# PHYSICAL RESOURCES OF KNOX COUNTY, MAINE

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PR-1

MAINE GEOLOGICAL SURVEY

DEPARTMENT OF CONSERVATION

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# PHYSICAL RESOURCES OF KNOX COUNTY, MAINE

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# INTRODUCTION

Rapid expansion of our technology, commercial-industrial base, and population, especially seasonal population, has created the need for thoughtful planning if our environment and way of life are to continue as we know them. Effective environmental planning by private, state, and local officials requires physical resources data in a form that is understandable and immediately useful.

This report comprises three phases of the physical resources inventory of Knox County, Maine, including *surficial geology*, *bedrock geology*, and *groundwater geology*. Each subject is presented in a separate section that includes maps, tables, and graphs, as well as an explanatory text.

The reader is cautioned that the information and maps in this report represent reconnaissance investigation, and are of necessity generalized. Accuracy is limited to the intensity of detail shown on the scale of map used (1:125,000). For certain community, regional, and state zoning and planning purposes, the intensity is satisfactory. Second level or more detailed information of a particular site or area is easily achieved by coupling this report with some additional evaluation and closer control.

The first section of the report discusses the kinds and distribution of unconsolidated surficial materials that overlie bedrock (ledge). These surficial materials control the location and quality of agricultural land, borrow and gravel pits, solid

waste and private sewage disposal, groundwater recharge and near-surface groundwater movement, and ultimately the location of industrial, residential, and seasonal structures.

Continental glaciation which waxed and waned across Maine ended about 12,000 years ago. Debris of all sizes transported by the ice was either "plastered" directly on the land surface by moving ice, or released during melting of the ice and carried forward and deposited by meltwater streams.

A surficial geologic map shows the distribution and composition of the unconsolidated surficial sediments in a two dimensional or map sense. Users must also consider the third dimension or vertical sense. A fold-out cross-section illustrates the vertical profile, sediment distribution, and sediment composition. Such information is particularly useful to the planner, developer, engineer, and others who must locate suitable building sites, liquid- or solid-waste facilities, groundwater supplies and recharge areas, and construction materials.

The second section of the report concerns the bedrock (ledge) that may be exposed at the surface or underlies unconsolidated glacial or marine sediments. The bedrock in Knox County was originally laid down in a marine environment as soft unconsolidated sediments much like those deposited today on the Continental Shelf. Subsequent vertical and horizontal forces of great magnitude originating deep within the earth's crust, accompanied by huge plutonic intrusions of molten granitic rock, folded, "cooked", distorted, fractured and substantially changed the original character and composition of the rocks. Rocks that

have undergone physical and chemical changes because of intense heat and pressure are called *metamorphic rocks*. Fracture systems of varying density and spacing within the dense, crystalline metamorphic rocks of Knox County may be the loci for mineral deposits, groundwater reservoirs, and the planes of weakness for the easy extraction of blocks from stone quarries.

Correct bedrock information is essential to large construction projects such as buildings, to rock quarry operations, to mining and tunneling operations, and to environmental studies concerning such things as locations of atomic power plants, dams, groundwater supplies, and liquid- and solid-waste storage and disposal facilities.

The third section of the report considers the occurrence and movement of groundwater in the surficial sediments and in the underlying bedrock. A discussion of groundwater principles and the existing groundwater conditions in Knox County and the mid-coastal area in general is presented. Well depths and yields, groundwater flow directions in both surficial materials and bedrock, water recharge, and groundwater quality are considered and explained. Also included is a brief discussion of salt water intrusion. Numerous charts, diagrams, and maps are included in this section.

Groundwater information has obvious importance to individuals and communities seeking dependable supplies of potable water, even those utilizing surface water. Ground and surface waters

are very much interrelated. It is of equal importance to planners and engineers who are looking for suitable and safe waste-disposal sites. To protect groundwater resources, they must know the locations of aquifers and must know directions and rates of water movement into and out of these aquifers.

ACKNOWLEDGEMENTS

Numerous people in addition to the authors of the three sections of this report, have contributed to the accumulation of physical resources information of Knox County. Some of the earliest geologic maps of the Rockland - Vinalhaven - North Haven area were done by Bastin (U.S. Geological Survey Rockland Folio, No. 158, 1908) and Smith, Bastin and Brown (U.S. Geological Survey Penobscot Bay Folio, No. 149, 1907). Björn G. Andersen (Univ. of Oslo, Norway) helped initiate surficial geologic mapping of Knox County in the summer of 1973. Philip H. Osberg (Univ. of Me. at Orono), Charles V. Guidotti (Univ. of Wisc.), Stephen A. Norton (Univ. of Me. at Orono), and Arthur M. Hussey II (Bowdoin College) contributed significantly to the present interpretation of the bedrock geology of Knox County. Water-well data were obtained from the records of well drillers in the mid-coastal region. The Water Well Drillers Association of Maine endorsed and promoted the groundwater data inventory. The cooperation and help of the Association and of the many individual drillers has been invaluable to the success of the program.

Preparation of the plates, figures and text was accomplished with the help of the Maine Bureau of Geology staff, especially E. Melanie Lanctot and Bennett J. Wilson.

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Section I

# SURFICIAL GEOLOGY

By

Geoffrey W. Smith

## INTRODUCTION

Surficial geology is that branch of geology that deals with the surface of the earth. It includes the study of all those processes, materials, and landforms that are to be found within the environment of man's everyday existence. The surficial materials and landforms throughout the State of Maine can be attributed, for the most part, to the work of large continental ice sheets that covered the State during that part of geologic time called the Pleistocene Epoch (Table 1). These large bodies of ice advanced over the State on at least four separate occasions. Each glacial advance was followed by a non-glacial period during which climate became warmer and ice retreated to much its present distribution.

The great variety of glacial deposits that cover the land surface of Maine today can be attributed to the advance and retreat of the last ice sheet to cover the State. Materials deposited during each of the three preceding glacial episodes were either eroded by advancing ice or covered by younger sediments. As the last glacier advanced southward over the State, it picked up loose soil and rock, transported the material for some distance, and then deposited it. Hills were eroded and streamlined; valleys parallel to the direction of ice

| SUBDIVISIONS OF GEOLOGIC TIME | | AGE MILLIONS OF YEARS AGO | |
|---|---|---|---|
| ERAS | SYSTEMS/PERIODS | | |
| | | 0 | Recent Epoch |
| CENOZOIC | QUATERNARY | | Pleistocene Epoch |
| | | 2? | |
| | TERTIARY | 6 | |
| | | 22 | |
| | | 36 | |
| | | 58 | |
| | | 63 | |
| MESOZOIC | CRETACEOUS | | |
| | | 145 | |
| | JURASSIC | | |
| | | 210 | |
| | TRIASSIC | | |
| | | 255 | |
| PALEOZOIC | PERMIAN | | |
| | | 280 | |
| | PENNSYLVANIAN | | |
| | | 320 | |
| | MISSISSIPPIAN | | |
| | | 360 | |
| | DEVONIAN | | |
| | | 415 | |
| | SILURIAN | | |
| | | 465 | |
| | ORDOVICIAN | | |
| | | 520 | |
| | CAMBRIAN | | |
| | | 580 | |
| PRECAMBRIAN | | 1,000 | |
| | | 2,000 | |
| | | 3,000 | |
| BIRTH OF PLANET EARTH | | 4,650 | |

TABLE 1
THE GEOLOGIC COLUMN

movement were deepened; and bedrock was smoothed and scratched by the overriding ice. Polished and scratched bedrock surfaces indicate that ice movement was generally toward the southeast.

The advancing ice deposited poorly-sorted accumulations of soil and rock (till) as a cover of ground moraine over the preglacial topography. Thick accumulations of ground moraine were molded by flowing ice to form streamlined hills, called drumlins, parallel to ice movement.

The complex nature of glacial retreat resulted in deposition of a wide variety of sedimentary materials. Ridges of till and sand and gravel accumulated along parts of the ice margin during brief periods when the ice remained stationary or readvanced for a short distance. These ridges, called end moraines, outline the general pattern of ice retreat.

Melting of glacial ice released large volumes of water and sediment. Sea level, which had been lowered several hundred feet during glaciation, began to rise as water from the melting ice was returned to the ocean. Fine-grained marine sediments were deposited in the rising sea. Deltas were constructed where meltwater streams entered the sea. Several of these deltas were built into the ocean along the ice margin, indicating that ice stood in the ocean during some part of the period of glacial retreat. The present distribution of deltas and beach features indicates that at the time of maximum submergence, the sea stood nearly 300 feet above present sea level. Uplift of the region in response to removal of the very heavy load of ice has brought these features to their present elevations.

In Recent time, alluvial sediments have been deposited along major rivers. Peat and muck have accumulated in numerous swamps and marshes.

## DIRECTION OF ICE MOVEMENT

Glacial lineations, recording the directions of final ice movement have been mapped throughout Knox County. Large-scale drumlinoid features (see below) record south-southeastward movement of ice during the last glacial advance. Striations and related small-scale features display a more random orientation, illustrating the local influence of topography on the direction of ice movement.

Two sets of intersecting striations occur at several localities in Knox County. The older, less well-defined set of striations records ice advance to the south-southeast. The younger, more prominent set of striations is always aligned at right angles to adjacent end moraines. This latter set of glacial scratches was produced by minor readvances of the ice margin during general glacial retreat.

## PLEISTOCENE STRATIGRAPHY

The surficial materials of Knox County consist of a complex succession of glacial deposits of the last stage of regional glaciation, and varied late-glacial and postglacial stream and marine sediments. These materials occur as units of mappable extent that can be placed in a loose framework (Table 2) illustrating their relationships in time and space,

| TIME OF DEPOSITION | ENVIRONMENT OF DEPOSITION | | | | | | |
|---|---|---|---|---|---|---|---|
| | GLACIER | GLACIO-FLUVIAL | GLACIO-MARINE | GLACIO-LACUSTRINE | FLUVIAL | MARINE | SWAMP |
| YOUNGEST<br>POSTGLACIAL | | | | | Floodplain alluvium | Coastal sediments | Swamp deposits |
| LATE-GLACIAL | | | | | * Outwash (terrace) | Outwash delta | |
| | Stratified moraine | Esker | Ice-contact delta | * Lake-bottom sediments | | Marine sediments | |
| | | * Kame | | | | | |
| LAST REGIONAL GLACIATION | | * Channel deposits | Marine sediment | | | | |
| | Washboard moraine | | | | | | |
| | Ground moraine | | | | | | |
| GLACIAL<br>OLDEST | | | | | | | |

* Not delineated in present report.

TABLE 2
ENVIRONMENTS OF GLACIAL DEPOSITION

that is, their stratigraphy.

The arrangement of the materials in terms of time of deposition is based on the stratigraphic principle that younger sediments are deposited on top of older sediments. The environment of deposition for each sedimentary unit has been inferred from study of surface form, location, and internal physical properties of each deposit. The surficial distribution of sediments is shown on Plate 1 (Surficial Geologic Map), and their stratigraphic relationships are depicted schematically in Figure 1.

*GLACIAL TILL*

Glacial till is the most widely distributed glacial deposit in the county. It occurs at the surface above the limit of marine sediments, and is inferred to underlie extensive areas beneath younger deposits (Figure 1). On rocky uplands, till commonly occurs as a thin, patchy veneer (Figure 1). No effort has been made to map such thin till as a unit separate from bedrock.

*Ground Moraine*: Till occurs most commonly as ground moraine, a blanket deposit that lacks distinctive ridge-like form. In fresh exposure, the till is gray in color; when weathered, it is oxidized to a gray-brown color. Ground moraine varies markedly in character depending upon whether it occurs above or below the limit of marine submergence.

Above the limit of marine submergence, the till is characteristically compact and displays a distinctive platy

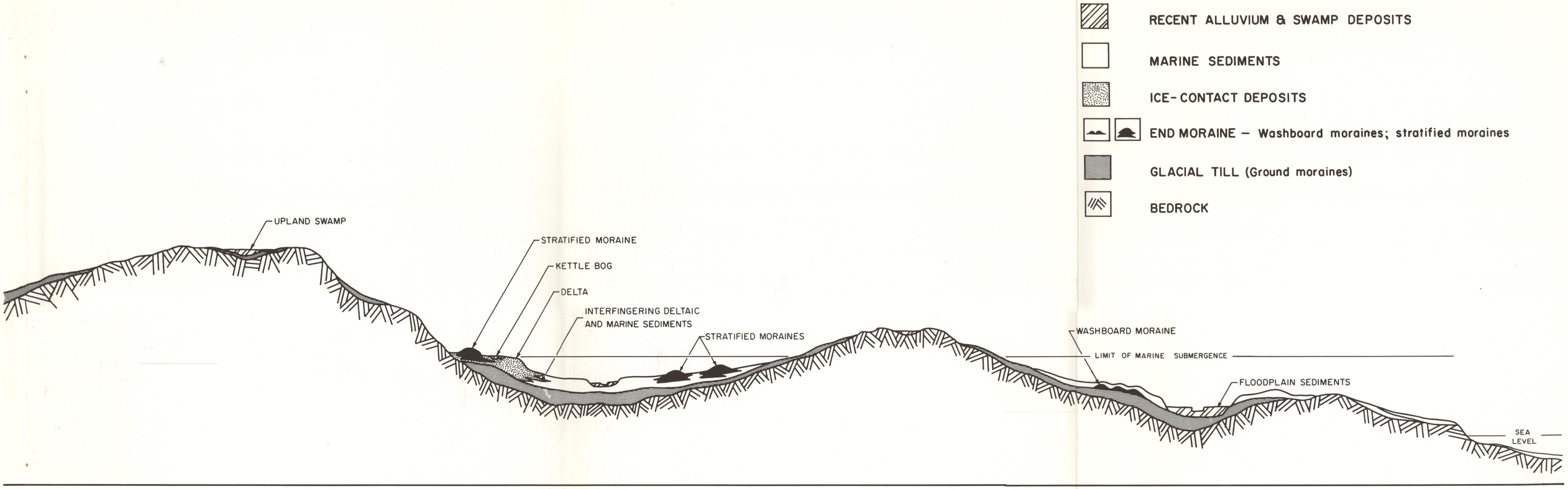


FIG. I

DIAGRAMATIC CROSS-SECTION OF SURFICIAL GEOLOGY

KNOX COUNTY, MAINE

structure (fissility). Boulders and cobbles are set in a sand-silt-clay matrix. Composition of the matrix material closely reflects the composition of the underlying bedrock from which the till has been derived.

Below the limit of marine submergence, the till has been reworked by waves and ocean currents. Silt- and clay-size material has been removed from the matrix, producing a much less compact, non-fissible, sandy till. This reworking of the till has also resulted in the concentration of boulders on the till surface below the marine limit.

Till, in general, has only a limited ability to store and transmit groundwater, that is, moderate permeability. Shallow wells in till yield small but adequate supplies of groundwater for household use. The reworked till below the marine limit tends to be more permeable and better drained. However, the concentration of boulders renders it less suitable for agricultural utilization.

*Drumlins and Related Streamlined Features*: Features mapped as drumlins actually include a wide assortment of streamline-molded topographic forms. Some consist of till and varying amounts of stratified sediments, while others consist largely of bedrock. Most drumlinoid features are comprised of bedrock cores against which till has been deposited as a cover of variable thickness. Orientations of long axes of drumlinoid features generally parallel the direction of last regional ice movement.

*End Moraines*: End moraines are ridge-like accumulations of glacial sediment that formed along the margin of the glacier either during periods of stillstand or minor readvance of the ice front. Two distinct varieties of end moraines are recognized in Knox County, though the limitation of scale precludes their delineation on Plate 1. The two types of moraines can be readily distinguished in the field on the basis of morphology (size and shape), composition, and mode of occurrence.

*Washboard moraines* occur as regularly-spaced clusters of well-defined ridges that are generally arcuate in plan and are commonly arranged in en echelon fashion. They range from 5 to 15 feet in height, 25 to 50 feet in width, and are up to one-half mile in length. Wherever they are found, they occur in topographic lows, always below the limit of marine submergence. They are composed of till, and are commonly veneered with marine sediment.

Morainal ridges consisting wholly or mostly of stratified sand and gravel are here called *stratified moraines*. These features are more prominent topographically than the washboard moraines. They are between 100 and 400 feet wide, and from 50 to 75 feet high. Individual moraine segments are up to three miles long. They occur on uplands as well as in topographic lows, and have been mapped both above and below the marine limit. Composition of the stratified moraines is variable, though they generally consist of a combination of ice-contact stratified sediments (see below) and till. In several situations they occur in close association with ice-contact marine deltas.

The stratified moraines are an important source of sand and gravel. They are most often well-drained. Under certain conditions, these deposits are potential sources of a significant volume of groundwater. They should be considered as important areas of recharge to underlying bedrock fractures (see Section III).

*ICE-CONTACT STRATIFIED DEPOSITS*

These materials include sediments that were deposited in streams, lakes, or the ocean in direct contact with glacial ice. They differ from till in that they have been sorted and stratified by running water. They often contain local bodies of till, and generally display slumped and contorted stratification, the result of melting or movement of adjacent ice. The ice-contact deposits are gradational into sediments that accumulated away from the direct influence of the ice. They include a wide range of topographic forms among which are eskers, kames, and ice-contact (kame) deltas. The stratified moraines described in a previous section might well be included in this group of deposits since they were formed in direct contact with the ice, and display those physical characteristics generally associated with ice-contact deposits. The stratified moraines, however, indicate the position of the ice margin at a particular time during the long period of glacial retreat, and are therefore mapped separately.

The most important group of ice-contact deposits in Knox County are the *ice-contact deltas* that formed while ice stood in the sea during the period of glacial retreat. The deltas are

typically flat-topped accumulations of sand and gravel that are up to as much as a mile or more in width. The delta surface may be marked by irregular patterns of distributary channels, formed by the streams that carried sediments across the delta surface. Kettle holes (depressions once occupied by detached blocks of ice) are common, particularly toward the head of the delta surface.

The ice-contact deltas consist of well-sorted sand and gravel, and display sloping foreset beds and flat-lying topset beds. Sediment size increases toward the delta head, where boulder-size gravel may mark the transition to a stratified moraine. At the delta front, sand and gravel of the delta are gradational into and intertongue with marine silt and sand.

*Eskers* - sinuous ridges of sand and gravel deposited by streams flowing in tunnels in the melting ice - have been mapped in a few localities as surface features. They occur more commonly in valleys where they have been covered by marine sediments. Most of the eskers that have been mapped consist of short ridge segments, some of which terminate at delta heads. Compositionally, the eskers consist of materials similar to those of the ice-contact deltas, though bedding is generally more severely contorted and sediments are less well-sorted.

All ice-contact deposits are sources of sand and gravel, and are most often well-drained. They may be locally important sources of groundwater, and should be considered as important areas of recharge to underlying bedrock fractures.

*MARINE SEDIMENTS*[1]

Marine sediments occur throughout the county below the limit of marine submergence. The sediments overlie glacial till and bedrock and intertongue with stratified deposits of ice-contact deltas and stratified moraines (Figure 1). The maximum altitude at which marine sediments are found increases inland, to the northwest, because of differential uplift of the land surface following ice retreat. Generally, the upper limit of marine sediments is considerably below (as much as 100 feet) the highest established shoreline features. Locally, however, the two are nearly coincident.

Thickness of the marine sediments is highly variable, changing abruptly within short distances. The variability is due largely to the fact that the sediments were deposited on an irregular surface where they filled valleys and thinned against adjacent hills.

The marine sediments consist most typically of poorly-sorted silty clay. Near the inland limit of marine deposits and in proximity to ice-contact deltas and stratified moraines, the marine sediments contain large amounts of sand and gravel. Boulders are common in the marine sediments in coastal areas. At any given locality, there is a general increase in grain size upward in the section of marine sediments.

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[1] These sediments are presumed to be equivalent to the Presumpscot Formation that is well-exposed in the valley of the Presumpscot River in Cumberland County, Maine. This marine formation is widespread throughout coastal Maine, and was named and described by A.L. Bloom, 1960, *Late Pleistocene Changes of Sealevel in Southwestern Maine*; Maine Geological Survey.

Color of the sediments is gray or blue-gray in fresh exposure, brownish gray in weathered exposure. Cold water species of marine invertebrate fossils (eg., mussels, scallops, barnacles) are locally abundant in the marine sediments.

The marine sediments are most often poorly-drained, and do not yield much groundwater to shallow wells. Recharge to underlying bedrock fractures is impeded by these relatively impermeable sediments.

*RECENT ALLUVIUM AND SWAMP SEDIMENTS*

*Recent alluvium* is present on the floors of all stream valleys, but is extensive only along major rivers (Figure 1). In smaller valleys, the alluvium consists largely of gravel and sand, though it is commonly covered by a few feet or inches of silt, clay, or organic matter. These floodplain sediments are for the most part less than 15 feet thick, and in many places consist of less than 5 feet of bouldery or cobbly gravel. Floodplains of larger rivers are considerably wider and consist predominantly of overbank silt and sand. Gravel occurs within the present channel and as local lenses throughout the alluvial fill.

Considerable areas of alluvial fan deposits and other materials washed in from adjacent slopes have been included in the mapped distribution of Recent alluvium. The limitation of scale precludes delineation of these materials as separate map units on Plate 1.

*Swamp deposits* occupy poorly-drained depressions on the surface of unconsolidated sediments and bedrock (Figure 1). These deposits consist largely of undecomposed or partially decomposed plant material, but also contain significant amounts of fine inorganic material washed in from adjacent hillslopes. The most extensive swamp deposits occur in shallow bedrock depressions on flat upland surfaces or adjacent to streams in lowland areas. Local bodies of bog sediment occupy kettle hole depressions in ice-contact deposits. Some areas of coastal lagoon and tidal estuary have been included in the mapped distribution of swamp sediments.

Recent alluvium and swamp sediments are poorly-drained, although coarse-textured alluvial deposits adjacent to rivers map be significant sources of groundwater. The fertility of some floodplain deposits makes them excellent agricultural land.

Section II

# BEDROCK GEOLOGY

By

Arthur M. Hussey II

## INTRODUCTION

The bedrock of Knox County consists of a variety of *intrusive igneous rocks* (crystallized at great depth from molten rock, or magma), *volcanic rocks* (formed from both liquid lava flows and solidified lava fragments blown from volcanic vents), *metamorphosed sedimentary rocks* (changed by heat and pressure), and *metamorphosed volcanic rocks*. The metamorphic rocks were initially deposited between about 500 and 370 million years ago during that part of geologic time referred to as the *Ordovician*, *Silurian*, and *Devonian* periods. These rocks accumulated in a rapidly subsiding trench bordering the North American Continent and extending from Newfoundland to Alabama. During the Devonian period, great horizontal stresses within the earth's crust caused much of this thick pile of sedimentary and volcanic rocks to be deformed into extensive *folds*, and ruptured by *faults* (breaks in the crust along which movement has taken place) and *joints* (cracks in the crust where no movement has occurred). These rocks were depressed several miles into the earth where they were metamorphosed by the great pressure and heat there. The rocks most deeply buried were heated sufficiently to partly melt them forming the large masses of igneous rocks, mostly *granite*, in the area. From late in the

Devonian period to the present, slow uplift and erosion has gradually exposed these rocks. During the *Pleistocene Epoch* (the past 1-2 million years) *continental glaciers* spread over this area several times and the rocks were scraped clean of weathered material produced during the long period of erosion, leaving fresh rock at the surface. During the last retreat (final melting away) of glacial ice, bedrock was partially buried by sand, gravel, and clay derived from the melting ice; consequently the geologist's task is to reconstruct the extent of various rock units or "formations" from the scattered outcrops (exposures of bedrock) that protrude through these surficial sediments.

## THE BEDROCK GEOLOGY MAP

The bedrock geology map of this report (plate 2) shows the regional distributions of the various rock types that have been mapped in Knox County. Rocks are differentiated on the basis of mineral content, texture, and color - fresh and weathered. Because of its small scale, the bedrock map is of necessity a generalized portrayal of rock types in the different belts in the area. These belts are labeled on the basis of the predominant rock type present. Local variations in rock types are to be expected when the belts are examined in detail. Such detailed variations are beyond the scope of the map scale to resolve. For specific site evaluations, detailed examination of local outcrops and well or boring data must be made.

Boundary lines between rock units shown on the map are of three types. Thin lines show original *depositional boundaries* along which there has been no movement of rocks. In the field, such boundaries may be sharp or they may be gradational. Heavy lines separate units that have been brought into contact by movement along *faults*. Heavy lines with "teeth" distinguish faults where the plane of contact between the broken rock units is inclined at a low angle. Heavy lines without "teeth" indicate faults inclined at a steep angle. The faults in Knox County have been recognized and mapped primarily on the basis of abrupt cut off of rock types, rather than physical breaks in the rock.

Rocks in fault zones commonly are weak due to the crushing and granulation that goes on during fault movement. However, in areas where such zones are subsequently melted and altered by metamorphism, the weak, crushed material along the fault zone may be healed by recrystallization, and be made as mechanically strong as the nonfaulted material. The user of the bedrock geologic map must thus be aware that mapped fault zones may or may not be zones of rock weakness. For any major engineering projects near such zones, the actual mechanical characteristics of the faulted rocks would have to be determined by detailed examination of outcrops in the area. It may be necessary, if mechanical strength of bedrock is important, to sample the rocks through the fault zone by diamond core drilling from the surface.

Bedrock geologic maps are of value to planners, contractors,

and government administrators in the following ways:

1. Identification of areas where rock has potential value.
2. Prediction of quality and availability of ground-water derived from wells drilled into bedrock.
3. Prediction of general mechanical properties and qualities of rocks, as, for example, blasting character; drilling characteristics; rippability; slope stability (especially where sizeable vertical cuts are anticipated); permeability of the rock; rock strength and durability in terms of suitability as road surfacing aggregate; and reaction to weathering when extensive exposures are excavated.

## DESCRIPTION OF MAP UNITS

### Intrusive Igneous Rocks ("granites")

*GRANITE* - An igneous rock formed by crystallization of a pool of molten rock material (magma) at depths of several miles in the earth's crust. The term often is used to describe all coarse-grained intrusive igneous rocks including *syenites* and *gabbros* (see below). Here, the term *granite* refers to light colored, coarse-grained igneous rocks containing relatively abundant orthoclase feldspar and quartz, with subsidiary amounts of dark iron-magnesium minerals.

Areas of Occurrence: Five Principal Belts

1. Northwestern part of the map in the Stickney Corner area.
2. Western edge of Knox County extending northwest from the Friendship area.
3. South Thomaston - St. George - Spruce Head area.
4. Vinalhaven Island.
5. Isle-au-Haut.

In addition to the five principal belts, there are many small areas of granite outcrop scattered throughout the map area.

Appearance and Mineral Composition:

Areas 1 and 2, and most of the small granite bodies: Light to medium gray, fine to medium grained, unevenly textured granite with numerous streaks of a dark, biotite-(black mica) rich material, and irregular patches of coarse-grained very unevenly textured pegmatite. The granite is composed of light gray orthoclase and plagioclase feldspars, clear quartz, dark flaky biotite in very small grains, and clear, flaky muscovite (white mica), also in small grains.

Area 3: Medium to coarse-grained medium gray to slightly pinkish gray granite, also tending to show uneven texture. Mineral composition same as granite of Areas 1 and 2.

Area 4: Vinalhaven granite. Pinkish-buff, medium gray in color, with coarse-grained even texture, locally more fine-grained. Composed of slightly pinkish-buff orthoclase feldspar, smokey quartz, milk-white plagioclase feldspar, and black mica. Extensively quarried in the past; no quarries active today.

Area 5: Isle-au-Haut granite. Pink, rather coarse-grained; becoming finer-grained, and gray in color near Moore Harbor.

Fracturing Characteristics:

Granite is cut generally by conspicuous *joints*, and *sheets* (nearly horizontal fractures essentially parallel to the topography). Where sheeting surfaces are distantly enough spaced, the granite is structurally suitable for quarrying. Many granite bodies are more densely fractured and jointed at their margins.

*PORPHYRITIC SYENITE* - Dark gray to brownish gray, unevenly textured rock consisting of conspicuous large (up to 1 1/2 inches) dark brownish or purplish gray orthoclase feldspar grains set in a medium to fine-grained groundmass of orthoclase feldspar, biotite, amphibole and pyroxene. Rock in the Razorville area is not closely jointed or sheeted and forms very hilly and knobby topography.

*PORPHYRITIC GRANITE*: Light gray medium-grained *foliated* (parallel fabric caused by segregation of different minerals into layers) rock composed of quartz, plagioclase feldspar, microcline, and biotite, with conspicuous large crystals of microcline feldspar up to 2 inches long.

*DIORITE AND GABBRO*: Dark gray to black, fine to medium-grained, granular rock, composed of dark plagioclase feldspar, pyroxene, hornblende, and occasionally olivine. Rock is commonly cut by later (younger) veins and dikes of granite.

## Extrusive Igneous Rocks
(volcanics)

*RHYOLITE*: White- to buff-weathering rock, commonly with texture of flint. Fresh rock is dark gray or brownish gray in color, and tends to be strongly fractured in many directions. Rhyolite is a very durable, brittle rock, suitable for such commercial uses as road metal aggregate.

*ANDESITE*: Strongly fractured dark greenish gray rock in which mineral grains are not visible or identifiable without a microscope. Weathers light greenish gray. Andesite is hard and quite satisfactory as road metal aggregate.

## Metamorphosed Sedimentary Rocks

*NONRUSTY LIGHT-COLORED SCHIST*: Light gray rock composed of

muscovite. Mica flakes are parallel to each other and are distributed throughout, giving rock a very easy splitting direction (foliation). Joints are common but may be fairly tight because of clogging by mica grains. *

*BIOTITE QUARTZITE and QUARTZ-MICA SCHIST:* Medium gray, relatively hard rock composed mostly of fine-grained quartz with minor feldspar, and biotite. Joints and fractures common and likely to be less tight than those of the nonrusty schist. Rock has appearance of weathered wood.

*WHITE and LIGHT GRAY QUARTZITE and QUARTZITE CONGLOMERATE*: Very light gray, hard, brittle rock composed almost entirely of quartz. Quartzite is fine-grained; quartzite conglomerate has pebble sized grains. Usually closely fractured and jointed. Very suitable as road metal aggregate.

*GRAY SWIRLY QUARTZ-MICA SCHIST*: Medium gray fine-grained quartz-rich biotite schist with 1/2 to 1 inch ribs of quartzite. Looks like the biotite quartzite and quartz-mica schist except for the quartz ribs and the swirly nature of the micaceous layers. Joints and fractures relatively common.

*RUSTY SCHIST and GNEISS*: Very rusty (brown and orange)-weathering mica schist and gneiss with abundant sillimanite in places. High iron sulfide content contributes to rapid weathering of the rock. Water from wells in this rock likely to have high iron content. Rock in artificial excavations subject to rapid weathering, decomposition and disintegration, and

consequently is likely to heave and expand. Fracturing and jointing variable and likely to be tight except where active weathering has penetrated deeply.

*GRAY and CHOCOLATE-BROWN QUARTZ-GARNET BIOTITE SCHIST and THIN-BEDDED QUARTZITE*: Dark gray to chocolate brown thin bedded quartz-biotite schist and biotite quartzite with prominent bands rich in garnet. Rock is very fine-grained. Fracturing and jointing variable, likely to be tight. Moderately rusty weathering in places.

*FELDSPATHIC BIOTITE and CALC-SILICATE QUARTZITE and GRANULITE*: Medium gray to brownish gray fine-grained quartz-feldspar-biotite granulite and feldspathic biotite quartzite with thin beds of greenish gray calc-silicate granulite composed of quartz, feldspar, dark green hornblende and light green diopside. Jointing and fracturing frequent and blocky.

*SLIGHTLY CARBONACEOUS GRAY MICA SCHIST and QUARTZITE*: Medium to dark, silvery gray muscovite-biotite schist with abundant sillimanite or andalusite locally. May have small quantity of graphite. Thin gray, micaceous quartzite beds occur infrequently throughout the rock unit. Joints and fractures tight and variable in distribution.

*MARBLE*: Light gray fine to medium grained rock composed almost wholly of calcite. Joints are variable in spacing, but tend to be open due to solution by groundwater. Included with this unit is dark chocolate-gray fossiliferous, hackly fractured

siltstone and clay-rich limestone on North Haven Island. Near Rockland, the marble has been and is still being quarried for cement and agricultural lime production. It is quarried for agricultural uses near Union.

*AMPHIBOLITE*: Dark greenish gray rock composed principally of plagioclase feldspar and hornblende.

*GREENSTONE*: Medium greenish gray very fine-grained rock composed of microscopic grains of amphibole, epidote, quartz, and plagioclase.

*QUARTZ-FELDSPAR GNEISS*: Medium to light gray quartz-feldspar-biotite gneiss with light and dark components segregated into separate bands. Fracture and joint development irregular and tight. Contains large pegmatite masses.

*INTERBEDDED SCHIST and METAMORPHOSED VOLCANIC ROCKS*: Greenish gray, purplish gray, and light gray muscovite and chlorite-rich schists and feldspar-quartz gneiss, generally thin and well bedded.

## GLOSSARY *

AMPHIBOLE - A group of usually dark, rock-forming, iron-magnesium silicate minerals of which hornblende is the most common member.

ANDALUSITE - A brown, yellow, green, red, or gray aluminum mineral that occurs in thick, nearly square prisms. It forms at medium temperatures and pressures of a regionally metamorphosed sequence of rocks.

BIOTITE - A widely distributed and important rock-forming mineral of the mica group. It is generally black, dark brown, or dark green.

CALCITE - A common rock-forming mineral: calcium carbonate. It is usually white, colorless, or pale shades of gray, yellow, and blue. It is the principal constituent of limestone and marble.

CALC-SILICATE - Said of a metamorphic rock mainly consisting of calcite and calcium-bearing silicates.

CARBONACEOUS - Said of a rock that is rich in carbon.

CHLORITE - A group of platy, usually greenish hydrous silicate minerals of magnesium, iron, and aluminum. Chlorites are associated with and resemble the micas and are widely distributed in low-grade metamorphic rocks.

CONGLOMERATE - A coarse-grained sedimentary rock composed of rounded fragments such as granules, pebbles, cobbles, and boulders set in a fine-grained matrix.

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*These are simplified definitions taken in part from: *Glossary of Geology*, 1972, American Geological Institute.

CRYSTALLIZATION - The process of matter becoming crystalline, from a gasseous, fluid, or dispersed state.

DIOPSIDE - A calcium-magnesium silicate mineral that varies in color from white to green; occasionally transparent.

DIORITE - An intrusive igneous rock with granitic texture composed of dark-colored amphibole (esp. hornblende), plagioclase, pyroxene, and little or no quartz.

EPIDOTE - A yellowish-, pistachio-, or blackish-green hydrous silicate mineral containing calcium, aluminum, and iron. It commonly occurs in low-grade metamorphic rocks.

FELDSPAR - A group of abundant rock-forming aluminum silicate minerals that may contain potassium, sodium, calcium, barium, rubidium, strontium, and iron. Feldspars are the most widespread of any mineral group and constitute 60 per cent of the earth's crust.

FELDSPATHIC - containing feldspar.

FOSSILIFEROUS - containing fossils.

GABBRO - An intrusive igneous rock composed of plagioclase, pyroxene (esp. augite), and often olivine. It is similar to diorite except in the composition of the plagioclase, which contains much more calcium than sodium.

GARNET - A silicate mineral that is brittle and transparent to subtransparent, has a glassy luster, and is most often red.

GNEISS - A foliated metamorphic rock in which bands of granular minerals alternate with bands in which minerals having flaky or elongate crystal habit predominate.

GRANULITE - A metamorphic rock consisting of evensized, interlocking mineral grains.

GRAPHITE - A mineral of carbon. It is opaque, lustrous, very soft, greasy to the touch, and black in color.

HACKLY - Said of a mineral or rock fracture that gives a jagged surface.

HORNBLENDE - The commonest mineral of the amphibole group. It is commonly black, dark green, or brown.

IGNEOUS - Said of a rock or mineral that solidified from molten or partly molten material, i.e., from a magma.

MARBLE - A metamorphic rock consisting predominantly of fine- to coarse-grained recrystallized calcite and/or dolomite (calcium-magnesium carbonate).

METAMORPHISM - The mineralogical and structural adjustment of solid rocks to physical and chemical conditions which have been imposed at depth below the surface zones of weathering and cementation, and which differ from the conditions under which the rocks in question originated.

MICACEOUS - containing mica.

MICROCLINE - A form of potassium feldspar that is a common rock-forming mineral in granites and pegmatites.

MUSCOVITE - A mineral of the mica group. It is usually colorless, whitish, or pale brown.

OLIVINE - An olive-green, grayish-green, or brown iron-magnesium mineral.

ORTHOCLASE - A colorless, white, cream-yellow, flesh-reddish, or grayish potassium feldspar.

PEGMATITE - An exceptionally coarse-grained igneous rock, with interlocking crystals, usually found as irregular dikes, lenses, or veins. Their composition is often that of granite, and may include rare minerals.

PLAGIOCLASE - A feldspar containing various combinations of sodium and calcium.

PORPHYRITIC - Said of the texture of an igneous rock in which larger crystals are set in a finer groundmass.

PYROXENE - A group of dark, rock forming minerals including augite and diopside. They are similar in appearance to the amphiboles.

QUARTZ - Crystalline silica, an important rock-forming mineral: silica dioxide. It is next to feldspar, the commonest mineral.

QUARTZITE - A metamorphic rock consisting mainly of quartz and formed by recrystallization of sandstone or chert.

SCHIST - A strongly foliated metamorphic rock that can be readily split into thin flakes or slabs due to the well developed parallelism of the minerals present, for example, mica.

SILLIMANITE - A brown, grayish, pale-green, or white aluminum silicate mineral that occurs in long, slender, needle-like crystals. It forms at the highest temperatures and pressures of a regionally metamorphosed sequence of rocks.

SILTSTONE - A rock formed from silt.

SYENITE - An intrusive igneous rock containing potassium feldspar, calcium-sodium feldspar, iron-magnesium minerals, and little, if any, quartz. It is similar to granite except for the lack of quartz.

Section III

# GROUNDWATER GEOLOGY

By

W. Bradford Caswell, Jr.

## INTRODUCTION

The groundwater information presented here results from an inventory of drilled water wells in Knox and several adjacent coastal counties. Collection and analysis of these readily available data are essential first steps for the optimum location of groundwater supplies and the protection of those supplies from contamination and misuse.

## GROUNDWATER HYDROLOGY

Hydrology is the science that deals with the movement of water above, on, and beneath the earth's surface in what is called the *hydrologic cycle*. In this cycle, water rises continuously from the earth's surface into the atmosphere by the process of evaporation and transpiration, falls to the surface as various forms of precipitation, and flows both over and under the surface in its journey to the ocean (fig. 2). Observations have revealed that of all the precipitation that falls about 20 per cent infiltrates the ground and migrates downward through the openings in both loose sediments and bedrock. At some depth, which varies from place to place because of differences in precipitation, topography, and porosity, the openings are filled with water, that is, the rocks and sediments are saturated.

The upper surface of this saturated zone is called the *water table*. Water that is in the unsaturated material above the water table is called *soil moisture* and is the water utilized by most varieties of vegetation. Water below the water table is called *groundwater*.

## Groundwater in Overburden and Bedrock

Groundwater in unconsolidated, or loose, overburden is contained in the spaces among the constituent particles. Dug and other types of "gravel" wells tap the groundwater in these loose sediments. Commonly, the spaces, or *interstices*, are numerous and interconnected enabling groundwater to move with equal ease in all directions. The ease of movement, or *permeability*, varies considerably between coarse deposits such as gravel, and fine deposits such as clay. Gravel is permeable because the interstices are large and interconnected, while clay is nearly impermeable because the interstices, although numerous and interconnected, are very tiny. Movement of groundwater through these minute openings is retarded significantly by capillary forces.

Underlying the surficial materials in much of Maine is crystalline bedrock in which the only significant openings are *fractures*. Fractures include joints, faults, and bedding planes, all of which are planar or sheet-like features. Although there are likely to be many fractures, very few are large and extensive enough to store and transmit a large

volume of groundwater. Those that yield one pint or more per minute to a water well are defined here as *veins*, a term often used by water-well drillers. If a water well were drilled to a depth of 500 or so feet into bedrock, it would encounter on the average only 7 veins (fig. 3). Veins are widely spaced vertically and do not appear to be continuously interconnected over extensive geographic areas as are the openings in an extensive body of sand and gravel. Crystalline bedrock is not very permeable and groundwater flow is restricted to the direction of a particular single vein or hydraulically connected series of veins.

## Yield of Water Wells

The yield of dug or driven wells is dependent largely upon the permeability and saturated thickness of the sediments in which they are constructed. Wells in gravel yield more water than wells in till because in gravel the spaces between the larger particles are not filled with finer material. The better sorted the gravel, the more open the spaces are between individual grains. Till, being a very poorly sorted material, has smaller and less interconnected interstices than a well-sorted gravel. Wells in a thick and saturated permeable material yield more water than wells in a similar but thin deposit because of the greater head that causes the flow of water into the well. This assumes the well in the thick deposit penetrates the full saturated thickness.

The type of surficial material in a given area and its

probable permeability can be ascertained from the surficial geologic map, plate 1, while the probable thickness of that deposit can be determined from the overburden thickness map, plate 6. Although the saturated thickness is unknown, the geology and thickness of the overburden are excellent clues to the likely yield of a well that is dug or driven in a particular area. Yield in clay will be only a fraction of a gallon per minute (gpm); in till, a few gpm; and in gravel 10 to possibly 1000 gpm.

Determining the yield of a potential rock well in a certain area is much more difficult because the factors affecting rock well yield are not easily analyzed from observations at the surface. Rock wells in Knox County range in yield from 0 to at least 100 gpm. Figure 4 shows that about 92 per cent of the wells yield 2 or more gpm, but only 38 per cent 10 or more gpm. Rock well yield varies considerably from place to place, often within a few feet, but there are areas where the majority of wells yield 10 or more gpm, or conversely, the majority yield less than 10 gpm. Plate 3 shows that a high yield area is present in the Owls Head region, and a low yield area is present in the vicinity of Union and Washington. Other high and low yield areas also can be detected. These variations in well yield do not appear to be related significantly to well depth, type of bedrock, slope of the bedrock surface, or slope of the land surface. More importantly, there appears to be no correlation between well yield and the number of veins

intersected. Wells with four veins do not necessarily yield more than wells with only one vein. Nearly half of the wells drilled intersect only one vein (fig. 5), yet these one-vein wells show a wide range in yield. Obviously, well yield is highly dependent upon the capacity of veins to transmit and store groundwater. The range of vein yield is illustrated in figure 6, which shows that 48 per cent of the veins yield 2 or more, and 15 per cent yield 10 or more gpm. This figure represents average conditions over a wide area; as described above, the average well yield, and presumably vein yield, can be unusually high or unusually low in a particular area.

Why there are high-yield veins in certain locals is not yet known. Their occurrence may be related to relatively active fracturing of the earth's crust that is taking place on a global scale as part of the process known as continental drift. Satellite imagery (ERTS) and high-altitude aircraft photographs (U-2) reveal the presence in Maine of numerous fractures that are apparently geologically young and may hold large volumes of groundwater. Investigations of this possibility are in progress.

## Water Table and Piezometric Surface

Unconsolidated materials have numerous interconnected spaces that extend to the land surface, so that groundwater contained in these materials is in free contact with the atmosphere. The water table is not confined by any impermeable overlying material or strata, and is therefore

at atmospheric pressure everywhere. The static water level in shallow dug and driven wells is the same elevation as the surrounding water table, and likewise is at atmospheric pressure. When the well is pumped, water flows into it by gravity flow, producing a dewatered *cone of depression* in the surrounding sediments.

Veins in bedrock do not have free access throughout their length to the atmosphere because of the confining bedrock walls. The confined water is under pressure in addition to that of the atmosphere because it must support in part the weight of the confining rock and the weight of the water at higher elevations in any connected veins. When a hole is drilled from the surface into a vein, the water rises up the hole until inflow from the vein is balanced by the weight of the atmosphere and the column of water in the well. Its static water level represents not a water table, but a *piezometric surface*. This imaginary surface describes the level to which water in an *artesian well* will rise naturally. Under certain conditions, the piezometric surface lies above the land surface so that artesian wells flow without pumping.

Removal of water from an artesian aquifer through pumping of a bedrock well decreases the pressure within the aquifer forming a *cone of pressure relief* in the piezometric surface around the well. The pumped water is not obtained by dewatering the aquifer, but by the decrease in pressure that allows some expansion of the confined water and slight closing of the vein walls. The volume of water released

from storage per unit volume of an artesian aquifer is much less than that released per unit volume from a water-table aquifer. Consequently, for the same volume of groundwater pumped, the cone of pressure relief is much greater in extent than the cone of depression.

Artesian groundwater conditions can also occur in surficial deposits where saturated permeable material, such as gravel, is overlain by less permeable material such as clay. The clay confines the water in the underlying gravel just as bedrock confines water in a vein. Water in a well drilled into such gravel will rise above the contact between the gravel and clay, occasionally high enough to flow naturally The static water level of such artesian wells represents a piezometric surface entirely separate from that associated with adjacent rock wells.

A particular location may have one or more water-table systems (*perched water tables*), and one or more artesian systems. A piezometric surface may be either higher or lower than an adjacent water table depending on hydrogeologic conditions. Artesian and water-table aquifers function differently and respond differently to recharge and pumping, and adjacent systems may have entirely different characteristics of yield and water quality. It is essential when considering groundwater quantity and quality in a particular location to differentiate the various groundwater systems.

## Flow of Groundwater in Overburden and Bedrock

Groundwater, being part of the hydrologic cycle is moving constantly from points of recharge to points of discharge. Movement is caused by gravity, but directions and rate of movement are controlled by the physical characteristics, chiefly the topography and permeability, of the geologic materials in which it is contained. Regardless of the material within which the water is transmitted, all groundwater must flow from points of high flow potential to points of low flow potential. Flow potential, being a result of gravity, is closely related to the elevation of groundwater at one point in a flow path relative to another point in the same flow path (fig. 7).

The water table describes the gradient of groundwater flow in unconsolidated materials and is often a subdued replica of the land surface. Figure 7 shows this general relationship between the topography and underlying water table. The hills are predominently recharge areas of high flow potential, and the valleys are predominently discharge areas of low flow potential. The water that discharges into surface water bodies may flow in an apparent uphill direction as shown by the flow lines in figure 7; however, the overall line of flow always is from areas of high flow potential to areas of low flow potential.

Surface topography has strong influence over flow directions in overburden because it determines the location of groundwater divides, as shown in figure 7. Where the

overburden is thick and extensive, *intermediate flow systems* may occur. The horizontal distance between the recharge and discharge points of intermediate systems is greater than for *local flow systems*. Surface topography does not affect the direction of intermediate flow as much as does the topography of the bedrock surface. Thus, the topography of both the land surface and the bedrock surface influence groundwater flow directions in overburden.

Groundwater in fractured bedrock generally is under artesian conditions and therefore flow directions follow the gradient of an imaginary piezometric surface rather than a water table. Flow in fractures obeys the same physical laws as does flow in overburden; however, all flow paths must follow water-bearing fractures. The form of any flow systems in bedrock is limited by the geometry of the fractures, that is, their location, attitude, and interconnections. There is little direct knowledge of the geometry of fractures and resultant flow of groundwater in crystalline bedrock. However comparison of plates 7 and 5 shows that the piezometric surface conforms generally with the topography of the bedrock surface, and it appears that the piezometric surface in fractured crystalline bedrock is a subdued replica of the bedrock surface, much the same as the water table is a subdued replica of the land surface. The bedrock highs may be areas of high flow potential and define groundwater flow divides. Bedrock lows may be discharge areas of low flow potential. Whether or not local, intermediate, and

possibly *regional* flow systems occur in fractured bedrock is not known at this time. But if these types of flow do occur in bedrock, their directions are defined by the piezometric surface illustrated in plate 7.

Recharge of Bedrock Aquifers

Most of Maine is blanketed by at least a thin cover of surficial materials that absorbs precipitation and transmits it to veins in the underlying bedrock. Overburden, in terms of recharge to bedrock aquifers, functions as both a temporary storage and transmitting medium. Investigations in Knox and adjacent coastal counties have revealed that the hydraulic characteristics of the overburden affect the availability of groundwater from bedrock. Figure 8 shows that increasing the thickness of highly permeable overburden (sand and gravel) increases the yield of rock wells, implying that the saturated thickness is often directly related to overburden thickness. Less permeable overburden, such as till, lessens this affect, and clay even reverses it. Thus, the saturated thickness and permeability of surficial deposits affects the average yield of rock wells.

Thick deposits of very permeable sediments are important to groundwater supplies in the bedrock because they contain and transmit water that rapidly recharges underlying veins. Areas of less permeable sediments are not particularly good recharge sites. The important fact

to realize is that what affects the quantity and quality of water in overburden will affect the quantity and quality of water derived from a local rock well. Contamination of water in overburden, especially sand and gravel, will ultimately lead to contamination of water in the bedrock. A decrease in the infiltration capacity of the surface or a decrease in the thickness of overburden ultimately may lead to a decrease in the yield available from a local rock well.

Freshwater-Saltwater Interface

The regional direction of groundwater movement in either a water table or artesian aquifer is from higher inland areas to the ocean, into which a substantial volume of groundwater is discharged directly. The fractured rocks of the ocean basin are saturated with salt water, while those below the land are saturated with fresh water. The division between these two bodies of water is called the *saltwater-freshwater interface* (fig. 2). The interface is located such that fresh water is discharged below the point of contact between the ocean surface and the land, making it possible for wells very near the coast to pump fresh water.

Two basic facts responsible for the hydrodynamics of groundwater flow near the coast are (1) that fresh water is less dense than salt water and therefore floats on the salt water similar to an iceburg, with its greatest volume below sea level, and (2) that the elevation of the water

table or piezometric surface is greater than that of the ocean surface, thus the lens of fresh water is at a higher flow potential than the ocean water, and its flow is always in the direction of the ocean.

The position and form of the saltwater-freshwater interface varies with the tidal cycles, the character of the water-bearing medium, and with changes in the elevation of the water table or piezometric surface adjacent to the coast. The interface is not a definite line as shown in figure 2, but even in its simplest form is a zone that grades from salt to fresh water. The hydrodynamic forces that determine the dividing line are altered daily by the elevation of the tide, thus a zone of mixed water invariably is present.

Under ideal conditions where the aquifer is isotropic and homogeneous, for example in a well-sorted sand deposit, the interface has a shape and location approximately as shown in figure 9. The depth below sea level to the interface is approximately 40 times the height of the water table above sea level. Pumping a well located very near the coast depresses the water table (or piezometric surface) locally, which causes the saltwater-freshwater interface to be displaced vertically upward. The rise in the interface is about 40 times greater than the corresponding fall in the water table because of the higher density of the salt water. Prolonged pumping of a well under these conditions can lead to saltwater intrusion and eventual contamination of the well and adjacent aquifer.

Under ideal conditions, the correct distance a well should be from mean high water, its total depth, and rate of pumpage could be determined. However, where flow is restricted to veins in bedrock, flow directions and rates are much less predictable and a condition different from the ideal case shown in figure 9 must result. Calculation of exact interface conditions is probably impossible without additional investigation. In general, to avoid having a coastal well that produces salt water, it is advisable to stay as far back from the water as possible, not to drill to excessive depths, and not to pump the well too hard.

## Conclusion

The principles of groundwater flow are the same regardless of what porous materials contain the water. However, the geology of the porous materials significantly alters the effect of these principles. Surficial and bedrock geology are firmly linked to the groundwater conditions present in Knox County and in Maine. Groundwater phenomena in fractured crystalline bedrock are the most difficult to decifer, yet bedrock is Maine's most important source of potable groundwater. The principal thrust of this groundwater investigation and of the preceding discussion is to relate readily available data to some important aspects of groundwater in the type of bedrock present throughout the state. With knowledge of these groundwater principles as they apply in Maine, the groundwater data that follow can be utilized to help obtain, maintain, and protect our local groundwater resources.

## GROUNDWATER INVENTORY DATA

Groundwater data for Knox County are presented in plates 3-7, figure 10, and table 3. The information includes yield of rock wells, depth of rock wells, bedrock surface topography, thickness of overburden, piezometric surface, and water quality. Each plate, and the figure and table, is discussed briefly in the following sections.

### Total Yield of Rock Wells - Plate 3

Total yield of rock wells is shown on plate 3 broken into ranges of 0-2, 3-10, 11-30, and 31 or more gpm. The values given on the map are those reported by the well drillers and are subject to several limitations and biases, the most important of which are that (1) the pumping test conducted is normally of short duration, and (2) the drilling was stopped at a yield considered sufficient by both the driller and homeowner. Thus, yield measurements of domestic wells may not reflect the full potential of the rock aquifer, an important point to realize when considering the probable yield of proposed municipal or industrial-commercial wells. Such wells usually are designed and constructed to yield an optimum volume of water, thus their depth, diameter, and drawdown are carefully planned. The information in plate 3 is best suited for indicating to prospective domestic well owners the yield range to be expected in a given area. It also delineates high yield areas that should receive special attention when planning community water supplies or sites for waste disposal facilities.

Total Depth of Rock Wells - Plate 4

Total depth of rock wells is indicated in plate 4 in the ranges of 0-100, 101-200, 201-300, and 301 or more feet. The total depth of a domestic well is dependent upon a number of variables including the thickness of the overburden that must be penetrated before drilling into bedrock, and the sufficiency of the yield versus the well depth. As a well is drilled deeper and deeper in search of adequate water, homeowners tend to settle for a smaller and smaller yield as sufficient for their domestic use. The information on this map gives those interested in having a well constructed an indication of the probable well depth required to produce a suitable yield in their particular area.

Bedrock Surface Contours - Plate 5

The bedrock contour map, plate 5, shows the topography of the bedrock surface with the more familiar land surface topography removed. Bedrock slope is often a determining factor in the flow directions of groundwater moving through the overburden, and may be, as pointed out earlier in this section, a determining factor in the direction of flow through bedrock. Where the overburden is perhaps less than 40 feet in thickness, which is the case in much of the county, the bedrock highs are essentially the same as the groundwater divides. Thus, with this map the general directions of groundwater flow, especially the directions of intermediate flow systems (fig. 7) can be determined.

Flow directions are extremely important to consider when planning the location of potential sources of pollution including sanitary landfills and sewage leaching fields or other forms of sewage disposal. Water sources down gradient are likely to be affected by the waste facilities, while sources up gradient are not likely to be affected.

Thickness of Overburden - Plate 6

Overburden thickness is shown in plate 6 by *isopachous lines*, which connect points of equal thickness. It is analogous to a topographic map in which contour lines connect points of equal elevation. This information, in conjunction with the surficial geology map (plate 1), is important to the determination of the potential yield of dug and driven wells, the potential recharge to bedrock aquifers, and the movement and natural attenuation of liquid and solid wastes introduced into the overburden. Overburden thickness is also a factor to be considered in the operation of gravel pits and mines, and in the construction of buildings, bridges, and dams.

Piezometric Surface of Bedrock Wells - Plate 7

The piezometric surface map, plate 7, is constructed from static water level elevations in rock wells, all of which are assumed to be artesian. Just as the water table indicates the varying gradient of the near-surface groundwater flow systems, the piezometric surface represents the gradient of the artesian water systems in the underlying bedrock.

Plate 7 can be used to determine the most probable directions of groundwater flow in bedrock.

It is impossible at this time to know how extensive any particular artesian system is in the bedrock because the geometry of the fractures is unknown. The map suggests that each bedrock high may be a recharge area of high flow potential, and each bedrock low may be a discharge area of low-flow potential. Although the hydraulics of the artesian systems in crystalline rocks are poorly understood, it is certain that if groundwater contaminants are introduced into the bedrock, they always will move down the gradient and possibly reappear in down gradient water wells or at other points of groundwater discharge.

Quality of Groundwater From Rock Wells - Figure 10 & Table 3

The quality of water derived from rock wells is dependent largely upon the source of recharge, the type of rock in which the water is stored and transmitted, and the length of time the water is contained in the veins. The latter varies directly with the length of flow paths followed by groundwater as it moves through a vein or system of veins. The proximity of a well to natural and man-made sources of contamination can significantly affect water quality.

Road salting contributes chloride to groundwater, but the effect is usually restricted to the vicinity of highways. Natural concentrations of salt water in overburden and bedrock have been reported at a few places in the state.

Much of our present day inland coastal area was covered by ocean at the close of the last glacial period. Rock and sediments within the inundated areas were saturated with sea water. After the ocean withdrew, the sea water was flushed out of most of the rocks and sediments, but apparently small pockets of this sea water are trapped by unusual hydrogeologic conditions. Wells drilled into these pockets yield water that is very high in chloride. Chloride also varies with proximity to the ocean because on-shore winds carry it inland where it eventually contributes to the chloride content of local groundwater. Very near the present day coast, high concentrations of chloride most likely are caused by direct pumpage of brackish water from the sea. Table 2 gives the range of chloride concentrations encountered in wells in the various townships of the county. A concentration of 250 ppm (parts per million) is considered unsuitable for potable water.

Hardness of groundwater is related to the concentration of a number of dissolved constituents, most notably calcium carbonate. Water in carbonate rocks (limestone and marble) tends to be harder than water from other rock types such as granite. The distribution of these various rock types is shown on the bedrock geologic map (plate 2). Table 3 indicates the ranges of hardness encountered within the county. Water with 75 ppm or less hardness is considered soft; that with 300 ppm is considered very hard. Most groundwaters fall within these extremes.

| TOWN | pH | CHLORIDE ppm | HARDNESS ppm | NUMBER OF WELLS CONSIDERED |
|---|---|---|---|---|
| Washington | 6.3 - 7.2 | <10 - 44 | 12 - 128 | 21 |
| Appleton | 6.8 - 7.9 | <10 - 26 | 24 - 152 | 11 |
| Union | 6.5 - 7.9 | <10 - 58 | 20 - 178 | 30 |
| Hope | 6.2 - 7.9 | <10 - 106 | 16 - 124 | 13 |
| Camden | 6.1 - 8.2 | <10 - 231 | 14 - 146 | 38 |
| Warren | 6.7 - 7.7 | <10 - 198 | 0 - 182 | 33 |
| Rockport | 6.5 - 8.7 | <10 - 65 | 24 - 226 | 30 |
| North Haven | 6.1 - 8.6 | <10 - 52 | 34 - 60 | 5 |
| Vinalhaven | 6.3 - 7.8 | 11 - 600 | 0 - 410 | 21 |
| Rockland | 6.9 - 7.9 | <10 - 55 | 32 - 250 | 9 |
| Owls Head | 6.7 - 8.1 | <10 - 870 | 0 - 974 | 46 |
| Thomaston | 6.7 - 7.4 | 15 - 53 | 68 - 195 | 8 |
| So. Thomaston | 6.3 - 7.7 | <10 - 8640 | 22 - 226 | 25 |
| Cushing | 6.5 - 7.9 | <10 - 58 | 10 - 168 | 25 |
| St. George | 5.9 - 7.9 | <10 - 1780 | 0 - 280 | 75 |
| Friendship | 6.7 - 7.7 | <10 - 178 | 16 - 330 | 32 |

TABLE 3

RANGE IN VALUES OF pH, CHLORIDE, AND HARDNESS
FOR BEDROCK WELLS IN EACH TOWN
OF KNOX COUNTY

(Data adapted from Maine Department of Health and Welfare.)

Many rock types contain iron and magnesuim sulfides, which are rather consistant contributors to poor groundwater quality in the mid-coastal area. Rock types described as "rusty" on plate 2 are more likely to contain groundwater high in iron and magnesium. More detailed information on the distribution of groundwater high in these two constituents is unavailable at this time. A combined concentration of iron and magnesium of greater than 0.3 ppm is considered unsuitable for a potable water supply.

The acidity of water is measured by pH, which is a notation indicating the concentration of hydrogen ions ($H^+$). A pH of 7 is neutral; any value less than 7 is acid, while any value greater than 7 is alkaline. The acidity of groundwater is determined by a number of complex factors, but in general is related to the chemical composition of the bedrock and overburden. Groundwater in limestone tends to be more alkaline than that in schist and granite. Table 3 indicates the range of pH values measured within the county. Although pH is rarely a limiting factor in the potability of groundwater, acid water tends to dissolve metals such as copper from water pipes.

Figure 10 shows for each township in Knox County, the median value of pH, hardness, and chloride. The information pertains only to water derived from bedrock aquifers. It is generalized, but indicates the broad varieties in water chemistry that are encountered within the county and mid-coastal area in general.

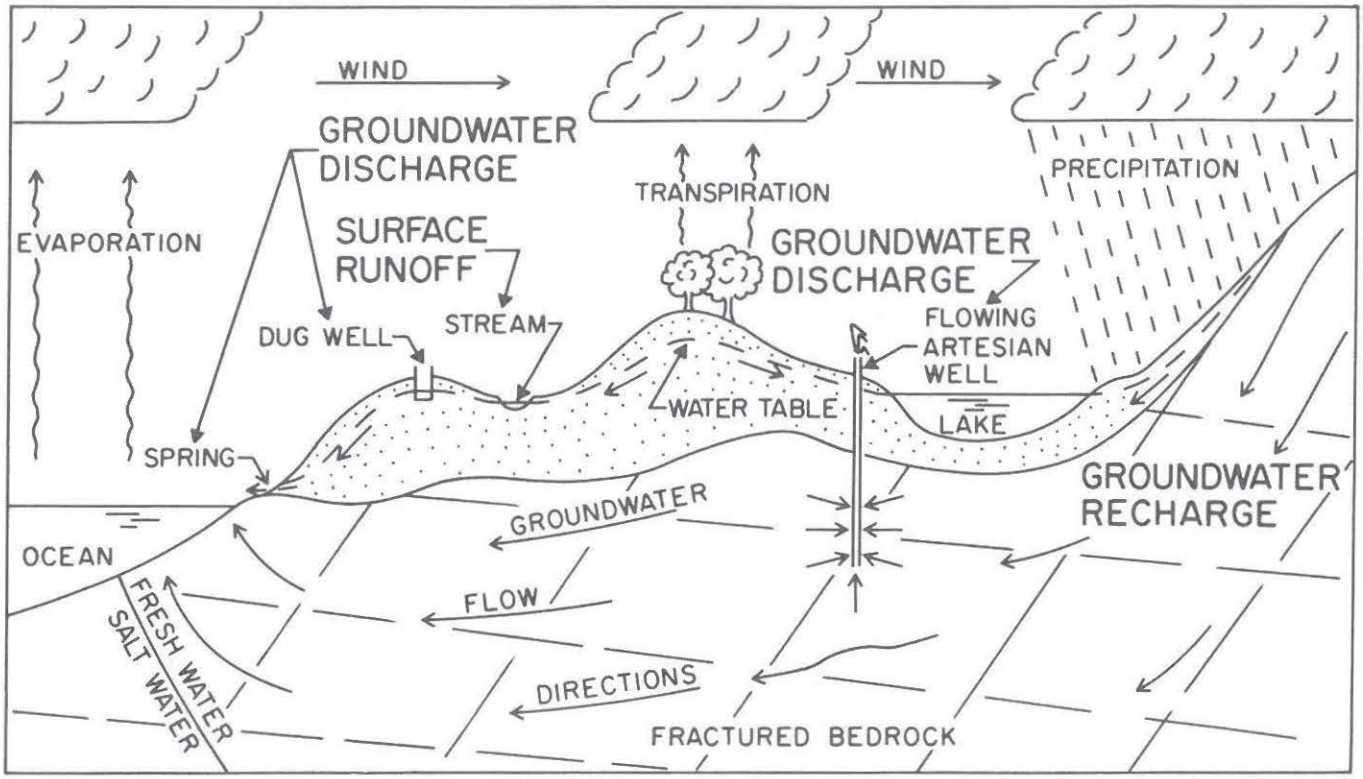



FIG. 2

THE HYDROLOGIC CYCLE

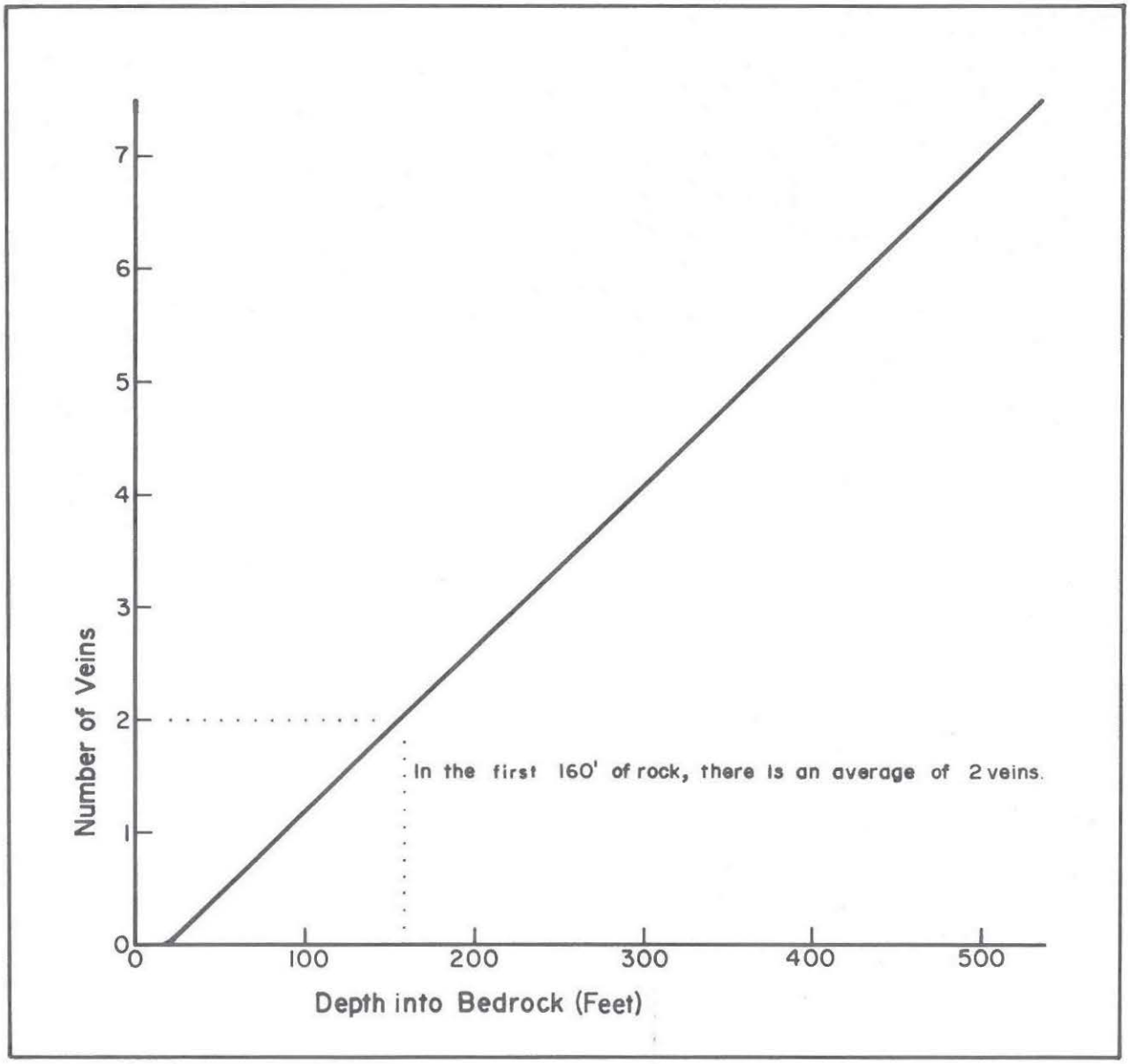



FIG. 3

AVERAGE NUMBER OF VEINS AT VARIOUS BEDROCK DEPTHS
(Data from 581 wells in Cumberland and Sagadahoc Counties, Maine.)

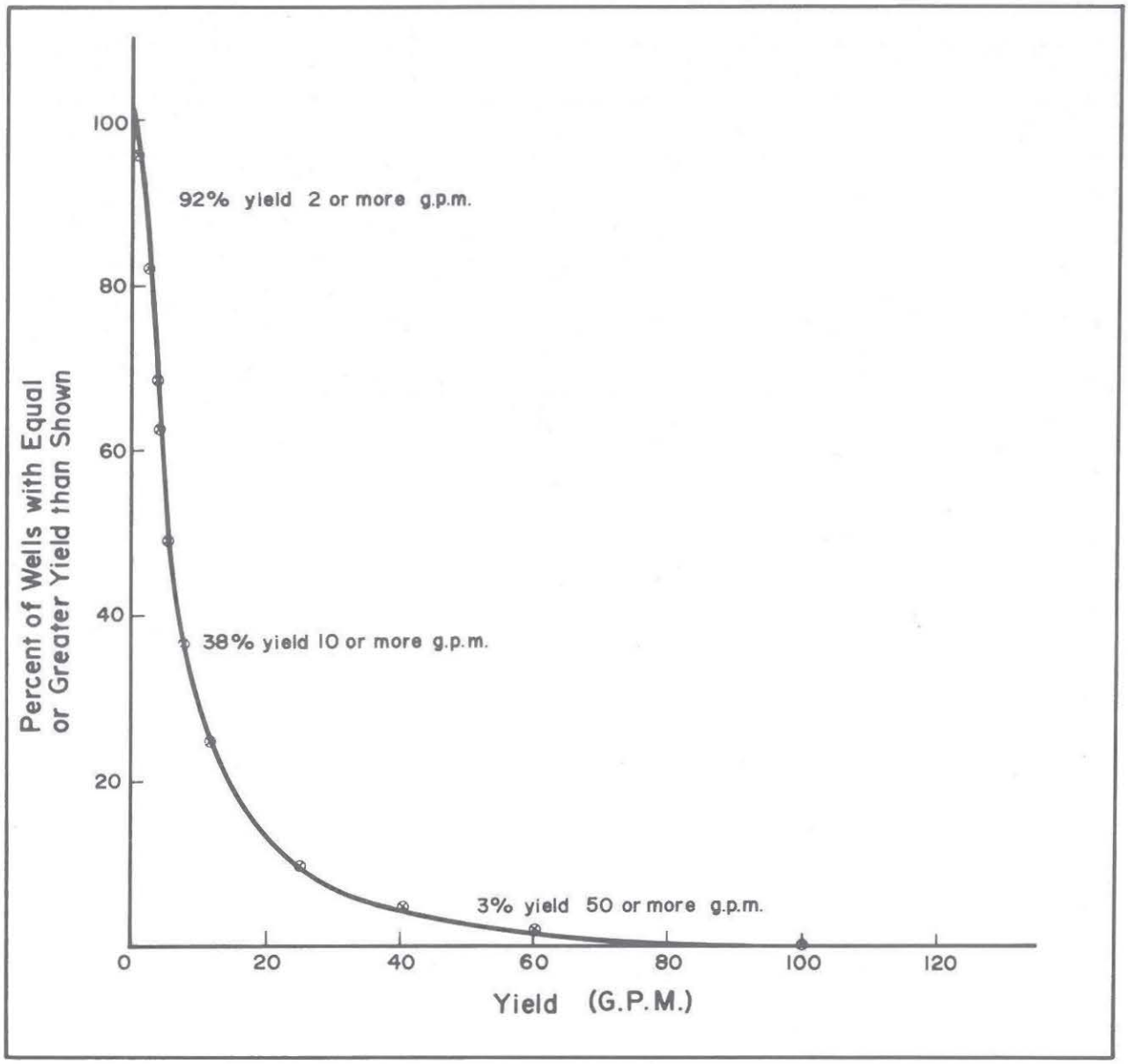



FIG. 4

TOTAL YIELD OF BEDROCK WELLS IN KNOX COUNTY, MAINE

(Data from 798 wells.)

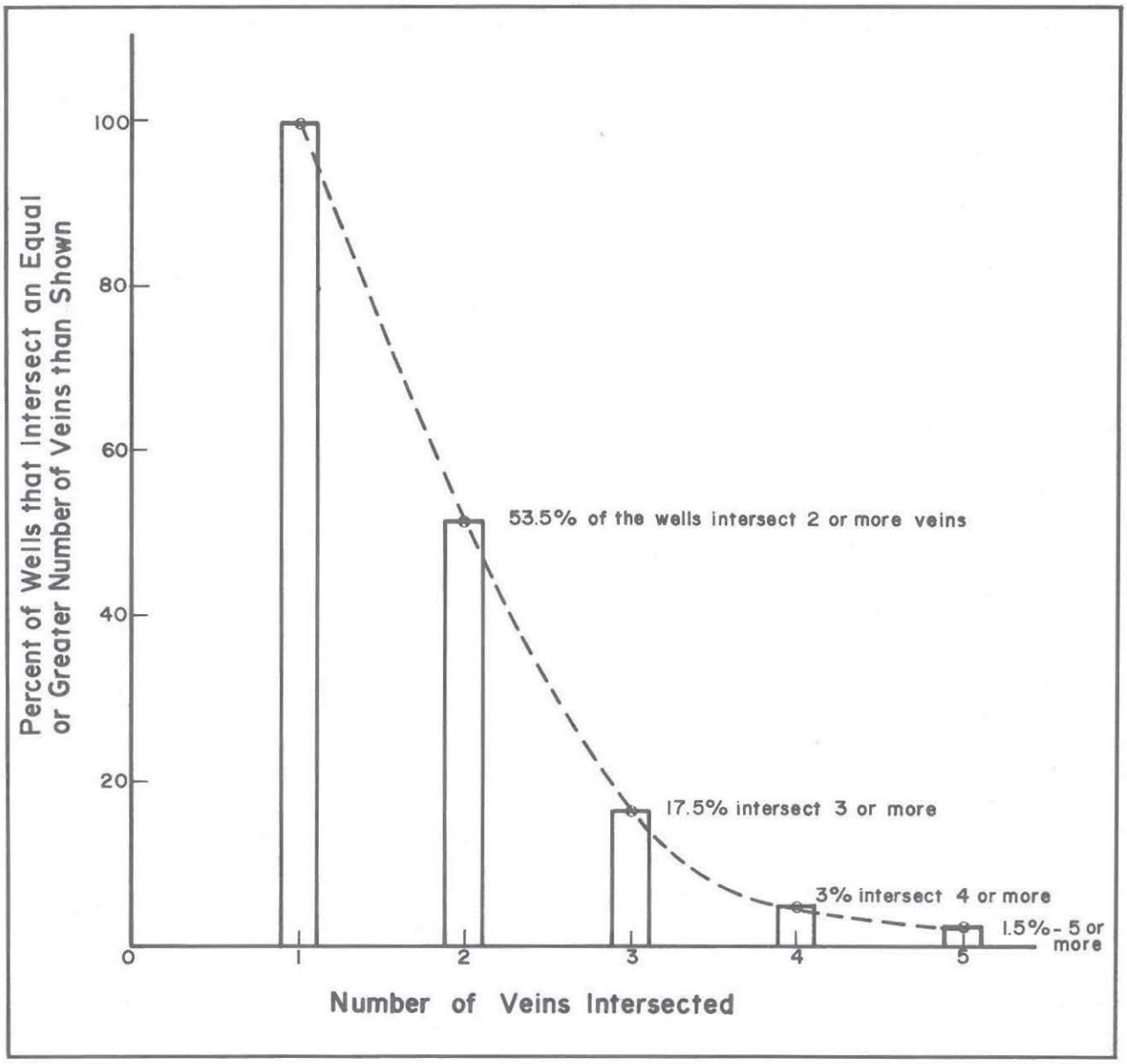



FIG. 5

NUMBER OF VEINS IN BEDROCK WELLS

(Based on 794 wells in Cumberland and Sagadahoc Counties, Maine.)

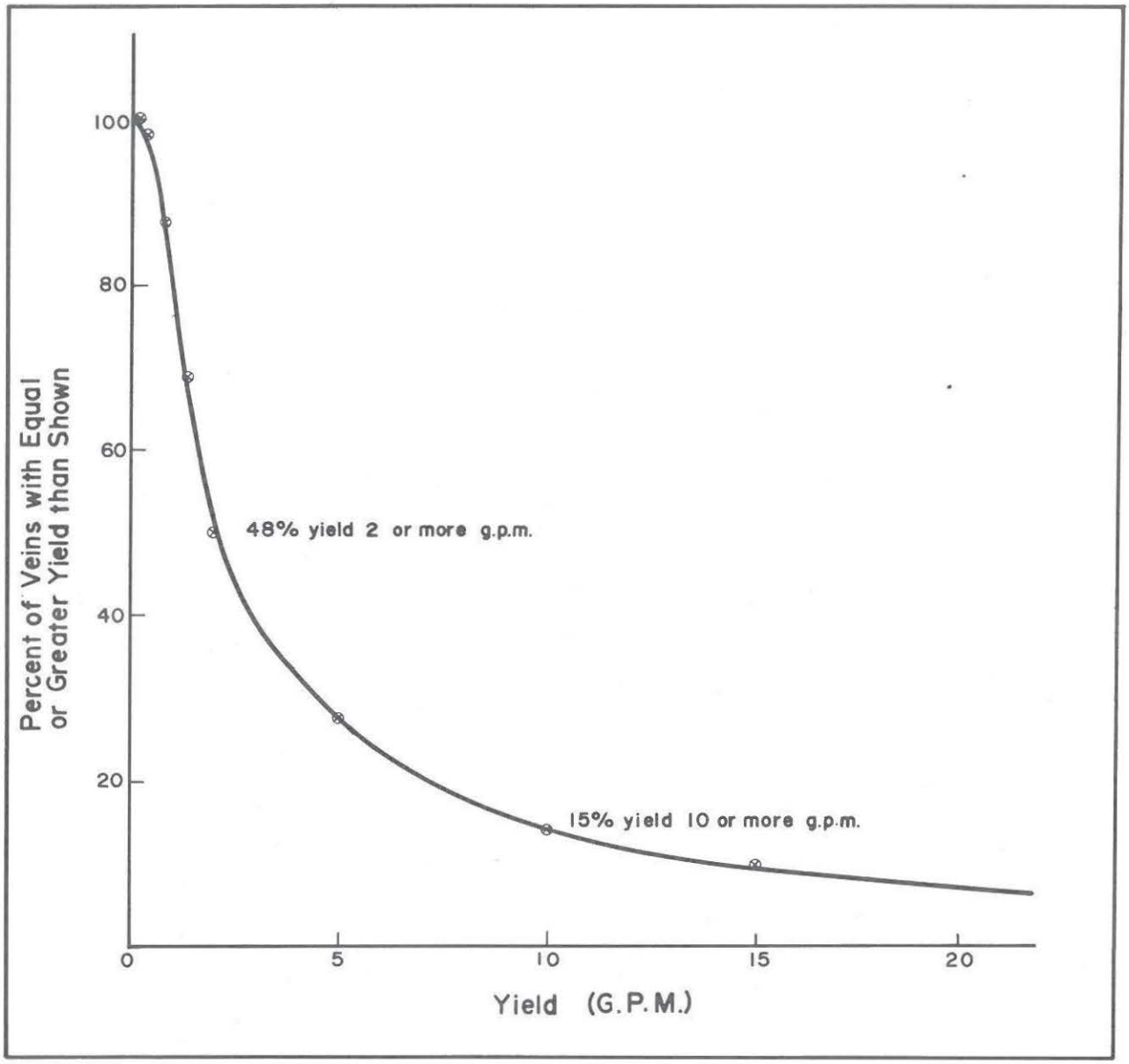



FIG. 6

YIELD OF VEINS IN BEDROCK WELLS

(Based on 1022 veins in wells

in Cumberland and Sagadahoc Counties, Maine.)

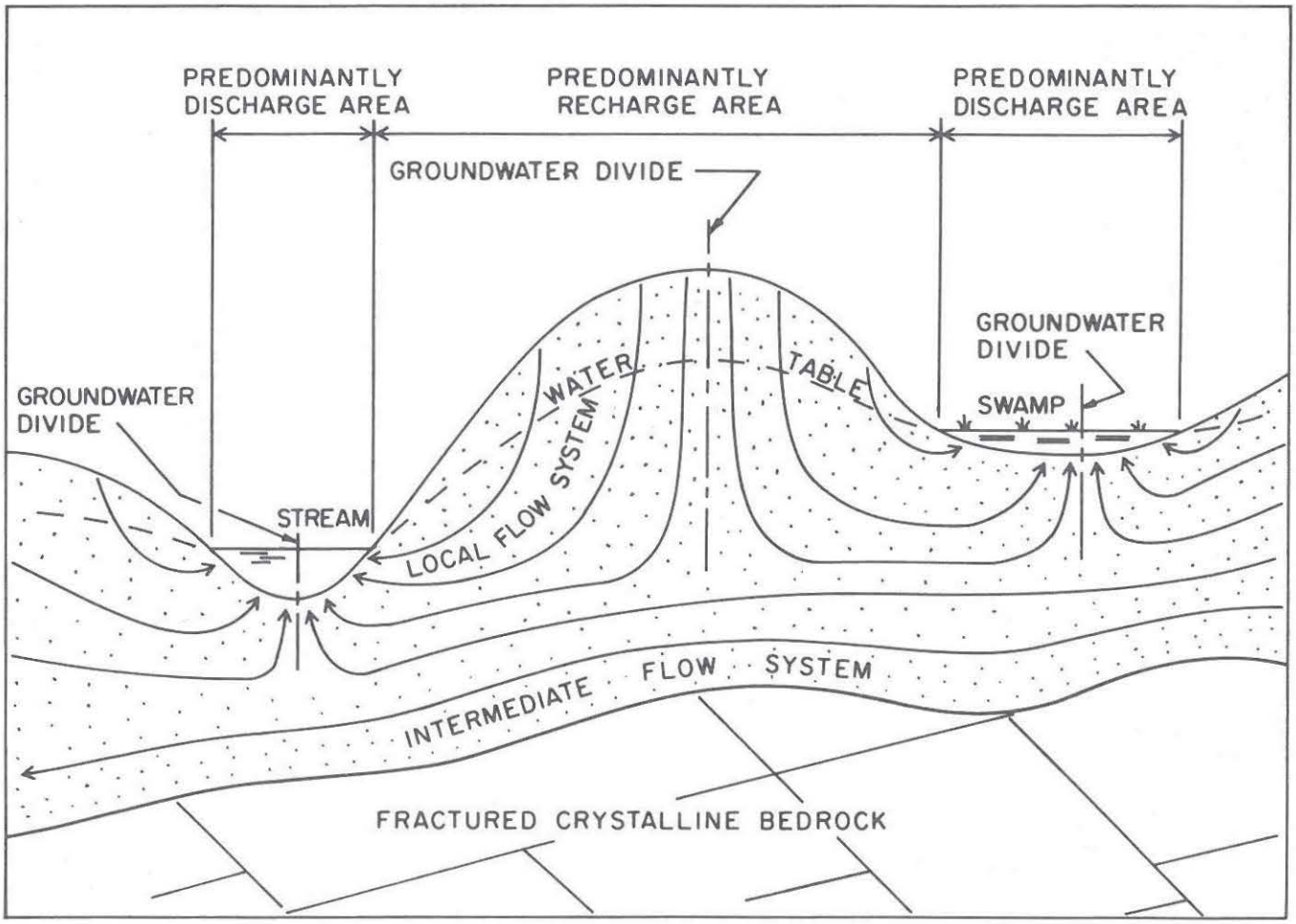



FIG. 7

GROUNDWATER FLOW SYSTEMS IN UNCONSOLIDATED MATERIALS

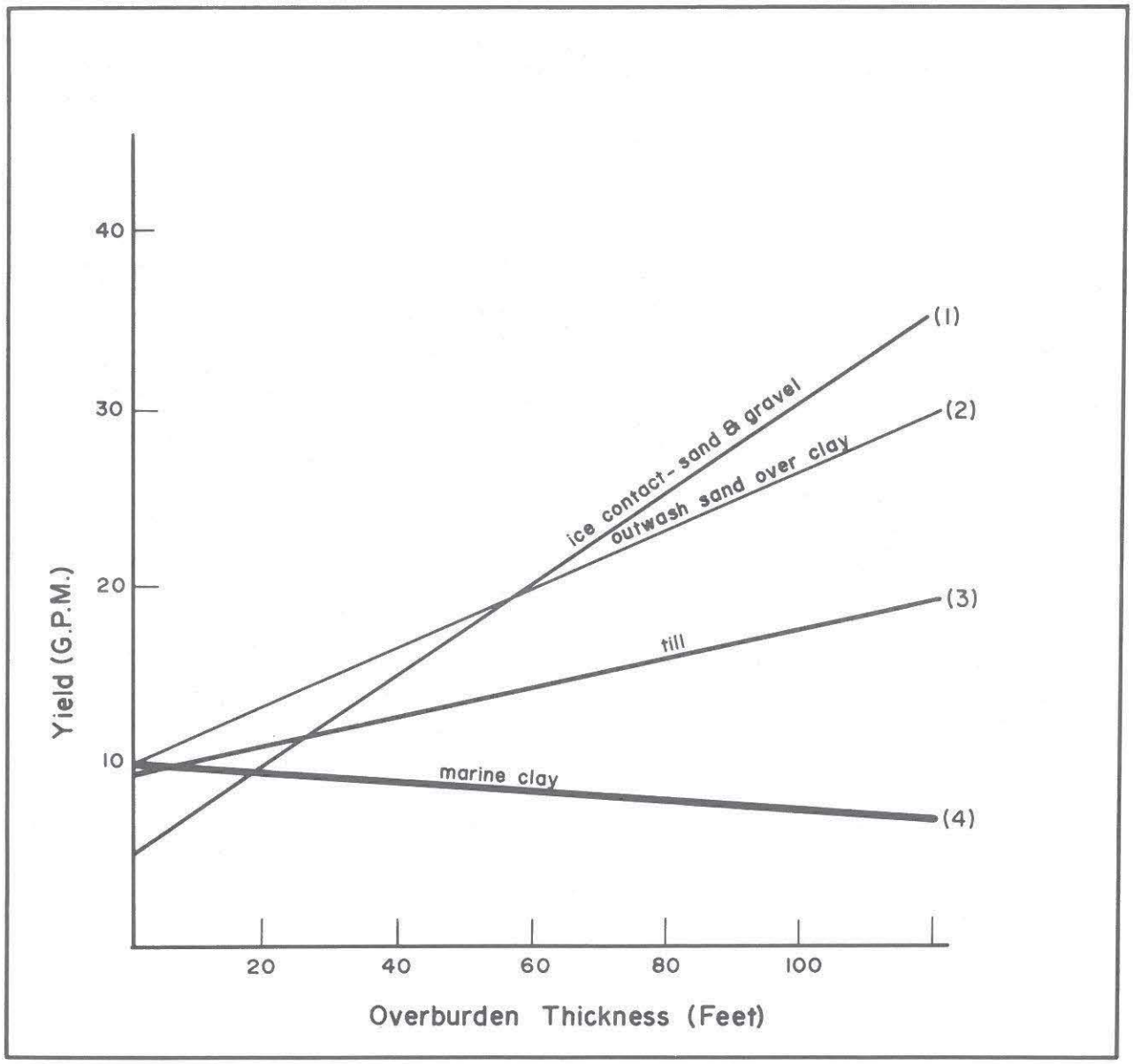



FIG. 8

RELATIONSHIP BETWEEN BEDROCK WELL YIELD AND THE THICKNESS AND TYPE OF OVERBURDEN

(Data from Cumberland, Sagadahoc, and Knox Counties, Maine. Regression line 1 based on 80 wells; 2 on 145 wells; 3 on 248 wells; and 4 on 206 wells.)

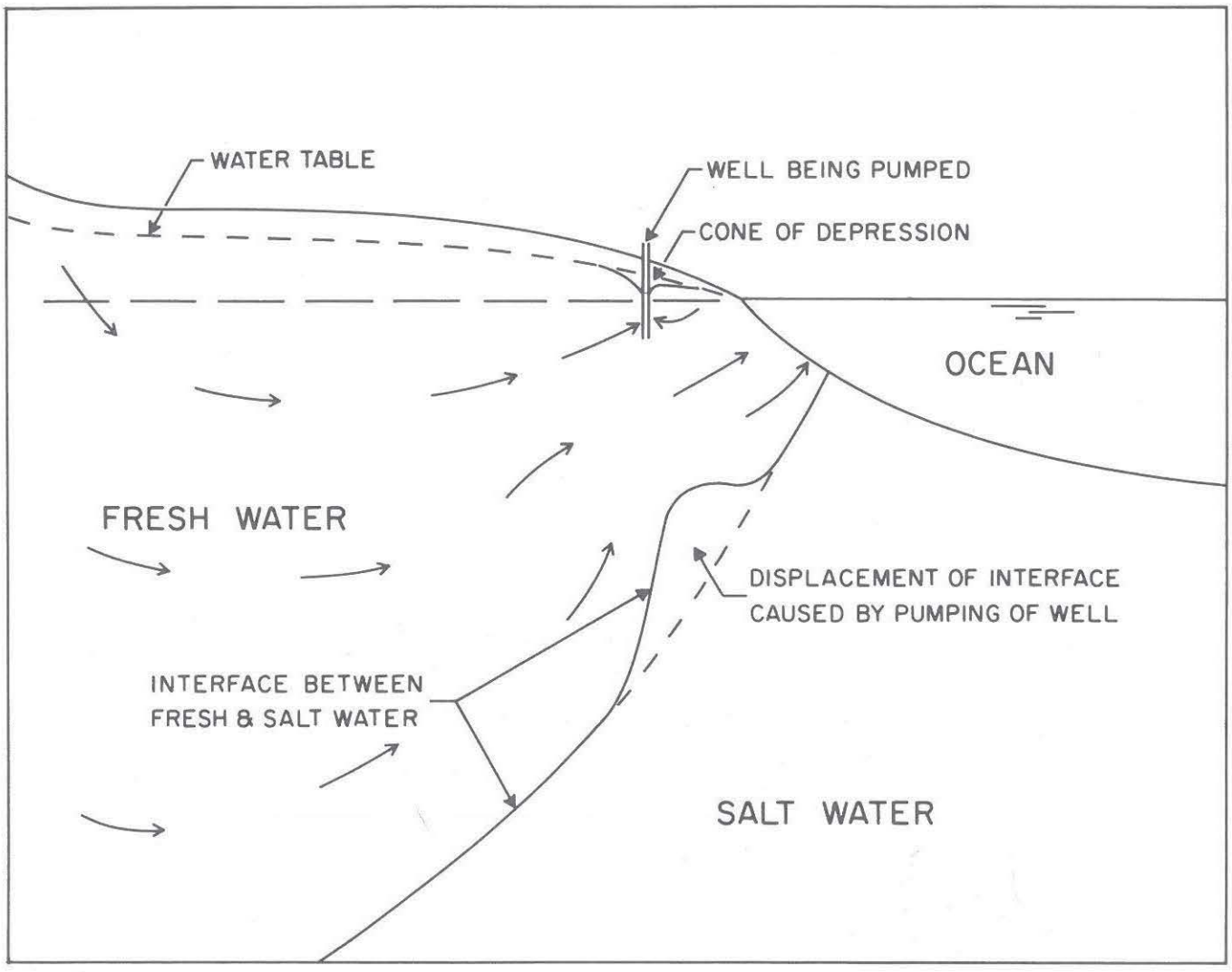



FIG. 9

IDEALIZED GROUNDWATER FLOW NEAR THE SALTWATER- FRESHWATER INTERFACE

(The general relationships hold true for either a water-table aquifer, as shown, or an artesian aquifer.)

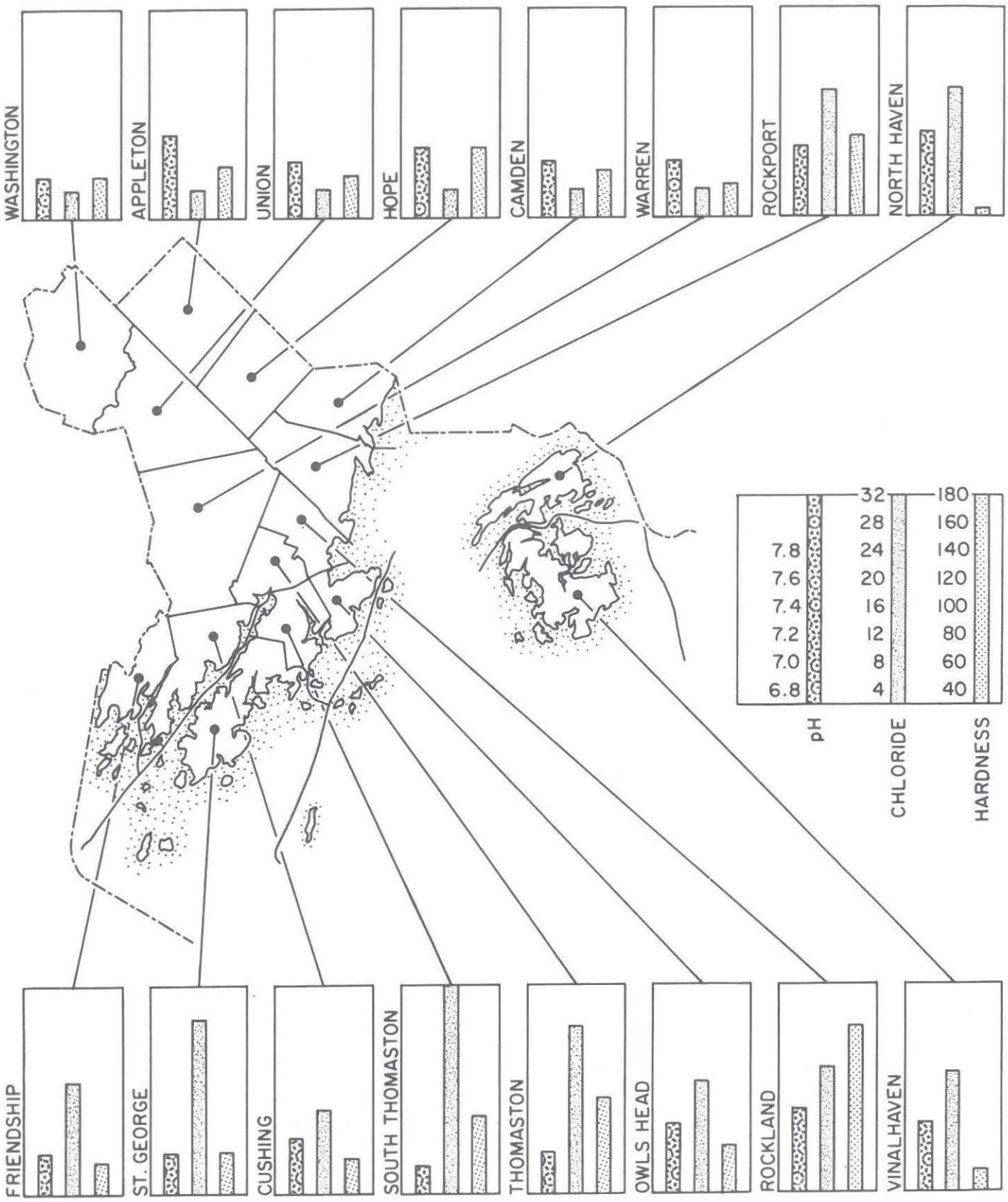



FIG. 10

MEDIAN VALUE OF pH, CHLORIDE, AND HARDNESS OBSERVED IN ROCK WELLS IN EACH TOWN OF KNOX COUNTY, MAINE

(Data adapted from Maine Department of Health and Welfare.)

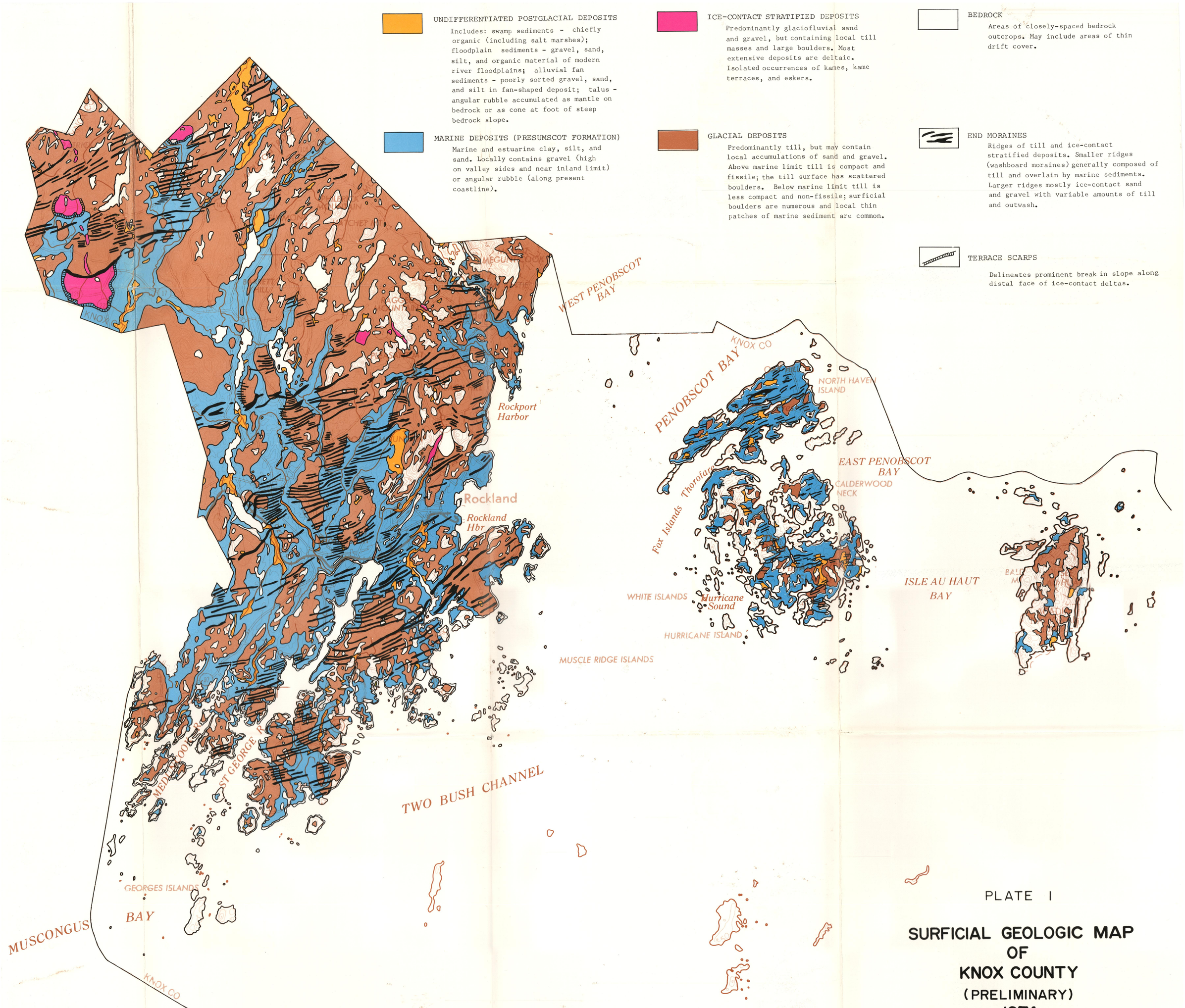



PLATE I

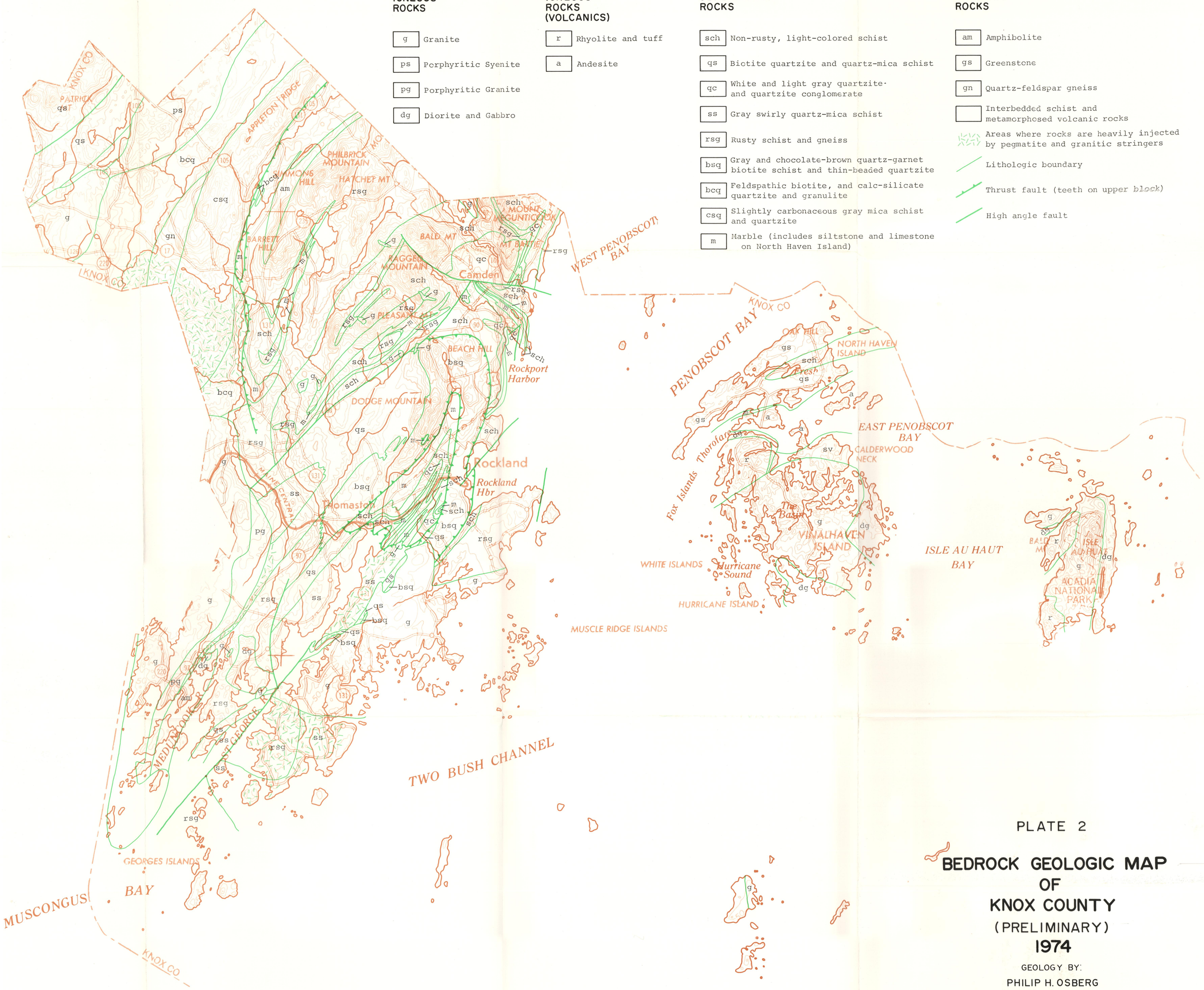
# SURFICIAL GEOLOGIC MAP OF KNOX COUNTY (PRELIMINARY) 1974

GEOLOGY BY:
GEOFFREY W. SMITH
BJÖRN G. ANDERSON

SCALE - 1:125,000

0 1 2 3 4 5 6 7 8 9 10 mi.

PHYSICAL RESOURCES SERIES
BUREAU OF GEOLOGY
DEPARTMENT OF CONSERVATION
STATE OF MAINE




## INTRUSIVE IGNEOUS ROCKS

- g — Granite
- ps — Porphyritic Syenite
- pg — Porphyritic Granite
- dg — Diorite and Gabbro

## EXTRUSIVE IGNEOUS ROCKS (VOLCANICS)

- r — Rhyolite and tuff
- a — Andesite

## METAMORPHOSED SEDEMENTARY ROCKS

- sch — Non-rusty, light-colored schist
- qs — Biotite quartzite and quartz-mica schist
- qc — White and light gray quartzite and quartzite conglomerate
- ss — Gray swirly quartz-mica schist
- rsg — Rusty schist and gneiss
- bsq — Gray and chocolate-brown quartz-garnet biotite schist and thin-beaded quartzite
- bcq — Feldspathic biotite, and calc-silicate quartzite and granulite
- csq — Slightly carbonaceous gray mica schist and quartzite
- m — Marble (includes siltstone and limestone on North Haven Island)

## METAMORPHOSED VOLCANIC ROCKS

- am — Amphibolite
- gs — Greenstone
- gn — Quartz-feldspar gneiss
- Interbedded schist and metamorphosed volcanic rocks
- Areas where rocks are heavily injected by pegmatite and granitic stringers
- Lithologic boundary
- Thrust fault (teeth on upper block)
- High angle fault

PLATE 2

# BEDROCK GEOLOGIC MAP OF KNOX COUNTY

(PRELIMINARY)

**1974**


GEOLOGY BY:

PHILIP H. OSBERG

CHARLES V. GUIDOTTI

STEVEN A. NORTON

COMPILED BY:

ARTHUR M. HUSSEY II


SCALE - 1:125,000

0 1 2 3 4 5 6 7 8 9 10 mi


PHYSICAL RESOURCES SERIES
BUREAU OF GEOLOGY
DEPARTMENT OF CONSERVATION
STATE OF MAINE

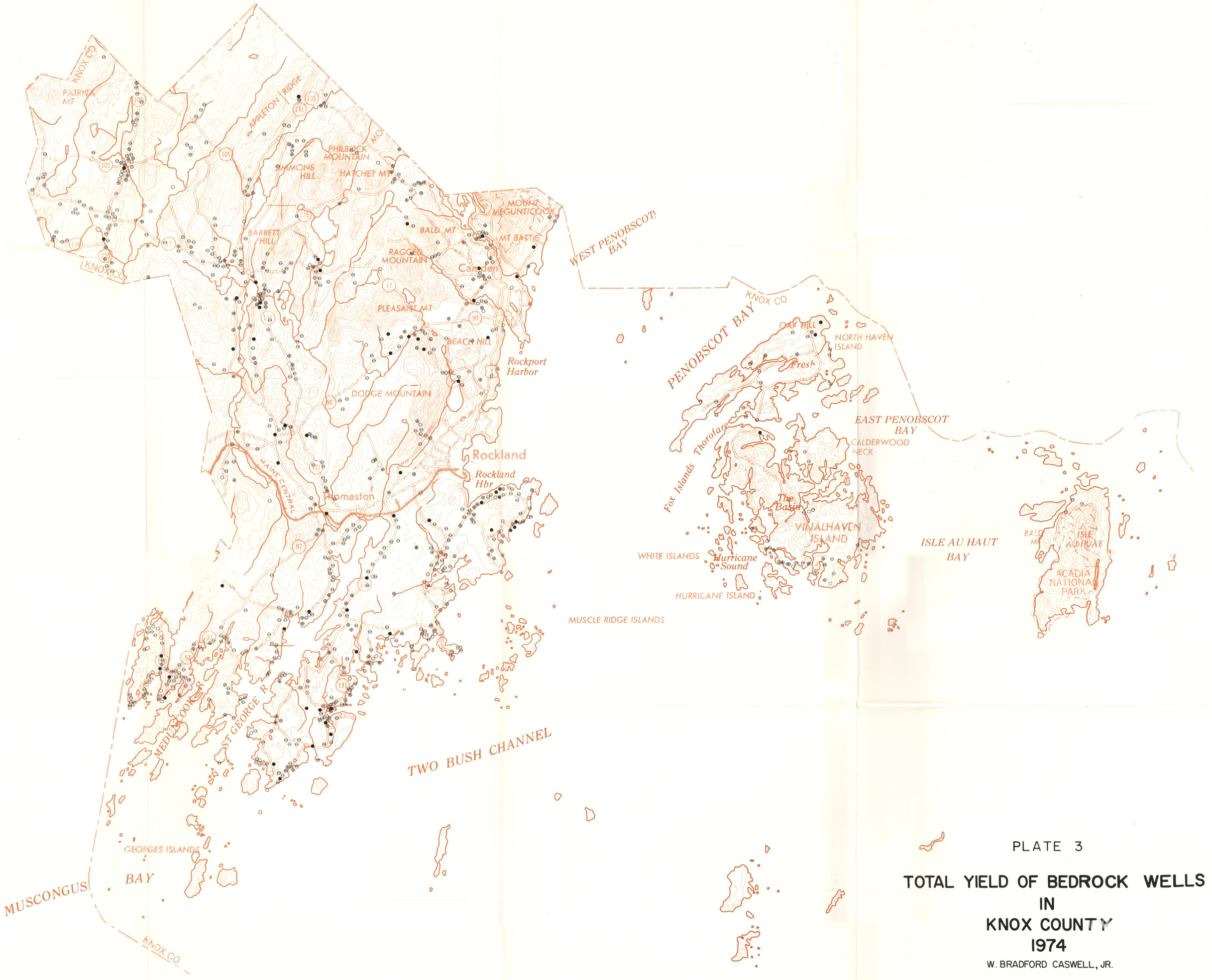



PLATE 3

# TOTAL YIELD OF BEDROCK WELLS IN KNOX COUNTY 1974

W. BRADFORD CASWELL, JR.

SCALE - 1:125,000

1 0 1 2 3 4 5 6 7 8 9 10mi

PHYSICAL RESOURCES SERIES
BUREAU OF GEOLOGY
DEPARTMENT OF CONSERVATION
STATE OF MAINE

EXPLANATION

○ 0 – 2 GPM

⊖ 3 – 10 GPM

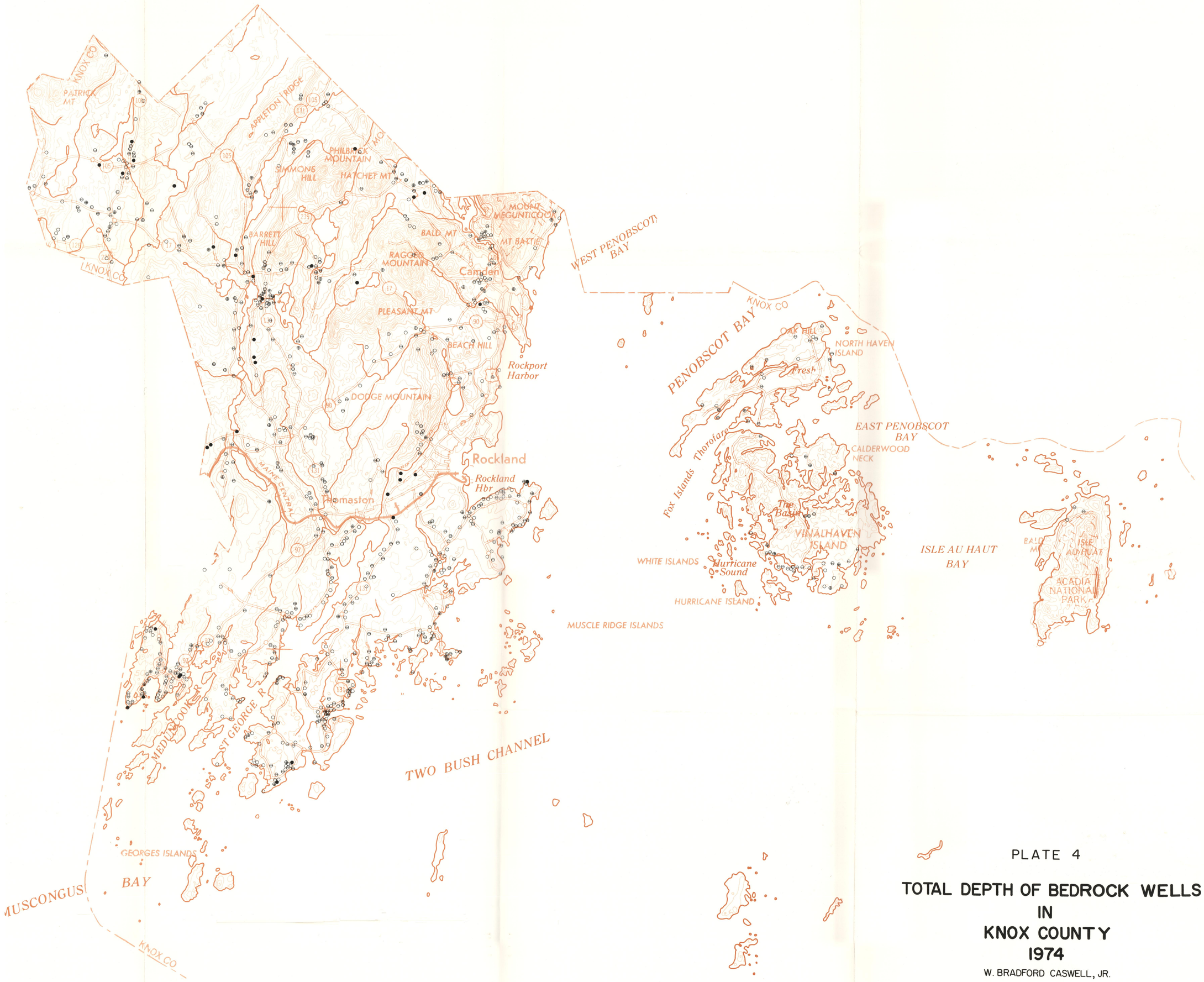



PLATE 4

# TOTAL DEPTH OF BEDROCK WELLS IN KNOX COUNTY 1974

W. BRADFORD CASWELL, JR.

SCALE - 1:125,000

1 0 1 2 3 4 5 6 7 8 9 10 mi.

PHYSICAL RESOURCES SERIES
BUREAU OF GEOLOGY
DEPARTMENT OF CONSERVATION
STATE OF MAINE

EXPLANATION

- ○ 0 – 100 FT
- ⊕ 101 – 200 FT
- ⊕ 201 – 300 FT
- ● 301 FT AND GREATER

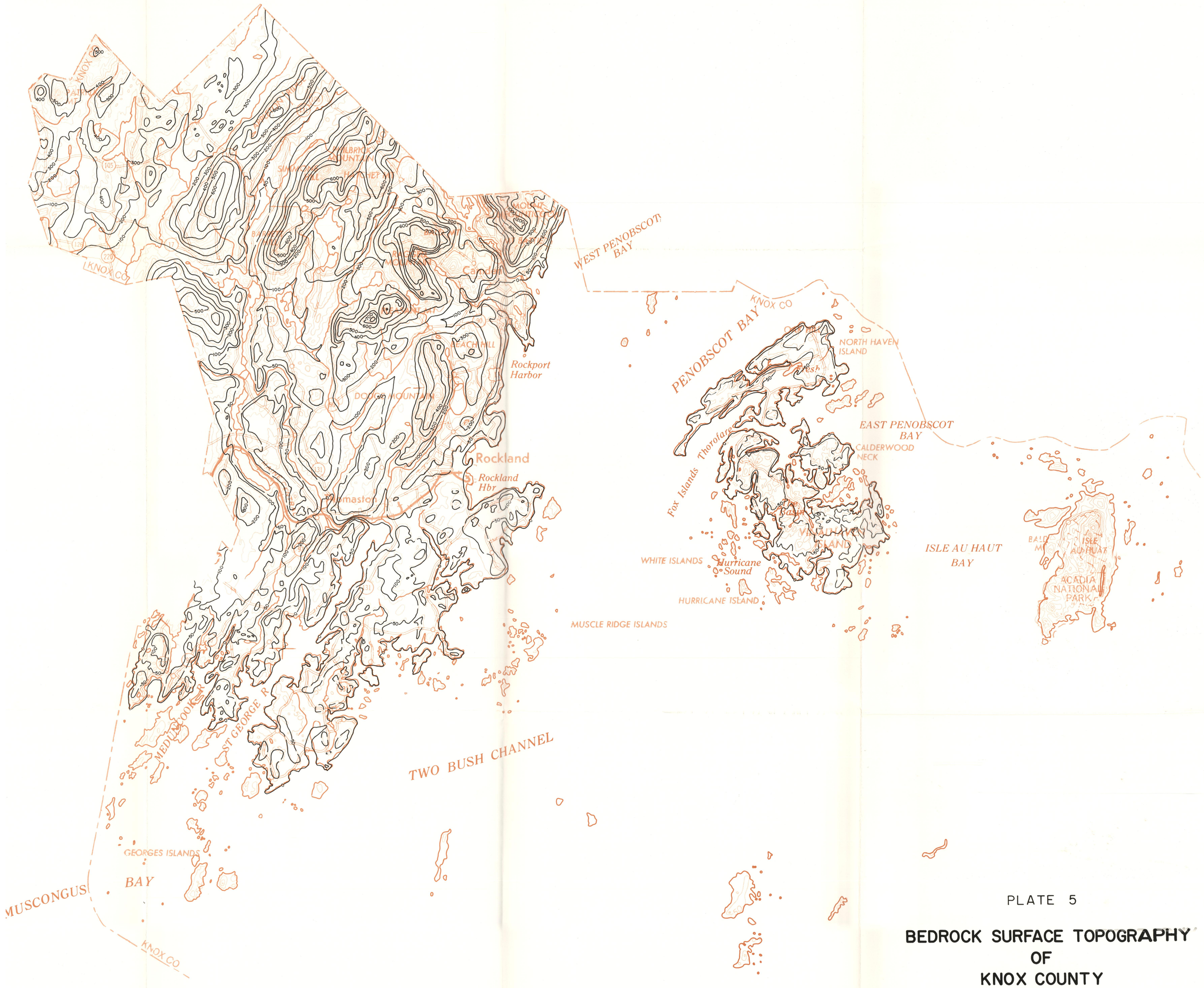



PLATE 5

# BEDROCK SURFACE TOPOGRAPHY OF KNOX COUNTY 1974

W. BRADFORD CASWELL, JR.

SCALE - 1:125,000

1 0 1 2 3 4 5 6 7 8 9 10mi.

CONTOUR INTERVAL 100 FEET

PHYSICAL RESOURCES SERIES
BUREAU OF GEOLOGY
DEPARTMENT OF CONSERVATION

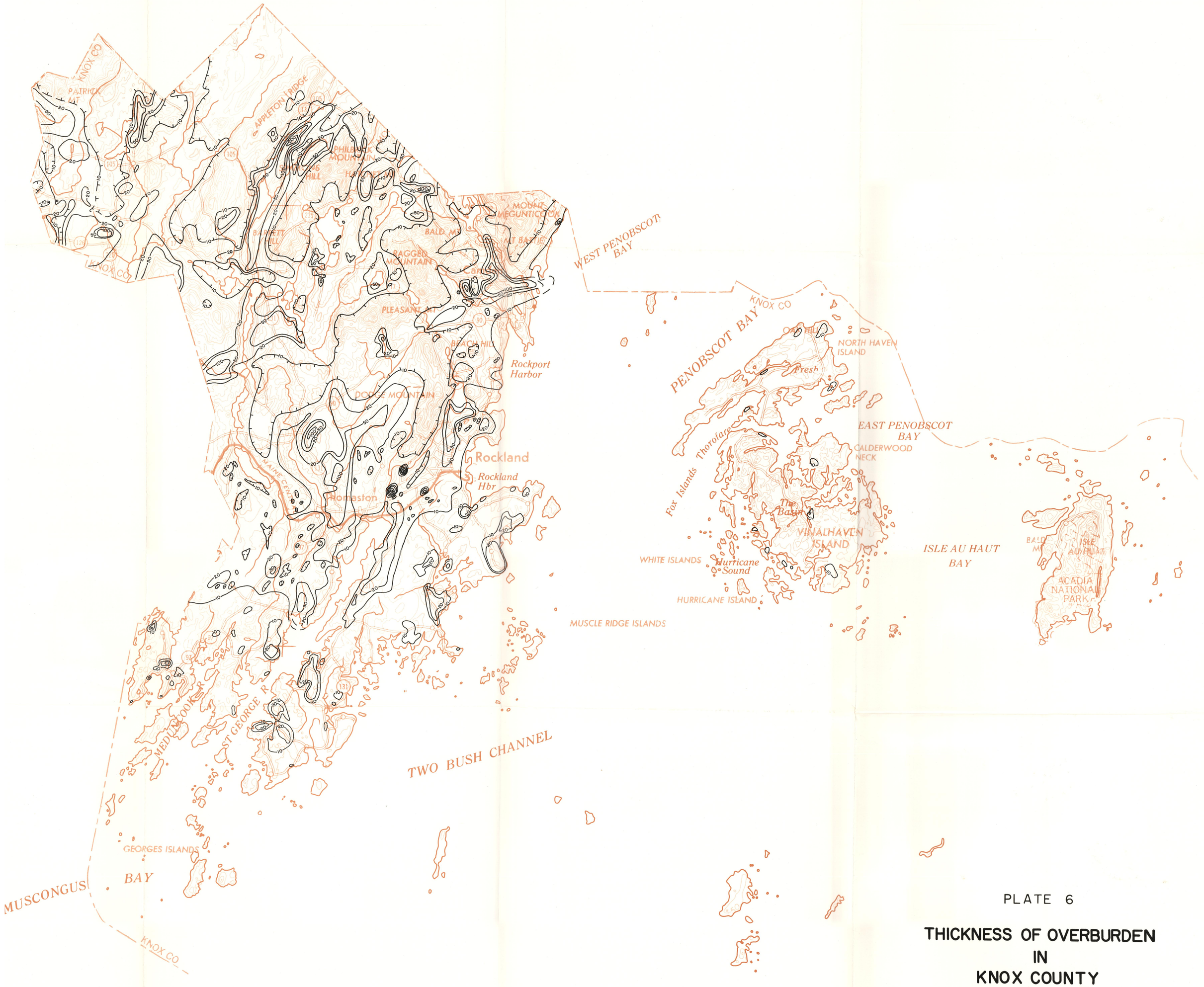



PLATE 6

# THICKNESS OF OVERBURDEN IN KNOX COUNTY 1974

W. BRADFORD CASWELL, JR.

SCALE - 1:125,000

1 0 1 2 3 4 5 6 7 8 9 10 mi.

ISOPACK INTERVAL 10, 20, 50, & 100 FEET

PHYSICAL RESOURCES SERIES
BUREAU OF GEOLOGY
DEPARTMENT OF CONSERVATION
STATE OF MAINE

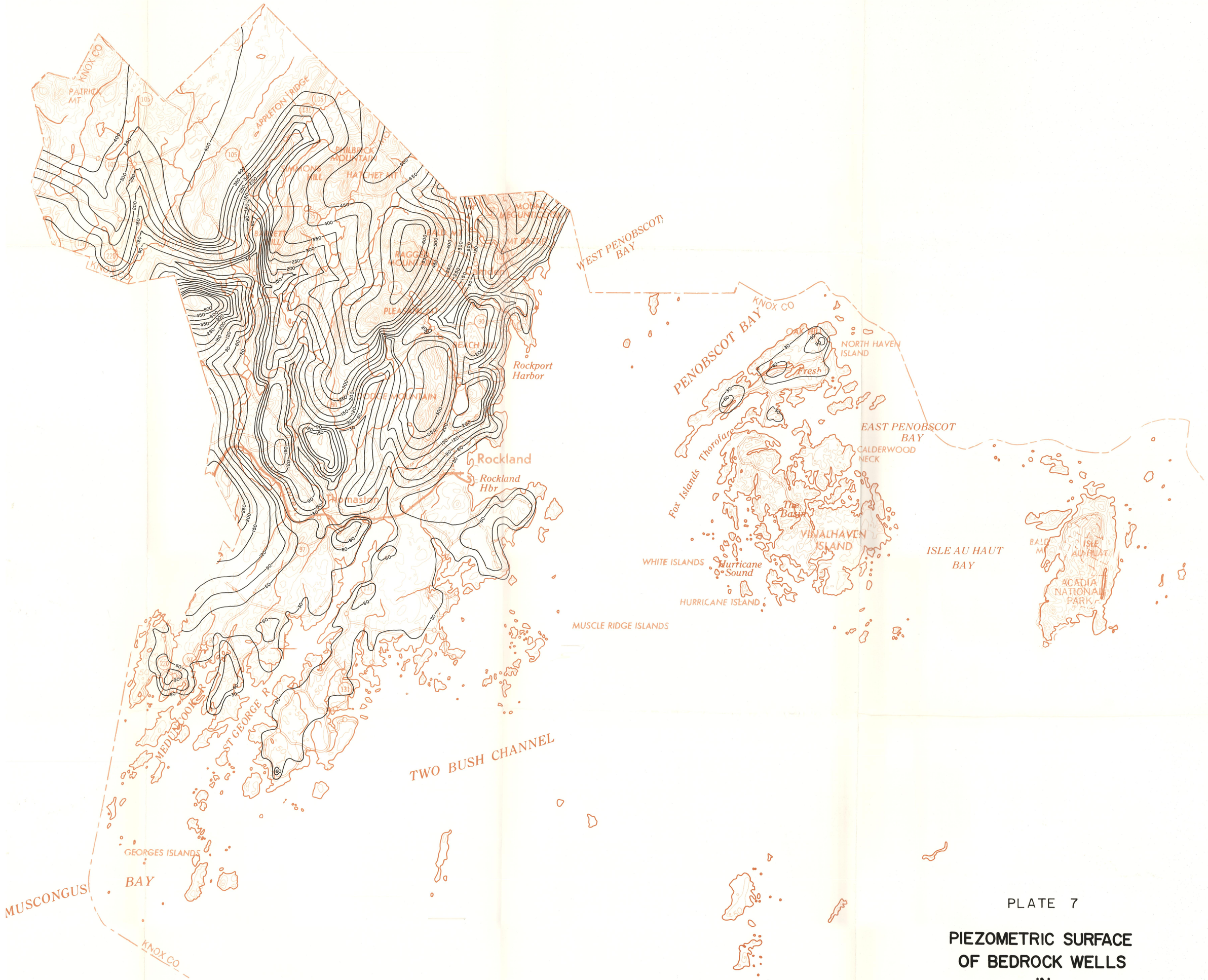



PLATE 7

# PIEZOMETRIC SURFACE OF BEDROCK WELLS IN KNOX COUNTY 1974

W. BRADFORD CASWELL, JR.

SCALE - 1:125,000

1 0 1 2 3 4 5 6 7 8 9 10mi.

ISOPOTENTIAL INTERVAL 30 & 50 FEET

PHYSICAL RESOURCES SERIES
BUREAU OF GEOLOGY
DEPARTMENT OF CONSERVATION
STATE OF MAINE