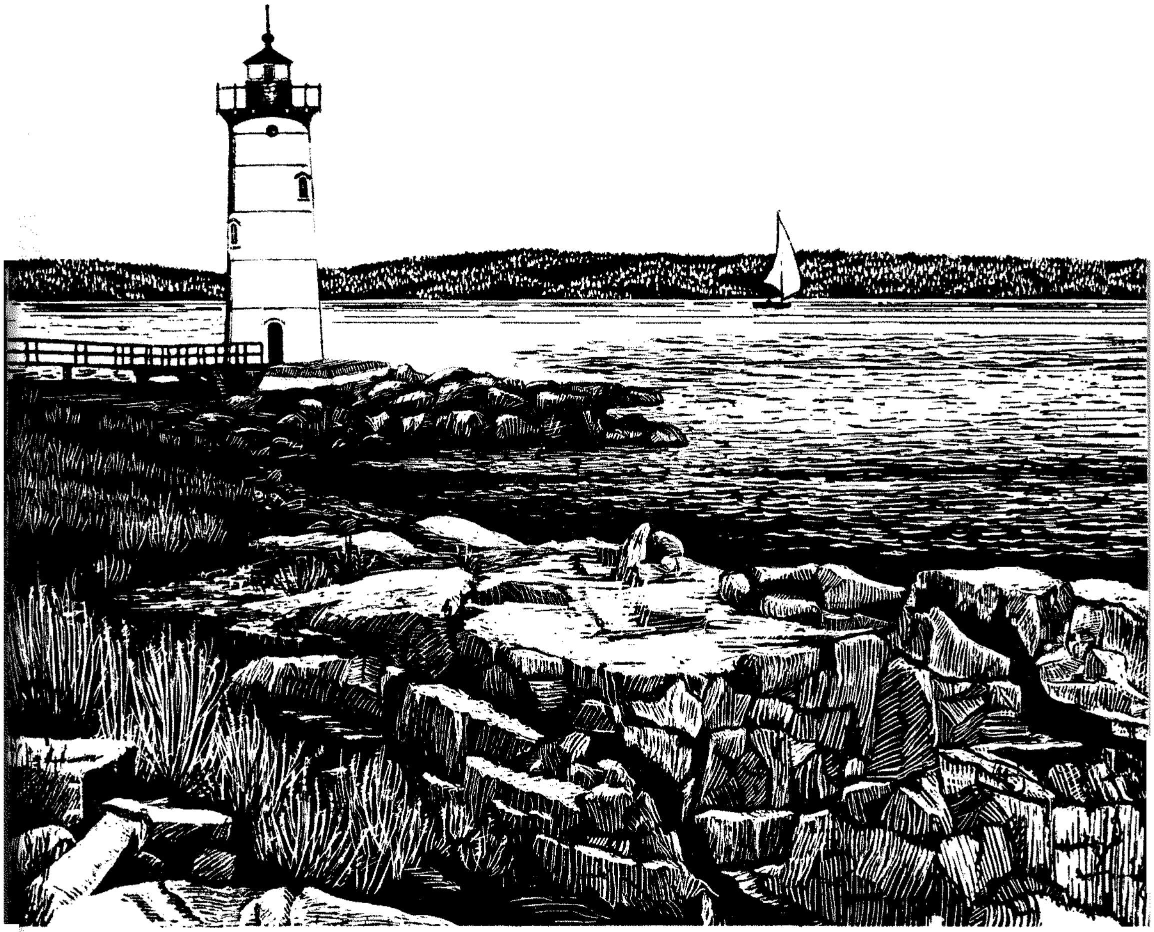

The Geology of the
SEACOAST REGION
New Hampshire

By Robert F. Novotny

Published by
NEW HAMPSHIRE DEPARTMENT of RESOURCES and ECONOMIC DEVELOPMENT

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SEACOAST REGION, NEW HAMPSHIRE

By Robert F. Novotny

Edited by T. R. Meyers

Prepared for the
NEW HAMPSHIRE DEPARTMENT OF RESOURCES
AND ECONOMIC DEVELOPMENT
CONCORD, NEW HAMPSHIRE 1969

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FOREWORD

Major geological field studies in southeastern New Hampshire were initiated in 1839 by Charles T. Jackson, the first state geologist. Since then there have been many studies in southeastern New Hampshire. The most recent detailed study was done in 1953-1954 by the late Dr. Robert F. Novotny, then a graduate student at The Ohio State University. The study provided the basis for his doctoral dissertation "Bedrock Geology of the Dover-Exeter-Portsmouth Region, New Hampshire" (1963). A copy of the dissertation has been provided for open-file reference at the office of the undersigned by the Chairman, Department of Geology, The Ohio State University.

Due to the untimely death of Dr. Novotny, his plan to prepare a report on the geology of the Seacoast Region, to be published by the New Hampshire Department of Resources and Economic Development, was never undertaken.

At the suggestion of the Mineral Resources Advisory Committee, Department of Resources and Economic Development, Professor T. R. Meyers was asked to make a field check of Dr. Novotny's map and to prepare a nontechnical manuscript on the geology of the Seacoast Region to accompany the map. With but a few small changes, the accompanying map is essentially that of Dr. Novotny's dissertation. The text, however, has been completely rewritten.

Although a serious attempt has been made to keep the number of technical terms at a minimum, many have been used. The reader should find most of them explained in any recent college-type dictionary.

The purpose of the booklet is to provide a brief summary and review of the geologic materials, processes, structures, and history of the Seacoast Region, New Hampshire.

GLENN W. STEWART
State Geologist

ACKNOWLEDGMENTS

The map for this booklet was derived in large part and the text, in part, from "The Bedrock Geology of the Dover-Exeter-Portsmouth Region, New Hampshire," the doctoral dissertation of the late Robert F. Novotny, which he wrote in 1963. The field work was done during the summers of 1953 and 1954. The doctoral study was made under the direction of Professor Carl A. Lamey, Department of Geology, The Ohio State University. Financial assistance was provided to Dr. Novotny by the Geological Society of America, The Ohio State University, the American Academy of Arts and Sciences, and the State of New Hampshire.

The people of southeastern New Hampshire are indebted to Dr. Novotny for his intensive studies of the geology of the Seacoast Region. His work in the field, laboratory, and reference libraries occupied much of his time from 1953 to 1963. The people of the entire state are indebted to him, and to many others like him, who have given a significant portion of their lives to the deciphering of New Hampshire geology. As a result, both layman and professional alike have gained insight into an important segment of our physical environment.

Helpful suggestions and critical comment related to the present non-technical booklet have been made by Professor Marland Billings, Harvard University; Professor John Lyons, Dartmouth College; Dr. Lincoln Page, U. S. Geological Survey; and Professor Glenn W. Stewart, New Hampshire State Geologist.

The excellent art work, drafting and pamphlet design were done under the direction of Mrs. Alice E. Cosgrove, Graphic Arts Section, New Hampshire Department of Resources and Economic Development.

INTRODUCTION

Geographic Setting

The seacoast region encompassed in this report includes about 286 square miles of southeasternmost New Hampshire (Figure 1, inset). It is an area of rapid population and industrial growth that forms a part of the Northeastern Industrial Complex of the United States. Means of transport are varied in the area. Highways serve the area effectively. These include Interstate 96, U. S. 4, and a network of state and town roads. Portsmouth Harbor serves the Portsmouth Naval Shipyard and provides for major imports of petroleum products, gypsum, coal, and salt. The gypsum is processed locally into plaster, plaster board, and related products. These, along with the other mineral imports, are distributed widely in New Hampshire, southwestern Maine, and beyond. Marine cable is manufactured in Newington and distributed widely from the port. Many fine homes and recreational facilities have been developed along the 27-mile shoreline. Lobster fishing is practiced actively along the entire New Hampshire shore. Freight service is provided to all cities of the area by numerous trucking lines and by the Boston and Maine Railroad. Human transport is limited to private cars and buses. Although the Pease Air Force Base is located in the area, there are no scheduled air line stops at this time.

The Landscape

The Seacoast Region encompassed in this report (See map in pocket) is included in the Seaboard Lowland section of the New England province as defined by Fenneman (1938).* It is a low undulating surface that rises gently to the northwest.

To the southeast of Dover and Exeter, approximately two-thirds of the area, elevations are generally under 100 feet. To the northwest of these two cities, elevations of 100 to 200 feet are common. The highest point, 386 feet, is on Green Hill, Barrington.

Although stream drainage is generally southeastward to the sea, there are sections of the larger streams and many tributaries that trend northeasterly or southwesterly, producing a subrectangular drainage pattern. Such a pattern shows that the distribution of underlying rocks and rock structures has had an effect upon stream development. Detailed information on the rocks and structures is presented later.

Most hills are of two types: (1) bedrock, usually thinly veneered with glacial drift, and (2) drumlins, consisting largely or entirely of

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* References are listed alphabetically at the end of the report.

glacial till. The most conspicuous bedrock hills are Green Hill in Barrington and Great Hill in Newmarket. Scores of drumlins, whaleback-shaped hills, are widely distributed. They are especially abundant in the town of Kensington. These hills are about one mile in length and stand 100 to 150 feet above their surroundings. Great Boars Head in Hampton, once an island, is a drumlin that has been largely removed by wave erosion. The detritus from this erosion was used by the sea to build a natural bar which now connects the island to the mainland. There are a few hills of glacial stream deposits in the area. Because of the sorting action of the flowing water which formed them, these hills contain stratified deposits of sand and gravel. Good examples are Pudding Hill and Fancy Hill in Madbury, and Keene (Cuse) Hill in south central North Hampton. Such hills, as well as less conspicuous deposits of stratified glacial deposits, contain rudely conical or bowl-like depressions called kettle holes. The deeper ones may extend below the water table, producing ponds such as Willand Pond in Somersworth, Barbadoes Pond in Madbury, Winkley Pond in Barrington, and a number of small unnamed ones in North Hampton.

There is evidence that southeastern New Hampshire has been uplifted in post-glacial time approximately 200 feet above present sea level. The evidence is of two types, depositional and erosional. Shore deposits of beach and delta-like type may be observed in the town of Rochester. These have been traced southwesterly somewhat to the west of the Seacoast Region. In addition, scattered patches of deposits similar to the fine sands, silts and clays accumulating along the shore today have been mapped throughout the area at various elevations under 200 feet (Goldthwait, 1953). As marine fossils have been found in these silty clays in at least two places, a marine origin is now accepted.

A number of drumlins in the Seacoast Region have erosional notches on their southeast ends or flanks, each consisting of a narrow terrace and a wave-cut cliff. These notches, often associated with beach-like deposits, are approximately 200 feet above present sea level. They do not determine a horizontal plane, but one that slopes gently southward to intersect the sea in the Boston area. This differential uplift of the region is attributed to recovery from coastal depression caused by the weight of thousands of feet of glacial ice during the Ice Age (Pleistocene). As the ice was thinner to the south, the depression was less, consequently, the uplift has been less to the south. The exact amount the land was raised is not known at this time. Although locally it must have been at least 200 feet, it may have been much more than this figure, for the level of the sea must have risen significantly due to the meltwater from wasting glaciers.

Although the preceding discussion generally implies a plane-like uplift of the area when relieved of its load of glacial ice, this is not entirely true. The surface seems to have warped locally. Great and Little Bays represent an uneven sag in the surface. Their connection to the sea has been maintained only by the intense scouring action of tidal currents in the Piscataqua River.

Another shore feature of local interest is the "Drowned Forest" in the small cove at Odiorne's Point, Rye. At times of very low tide the floor of the cove is exposed. It consists of patches of cobbles, pebbles and sand alternating with shallow tidal pools. Here and there the lower portion of a heavy stump may be seen. These are not conspicuous as they have been ground off level with the cove floor by rock fragments which have been dragged back and forth by wave action. Occasionally a whorl of heavy roots may be seen surrounding a stump. Beneath the forest remnants and cove floor is a deposit of peat of unknown thickness.

The cause of the "drowning" may be accounted for in a variety of ways. There may have been a local coastal sag, as in the case of Great Bay and Little Bay. It may be due to a world-wide rise in sea level caused by continuing glacial wastage. Quite probably, a number of feet of depression may be accounted for in a different manner. The beach ridge, at the head of the cove now occupied by the forest, must have formed much nearer the mouth of the cove. It was driven landward periodically by giant storm waves, a process which still continues. As the beach overrode the forest with its underlying peat, the floor of the forest must have been depressed by the weight of the beach ridge compacting the peat. Whether or not this subsidence could account for all of the depression involved in the drowning is unknown, which leaves an intriguing problem for some future geologist to solve.

There have been brief glimpses of two other drowned forests in the Town of Rye. One of these is southwest of Straw Point and the other is at Wallis Sands. The question of age of the drowned forests has been raised on many occasions. Recently, the age of wood from one of the forests has been determined by means of the Carbon-14 technique. The age reported is 3640 ± 230 years. (Personal communication from Mr. Abbot B. Drake to the N. H. State Geologist.)

The Geologic Map

The geologic map of the Seacoast Region is of the bedrock type. It shows the area as if it was stripped of its discontinuous veneer of loose boulders, sand, gravel, silt and clay.

In fact, the bedrock map is the geologist's description of the rock types and his interpretation of their distribution and structural rela-

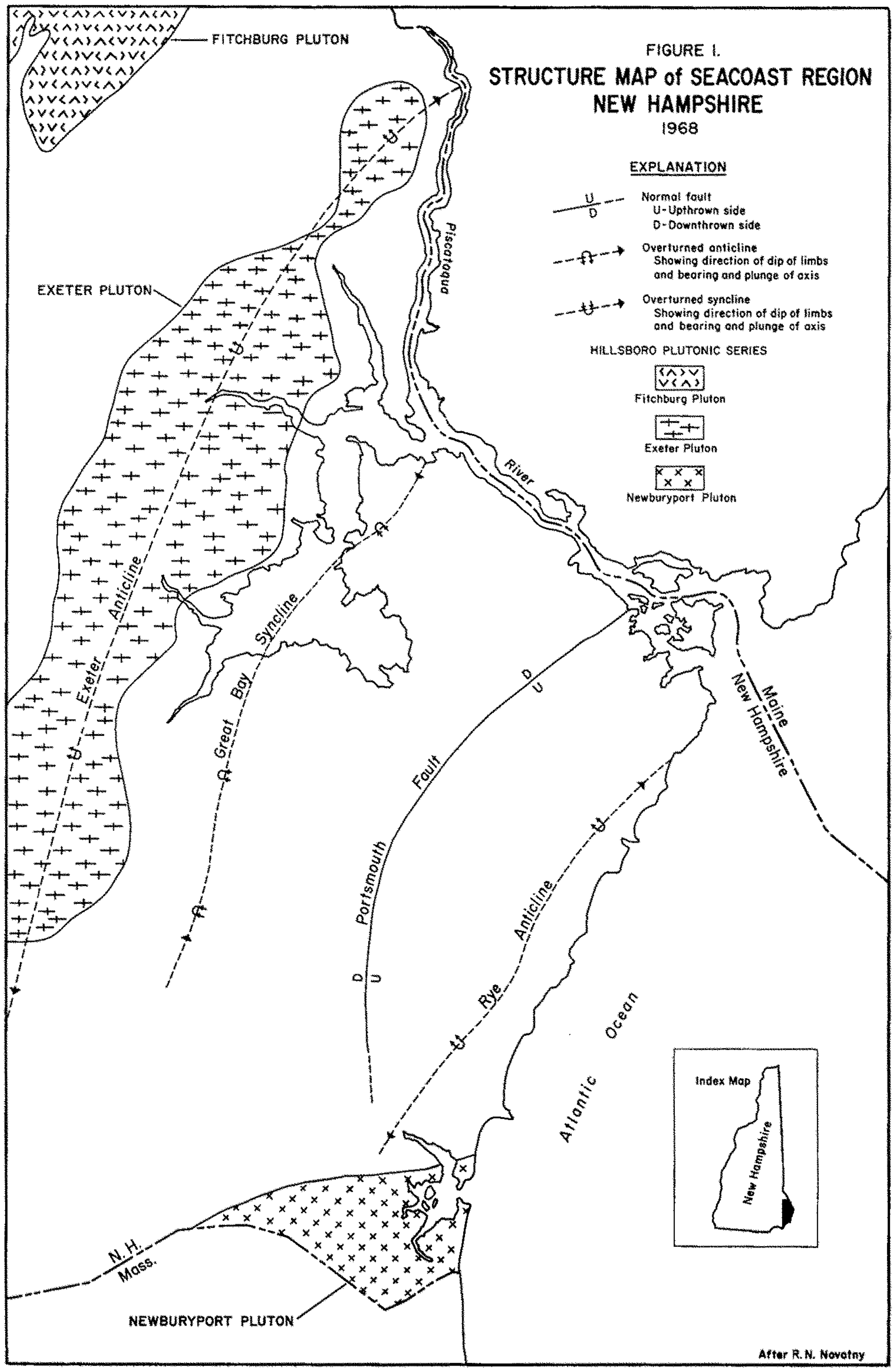


FIGURE I.
STRUCTURE MAP of SEACOAST REGION NEW HAMPSHIRE
1968

After R. N. Novotny

tionships. Where outcrops are abundant, he maps with confidence. Where they are scarce and widely spaced, he maps with much less certainty. Under such circumstances, he may offer approximations or alternate interpretations of structural and stratigraphic relationships.

To prepare a geologic map, it is necessary to examine thousands of rock outcrops wherever they may be found and to plot the position of outcrops upon field maps. The larger exposures, which often present much information, are most often found along streams and rocky shores, in road and railroad cuts, on rocky hillsides, and in active and abandoned quarries. Elsewhere the bedrock may be blanketed by inches to many feet of loose rock material. As a result of this cover, it is rare for a geologist to actually see more than a very small percentage of the bedrock. Most of his map, therefore, must be his interpretation of bedrock distribution based upon limited direct observation. Nevertheless, using techniques of the profession, and experience gained in similar geologic situations, his map is usually a close approximation to reality.

The bedrock map of the Seacoast Region shows the distribution of each rock type means of a distinctive-colored pattern. Even a casual examination of the map shows that most of the rocks trend in a north-northeasterly direction. This is the common trend of most of the older rocks in northern New England.

A closer look at the map and its "Explanation" shows that the bedrock consists broadly of two groups. The older of these is made of ancient sediments and some volcanics that have been deformed and recrystallized (metamorphosed). They include metasedimentary units "Orm," "Orv," "Sk," "Se," "Sb," and "Dl." The members of the younger Hillsboro Plutonic Series are "gr," "nqd," "pqm," "exd" and "qm." These latter were once molten and injected into the ancient sediments.

A still closer look at the smallest map details will reveal symbols used to indicate the nature and orientation of rock structures found in each rock type. When the geologist plots and relates all he has observed, he is able to prepare sections such as the three given with the map, and to draft a structure map (Figure 1). The structure sections show the relationship of each rock unit to the other units with which it comes in contact. These sections also indicate the probable thickness of the various sedimentary units. The structure map indicates the geographic extent of the major structures present in the region.

In a sense, the map represents the accumulation of data gathered by many workers for more than a century. As more data are accumulated and newer ideas evolve, future geologic maps of the Seacoast Region will denote this growth.

THE STORY OF THE ROCKS

The Seacoast Region contains a wide variety of bedrock types, including many that have had a long and complex history. The many types have been divided broadly into two groups: those derived from ancient sediments and volcanics and those that crystallized from once-molten rock material known as magma. The former have all been recrystallized and are referred to as metamorphic rocks. The latter are called igneous or plutonic rocks.

The sequence of development of the members of the two groups as determined by structural relationships, is given in the "Explanation" of the geologic map. The rocks decrease in age from the bottom towards the top of the column. The age of each rock unit, in terms of the geological time scale, is also given.

The very young, loose material which veneers the bedrock is not shown on the map. General information about each of the rock types will be reviewed briefly.

The Ancient Sediments

All of the rock formations listed under "Metamorphic Rocks" on the geologic map, consisted originally of sedimentary deposits and some volcanics. Most of the sediments seem to have been derived from the chemical and mechanical breakdown of rock materials flanking an ancient sea which is known to have extended at times from Alabama through New Hampshire to the Maritime Provinces, and probably beyond. Not only were sand and muds washed from the adjacent lands and deposited in the sea, but volcanic materials were provided as well. Most of the latter appears to be of the fragmental type, produced where volcanoes erupt explosively. One or two submarine flows have been recognized in the Rye formation by means of their pillow structure. A few thin layers, lenses, or nodules of calcareous material were deposited also. The total thickness of sedimentary and volcanic materials in the southeastern part of the state must have exceeded 20,000 feet. They range in age from Ordovician (?) to Lower Devonian (?) (Novotny, 1963) (Table 1).

All of the material that accumulated in the ancient sea has been deeply buried and compressed and contorted by mountain-building forces. In addition, the injection of molten rock provided heat and chemically-active substances to promote recrystallization and recombination of chemical compounds. As a result of these changes, a host of metamorphic rock types was created from the ancient sediments. Some details will be provided for each formation.

Rye Formation

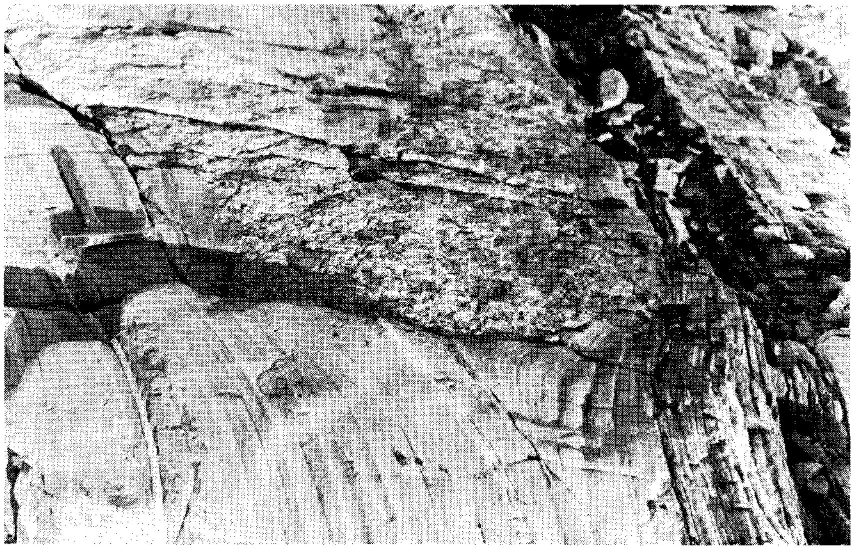
The Rye formation, so named by Billings (1956) from its excellent exposures in Rye, New Hampshire, is the oldest of the sedimentary units exposed in the Seacoast Region, and is one of the oldest formations to be seen in the State. The unit has an exposed width of four miles in the Rye area and narrows gently to the northeast. It disappears beneath the waters of the Atlantic after extending across Gerrish Island, Maine. To the southeast, it has been reported present at the Isles of Shoals (Fowler-Billings, 1959). To the northwest and southwest it passes beneath younger formations. It may be equivalent in age to the Ordovician Ammonoosuc volcanics of western New Hampshire (Billings, 1956). To the southwest it apparently reappears at the surface as the Boxford Formation in the South Groveland Quadrangle, Massachusetts (Castle, 1965). In New Hampshire massive outcrops are commonly conspicuous and abundant along the shore, tidal inlets and highways.

Two important subdivisions are recognized by Billings (1956), a lower metasedimentary member (Orm) and an upper metavolcanic member (Orv). Both are rather coarse-grained and distinctly banded, due to alternating concentrations of light and dark-colored minerals. There is a distinct predominance of light minerals such as plagioclase feldspar and quartz in the lower member (Plate IA and B), and abundant concentrations, of dark minerals such as biotite, hornblende, and actinolite in the upper member. The latter indicate the addition of iron-rich volcanic materials to the original sediment, providing the basis for dividing the formation into two members. Common rock types in the lower member are light-colored to gray schists, quartzites, and gneisses. These also appear in the upper member, but they are subordinate to dark gray, green, or brown schists, gneisses, and amphibolites. Quantitative mineralogic descriptions of the various rock types of the Rye Formation are given in Tables 1 and 2 of the Appendix.

Injected into the formation are many younger plutonic structures containing rocks such as granite, pegmatite and diabase. With one exception, the structures containing these rocks are too abundant and too small to show on the map. They are described more fully later under, "Intrusive Igneous Rocks."

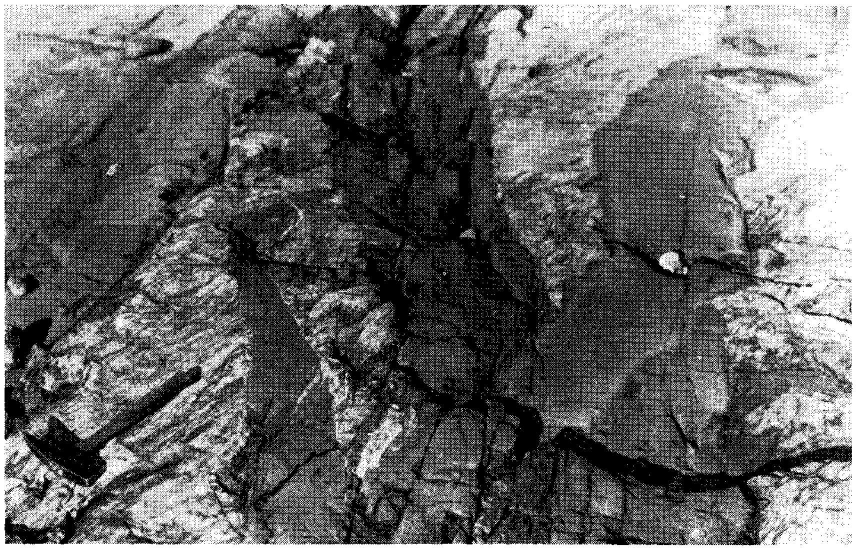
Kittery Formation

This sedimentary unit was first named the Kittery Quartzite by Katz (1917) from the excellent exposures to be seen along the Piscataqua River in Kittery, Maine. Here he estimated the thickness of the formation to be 1500 feet. Because of the diversity of rock types



A. Banded metasedimentary member of the Rye Formation cut by coarsely granulated pegmatite, Rye North Beach, Rye.

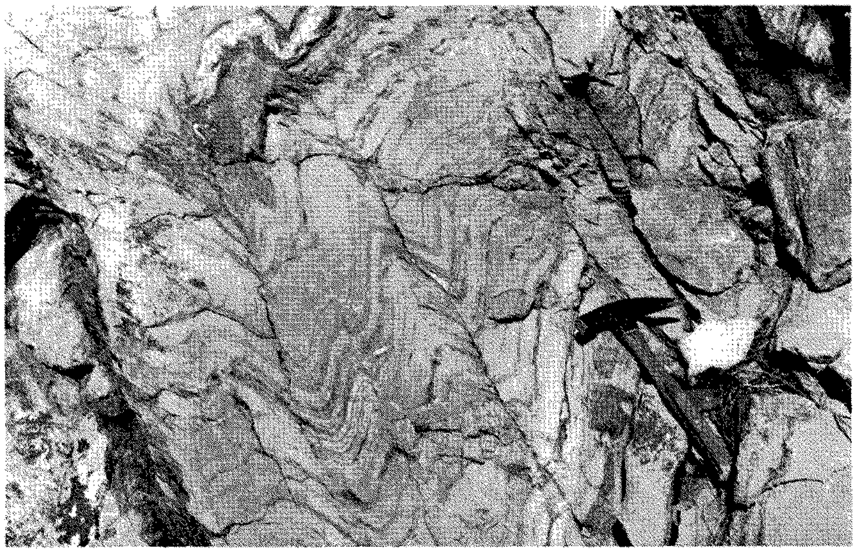
PLATE I



B. Banded and intricately folded metasedimentary member of the Rye Formation (under hammer) cut by several diabase dikes of the White Mountain plutonic series as seen near the Farragut Hotel, Rye.

A. Steeply plunging minor fold in the Kittery Formation, Cedar Point, Durham. The exposed surface is nearly horizontal. Cyclic deposition and graded bedding are indicated by the alternation of thicker granular with thinner foliated bands.

PLATE II



B. Tightly folded Eliot Formation in road cut at Lee Five Corners, Lee. Note the slaty cleavage parallel to the axial planes of the folds.

present within the unit, Novotny (1963) proposed that the name be changed to Kittery Formation. In New Hampshire abundant exposures are to be seen along the Piscataqua River opposite the type area, along the western shore of Great and Little Bays, and along Interstate 95 which traverses the entire length of the major belt of the Kittery Formation in New Hampshire. A second belt, now largely displaced by the Exeter pluton, consists of four separate remnants which now flank the pluton (Plate 1).

In the field, most outcrops of the Kittery Formation show gray, brownish-gray or dark green, fine-grained, banded, impure quartzite. Technically, the use of the term quartzite for a significant portion of the Kittery Formation may well be questioned (Lyons, John B., Personal communication). Modal analyses by Novotny (Table 3, Appendix) and in southwestern Maine by Woodard (1968) indicate that the lighter beds of the formation might well be termed fine-grained, lime-silicate granofels. However, as the association of the term quartzite with the formation is widespread, the questioned portion is considered as impure quartzite in this report. This type of rock is often interbedded with slate, phyllite, or fine-grained schist. As the latter rocks decompose and disintegrate more rapidly than the quartzite, a false impression is often gained that the formation consists almost entirely of quartzite. A characteristic of the quartzitic portions of the formation relates to jointing. A number of sets of joints and incipient fractures criss-cross the brittle quartzite. These rarely intersect near right angles, as is common in many rocks. A result of this unusual jointing is the production of distinctive, highly irregular and angular fragments as the rock disintegrates.

Banding in the impure quartzite horizons resembles that of varved clays and silts of glacial areas. Seasonal banding is indicated (Plate IIA). At this time, however, there is no evidence, other than appearance, to support a relationship to glaciation. Chemical analyses of the light and dark bands are given by Billings and Wilson (1964).

Detailed information of the various rock types in the Kittery Formation, with the mineral content of each, is given in Table 3, Appendix.

Eliot Formation

The name Eliot slate was given to the metamorphosed argillaceous sediments that are well exposed in the town of Eliot, Maine (Katz, 1917). Because other lithologic types are present also, Freedman (1950) proposed the use of Eliot Formation for this stratigraphic unit which he computed to be 6500 feet in thickness in the adjacent

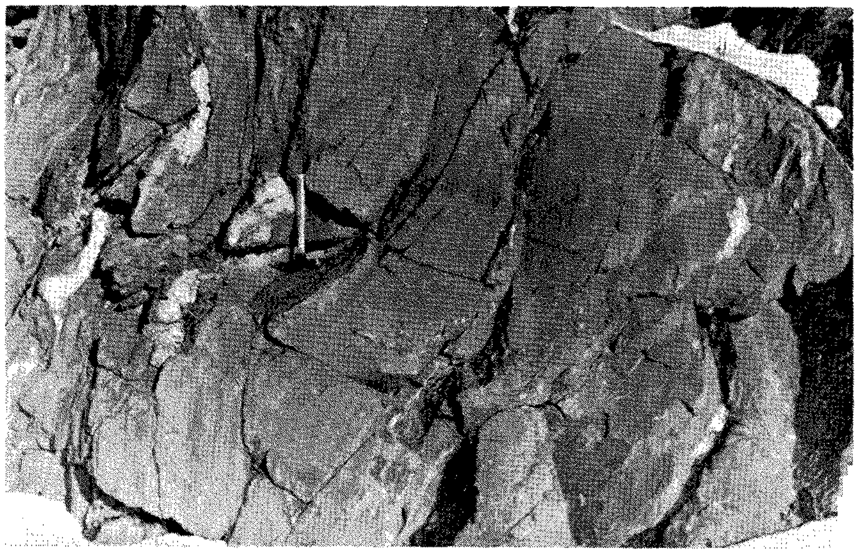
Mount Pawtuckaway quadrangle. The formation thins rapidly to the north where it rests unconformably upon the Kittery Formation. This relationship is to be seen at the mouth of the Great Works River, in South Berwick, Maine.

The formation is present in two belts flanking the Exeter pluton with its associated remnants of the Kittery formation. The eastern belt divides at the Piscataqua River with the broader portion traceable northeastward into Maine to the Agamenticus Complex (Hussey, 1962). The narrower extension of the eastern belt extends northward to the state line where it meets the western belt. To the southwest of the Exeter pluton, in part beyond the area mapped, the belts unite and continue to become part of the Merrimack group of northeastern Massachusetts (Billings, 1956).

Despite the considerable distribution of the Eliot Formation in the Seacoast Region, good outcrops are seldom seen except in places of active erosion by nature or man. This is due to the softness and susceptibility to weathering of most of its rock types. However, good exposures may be seen along the Piscataqua River, the south bank on the Cocheco River east of the City of Dover, and along the shores of Great and Little Bays. An excellent section has been recently exposed in a major road cut near the west end of the Durham bypass, just to the southwest of Lee Five Corners (Plate IIB). Occasional outcrops are to be seen elsewhere, commonly at the summits of low, kame-like elevations. These outcrops are related to siliceous, more weather-resistant horizons of the formation.

The original sedimentary materials of the formation consisted largely of thin-bedded deposits of clays, silts and fine sands with some calcium carbonate that accumulated during Middle Silurian (?) time. A gray quartz conglomerate may be seen resting uncomformably upon the Kittery formation at the mouth of the Great Works River, in the town of South Berwick, Maine, just outside the area of the map. These data, along with the distinct thinning of the Eliot Formation to the north, indicate a time break between the Kittery and Eliot Formations. Further study may show the Kittery to be Ordovician in age, rather than Silurian (?).

Metamorphism has converted the sedimentary materials to slate, crinkled and contorted phyllite and micaceous schists, and rather poorly recrystallized pyritic quartzite. When freshly exposed, the rocks of the chlorite zone are usually light gray or silvery-gray in color. In the biotite zone, they are usually dark gray or purplish-gray in color. Upon exposure to weathering the color rapidly alters to tan or brown. Detailed mineralogic information on these rock types is given in Table 4, Appendix.



A. Thick bedded, dark, granular Berwick formation, near Bellamy River dam, Madbury. A minor fold is to be seen at the hammer.

PLATE III

Berwick Formation

The Berwick Formation is present only in the northern and northwestern part of the Seacoast Region. This unit was originally called the Berwick Gneiss by Katz (1917), who also considered it to be the oldest of the ancient sedimentary units of the area. The limited amounts of gneiss present, by current definitions of this rock type, and the abundance of schist and lime-silicate rock, prompted Freedman (1950) to propose a change in name to Berwick Formation. The thickness of the unit is given as 2000 feet by Freedman, (1950) and after further field study, as 10,000 feet thickness by Billings (1956).

The Berwick Formation rests conformably upon the Eliot Formation with no known erosional break. The change from the silver-gray Eliot to the predominating dark gray of the Berwick is quite abrupt, commonly within a few hundred feet. As the change follows quite closely the isograd separating the chlorite and biotite zones, Billings (1956) has suggested that the difference between the two is the difference in metamorphic grade. This is certainly true in part. In addition there is noticeably less quartizite in the Berwick than in the Eliot Formation. As seen in the field, the prime difference is in texture. The Eliot is distinctly foliated, the Berwick is predominantly granular.

Originally the Berwick Formation must have consisted largely of argillaceous limestones. These yielded, upon metamorphism, a granular rock about two-thirds of which is dark-gray to brown biotite schist (Plate III A) and the remainder consists largely of beds and lenses of gray-green lime silicate rock. Outcrops of this formation are abundant and widely distributed, which is in decided contrast to the limited number for the Eliot Formation.

Detailed mineralogical information about the rocks of the Berwick Formation is presented in Table 5, Appendix.

Littleton Formation

A small, narrow band of New Hampshire's most widely distributed rock unit, the Littleton Formation, is present in the northwestern corner of the area mapped. Although the contact between the Littleton Formation and the underlying Berwick Formation was not observed in the field, structural evidence indicates that the relationship is a conformable one (Novotny, 1963).

The original sedimentary material of the Littleton Formation of this area appears to have been largely clay. Through metamorphism, the present silvery-gray schist, with abundant garnet and staurolite, was produced. Two mineralogical analyses of the Littleton Formation are given in Table 5, Appendix.

No sedimentary bedrock unit younger than the Littleton is known to exist in southeastern New Hampshire.

IGNEOUS ROCKS

General

Southeastern New Hampshire presents intrusive igneous rocks in great variety. There is variation in structural size, shape, rock type and age. In the Exeter pluton, for example, there are innumerable aplite dikes, a few millimeters to a few inches in thickness, while the pluton itself, which is largely diorite, has maximum surface dimensions of approximately four by twenty miles. Two plutonic series of rocks have been identified in the area, the older Hillsboro Plutonic Series and the younger White Mountain Plutonic Series. Five mapable units have been included in the Hillsboro series, which is thought to be of Upper Devonian (?) age, and equivalent to the New Hampshire Plutonic Series of western New Hampshire. The White Mountain series is limited locally to dark-colored dikes and sills which are considered to be of Upper Triassic age. These latter instrusives are numerous and widely distributed, but are too small to be shown on the geologic map (Novotny, 1963). Each rock type will be reviewed briefly.

Hillsboro Plutonic Series

Neither the absolute nor the relative ages of the members of this series are known with certainty. In the absence of such information, Novotny (1953) has arranged them in order of decreasing foliation and granulation imposed upon them during the Acadian orogney of Late Devonian (?) Time.

Granite and Pegmatite

These tan to near-white, moderate to coarsely-crystalline foliated rocks are intimately related to one another. In places, they may be seen to grade from fine-grained granite to coarse pegmatite. Most are present as small sills or lenses in the Rye Formation and are oriented paralled to its foliation. Locally, however, dikes cut across foliation and bedding. The highest concentration and largest masses of granite and pegmatite are to be seen in the Breakfast Hill area in the northwestern part of the Town of Rye. Foliation and pronounced fracturing of these rocks are common (Plate I A).

Primary minerals present in both the granite and pegmatite are quartz and feldspar species such as microcline, albite, and oligoclase. The latter is especially common in the pegmatite, along with some muscovite, biotite, black tourmaline and garnet. Secondary minerals such as sericite, chlorite, and epidote may be observed with the aid of a microscope. Detailed mineral analyses of the granite and pegmatite are given in Table 6 of the Appendix.

B. The Newburyport quartz diorite contains abundant inclusions of nearly black diorite as shown near the east end of Rock Road, Seabrook.

PLATE III

Newburyport Quartz Diorite

This dark, medium-grained, lightly-foliated quartz diorite is present in the southeastern part of coastal New Hampshire. It was named by Emerson (1917) for the city of Newburyport, Massachusetts, which lies about four miles to the southwest.

For many years there has been uncertainty and diversity of opinion as to the age of the Newburyport quartz diorite. Novotny (1963) considers it to be Late Devonian (?). Castle (1965) reviews the data at hand in New Hampshire and northeastern Massachusetts and tentatively concurs with Novotny's dating.

Inclusions are common in the Newburyport, with nearly black diorite most common (Plate III B). In places the inclusions make up the bulk of the bedrock. Novotny considers the diorite fragments to be from an earlier phase of the Hillsboro Plutonic Series. Detailed mapping is needed to show the extent of this intrusive breccia.

Mineral analyses of the quartz diorite and its inclusions are given in Table 6 of the Appendix.

Porphyritic Quartz Monzonite

The porphyritic quartz monzonite member of the Hillsboro Plutonic Series is limited in extent, in the area mapped, to the extreme southeastern part of New Hampshire. It is a lightly foliated medium gray plutonic rock consisting largely of quartz with light phenocrysts of microcline. Two mineralogical analyses of the quartz monzonite are given in Table 6 of the Appendix.

As in the case of the Newburyport quartz diorite, there is some question as to the age of the porphyry. Novotny believes that it is a differentiate of the Newburyport quartz diorite, and entirely enclosed by the latter. Additional data on this point may be provided as the current mapping program of the United States Geological Survey in northeastern Massachusetts progresses.

A small amount of aplite and pegmatite are present in the quartz monzonite. They are lighter in color, but have approximately the same mineralogy. The exception is in the pegmatite where plagioclase is sodic rather than calcic.

Exeter Diorite

The Exeter diorite is the most widely distributed and abundant unit of the Hillsboro Plutonic Series. The major portion is in a large pluton whose maximum dimensions are approximately four by twenty miles. In addition, there are eight satellitic bodies. The large pluton has displaced the bulk of the westernmost of the two belts of Kittery quartzite. Six of the eight smaller bodies are in the eastern belt of the Kittery. The other two are immediately adjacent to it. The general trend of the diorite conforms quite closely to regional structure.

A. Highly sheared Exeter diorite and aplite dike, intersection of U. S. 4 and N. H. 108, Durham. Observe the displacement of the dike below and to the left of the hammer.

PLATE IV

Although much of the Exeter diorite is monotonously the same in appearance, there are a few distinctive variations. In the large pluton, the southern end is quite dark and is identified as a gabbro. The bulk of the remainder resembles diorite in hand specimens. Microscopic examination often shows the presence of considerable microline and quartz to the north in Durham, Dover and Rollinsford, indicating the presence of quartz diorite and quartz monzonite. Detailed mapping to show the distribution of each of these rock types has not been done.

Cutting the diorite in many outcrops are small dikes of off-white aplite. These are a few millimeters to a few inches in thickness (Plate IV A). Their planeness, orientation, and texture suggest that they occupied the first joints to form in the diorite.

Outcrops of the diorite are large, abundant, and widely distributed. Glacial erosion has shaped large numbers of them into roches moutonnées.

Mineral analyses of four rock species to be found in the Exeter pluton are given in Table 7 of the Appendix.

Quartz Monzonite

The northwestern corner of the Seacoast Region map (Plate 1) shows the presence of quartz monzonite. This is but a minute portion of the northern end of a major plutonic complex which Emerson (1917) called the Great Central Batholith. He traced it from Barrington, New Hampshire, across Massachusetts into Connecticut. Billings (1956) has mapped the New Hampshire portion of this structure as the Fitchburg pluton.

In the area shown on the geologic map, the quartz monzonite is dominantly a medium- to coarse-grained, light-gray to buff rock which consists essentially of microcline, albite-oligoclase, and quartz. Two mineralogical analyses of the quartz monzonite are given in Table 7 of the Appendix. Cutting the quartz monzonite are large numbers of granite pegmatites.

White Mountain Plutonic Series

The White Mountain Plutonic-Volcanic Series of New Hampshire involves a complex variety of intrusive and extrusive rocks. In the Seacoast Region, however, the series is limited to the dark, fine-grained, often porphyritic diabasic sills and dikes that are to be seen throughout the region. They are so numerous and small in size, usually under ten feet thick, that they could not be shown on the geologic map.

These rocks are injected into tension fractures that formed widely in the region following the long interval of crustal compression which affected all of the ancient sediment and the older members of the Hillsboro Plutonic Series. Such a reversal of forces is the normal sequence in regions of complex mountain development. A review of the nature and causes of structures to be seen locally is given in the next section of this report. Mineral analyses of two variations of diabase are given in Table 8 of the Appendix.

The geologic age of these sills and dikes of the White Mountain Plutonic-Volcanic Series has been in doubt for many years. Through the work of Lyons and his associates (1957) a mean age of 186 million years for the series has been determined. Hatch (1963) using Lyons' figure and the most recent geologic time scale of Holmes (1959), assigns an Upper Triassic geologic age to the series.

STRUCTURES

General

The earliest evidence of structural development in the Seacoast Region began with the sagging of an unknown surface beneath the sea to form a northeasterly-trending trough in which sedimentary and volcanic materials accumulated. The total thickness of the sedimentary materials is unknown, but it must have totaled a few tens of thousands of feet. Such a trough, with its contents of sediments, is known as a geosyncline. It is a portion of the complex Appalachian geosyncline which has been traced from Nova Scotia to Alabama.

Subsequent to the local filling of the extensive geosynclinal sedimentary trap, many kinds of structures from mountainous to microscopic size have been created. These were formed during a time of structural development, including mountain building, which geologists refer to as "Acadian orogeny" (Figure 1). Each of the structural types recognized locally is considered briefly.

Folds

Folds, as is true also of other local structures, vary widely in size. They were produced by accumulation of sufficient earth crustal pressure to wrinkle, or fold, the sedimentary materials held in the geosyncline. Most of the folds trend northeast-southwest. It is reasoned, therefore, that the direcion of greatest pressure must have been oriented in a northwest-southeast direction. When folds contain material that has been arched they are referred to as anticlines. Where depressed, they are synclines. Two giant anticlines are shown in the sections on the geologic map. Imagine if you will, Section A-A and B-B joined to form a single section at "exd," the Exeter diorite. Note that the upward projection of the Kittery and Eliot formations would form an arch over the Exeter diorite. This arched structure is the Exeter anticline. About four miles to the southeast is the downwarped Great Bay syncline, and at the Atlantic shoreline is the Rye anticline with most of its eastern limb submerged.

Smaller, unnamed folds, inches-to-feet in size, may often be seen in any of the ancient sedimentary rocks which form the limbs of the major folds (Plate II B). Minute folds have been found in thin sections of these rocks. Most of the minor folds have their parts parallel to those of the great folds of the area, but this is not strictly true of all folds, as will be noted later.

B. The Portsmouth fault as exposed near the New Hampshire Vocational Institute, U. S. 1 By-pass, Portsmouth. The nearly vertical, brecciated fault zone separates the upthrown Rye volcanic member on the right from the downthrown Kittery Formation on the left.

PLATE IV

Faults

Faults are fractures along which displacement or faulting, has taken place. Numerous small faults are to be seen in all rock units of the region (Plate IV A). Quantitatively, their abundance appears to be rudely related to the brittleness of the rock containing them. Most involve displacement of a few inches or feet. Only one was deemed by Novotny (1963) to be sufficiently important to show on the geologic map. This is the Portsmouth fault which forms the Rye-Kittery contact for approximately nine miles (Plate IV B). There are so few outcrops of the fault zone, and these are poor, that no attempt was made to calculate the fault displacement.

Earlier, Billings (1956) interpreted the northern limit of the Newbury quartz monzonite as a thrust fault. Since the work of both Billings and Novotny, there has been considerable detailed mapping in Essex County, Massachusetts. In a preliminary summary of findings, Castle (1965) shows the presence of a major fault trending northeastward through Lawrence and Groveland. As subsequent work is carried on towards southeasternmost New Hampshire, it may be possible to relate the Massachusetts fault to one or the other of the faults noted above.

Major Plutons

There are three major plutons represented on the geologic map. Only one, the Exeter pluton, lies largely within the bounds of the Seacoast Region map. In general, it is aligned in a northeasterly direction and conformable to the regional trend of fold axes imprinted upon the metasedimentary rocks by the Acadian orogeny.

Joints

Joints are plane or gently-curved fractures in rocks along which there has been limited displacement of the opposing rock surfaces. These structures are to be seen in all local rock types.

Careful measurement of the orientation of 112 joints in the Rye and Kittery Formations, and the granite and pegmatite injected into the Rye Formation was made by Novotny (1963). A graphic analysis of the data demonstrated that most joints were vertical or nearly so. The most common trend is in a northeast-southwest direction, with most of the remainder trending east-west.

Although the origin of joints is not always readily determined, the nature of the force or forces that ruptured local rocks can often be determined. In the dark dikes and sills of the region many of the fractures extend through the rock at right angles to the enclosing walls. Coarse prisms of rock result, which rudely resemble stacked cordwood. These joints are tension fractures resulting from the cooling and shrinking of the once-liquid rock.

Many, possibly most, of the local joints are shear joints. If there is a direction of major pressure, rock will be compressed in this direction. At right angles to the pressure, the rock tends to elongate. Between these two directions there must be a shearing action. If the force applied is sufficiently great the rock will be ruptured, forming shear joints.

Shear joints and other structures may be caused by two forces acting against each other, but not in direct alignment. Such an arrangement of forces tends to produce a rotary motion in the mass upon which they act. If sufficient force is present, rocks may develop shear joints, faults, or minor folds. There is accumulating evidence to suggest that such a shear couple left its structural imprint in the Seacoast Region during late Acadian orogeny. These evidences include the distinct, pinching of the Exeter Pluton just south of Dover; the sawtooth margins of the Exeter pluton, especially on the east; the clockwise rotation of Kittery Formation bedding east of the Exeter pluton; as well as minor faults, folds, crinkles and shear joints that are not in harmony with the main Acadian thrust.

Minor Structures

Structural features of small size, in addition to small folds, faults and fractures as noted previously, are often common in many of the rocks of the Seacoast Region. Such minor structures are relatable to stress and are of prime importance to structural and metamorphic geologists and petrologists. The most commonly observed of these is foliation. This is a structure resulting from the parallel alignment of platy minerals such as muscovite, biotite, sericite and chlorite under directional stress. Foliation is of the schistose type where coarse-grained, and is of the slaty cleavage type where microfoliation is involved. Alternating bands of schistose and granulose metamorphic minerals constitute gneissic structure. On occasion elongate minerals such as sillimanite, actinolite, or hornblende are formed in parallel alignment in schistose or gneissic rocks. This constitutes a structure known as lineation.

METAMORPHISM

Those portions of the earth's outer rocky shell that show evidence of profound deformation of sedimentary materials, and intrusion of plutonic rocks, as has been documented for the Seacoast Region in preceding pages, have had distinct changes made in the mineralogy or structure of the original sedimentary and older igneous materials. These changes result from a complex of causes known as metamorphism. The resulting changed rocks are metamorphic rocks.

Major causes of metamorphic change in rocks are: loading by thousands of feet of overburden; directed pressure of mountain-building magnitude; heating through deep burial, radioactivity, or heat from igneous intrusion; and material exchange, by partial or complete replacement of minerals in a rock by material introduced in a fluid from an outside source.

The high directed pressure of the Acadian orogeny, along with loading, heating and some material exchange, account for the abundance of slate, phyllite, schist, and gneiss in the ancient sedimentary and older plutonic rocks of the region. Quartzites and granulites could have been produced without directed pressure, but the latter is intimately related to most local rocks. Material exchange is involved in the production of lime-silicate rocks in the Rye, Kittery and Berwick Formations, and the abundant garnet and staurolite of the Littleton Formation.

Geologists have devised several means to indicate the degrees or levels of metamorphism. The system chosen by Novotny (1963), and used here, is that of Turner and Verhoogan (1960). In this, rock units shown on geologic maps are divided into metamorphic zones by means of lines of separation known as isograds. It is possible to do this as certain minerals have pressure-temperature minima beneath which they cannot form. The key minerals used here, in order of ascending degree of metamorphism, are: chlorite, biotite, oligoclase-actinolite, and sillimanite. The intensity of metamorphism increases both to the northwest and to the southeast from the center of the Seacoast Region map area, and that the intrusion of the Exeter diorite has had no apparent effect on the distribution of the isograds.

HISTORICAL SUMMARY

The known sequence of geologic events in the Seacoast Region is long and remarkably varied. The major events, with both the relative geologic age and the absolute time of each event in years, have been tabulated and are shown in Table 1. Until the coming of the "Nuclear Age," geologists were forced to use relative time terms to indicate the age of all but the most recent geologic events. These relative time terms are given in columns headed "ERA," "PERIOD," and "EPOCH." The "TIME" column indicates the number of years since the beginning of the various eras, periods and epochs listed. These particular data have been compiled by Kulp (1961) from many radioactive dating studies of minerals and rocks. With continuing improvement of radioactive dating techniques, and rapidly increasing number of confirmatory time determinations made, geologists are placing more and more confidence in the accuracy of the absolute geologic time scale.

To assist the reader to envision the ever changing geology of the region a series of diagrams has been included.

Figure 2 is Stewart's (1961) concept of the geologic setting in New England during Early Devonian time. He shows the close of sedimentation in the geosyncline. This process continued for more than 100 million years since the beginning of deposition of the Rye formation. It may have begun before this event. During the long interval of sedimentation, it was necessary for the floor of the geosynclinal trough to subside to make room in the sea for the accumulating materials.

The total thickness of sediments that accumulated locally may never be known with certainty. Data and estimates from various sources suggest that the thickness may have been as much as 30,000 feet (Figure 3). What may have accumulated beneath the Rye Formation may be hidden permanently. Probably only a small portion of the Littleton Formation remains. The rest has been removed by erosion.

The sequence of sedimentary materials was intensely deformed during the Upper Devonian (Acadian orogeny). This was accompanied by the successive intrusion of granite and pegmatite into the Rye Formation, of the Newburyport quartz diorite and the porphyritic quartz monzonite of southeasternmost New Hampshire, and of the Fitchburg pluton and the Exeter diorite into the central and northwestern part of the area mapped. It is probable that local relief was truly mountainous at this time, but never so high as projected in Figure 4. Erosion would have subdued the ranges as folding progressed.

ERA	PERIOD	EPOCH	TIME (yrs. since beginning)		SEQUENCE OF GEOLOGICAL EVENTS	
CENOZOIC	Quaternary	Recent	25,000		Erosion Drowning of forest Growth of forest at Odiorne's Point Deposition of peat Uplift	
		Pleistocene	1 M.		Deposition of glacial lake and marine deposits Deposition of glacial stream outwash Deposition of drumlins and till blanket	
	Tertiary		65 M.		Erosion	
MESOZOIC	Cretaceous				Erosion	
	Jurassic					
	Triassic	Upper			White Mountain Plutonic Series Diabase dikes and sills intruded	
		Lower	230 M.		Erosion	
PALEOZOIC	Permian		280 M.		Erosion	
	Pennsylvanian		310 M.			
	Mississippian		345 M.			
	Devonian	Upper	365 M.	Hillsboro Plutonic Series	Quartz monzonite intruded Exeter diorite intruded Major folding and recrystallization end Porphyritic quartz monzonite intruded Newburyport quartz diorite intruded Granite and pegmatite intruded Folding and recrystallization begin	Acadian Orogeny
		Lower	405 M.		Littleton Formation deposited	
	Silurian		425 M.		Berwick Formation deposited Eliot Formation deposited Erosion Kittery Formation deposited	
	Ordovician		500 M.		Rye Formation deposited Volcanic member Metasedimentary member	
	Cambrian		600 M		No record	

Table 1. Geologic Time and Events of the Seacoast Region
(Not to scale. M = Million)

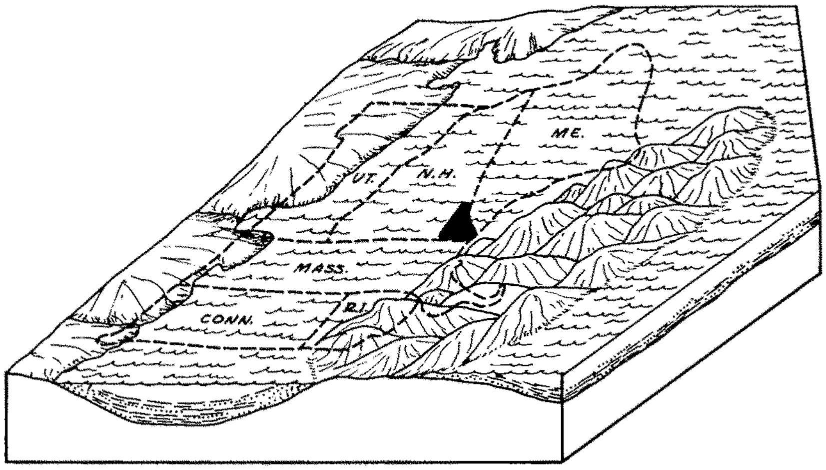


Figure 2. A geologist's interpretation of the inland sea which flooded much of New England during the Early Devonian period and received sediments from adjacent land areas. The location of the Seacoast Region (after Stewart, 1961) is shown in southeastern New Hampshire.

The intrusion of the last two plutons, Exeter and Fitchburg, took place at the close of the Acadian orogeny. Some crustal deformation followed shortly thereafter, causing minor fold, fault, and shear joint structures by forces tending to rotate the Seacoast Region in a clockwise direction.

Erosion must have reduced the Acadian mountain structures to within a few thousands of feet of the present surface by Upper Triassic time, when the dark diabase dikes and sills of the White Mountain Plutonic Series were intruded. The pronounced chilled margins suggest a near-surface temperature of the enclosing bedrock. And the presence in the diabase of gas bubbles, now filled with white calcite, suggest near-surface pressure on the molten rock, thus permitting gas to escape from solution. Further modest erosion lowered the bedrock surface essentially to its present level as shown in Figure 5.

In the Pleistocene epoch, southeastward flow of glacial ice scoured the rock surface. As the ice flow lost its vigor it deposited a blanket of glacial till and the streamlined drumlins. Meltwater streams from the wasting ice deposited a variety of ice-contact sands and gravels upon portions of the till sheet. In the coastal lowlands, which were then flooded by the sea, clays and silts accumulated. Withdrawals of the sea permitted recent stream, shore, and swamp deposits to form. A diagrammatic illustration of the various Quarternary deposits is given in Figure 6. This brings up-to-date a résumé of the long and complex geologic story that has been deciphered in the Seacoast Region.

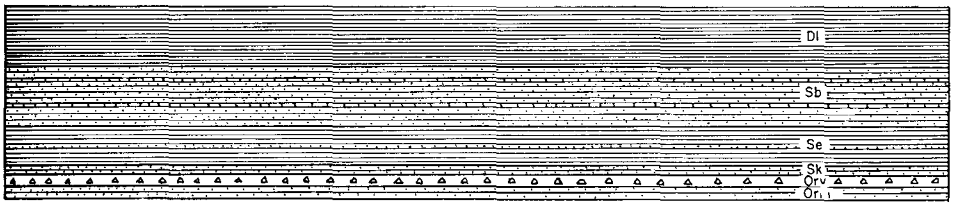


Figure 3. Diagrammatic section of sediments and volcanics accumulated in the Seacoast Region before deformation, igneous intrusion and metamorphism.

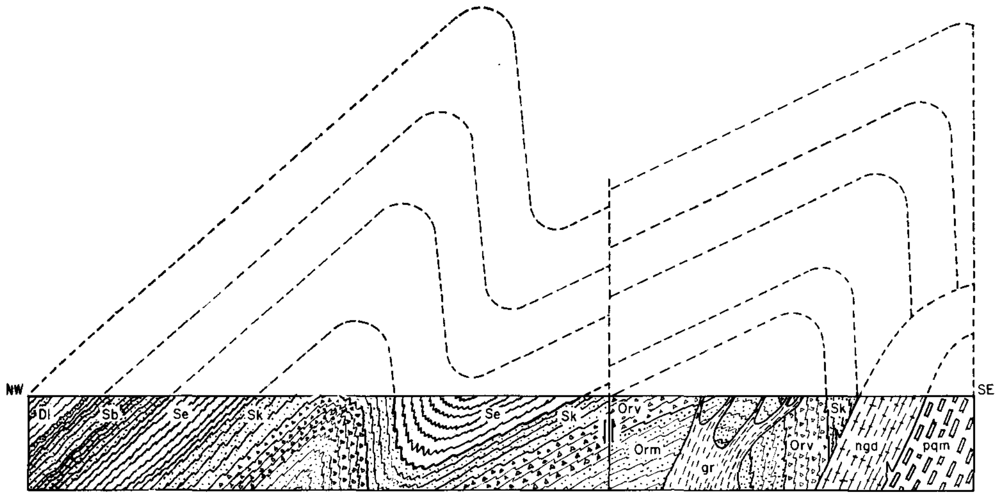


Figure 4. Diagrammatic section at close of Acadian orogeny to show mountainous structures by projection above present-day surface. Effects of erosion are not included.

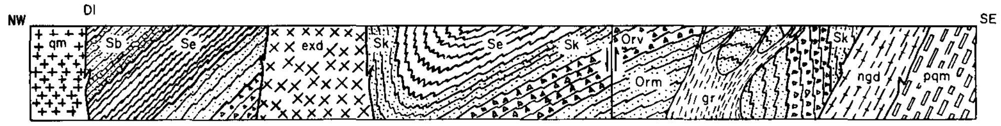


Figure 5. Diagrammatic section prior to Pleistocene glaciation. Erosion of the bedrock essentially completed.

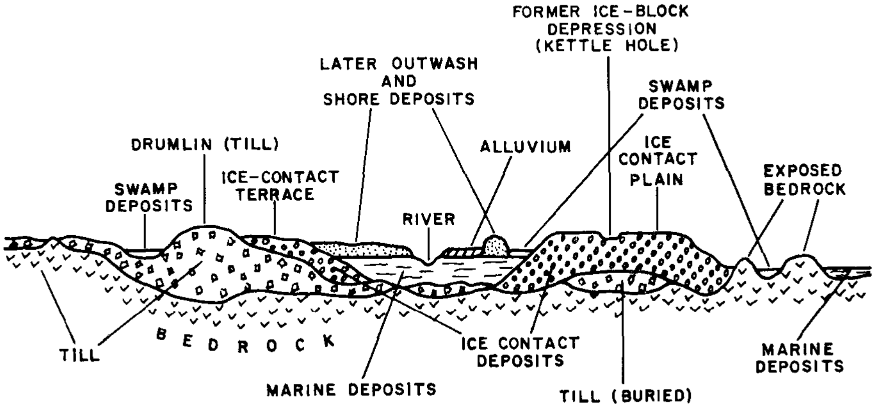


Figure 6. Diagrammatic sketch to show the variety of Pleistocene deposits and Recent alluvial and swamp deposits. (From Meyers and Bradley, 1960)

ECONOMIC GEOLOGY

Present production of mineral commodities in the Seacoast Region consists largely of sand, gravel, clay and stone. Sand and gravel are produced regularly in sufficient quantities to meet local construction needs. In recent years large quantities of these materials have been shipped by rail from the Town of Madbury to the Boston, Massachusetts, area. It is possible that special-purpose sands could be produced (Meyers, 1950). Sands and gravels are extracted from the rather widely-distributed glacial outwash deposits.

Marine clay is present in many low-lying portions of the Seacoast Region. Persistently, since the area was first settled in 1623, clay has been used for the manufacture of New England-type brick. At times tile and drain tile have been manufactured. In recent years, local potters have learned to use the clay in art ware. The general distribution of the clays was determined by Goldthwait (1963). The physical and chemical property of these clays has been reported by Chapman (1950). Some of the clays possess excellent bloating properties and could be used in the manufacture of lightweight aggregate (Stewart, 1959.) Bricks are manufactured currently at Exeter and a few miles outside the area encompassed by this report, in the towns of Epping and Rochester.

Crushed stone and riprap are produced from the quarry at Peverly Hill, Portsmouth.

Peat has been produced in the Town of Hampton (White, 1941) and has been reported at Odiorne's Point, as noted earlier in this report.

Metallic minerals have been observed in a few small quartz veins in the Exeter diorite. These minerals are argentiferous galena, sphalerite, pyrite, and traces of chalcopyrite.

There has been some prospecting of the pegmatites associated with the quartz monzonite in the northwestern part of the region. Feldspar has been produced to the southwest, in he Town of Raymond.

A major concern of the region is its supply of fresh water. The lower courses of major streams are tidal estuaries as far inland as Rollinsford, Dover, Durham, Newmarket, and Exeter. Upstream from these communities, the larger streams are lightly-to-heavily polluted by human and industrial waste. Currently an intense surface water improvement program is under way. Within a few years there should be marked improvement in the quality of local surface water supplies.

Ground water is an important source of domestic and industrial water supplies in the Seacoast Region. Small amounts are withdrawn from many thousands of wells dug into Pleistocene glacial deposits, or from wells drilled into the bedrock. A few driven wells draw water from recent beach deposits. Major municipal supplies are withdrawn through gravel-wall wells or well fields in glacial outwash. A considerable body of information is available on local ground water supplies. These include reports by Meyers and Bradley (1960). Bradley and Peterson (1962), Bradley (1964), and Stewart (1968).

APPENDIX

Tables 1-8 of the Appendix have been taken directly from the doctoral dissertation of Robert F. Novotny (1963).

TABLE 1 APPROXIMATE MODES OF THE RYE FORMATION, LOWER METASEDIMENTARY MEMBER

Minerals	Specimen												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Porphyroblasts													
Biotite	----	13	7	9	----	----	10	5	18	7	----	----	----
Garnet	----	38	----	13	----	8	20	23	----	----	----	----	----
Sillimanite	----	----	----	----	----	----	----	----	11	9	----	----	----
Hornblende	----	----	----	----	----	----	----	----	----	----	----	20	----
Diopside	----	----	----	----	----	----	----	----	----	----	----	22	----
Groundmass													
Quartz	43	27	44	41	58	58	31	27	30	20	48	8	13
Plagioclase	28	3	23	22	24	24	17	10	16	13	8	41	40
Microcline	1	tr	----	3	3	----	----	6		----	----	----	----
Biotite	22	19	12	12	9	8	19	13	14	9	21	tr	8
Chlorite	2	tr	tr	----	4	2	----		2		4	----	----
Muscovite	1	tr	14	tr	tr	----	tr	13	1	31	3	----	----
Sericite	tr	----	tr	----	2	----	3	----	----	----	----	----	----
Sillimanite	----	----	----	----	----	----	----	----	7	9	14	----	----
Hornblende	----	----	----	----	----	----	----	----	----	----	----	8	36
Tourmaline	1	tr	tr	tr	----	----	tr	3	----	tr	1	----	----
Apatite	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr
Zircon	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr
Epidote-zoisite	1	----	tr	tr	tr	----	tr	----	tr	----	----	----	----
Sphene	----	----	----	----	tr	----	----	----	----	----	----	1	2
Magnetite	1	tr	tr	tr	tr	tr	tr	----	1	2	1	tr	1
Per cent anorthite in plagioclase	32-37	15	28-32	10-13	10-15	35	31-35	15	31-36	15	35	54-65	59-64
Size of porphyroblasts (mm.)	----	.80- 1.80	.30- 2.52	.30- 3.00	---- ----	.45- .60	.30- 2.40	.30- 2.40	2.80- 3.60	.40- 1.50	---- ----	1.30- 3.50	---- ----
Size of groundmass (mm.)	.005- 1.30	.005- .30	.004- .19	.095- .28	.005- 1.32	.06- .30	.004- .24	.006- .20	.01- 1.80	.06- .22	.005- .60	.19- .66	.19- .66
Texture	S	S	S	S	G	G	S	S	S	S	S	S	S

Mineral sizes are complete range observed

S = Schistose

G = Granoblastic

1. Quartz-plagioclase-biotite schist
2. Garnet-biotite-quartz schist
3. Quartz-mica-plagioclase schist
4. Quartz-biotite-garnet-plagioclase schist
5. Feldspathic quartzite
6. Garnetiferous feldspathic quartzite
7. Garnetiferous quartz-biotite schist
8. Garnetiferous quartz-mica schist
9. Quartz-sillimanite-biotite schist
10. Quartz-sillimanite-mica schist
11. Quartz-biotite-sillimanite schist
12. Plagioclase-diopside amphibolite
13. Plagioclase amphibolite

TABLE 2
APPROXIMATE MODES OF THE RYE FORMATION, UPPER METAVOLCANIC MEMBER

Minerals	Specimen								
	1	2	3	4	5	6	7	8	9
Porphyroblasts									
Plagioclase	----	----		----	12	31	29	----	----
Hornblende	----	----	----	----	----	----	----	27	----
Groundmass									
Quartz	29	41	12	87	40	38	23	26	tr
Plagioclase	16	25	13	2	23	7	19	29	35
Microcline	1	1		----	2	2	----	----	----
Biotite	52	----	75	7	21	16	16	2	1
Chlorite	tr	----	----	tr	1	1	6	----	----
Muscovite	tr	----		----	tr	2	----	----	----
Sericite	1	----	tr	----	tr	tr	1	2	tr
Garnet	—		----	4	----	1	----	----	----
Actinolite	----	23	----	----	----	----	----	----	----
Hornblende	----	----	----	----	----	----	----	9	58
Calcite		1	----	----	----	----	tr	----	----
Tourmaline	tr	----	tr	----	----	----	----	----	----
Apatite	tr	tr	tr	tr	tr	tr	tr	tr	tr
Zircon	tr	tr	tr	tr	tr	tr	tr	—	tr
Epidote-zoisite	1	8	----	----	tr	1	1	2	1
Sphene	tr	1	----	----	tr		4	2	3
Magnetite	tr	tr		----	1	1	1	1	2
Pyrite	tr	----	tr	----	----	----	----		tr
Per Cent anorthite in plagioclase	32-39	33-47	15-17	13	11-15	13-16	14-16	25-49	25-48
Size of porphyroblasts (mm.)	----	----	----	----	.30-3.9	.07-9.10	.30-4.20	.30-1.14	----
Size of groundmass (mm.)	.005-.158	.005-.152	.019-.133	.06-.12	.001-.19	.005-.04	.008-.06	.019-.19	.005-.76
Texture	S	S	S	G	Gn	Gn	Gn	S	S

Mineral sizes are complete range observed

S = Schistose

G = Granoblastic

Gn = Gneissic

1. Feldspathic quartz-biotite schist
2. Feldspathic quartz-actinolite schist
3. Biotite schist
4. Quartzite

5.-6. Quartz-biotite-plagioclase gneiss
7. Injection and permeation gneiss
8. Quartz-plagioclase-hornblende schist
9. Plagioclase amphibolite

TABLE 3
APPROXIMATE MODES OF THE KITTERY FORMATION

Minerals	Specimen								
	1	2	3	4	5	6	7	8	9
Porphyroblasts									
Actinolite	----	----	----	----	----	----	----	22	----
Groundmass									
Quartz	23	15	52	5	50	79	72	45	52
Plagioclase	2	tr	----	----	15	5	12	19	13
Microcline	----	----	----	-	----	----	----	3	----
Biotite	.		42	47	29	----	----	tr	7
Chlorite	2	53	tr	7	----	7	4	3	10
Sericite	68	28	4	36	5	2	2	3	----
Actinolite	----	----	----	----	----	----	----	----	9
Calcite	tr	----	tr	----	----	3	1	----	----
Tourmaline	----	----	----	----	tr	----	----	tr	----
Apatite	.	. .	----	tr	tr	----	----	tr	tr
Zircon	tr	tr	tr	----	tr	tr	----	tr	tr
Epidote-zoisite	5	----	tr	----	----	----	----	3	8
Sphene	.	--	.	--	--	-	----	1	1
Pyrite	tr	4	2	2	1	4	1	1	tr
Limonite	----	----	----	3	----	----	--	----	----
Ilmenite	----	----	----	tr	----	----	8	----	----
Per cent anorthite in plagioclase	7-9	9	----	----	36-47	5	8	31-34	31
Size of porphyroblasts (mm.)	----	----	----	----	----	----	----	.114- .76	----
Size of groundmass (mm.)	.008- .057	.007- .057	.009- .475	.010- .076	.009- .878	.008- .19	.009- .019	.019- .095	.005- .19
Texture	S	S	S	S	S	G	G	G	G

Mineral sizes are complete range observed

S = Schistose

G = Granoblastic

1.-2. Phyllite
3. Quartz-biotite schist
4. Biotite-sericite schist
5. Feldspathic quartz-biotite schist
6. Quartzite
7. Feldspathic quartzite
8.-9. Lime-silicate rock

TABLE 4
APPROXIMATE MODES OF THE ELIOT FORMATION

TABLE 4
APPROXIMATE MODES OF THE ELIOT FORMATION

Minerals	Specimen											
	1	2	3	4	5	6	7	8	9	10	11	12
Porphyroblasts												
Dolomite	----	----	12	----	----	----	----	----	----	----	----	----
Biotite	----	----	----	31	----	----	----	----	----	----	----	----
Actinolite	----	----	----	----	----	----	----	----	----	----	----	18
Groundmass												
Quartz	48	10	22	47	60	20	49	60	59	76	52	61
Plagioclase	7	4	10	5	13	5	5	----	15	6	25	15
Biotite	----	----	----	9	19	67	----	----	tr	1	----	----
Chlorite	----	21	51	3	8	----	----	25	tr	----	----	----
Sericite	45	62	----	5	----	3	6	15	12	7	----	tr
Actinolite	----	----	----	----	----	----	----	----	----	----	8	----
Dolomite	----	----	----	----	----	----	40	----	----	----	----	----
Calcite	----	----	----	----	tr	tr	----	----	14	10	tr	tr
Tourmaline	tr	----	----	tr	tr	tr	----	----	tr	tr	----	----
Apatite	----	tr	----	tr	tr	----	----	----	----	----	----	----
Zircon	----	----	----	----	tr	tr	----	----	tr	tr	tr	tr
Epidote-zoisite	----	----	----	tr	tr	----	----	tr	tr	----	15	6
Sphene	----	-	----	tr	----	----		----	----	tr	----	tr
Pyrite	tr	3	----	----	tr	2	tr	----	tr	tr	----	tr
Limonite	tr	----	5	----	----	3	tr	tr	tr	tr	----	----
Rutile	tr	tr	----	tr	tr	----	----	tr	tr	----	----	tr
Per cent anorthite in plagioclase	7	8	7-8	9-13	11-14	13	8	6	9	15	44-49	35-44
Size of porphyroblasts (mm.)	---- ----	---- ----	.247- .95	.057- 1.14	---- ----	---- ----	---- ----	---- ----	---- ----	---- ----	---- ----	.25- .38
Size of groundmass (mm.)	.019- .19	.09- .38	.018- .133	.019- .038	.008- .19	.019- .095	.017- .380	.009- .114	.016- .380	.018- .080	.038- .285	.036- .133
Texture	S	S	S	S	S	S	G	G	G	G	G	G

Minerals sizes are complete range observed

S = Schistose

G = Granoblastic

1. Slate
2. Phyllite
3. Dolomitic phyllite
4. Quartz-biotite schist
5. Feldspathic quartz-biotite schist
6. Biotite schist
7. Dolomite quartzite
8. Chlorite-sericite quartzite
9. Feldspathic quartzite
10. Quartzite

11.-12. Lime-silicate rock

TABLE 5 APPROXIMATE MODES OF THE BERWICK AND LITTLETON FORMATION

Minerals	Specimen									
	1	2	3	4	5	6	7	8	9	10
Porphyroblasts										
Biotite	21	----	29	3	----	5	----	----	18	----
Muscovite	----	----	----	----	----	----	----	----	22	----
Garnet	----	----	----	----	----	12	----	----	----	12
Staurolite	----	----	----	----	----		----	----	25	----
Actinolite	----	----	----	----	----	25	8	23	----	----
Diopside	----	----	----	----	----	----	22	----	----	----
Groundmass										
Quartz	40	50	31	40	67	45	40	50	35	37
Plagioclase	----	11	----	----	21	10	27	19	----	----
Microcline	----	5	----	----	----	----	----	----	----	----
Biotite	9	13	11	----	8	----	----	----	----	20
Chlorite	----	tr	tr	6	1	tr	----	----	tr	----
Muscovite		3	----	----	----	----	----	----	----	30
Sericite	27	8	25	50	----	----	----	8	----	----
Calcite	----	10	----	----	----	2	tr	tr	----	----
Tourmaline	2	tr	3	tr	tr	----	----	tr	tr	tr
Apatite	----	----	----	----	tr	tr	----	tr	----	----
Zircon	tr	----	----	----	tr	tr	tr	tr	tr	tr
Epidote	----	----	----	tr	3	----	1	----	----	----
Sphene	----	----	----	----	tr	1	2	----	----	----
Magnetite	----	----	----	----	----	tr	----	----	tr	1
Pyrite	1	tr	1	1	tr	tr	tr	----	tr	----
Limonite	----	----	----	----	----	----	tr	----	----	----
Per cent anorthite in plagioclase	----	5-12	----	----	14-16	35-40	30-37	25-27	----	----
Size of porphyroblasts (mm.)	.20- .48	---- ----	.380- .665	.19- .38	---- ----	.28- 2.85	.19- 4.18	.41- .75	.76- 3.42	1.14- 1.32
Size of groundmass (mm.)	.019- .170	.016- .228	.015- .018	.019- .057	.018- .855	.04- .30	.016- .07	.095- .285	.283- .413	.25- .33
Texture	S	S	S	S	G	G	G	G	S	S

Mineral sizes are complete range observed

S = Schistose

G = Granoblastic

Berwick Formation
1. Quartz-biotite-sericite schist
2. Feldspathic quartz-biotite schist
3. Biotite-quartz-sericite schist
4. Quartz-sericite schist
5. Feldspathic quartzite
6.-8. Lime-silicate rock

Littleton Formation
9. Quartz-staurolite-mica schist
10. Quartz-garnet-mica schist

TABLE 6 APPROXIMATE MODES OF THE HILLSBORO PLUTONIC SERIES

Minerals	Specimen														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Phenocrysts															

TABLE 6 APPROXIMATE MODES OF THE HILLSBORO PLUTONIC SERIES

Minerals	Specimen														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Phenocrysts															
Microcline	----	----	----	----	----	----	----	----	----	----	----	42	24	----	----
Groundmass															
Quartz	15	17	24	8	20	21	19	23	30	6	3	18	12	21	23
Plagioclase	25	19	17	35	43	40	60	55	19	20	42	31	46	14	43
Microcline	53	45	56	38	15	----	----	----	48	----	----	----	----	58	25
Biotite	1	----	----	1	----	13	13	17		10	tr	1	7	1	----
Chlorite	1		1	1	----	3	tr	2	tr	----	2	6	11	tr	----
Muscovite	1	12	----	8	12	----	----	----	tr	----	----	----	----	----	2
Sericite	2	5	tr	9	10	1	4	1	2		----	1	tr	----	----
Hypersthene	----	----	----	----	----	----	----	----	----	5	----	----	----	----	----
Augite	----	----	----	----	----	----	----	----	----	54	----	----	----	----	----
Hornblende	----	----	----	----	----	20	----	----	----	----	50	----	----	----	----
Garnet		1	----	----		----	----	----	----	----	----	----	----	1	1
Tourmaline	tr	----	2	tr	tr	1	2	tr	----	----	----	----	----	4	5
Calcite	----	----	----	----	----	----	----	----		----	----	----	tr	----	----
Apatite		----	----	----	----	----	----	----	1	----	----	----	----	1	1
Zircon	tr	----	tr	tr	tr	tr	tr	tr	----	----	----	tr	tr	----	----
Epidote-zoisite	tr	----	tr	----	tr	tr	tr	tr	----	2	1	tr	tr	----	----
Sphene	----	----	----	----	----	----	1	----	----		----	----	----	----	----
Magnetite		1	----	----	----	1	1	2	----	3	2	1	tr	----	----
Pyrite	2	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Per cent anorthite in plagioclase	3-10	7-13	9-16	8-14	8-14	32-37	25-30	37-52	14	36-38	33-43	30-32	30-36	6-12	7-12
Size of phenocrysts (mm.)		----	----	----	----	----	----	----	----	----	----	18	27	----	----
Size of groundmass (mm.)	.005- 1.14	.005- 2.28	.002- 3.04	.012- 9.60	.008- 13.10	.12- 2.28	.12- 2.70	.12- 3.30	.06- 11.40	.12- 4.20	.12- 1.38	.06- 2.52	.12- 5.10	1.80 14.40	.06- 1.80
Texture	C-G	C-G	C-G	P, C-G	P, C-G	H	H	H	P	H	H	H,Por	H,Por	P	A

Mineral sizes are complete range observed

C-G = Coarse grained, gneissic P = Pegmatitic H = Hypidiomorphic Por = Porphyritic A = Aplitic

Granite and pegmatite
1.-3. Granite
4.-5. Pegmatite

Newburyport quartz diorite
6.- 8. Quartz diorite
9. Pegmatite
10.-11. Diorite autolith

Porphyritic quartz monzonite
12.-13. Porphyritic quartz monzonite
14. Pegmatite
15. Aplite

TABLE 7 APPROXIMATE MODES OF THE HILLSBORO PLUTONIC SERIES

Minerals	Specimen													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Quartz	2	1	1	6	4	22	13	23	1	2	12	33	25	28
Plagioclase	23	13	61	57	59	43	20	33	71	56	52	18	38	35
Microcline	----	----	----	2	----	21	62	39	----	12	17	47	30	28
Hypersthene	8	----	6	----	----	----	----	----	----	----	----	----	----	----
Augite	59	59	21	14	----	----	----	----	5	----	----	----	----	----
Hornblende	----	----	----	----	25	----	----	----	----	----	----	----	----	----
Uralite	----	11	----	8	----	----	----	----	4	----	----	----	----	----
Biotite	4	5	6	3	8	10	1	3	----	15	4	tr	----	6
Chlorite	----	6	----	5	1	tr	2	tr	7	5	8	1	----	1
Muscovite	----	----	----	----	tr	----	----	tr	----	----	----	tr	4	2
Sericite	3	1	tr	1	2	4	2	1	6	6	3	----	----	tr
Calcite	----	----	----	----	tr	tr	----	----	1	1	1	----	----	----
Zircon	----	----	tr	----	tr	tr	----	----	----	tr	----	tr	----	tr
Apatite	----	tr	tr	tr	tr	----	----	1	tr	tr	----	tr	1	----
Garnet	----	----	----	----	----	----	----	----	----	----	----	----	2	----
Epidote-zoisite	----	2	tr	----	1	tr	tr	tr	1	3	----	tr	----	----
Sphene	----	tr	----	tr	tr	tr	----	----	----	----	1	tr	----	----
Magnetite	1	2	5	4	tr	tr	----	tr	4	tr	2	1	tr	tr
Per cent anorthite in plagioclase	41-46	50-54	25-38	33-45	28-38	29-37	4-15	24	43-51	28-33	31	11-13	9-15	23
Grain size (mm.)	.36-4.80	1.20-4.20	.18-3.30	.12-5.70	.42-6.00	.12-5.58	.30-6.18	.24-1.92	.60-4.32	.18-.90	.12-4.20	.12-.90	.30-1.80	.60-3.60
Texture	H	H	H	H	H	H	H	A	H	H	H	A	H	H

Mineral sizes are complete range observed

H = Hypidiomorphic

A = Aplitic

Exeter diorite pluton
1.-2. Gabbro
3.-5. Diorite
6. Quartz monzonite
7. Granite
8. Aplite

Exeter diorite bosses
9. Gabbro
10. Diorite
11. Quartz diorite
12. Aplite
Quartz monzonite
13.-14. Quartz monzonite

TABLE 8
APPROXIMATE MODES OF THE WHITE MOUNTAIN PLUTONIC-VOLCANIC SERIES

Minerals	Specimen			
	1	2	3	4
Phenocrysts				
Chlorite	----	4	4	----
Labradorite	----	1	----	----
Titanaugite	----	3	2	----
Groundmass				
Quartz	----	----	----	40
Plagioclase	55	41	47	----
Microcline	----	----	----	52
Titanaugite	19	8	9	----
Barkevikite	----	30	17	----
Biotite	tr	tr	4	----
Chlorite	14	3	7	----
Sericite	1	1	2	----
Calcite	4	2	1	1
Talc	tr	----	tr	----
Apatite	tr	tr	1	tr
Epidote-zoisite	1	----	----	3
Sphene	----	----	----	2
Ilmenite	----	----	----	1
Magnetite	6	7	6	----
Pyrite	----	----	----	1
Per cent anorthite in plagioclase	52-67	57-64	57-59	----
Size of phenocrysts (mm.)	---- ----	.31- 2.28	.48- 2.09	- ----
Size of groundmass (mm.)	.038- .342	.133- .228	.057- .300	.010- .300
Texture	S	S-P	S-P	M

Mineral sizes are complete range observed

S = Subophitic
S-P = Subophitic-porphyritic
M = Micrographic

1.-3. Camptonite
4. Granophyre

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