THE

GEOLOGY

OF THE

TWO LIGHTS AND CRESCENT BEACH STATE PARKS AREA, CAPE ELIZABETH, MAINE

by

ARTHUR M. HUSSEY II

Maine Geological Survey

DEPARTMENT
OF
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ARTHUR M. HUSSEY II
Bowdoin College

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Walter A. Anderson, State Geologist

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CONTENTS

ILLUSTRATIONS

PREFACE

Two Lights and Crescent Beach State Parks are located within a mile (2 km) of each other in the township of Cape Elizabeth in Cumberland County, Maine (Figure 1). The parks are easily accessible by automobile from State Highway 77. Two Lights State Park encompasses 41 acres of rocky headlands and associated uplands. The park's name is derived from the two lighthouses located nearby. Crescent Beach State Park consists of 255 acres which include a small pond, some forested land and a mile of sandy beach. The parks offer opportunities for picnicking, swimming, and enjoying the ocean view.

The purpose of this booklet is to give the visitor some idea of the geologic history of the area. Special emphasis has been placed on the geologic ideas and theories that help to explain the origin of the rocks and sediments seen in the parks. The report is written in a semi-popular style and is intended to be of use to anyone who desires to increase their knowledge of the geology of southwestern Maine.

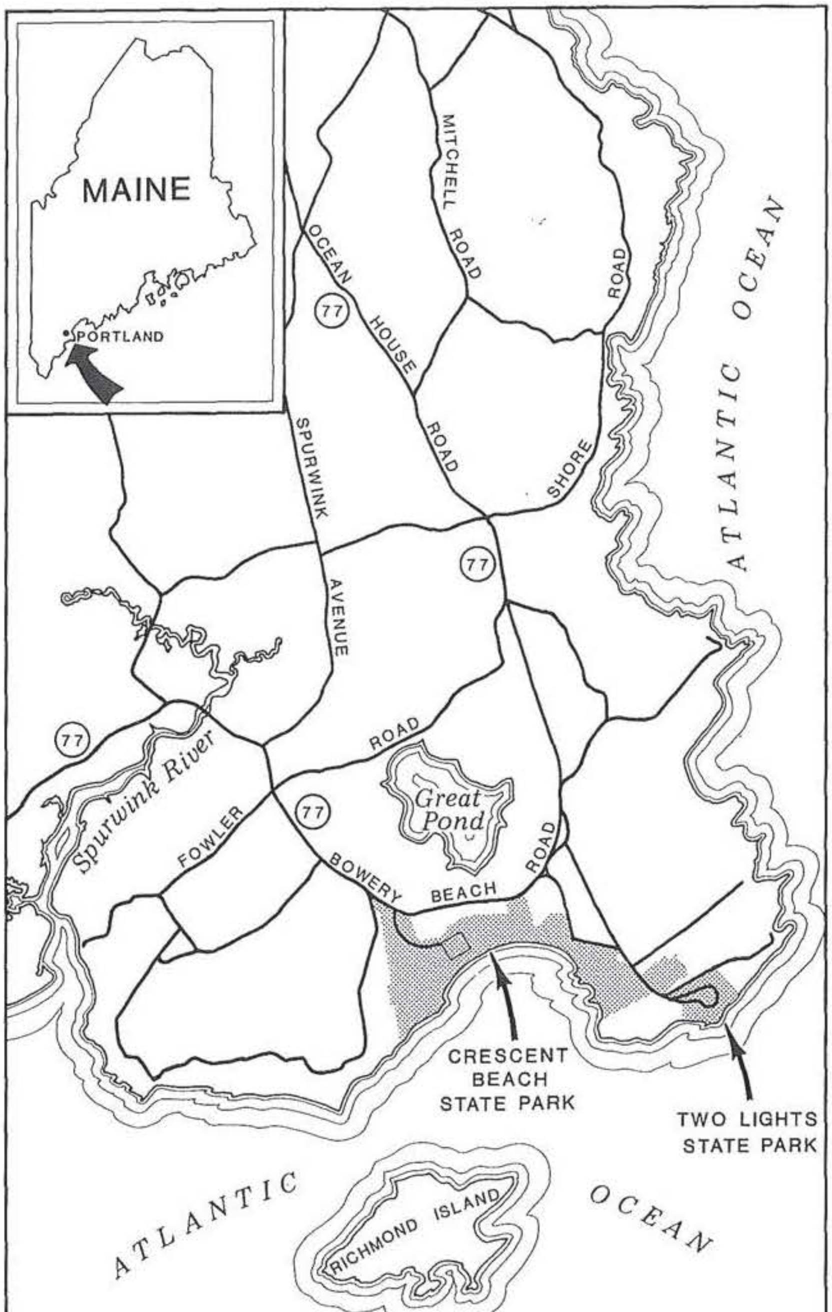

Figure 1. Geographic location of Two Lights and Crescent Beach State Parks.

ACKNOWLEDGEMENTS

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INTRODUCTION

Rugged cliffs and ledges at Two Lights State Park contrast sharply with the low, gracefully sweeping sand beach at nearby Crescent Beach State Park. During coastal storms when ocean waves make their assault on the shoreline, towering breakers crash with unbelievable power onto the ledges at Two Lights, sending billows of spray high into the air. At Crescent Beach, the large wind-driven waves roll toward the beach and break into thundering walls of water, expending their final energy as turbulent foam, washing up the beach face to return seaward before the next swash sweeps by. The tremendous energy of storm waves clearly demonstrates the dynamic processes at work today shaping the coastal zone. At Two Lights, wave erosion is slowly but relentlessly wearing back the land, grinding rocky ledges into pebbles and sand. In contrast, the waves and longshore currents at Crescent Beach deposit sand to form and mold the beauty of the beach.

But this is not where the geologic story of this area begins. To understand that story, the geologist ponders such questions as how the rock ledges were formed from sediments; how they were recrystallized by heat and pressure; how dynamic forces caused them to become tilted, folded, and broken; how these deformed and recrystallized rocks were gradually brought to the earth's surface; how large ice sheets affected the area during the last million years; and how ocean processes sculptured the final coastal landscape. We shall begin our exploration of geologic history with an examination of the area's rocks and the structures preserved in them.

Note: Italicized words are defined in the Glossary of Geologic terms.

THE ROCKS OF THE TWO LIGHTS – CRESCENT BEACH AREA

Figure 2 is a geologic map of the area around Two Lights and Crescent Beach State Parks. The map shows the distribution of the different types of *bedrock* that would be exposed if all the vegetation, soil, and unconsolidated surface sediments — clay, sand, and gravel — were removed. By studying the existing exposures of bedrock in the area, geologists have divided the rocks into distinctive units called "*formations*". Each formation includes similar types of rocks, and is given the name of an area where it is typically exposed, e.g., the Cape Elizabeth Formation, which is typically exposed in the Two Lights area of Cape Elizabeth.

The rocks of the Cape Elizabeth area are divided into seven formations, each with its own name as indicated in Table 1. These seven formations are collectively referred to as the Casco Bay Group. Only two formations of the Casco Bay Group, the Cape Elizabeth Formation and the Scarboro Formation, are exposed within the limits of the two state parks. The Cape Elizabeth Formation forms the bold cliffs at Two Lights State Park and the Scarboro Formation is exposed in Crescent Beach State Park at the western end of the beach and in small road cuts between the gatehouse and the parking area.

THE CAPE ELIZABETH FORMATION AT TWO LIGHTS STATE PARK

The Cape Elizabeth Formation forms the cliffs in the Two Lights area and is composed of tan *quartzite* and dark gray *phyllite.*

Phyllite is a rather soft *metamorphic rock* of such fineness of grain that the individual *mineral* particles can only be seen under a microscope. If you were to examine a thin slice of this rock with a microscope you would find that it is composed mostly of fine grains of white and dark colored *mica*, minerals that readily split into sheets. Partly due to the presence of large quantities of mica, phyllite splits easily in one direction, parallel to the mica flakes. We say it has "*cleavage*". In this respect, phyllite is somewhat like slate, except that its cleavage is wavy or crinkled rather than smooth like that of slate.

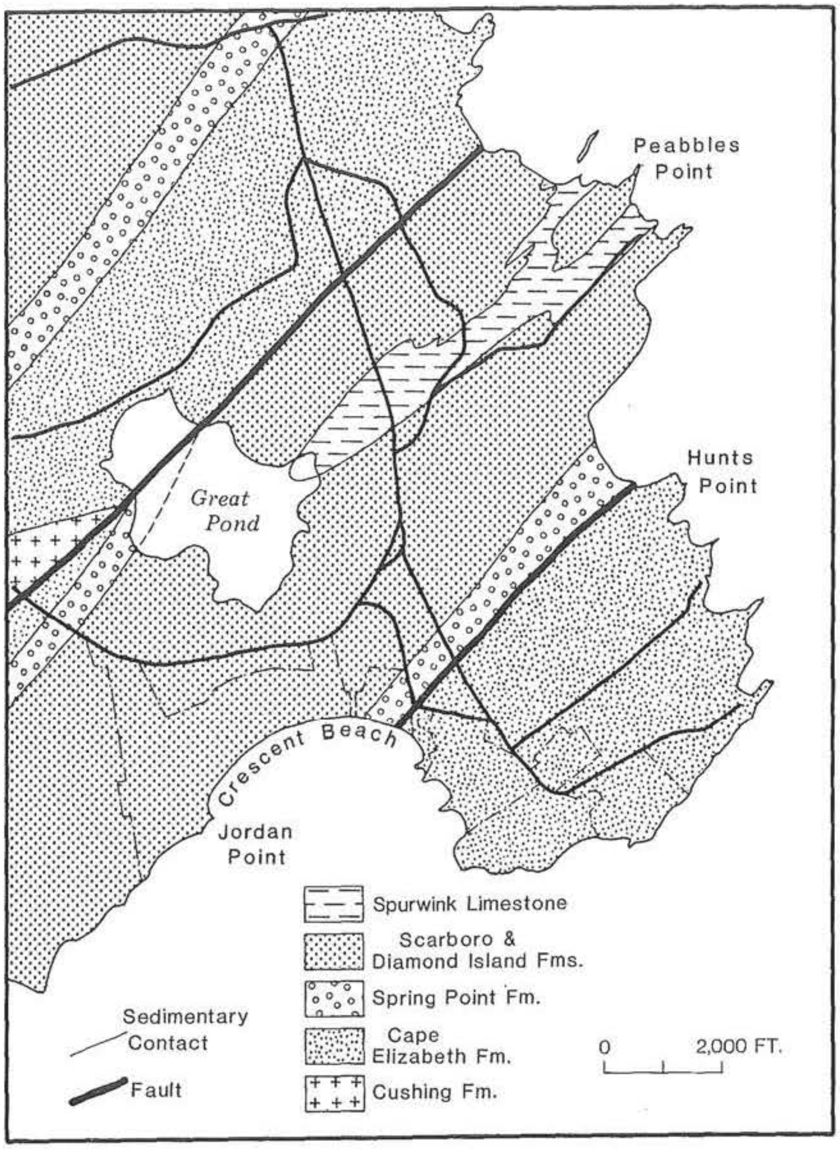


Figure 2. Bedrock geologic map of the Two Lights and Crescent Beach State Parks area.

TABLE I

FORMATIONS OF THE CASCO BAY GROUP

Formation	*Description*
Jewell Formation	Rusty and non-rusty *weathering* mica-rich *schist* and phyllite.
Spurwink Formation	Thinly bedded gray *metalimestone* and phyllite.
Scarboro Formation	Rusty and non-rusty weathering mica-rich schist and phyllite with minor thin-bedded *limestone*.
Diamond Island Formation	Coal-black rusty-weathering phyllite composed of *quartz*, white mica *(muscovite)*, *graphite*, and *pyrite*.
Spring Point Formation	Typically greenish gray *amphibolite-chlorite* schist; minor quartz-*feldspar*-mica *gneiss*.
Cape Elizabeth Formation	Thinly bedded light gray to slightly reddish brown weathering impure quartzite and dark gray phyllite.
Cushing Formation	Predominantly feldspar-quartz-*biotite* gneiss; minor amphibolite and rusty-weathering gneiss with abundant *garnet*.

Quartzite is a metamorphic rock composed almost entirely of the mineral quartz and is very hard and resistant. Quartzite of the Cape Elizabeth Formation, when examined with a microscope, has small amounts of mica, feldspar, and two carbonate minerals (calcite and ankerite); thus it is not a pure quartzite.

Originally these rocks accumulated as alternating layers *(beds)* of muddy sand and mud on the floor of an ancient ocean. The deposition of minerals between the sand grains to cement them together and the compaction of the mud by the weight of sediments that accumulated above them transformed these sediments into hard shaly *sandstone* and *shale*. When the *sedimentary rocks* were deeply depressed into the earth's crust by powerful compressional forces (which will be discussed fully a little later) they were recrystallized, or metamorposed, the shale becoming the dark phyllite, and the shaly sandstone becoming the tan quartzite.

One of the most conspicuous aspects of the Cape Elizabeth Formation is its striking resemblance to weather-beaten wood (Figure 3). Indeed, one of the most frequently asked questions is

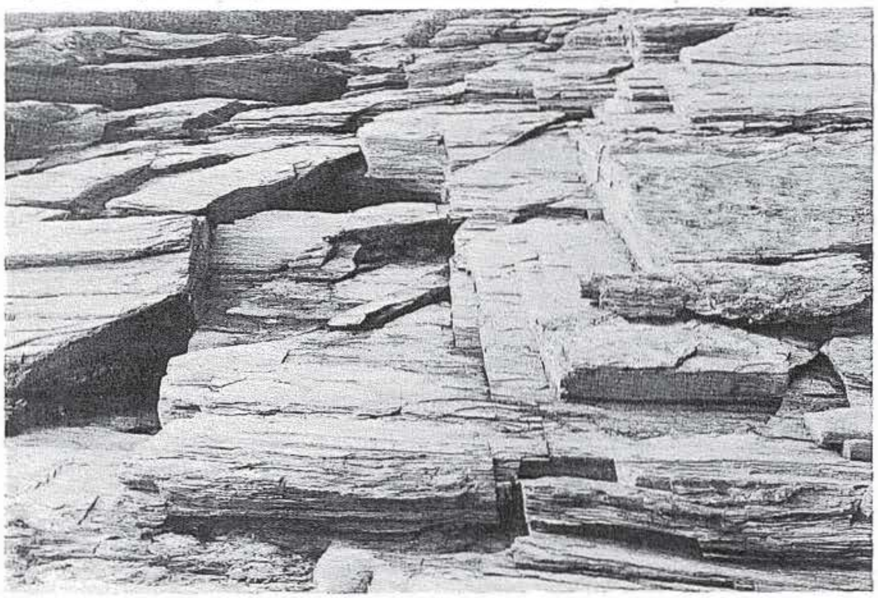


Figure 3. Quartzite of the Cape Elizabeth Formation, Two Lights State Park. Note the woody appearance. The rock is broken into blocks by two sets of nearly vertical planar joints. One joint set trends away from the viewer, the other trends diagonally from lower left to upper right.

how all the petrified wood was formed at the park. Actually, there is no petrified wood here, and the similarity is in superficial appearance only since all the materials of the Cape Elizabeth rocks are of inorganic sedimentary origin. The woody appearance is due to the presence of very closely-spaced microscopic fractures which cause the quartzite, in particular, to weather to a wood-grain appearance.

As you examine the Cape Elizabeth Formation you will become aware of the sedimentary layering or *bedding* of these metamorphic rocks. This bedding indicates that the rocks were originally sediments prior to compaction and metamorphism. You may occasionally observe beds like those to the right of the hammerhead in Figure 4. Notice that each smooth light-colored

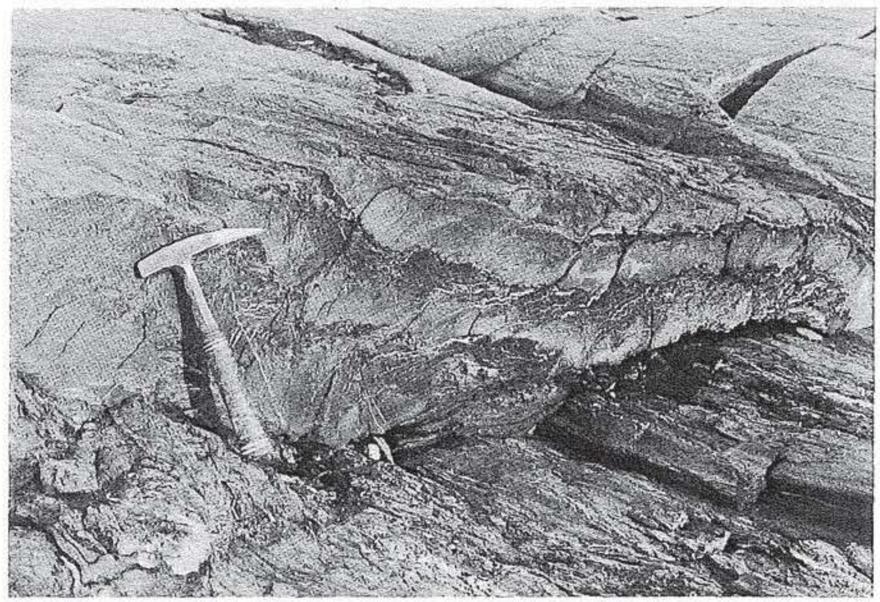


Figure 4. Graded beds of the Cape Elizabeth Formation, Two Lights State Park. Lighter quartzite layers grade upward into darker phyllite layers. Such beds are deposited in relatively deep water by turbidity currents.

quartzite layer grades progressively into the rough dark-colored phyllite layer above, followed at an abrupt boundary by the quartzite layer next above. We refer to this as *graded bedding*. At the time of deposition, the quartzite was the coarser-grained part, and the phyllite the finer-grained part of a graded bed. Graded

beds are useful in determining the sequence in which beds were deposited, especially in areas like Two Lights State Park where the rocks have been strongly deformed by folding. Of perhaps greater significance is the fact that these graded beds suggest that the Cape Elizabeth Formation accumulated in relatively deep water, possibly at the foot of an ancient oceanic *island arc* slope. The sediments were deposited by *turbidity currents* which required relatively steep submarine slopes down which to transport their sediment load. At the base of the slope, the turbid mass of sediment-laden water slowed, and as it did the coarser materials settled out first, followed by the finer materials, thus producing a graded bed such as seen in Figure 4.

In addition to the quartzite and phyllite that comprise the Cape Elizabeth Formation, two other rock types are present — vein quartz and *basalt.* When the rocks of the Cape Elizabeth Formation were deformed and metamorphosed, vein quartz was formed by the precipitation of quartz in fractures in the rock. Veins of this white milky quartz occur throughout the Cape Elizabeth Formation in a variety of shapes ranging from short, relatively straight veins to very thin crinkled veins and irregular pods. Basalt is an *igneous rock* formed from molten rock that we call *magma*. Near the northwest boundary of the State Park, basalt occurs in the form of a three-foot (one meter) thick tabular, sheet-like body called a *dike.* The rock itself is dark gray on newly broken fresh surfaces, but weathers to a slightly rusty color due to the presence of minute amounts of the iron sulfide mineral pyrite. The individual mineral grains that make up the basalt are generally too small to be identified without the aid of a microscope. This dike originated when molten rock from a great depth below the surface rose through and solidified in vertical tension cracks of the earth's crust. We will refer to this feature later when we discuss the geological history of the area, particularly as it relates to the formation of the Atlantic Ocean.

STRUCTURAL FEATURES OF THE CAPE ELIZABETH FORMATION

The rocks of the Cape Elizabeth Formation are broken into large rectangular blocks by fractures called *joints.* Joints are planar rock fractures along which no perceptible movement

has taken place. Joints do not form individually but occur in sets of parallel fractures; commonly two or more sets having different orientations are developed. In Figure 3, two sets of joints are visible; still other sets occur elsewhere in the formation. These joints may have been formed during the late stages of a period of uplift and erosion which brought the deeply-buried rocks of the Cape Elizabeth Formation to the surface and relieved the internal stresses in the rock.

Probably the most interesting and significant of the structures of the Cape Elizabeth Formation in the Two Lights State Park area are the folds into which the rock layers have been bent. When compressed, layered sequences of rock *strata* are bent into down-bowed folds called *synclines* or up-bowed folds called *anticlines* (Figure 5). In order to describe the shape and orientation of such

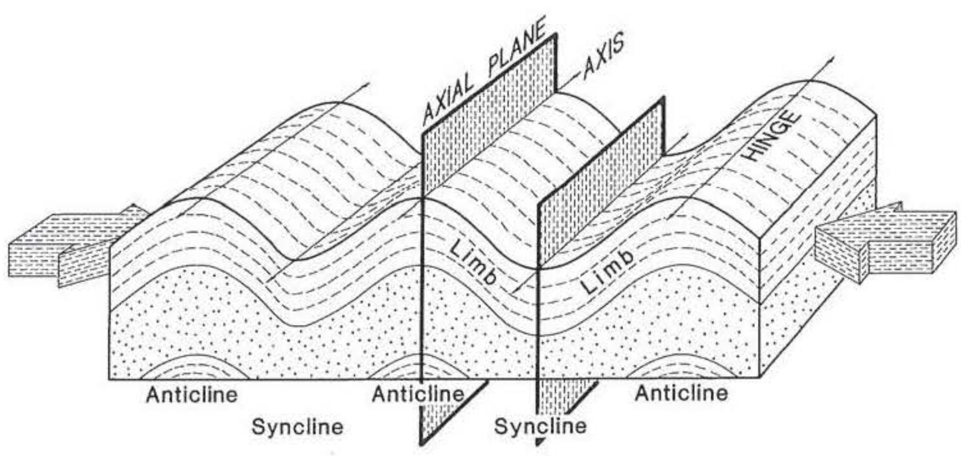


Figure 5. Anticlines and Synclines.

folds, geologists make use of two geometric reference features, the *axis*, and the *axial plane*. An axis is an imaginary line drawn along the points of greatest curvature of a folded rock layer, and an axial plane is an imaginary plane that passes through all the axes in a single fold (Figure 5). The folds shown in Figure 5 all have vertical axial planes, although it is possible for axial planes of other

folds to be inclined or horizontal. In a later section you will have a chance to see why these geometric considerations are so necessary and important when we compare two different sets of folds in the Cape Elizabeth Formation.

The inclined part of a fold between adjacent axial planes is the *limb* of a fold, and the region where the axes are is the *hinge* (Figure 5). Note that the limb of a syncline is also the limb of an adjacent anticline.

Let's take a look at some actual examples of folds that you are likely to see as you walk over the ledges at Two Lights State Park. Figure 6 shows beds of the Cape Elizabeth Formation bent into a gentle syncline. We say "gentle" because the inclination of the limbs toward the axis is very slight. The axial plane of this

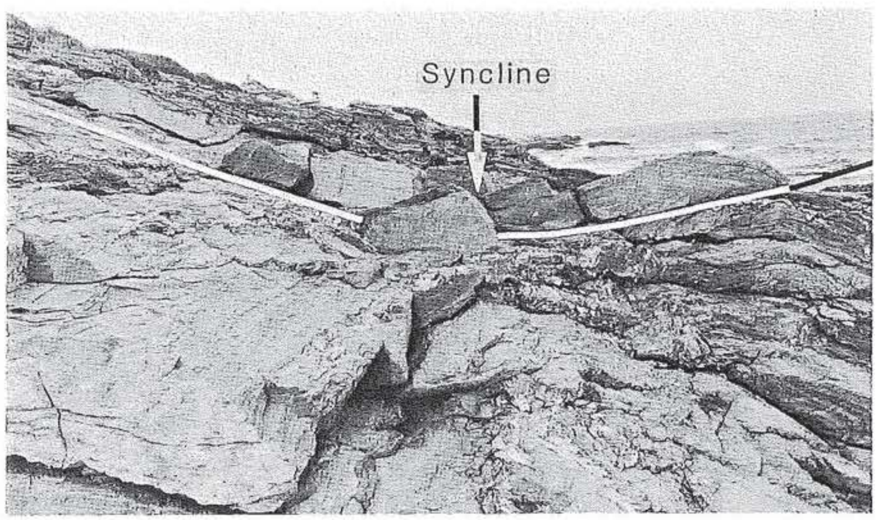


Figure 6. Gently folded upright syncline, Cape Elizabeth Formation, Two Lights State Park.

syncline is nearly vertical. Figure 7 shows several small anticlines and synclines with vertical axial planes. A close look at the area within the box in Figure 7 (Figure 8a) reveals the complexity of folding that has affected the Cape Elizabeth Formation. Figure 8b is an interpretative sketch of the two different sets of folds that are present. To the left of center in this closeup one can see some small-scale folds whose axial planes are essentially horizontal; these folds lie on their sides, and we say they are *recumbent.* Note in Figure 8a the closely-spaced fractures that are roughly horizontal and parallel to the axial planes of the recumbent folds. These fractures form what we call an *axial plane cleavage.* They were formed at the same time and by the same forces as the recumbent folds. Another very important relationship shown in Figure 8a is the warping of the axial plane cleavage; it is deformed very gently by the same set of folds with the vertical axial planes that we noted in Figures 6 and 7. It is evident that the rocks of the Cape Elizabeth Formation have been subjected to at least

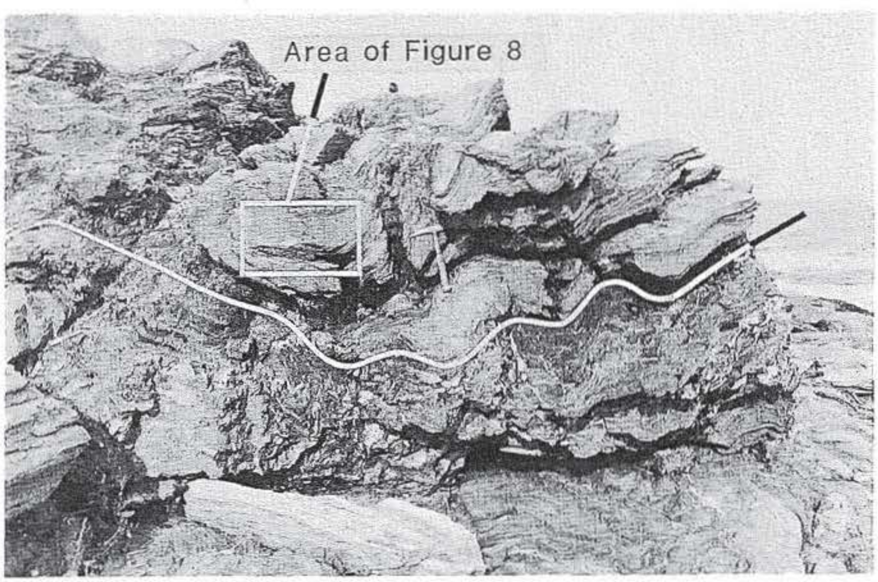


Figure 7. Small upright anticlines and synclines of the Cape Elizabeth Formation, Two Lights State Park. Lighter layers are micaceous quartzite. Darker layers are phyllite.

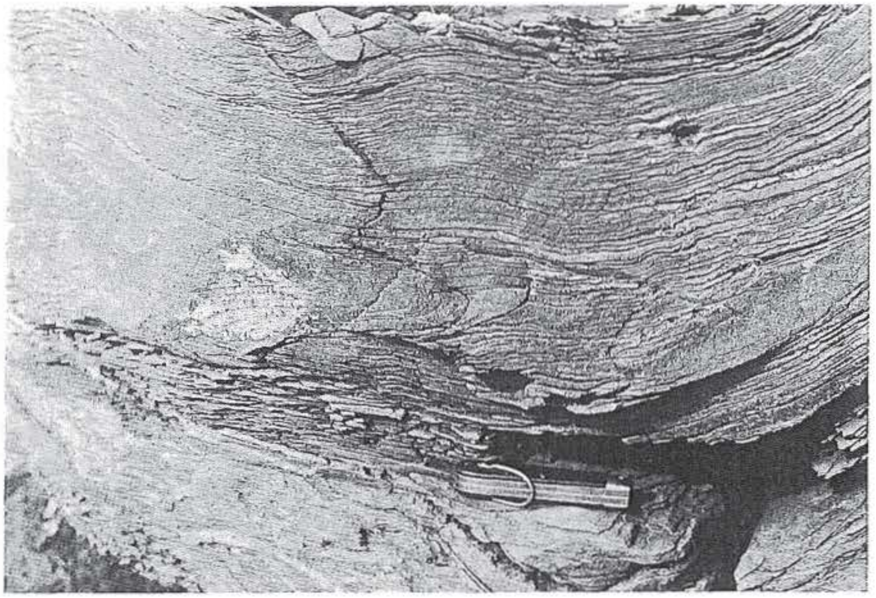
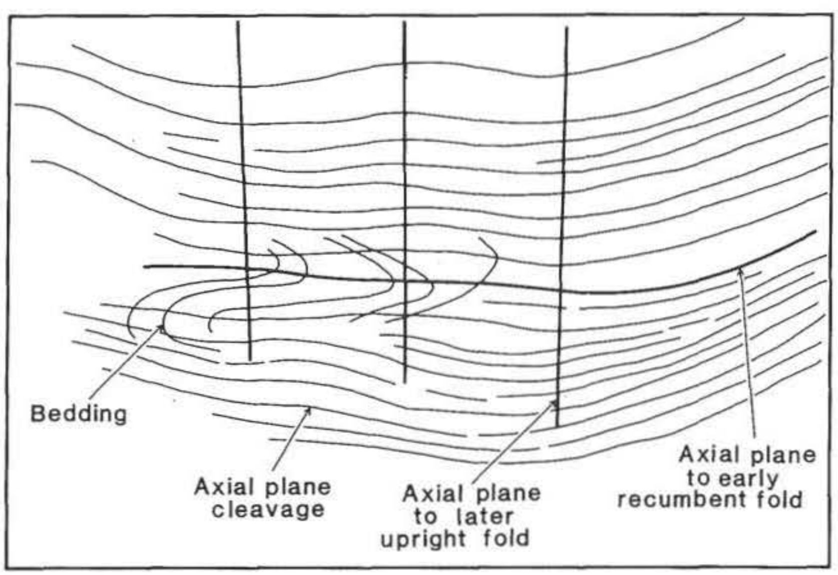


Figure 8. Multiple folding of the Cape Elizabeth Formation, Two Lights State Park. a) Earlier recumbent folds with closely-spaced fractures (axial plane cleavage) parallel to the axial planes of the recumbent folds. This axial plane cleavage is gently flexed by the later upright folds. b) Interpretative sketch of features shown in the photograph.



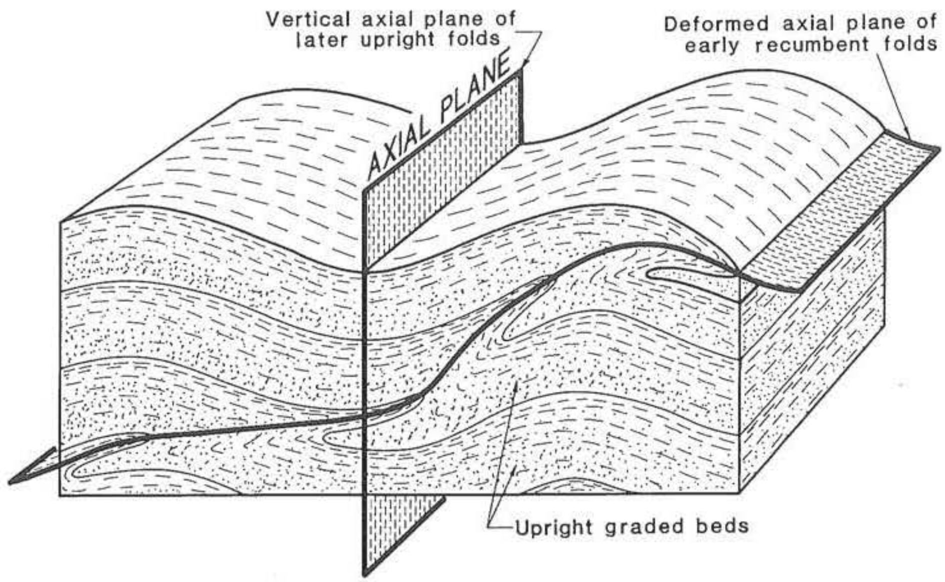


Figure 9. Schematic diagram of early recumbent folds refolded by later upright folds.

two episodes of folding. Figure 9 will, perhaps, help you visualize and understand the relations of these folds to each other — tight recumbent folds formed during an early period of compression, gently deformed by open, upright folds of a later compressional episode.

You can now see that the rocks of the Cape Elizabeth Formation preserve within them quite a bit of history: deep-water sedimentation by turbidity currents at the foot of an ancient island arc slope; burial to great depths in the Earth's crust where metamorphism took place; and multiple episodes of compressional deformation during each of which folding occurred. During a long period of uplift and erosion, these rocks were brought from the depths of the Earth's crust to the surface where they originated, but with a totally changed appearance.

THE SCARBORO FORMATION AT CRESCENT BEACH STATE PARK

The ledges located at the southwest end of Crescent Beach expose three different rock types that make up part of the Scarboro Formation. As you walk southward and come to Jordan Point at the end of the sandy beach, the first rocks you encounter are gray and slightly greenish phyllite. Tiny red garnet crystals can be seen in some beds. Upon rounding the point where the 10-foot (3 meter) high seacliff begins, you walk across about 30 feet (9 meters) of medium gray limestone intermixed with thin beds of dark gray phyllite. The remainder of the ledge to the south consists of rusty-stained and contorted phyllite and gray quartzite beds up to two feet thick. The rust staining is the result of the weathering and decomposition of a small amount of pyrite. Before being metamorphosed, the rocks of the Scarboro Formation were marine shales with a thin unit of limestone. As you walk along these ledges, be on the lookout for folds, joints, and quartz veins like those described for the Cape Elizabeth Formation. Note that the beds of the Scarboro Formation are more steeply inclined than those of the Cape Elizabeth Formation at Two Lights.

FAULTS

Two *faults* have been mapped in the general vicinity of the two state parks (Figure 2). A fault is a surface along which rocks have been broken and then have moved past one another. When fracture and movement occur, earthquake tremors are usually generated.

One fault, extending from west of Peabbles Point southwesterly to Ram Island Farm in the far western part of Cape Elizabeth (just to the west of the edge of Figure 2), is recognized on the basis of the abrupt termination of the Cushing and Spring Point Formations as shown on Figure 2. In addition, a zone of massive white quartz (which geologists refer to as a "*silicified zone*") has been formed along the fault and can be seen on the road leading to Ram Island Farm. This vein quartz, in places up to 20 feet (7 meters) wide, can be followed for approximately a mile and a half (2km) along the fault. The other fault is covered by surficial materials and its location is inferred from evidence visible in the surrounding rock *outcrops*.

GEOLOGIC HISTORY PRIOR TO GLACIATION

Now that we have examined the rocks and their structures, let's turn our attention to the history of the geologic events that have affected this area. When were the oldest rocks formed? The youngest? How did the area change over the long span of geologic time? Were there seaways where we now have land? Were there ever volcanoes in the area? Was the region ever mountainous, and if so, how did the mountains originate? Has the present Atlantic Ocean existed throughout the geologic history of the area? These are but a few of the many questions we raise in order to interpret the record of events preserved by the bedrock of the area. It is not possible to reconstruct all these events from geologic relations seen only within the bounds of the two state parks, and evidence from a broad area of Maine must be examined in order to understand what has happened in this local area.

As we move along in this discussion of the geologic history of the area, you will have to become used to thinking in terms of tens or hundreds of millions of years. A million years is an utterly unattainable time span in terms of a human life, yet in our deliberations on the geologic history of this or any region of the earth, a million years is like the passage of merely a week in the life of a human being (Figure 10).

Our geologic record begins approximately 500 million years ago at the end of the Cambrian Period or beginning of the Ordovician Period. An ocean covered all of Maine at that time, and the shoreline of the North American continent was located almost 300 miles to the northwest. In what is now the Portland area a great thickness of mud, sand, and limy mud accumulated on the ocean floor to form the Cape Elizabeth, Scarboro, Diamond Island, Spurwink, and Jewell Formations of the Casco Bay Group. Islands rising from the ocean floor somewhere in the general area were the sites of active volcanoes emitting great volumes of ash and lava flows that accumulated to form the Cushing and Spring Point Formations. We can picture the Portland area as part of a long narrow belt of sedimentation and volcanic activity extending from Newfoundland to Alabama. The geography of that time was probably similar to the present area of the Japanese Islands and the sea to the west between Japan and the Chinese Mainland — a

Era	*Period*	*Epoch*	*Million years before present*
CENOZOIC	Quaternary	Holocene Pleistocene	1
	Tertiary		65
MESOZOIC	Cretaceous		135
	Jurassic		192
	Triassic		230
PALEOZOIC	Permian		290
	Pennsylvanian		320
	Mississippian		350
	Devonian		410
	Silurian		435
	Ordovician		485
	Cambrian		560
PRECAMBRIAN			

Figure 10. Geologic time scale.

string of volcanic islands with a sea between them and the main continent. In the early part of the Ordovician Period, the rocks of the Casco Bay Group were folded during an episode of compression (an *orogeny*). The set of recumbent folds noted in Figure 8 may have been formed at this time.

During Late Ordovician, Silurian, and Early Devonian time, several thousand feet of sand and mud without volcanic eruptions were deposited in what is now southwestern and central Maine. The formations that comprise this sedimentary sequence are not present in the Two Lights-Crescent Beach State Parks area, but are seen to the west of the Casco Bay Group (for example, the Westbrook-Gorham area). These formations may once have extended over this area but were subsequently eroded away.

At the end of Early Devonian time, about 390-400 million years ago, the area underwent a second and much more extensive compressional upheaval known as the Acadian Orogeny. During this orogeny the rocks were again folded, forming the second set of folds noted in Figures 7 and 8 (these have the vertical axial planes). As a result of the compression, the sedimentary and volcanic rocks of the Casco Bay Group were depressed deep into the Earth's crust, where high pressure and temperature metamorphosed them into phyllite, quartzite, and other associated rocks that we now see. The clay minerals contained in muds recrystallized to form fine flakes of mica seen with the aid of a microscope. At the same time, the most deeply depressed sediments began to melt and form large quantities of molten rock called magma. This magma, injected into the remaining metamorphic rocks as large masses, gradually cooled and crystallized to form the extensive *granite* and *pegmatite* bodies commonly seen to the north and west of Portland. Geochemists have determined that these granites formed at depths of between 10 and 15 miles below the land surface. At that time, southwestern Maine was probably a mountainous area, with peak elevations rivaling those of the Rocky Mountains and the Sierra Nevada. This gives us some idea of how much erosion of the land mass has occurred from Early Devonian time to the present.

Toward the close of the Acadian Orogeny, the major faults that cut and displace the rocks in this area underwent their major movement. Additional fault movement occurred during the Mississippian, Pennsylvanian, and possibly Permian Periods (see

Table II). These faults extend from New Brunswick to Connecticut.

In late Permian to early Triassic time, approximately 225 million years ago, magma was again generated and injected into the metamorphic rocks and older granites in the Mt. Agamenticus area in York to the south. In late Triassic time, basaltic magma was injected into numerous tension fractures in the older rocks, forming dikes of fine-grained black basalt like the one that can be seen in the northwest part of Two Lights State Park. Similar dikes are sparse in the Portland area but are very common to the south between Biddeford and Kittery. Finally, during the Cretaceous Period, approximately 120 million years ago, renewed volcanic activity and magmatic intrusions occurred in the York, South Berwick, and Alfred area. No further *tectonic* events, except sporadic crustal uplift and continued erosion, are recognized in the bedrock record for this area.

MIGRATING CONTINENTS AND SPREADING SEA FLOORS

You may now be wondering how the different periods of compression came about. What was the cause of these orogenies that deformed the rocks, metamorphosed them, and caused the granites and pegmatites to form? The answer is best found in our modern geological notions of mobile, spreading sea floors and the movement of large continental plates.

In 1912, a German climatologist, Alfred Wegener, proposed the revolutionary idea that continents had not always been in their present positions relative to one another. He pulled together several lines of evidence which suggested that the continents of the earth had long ago formed a single super landmass which he called *Pangea.* Wegener hypothesized that Pangea broke up into several separate pieces to form the present continents, and that these then drifted apart. Although the years between 1920 and 1950 were unkind to Wegener and his grand idea, we now realize he planted the seeds of a very cogent global concept. We have now returned to a modified version of "continental drift" in which the continents are considered to have been displaced relative to one another by a process which we call "*sea-floor spreading*".

Oceanic and continental *lithosphere* rest upon a shell of material capable of movement when heated from below. This shell, which is referred to as the *mantle**, extends down to a depth of about 1900 miles (2900 kilometers). Beneath the mantle is the earth's core, which is composed of iron and nickel. It is in the mantle where the motions originate that cause the sea floors to move laterally. Due to heating, probably from the decay of radioactive elements, *convection currents* form in the mantle which cause the lithosphere to move (Figure 11).

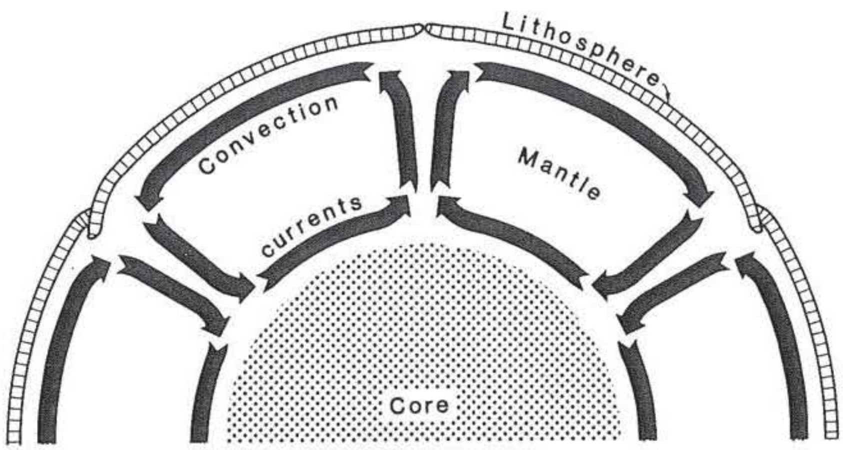


Figure 11. Schematic diagram of convection currents in the earth's mantle.

We now realize that the imposing mid-ocean ridges, such as the Mid-Atlantic Ridge which extends down the middle of the Atlantic Ocean, are areas where new oceanic crust constantly forms and spreads to either side. Just as oceanic lithosphere forms at these mid-ocean ridges, it must return to depth somewhere else to complete the cycle. The sites of this return, we believe, are the deep, narrow, and linear to gently curving ocean-bottom trenches such as those so well developed in the Pacific Ocean. At these *subduction* zones, plates of ocean lithosphere slide diago-

*The professional geologist will recognize that this is not a precise definition of the layers of the Earth. Technically the lithosphere includes the upper, rigid part of the mantle. For simplicity, we will refer to the mantle as the shell between the lithosphere and the core.

nally downward into the mantle. It is also along active subduction zones where the largest earthquakes take place. The trenches and the earthquakes are created by the downward drag of these subsiding plates (Figure 12). As the oceanic lithosphere slab descends into the mantle, heat begins to melt it and form magma which works its way toward the surface. This magma pours out through *volcanic vents* to begin the formation of a chain of volcanic islands (an island arc) on the opposite side of the trench from the moving and descending plate. As the island arc builds to a relatively large size, some of the magma produced from the subsiding slab is injected into the rocks of the arc to form large bodies of coarse-grained igneous rocks.

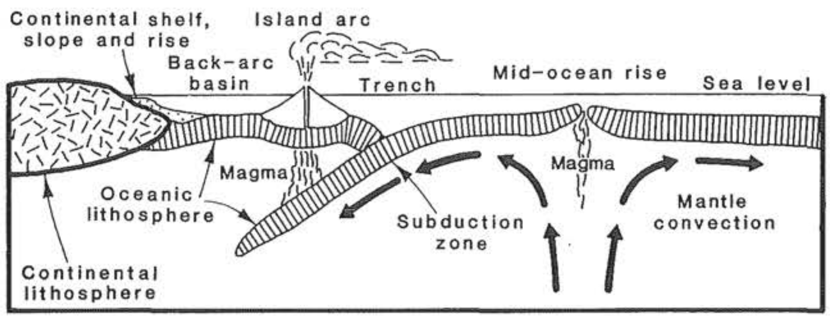
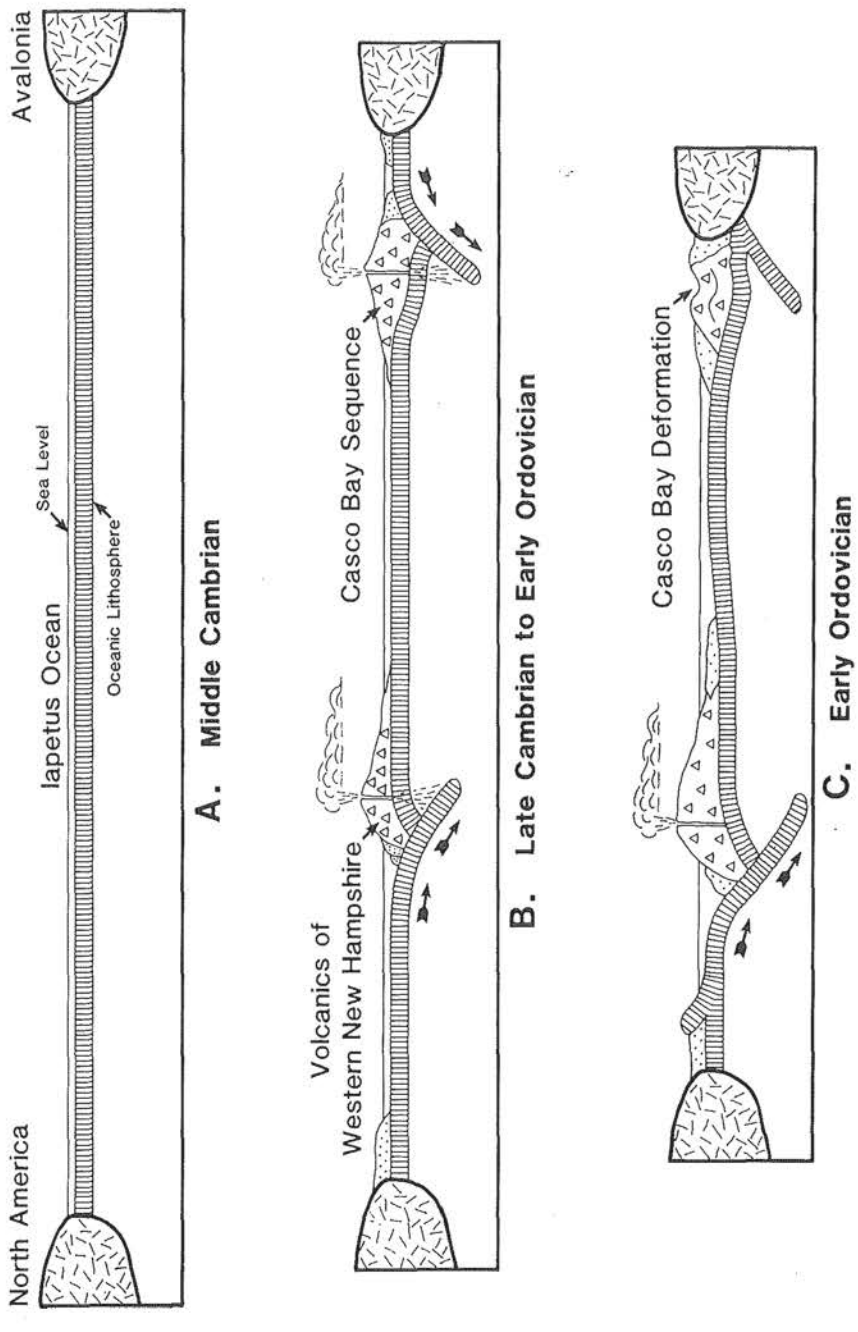


Figure 12. Relationships between island arcs, trenches, and oceanic lithosphere.

With this brief introduction to the concept of *Plate Tectonics*, we can now proceed to outline the broad picture of how the rocks throughout the northern part of the Appalachian Mountain belt may have evolved, and how the rocks of the local area fit into this grand scheme. Figure 13 presents a series of cross-sections that illustrate in generalized form the stages in the development of the area in terms of plate tectonic theory. Our understanding of the details of this evolution is still very sketchy and will be refined as future studies clarify our knowledge of the regional geology.


North America
Avalonia
Iapetus Ocean
Sea Level
Oceanic Lithosphere
A. Middle Cambrian
Volcanics of
Western New Hampshire
Casco Bay Sequence
B. Late Cambrian to Early Ordovician
Casco Bay Deformation
C. Early Ordovician

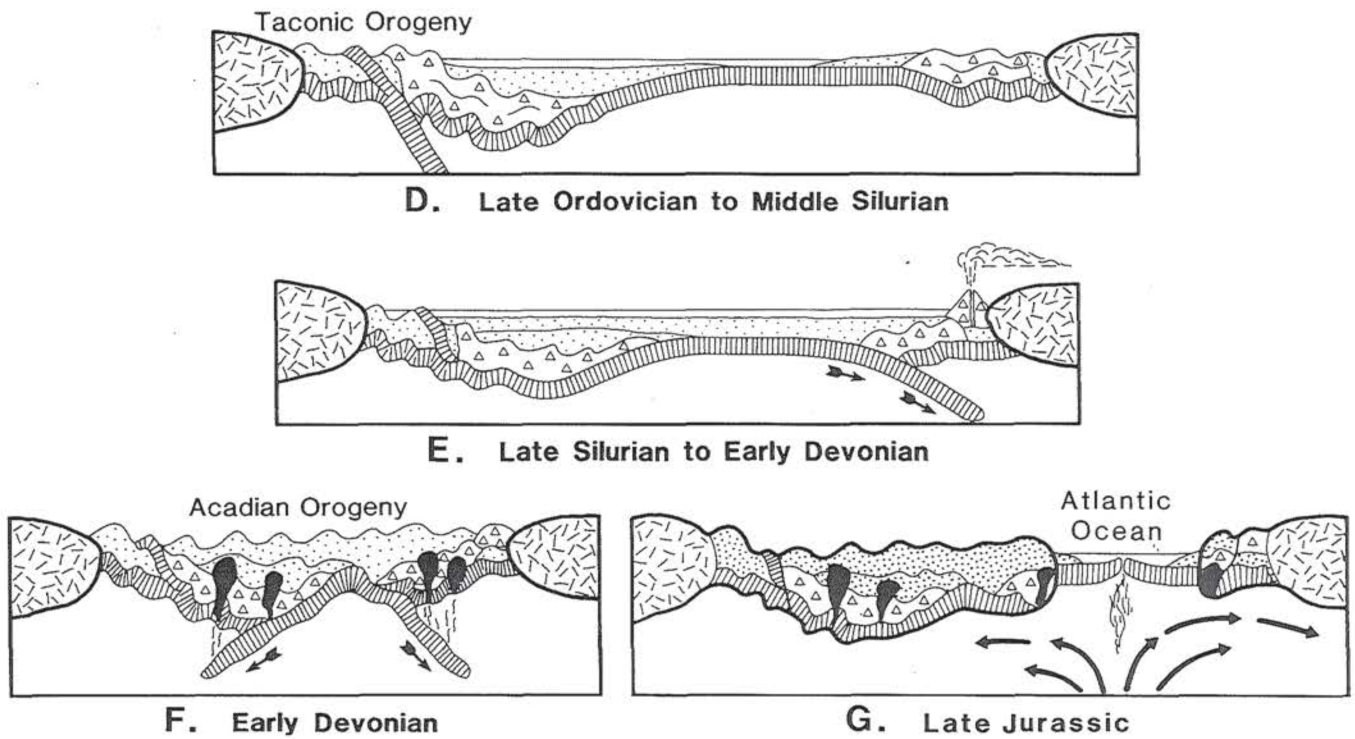


Figure 13. Generalized evolution of the northern part of the Appalachian tectonic belt.

Our narrative begins back in Middle Cambrian time, about 530 million years ago. At that time an ocean much like the Atlantic Ocean covered our area (Figure 13a). On the western margin of this ocean was a continental landmass, ancient North America, and on the eastern margin, a landmass geologists refer to as *Avalonia* (after the Avalon Peninsula in Newfoundland which is believed to be part of that ancient landmass). The ocean between the two has been given the name *Iapetus*. Although it existed in much the same area as the present Atlantic Ocean, Iapetus closed (as I note below), and much later the present Atlantic Ocean opened.

In Late Cambrian to Early Ordovician time, volcanic activity commenced in our area with the deposition of volcanic ash and related material that make up the Cushing Formation. Similar eruptions began about the same time in western New Hampshire. Geologists believe this volcanic activity resulted when Iapetus started to close. Closure took place when slabs of oceanic lithosphere began to descend back into the mantle along subduction zones (Figure 13b). Upon reaching sufficient depth, these slabs, along with the oceanic sediments dragged down with them, began to melt and form magma that worked its way to the surface and erupted, initiating an island arc. The Cushing and Spring Point Formations are evidence of this island arc activity. As the exposed parts of the island arc eroded, the rocks of the Casco Bay Group were deposited as an apron of sediments around the edge of the arc. Eventually the oceanic slab was consumed beneath the island arc, and the arc collided with the Avalonian landmass (Figure 13c), resulting in the first deformation of the rocks of the area. This probably happened in Early Ordovician time and is the event during which the recumbent folds were likely developed.

A similar island arc that formed in what is now western New Hampshire collided with ancient North America in Late Ordovician time as the intervening ocean slab was consumed by subduction beneath the arc. This collision resulted in the deformation of the rocks of that arc, an event that we refer to as the Taconic Orogeny (Figure 13d). Following this deformation, sedimentary rocks of Silurian and Early Devonian age accumulated in the remaining part of Iapetus (Figure 13d). Continued shrinkage of Iapetus by subduction at its eastern edge produced volcanic activity on the edge of Avalonia, presumably just east of the Portland area (Figure 13e). Finally, in Early Devonian time, Avalonia collided with North America, completely closing Iapetus and causing the

Acadian Orogeny (Figure 13f). This took place about 390 million years ago and completed the consolidation of New England as part of the North American continent. Along with this deformation, during which the upright folds of the Casco Bay Group were formed, granitic magma was generated and injected into the deformed rocks, forming the large granite masses and numerous small pegmatitic bodies that are common in the general area (Figure 13f). The deformed rocks were also metamorphosed at this time.

Parts of southwestern New England, New Brunswick, and Nova Scotia record still another deformational event, the Alleghenian Orogeny, during Pennsylvanian to Permian time. Geologists believe this may have been a result of the collision of Africa, South America, and Eurasia with North America. It is possible that some of the faults of the Portland area may have moved during this time; however, most of the fault movements appear to be related to the Acadian Orogeny.

About 190 million years ago, in Late Triassic time, convection currents of hot mantle material began rising and spreading apart below the newly consolidated supercontinent called Pangea. Under this tension the lithosphere cracked and formed *rift basins* such as the Connecticut River Valley and Fundy Basin. These basins rapidly filled with sediment and served as ideal habitats for dinosaurs which roamed the shallow marshes and mudflats of the time. By the end of the Jurassic Period, rift basins east of the present coastline began to split open as new ocean lithosphere formed along the rift. Continued upwelling of oceanic lithosphere caused the rift margins to move farther apart, eventually allowing inundation by the sea to form the Atlantic Ocean (Figure 13g). This activity, the upwelling and emplacement of oceanic lithosphere along the rift axis, the Mid Atlantic Ridge, is still going on today, resulting in an ever-widening Atlantic Ocean. The basalt dikes described above, one of which can be seen in the northwestern part of Two Lights State Park, are believed to have formed during the Late Triassic to Late Jurassic episode of lithosphere tension and fracturing. Table II summarizes the geological events of the area surrounding the two state parks.

TABLE II

GEOLOGIC EVENTS IN THE GREATER PORTLAND AREA

Eras	*Periods*	*Epochs*	*Events*	*Million years before present*
Cenozoic	Quaternary	Recent	Glacial ice melts; beaches formed.	13,000*
		Pleistocene	Continental glaciers cover the land.	1-2
	Tertiary		Erosion.	65
Mesozoic	Cretaceous		Erosion; eruption of volcanoes in southwestern Maine and central New Hampshire; gabbro intrusions.	135
	Jurassic		Erosion; eruption of volcanoes in central New Hampshire. Atlantic Ocean begins to open.	192
	Triassic		Rift faulting; intrusion of basaltic dikes.	230
Paleozoic	Permian		Erosion; intrusion of the igneous rocks of the Agamenticus complex in southwestern Maine and of syenite in south-central Maine; faulting(?).	290
	Pennsylvanian		Erosion; faulting.	320

*years before present

Paleozoic	Mississippian		Erosion; faulting; granite intrusion in southwestern Maine (Lyman Pluton).	350
	Devonian		Granite and pegmatite intrusions in greater Portland area. Final closing of Iapetus Ocean results in collision of Avalonian subcontinent producing the Acadian orogeny; later upright folds and metamorphism.	410
	Silurian and Late Ordovician		Deposition of sediments west of Portland area.	435
	Ordovician		Partial closing of Iapetus Ocean brings about collision of island arc of western New Hampshire with North America resulting in the Taconic Orogeny. Collision of Casco Bay island arc with Avalonia results in deformation of rocks of Casco Bay Group. Deposition of formations of the Casco Bay Group; volcanism associated with ocean lithosphere builds island arc.	485
	Cambrian			560
Precambrian			Iapetus Ocean begins to open in late Precambrian time.	

GEOLOGIC HISTORY DURING AND AFTER GLACIATION

One to two million years ago global temperatures cooled a few degrees to usher in the Pleistocene epoch, during which time huge masses of ice built up on the northern continents. At least four times in this epoch such masses of ice — continental glaciers — formed and spread southward covering more than half of North America and Eurasia. During each glaciation, the level of the earth's oceans lowered by as much as 450 feet (140 meters) due to the water frozen on land as glacial ice.

In Maine we see only the effects of the last glacial ice sheet which covered our area between about 20,000 and 13,000 years ago. The advance of this ice mass and its subsequent pulsing retreat is recorded in the *surficial sediments* — sand, gravel, and clay — found blanketing the bedrock of much of the region. It is not possible for much of this record to be understood from observations within the area of the two state parks inasmuch as there are neither natural nor artificial exposures of the surficial sediments. We have to look at a much broader area of the state in order to piece together how the last continental glacier advanced over this area, how thick the ice was, how the ice sheet retreated, and how relative sea level changed in response to the melting of the glacier.

Figure 14 is a geologic map of the surficial deposits in the Cape Elizabeth area, and Table III briefly describes the general characteristics of these sediments.

GLACIAL FEATURES AND DEPOSITS

In many places around the greater Portland area, outcrops of bedrock have a very smooth surface on which one can often see parallel grooves. As the continental ice sheet advanced over our area with its base loaded with rock rubble, it scraped away all the weathered material, and smoothed and streamlined the underlying bedrock surface. The grooves on such surfaces were cut by pebbles and cobbles held tightly in the base of the ice sheet as it passed over the rock. These grooves, called glacial *striae or striations*, indicate to us the direction the glacier moved. In the Cape Elizabeth area, these striae are generally oriented about S 10° E (Figure 14) which means the ice advanced from the northwest.

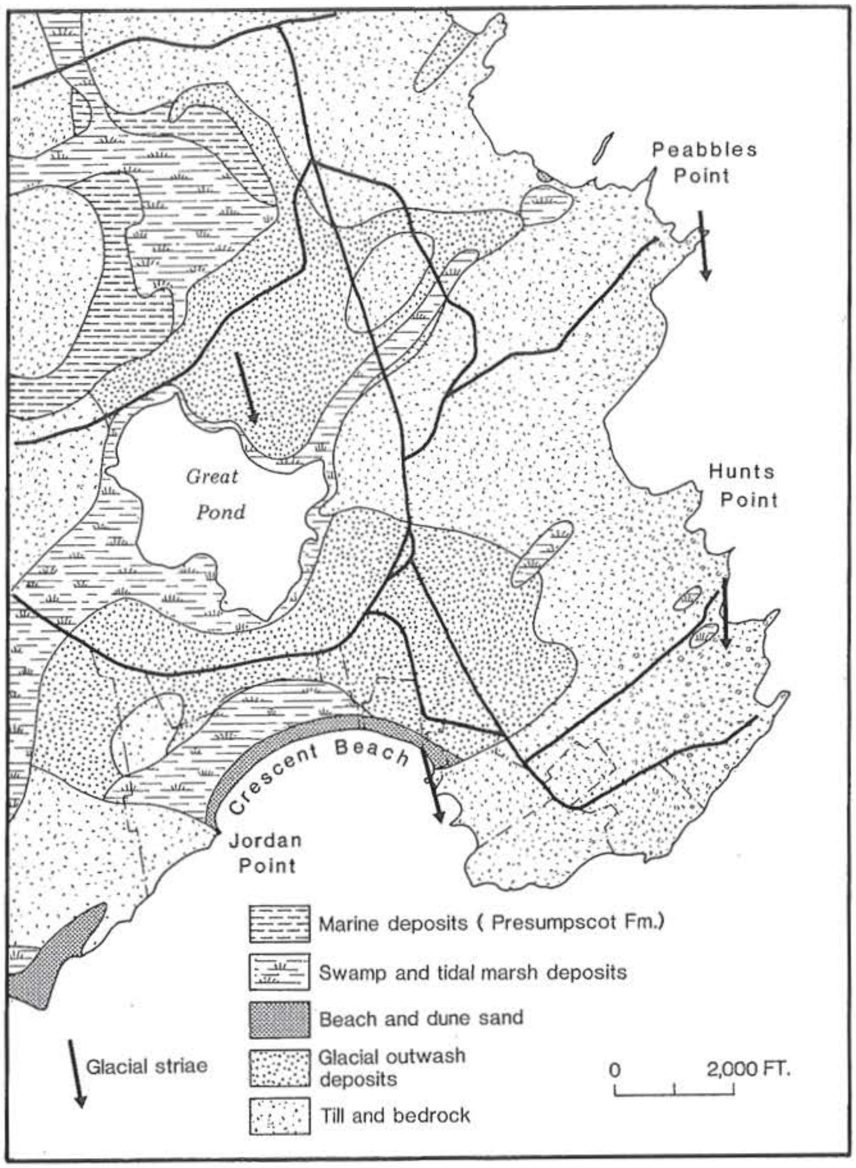


Figure 14. Surficial geologic map -ᵉ the Two Lights and Crescent Beach State Parks area.

TABLE III

SURFICIAL SEDIMENTS OF THE CAPE ELIZABETH AREA*

Type of Deposit	*Characteristics*
Swamp and tidal marsh	Peat and organic muck; some interstratified silt, clay, and sand.
Beach and dune	Fine, well-sorted sand of coastal beaches, and windblown sand of associated dunes adjacent to beaches.
Marine	Dark blue-gray silt, clay, and fine sand, occasionally with marine fossils. The Presumpscot Formation of Bloom (1959, Late Pleistocene changes of sea level in southwestern Maine: Maine Geological Survey; 143 p.). Deposited in marine waters during deglaciation, when the terminus of the retreating ice sheet stood in the sea.
Glacial outwash	Stratified deposits of sand and gravel deposited by meltwater from retreating ice sheet.
Till	Unsorted and unstratified mixture of clay, silt, sand, pebbles, cobbles, and boulders. Forms a variable thickness cover over bedrock.

*Adopted from Prescott, Glenn C. Jr., 1976, Ground water favorability and surficial geology of the Portland area, Maine: U.S. Geological Survey map HA-561.

The *till* with the high clay and silt content was deposited during ice advance (see Table III). This variety of till, which is very compact and impermeable, is referred to as *lodgement till*. In places, the base of the advancing ice sheet picked up more rock debris and soil than it was capable of transporting and consequently had to deposit this overload even as the ice moved on its way. This material was subjected to the weight of a great thickness of ice above it, and also to the shearing action of the moving ice. In the Portland area, lodgement till generally forms only a thin irregular veneer on top of bedrock.

When the ice sheet had made its furthest advance to the south it covered the entire state of Maine, probably extending out to the area of Georges Banks at the outer edge of the Gulf of Maine. How thick the ice sheet may have been over our area is not exactly known. We do know that it overtopped all mountain peaks of the White and Longfellow Mountains. On top of Mount Washington in New Hampshire, elevation 6,288 feet (approximately 1950 meters), boulders can be found of rock types unlike those which make up the bedrock foundation of the mountain, but which occur in ledges of areas to the north. These boulders, called *glacial erratics*, were deposited from the glacial ice as it melted. Thus we know in central New Hampshire and Maine that the top of the ice sheet had an elevation of perhaps 7,000 feet (2100 meters). It is not unreasonable to suspect that it was at least a few thousand feet thick in the Portland area. The weight of the ice that existed over this area depressed the crust of the earth by about 787 feet (240 meters). This was to have a great effect upon the way the ice sheet disappeared from this area, and the types of deposits left during and after deglaciation.

About 13,000 years ago, global temperatures warmed and the ice sheet began to diminish. The ice front quickly receded by melting, releasing tremendous quantities of meltwater and the load of *rock flour*, sand, pebbles, cobbles, and boulders the ice had been carrying. Meltwater streams in front of the melting ice sheet deposited copious amounts of sand and fine gravel which was very well sorted and bedded, called *outwash*. Outwash deposits are present in the vicinity of the two state parks (Figure 14). Both the outwash and glacial gravels deposited near and around glacial ice are extensively used for fill and highway construction because they are free of the finest sediment particles, silt and clay, and

therefore do not retain water. They drain well and pack down firmly, forming ideal surfaces for highway and building construction.

Close to the retreating ice front, in quiet waters away from the mouths of meltwater streams, fine silt and clay — rock flour of the glacial load — were laid down over the previously deposited glacial sediments. We see this silt and clay, locally with abundant marine shells, throughout much of coastal Maine up to elevations of 70 meters (220 feet) above present sea level, and at even higher elevations further inland. This marine clay, as it is most commonly called, is named the Presumpscot Formation. How did the Presumpscot Formation get to be at such high elevations? When glacial ice covered this area, its weight was sufficient to depress the land considerably. As the ice melted, two events happened to change relative sea level: 1) meltwater was released to the ocean to raise sea level, and 2) with the ice gone from the area, the earth's crust began to rise back to its original level; it began to rebound. At first, sea level rose *eustatically* (i.e. by the addition of meltwater to the ocean) at about the same pace as crustal rebound, thus resulting in little relative change of sea level, and also maintaining the coastline close to the retreating ice front. In time, however, the rate of crustal rebound exceeded the rate of eustatic sea level rise, and consequently the land began to emerge from the ocean waters. When crustal rebound was completed about 8,000 to 10,000 years ago, the Presumpscot Formation could be found at elevations as high as about 220 feet (70 meters) above sea level in the Portland area.

SEA LEVEL CHANGES AND BEACH FORMATION

Glacial geologists suggest that sea level stood as much as 65 to 100 feet (20-30 meters) below its present level 8,000 years ago when the crust had completed its rebound. Between 8,000 and 5,000 years before the present, sea level rose rapidly as the ice sheets quickly melted, and by 5,000 years ago had risen to a level perhaps 8 to 12 feet (3-4 meters) below its present level. Since then, sea level has risen at a much slower rate, and it is during this time that the present beaches have evolved. Prior to 5,000 years ago, the rate of sea level rise was probably too rapid to allow

beach-forming processes time to effectively operate. However, with the lower rate of rise after that time, beaches began to form several hundred feet further offshore than their present position, and 8 to 12 feet (3-4 meters) lower. They started as offshore barrier islands and as spits attached to rocky headlands. Behind these beaches shallow lagoons gradually filled with silt and sand, and vegetation began to grow to form the extensive salt marshes we see today.

These beaches were gradually forced landward over the marsh deposits as sea level rose to its present position. This migration will continue if sea level continues to rise (a lesson we should heed well as we contemplate shoreline development projects).

Referring to Figure 14, you will note that the sand of Crescent Beach fringes a zone of swamp deposits representing the remnants of a formerly larger salt marsh. At the eastern edge of the beach, sand has retreated completely across the former marsh and now rests against glacial outwash deposits. At both its eastern and western ends, Crescent Beach is anchored to ledges of the adjacent headlands.

CONCLUSION

The formation and evolution of the beaches of the area brings to a close our examination of the geologic history of the Two Lights and Crescent Beach State Parks area. The rocks and sediments of the area preserve a treasure of information about the dynamic changes that shaped the rocks and scenery over a period of half a billion years. This time included deep-sea sedimentation, volcanism, the closing of an ancient ocean, deformation of the rocks and their transformation by heat and pressure, a protracted period of erosion of mountainous terrains following deformation, the opening of the present Atlantic Ocean, climatic changes late in the history that have resulted in major ice advances and retreats, and finally the evolution of beaches and marshes fringing the land.

I hope this narrative will enhance your understanding and appreciation of the geology and scenery during your visit to the two state parks and surrounding area of Southwestern Maine.

GLOSSARY OF GEOLOGIC TERMS

Amphibolite: A dark metamorphic rock composed mostly of amphibole, an iron-magnesium bearing mineral.

Anticline: An upwardly convex fold of layered rocks.

Avalonia: An ancient land mass that formed the eastern edge of the Iapetus Ocean during Cambrian, Ordovician, Silurian, and Early Devonian time.

Axial plane: In folded rocks, an imaginary plane that passes through all points of maximum curvature of beds in an anticline or syncline.

Axial plane cleavage: Closely-spaced rock fractures oriented parallel to the axial planes of anticlines and synclines.

Axis: In folded rocks, an imaginary line extending along the points of maximum curvature of a bed in the crest of an anticline or the trough of a syncline.

Basalt: A dark fine-grained igneous rock containing little quartz. May be extruded at the surface as a lava flow or solidify beneath the surface as thin dikes or sills.

Bed: An individual layer of a sedimentary rock.

Bedding: The layering characteristic of sedimentary rocks and metamorphic rocks derived from sedimentary rocks.

Bedrock: The solid rock that underlies unconsolidated surficial materials.

Biotite: A common, iron-rich black mica found in a wide variety of rocks.

Chlorite: A pale-green, iron-magnesium-aluminum rich mineral with a platy form similar to mica.

Cleavage: The tendency of certain metamorphic rocks to break along a set of closely-spaced parallel fractures. Particularly characteristic of slate and phyllite.

Convection current: A circulation pattern in which warmer material rises and colder material sinks. Thought to occur in the mobile part of the earth's mantle due to heat produced by disintegration of radioactive elements deep in the earth's interior.

Dike: A thin tabular igneous rock body that cross-cuts the bedding of the rock that it intrudes.

Eustatic: Referring to sea level fluctuations due to glacial buildup or melting. Glacial buildup subtracts water from the ocean and results in lowering of sea level; glacial melting results in the return of water to the ocean causing a rise of sea level.

Fault: A fracture of the earth's crust along which movement occurs. Earthquakes are most commonly caused by such movements.

Feldspar: The most abundant mineral in the earth's crust. Composed of aluminum, silica, and sodium, potassium, or calcium.

Formation: A regionally distinctive sequence of sedimentary or metamorphic rocks that is extensive enough to be mapped.

Garnet: A red or red-brown aluminum-rich iron-magnesium silicate mineral.

Glacial erratic: A boulder picked up and transported by glacial ice. The rock type of the boulder differs from that of the underlying bedrock.

Gneiss: A metamorphic rock whose minerals tend to be segregated into bands.

Graded bedding: Sedimentary layering which displays a gradual change in particle size, usually from coarse particles at the base of the bed to fine particles at the top. At the top of each bed there is an abrupt change back to the coarse particles of the next bed.

Granite: An intrusive igneous rock of medium grain size composed of quartz and feldspar.

Graphite: A crystalline form of the element carbon. Characterized by a grey-black color and soft, greasy texture.

Hinge: The point of maximum curvature or bending of a fold.

Iapetus: An ocean that once extended through the New England area from Late Cambrian to Early Devonian time. Subduction of ocean lithosphere closed the ocean by Early Devonian time.

Igneous rock: A rock that has solidified from molten rock material or magma.

Intrusive rock: An igneous rock that solidified from molten rock material that was injected into older rocks below the earth's surface.

Island arc: A chain of volcanic islands adjacent to a deep ocean trench where subduction is occurring. Melting of descending oceanic lithosphere provides the molten rock material to build the volcanic islands.

Joints: Planar fracture surfaces in rock along which there has been no movement.

Limb: The sloping portion of a fold between the axial planes of a syncline and anticline.

Limestone: A sedimentary rock consisting chiefly of calcium carbonate. Formed in marine waters by organic or inorganic processes.

Lithosphere: The solid outer shell of the earth consisting of the earth's crust and solid upper mantle.

Lodgement till: Compact unstratified, unsorted glacial sediments deposited at the base of moving glacial ice.

Magma: Molten rock material.

Mantle: The shell of the earth between the crust and the core. The upper part of the mantle is rigid, whereas an intermediate zone is quite mobile and contains convection currents. The lowest part of the mantle is solid.

Metalimestone: Metamorphosed limestone.

Metamorphic rock: A rock whose original mineral composition or texture has been changed by recrystallization at high temperatures and pressures, but has not melted.

Metamorphism: A process where rocks are recrystallized by heat and pressure in the earth's crust. Metamorphism is a process that usually accompanies orogeny.

Mica: A group of silicate minerals characterized by a plate-like form. Two common varieties are biotite and muscovite.

Mineral: A naturally occurring inorganic element or compound, having a regular internal crystalline structure.

Muscovite: A common, iron-free white mica found in a wide variety of metamorphic and some igneous rocks.

Orogeny: The process whereby the deformation structures—folds, thrust faults, etc.—of mountain belts are formed.

Outcrop: An exposure of bedrock at the earth's surface.

Outwash: Stratified sand and gravel deposited by meltwater streams in front of a glacier.

Pangea: A hypothetical supercontinent thought to have existed during Permian time and to have included all continental masses. Pangea broke up in Jurassic time, forming the present continents which reached their present positions as a result of sea-floor spreading.

Pegmatite: A very coarse-grained igneous rock commonly of granitic composition. Frequently contains semi-precious minerals such as topaz, beryl, and tourmaline.

Phyllite: A soft fine-grained metamorphic rock composed of mica and characterized by a lustrous and crinkled cleavage.

Plate Tectonics: The theory and study of the formation, movement, and interaction of the rigid plates that make up the earth's crust and upper mantle.

Pyrite: A common iron sulfide mineral sometimes known as "fool's gold" because of its metallic brass-yellow color.

Quartz: One of the most common minerals. Composed of silicon and oxygen, and typically clear or slightly milky or smoky.

Quartzite: A very hard metamorphic rock composed almost entirely of the mineral quartz. Before metamorphism quartzites were quartz-rich sandstones.

Recumbent fold: A fold with a horizontal axial plane. A recumbent fold is one which might be characterized as "lying on its side."

Rift basin: A basin formed when a continental plate breaks apart.

Rock flour: A glacial sediment composed of finely ground rock formed by abrasion at the base of the glacier.

Sandstone: A sedimentary rock composed of sand-sized particles, commonly quartz or feldspar.

Schist: A coarse-grained mica-rich metamorphic rock characterized by aligned mica flakes.

Sea-floor spreading: A hypothesis that oceanic lithosphere forms at mid-ocean ridges and spreads laterally away from these ridges. It is thought to be the principal means of continental movement.

Sedimentary rock: A rock formed by the accumulation and cementation of mineral grains transported by water (and less commonly by wind or ice), or by the precipitation of minerals from water.

Shale: A sedimentary rock composed of silt and clay sized particles.

Silicified zone: A narrow zone, usually along faults or joints, where quartz has been extensively injected.

Strata: Layers of sedimentary rocks.

Striae, striations: Parallel grooves on bedrock surfaces produced by the abrasive action of pebbles frozen into the base of an actively moving glacier.

Subduction: The process whereby one lithosphere block descends diagonally under another block. A result of sea-floor spreading.

Surficial sediments: Unconsolidated sedimentary material such as gravel, silt, sand, clay or till.

Syncline: A downwardly convex fold of layered rocks.

Tectonic: Relating to large-scale structural features of the earth and their origin.

Till: Unsorted and unstratified glacial sediments.

Turbidity currents: A sediment-laden current that moves rapidly down the surface of a submarine slope.

Volcanic vent: The opening of a volcano through which lava, gas, ash, and dust are emitted.

Weathering: The physical or chemical breakdown of rock.