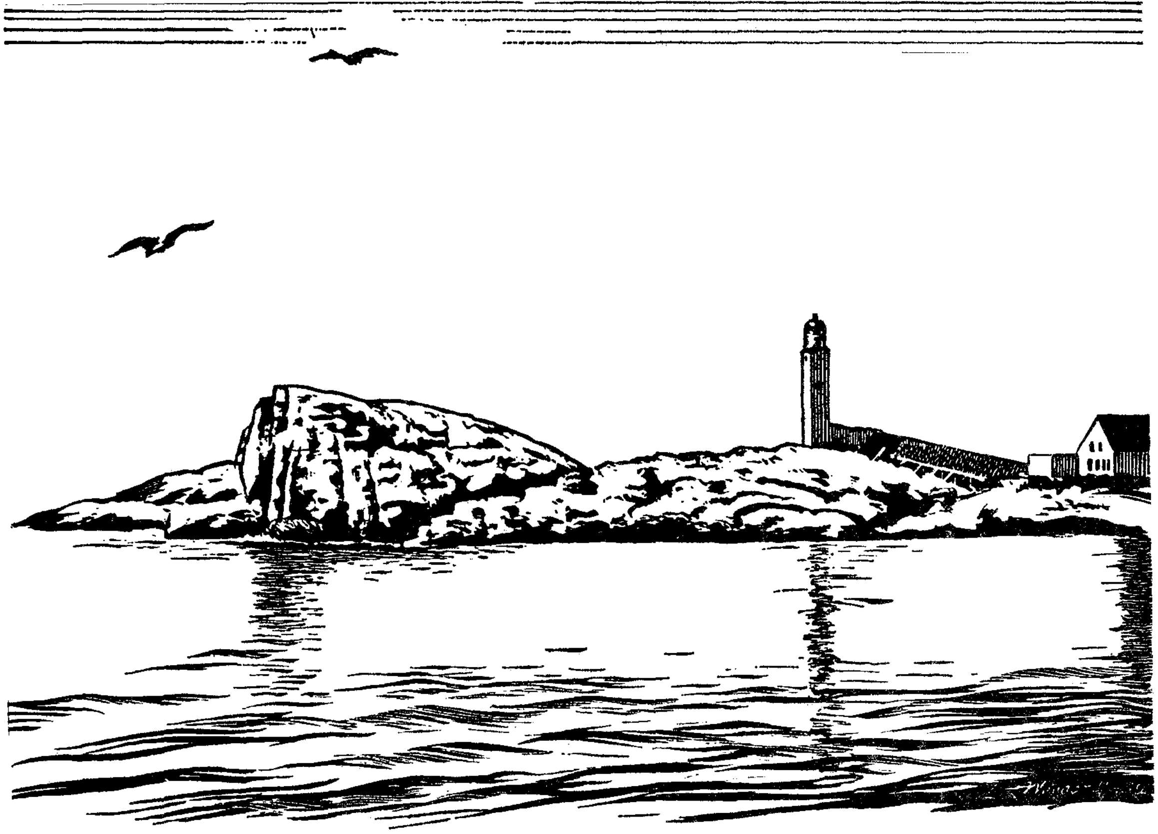

# GEOLOGY of the ISLES of SHOALS

by

KATHARINE FOWLER-BILLINGS

Published by
NEW HAMPSHIRE DEPARTMENT of RESOURCES and ECONOMIC DEVELOPMENT

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**NEW HAMPSHIRE**
**DEPARTMENT of RESOURCES and ECONOMIC DEVELOPMENT**
**DIVISION OF FOREST and LANDS**

George Gilman, Commissioner
Theodore Natti, Director, Forests and Lands
Glenn W. Stewart, State Geologist

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## MINERAL RESOURCES ADVISORY COMMITTEE

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## FOREWORD

This is the nineteenth of a series of non-technical pamphlets on the geology of various quadrangles in New Hampshire which have been issued by the New Hampshire State Planning and Development Commission since 1935. The Isles of Shoals are a group of nine islands off the coast of New Hampshire, half of which are in New Hampshire, and half in Maine. Dr. Lyman Rutledge, in his pamphlet "*Ten Miles Out*" gives a summary of their history, from their early discovery to their present role as a center for educational and religious conferences which are held on Star Island throughout the summer. He includes a brief discussion of the rocks based on information he was able to glean from visiting geologists. It was through his persuasion that the writer has undertaken a geologic study of the islands, since this had not been done previously. The visitors to the islands have been intensely interested in their rocky surroundings, and have expressed a desire to know more about their geologic history. This paper will attempt to present the geology in a way which will be understandable to all. Technical words have been avoided where possible, and the geological terms used have been defined in the text. Maps of the individual islands are included so that each island can be studied separately, if opportunity arises. The pamphlet will also include much of scientific interest, so that the professional can bring himself up to date on the geology of the islands.

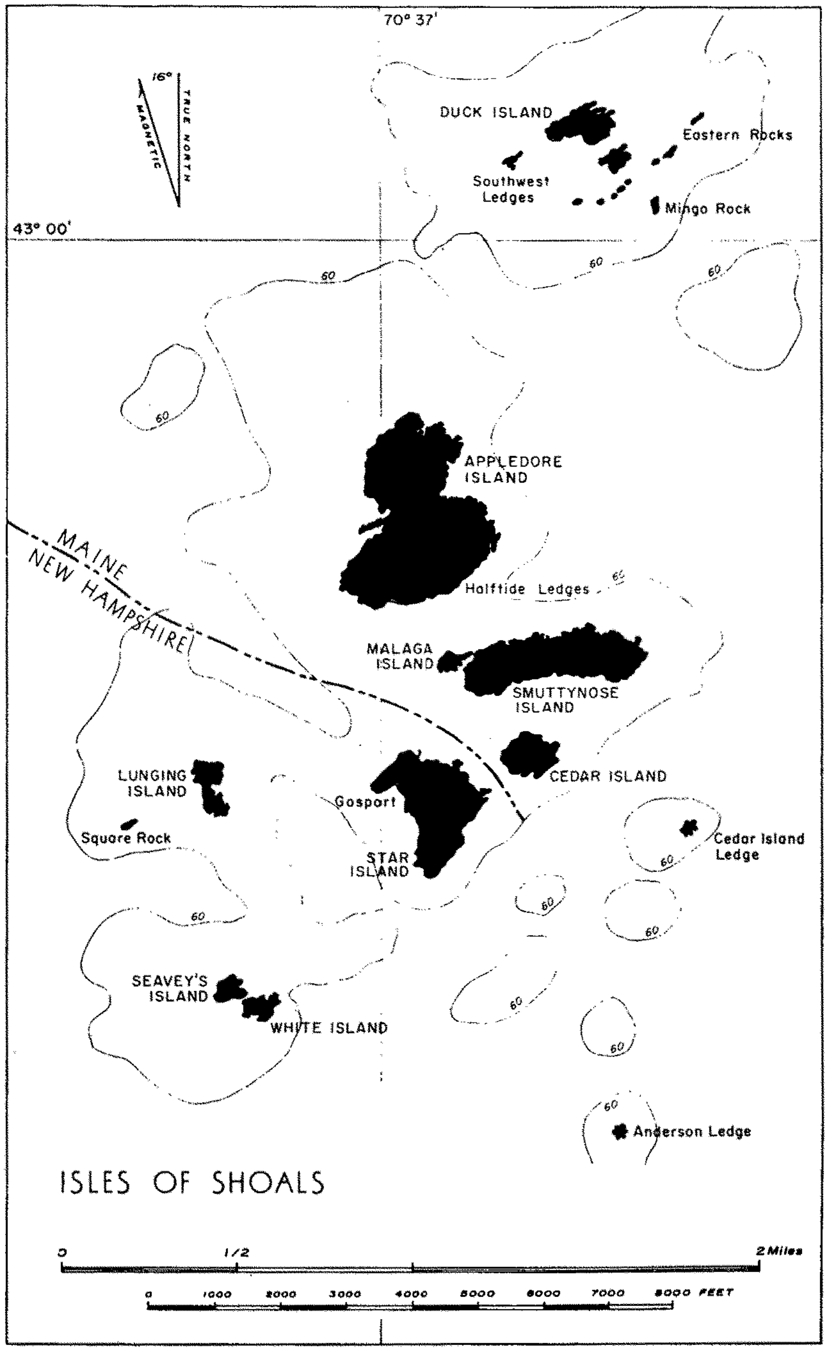


**Fig. 1.** Map of the Isles of Shoals. Sixty feet depth contour is included to show area of islands if sea level were to drop 60 feet.

# GEOLOGY OF THE ISLES OF SHOALS

## INTRODUCTION

Visitors to the Isles of Shoals are understandably curious about their origin. Why are they here? What kind of rocks make up these bleak, treeless islands? In short, what is their geologic history? This pamphlet has been prepared to answer these questions, so that the meaning of the rocks can be understood by anyone interested. It is hoped that the curiosity of the visitor will be stimulated so that he can comprehend the fascinating story of the rocks as he wanders about the rugged shoreline. To many, it will be a real thrill to recognize a black trap dike which was forced into the granite as molten material hundreds of millions of years ago; or to find mica, garnet, and tourmaline.

In order to unravel the story of the rocks, all the available outcrops on the islands have been examined in as systematic a way as possible. After collecting all the facts, and studying thin sections of many specimens under the microscope, the sequence of events at the Isles of Shoals has been pieced together. It has been like putting together a picture puzzle — a clue here, a shred of evidence there, all fitted together to make the story of the rocks. The following chapters will first tell the geologic history of the region, and then each island will be discussed separately, so that the visitor may know where to find the most interesting geologic features. In this way, he can have the fun of reconstructing the story of the rocks, and can hunt for further evidence to help understand their meaning.

Figure 1, a black and white map of the nine islands which make up the Isles of Shoals, also shows some of the larger ledges or "rocks." It will be noted that about half of the islands lie in Maine, and half in New Hampshire. The 60-foot depth contour is included on this map in order to show the area of the islands if sea level were to drop 60 feet. Separate black and white maps of each island are included in the chapters discussing the interesting features of the separate islands. Points of geologic interest, as well as structural data, dikes, and the main rock formations, are included on these maps. The scale of the maps varies for reasons of clarity, an approximate scale being indicated on each map. Since there is a difference of eight feet between high and low tide, and because the base maps used are on a very small scale, it is often difficult to locate the geologic features accurately. It is hoped that the directions in the text are clear enough so that localities will be found without undue troubles.

Two base maps of the Isles of Shoals are available. One is published by the *U. S. Coast and Geodetic Survey,* and can be obtained for 25 cents by writing to the Director of the U. S. Coast and Geodetic Survey, Washington, D. C. This map is scaled in *yards* and *nautical miles,* so that a mile equals about 3.5 inches. The highest points on Appledore and Star Islands are more than sixty feet above sea level, as shown by the contour lines on this map. The ocean depths are indicated by numbers giving the soundings in feet at mean low water, and the positions of the ledges are accurately marked for the navigator. The area covered by the islands is three miles long and one and a half miles wide. The largest island, Appledore, is only a little over half a mile long and half a mile wide. But to walk around the shore is a rough two miles, and could take a whole day, if one wanted to scramble up and down the cliffs and examine the geology in detail.

The second map is a topographic map called the "Isles of Shoals Quadrangle, Maine - New Hampshire", and was published by the U. S. Geological Survey in 1956. It can be obtained by writing to them at Washington, D. C., and can also be purchased in some local bookstores. This map has the topographic and depth contours in feet. The scale is in feet, 1 inch equalling 2,000 feet, or 1 mile is a little over 2½ inches. The same area was covered on a scale of 1 inch to the mile in the York 15-minute quadrangle of 1916, also published by the U. S. Geological Survey.

## GENERAL FEATURES OF THE ISLANDS

As one approaches the Isles of Shoals from the northwest after a ten-mile ocean voyage from Portsmouth, N. H., the low-lying rocky shores appear deceptively smooth, for thick glacial ice passed over the islands many thousands of years ago, scouring them until they look like "whale-backs" partially submerged in the ocean. A closer view of the islands reveals rocky cliffs on the northeast, east, and southeast, for this is the direction from which storms attack the islands in a relentless attempt to destroy them. The southeast side of the islands is the lee side of the movement of the Ice Sheet, where "plucking", rather than scouring, took place, leaving jagged surfaces.

If one steps ashore on any of the islands, most of the rocks are found to be a fine-grained granite, broken up by many "joints." Joints are cracks or smooth fracture planes found in all rocks (Fig. 9). They are developed due to various causes, and are prominent features of the rocks at the surface of the earth. Looking at the granite more closely, one sees that it is made up of innumerable tiny minerals: greasy white quartz that breaks irregularly; grayish or yellowish feldspar, recognized by its "cleavage" that causes light to reflect as from a mirror as the specimen is turned from side to side; and little flakes of white or black mica whose individual flakes flash when light is reflected from their smooth cleavage surfaces.

There is also a coarse type of granite associated with, or cutting across, the finer granite, called "pegmatite". The pegmatites were formed because of the presence of gases in the original melt from which the granite was derived, allowing the growth of large crystals of feldspar from an inch up to as much as a foot in diameter. Thus, the pegmatites are simply a coarse kind of granite that crystallized late in the formation of the granite (Fig. 9).

In contrast to the light-colored granites, bands of a fine-grained, black rock may be found cutting across the granite in straight lines. These are "trap dikes", which were forced into cracks in the granite as molten material when the granite was far below the surface of the earth.

There are other black and gray rocks, called "metamorphic rocks", which appear to have been caught up in the granite, or stranded in it, much as icebergs in a sea: some "floating", and some attached as if they had not been moved from their original position. These are not dikes, for they were here before the granite. They are the oldest shreds of geologic history found in the islands, and are consequently the hardest to decipher. In many ways, these are the most interesting of the rocks because of their variety and contorted character. It is by studying their structure — that is, their folds and their relative positions — that the geologist is able to reconstruct the geologic past.

## THE STORY OF THE ROCKS

### The Oldest Rocks: the Metamorphic Rocks

The oldest rocks on the Isles of Shoals are numerous belts or small fragments of so-called "metamorphic" rocks, meaning "changed form". They were originally muds, sands, and even impure limestones, which were deposited in a shallow sea when most of New England, including the Isles of Shoals, was part of an inland sea whose eastern shore was somewhere in the present Gulf of Maine. Land lay east of what is now the Gulf of Maine. Volcanoes were erupting in the vicinity, for volcanic ash was mixed with the sediments that were deposited in this shallow basin. The first of these muds, sands, and volcanic debris were deposited more than 360 million years ago, in what is known, geologically, as the Ordovician period. The accumulation of sediments in the inland sea continued for millions of years throughout the Silurian period, and on into Devonian times, until thousands of feet of sediment were laid down (Fig. 2).

The original muds, sands, impure limestones, and volcanic ashes of the Isles of Shoals region were changed gradually by heat and pressure into the "metamorphic rocks". New minerals were developed by a process of chemical reorganization; the muds were transformed into "schist" — a fine-grained, micaceous, quartzose, feldspathic rock that splits easily along the mica planes. The sandy muds became a black and white banded rock called "gneiss", or a compact, gray, granular rock called "granulite". The pure sands became compacted into what is known as "quartzite".

The impure limestones are harder to identify after metamorphism, and must be studied under the microscope to determine their origin. They became "lime-silicate" rocks or "actinolite granulites", with pyroxene or amphibole as their distinguishing minerals.

The volcanic ashes, likewise, have changed their form and developed new minerals under the heat and pressure during their long history. In fact, in some instances, it is impossible to know whether some of the light-gray banded rocks were originally light-colored ash, or whether they were sandy muds, for the two intermingled, and had very much the same composition. They have been metamorphosed into gray "granulites". But the dark-colored ash beds are easily distinguished from the sediments, for they retain their black color and, because of metamorphism, contain more than 50% needles of dark-green amphibole — hence they are called "amphibolites". These amphibolites represent "basic" or dark ash that was thrown out from volcanoes, and accumulated in thin layers on the bottom of the inland sea.

## Folding

After sedimentation was completed, sometime during the Devonian period, folding of the rocks throughout the basin area began. The whole region was squeezed, and the seas withdrew as the rocks were pushed upwards forming mountains that were immediately attacked by the forces of erosion (Fig. 3). Bodies of magma — semi-liquid molten material from the depths of the earth — began to move into the area far below the surface (Fig. 4). It was the heat and pressure involved in the folding, as well as the accompanying magmatic intrusions, that caused metamorphism.

## Intrusion of Diorite

The oldest of the magmatic intrusions forced into the folded rocks of the Isles of Shoals area is a coarse-grained, dark-colored igneous rock called "diorite". The diorite cuts across the folded sediments, and contains fragments of the sediments. There were thousands of feet of rock overlying the diorite when it was intruded, for it cooled slowly, forming quarter-inch crystals of feldspar, hornblende, and biotite. Because of its dark color, it is easy to recognize the large body of diorite along the southeast corner of Appledore as one skirts the shore in a boat. This is the only area in the islands in which the diorite occurs. It was intruded in middle Devonian time (Fig. 4).

## Intrusion of Granite

The incoming of great bodies of granite at least 300 million years ago, in middle Devonian time, was the next event in the geologic history of the region. The granite moved into the folded metamorphic rocks at great depths in the form of molten magma, and cut across the older diorite with sharp contacts, or intruded it as dikes (Fig. 4).

The granite magma completely engulfed the folded metamorphic rocks of the islands, pushing them aside in some places, thrusting them upwards, or even absorbing them by replacement. There are some areas in which great fragments of the metamorphic rocks are preserved in the granite as "roof pendants" — that is, slabs of the metamorphic rocks hang down into the granite-like jagged shingles of a roof (Fig. 6, 11, and 12).

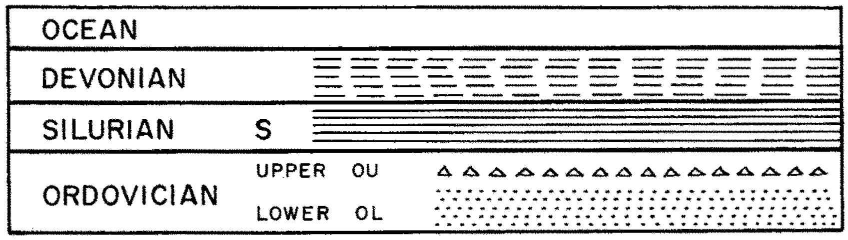


**Fig. 2.** Cross section of the Isles of Shoals region toward the middle of the Devonian period, showing the accumulation of muds and sands in a shallow sea — S = Silurian; OU = Upper Ordovician; OL = lower Ordovician.

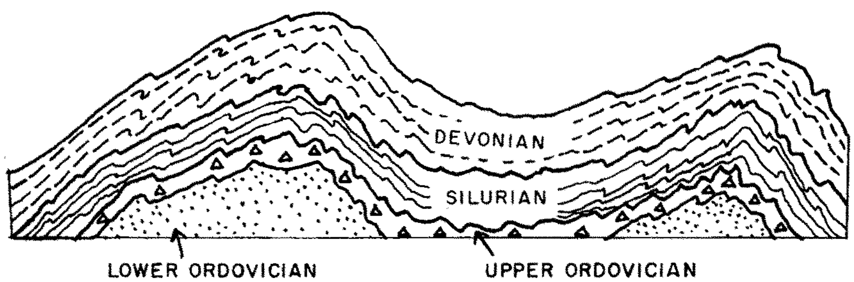


**Fig. 3.** Cross section of the Isles of Shoals region some time during the Devonian period. The seas withdrew, and the rocks were folded.

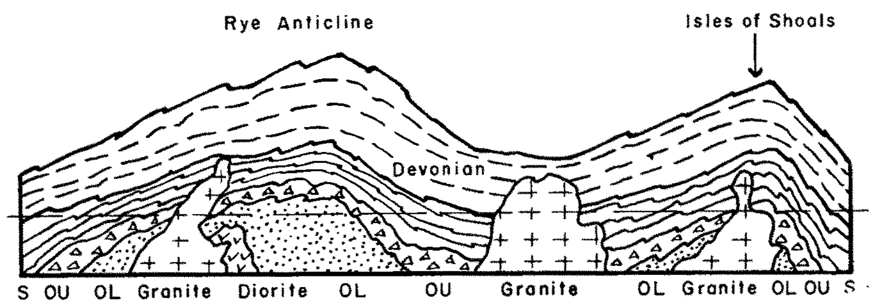


**Fig. 4.** Cross section of the Isles of Shoals region during the Devonian period showing the intrusion of diorite and granite into the folded rocks of Ordovician (OL = lower Ordovician and OU = upper Ordovician), Silurian (S), and Devonian time. The dashed line represents the level to which the rocks were eroded during the succeeding millions of years to expose the present surface as seen in Fig. 5.

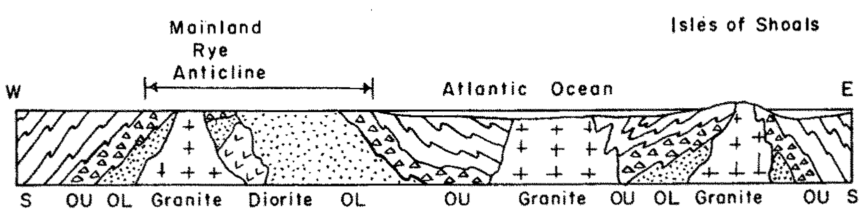


**Fig. 5.** Cross section of the Isles of Shoals region at the present time showing their relationship to the rocks of the mainland. S = Silurian; OU = upper Ordovician; OL = lower Ordovician.

## Pegmatites

As the granite cooled, the last liquids of the magma crystallized in small or large pockets, or pushed into cracks of the already cooled granite to form dikes (Fig. 9). These "endstage" juices formed what are known as "pegmatites", from the peg-like structure of their interlocking crystals. The minerals of the pegmatites are much larger than the minerals in the granite because the presence of gases in the pegmatite fluids allowed the growth of large crystals. These pegmatites are really coarse granite, but may contain quartz veins or stringers of quartz that was the last material left to crystallize from the magmatic juices. Some of the quartz is in the center of the pegmatite as an irregular filling, or "vein", or it may even occur as a dike-like mass. It is interesting to study these pegmatites because their minerals are easy to identify. Crystals of feldspar up to a foot in diameter may be found, as well as large "books" of mica. Garnet and black tourmaline are also present.

The high land along the southeast side of Star Island, as well as the eastern promontory of White Island, stand high because they are underlain by unusually large bodies of pegmatite, which is especially resistant to erosion.

## Trap Dikes

Long after the granites had cooled, there was still another disturbance in the area. This is evidenced by the presence of numerous black trap dikes which cut across the granite and schist in clean-cut lines. They were intruded far below the present surface in fractures in the earth's crust during the Triassic Period. Some of the dikes contain fragments of the granite, and are called "breccias". Others are "porphyritic" — that is, they contain large crystals of feldspar or augite. Their composition, from a microscopic study, indicates that all the trap dikes probably come from the same magmatic reservoir, for they are made up of interlocking crystals of plagioclase feldspar (andesine or labradorite) and augite. The original minerals have been altered to new minerals in many of the dikes examined, so that their technical name is "metadiabase" (Fig. 10, 21).

An interesting feature of the dikes is the fine-grained "chilled" border caused by the rapid cooling of the molten magma coming in contact with the cold rock into which it was intruded. The central portions of the dikes are coarser grained due to slower cooling, and may have a pitted character on their weathered surfaces due either to the erosion of some of the coarser minerals or to the presence of gas bubbles in the original fluid.

Another characteristic feature of the trap dikes is their "columnar jointing", which causes the dikes to split at right angles to their length, so that column-like sections of dike can be removed by the waves and other erosional forces. This jointing developed due to the forces of contraction set up during the cooling of the trap magma. Because the trap dikes have this characteristic jointing, as well as the chilled borders, they can be distinguished from the older dark diorite and the black metamorphic rocks that lack these characteristics. Also, the diorites and metamorphic rocks are cut by the granite which intruded them, whereas the trap dikes are never cut by the granite, since they came in long after the granite.

## Erosion

At the time of the intrusion of the trap dikes, the land must have stood higher than the present surface. There followed many millions of years of wearing down of the land by forces of erosion to remove the thousands of feet of metamorphic rocks and expose to view the granite and trap dikes (Fig. 5). Rolling hills presumably existed for millions of years, with the ocean far to the east. The Isles of Shoals were part of the mainland during this time, and stood up as hills. There were complicated uplifts of the land, and a rise of sea level at the end of the erosion period. But evidence for these shifts has to be found elsewhere.

## The Great Ice Age

There was still one more stage in the geologic history of the region. This was the coming of the Great Ice Age, which was to leave its mark upon the Isles of Shoals. The landscape was much as it is today when the Glacial Period began, although the Islands were probably part of the mainland. A great Ice Cap spread out slowly from northern Canada tens of thousands of years ago, covering the whole area with a sheet of ice many thousands of feet thick. The Ice Sheet scraped away the soil, scoured the rocks and ledges, rounded the hills, and deepened some of the valleys. Boulders weighing many tons were pushed along under the ice or were carried in the Ice Sheet. The weight of the Ice Sheet caused the land to be depressed, and sea level at this time was several hundred feet lower than at present, because the enormous Ice Cap was made up of water evaporated from the sea. The map of the islands (Fig. 1) shows the 60 foot depth contour, so that one can see the large area that would be occupied by the islands if sea level were 60 feet lower. Finally, the Ice Sheet melted, and the land emerged much as it is today. The shore line took up its present position after numerous fluctuations, as the melting of the ice returned the water to the ocean. The lowlands and valleys along the sea-front were "drowned" by the ocean flooding far inland, and the Isles of Shoals, which had been hills in the lowland, became Islands. The melting away of the Ice Sheet and the rise in sea level to make islands of the Isles of Shoals took place about 10,000 years ago.

There are many marks of the Ice Age preserved on the Isles of Shoals. The "whale-backed" or "roches moutonnées" shape of the islands and ledges indicates that the ice passed over the islands from northwest to southeast, leaving a smooth northwest or "stoss" side, and a jagged southeast, or "lee" side. The soil was removed, and the rocks were scoured and smoothed as the ice pushed southeasterly, plucking or quarrying out great blocks from the jointed surfaces on the lee side by a process of freezing and thawing. Glacial scratches and grooves made by rocks caught in the base of the ice can be found on some of the smooth surfaces. Glacial erratics, or stray boulders of various sizes dropped by the melting ice, are numerous. Some of these must have traveled some distance in the ice, for they are not the local rock. Even a large rounded hole called a "pot-hole", is found on Star Island. This must have been formed by the churning, eddying waters of a stream pouring out from the melting Ice Sheet when the sea level was lower, for ocean waves are not known to make pot-holes of this sort.

## Present Day Erosion

Since the melting of the Ice Sheet, the forces of erosion have been hard at work in an unceasing attempt to destroy these rocky islands. The sea is engaged in a relentless attack, forming steep cliffs on the eastern shores where the waves of winter storms roll in from the northeast and southeast. Ice and frost action help in this process by freezing and thawing, loosening the rocks along small cracks or "joints". The jagged shorelines and bays are controlled by the sea quarrying away the rocks along these joints. Since the eastern side of the islands was also the lee side of the Ice Sheet, the attack has been aided by the rough "plucked" surfaces left by the glacial ice.

The metamorphic rocks are more easily broken down by the forces of erosion than the granite, for they break away easily, or split along the mica cleavages and bedding planes. Hence, in areas where there are abundant metamorphic rocks, there are depressions, and the rocks are broken down more readily than the surrounding granite.

Although the trap dikes are a hard, tough rock, their characteristic "columnar jointing" causes them to split into columns which are easily quarried away by the waves or forces of erosion. The result is that deep clefts or gullies are formed by the removal of the dike material. The deep gorge on the east side of Star Island is caused by the quarrying away of one of these trap dikes by the waves (Fig. 10). At the north end of the dike, blocks of pegmatite collapsed into the gorge, leaving natural caves under the blocks. This is where Betty Moody and her children hid from the Indians.

The soil of the islands is made up almost entirely of decayed vegetable matter or "humus", and particles or small fragments of minerals accumulated from the breaking down of exposed rock surfaces. All of the original soil was removed by the scouring action of the Ice Sheet, and very little gravel was deposited by the melting ice. A few surfaces still show the original surface polished by the ice, especially where it has been protected by soil. But most of the surfaces have been attacked by the forces of erosion, and are now rough. The mineral grains are being broken up by various mechanical and chemical forces to contribute their bit to the poor soil. In some places, little or no rock has weathered away, and in others, an inch or more has crumbled under weathering conditions. Thus by reconstructing the shape of the smooth, glaciated surfaces, one can estimate the amount of erosion in the 10,000 years or so since the Ice Sheet retreated.

## STRUCTURES OF THE ROCKS

In order to understand the geologic history of a region, the geologist must study various structures found in the rocks, and even examine many thin sections of the rocks under the microscope. For it is only by careful measurements in the field and the plotting of innumerable observations that the story unfolds. The method of unraveling the geology can be compared to the way in which an historian studies manuscripts or hieroglyphics from an ancient civilization, piecing together all the available clues to decipher the past.

The metamorphic rocks on the Isles of Shoals have many structural features that are evidence of intense movements in the distant past. Among these features are folds, cleavage, joints, lineation, and faults, all of which are described below.

Many of the metamorphic rocks are bedded — that is, layered. This is because they were originally deposited as alternating horizontal layers of mud, sand, or volcanic ash a few inches or a few feet thick. The beds are no longer horizontal, but are inclined at various angles. Subsequent to their deposition they were folded, just as a horizontal pad of paper may be folded if the two ends are pushed together. An upfold is an "anticline", a downfold is a "syncline". But the tops of the folds have been eroded away, so that only the lower part of each fold is preserved (Fig. 4 and 5). The strike of a bed is the direction one would walk if he were to follow the same bed (Fig. 12). The dip is the angle of inclination of a bed — the dip of a horizontal bed is zero, that of a verticle bed is 90 degrees.

In the Isles of Shoals the larger folds — those more than a few feet across — must be inferred. But some minor folds, a foot or less across, may be observed. On the Isles of Shoals these minor folds plunge consistently southwest. To understand this, fold a piece of paper. The crease is the axis. If this axis is inclined toward the southwest, the fold is said to plunge southwest. This uniform southwest plunge is consistent with the folds on the mainland.

Other structures which must be distinguished from the bedding are "cleavage" and "joints". Cleavage is the splitting of the rock along parallel planes. In schists, it is referred to as "schistosity" or "foliation", and develops as closely spaced planes which can cut right across the bedding. Cleavage developed during the folding, and cleavage planes are found to follow a consistent direction.

Joints are much wider spaced cracks or breaks in the rocks than the cleavage planes. They are common throughout all types of rock, and may trend in many directions. They are especially prominent in the granite, in which three sets of joints developed at right angles (Fig. 9).

Still another type of streaking or lining up of the minerals occurs along the cleavage planes. This is called "lineation" and is a distinct lining up of the micas or other minerals in parallel lines. It is developed by the forces of folding, and gives a clue to the direction in which the folds "plunge" or point downwards. The lineation is consistent over a large area, and is therefore helpful in correlating the beds over a wide area.

"Faults" are fractures along which the rocks on opposite sides have slipped past one another. The shiny, streaked surfaces where the rocks have slid across each other are called "slickensides", and show the direction of movement. "Gouge" or crushed rock, together with broken fragments or "breccia" is sometimes found along fault planes.

When all the structural measurements of the rocks of the Isles of Shoals are plotted, a consistent northeast-southwest trend or "strike" of the metamorphic rocks is apparent on all the islands. The dips of the beds are variable, but tend to be steep, indicating that the original layers have been squeezed and folded until they were "upended". A series of large anticlines and synclines can be worked out

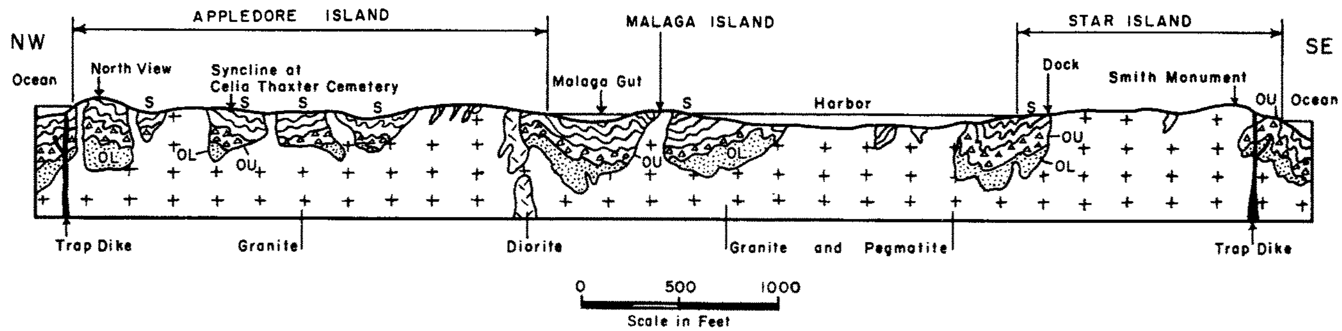


**Fig. 6.** Cross section of the Isles of Shoals from the northwest corner of Appledore Island to the southeast end of Star Island to show the various anticlines and synclines in the remnants of metamorphic rocks. It will be noted that upper Ordovician rocks (OU) are exposed in an anticline at the southeast corner of Star Island, and that the lower Ordovician rocks (OL) are not exposed. This interpretation supposes that the folded metamorphic rocks on the northwest end of Star Island are Silurian (S) in age, as are those on Malaga Island and Appledore Island. The granite has all but engulfed the folded sediments, as well as the diorite on the southeast corner of Appledore Island. Trap dikes are shown cutting across all the rocks.

from one island to the other, so that a cross-section can be drawn across Appledore to Star Island, giving an interpretation of the relationship of the beds on the islands (Fig. 6). The diagram is an imaginary trench with the major folds plotted to show how they would appear beneath the surface. There is an anticline extending northeast-southwest at the North View of Appledore, with a syncline through the area of Celia Thaxter's grave-yard. Another anticline is apparent along the south shore of Appledore, whereas Malaga makes a syncline. The southeastern part of Star Island appears on the southeast limb of an anticline.

The metamorphic rocks along the southeast sides of White Island, Star Island, Cedar, and Smuttynose, are apparently the same formation, and dip under the beds to the northwest. The fragmentary remains of folded metamorphic rocks on Lunging Island are correlated with the rocks between Appledore and Malaga. The schists on Duck Island can presumably be correlated with those of the northern part of Appledore.

## AGE OF THE ROCKS

The structural study of the metamorphic rocks on the Isles of Shoals has made it possible to correlate them with the mainland. A theoretical cross-section (Fig. 4 and 5) shows the rocks of the so-called Rye anticline of the mainland continuing eastward under the ocean as a syncline, reappearing in an anticline at the Isles of Shoals. Since the exposed rocks of the Rye anticline are presumed to be Upper Ordovician in age, and since they are similar to the volcanic rocks on the southeast of Star Island, it is probable that they are the same age, — and therefore these Star Island volcanics are called Upper Ordovician (Fig. 5 and 6). Overlying the Upper Ordovician in the Rye anticline are rocks of Silurian age. They are made up of various types of calcareous rocks, granulites, schists, etc., which can be compared with similar metamorphic rocks found on Appledore Island. It therefore seems logical to correlate the rocks on Appledore Island with those of Silurian age of the mainland and assign them to the Silurian (Fig. 5 and 6).

A study of the structure of the igneous rocks is helpful in determining their age, as well as correlating them with the igneous rocks of the mainland. The diorite of Appledore shows a certain amount of granulation, indicating that it came into the metamorphic rocks when the folding was almost over. It is similar in composition and structure to the bodies of Exeter diorite on the mainland which intrude the rocks of Silurian age. Since the Exeter diorite is considered to be middle Devonian, the diorite of Appledore Island is called middle Devonian. The granites of the Isles of Shoals cut the diorite, and hence came in later than the diorite. They show a certain amount of granulation, as do the granites of the New Hampshire magma series of the mainland. They are also similar in composition. They are therefore correlated with the New Hampshire magma series, and are presumed to have been intruded in the middle Devonian at the close of the folding. The pegmatites seem to have been intruded and crystallized after the folding was completed, for they do not show granulation.

The trap dikes of the Isles of Shoals are similar to those of the mainland. They tend to have a northeasterly trend, and run more or less parallel to each other, suggesting that they were intruded at about the same time. Some are found to connect together in a network, showing their close relationship to each other (Fig. 19). Some of the dikes may continue under the water from one island to another. It is not always possible to predict which dike connects with which, for there are numerous bends and occasional offsets in the dikes, due to some later movement of the rocks. Some show offshoots, or small dikes coming out at angles from the main dikes, while others are seen to die out, and then pick up again, as if they had been unable to force their way through the rocks at that particular point (Figs. 15, 16, 19). Since the trap dikes are the youngest rocks of the area, it is impossible to give them an exact age. They probably were intruded during Triassic time.

## INTERESTING GEOLOGIC FEATURES ON THE VARIOUS ISLANDS

### Star Island

Although only about a third of a mile long and a third of a mile wide, Star Island abounds in a wealth of geologic features (Fig. 7 and 8). Most of Star Island is made up of coarse, gray, well-jointed granite. One of the best places to see the joints is near the Engine House, where the rock has been quarried (Fig. 9). Prominent jointing is present in the granites along the west shore of the island, as well as at the southern tip of the island, where parallel "sheeting" is produced by closely spaced, flat or low-dipping joints.

Coarse pegmatites make up the highest parts of the southern and eastern sides of Star Island. This same belt of pegmatite continues southwesterly to reappear on White Island, where it makes up the high promontory by the lighthouse. The pegmatites are unusually resistant to erosion, and consequently have remained the highest parts of the islands. These large bodies of pegmatite grade into the granite, for they represent the last crystallizing fluids of the granite magma. In many places the pegmatites occur as dikes or small stringers that cut across the granite and metamorphic rocks, having forced their way into cracks (Fig. 9). Some good examples of the "dike-like" pegmatites are found along the west shore of Star Island. The common minerals of the pegmatites are quartz, feldspar, and mica. Garnets and black tourmalines occur in some localities — notably between Moody Cave and Smith Monument, and at the height of land near the southern tip of Star Island.

Perhaps the most striking rocks of Star Island are the black trap (diabase) dikes. Along the eastern side of the island, just southwest of the breakwater, a cleft contains Betty Moody's Cave. This depression is made by a black trap dike four feet wide that has been partially quarried away by the ocean (Fig. 10). The cave was made by the collapse of granite blocks into the depression left by the erosion of the dike. As one follows south from the cave, the dike becomes exposed, and extends in a southwest direction the whole length of the island. The "marine gardens" lie along this dike, where the seas have quarried it away, bit by bit, for the columnar jointing of the dike makes it vulnerable to attack. The dike is interesting because of its "chilled borders" and coarsely crystalline central portions which cooled more slowly.

The depression along the northwest corner of Star Island parallel to the shore, but just above high water mark, is also caused by a

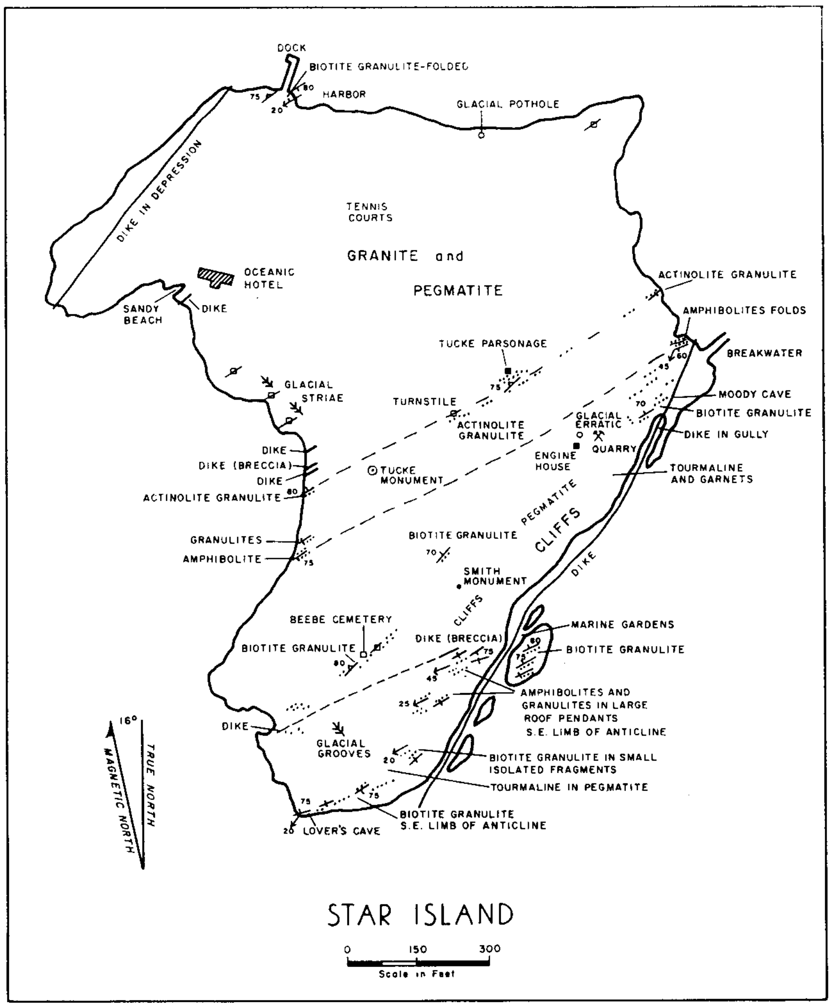


**Fig. 7.** Map of Star Island showing important geologic features. Fig. 8 explains the symbols used on this and other geological maps.

trap dike that runs in a northeasterly direction the length of the island. This depression shows up as a conspicuous line in the air photos. The dike is five feet wide, and is only exposed in outcrops at the northeast and southwest ends. Elsewhere, the granite has collapsed into the depression left by the more easily eroded dike, as at Betty Moody's Cave, although blocks of dike material are present.

There are several other trap dikes exposed on Star Island, but

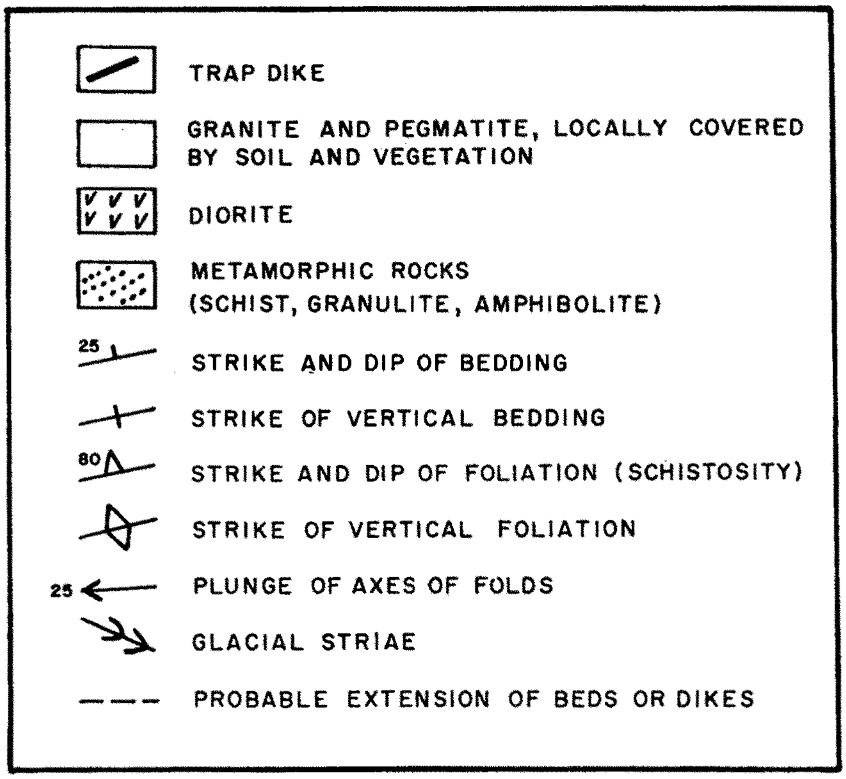


**Fig. 8.** Explanation of symbols used on maps of the individual islands.

they cannot be followed for more than a few feet. The largest of these is a dike eight to ten feet wide found along the shore just southwest of the hotel. It has beautiful "chilled borders", and the coarser central part that cooled more slowly contains crystals of feldspar and augite visible to the naked eye, so it is called a "porphyry". It is possible that the harbor by the dock on the north shore of the island owes its existence to the presence of this dike.

Three interesting trap dikes are exposed along the shore due west of Tucke Monument. The middle dike is four feet wide, and is a breccia containing fragments of granite, diorite, and quartz, as well as rounded augite crystals one to two inches across. Two feet south of this breccia, and parallel to it, is a fine-grained trap dike five-feet wide. All of these dikes extend in a northeasterly direction, but can only be followed for a few feet.

The only other brecciated dike on Star Island is found in the de-

**Fig. 9.** Steeply dipping joint planes in granite on Star Island in quarry east of Engine House. Note pegmatite dike, two feet wide, in center of picture cut by horizontal sheeting.

pression at the foot of the cliffs due south of Smith Monument, and is probably the controlling factor for the base of the cliffs at this point. It is four feet wide, and contains fragments several inches across (Fig. 13). The deep depression extends southwesterly for a number of feet, and then the dike becomes lost. However, the vague depression which one can follow in a southwesterly direction may represent a continuation of the dike. The coarse-grained dike eight feet wide which outcrops on the southwestern side of the tip of the island may be related to the breccia, since it appears along the same strike. A dashed line on the map shows the possible connection (Fig. 7).

Star Island has many interesting exposures of metamorphic rocks scattered along the shoreline. They are shown on the map by strike and dip symbols, if they are large enough to be of significance. Continuous beds are indicated by dashed lines. The largest belt of these rocks is a huge roof pendant several hundred feet wide, prominently exposed due south of Smith Monument, at the base of the cliffs. The dark-colored metamorphic rocks can be easily distinguished from the light granite which cuts across and surrounds them. The belt of metamorphic rocks extends east across the "marine gardens" to the ocean, and includes the easternmost point, which is an island at high tide.

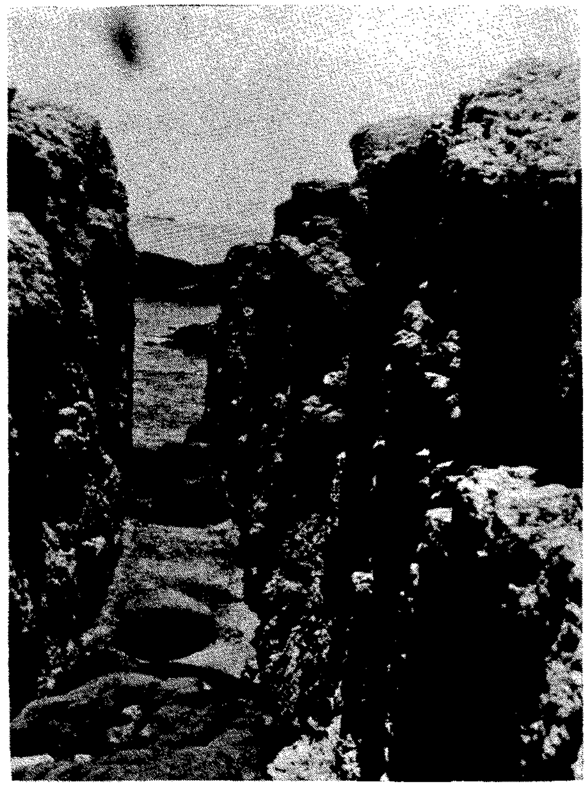

Fig. 10. Dike on Star Island that forms Moody Cave. View looks south, and shows how dike has been eroded leaving vertical walls of jointed pegmatite.

A cross section of the rocks is shown in Figure 13. The width of the exposures varies greatly from place to place due to the intricate folding of the sediments. There are many isolated fragments of the metamorphic rocks which line up with the main body just south of the main belt (Fig. 11). The composition of the various layers varies greatly, since they represent an accumulation of volcanic ash, sand and mud that was deposited in a shallow sea. The beds were consolidated into rock, folded, and then eroded, so that all that remains of the vast series of sediments are fragments in the granite like the shingles of a roof — hence the term "roof pendant". The black layers were originally beds of volcanic ash, and contain about 75% of black needles of hornblende. The gray layers were probably a mixture of

Fig. 11. Angular fragments of gray granulite cross-cut and surrounded by intruding granite. View is taken on Star Island looking towards "Marine Gardens" that are hidden from view in gully, or crack, formed by eroded trap dike. The gray rocks in the upper right hand corner of the picture beyond the Marine gardens are a large roof pendant of gray granulite that are part of the same formation seen in foreground. The beds are in a vertical position.

mud, sand, and ash. The layers trend in a northeasterly direction, and dip steeply. If one examines the vertical faces of the cliffs, intricate, close folding is evident, showing that the beds underwent a tremendous squeezing. The details of these myriads of folds in the individual layers gives the clue to the folding of the rocks. The folds and small crinkles "plunge" to the south at an agle of 20 degrees. In some places, the beds plunge underneath the granite which cuts across them. A few small dikes of granite and veins of quartz are folded with the metamorphic rocks, indicating that some of the granite had come into the region while the folding was going on.

There is a very interesting long, narrow roof pendant at the extreme southern end of Star Island (Fig. 12). It makes the floor of "Lover's Cave", is about six feet wide, and can be followed northeasterly for several hundred feet. It is now a biotite granulite, having been originally an impure mud. The biotites break down easily, giving the surface a pitted character.

Other interesting roof pendants occur along the shore for several hundred yards northwest of the breakwater on Star Island. The ones

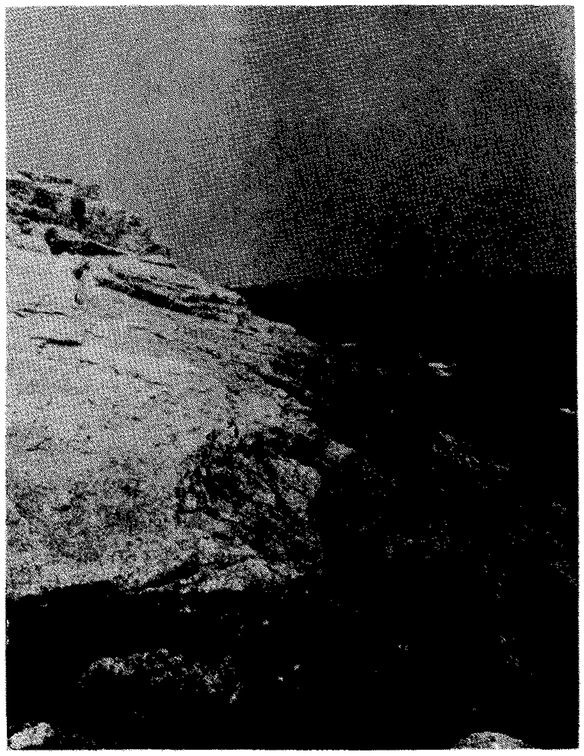

Fig. 12. Roof pendant of gray granulite just north of Lover's Cave at the southern tip of Star Island. The beds are vertical, and strike parallel to the shore. They are more easily eroded than the coarse granite of the cliffs above.

nearest the breakwater are highly folded, black amphibolite, the largest being six feet across. There appear to be three separate pendants which may be the same bed, folded and cut by the granite. The folds plunge to the southwest, and they are probably the same series of sediments seen in exposures southwest of Tucke Monument, as indicated on the map by a dashed line (Fig. 7). These latter exposures are especially interesting, since they contain beds of the black amphilolite, gray biotite, and some actinolite granulite. A small cross-fault offsets the dark and light layers at one point. About 500 feet northwest of the breakwater is a 30 foot wide band of dark actinolite

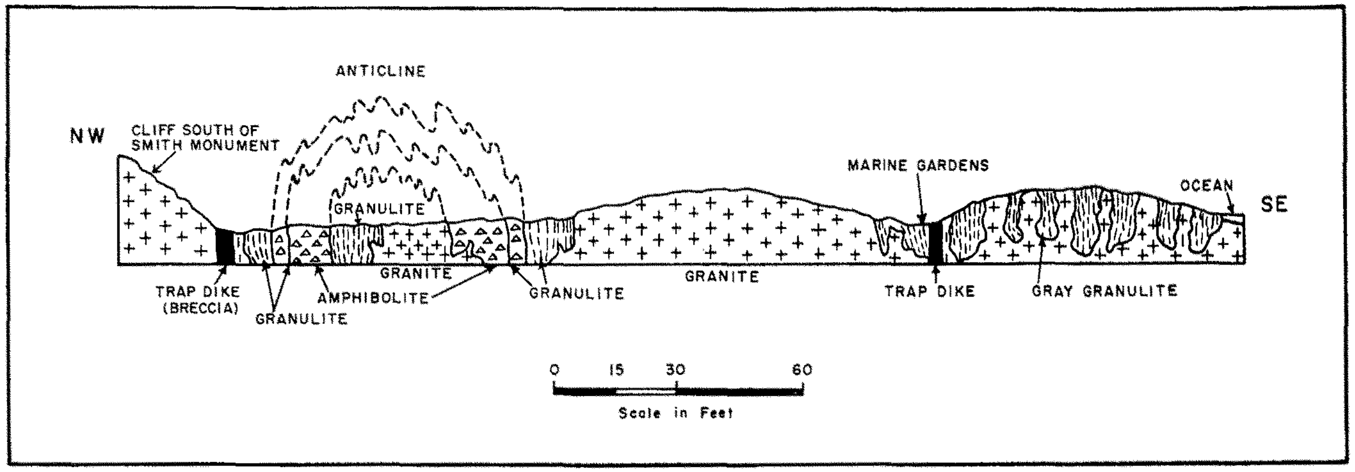


**Fig. 13.** Cross section of roof pendant south of Smith Monument on Star Island. The thin bed of gray granulite in the amphibolite is the basis for indicating an eroded anticline southeast of the brecciated trap dike.

granulite, which was originally an impure limestone. This exposure is especially interesting because of the pitted character of the surface, due to the erosion of the actinolite needles. Once a small pit starts, it becomes gradually enlarged and deepened. Another unusual feature of this actinolite granulite is the presence of folded quartz veins, which contrast with the darker colored, finely bedded, highly contorted layers. This same actinolite granulite can be followed intermittently across the island in a southwesterly direction, as indicated by the dashed line on the map (Fig. 7). It is well exposed at the Tucke Parsonage and at the Turnstile, as well as along the western shore slightly southwest of Tucke Monument.

There are exposures of biotite granulite, schist, and gneiss on both sides of the dock on Star Island. They were originally sandy muds which have been folded and contorted. The granite intrudes and cuts across them, isolating fragments. Other exposures of schist and biotite granulite occur in a long, intermittent belt starting near the breakwater, and continue southwesterly in occasional outcrops, notably in the depression by Beebe Cemetery.

There are many glacial features to be observed on Star Island. Perhaps the most unusual one is a pothole 2½ feet wide and four feet deep, just above high tide mark, northeast of the tennis courts. This deep, round hole was scoured out of the granite by the grinding action of pebbles churning in a whirlpool made by a torrent pouring out of the melting Ice Sheet. A pot hole such as this is not the work of the ocean.

The scouring action of the Ice Sheet as it rode across Star Island is preserved in the "roches moutonnées" shapes of some of the granite ledges, the northwest side having been smoothed off, and the southeast "plucked". Some glacial striae and glacial polishing of the rocks can be found, especially in places where the soil has been recently removed, and weathering has not had a chance to break down the surface of the granite. One of the best places to see the striae is above high tide mark along the western shore of the Island, south of the Hotel, where the sod is being removed by erosion. There are some excellent glacial gouges made by large boulders dragged along in the bottom of the Ice Sheet, south of Beebe Cemetery.

Many glacial erratics dropped by the melting Ice Sheet can be found scattered about the island. The largest of these is a conspicuous boulder 8 feet high, and 9 to 12 feet across, just north of the Engine House. This boulder may not have travelled far, for it is coarse pegmatite that could have been "plucked" locally by the ice.

Finally, the ever present wave attack on the islands can be seen along the eastern cliffs of Star Island. Here, the sea is engaged in a relentless quarrying away of the rocks. The dike along the eastern side is especially susceptible to wave attack because of the closely spaced joints, which allow frost action to penetrate the cracks and loosen blocks for the waves to carry away. Thus a deep cleft has developed where the dike has been and is still being removed (Fig 10).

## Appledore Island

Appledore Island is the largest of the Isles of Shoals (Fig. 14). It is over half a mile long, and half a mile wide across the southern end. Because of the many coves and the ruggedness of the north and east coasts, as well as the density of the shrubs away from the shore line, a full day can easily be spent walking around the island to study the variety of geological formations. If time does not allow this, shorter excursions can be made to points of interest, depending upon where one lands.

From a boat, the western shore presents a gentle slope with "roches moutonnées" surfaces in many places, for the Ice Sheet pushed across the island from the northwest, smoothing and scouring the rocks. An interesting dark-colored glacial erratic six feet in diameter, brought from the mainland and dropped by the melting Ice Sheet, can be seen just below high tide line on the southwest corner of the island.

As one skirts along the southeast shore north of Smuttynose Island, the black bedrock is clearly visible north and south of Devil's Glen. This black rock is a "diorite", and is the oldest intrusive rock of the region. It is cut by wide bands of light-colored granite. Devil's Glen is controlled by a trap dike eight feet wide that is probably the same dike as the one that extends northward from Moody Cave on Star Island and across the western end of Smuttynose Island. The cliffs along the eastern shore are rugged, most of them having been cut in the granite that is being quarried by the waves working along joint planes. The north coast is even more spectacular, and is one of the best places to observe how the sea attacks along the joint planes of the granite.

Babb's Cove, halfway along the shore on the western side of Appledore Island, is the best harbor, for it is protected on the north by Babb Rock. Since this is the usual landing place, the points of geological interest in this vicinity will be discussed first. There are many roof pendants of schist, gneiss, and granulite in the granite north and south of the Swimming Pool north of Babb Cove. These trend about N. 60°E. and probably extend across the Island, reappearing

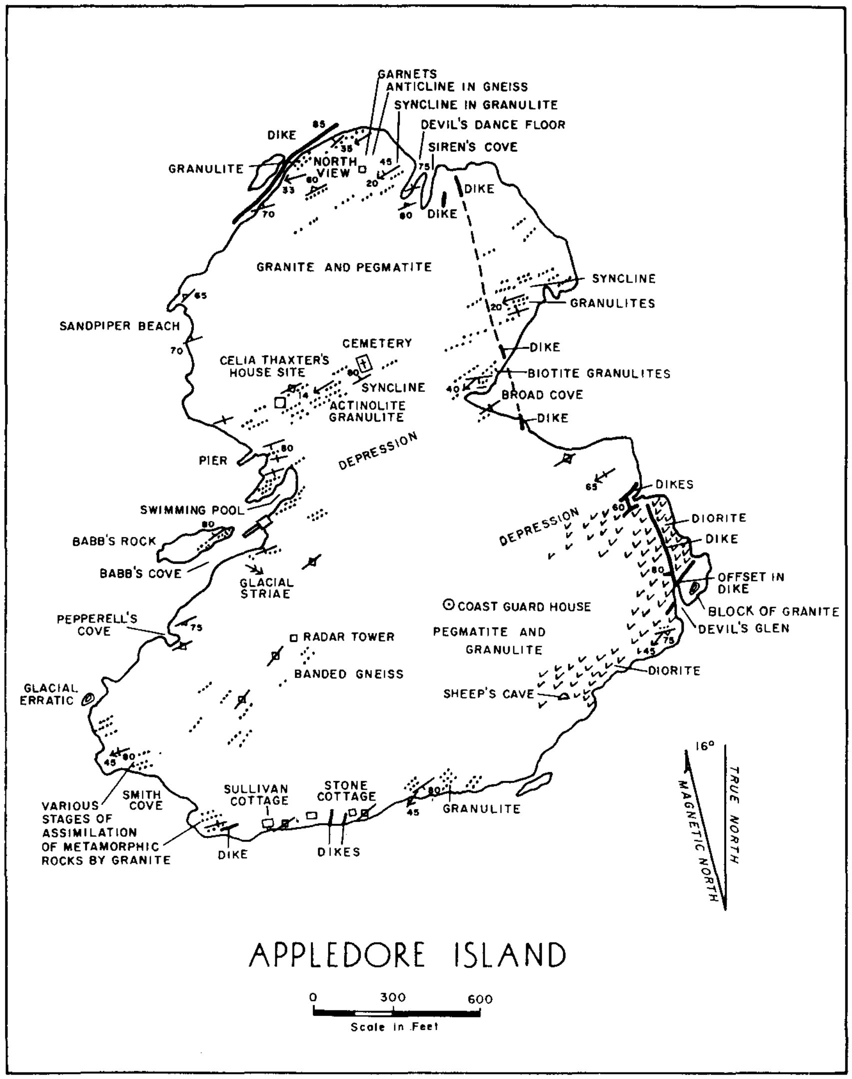


**Fig. 14.** Map of Appledore Island showing important geologic features. (See Fig. 8 for explanation of symbols).

as exposures of schist, gneiss, and granulite north and south of Broad Cove, on the east side of the island. Since the metamorphic rocks are more easily eroded than the surrounding granites, they account for the depression between the northern and southern half of Appledore, forming Babb Cove and the Swimming Pool at the western end, and Broad Cove on the east. There is no evidence of a dike across this low area. The metamorphic rocks were originally muds and impure sandstones with an occasional bed of volcanic ash, all of which have been folded, so that they dip steeply, and are streaked by the intruding granite. The eastern end of Babb Rock is made up of roof pendants of granulite and gneiss, whereas the western half consists of coarse granite and pegmatite.

As one skirts the shore north of the Swimming Pool, there are some small black stringers in the granite. The ones that contain quarter inch long needles of black hornblende were originally thin beds of volcanic ash, and should not be confused with the finer-grained, well-bedded, black to greenish-colored roof pendants that appear in a broad belt southwest of Celia Thaxter's house. These latter are diopside-actinolite-granulites that were originally impure limestones. They make a broad band several hundred feet wide extending in a northeasterly direction from Celia Thaxter's house, across to the graveyard where she is buried. The actinolite granulites reappear in the shore section north of Broad Cove. A syncline or "downfold" in these altered limestones can be seen in a 15 foot high northeasterly facing cliff exposure about half way between Celia Thaxter's house and the cemetery. The beds are thin, alternating layers a few inches thick, composed of dark-green actinolite and lighter greenish bands containing diopside. The beds are highly contorted, and the folds plunge about fourteen degrees towards the southwest.

The best place to study the varied beds of the metamorphic rocks, and the intricacy of their folding, as well as the repetition of the beds, is on the east side of the island, north of Broad Cove. In one area just north of Broad Cove, the schists are so broken by the intruding granite that a breccia has been formed. As one goes northward and approaches the center of the syncline that is the extension of the one at Celia Thaxter's house, one crosses alternating layers of light and dark metamorphic sedimentary rock. The center of the syncline is in beds of gray granulite and schist. Underneath these beds on the north is a bed, 50 feet wide, of the black actinolite granulite that is probably the same bed seen in the syncline near Celia Thaxter's house. The strike of the metamorphic rocks is N. 60° E, and the folds plunge from 20 to 40° southwest.

Another area on Appledore Island that contains an interesting section of folded schists, gneiss, and granulites, is near the old summer house at "North View" at the extreme northern end of the island. This locality is best reached by walking along the west shore north of Babb Cove. The region in the vicinity of Sandpiper Beach, as well as the whole upland north of Celia Thaxter's house, is made up mostly of granite and pegmatite. A few isolated roof pendants and slivers of schist, granulite, and amphilolite, with northeasterly trends, are found in the granite. Near North View, the rocks are twenty-five percent schist and gneiss, and seventy-five percent granite and pegmatite. Here, the structure of the schists controls the topography. The schists have a northeasterly strike, and dip northwesterly. Erosion has made a hog-back ridge parallel to the strike, with the northwest slope parallel to the dip of the schists. The jagged headland with the spectacular indentations in the Cliffs at North View, is due to the quarrying away of the granite along joint planes parallel to and at right angles to the strike of the schists. The intruding granite forced its way into the sediments, pushing them aside, or absorbing them. Thus, the granite predominates at sea level, and the roof pendants can be seen hanging down into the granite along the higher cliffs. If one goes seventy-five feet in a direction N. 52° E. from the monument at North View, and climbs 20 feet down the cliff, a single fold, or anticline 20 feet across, can be observed in the gneiss. The individual crinkles in the layers are prominent, the folds plunging in a southwesterly direction 0 to 20 degrees. Nearby, but in a N. 20° E. direction, 75 feet from North View, some large red garnets, three inches across, may be found in a pegmatite close to a quartz vein a foot wide.

The cliffs along the north west side of the Devil's Dance Floor, east of North View, are controlled by the steep northwesterly dip of the schists. The cliffs are undercut slightly in places. A small downfold, or syncline, can be found in the schists in the cliffs above the Devil's Dance Floor on the north side. The depression causing the Devil's Dance Floor is probably due to the presence of more easily eroded sediments, for its sides parallel the strike of the schists, and there is no visible trap dike in the vicinity which could account for an indentation. The "floor" is covered with boulders that have been rounded by the churning action of the waves.

The long depression that runs in a northeast direction, west of North View between the high hogback ridge of schists and the westerly islands of pegmatite and granite, is caused by a black trap dike, which can be seen at various points along the depression. The dike is

2 to 4 feet wide, and because of its jointing, has been more easily quarried away by the waves than the granites and schists. The southern end of the dike can be followed for 200 feet or more near the high tide line. In one place it cuts across a 12 foot wide band of metamorphic rocks.

Siren's Cove, just east of Devil's Dance Floor, is possibly controlled by an unexposed dike, for there are some boulders of trap rock at the head of the cove. The cove cuts across the trend of the schists at this point, and the walls are parallel to prominent joints in the granite. Granite is the dominating rock, with a few schist remnants in the northeastern section.

A few hundred yards east of Siren's Cove, a trap dike 12 feet wide forms a depression or flume that extends S. 20°E. It can be followed by the boulders of trap to the north side of Broad Cove, where it is 8 feet wide. Across the Cove to the south, it can be picked up in a gully, and it is then lost in the undergrowth. The trap dike three feet wide, just west of the northern end of this dike near Siren's Cove, is probably an offshoot of this same dike.

Perhaps the most interesting geological locality in the southern half of Appledore Island, is Devil's Glen, locally known as "Money Gut", because a wrecked Spanish ship scattered silver coins all about the rock crevices. The gully itself is controlled in part by a trap dike, eight feet wide, that has been quarried away from the eastern side of Devil's Glen (Fig. 15). The joint planes of the granite largely control the present form of the 50 feet wide gully. Near the head, or north end of the gully, there is a 30 foot offset in the dike, so that the dike appears on the west side of the gully instead of the east, as it heads north. A small offshoot two feet wide, extends northeasterly from the eastern point of offset. There is a second offshoot from the main dike near its southern end. This is a dike two feet wide that extends southwesterly for 100 yards, and is exposed in the bottom of a "slot" in the granite, which was made by the quarrying away of the dike. This cavity can be followed until the dike bends, narrows, and disappears under the granite into which it intruded.

The Devil's Glen dike may conceivably be the northward extension of the dike found along the eastern end of Star Island and the western end of Smuttynose Island. Both dikes show bends and offsets. They are also similar in composition.

The Devil's Glen dike can be followed northward from the Glen for some distance, until it ends abruptly in boulders at the large depression north of the Glen (Fig. 16). The joints in the granite on the south side of this depression are very prominent, and control the

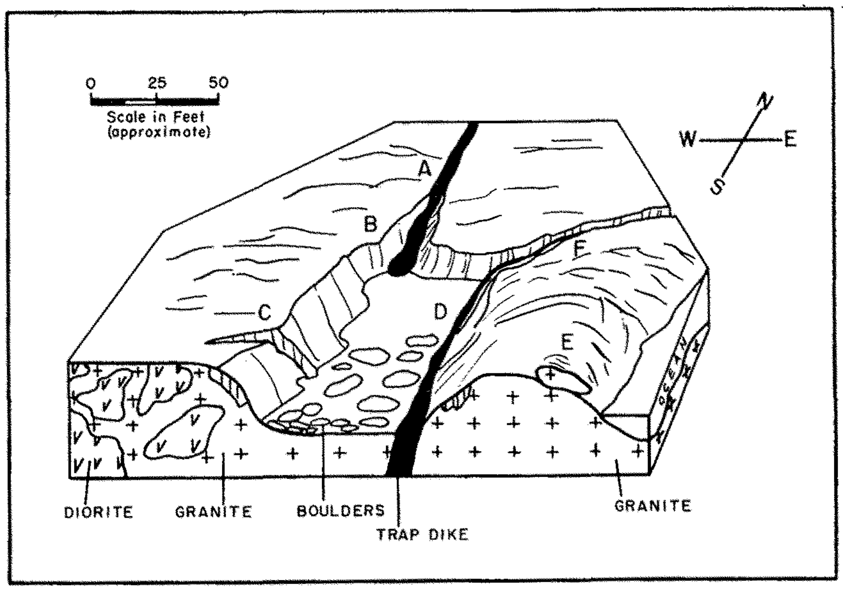


**Fig. 15.** Block diagram of Devil's Glen to show the relationship of the trap dikes and their control of the gully. Dike A and dike D are probably the same dike, offset at the head of the gully. Dike D controls the east wall, whereas the joint planes of the granite into which dike A was intruded, control the west wall. Dike F, two feet wide, is an offshoot at the north end of dike D. There is a small dike offshoot, two feet wide, at C, that is hidden in the cleft of the granite. It can be followed for 100 yards. There is a large block of granite at E called "Dollar rock". Diorite is the predominant rock north and west of Devil's Glen. West of C it is very much cut up by the granite, appearing as a breccia in places. A diorite sliver in the granite is cut by dike D at the southern end of the gully. A folded remnant of schist in the granite can be seen at B in the wall above dike A.

cliffs. A trap dike six feet wide runs down the middle of this depression in a southwesterly direction. It has an offshoot 2 feet wide that heads north, and then connects with another offshoot 3 feet wide that heads northeasterly (Fig. 16). This criss-crossing and right-angled pattern of the dikes suggests the possibility that the large dike that cuts across the northeastern end of Appledore may be related to the Devil's Glen dike by a series of angular offsets.

The large body of dark-colored diorite, which was intruded by the later granites, is well exposed north and southwest of Devil's Glen. North of the Glen the fine-grained trap dike cuts across the coarser-grained black diorite and granite. Broad bands of light-colored granite cutting across the diorite are so conspicuous that they can be seen from a distance. One way to distinguish the trap dikes from the diorite is that the granite always cuts the diorite, but never cuts the trap dikes, since the latter are much later. The trap dikes have

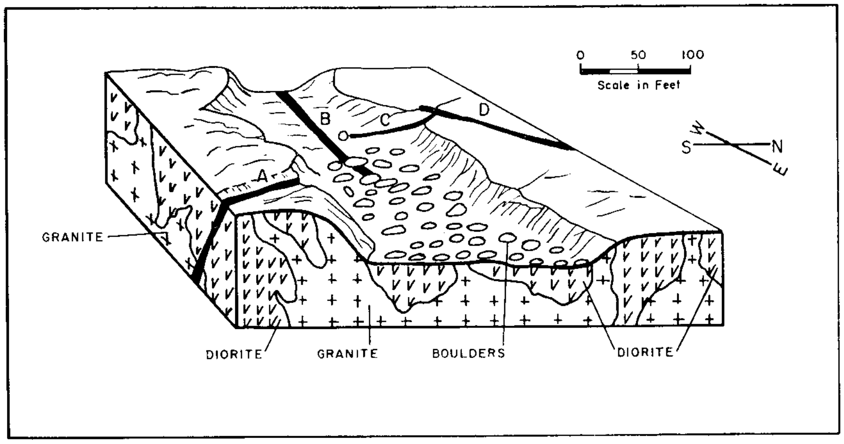


Fig. 16. Block diagram of the depression 300 feet north of Devil's Glen showing the relationship of the trap dikes in this vicinity. Dike A is the Devil's Glen dike, eight feet wide. Dike B is six feet wide and extends in a southwesterly direction down the middle of the depression. Dike C is a 2 feet wide offshoot of B, and dike D is a dike 3 feet wide which connects with C. Although diorite is the predominent rock of the depression, the south wall is controlled by joint planes of the intruding granite.

"chilled borders", as well as columnar jointing, which the diorite lacks, since it was intruded as a large body into the metamorphic rocks, and its outer borders have been destroyed by the granite magma that engulfed it. In several places just west of Devil's Glen, the intruding granite has made a breccia of the diorite, breaking off blocks of it. There is an interesting sliver of diorite in the east wall of Devil's Glen (Fig. 15). It can be traced across to the western side where it becomes a large inclusion in the granite. The promontory to the east of Devil's Glen is made up predominantly of coarse granite, with a large block of the same granite perched precariously on the cliffs (Fig. 15). In time, this granite block will be undermined.

There are a few remnants of the metamorphic rocks in the vicinity of Devil's Glen, some of which are cut by the trap dike. An interesting exposure of folded gneiss and schist making a small anticline can be seen in the western granite wall, at the north end of Devil's Glen. It is exposed in the granite above the eight feet wide dike where the dike cut across the folded inclusion, and the erosion of the dike left high walls on both sides (Fig. 15). Remnants of schist, which are common in the granite in this same vicinity, strike in a northeasterly direction. Some schistose phases of the diorite appear to be due to the presence of inclusions of metamorphic rocks caught up in the diorite. These are not common, possibly because most of the metamorphic fragments were absorbed.

The diorite body can be followed southwesterly from Devil's Glen along the cliffed shore until it is cut off completely by the engulfing granite at a point about due north of the western corner of Malaga Island (Fig. 14). Here, the cross-cutting character of the granite is especially interesting. North of these westernmost exposures, and inland from the cliffs, is a low depression overgrown by dense scrub. At the southern edge of the depression, hidden by a 10 feet overhang of granite, is Sheep's Cave. The floor of the cave is on the diorite, which makes a shelf 20 feet wide and 25 long underneath the granite. The low areas north of the cave are apparently in extensions of the diorite. The contact of the granite and diorite is very irregular along the western boundary of the body. The northern boundary of the diorite is along the large depression north of Devil's Glen, and may account, in part, for the depression (Fig. 16).

The southern half of Appledore Island is made up largely of granite and pegmatite, with streaks of schist and small roof pendants of metamorphic rocks, with northeasterly strikes. In the vicinity of the Radar Tower, the granite becomes a banded gneiss that developed by a process called "granitization" — that is, the granite soaked the metamorphic rocks, absorbing them, and developed large feldspars parallel to the structure of the metamorphic rocks. This soaking of the schists by pegmatite and granite is especially well displayed at the extreme southwest point of Appledore, west of Smith Cove (Fig. 17). Here, pegmatites penetrate and absorb the schists. An isolated fold of biotite granulite is found completely surrounded by a coarse granite with large feldspar crystals. In other places, replacement of the metamorphic rocks has progressed so far that a rough alignment of the micas in the pegmatite and granite is all that is left to show the former presence of the sediments. The resulting rock is a granite with feldspars of different sizes surrounded by biotite, giving it a "birds-eye" texture. In some places, the schists have recrystallized and become banded gneisses without replacement by the granite.

Another place to study the granitization of the metamorphic rocks is on the point east of Smith Cove. A mixture of gray granite and pegmatite alternates with, or penetrates, pendants of schist, black actinolite schist, granulite, and gneiss.

The southern shore of Appledore Island east of Stone Cottage is held up by steeply dipping beds of schist. These schists may be responsible for the channel between Appledore and Smuttynose Islands, for they are easily eroded, and dip towards the channel. If one goes

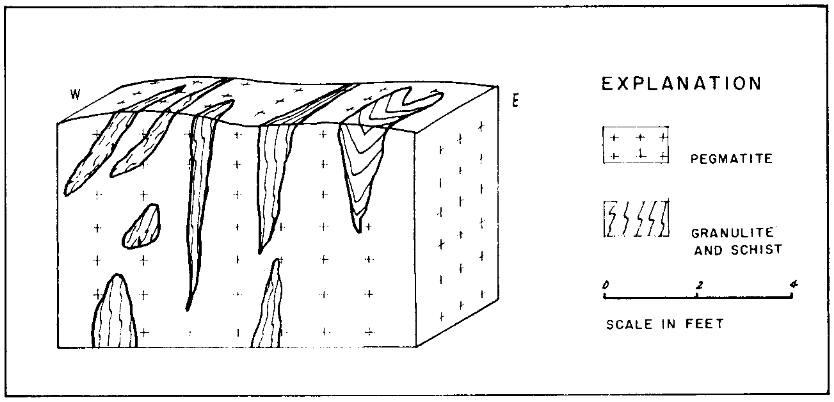


**Fig. 17.** Block diagram to show schist inclusions in granite at the southwest corner of Appledore Island. Bedding of granulite and schist is shown by lines.

inland fifty feet, 100 yards east of Stone Cottage, one comes to the center of an anticline, with a black actinolite schist making up the center of the fold.

Just west of Stone Cottage two small trap dikes strike northeast. The one nearer the house is 2 feet wide, and controls the east side of a conspicuous gully in the jointed granite. The foot-wide dike 100 yards to the west, is interesting because it bends. The only other dike on this southern shore is a dike five feet wide that strikes N. 60° E. a few hundred yards west of the Sullivan Cottage. The wide conspicuous gully underneath the cottage was quarried out of the granite, the joint planes forming the vertical sides.

The western shore of Appledore south of Babb Rock is mostly granite that has been scoured by glacial action; some glacial striae can be seen where the soil has been stripped away recently about high tide line. The striae strike S. 65° E., indicating that the Ice Sheet passed across the island in this direction. A prominent set of joints controls the southern shore of Babb Cove. Pepperell's Cove to the southwest has been used as a rock quarry, use having been made of the joint planes in the massive granite.

Many glacial erratics were dropped by the Ice Sheet as it passed over Appledore Island. Some large blocks of granite were plucked from their original position, and dragged only a few feet. Other boulders were brought from some distance, as was the black diorite erratic, six feet across, that is found at the southwest corner of the Island, north of Smith Cove. This diorite is related to the Exeter diorite of the mainland, and is the same age as the diorite found in the vicinity of Devil's Glen. It contains a few slivers of schist two inches long, proving that it was an intrusive into the metamorphic rocks.

## Smuttynose Island

Smuttynose Island is a long narrow island, half a mile long and one-eighth of a mile wide, extending in an east-west direction, half way between Appledore and Cedar Islands (Fig. 18). The north coast has a rugged, cliffed shoreline, for the northeast storms have quarried away the granite along prominent joint planes. In contrast, the southern shore has gentle slopes and a few bouldery coves.

Smuttynose Island is made up largely of granite and pegmatite, with some remnants of the metamorphic rocks, and several interesting trap dikes. There are large quarries 100 yards in diameter in the center of the island, in a gray, massive granite made up of quartz, feldspar, muscovite, and biotite. Granite and coarse pegmatites make up the higher parts of the island. In the vicinity of the "Cairn" on the highest point in the eastern part of the island, a slight northeast-southwest foliation, parallel to the trend of the remnants of the metamorphic rocks, is present in many places. The "roches moutonnées" west of the "Cairn" are especially striking. Here, the pegmatites and granite have smooth northwest slopes, but cliffs on the southeast, due to glacial plucking as the Ice Sheet rode across the island.

The southern shore of Smuttynose is mainly granite and pegmatite, with good examples of "roches moutonnées". Glacial striae and glacial grooves are found just above high water mark. Maren's rock, on the southeast point, is a glacial erratic of granite 15 feet long, 15 feet across, and 7 feet high. Since it is very angular, and shows little wear, it was presumably plucked from nearby granite by the Ice Sheet. In fact, it may have moved only a few feet, since it almost matches the same gray streaked granite on which it rests. It was here that Maren Hontvet hid the night of the Smuttynose murder.

The metamorphic rocks along the eastern end of Smuttynose Island west of Maren's rock, in the low area that is partially covered by high tide, are especially interesting. They appear to be the extension of the belt of metamorphic rocks found along the southeastern side of Star and Cedar Islands. They consist of roof pendants of granulites, biotite schist, impure quartzites, and black actinolite granulites. They make up from 3 to 10% of the rocks in this area, and tend to occupy the lower depressions, since they are more easily eroded than the granites which intrude them. They have a northeasterly strike, and show folds that plunge southwesterly.

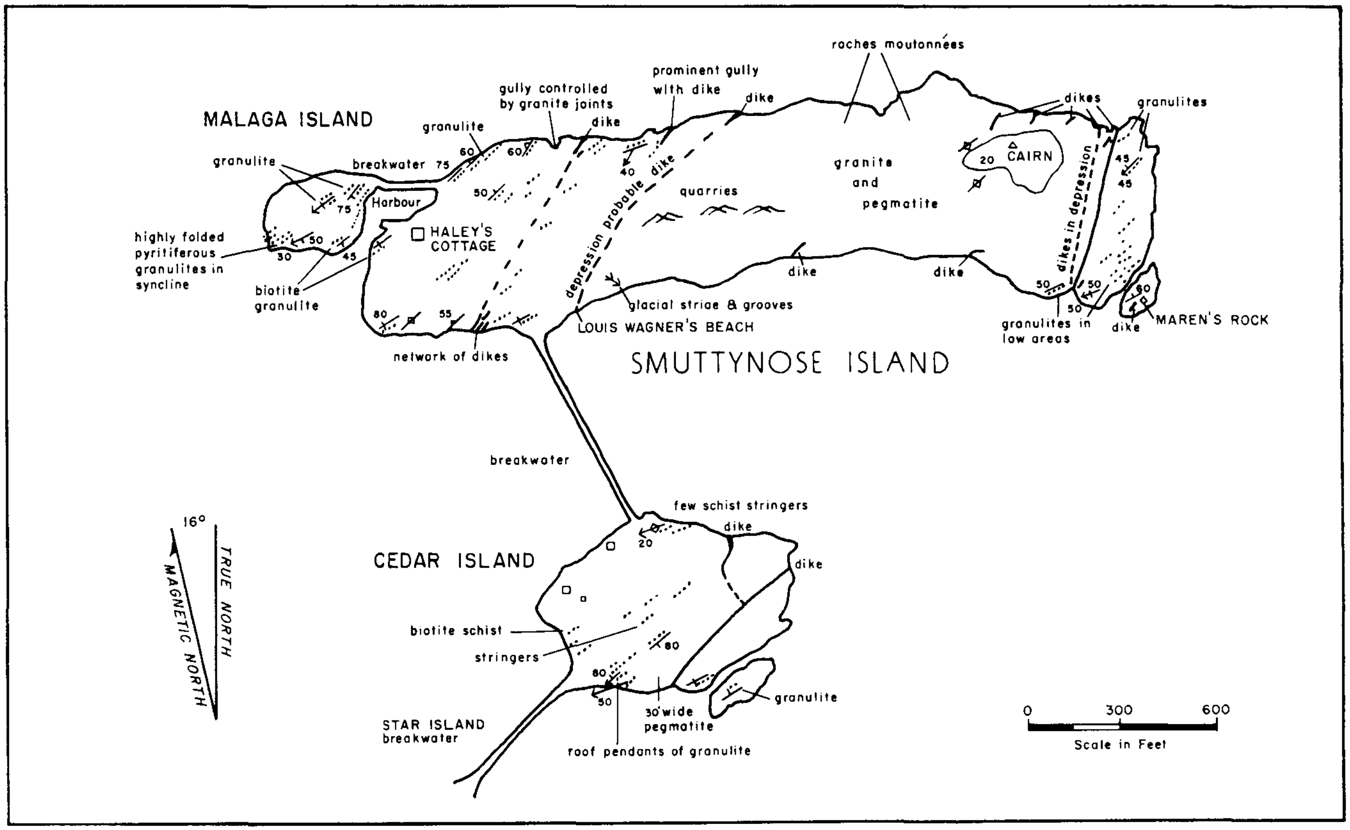


**Fig. 18.** Map of Smuttynose, Malaga, and Cedar Islands showing important geologic features. (See Fig. 8 for explanation of symbols).

Other smaller roof pendants are scattered over the island, especially in the area east of Haley's cottage and north of the Cedar Island breakwater. The pendants of biotite granulite and schist along the north shore, east of the breakwater to Malaga Island, control the edge of the cliffs facing Malaga Island. These metamorphic rocks strike northeasterly, and dip northwesterly, forming the eastern side of a syncline that is responsible for the depression, or cove, between Smuttynose and Malaga Islands.

The wide, bouldery depression, extending in a northerly direction east of the "Cairn", is made by two, and possibly three black trap dikes. The easternmost dike is the most prominent. It is a porphyritic dike 12 ft. wide, and strikes north-south to northeasterly. It is well exposed at the north and south ends. This dike is possibly the one that crosses the southeasterly end of Cedar Island, and may connect with the brecciated dike found south of Smith Monument on Star Island. In one place near its northern end it cuts across a small sliver of bedded granulite. In this vicinity, a few yards west of the main dike, a small offshoot of the larger dike is found. On the northern side of the island, one hundred years west of the main dike, a non-porphyritic dike, seven feet wide, parallels it, and appears to be independent of the main dike, although the two may connect at the south. At the southern end of the depression made by the dikes, the 12 foot wide dike appears to split. Great blocks of granite are found surrounded by the dike. Offshoots of the dike one foot wide parallel it on both sides. This tendency to split suggests that the dikes in the depression are related, and were thrust into the granite from the same source.

The large depression that runs northeasterly across Smuttynose Island, west of the quarries, is apparently caused by a trap dike 10 feet wide that is exposed on the northern shore. This dike is porphyritic, and could be an extension of the dike exposed south of the hotel on Star Island. The depression starts in the vicinity of Louis Wagner's Beach, where a few boulders of trap suggest its presence. Trap boulders appear in the stone walls west of the quarries, as one follows the low area northeasterly, indicating that the dike is in the depression. There is a prominent gully along the north shore a few hundred yards west of this dike. It contains an exposure of a dike three feet wide, and many dike boulders. This gully may be controlled in part by the foliation of the roof pendants as well as by the dike, since it parallels the structure of the metamorphic rocks.

The trap dikes 100 yards west of the Cedar breakwater on the southern shore of Smuttynose Island are interesting (Fig. 19). These

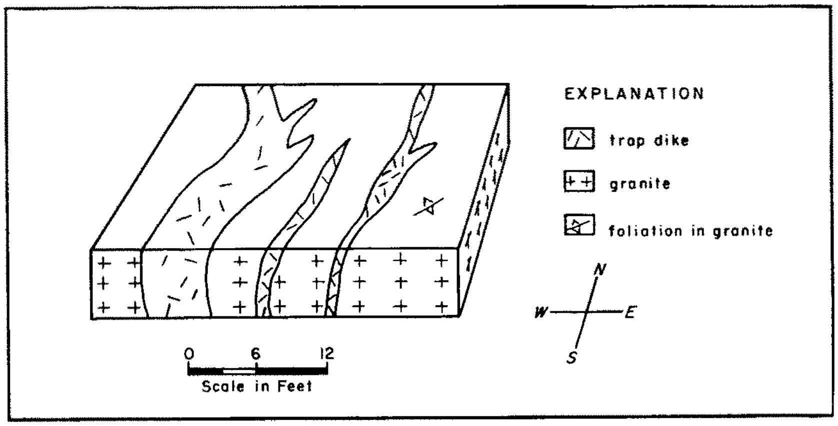


**Fig. 19.** Block diagram to show network of trap dikes on the southwest shore of Smuttynose Island west of the breakwater.

dikes make a network, and show how intricate the intrusions must have been, proving that they are not always one simple straight dike. These dikes are in the same line of strike as the dike on the eastern side of Star Island, and are probably its extension. They may also connect with the Devil's Glen dike. The dike, three feet wide, exposed on the north shore northeast of this locality, is probably the continuation of this network, as indicated by the dotted line (Fig. 18). The large gully, or indentation in the coastline, a few yards west of this northern dike exposure, is controlled by joints in the granite. It does not contain a dike.

Three small trap dikes are exposed just north of the "Cairn". One of these is a curving dike three feet wide, 300 feet N. 30° W. of the "Cairn". Another dike, six inches wide at the edge of the cliffs, N. 10° E. of the "Cairn", is interesting because it zigzags and bends around the joints in the granite. Still another small vertical dike, six inches wide, is found N. 55° E. of the "Cairn". This one can be followed N. 25° E. for 100 yards along the cliffs.

Three small trap dikes on the south shore are worthy of mention. One, eight inches wide, lies 125 feet west of Maren's rock. It makes a depression in the granite. Another is a small curving dike, one foot wide, exposed on the south shore, a little west of due south of the "Cairn". The third, eight inches wide, is angular and bent. It is exposed along the shore S. 60° W. of the "Cairn."

## Malaga Island

Malaga Island is a tiny island, 300 feet long, west of Smuttynose Island, and connected to it by a breakwater (Fig. 18). Although granite and pegmatite make up the bulk of the island, there are many patches of metamorphic rocks that show interesting structures. The eastern side contains stringers of schist, and a fine-grained biotite granulite 12 feet long and a foot across. The structure of these metamorphic rocks indicates that the harbor between Smuttynose and Malaga is the center of the syncline. A roof pendant of well-bedded biotite granite twenty feet wide is found about half way along the southern shore. Folds in these beds plunge 30 degrees southwest. In a small cove near the southwest corner of the island, an exposure of well-bedded biotite granulite, 50 feet wide and 200 feet long, is stained dark brown because of the weathering of pyrite in the beds. These slightly folded beds are on the northern limb of a syncline. At the extreme southwestern corner of the island there are even more highly contorted schists.

A roof pendant of biotite granulite in the center of Malaga Island is in the line of strike with the exposures to the southwest. The folds show the same southwesterly plunge, and the structure shows that these exposures are on the northwestern limb of a syncline. Another belt of the biotite granulite is exposed on the height of land just west of the breakwater.

The granites along the north shore of Malaga Island show a curious pitting due to unequal erosion. Small cavities, started by the erosion of the softer biotites, gradually became enlarged. Many of the pegmatites in the granite occur as stringers up to a foot wide, and parallel the foliation and strike of the roof pendants. No trap dikes were found on the island.

## Cedar Island

Cedar Island is a low circular island about one seventh of a mile across, lying between Star and Smuttynose Islands (Fig. 18). It is connected to Star Island by a breakwater made up of enormous blocks of Rockport granite, and to Smuttynose Island by a breakwater of local granite taken mostly from the Smuttynose quarries. The Island is made up largely of a medium to coarse-grained gray biotite granite, with an abundance of pegmatite, especially in the western section. The granite is well foliated and granulated, indicating movement after it was intruded.

Granite in the higher central part of Cedar Island contains stringers of biotite schist that trend northeasterly and dip steeply. Small isolated inclusions occur along the western shore north of the breakwater. East of the breakwater, along the southern shore, several roof pendants of metamorphic rocks appear to be the same belt as that found along the southeastern part of Star Island and the eastern end of Smuttynose. They have a northeasterly trend, dip steeply, and folds indicate that they are on the southeastern limb of a syncline. Some of these beds are hornblende-biotite schist; others are biotite schist and gray granulite. Pegmatites intruded into these metamorphic rocks parallel to the bedding, contain micas one inch across. One pegmatite swells from a width of three inches to fifteen feet, and cuts across the schist and granite about 100 yards east of the breakwater. A large pegmatite 30 feet wide is found about half way along the north shore.

The southeast point of Cedar Island is separated from the main part of the island by a gully that is controlled by the joints in the granite. This point stands high due to the resistant massive granite and pegmatite of which it is composed. A pegmatite dike four feet wide is found here with quartz in the center. It contains 2 inch feldspars and muscovites. A few roof pendants of schist and granulite are found in the granite on this point. One of these is a light-gray biotite granulite 20 feet wide and 40 feet long. A belt of this same gray granulite, fifty feet wide, is found just west of the point.

The northern part of Cedar Island has a few scattered schist stringers that have been folded and cut by granite and pegmatite. The granite in this area shows some streaking, or foliation.

A black trap dike six feet wide cuts across the eastern quarter of Cedar Island in a northeasterly direction. It narrows and bends towards the south. This dike is a breccia that contains angular fragments of granite an inch or more in diameter, a large slab of granite several feet long, fragments of dark-colored volcanic rock, and hornblende crystals an inch in diameter. Its chilled borders are striking. This breccia is probably the continuation of the brecciated dike on Star Island just south of Smith Monument, and is probably the dike that cuts across the eastern end of Smuttynose Island (Fig. 18).

There is a trap dike 6 feet wide half way along the northern side of Cedar Island. It appears to be an offshoot from the brecciated dike to the south, although the connecting section is obscurred. This dike bends, twists, and narrows from six feet to one foot. It is lost in boulders as it heads south towards the brecciated dike.

## Lunging Island

Lunging Island is really two small islands, each 1/7 of a mile across, connected or "tied" together by a bar, called a "tombolo", made up of boulders deposited by the ocean waves (Fig. 20). The island is largely granite and pegmatite, and is cut by four sets of parallel trap dikes with vertical dips and northeasterly strikes. The largest of the dikes is 8 feet wide, and occupies a depression that cuts across the northwest corner of the island north of Honeymoon Cottage. It is best exposed at its northern end on the south side of the wide gully that indents the coast, north of the cottage. The gully is controlled by the quarrying away of the dike. There is a trap dike 2½ feet wide parallel to this 8-feet-wide dike, on the north side of the same gully. It is separated from the eight-feet-wide dike by a block of granite several yards across. A small offshoot of the larger dike can be found between them. Since these dikes are so close together, it is supposed that they are related, and that they may connect in the depression where their presence is indicated by boulders of dike rock. Only one dike is exposed at their southwest extension along the shore.

Northeast of the cottage, there are outcrops of a trap dike four feet wide, the northern end of which appears to have offshoots (Fig. 21). It is interesting to follow the bends and "splits" in this dike. A dike two feet wide parallels it a few feet to the west, and an offshoot one foot wide is a little west of the middle dike. The main dike extends southwesterly, apparently crossing underneath the tombolo, to reappear as a dike 3 feet wide that can be followed at low tide across the northwest reefs of the southern half of Lunging Island. A trap dike two feet wide parallels this dike a little south of it. It can be followed northeasterly across the reefs, and cuts across the eastern tip of Lunging Island, on the north side of the harbor.

A dike six feet wide cuts across the middle of the southern half of Lunging Island, extending northeasterly along the southern side of the harbor, which it more or less parallels. It is well exposed in a gully on the south shore due south of the tombolo. A small, northerly striking offshoot, six inches wide, can be seen near its southwestern end.

It is possible that one of the dikes of Lunging Island is the extension of the dike that cuts across the northwest corner of Appledore Island. But because of the great distance between the islands, this could only be a guess. Navy divers are said to have found a trench between Appledore and Smuttynose Islands occupied by a dike. If this is true, this dike could be the extension of one of the Lunging Island dikes.

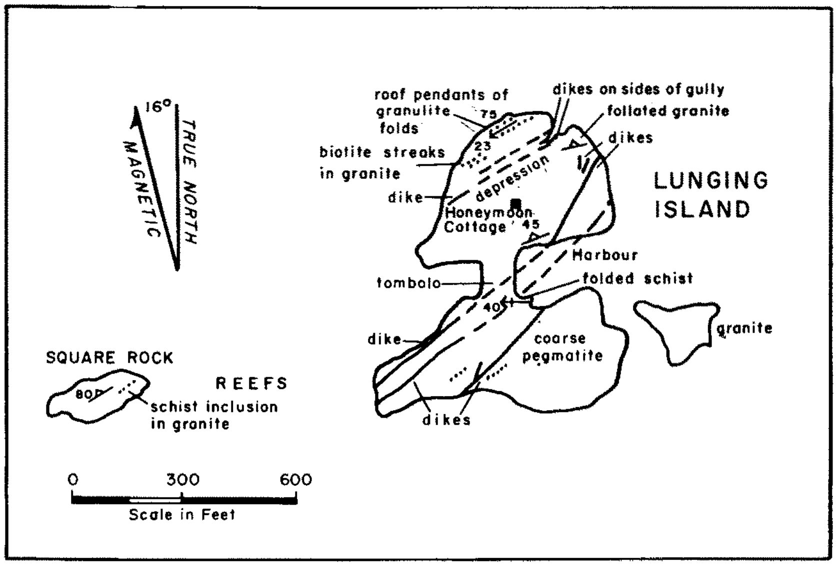


**Fig. 20.** Map of Lunging Island and Square Rock showing important geologic features. (See Fig. 8 for explanation of symbols).

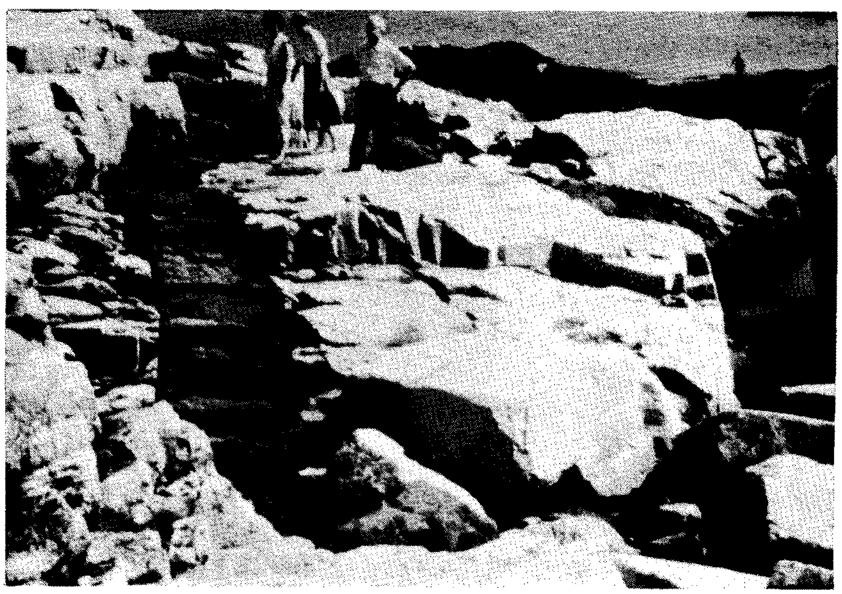

**Fig. 21.** Trap dike northeast corner of Lunging Island. Note how dike splits around granite in foreground. (Photo by Kirtley F. Mather).

Although most of Lunging Island is made up of granite and pegmatite, there are several roof pendants of metamorphic rocks in various localities. One of the most interesting exposures is found near the northwest corner of the island, just above high tide. Here, six or more beds of schist, gneiss, and granulite, occur as stringers 100 feet long, a foot or more in width, parallel to the shoreline. They dip northwesterly (Fig. 22). Their pinkish hue is caused by the presence of tiny, microscopic, pink garnets, which make up from 30 to 50% of some of the beds of granulite. The brown stain is from the oxidation of the iron in the biotite, which makes up about 10 percent of the rocks. The southwestern end of these exposures rolls over in an overturned anticline, with the individual crinkles of granulite and gneiss plunging 28 degrees southwesterly underneath the intruding granites. This folding may be seen in a northerly facing cliff due north of the cottage, on the height of land. South of these folds, the granite contains streaks of schist paralleling the northeasterly trend of the sediments. There are other places throughout Lunging Island which show this same streaking, indicating the presence of dissolved sediments.

South of the tombolo, at the southeast corner of the bar, at the southernmost point of the harbor, there are some small exposures of folded remnants of schist and granulite in the granite. These have the same southwesterly plunge and northeasterly trend as the folded metamorphic rocks along the northern end of Lunging Island. Just east of these exposures, on the small point, black tourmaline is found in the granite. A few scattered schist remnants, with the same northeasterly trend, are found in various places through the southern half of the island. Along the highest points in this southern section, the pegmatites contain feldspars up to four inches in size.

## Square Rock

Square Rock is a barren, whale-back shaped ledge about 100 yards long and 50 yards wide, lying 250 yards to the west of the southern part of Lunging Island (Fig. 20). It is made up almost entirely of a medium-grained grayish granite, with practically no pegmatite. There is a poorly defined northeasterly trend of the micas and quartz stringers in the granite. This is parallel to the N. 50° E. direction of an inclusion of biotite 20 feet long and six inches wide found at the eastern end of Square Rock. The foliation and granulation of the granite indicates that it was intruded during the late stages of folding. The foliation direction was controlled by the structure of the metamorphic rocks into which the granite was intruded.

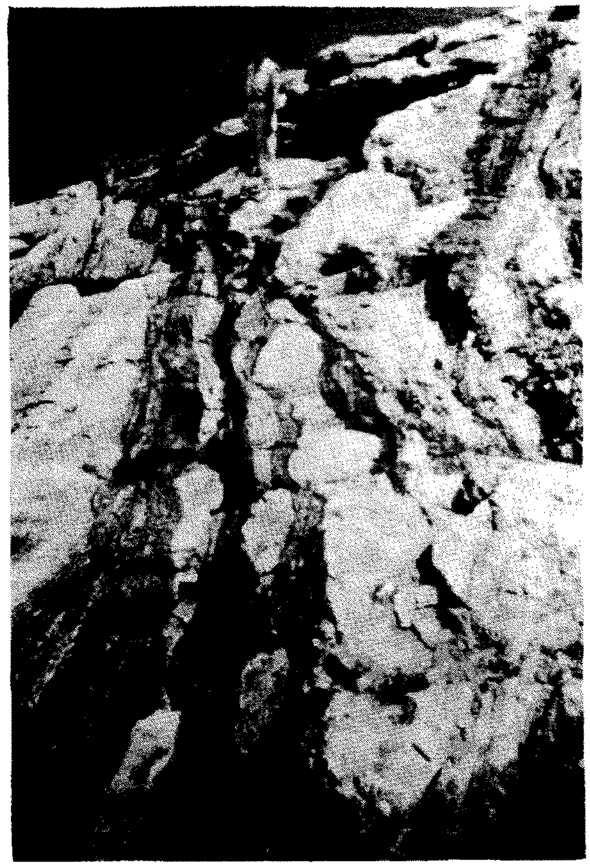

**Fig. 22.** Roof pendants of garnet-biotite-granulite on northwest corner of Lunging Island. Bedding is vertical (Photo by Kirtley F. Mather).

## Duck Island

Duck Island, Shag Rock, Eastern Rocks, and Mingo Rock, make up a group of islands about a mile northeast of Appledore (Fig. 23). They are unfortunately in a "restricted zone", and can no longer be visited because they are used by the government as bombing targets. Duck Island, the largest of the group, is about 1/7 of a mile long and 1/7 of a mile wide. It is made up largely of coarse pegmatite, with a little finer-grained granite. There is a poor foliation in the pegmatite and granite ranging in strike from northeast-southwest, to almost east-west. This is parallel to a belt of folded mica schist and granulite 200 feet long and 50 feet wide in the broad cove and depression near the middle of the southern shore. The folds in these metamorphic rocks plunge about 20 degrees west. A joint system in the pegmatites, parallel to the northeasterly strike of the schists, controls the shoreline and bays. The depression which runs northeasterly across the center of the island, is controlled by this same joint system, and is parallel to the foliation. This slightly sheltered area is the nesting place of a colony of cormorants.

The group of "Rocks" — Shag, Eastern, and Mingo — southeast of Duck Island, are excellent examples of "roches moutonnées", for they have been rounded and smoothed by glacial action. They are made up almost entirely of coarse, resistant pegmatite, with a little fine-grained granite. Their northeasterly trend is controlled by the joint planes. The channels between them were quarried away by the waves parallel to these joint planes. They may also represent areas of more easily eroded metamorphic rocks, since the channels lie parallel to the roof pendant on Duck Island, as well as parallel to the foliation direction.

## White Island

White Island, as seen from a boat, is a barren, rocky mass, one-tenth of a mile long, with cliffs 30 feet high along the northeast corner (Fig. 24). It is connected to Seavey's Island by a tombolo, or bar, that is covered at high tide. The vertical joint planes in the coarse white pegmatite that is the main rock of the island, control the southeast and east facing cliffs. The storm waves maintain the steep cliffs by "quarrying" the pegmatite along the joints planes. A deep trench controlled by the north-south set of joints separates the high promontory at the northeast corner from the southern part of the island on which the 85 foot high lighthouse stands. The gully, which cuts in a northeasterly direction across the center of the Island, passing underneath the covered walk which connects the lighthouse with the main building, is caused by a trap dike. A conspicuous belt of black rocks can be seen along the cliffs due south of the lighthouse, just above high tide mark. These are beds of black volcanic lavas, now amphibolite, that stand vertically so that the waves are attacking along the bedding planes. They are a roof pendant of the oldest rocks of the area, and are probably the same belt of metamorphic rocks found on Star Island just south of Smith Monument.

The gently sloping and smoothed western side of the northeast promontory, and the western end of the island, are excellent examples of "roches moutonnées" caused by the scouring action of the Ice Sheet as it pushed across the island from the northwest to southeast.

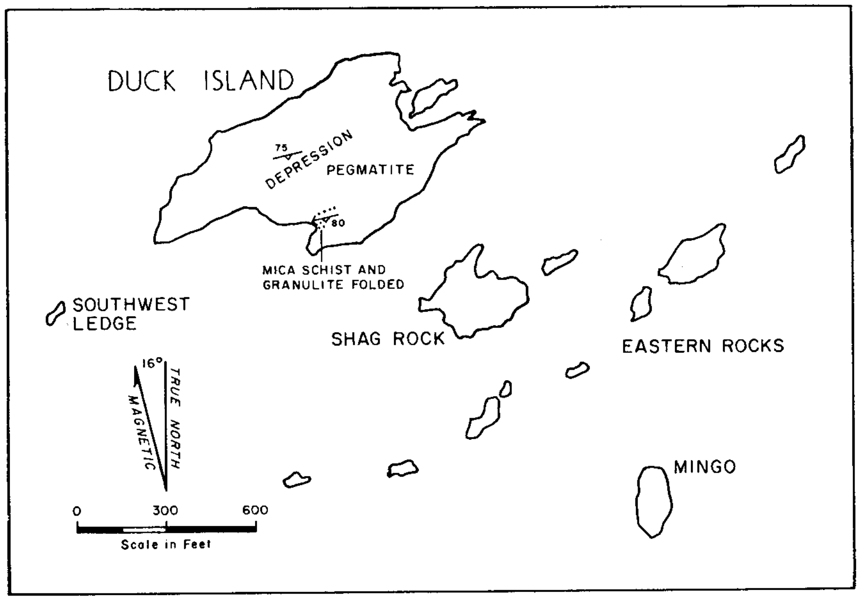


**Fig. 23.** Map of Duck Island showing geologic features. (See Fig. 8 for explanation of symbols).

A trip ashore on White Island is most interesting, for most of the rocks are an exceptionally coarse pegmatite. Feldspar crystals up to a foot in length are found on the higher parts of the island on the northeast promontory, where the pegmatite is made up of about 80 per cent feldspar, and 20 percent quartz, with some muscovite "books" or individual crystals several inches across. Black tourmaline crystals, ranging in size from 1/8 to 1/2 inch, and one crystal 4 inches across, as well as "rosettes" of tourmaline made up of tiny needles, are scattered through the pegmatite on the highest parts of the promontory. A few garnets are also present. A set of joints striking N. 30° W. makes the almost vertical, 30 foot high cliff on the extreme northeast corner of the island. This is the cliff that is so conspicuous from a distance, and is sketched on the front cover of this pamphlet. A second set of joints striking N. 50° E. controls the eastern cliffs and the trench between the promontory and the lighthouse. A third conspicuous set of joints, striking No. 40 E. is also present.

A black trap dike four feet wide cuts across the island in a northeasterly direction under the covered walk, causing a trench filled with blocks of pegmatite that have tumbled into the depression left by the more easily eroded dike. Just east of the south end of the dike,

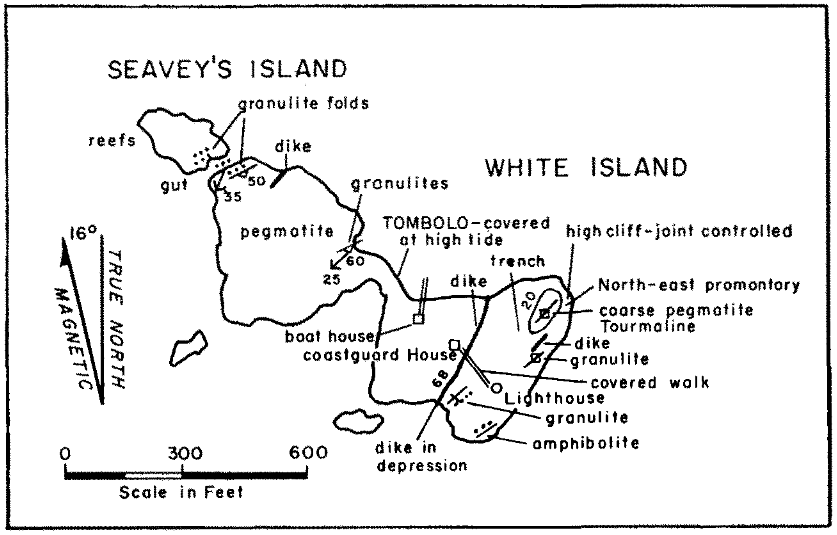


Fig. 24. Map of White and Seavey's Island showing important geologic features. (See Fig. 8 for explanation of symbols).

a small northeasterly striking roof pendant of biotite granulite, 30 feet long and 3 feet wide, is included in the pegmatite. The western part of the island is made up of a medium to coarse-grained granite, with some coarse granite.

An interesting roof pendant of the older metamorphic rocks, 100 feet long and 20 feet wide is found northeast of the lighthouse in the depression between it and the northeast promontory. The rocks, biotite, granulite and schist, strike northeasterly and are intruded by the pegmatite at their southerly end. The angular contact with the overlying pegmatite is well exposed just north of the lighthouse on a northeasterly facing cliff (Fig. 25). A small trap dike 1½ feet wide cuts diagonally across the roof pendant, heading southwesterly towards the lighthouse. South of the Lighthouse, a roof pendant of metamorphic rocks 40 feet long and 12 feet wide is well exposed on the cliff. They are black amphibolites interbedded with gray biotite granulite. These rocks were originally lava flows, ash and mud. Their strike is N. 650 E., with vertical dips, and they are cut by the pegmatite.

### Seavey's Island

Seavey's Island, sometimes called the "cow pasture", is connected to White Island by a narrow, bouldery tombolo that is covered at high tide (Fig. 24). It is a little smaller than White Island, containing

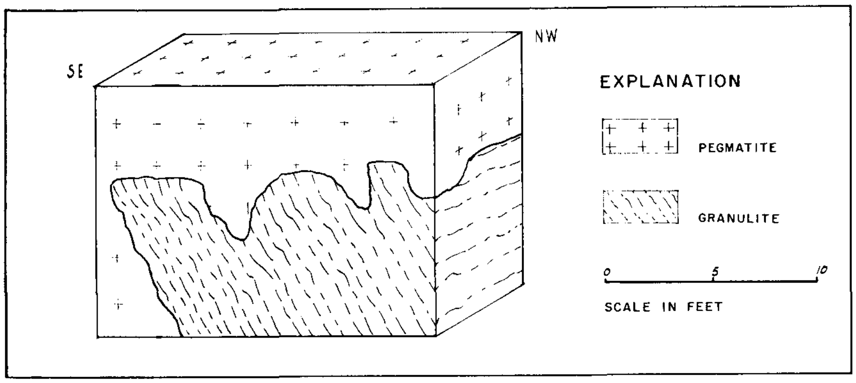


**Fig. 25.** Block diagram of roof pendant of granulite engulfed by pegmatite at foot of cliffs in depression just north of Lighthouse on White Island. Lines indicate bedding.

about 4 acres of land. Like White Island, it is made up primarily of coarse pegmatite with irregular stringers of finer granite. There are numerous vein-like masses of quartz in the pegmatite, as well as feldspar crystals up to a foot in diameter, with inch-long mica "books", and occasional garnets up to a quarter inch in size. The joints in the pegmatite are prominent along the northeast shore, and the quarrying away of the rock parallel to the joints by the work of the waves has made this section of the shore rugged. A poorly exposed, trap dike three feet wide, strikes northeasterly about half way along this northeast side.

About 100 yards north of the tombolo along the eastern side of the island, a small cave is caused by an easily eroded roof pendant of the older metamorphic rocks. The rocks are dark colored and pitted from weathering. They form a belt of biotite granulite and schist 50 feet wide, with a northeasterly strike and southwest dip. The folds plunge 25° southwest, and indicate that they are on the southeast limb of an anticline. They are cut across and overlain by the pegmatite, which rises above them in a cliff.

Another belt of folded, pitted biotite granulites, schist and impure quartzites, is found at the northwest end of Seavey's Island. This roof pendant strikes northeasterly, and the folds plunge southwesterly. The structure indicates that the beds are also on the southeast limb of an anticline. These easily eroded metamorphic rocks lie in the lower part of the northern end of the island, and are apparently responsible for the depression or "gut" 50 feet wide which separates a series of reefs to the north from the main part of Seavey's Island. A band 20 feet wide of these same metamorphic rocks can be seen on the reefs north of the depression, parallel to them.

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