cycle starts with igneous rock that is broken down into sedimentary rock or changed by heat and pressure into metamorphic rock. Sedimentary rock is either changed into metamorphic rock, melted and made into new igneous rock, or broken apart and made into new sedimentary rock. Metamorphic rock can be changed into igneous rock by melting, or into sedimentary rock by being broken up into little pieces. To understand the rock cycle better, we must take a closer look at the rocks themselves.

5. 5. IGNEOUS ROCKS

Rocks that have formed by the cooling and hardening of **magma** (melted rock) within the earth's crust are called igneous rocks (from the Latin word "ignis," meaning fire). This type of rock becomes increasingly abundant as one explores downwards into the earth.

Ninety-five (95%) percent of the outermost ten miles of the earth's crust is composed of rocks of igneous origin. On the earth's surface, however, they are much less common.

5. 5. 1. Intrusive or Plutonic Igneous Rocks

Some igneous rocks, for example, **granite** and **gabbro**, have cooled and solidified beneath the earth's surface. Since they formed from magma injected into the surrounding rocks, these are called **intrusive** or **plutonic**, igneous rocks. In general, the places where intrusive igneous rocks appear exposed on the earth's surface are areas that have undergone much erosion.

Igneous intrusions, or **plutons** are also commonly seen as veins or bands of igneous rock which have been forced into pre-existing rocks. These seemingly side-turned, tabular plutons are called **sills** and **dikes**. The plutons, which originally formed deep within the crust, have gradually emerged as the overlying and surrounding rocks have been worn away by wind, water, and weather.

Rocks formed from magma injected into the surrounding rocks are called intrusive or plutonic. These features near Pagan are remnant plutonic rocks.

5. 5. 2. Rock Crystals

Mineral crystals form within igneous rock according to that rock's cooling rate. A rock that cools slowly will form larger crystals. Small crystals form within rocks that cool more quickly. Some igneous rocks have no crystals at all, indicating very fast cooling.

Rocks with easily seen crystals are called **crystalline** rocks. Those without easily seen crystals are called **aphanitic** rocks. *Aphanes* is Greek, meaning *invisible*. In general, plutonic rocks often have large crystals, indicating that they cooled relatively slowly.

5. 5. 3. Extrusive Igneous Rocks

When magma spills out upon the surface, the melted or molten rock is called **extrusive** igneous rock, or **lava**. Extrusive or volcanic rock may force itself up to the surface in different ways. It may erupt through volcanoes, or flow out of great fissures in the earth's crust.

Volcanic eruptions through a central vent typically build mountains or **volcanic cones**. Lava that extrudes as **fissure flows** spreads out rather evenly over the surface in thick, horizontal layers. All the islands in our Northern Mariana Islands are volcanoes. The majority of these are considered active.

Obsidian rock is formed by lava that cooled so quickly that neither gas bubbles nor mineral crystals had time to form.

5. 5. 4. Igneous Rock Types

Basalt is the most common rock type of large lava flows. It is a black, dense, extrusive rock. **Rhyolite**, a light colored solidified lava, is also common. **Andesite**, a third type, more grayish in color, is less common elsewhere in the world. However, here in the Mariana Islands, most volcanic rock that is exposed is andesite.

Lava commonly reaches the earth's surface mixed with steam and gases. Thus, small bubbles fill some lava rock. One gas-filled lava rock is hardened "rock foam", called **pumice**. Pumice rock is filled with tiny **vesicles** or air pockets. Pumice has a spongy appearance. It is so light that it will float.

Another remarkable extrusive igneous rock is **obsidian**. Obsidian is natural volcanic glass, often smoky or black in color. This glass rock is formed by lava that cooled so quickly that neither gas bubbles nor mineral crystals had time to form.

When a volcano erupts explosively, molten rock and gases may be hurled thousands of feet into the air.

5. 5. 5. Pyroclastics

Not all extrusive igneous rocks consist of solidified lava flows. When a volcano erupts explosively, molten rock and gases may be hurled thousands of feet into the air. The lava spray generally cools and hardens while still in the air. It then falls to the ground as solid particles of volcanic dust, ash, and cinders. Sometimes it forms much larger rocks, called **volcanic bombs**, or lava bombs.

These materials are known collectively as **pyroclastics**—literally, "fire broken". Pyroclastics are common in areas where volcanism has taken place. The cinder cones of our northernmost islands consist of great mounds of this violently ejected volcanic debris.

Geologists find that volcanic magma having a higher amount of the mineral **silica** tends to be more explosive than magma with lesser amounts.

Silica forms the skeleton of single-celled marine algae called **diatoms**. Silica is especially abundant within magma formed near to where oceanic plates are subducted. Volcanic ash which reaches the ocean can encourage a *bloom* of these tiny plants. A silica-abundant volcanic rock found in our islands is the grey and whitish rock called **dacite**. (Ed. note: Be very careful when handling dacite due to its tiny silica (glass) shards. These can cut into skin or get into eyes easily if handled carelessly.)

The CNMI has several igneous rock formations. These include the Fina Sisu, Mt. Atchugau, and Denni Hills volcanic formations on Saipan. Bird Island on Saipan is mostly made of whitish volcanic dacite with a small bit of limestone on its top. The Talakaya area of Rota is mostly formed of igneous rock. It also has a limestone top with some exposed volcanic rock—the Sabana.

5. 6. SEDIMENTARY ROCKS

5. 6. 1. Cementation and Lithification

All sedimentary rock is composed of parts of pre-existing rock that was either broken up into little pieces or was dissolved in water. This broken up rock (called **sediment**) goes through a process called **cementation**. During cementation, the little rock particles become bound together.

Sediments may move from their point of origin through erosion. Streams, for example, carry sand and silt to the sea. As soon as the water pushing the sediments slows, the heaviness of the sediments, through gravity, overcomes the tendency to stay suspended, and the rock particles fall to the bottom. This is **sedimentation**.

The next thing to happen to the sediment is called **lithification**. Lithification means that the sediment rock particles get bound together so tightly that a new rock is formed. One way for lithification to happen is by compacting the rock together through pressure.

The Talakaya area of Rota is mostly formed of igneous rock.

5. 6. 2. Layering or Stratification

At certain places in our southernmost Mariana Islands, such as the trail going to "Forbidden Island" on Saipan, the landscape clearly consists of layer upon layer of *sedimentary* rock.

These layered, or **stratified**, rocks were originally loose deposits of sand, mud, and gravel. In the course of time these **unconsolidated** (meaning not cemented or hardened) sediments became hardened into layered beds of sedimentary rock. A single layer is called a **rock stratum** (pl. **strata**).

Because they consist largely of broken particles of pre-existing rocks, these rock fragments are called **clastic** or **detrital** sediments.

Sandstone, mudstone and **conglomerate** (coarse rock consisting of large to small, more or less rounded pebbles) are among the more common clastic sedimentary rocks. The roundness of many of these stones is due to the rock tumbling that naturally occurs in streams.

5. 6. 3. Inorganic Chemical Sedimentation

Chemical sediments originate quite differently. Inorganic chemical sediments were once dissolved in water. Evaporation **precipitates** them out of solution. **Gypsum**, **halite** (rock salt), and certain types of inorganic limestone are formed by this process.

5. 6. 4. Biochemical Sedimentation

Biochemical, or organic chemical sediments, are composed of the remains or products of ancient plants and animals. **Coal**, **coquina** (a mixture of loosely cemented shells), and **fossiliferous limestone** are examples of biochemical or organic sediments.

The most common sedimentary rock found in the CNMI is called limestone.

5. 6. 5. Extent and Educational Value of Sedimentation

Only about five percent of the outer ten miles of the crust consists of sedimentary rocks. However, these rocks make up roughly 75 percent of the rocks exposed on the earth's surface.

Sedimentary rock layers play an important role in reconstructing the geologic histories of our landscapes. **Ripple marks**, **cross-bedding**, mud cracks, and fossils provide valuable clues to the conditions under which the sediments were originally deposited.

5. 6. 6. Characteristics of Our Limestone

The most common sedimentary rock found in the CNMI is called **limestone**. Limestone consists of a chemical called **calcium carbonate**, **$CaCO_3$**.

Fossilized limestone is composed of the remains or products of ancient plants and animals.

Calcium carbonate reacts with **acid** to release a gas called **carbon dioxide**, **CO_2**. This gas is what causes the limestone to fizzle when acid is put on it. An acid test is one of the most common ways to identify limestone.

Many limestone rocks have fossils within them. Some inorganic limestones do not. Some organic limestone, which had fossils at first, later had its fossils decompose through chemical weathering (see below) into an undecipherable mass. By the way, what is the difference between organic and inorganic? Discuss this in class.

Limestone is very **porous**. This is why after a rain, in an area with limestone rocks, there is not much water left standing on the ground.

Limestone normally has a white color. When other substances are mixed into it, the color of limestone may vary greatly.

The CNMI has several limestone formations, including the Tapotchau, Mariana, and Tanapag formations on Saipan. Even Mt. Tapotchau of Saipan is made mostly of limestone. Its sedimentary rocks were once formed below sea level. The highest point of Tinian and much of Rota were formed below sea level as well.

The CNMI has several limestone formations.

5. 7. METAMORPHIC ROCKS

The third, and most complex, class of rocks are the metamorphic rocks. The term "metamorphic" derives from two Greek words which literally mean "change in form".

Either sedimentary or igneous rocks can compose these *re-formed* rocks. Thus, the process of metamorphism can transform a fine-grained limestone (sedimentary rock) into a harder, coarse-textured, crystalline, metamorphic rock called **marble**.

What forces are great enough to cause such a drastic physical change? Metamorphism comes about in a number of ways. During mountain building movements and other great crustal disturbances, powerful earth forces squeeze, bend, break, and rub the rocks in the crust.

Heat and pressure, produced while the rock is under this stress, may cause the minerals to become more closely crowded together. They then form a tightly interlocking mass.

At other times, rocks may be invaded by mineral-bearing gases and liquids boiling up from nearby magmas. When these materials seep into the surrounding rock, they may dissolve some of the original minerals and deposit new ones in their place.

As would be expected, metamorphic rocks are more common in areas that have been subjected to severe crustal intrusions.

Because they have had more time to undergo change, metamorphic rocks are usually of very great age. As mentioned earlier, there are relatively few metamorphic rocks here in our Commonwealth since our islands are relatively young, geologically speaking.

Our northernmost volcanic islands exhibit steep sides extending all the way down to the sea.

5. 8. GEOLOGIC PROCESSES — SHAPERS OF THE LANDSCAPE; AN INTRODUCTION

5. 8. 1. Introduction

The study of **topography**, or earth landscapes (or land shapes), and identifying the geologic causes for these shapes is called **geomorphology**.

Geomorphologists try to associate the land's various shapes with those forces which likely caused them to become this way. In the southernmost Marianas, we commonly see two shapes. We see both broad level, flat plains with steep cliff edges. In other areas, where there are running streams, we see sloping **V-shaped valleys**.

At our ocean's edges, we often see a **notch**, a seemingly curved *bite mark*. Also along our coasts, the rocky land above the first cliff line is heavily **pitted**. At some coastal spots there are white, smooth, sandy beaches.

Our northernmost volcanic islands exhibit steep sides extending all the way down to the sea. The landscape is rugged. In many places, the islands are barren of vegetation.

Instead of white sand beaches, the coastline beaches have grey black sand. These coastlines do not have the coastal rock-pitting features of our southern limestone-predominant islands.

5. 8. 2. Charles Lyell

How did all of these land shapes come to be? Why are these landscapes where they are? Can our understanding of current earth processes help us to determine the answers to these questions? One young scientist, in the very early days of *geology* as a science, suggested that students of geology do exactly this.

The caldera of Mt. Pagan and ash-covereed coconut trees.

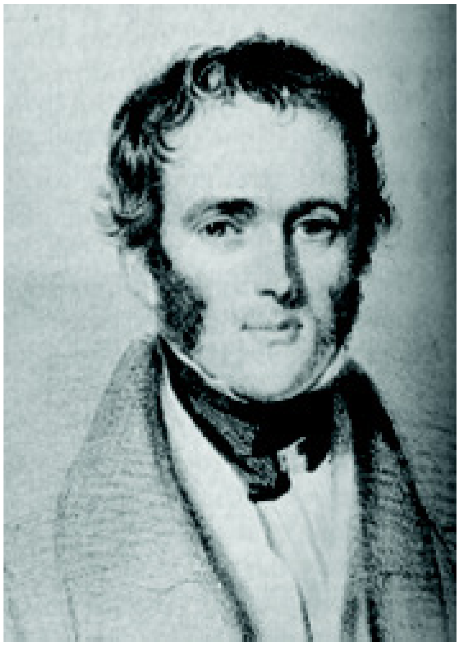
His name was Charles Lyell. Lyell suggested that geologists should carefully look at the ways and the speeds by which sediments settle. He encouraged studies into how volcanism occurs, and how it affects landscapes.

Lyell encouraged others to look at where geologic deposits occur and determine how they occurred. He encouraged researchers to then postulate reasons based on their observations. These ideas would then lead to predictions and these to experiments. Eventually, geomorphologists, including Lyell, made scientific conclusions on how the earth's land processes occur.

5. 9. VOLCANISM

The first process to form and shape the Mariana Islands was **volcanism**, the volcanic process. Remember that volcanoes are places where lava flows through a vent onto the earth's surface. There are three types of volcanoes—shield volcanoes, cinder cones, and stratovolcanoes.

The first volcanic type, the **shield volcano**, is a type found in Hawaii. These are large volcanoes with gentle sloping sides. They have relatively quiet eruptions. The lava that comes out of shield volcanoes is very liquid and flows like water over the surface of the earth. This lava often forms basaltic rocks.



Charles Lyell encouraged studies into how volcanism occurs, and how it affects landscapes.

The next type of volcano is the **cinder cone**. These relatively small volcanoes have explosive eruptions. They throw out much gas, and many rock fragments, called **cinders** and **volcanic bombs**.

If any lava comes out of a cinder cone, it is usually a thick lava that does not flow very far from the cinder cone. Cinder cones are usually very small volcanoes with steep sides.

The last type of volcano is called a **composite volcano**, which is the kind that formed the Northern Mariana Islands. These are now more commonly referred to as **stratovolcanoes**. This volcano is like a combination of the shield and cinder cone.

A composite volcano has alternating layers of lava flows and layers of cinders, caused by both calm and explosive eruptions. The stratovolcano is not as large as a shield volcano, but it is much larger than a cinder cone.

Once volcanoes formed the Marianas, other processes took over to shape our islands into the form they have today. These processes include reef development, faulting, changes in sea level, uplifting, weathering, and erosion.

This clearly visable earthquake fault is near Forbidden Island, Saipan.

5. 10. EARTHQUAKE FAULTS

A **fault** is a **fracture**, or break, in rocks. It occurs as a result of geologic movement in different directions. Faults have a major influence on the landscape. This is because of the uplifting and movement of the land that occurs along them. Faults are also places along which earthquakes happen.

The major faults in the Northern Mariana Islands are called **normal faults**. In a normal fault, the land on one side of the crack goes up while the land on the other side goes down.

5. 11. SEA LEVEL CHANGES AND ISLAND UPLIFTING

5. 11. 1. Introduction

The islands that we find here today have not always been at the same height above sea level. Over time, these islands have been uplifted above the sea, and then the sea has later covered and exposed portions of the islands again and again.

We might suspect that each rock in the southern arc group of the Marianas has at one time been covered by the sea because of the limestone found on the highest island peaks. Then again this may not be the case since different blocks of land move up and down at different rates and at different times. Newer volcanic rock may have vented through existing limestone rock.

We know that limestone can only form underwater. So, at one time, all of the limestone parts of Saipan, Rota, and Tinian must have been underwater. Then they were uplifted to their present height above sea level.

A fault is a fracture, or break, in rocks. This is the Chiget Fault on the island of Tinian.

5. 11. 2. Glacial Periods and Interglacial Periods

From the geologic record we know that our earth has recently gone through several glacial and inter-glacial cycles. The cycles tend to occur about 10,000 years apart.

During glacial times, ice forms at the poles faster than it can melt. During *interglacials*, the ice caps recede to a balanced level of growth and decline. Presently, we live in an interglacial period. The cause of the cycle is presently unknown.

During glacial periods, a lot of ocean water is trapped in polar ice cap snows and ice. This greatly lowers relative sea level. During interglacials, the waters rise to about their present point or higher.

Remember, at the same time our islands are being geologically uplifted. Therefore, what was below water earlier may be high and dry now. That is until the next interglacial, which might send seawater levels even higher.

Add to all of this, the present concern of human-caused global warming from greenhouse gases, and you can see that there is a great deal of ecological confusion with regards to the nature of sea levels.

5. 11. 3. Isostacy and Eustacy

How do these localized uplifts occur? One explanation is by the geologic process of **isostacy** (Eye-sos-sta-see). Isostacy is a balancing of the dense masses of the rock formations in an area. A downward movement of one rock formation results from an upward movement of another nearby.

A good demonstration of isostacy is bread kneading. When kneading bread, you push down in the middle of the loaf. The sides around the pushed-down area of the loaf are, in turn, pushed up.

Another example would be to imagine a pail of water with floating wood blocks in it. The upward movement of the nearby blocks when one of the wood blocks is forced down into the water is from isostacy.

Eroded sediments coming off a mountain cause more mass to come to rest and push down upon a downslope area. Isostacy causes an upward push of the areas nearby.

Besides putting limestone on peaks, isostatic uplifting and changes in sea level form three other features that are found on islands (see below).

These cliffs and terraces on Tinian were created by changing sea levels over millenia.

Eustacy (pronounced you-sta-see) is a similar process that occurs world-wide. It occurs during both ice ages and inter-ice ages.

During ice ages, snow and ice accumulate at the earth's poles. Less water is in the oceans, thus less weight is pushing down under the oceans and less buoying up of adjacent land areas occurs.

The reverse happens during inter-ice ages. There is less water frozen at the poles, and more water in the oceans, thus there is more downward pressure on the seafloor, and more buoying up of adjacent land masses.

Movement of blocks of land by these two causes is described as isostatic movement or eustatic movement, respectively.

5. 11. 4. Cliff and Terrace System

Cliffs, **terraces**, and **wave** and **bioerosion notching** are the three other features that uplifting and changes in sea level cause. When an island is slowly uplifted, the ocean waves erode new edges of the island, causing rock to fall into the ocean.

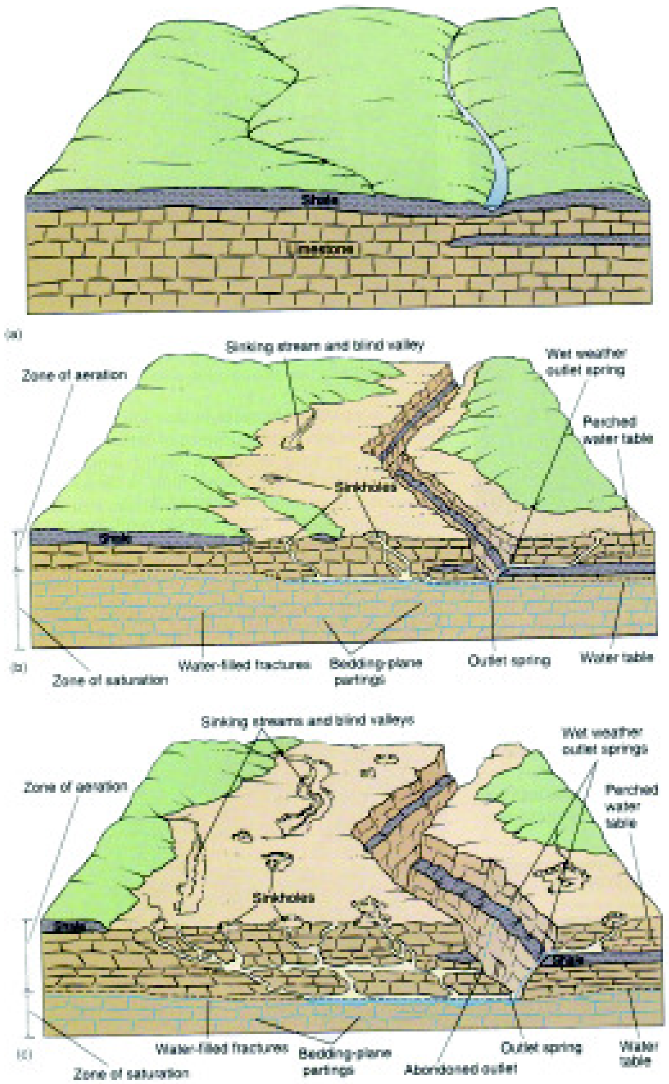
This process forms **cliffs** and **benches**. As the island continues to rise or as the sea level drops, the cliffs and benches come out of the water and form what geologists call a **cliff and terrace system**.

If we examine an island with a cliff and terrace system, it looks as if someone has cut steps leading from the ocean to the mountain top. An examination of the southernmost Mariana islands' physical profile reveals many cliff and terrace systems.

Dramatic evidence of bioerosion notching at Boyscout Beach, Saipan.

Wave action on a shoreline can cause **notching**. Constant high powered wave action will slowly erode a notch into the cliff.

Snails and other seashore life actually eat limestone, along with the calcareous algae contained within it. This also causes notching, probably even more so than waves do. This is called **bioerosion**. Notching can be seen on many of the cliffs in the CNMI. The above processes give our islands their general shape. However, two other processes, weathering and erosion, complete the details of the landscape.



The type of landscape formed by dissolved limestone is called a karst landscape.

5. 12. PHYSICAL WEATHERING AND EROSION

Weathering and erosion are two processes that work together to break up rock and move it to a new location. An important end product of weathering and erosion is the formation of soils.

Weathering is the process in which rock is broken down into smaller pieces or dissolved in water. **Erosion** is the process in which the broken or dissolved rock is moved to a new location.

Weathering and erosion are most rapid in tropical climates. Because of the rocks and climate found here, both of these processes are very active in the CNMI.

The kind of weathering that happens depends on the affected rock. Volcanic rock usually weathers by being broken into smaller particles. Weathering by stream flows is an active process here. Water will move other rocks in a stream which hit the volcanic rock and thus break it.

During this breaking of rock *by a stream*, both weathering and erosion happen at the same time. Sometimes water will get inside the rock and dissolve some of the minerals. With these minerals gone, the rock will just crumble.

Volcanic rock also weathers when the outside of the rock just flakes off. This flaking of rock pieces happens from heat or from pressure inside the rock. Another way in which both volcanic and sedimentary rocks can weather is by the actions of plants and animals. Roots of plants get into cracks in the rock and, during growth, break the rock.

Animals cause weathering by digging in the soil and bringing broken rock to the surface where it can weather faster. Because of rain and our warm climate, most volcanic rock weathers easily here.

Within the sea, the parrot fish causes weathering of limestone by eating coral and breaking it down into sand. Rock-boring sea urchins and other marine animals carve holes into reef rocks. This is discussed more in chapter 13.

5. 13. CHEMICAL WEATHERING AND KARST TOPOGRAPHICAL FEATURES

Water is the main agent in the weathering of limestone. Limestone weathers easily by the process of chemical weathering. Water will react with carbon dioxide to form a weak acid called **carbonic acid**.

This acid will dissolve the limestone. The type of landscape formed by this dissolved limestone is called a **karst landscape**. Major features of a karst landscape are caverns and caves, disappearing streams, and sink holes.

The name *karst* comes from the name of an area of Slovenia, in Europe, where this type of rock formation was first described. Some minor features seen on limestone islands in the Marianas include **pinnacles**, **surface pitting**, and **sponge karst**.

Rain, which dissolves pockets of rock on the surface, also forms pinnacles, finger-like formations rising up from the ground. Surface pitting is an extremely rough and sharp surface area that is found on limestone next to the ocean. It is very much like pinnacles, but rougher and smaller.

The feature called *sponge karst* is the formation of holes in and out of the rock so that it looks like a sponge. It is formed by a dissolving process caused by algae in coastal areas. [Ed. note: A friend once referred to these areas as where our 'moon rock' is. The name fits.]

5. 14. MOVEMENT OF WEATHERED ROCK

Two ways that weathered rock is moved in our Marianas are by mass-wasting and by the actions of water. **Mass-wasting** happens when land moves because of the pull of gravity. Therefore, mass-wasting needs sloping land, such as hills, mountains, or cliffs. Examples of mass-wasting are rockslides, rockfalls, slumping, and soil creep.

Mass-wasting needs sloping land such as hills, mountains, or cliffs.

Rockslides happen when rocks slide down a slope. Rock falls happen when rocks fall off a nearly vertical cliff. Slumping is the downward slipping of large bodies of rock and soil. It is more commonly called a **landslide**.

Soil creep is the slow motion of soil or rock down a slope. Water usually helps lubricate the soil in soil creep. The weight of the water, working with gravity, can cause mass-wasting, but water itself is also an agent of erosion.

Water moves rock, both on the surface and under the ground. Water can move rock particles and dissolved rock in streams. Also, when water runs over a sloping surface not protected by plants, sheet erosion can move soil and small rocks.

In sheet erosion, the surface layer of the ground flows in a broad flat surface, as water flows across glass. Water in the ocean can also move rocks and sand by current and wave action.

5. 15. UNRAVELING EARTH HISTORY

5. 15. 1. Introduction

At this point we will switch our discussion from physical geology to historical geology. Do you remember the difference? Go back and take a look if you need to.

Like so many pages in a book, the rocky layers of the earth's crust tell a fascinating story of natural forces that have been operating for a little under five billion years.

From igneous rocks we learn of great periods of volcanic activity—of lava floods, violent explosions, and showers of glowing cinders and ash. The metamorphic rocks reveal bits of information that aid in understanding the great crustal disturbances that have racked our planet since earth's time began.

They tell of a buckling crust, of minerals that were compressed and heated, and of new rock made from old. Yet for all the information that we glean from the igneous and metamorphic rocks, the geologist's most valuable clues to earth history are contained in sedimentary rocks.

In sedimentary rocks we find the tracks, bones, shells, pollen grains, and other fossils such as these Rhodoliths in Rota.

Sedimentary rocks, more than any others, reveal the remarkable series of events that have helped shape our modern landscape. From these rocks, we learn of the comings and goings of vast in-land seas, of flat lands and rolling rivers, of restless winds, and migrating sands.

To interpret earth history, geologists study rock formations, the structural relationships and arrangements of the formations, and the topography or general configuration of the land's surface. The record of ancient events is pieced together by studying the stony layers of the earth as one might study a giant history book.

Indeed, the sedimentary rocks are the rocky pages of earth history. In them, we find the tracks, bones, shells, pollen grains, and other fossils which reveal the intriguing story of life long ago.

5. 15. 2. Reading from the Bottom Up

The first chapter of earth history begins with the most ancient rocks known. Because they were formed early in geologic time, these rocks are normally found deeply buried beneath younger rocks which have been deposited on top of them. It is for this reason that earth history is read from the bottom up.

The earliest formed rock layers correspond to the opening pages in our earth history book. The later chapters are found in the upper, younger rocks, which are located nearer the surface.

Fossils are useful in deciphering and interpreting the geologic history of their respective regions.

Interpreting earth history is not as simple as one might think, however. In many areas the rock layers are not always in the same sequence in which they were originally deposited. Elsewhere, faults and their structural disturbances have caused some of the pages to become shuffled and out of place. Some are missing completely.

Then too, many rocks have been destroyed by erosion, or gradually altered by metamorphism. Their secrets are lost forever. These missing pages make the ancient story even more difficult to interpret, so geologists must uncover new clues that will permit them to *fill in the blanks*.

5. 16. FOSSILS; SILENT WITNESSES TO THE PAST

5. 16. 1. Introduction

Of all the features of sedimentary rocks, none is quite so informative as fossils. **Fossils** are the remains or evidence of prehistoric plants and animals that have been preserved in the earth's crust.

Through the science of **paleontology** (the study of fossils), life has been traced from its first clear, uninterrupted record, more than 800 million years ago, through its evolution into the more advanced forms of today.

These fossils range in size from the remains of tiny one-celled plants to great fossilized trees. They are useful in deciphering and interpreting the geologic history of their respective regions.

Curiously enough, one need not find the actual remains of an organism to have a fossil. Any trace or evidence of prehistoric life is also considered a fossil.

In many of the processes of fossilization, there is no direct evidence of the original organism. Instead, some trace or impression provides evidence of the plant or animal responsible for it.

5. 16. 2. The Present is the Key to the Past

The paleontologist can learn a great deal about ancient life forms by studying fossils. They usually furnish some clues as to where they lived, when they lived, and how they lived. They may even reveal evidence as to how they died.

In studying fossils and reconstructing the pages of history, the paleontologist relies on the **Principle of Uniformitarianism**. This is the concept that ancient organisms lived under conditions similar to those of their nearest living relatives.

More simply stated, it is believed that the *present is the key to the past*. For this reason, paleontological studies require the knowledge and techniques of both geology and biology. Here you will recall the early words of the young geologist, Charles Lyell.

Yes, the Principle of Uniformitarianism came to be understood mostly from the written works of Charles Lyell. In truth though, scientific credit for the concept is given to a scientist named James Hutton, who preceded Lyell.

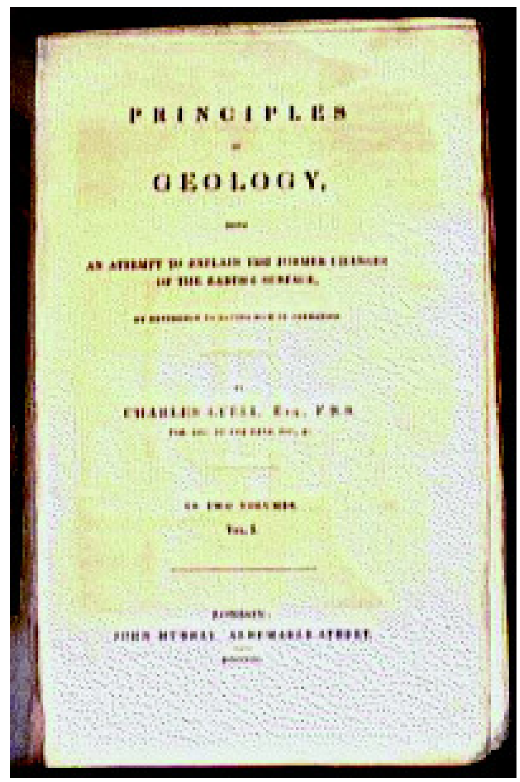
But Lyell did a far better job of explaining and providing examples of the principle in his comprehensive book, *The Principles of Geology: Being an Attempt to Explain the Former Changes of the Earth's Surface, by Reference to Causes now in Operation* (now more commonly called the *'Principles of Geology'*).

5. 16. 3. Ancient Habitats

Why is it helpful to know where an organism lived? We know, of course, that most varieties of plants dwell on the land. Therefore it is reasonably safe to assume the rocks that contain fossilized land plants were probably formed on land.

It is also known that certain species of plants and animals live only in seawater. Likewise, if we find the fossil remains of sea organisms embedded in a rock, this suggests that the rock was probably formed from sediments that were laid down on the floor of an ancient sea.

What is more important, certain species of marine fossils can even provide such detailed information as the approximate depth and temperature of the water that the original organism inhabited. These fossils may also indicate the direction that water currents were flowing, and whether the water was salty, fresh, clear, or muddy.



"Principles of Geology" by Charles Lyell.

5. 16. 4. Fossil Evidence for Organic Evolution Theory

Because they can be used to trace the development of plants and animals from the dawn of life to the present time, fossils also offer one the strongest lines of support for the **Theory of Organic Evolution** (see chapter 10).

This is possible because the fossils in the older rocks are usually primitive and simple. However, a study of the similar specimens that lived in later times reveals that organisms became progressively more complex and more advanced, as evidenced from fossils in the younger rocks. This theory, fundamental in the understanding of *island ecology*, will be discussed in more depth in later chapters.

5. 16. 5. Correlating Rock Layers and Revealing Unconformities

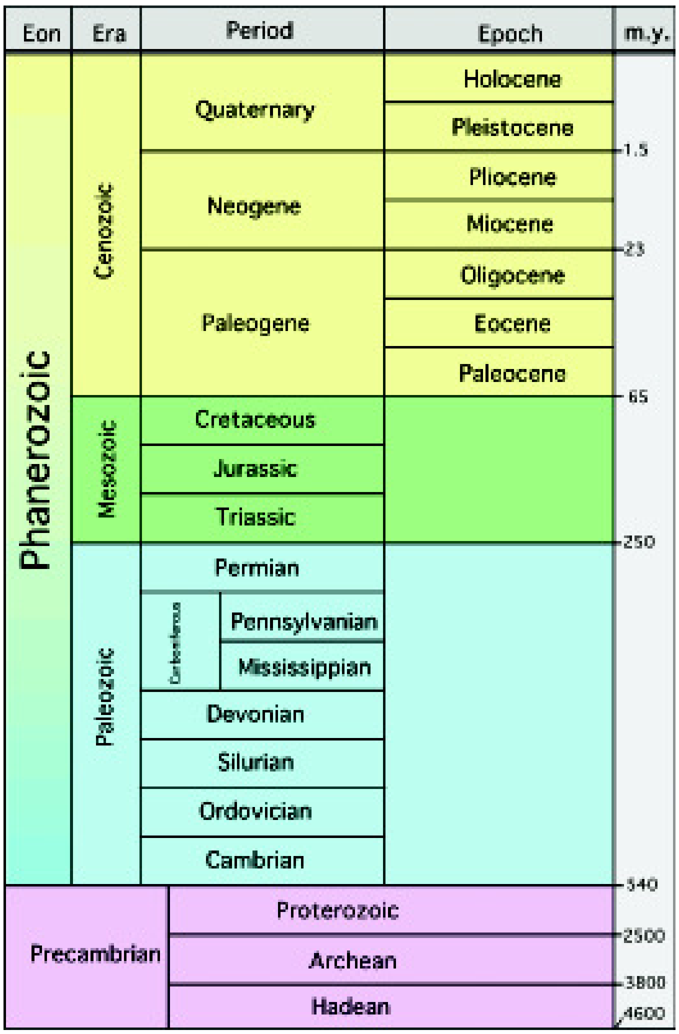
Fossils are useful in a number of ways and have provided the earth scientist with invaluable information about the earth and its history. One of the most important uses of fossils is for purposes of **correlation**. Correlation here refers to the comparison of ages of rock layers in widely separated areas.

Correlation by means of fossils is a good way to locate gaps or breaks in the fossil record. Scientists call these gaps, the missing pages in the fossil record, **unconformities**. They represent sediments that may have been removed by erosion before later sediments were deposited.

5. 17. THE GEOLOGIC TIME SCALE

5. 17. 1. Introduction

The earth historian, like the historian dealing with the development of human civilization, must have some method of relating important events to one another. For this purpose, the geologist has developed a special **geologic time scale**. This scale is composed of dated units of geologic time during which various rock groups were deposited.



The geologic time scale is composed of dated units of geologic time during which various rock groups were deposited.

The largest of these time units are called **eras**. Each era is divided into **periods**, which in turn may be subdivided into **epochs**. Arranged in **chronological order**, the units form a giant geologic calendar, which provides a standard by which the age of the rocks can be discussed. Thus rocks that formed during the Mesozoic era, extending from about 250 million years ago to about 65 million years ago, are said to be Mesozoic in age.

5. 17. 2. Relating Geologic Events to Time Periods

Unlike days and years, the units of the time scale are arbitrary and of unequal duration. This is because we cannot be certain as to the exact amount of time involved in each interval.

By referring to the geologic time scale it may be possible, for instance, to state that certain lavas were extruded during the Mesozoic Era. This reference would be like that of a historian who might speak of a certain fort as having been built during the Civil War or certain large stones carved during the ‘Latte Period’.

Each of these references, Mesozoic era and Civil War and Latte period, gives us a general idea as to the interval of time during which the lava was extruded, the fort constructed, or the stone carved.

5. 17. 3. The Law of Superposition

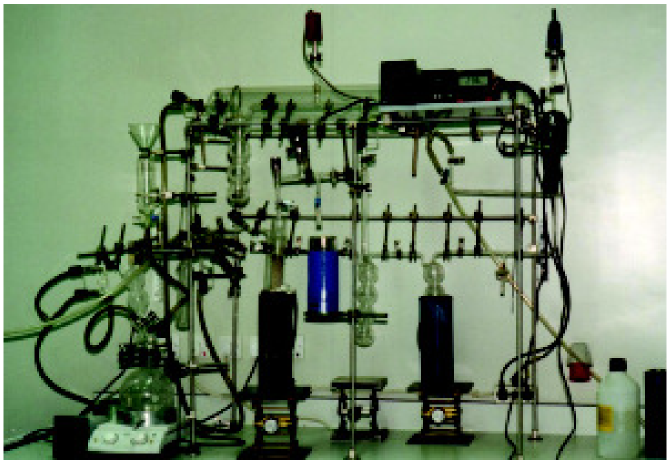
The geologic time scale was developed on the principle that, unless a series of sedimentary rocks has been overturned, a rock layer is older than the rock layers over it.

Likewise, a layer is younger than the strata beneath it. In short, this means that, in a normal sequence of rocks, the older rocks will always underlie younger rocks. This basic geologic idea is called the **Law of Superposition**. This is young Charles Lyell's second great hypothesis (again expounding from Hutton). Notice it is now referred to as a *Scientific Law*.

5. 17. 4. Relative and Precise Dating of Rocks

How do geologists determine the age of the rocks? They do this in the field by comparing the relative positions of the rocks and by studying any fossils that may be present in them. This may provide some indication of the relative age of the rocks. Relative age, however, does not imply age in years. Rather it fixes age in relation to other ages that are recorded in the rocks.

Within recent years, however, it has become possible to assign ages in years to certain rock units. This is accomplished by a system of very precise measurements of amounts of a **radioactive** mineral (such as Uranium-235 or Carbon-14). These minerals change or decay at such a uniform rate that they are almost natural radioactive "clocks".



Very precise measurements of amounts of a radioactive mineral such as Uranium-235 or Carbon-14 can be made in a lab such as this one.

This method of dating has made it possible to devise a measured time scale which gives some idea of the tremendous amount of time that has passed since the oldest known rocks were formed. Scientists have also used it to verify the relative ages of various rock units. This method will not work, of course, unless radioactive minerals are present in the rocks.

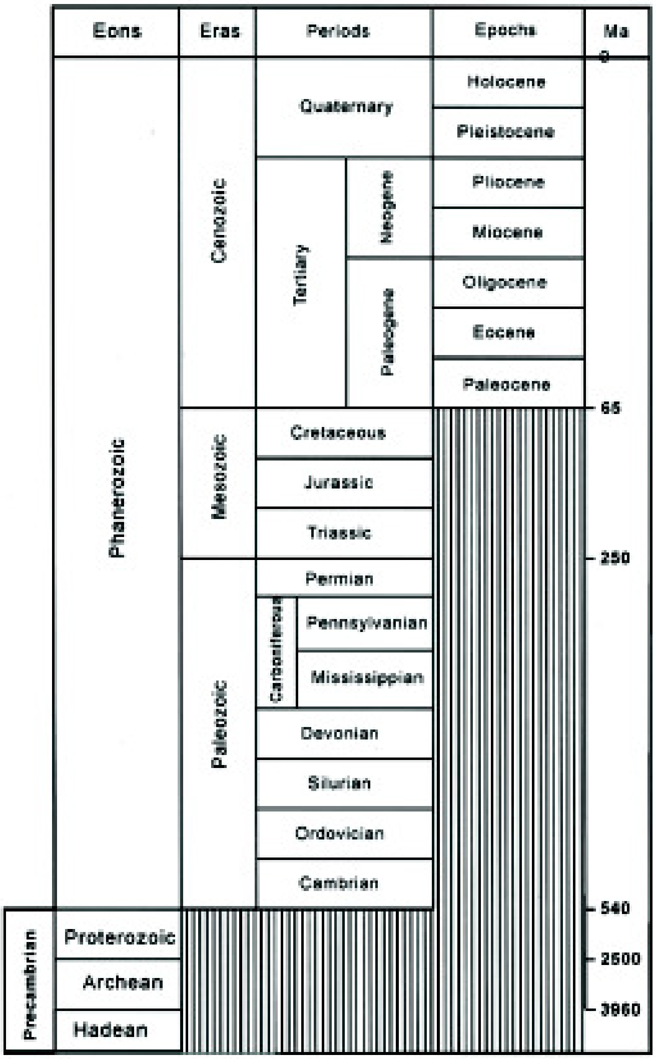
5. 17. 5. Time Period Names

As we look at the geologic time scale, one may wonder why some of the units have been given such odd and unusual names. Why have we not used simple English that would be easy to pronounce? In general, most of the names of the time units are derived from Greek and Latin words.

This has been done for two reasons: first, ancient Greek and Latin are both "dead" languages, and therefore not subject to change as a modern language would be; second, they are international languages and mean much the same thing to geologists all over the world.

Because geologic time terms are frequently used to describe certain features, a knowledge of their pronunciations and origins will be helpful. To pronounce a word, simply break it into syllables, for example 'Pa-le-o-zo-ic' (pay'-lee-uh-zo-ihk).

If we look up the origin of the word Paleozoic, we find that it derives from the Greek words *palaio*—"ancient"—and *zoe*—"life". This is a geologist's way of saying that the Paleozoic era was the time of ancient life. We express all of this in a single word that can be understood by scientists worldwide.



The geologic time scale is always read from the bottom of the scale upward.

5. 17. 6. Naming Geologic Eras

Below is a list of the five geologic eras, their pronunciations, and the meanings of their names:

Cenozoic [seen'-uh-zo-ihk] = recent life
Mesozoic [mess'-uh-zo-ihk] = middle life
Paleozoic [pay'-lee-uh-zo-ihk] = ancient life
Proterozoic [praht'-uh-ruh-zo-ihk] = fore-life
Archeozoic [ar'-kee-uh-zo-ihk] = beginning life

For convenience in reference, archeozoic and proterozoic rocks are commonly grouped together and referred to as Precambrian in age. Most Precambrian rocks have been greatly contorted and changed. The record of these eras of geologic time is difficult to interpret.

Precambrian time represents that segment of geologic time from the beginning of earth history until the deposition of the earliest fossil-bearing Cambrian strata. If the earth is as old as is currently thought, Precambrian time may represent as much as 85% of all earth history.

In looking at the geologic time scale, you will note that the oldest era is at the bottom of the list. Successively younger eras are above it. The geologic time scale is always read from the bottom of the scale upward. This is the order in which the various portions of geologic time occurred and during which the corresponding rocks formed.

5. 17. 7. Naming Paleozoic Periods

As noted, each era has been divided into smaller intervals of geologic time called **periods**. Most of the periods get their names from the places in which these rocks were first studied. Thus, the Devonian period is named for the shire (county) of Devon in England. The Pennsylvanian Period is named for rock exposures first studied in the US State of Pennsylvania.

The Paleozoic era encompasses about 270 million years. It is divided into seven periods of geologic time, each with its corresponding system of rocks. With the oldest at the bottom, these periods, the origin of their names, and a guide to their pronunciations are listed below;

Permian [pur'-mee-uhn]—for the province of Perm in the Ural Mountains of Russia.
Pennsylvanian [penn-sill-vay'-nee-uhn]—for the state of Pennsylvania.
Mississippian [miss-is-sip'-ee-uhn]—for the Upper Mississippi Valley.
Devonian [dee-vo-nee-uhn]—for Devonshire, England.
Silurian [sy-lur'-ee-uhn]—for the Silures, an ancient tribe of Southern Wales.
Ordovician [ord-ah-vish'-uhn]—for an ancient Celtic tribe that lived in Northern Wales.
Cambrian [kam'-bree-uhn]—for the Latin word "cambria," meaning Wales.

5. 17. 8. Naming Mesozoic Periods
The Mesozoic era lasted for approximately 170 million years. It is divided into three geologic periods:

Cretaceous (kree-tay'-shuhs), from the Latin word *creta*, meaning chalk. This refers to chalky limestones such as those exposed in the white cliffs of Dover, on the English Channel.

Jurassic (juh-rass'-ihk), for the Jura Mountains, between France and Switzerland.

Triassic (try-ass'-ik), from the Latin word *trias*, meaning triad or threefold. This refers to the natural threefold division of these rocks in Germany.


On islands, freshwater is retrieved by drilling wells and pumping the water upwards or by tapping sideways into flowing springs.

5. 17. 9. Naming Cenozoic Era Periods
The Cenozoic era began about 65 million years ago and continues through the present day. The two periods of this era have derived their names from an old outdated system of classification that divided all of the earth's rocks into four groups. The two divisions (periods) are the only names from that system that are in use today:

Quaternary (kwaht'-ur-nehr-ee), implying fourth derivation.
Tertiary (tur'-shee-ehr-ee), implying third derivation.

The Cenozoic is also divided into seven epochs. Two are in the Quaternary period and five are in the Tertiary period. The oldest rocks in the Marianas date back to the Eocene epoch in the Tertiary period or about 45 million years ago.

While the units discussed above are the major divisions of geologic time, during which large units of rock layers formed, geologists usually work with smaller units of rocks, called **formations**.

A geologic formation is identified and established on the basis of definite physical and chemical characteristics of the rocks.

Formations are usually given geographic names that are combined with the type of rock that makes up the bulk of the formation. For example, Tapotchau Limestone is a predominately limestone formation named for the highest peak of Saipan, Mt. Tapotchau.

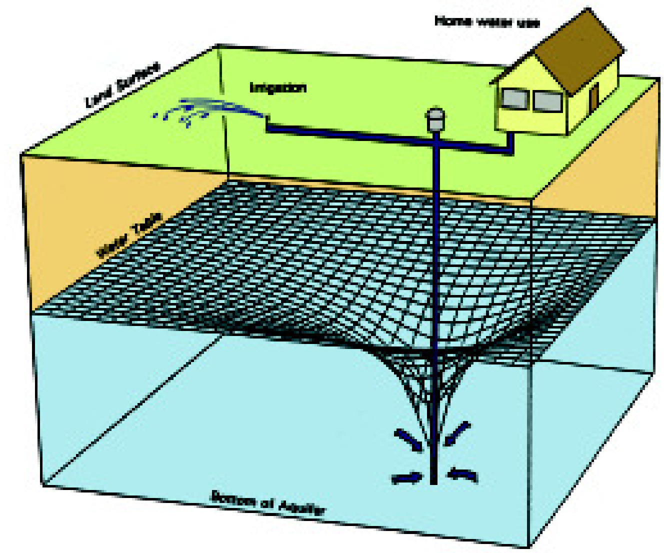

There is some sandstone at the peninsula near "Forbidden Island" on Saipan.

5. 18. GROUNDWATER AND CAVE FORMATIONS

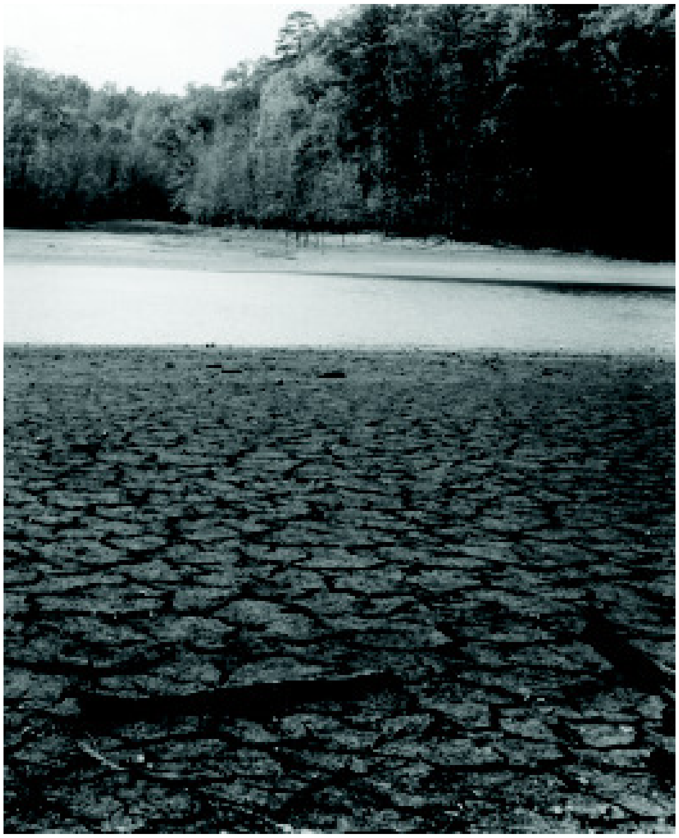
5. 18. 1. Introduction
We switch our focus from the surface of our islands to the processes occurring beneath their surfaces. Most important of these are the accumulation and effects of groundwater. Groundwater has been important in shaping the geology of our islands. Much of the rain that falls on our islands flows back to the ocean. Much of it also soaks into the soil. Groundwater is an important source of freshwater.

After water soaks into the soil, plants take it up, or it keeps moving downward through the sand and gravel below the soil. Eventually, this downward-moving water will fill the spaces within the rocks beneath the surface and become groundwater.

On islands, freshwater is mainly stored in the form of groundwater. It is retrieved by drilling wells and pumping the water upwards or by tapping sideways into flowing springs.



Permeable rock layers generally contain large reservoirs of water called aquifers.



Long periods of drought (little rainfall) or heavy use of groundwater can lower the water table.

5. 18. 2. Permeability of Rocks and Aquifers

Groundwater can only enter into and move through rock layers which have spaces in them; rocks with such spaces are said to be **permeable**. Two good examples of permeable rocks are sandstone and limestone. As discussed, limestone is very common in the CNMI's southernmost islands. In some places, such as at the peninsula near "Forbidden Island" on Saipan, there is also some sandstone.

Permeable rock layers generally contain large reservoirs of water called **aquifers**. Gravels and sands can be good aquifers because they have continuous openings throughout them. Openings in limestone, along cracks or between layers, may also be large and contain a good supply of freshwater.

5. 18. 3. Zone of Saturation and the Water Table

Eventually, the downward movement of groundwater stops. This can happen when water reaches a rock layer that is **impermeable** (has no spaces for water to fill). However, water movement may continue in other directions.

After traversing down into an aquifer, groundwater may move through the aquifer and across the surface of an impermeable rock layer. This water movement may proceed at a rate of only several centimeters a day. In a different aquifer, water may move at a rate of several meters a day.

Above the layer of impermeable rock, openings can become filled with groundwater. This area is called the **zone of saturation**. The upper surface of this zone is called the **water table**.

5. 18. 4. Changing Water Table Levels

The water table can rise and fall. Heavy rains or a heavy rainy season can raise the water table. Long periods of **drought** (little rainfall) or heavy use of groundwater can lower the water table. If the water table falls too low, wells may dry up and many trees may die because their roots can no longer reach water.

Because we are so close to the ocean, salt water can move through the ground and fill the areas where freshwater used to be.

How much water soaks into the ground depends on how permeable the ground is. Most volcanic rocks are impermeable. Thus, most rain runs off volcanic rocks into streams and rivers to oceans or lakes.

Limestone, on the other hand, is very permeable. Therefore, most of the rain that falls on limestone soaks into the ground to form groundwater. Groundwater is stored in two forms on islands. It can be either **basal groundwater**, or **high-level** (or '**perched**') **groundwater**.

5. 18. 5. The Ghyben-Herzberg Lens

Basal groundwater is found on almost all islands. It is stored in one or more lens-shaped aquifers called **Ghyben-Herzberg lenses**. Basal groundwater forms this lens of freshwater which floats on top of underground salt water. This is because freshwater is less dense than salt water.

During droughts, and when groundwater is over-pumped, the lens becomes thinner. Then, there is a chance of pumping salt water or **brackish water** (saltwater mixed with freshwater).

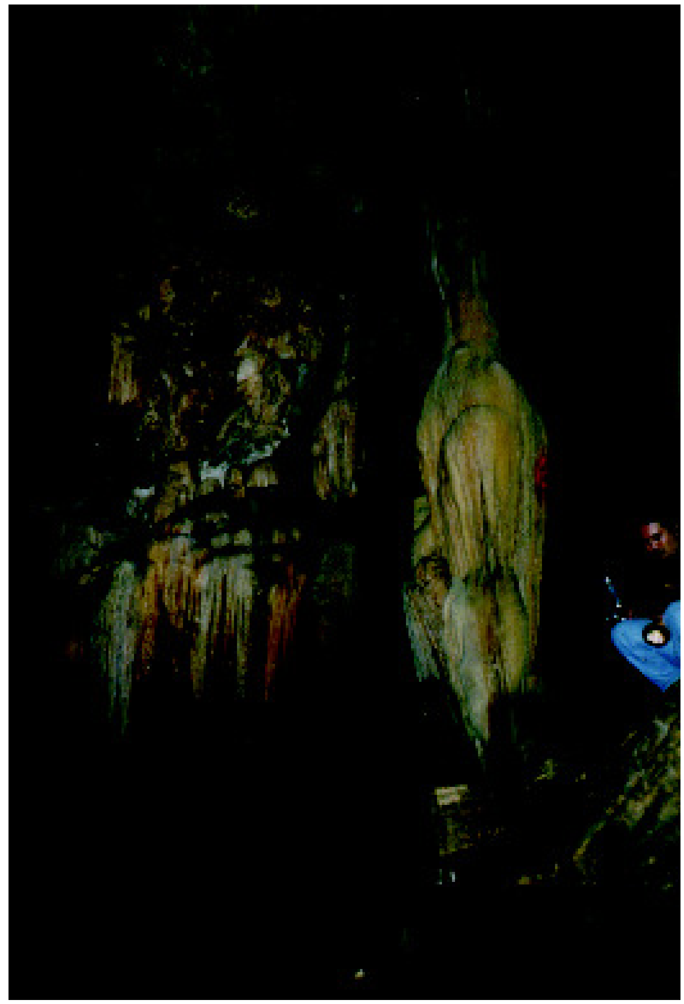
Basal groundwater usually contains more dissolved minerals than high level groundwater. Near the edges of an island, the freshwater in the basal groundwater sometimes flows out to the ocean from **seeps**.

5. 18. 6. Elevated Groundwater

High-level or 'perched' groundwater is found at a higher level on an island than basal groundwater. Often a permeable layer of rock will be found over a layer of impermeable rock. High-level groundwater is freshwater that has been trapped by a layer of impermeable rock.

The impermeable rock stops the downward motion of the water. This forms a raised or perched water aquifer. The groundwater in the aquifer often slowly overflows and moves downhill through the ground until it either seeps into the ocean, or comes out of the ground at a **spring**.

Donni Spring, near Capital Hill, Saipan, on the back side of Mount Tapotchau, is a place where high-level groundwater flows from the ground as a spring. Another good example of a spring is the water cave on the Island of Luta. These waters have not touched saltwater, nor have they formed a lens. High level groundwater is considered high quality freshwater. It has much lower levels of dissolved minerals than basal groundwater.



Over hundreds and hundreds of years, the process of rock molecules dissolving and being carried away results in the formation of our caves and caverns.

5. 18. 7. Oxidation and Chemical Changes to Rock

Above the zone of saturation, rock openings fill with air between rainstorms. In this zone, water and oxygen react with elements in the rock to form clays and oxidized carbonates.

The process of oxygen reacting with other elements is called **oxidation**, and this area is called the **zone of oxidation**. We are all very familiar with one form of oxidation—**rust**!!

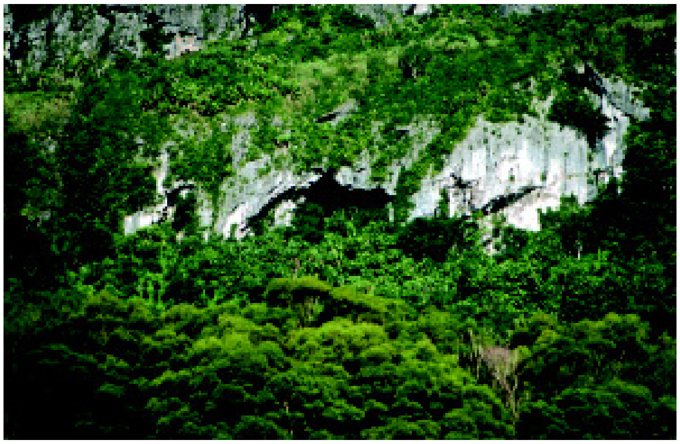
5. 18. 8. Acidic Groundwater Erosion

Rainwater is considered a weak acid that will dissolve calcium carbonate (limestone) over a long period of time. **Carbonic acid** is a combination of **carbon** and rainwater and is a slightly stronger acidic liquid.

As carbonic acid seeps downward into the limestone, the rock is slowly dissolved. The water becomes full of dissolved carbonates, and is then said to be "*hard*". These former rock molecules are carried away with retreating groundwaters.

Over hundreds and hundreds of years, this dissolving process can result in large openings beneath the surface of the earth. This is how our **caves** and **caverns** (very, very large caves) are formed. Large caves and caverns are often joined by narrow passages through which a stream of underground water flows.

Groundwater is capable of significant underground weathering of rock. It is the main force in the erosion of limestone. This is because it is easy for water to flow through the porous stone. As an erosive force, groundwater mainly moves rock by dissolving it.



Cave-formed rock develops only after the cave-forming groundwater recedes for some reason.

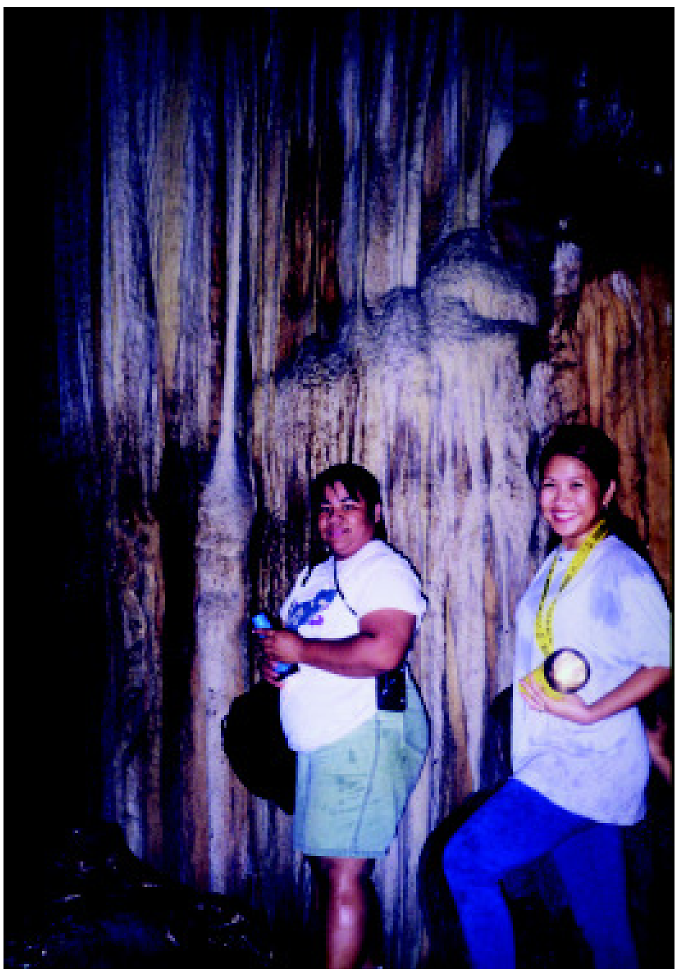
If dissolved rock minerals reach the ocean, marine animals can use it to make their shells. Then, it might later be redeposited as limestone within a coral reef, once again. It also may just precipitate out of the water, to form an inorganic limestone deposit.

5. 18. 9. Cave-formed Rock

Introduction

Cave-formed rock develops only after the cave-forming groundwater recedes for some reason. This usually occurs from some geologic action such as faulting and uplifting. After caves are drained of water and become filled with air, the slow process of **deposition** begins. During this phase of a cave's development, secondary lime deposits called *flowstone* and *dripstone* can form.

The material of most of these secondary limestone deposits is called **travertine**. In addition to being deposited within a cave, travertine can also deposited on the surface by hot and cold springs. If the redeposited calcium carbonate forms as a pure crystal, it is called **calcite**.



All cave rock formations are called speleothems, meaning a thing laid down in a cave.

Dripstone

All cave rock formations are called **speleothems**, meaning *a thing laid down in a cave*. Those formed from minerals redeposited by dripping groundwater are called **dripstone**. Deposits of this type include *stalactites*, *stalagmites*, *columns*, and *curtains*.

Dripstone gets deposited when surface water seeps downward through cracks in overlying rocks and eventually emerges on the ceiling of a cave. As the water moves downwards through the rocks, it can dissolve calcium carbonate from the limestone through which it passes. Drops of this now mineral-laden water can often suspend for some time on the ceiling. When they finally fall to the floor or evaporate into the cave's air, they can leave behind a thin layer of calcium carbonate.

Stalactites and Curtains

Over a long period of time, successive accumulations of these tiny, limey remnants form hollow tubes, which are suspended from the cave ceiling. These pendant-like deposits, called **stalactites** (from the Greek word meaning "oozing out in drops") literally cover the ceilings in many caves.

The simplest form of stalactite is called a *soda straw*. These long, straight, hollow pendants are quite fragile and represent an early developmental stage in stalactite formation. The water dripping from it flows through the interior canal and drops from its end. Eventually, however, it may become choked with calcium carbonate. The water then trickles down the outside. External deposition of *travertine* then causes an increase in the length and width of the stalactite.

Sometimes a row of stalactites grows downward from a crack in the limestone ceiling of a cave. These may join together and produce blade-shaped **curtains** that hang from the ceiling.

Coloring and Concentric Banding

If the seepage water contains impurities, such as iron, it will produce a yellow, red, or brown stain in the rock. The color is determined by the percentages of mineral impurities in the water.

When seen in cross section, dripstone deposits show distinct concentric layers, which resemble growth rings of trees. Normally of varying widths and colors, these layers mark interruptions in the growth of the speleothem. These may be due to changes in mineral composition or periods of deposition. Should the water stop dripping for some reason, the surface of the formation may dry out and become discolored. When deposition is resumed, a layer of clear calcium carbonate is then deposited over it.

Stalagmites and Columns

At times water drips from the ceiling at a more rapid rate, such that most of the carbonate solution falls quickly to the floor. Travertine deposited by this water forms a rising-from-floor deposit called a **stalagmite** (from the Greek word meaning a "dripping"). Stalagmites form broad-based, blunt inverted cones. Most will have a stalactite *feeding* it from above.

When a downward-growing stalactite meets an upward growing stalagmite a **column** is formed.

Flowstone Deposits

Deposits of travertine that form when mineral-laden water flows over the walls or floor of a cave are called **flowstone**. Flowstone deposits grow over a long period of time as successive layers of travertine are deposited one upon the other. As a result these deposits can grow to be quite thick. Like dripstone, flowstone will commonly display a banded effect resulting from intermittent periods of growth.

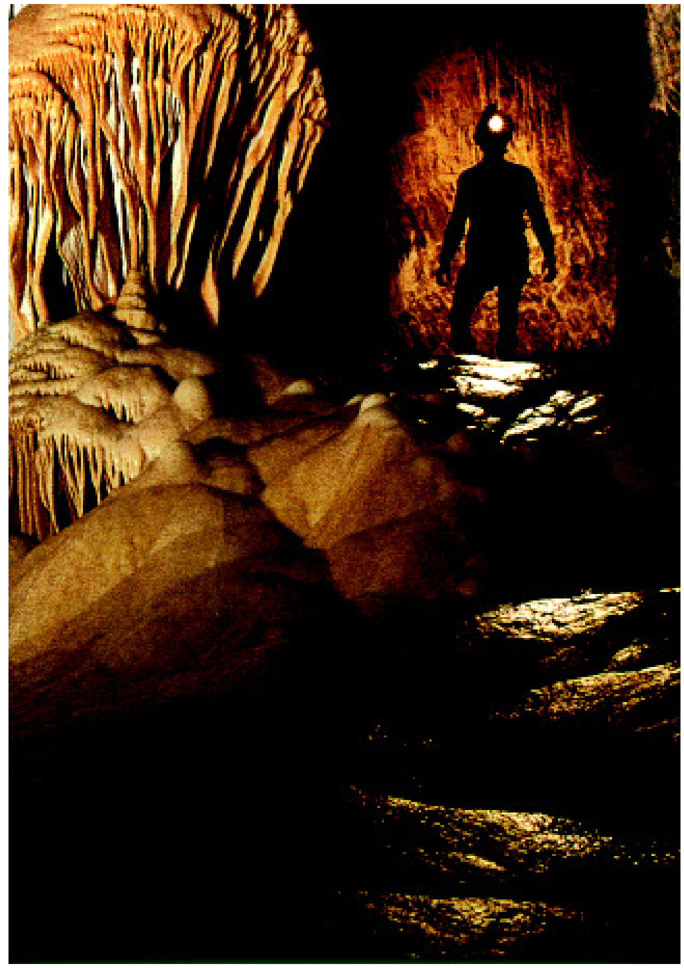
"Dead" Speleothems and "Live" Speleothems

A number of cave formations often appear to be dried and discolored. Some are almost dusty. These are said to be "*dead*" formations and are found in the drier parts of a cave, where deposition by groundwater is no longer active.

Other speleothems literally shine as they reflect light from their wet glistening surfaces; these are referred to as "*live*" formations. Such speleothems are actively growing and are mostly found in the wetter sections of caves.

Age of Speleothems

People often wonder about the growth rate of individual speleothems. How old are they? Unfortunately, there are so many variables involved that intelligent estimates are just not possible. One thing is certain, however. Cave deposits form very slowly and some are many thousands of years old. Because of their slow rate of deposition and their great fragility, visitors to each of our local caves are strongly discouraged from marring their natural beauty by handling or breaking them. Ed. note: Historic objects, such as bottles and tools, which are found in local caves, should always be left in place.



Deposits of travertine that form when mineral-laden water flows over the walls or floor of a cave are called flowstone.

N.° 24

Iles Mariannes 1819.

Costume des femmes de Guham allant à l'église.