Bedrock Geology of North Haven and Vinalhaven Islands

by
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Editor's Note: This map was a work in progress at the time of Olcott Gates' death. Based on his field notes and nearly completed manuscript maps and text, Henry N. Berry IV and Robert G. Marvinney compiled the present map.

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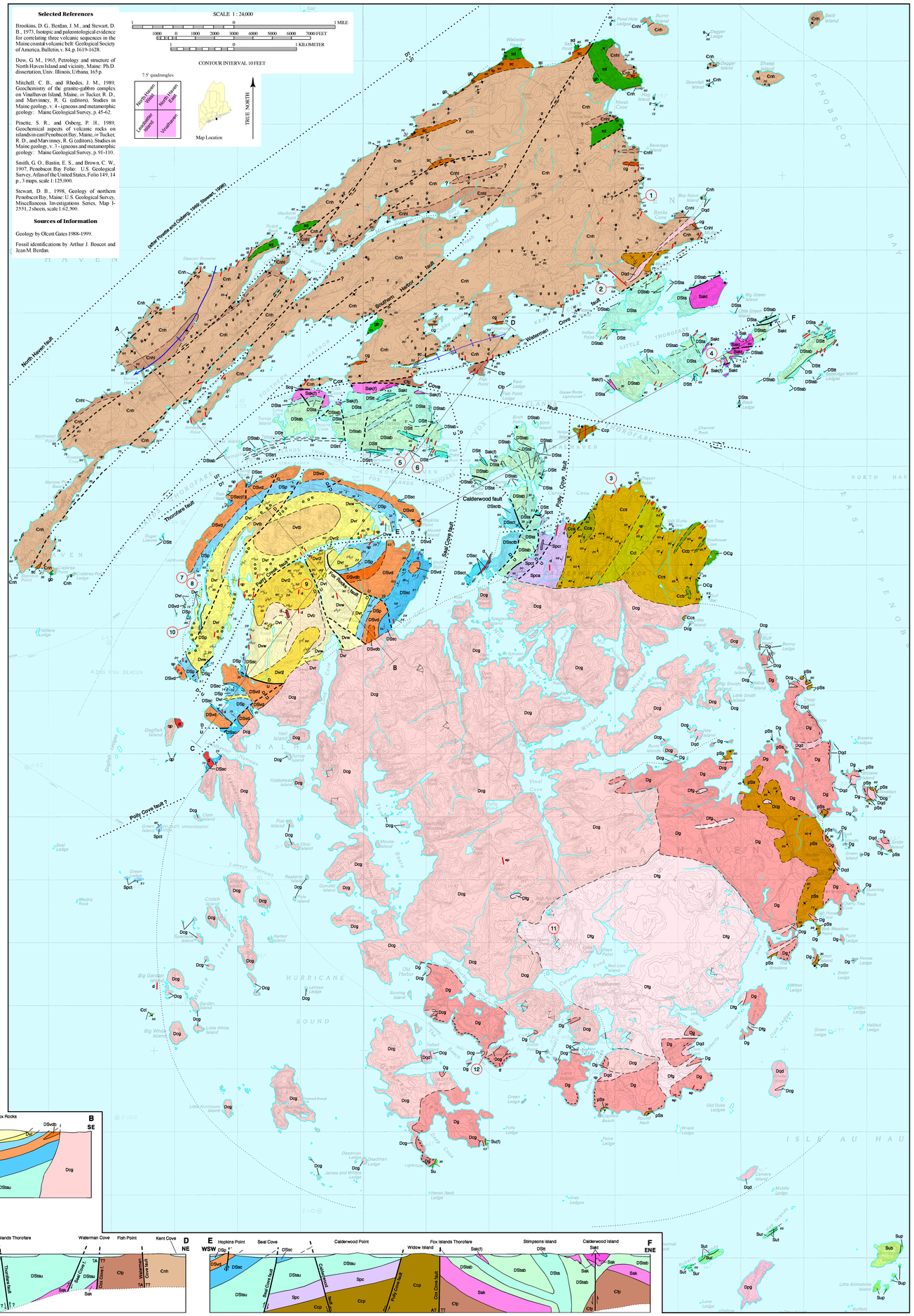
For additional information, see Open-File Report 01-373.



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Sources of Information

Geology by Olcott Gates 1988-1999.

Fossil identifications by Arthur J. Boucot and Jean M. Berdan.

Plutonic Rocks

Mississippian? Devonian?

ap — Aplite dike.

Dcg — Coarse-grained biotite-hornblende granite and quartz-monzonite with a few mantled feldspars. Enclaves and cognate inclusions are rare.

Dfg — Fine-grained biotite granite. Roof phase of Dcg.

Dqd — Granodiorite, quartz-diorite. Biotite, hornblende, remnant pyroxene. Includes a dike near Mullen Head.

Dg — Gabbro and diabase. Minor diorite. Olivine and pyroxene varieties.

Granitic and gabbroic magma mingling zone. Sloped blocks of gabbro, Silurian rock, and pre-Silurian schists are intruded by granitic and diabasic dikes and bounded by dikes consisting of diabase pillows with chilled margins in a matrix of granitic rock. The mingling of the two magmas indicates that some gabbro was still molten when intruded by the granitic magma.

Dpg — Quartz-perthite granite of Otter Island. Devonian age uncertain.

d — Diabase dike. Predominantly with northerly trends. Older than Dcg, Dfg, Dqd.

qp — Quartz porphyry on Dogfish Island and dikes elsewhere. Of uncertain age. Some are composite with the diabase dikes.

r — Rhyolite dike, of uncertain age.

Metamorphosed Plutonic Rocks

Ordovician? Cambrian?

OCg — Hornblende gabbro. Hornblende laths form strong lineation. Intrusive into €cs.

Stratified and Volcanic Rocks

Devonian

VINALHAVEN RHYOLITE

Dvr2 — Flow-banded rhyolite with autobreccia. This unit rests on several of the older units, locally along erosional unconformities, and is interpreted as a remnant of a late dome or flow. It overlies the Perry Creek fault and may have been erupted along it.

Dvb — Coarse, hydrothermally altered rhyolite breccia. Much perlite, possibly due to eruption into a lake in which Dvt was deposited.

Dvtb — Coarse, crudely bedded to massive crystal, lithic tuff-breccia. A variety of rhyolite fragments. Reworked coarse tephra.

Dvt — Thinly bedded fine-grained tuff. Waterlaid, possibly in a lake.

Dvw — Welded vitric, crystal lithic tuff, devitrified and altered. Base not welded. A massive unit without internal variation either in outcrop or in thin section.

Dvr — Rhyolite, flow-banded rhyolite, several varieties of autobreccia and mixed breccia. Spherulites, indicated by circles on the map, are common above bedded (once welt?) DSp rocks. Local perlite. Interpreted to be multiple flows, but locally intruded into soft DSp rocks.

Devonian - Silurian

PERRY CREEK FORMATION (new name)

DSp — Feldspathic tuffs, rhyolitic tuff-breccias, pebble conglomerates, siltstones, mudstones, and argillite. Cross-bedding, cut-and-fill structure, and lensing of different rock types indicate fluvial deposition.

VINALHAVEN DIABASE

DSvd — Diabase and basalt, hydrothermally altered. Diabase contains xenocrysts of quartz bordered by pyroxene or hornblende.

DSvdb — Breccia of angular basalt, locally with interstitial hematite, it overlies and was intruded by DSvd. Interpreted as a hydroclastite (peperite) remnant resulting from intrusion into very wet muds.

SEAL COVE FORMATION (new name)

DSsc — Maroon tuffaceous mudstone, feldspathic sandstone, and thinly bedded tan argillite. Laminated and thinly bedded mudstone and siltstone show fine-scale cross-bedding, flame structures, and soft sediment deformation. Metamorphosed to hornfels near the contact with Dcg. Contains unidentifiable small fossils, probably ostracodes near Smith Point. Map unit at Fish Head indicated by (f) contains fossils.

DSsct — Bedded tuffs.

DSsctb — Tuff-breccias. Locally contains small, pink feldspars or coarse chlorite clots with white rims. Some coarse conglomerates and tuff-breccias.

THOROFARE ANDESITE.

The Thorofare Andesite is a complex volcanic pile in which individual intrusive and extrusive units are discontinuous. Isolated lenses of bedded tuff-breccia and fine-grained tuffs as well as several blocks of fossiliferous Ames Knob Formation are included. The following units are not listed in stratigraphic order.

DSta — Green, purple, gray, and maroon andesite with plagioclase phenocrysts. Locally flow-banded. Some are intrusive, others are flows.

DStab — Purple to maroon andesite breccias and agglomerates, with minor andesite flows. Angular to subrounded blocks, up to a meter in diameter, are in an ovidized siliceous matrix, locally of mudstone. Some breccias are of andesite blocks only. Others are polymict, incorporating large blocks of andesite, bedded round-pebble polymict andesitic conglomerate, tuffaceous cross-bedded sandstone, bedded tephra, and fossiliferous Sak rocks.

DStb — A rhyolite vitric tuff of shards, collapsed pumice, and scattered broken quartz and plagioclase crystals.

DStn — Bedded to massive tuffs, argillite, maroon siltstone and mudstone, ann gdaloidal lavas with mud inclusions. Polymict agglomerate on the Sugar Loaves.

DSt — Intrusive latite on Babbidge Island. Oligoclase phenocrysts in a quartzo-feldspathic devitrified matrix.

Silurian

AMES KNOB FORMATION

Sak — Gray, maroon, tan shale, siltstone, limestone, pebble conglomerate, bedded tuffaceous sandstones, and a thin rhyolite sharply tuff. Map units in which fossils have been discovered are indicated by ann (f).

Sakt — Vitric tuff. Shards, collapsed pumice fragments, and perlite fragments. May also contain tuff-breccia, pebble conglomerate, lithic tuff, sandstone, siltstone, mudstone, and cherty limestone. Exposed east of Cox Cove and on Burnt Island and Calderwood Island.

Scg — Conglomerate. Angular to subround clasts of underlying €nh and of bull quartz in a hematitic matrix. It is a colluvium deposit that along its base contains blocks of the immediately underlying North Haven Greenstone. Might be basal to Sak, but it is faulted against the rest of the Ames Knob Formation.

POLLY COVE FORMATION (new name)

Scct — Gray argillite, shale, siltstone, pebble conglomerate, feldspathic bedded tuff and massive tuff-breccia. Folded and faulted. Hornfelsed near Dcg. Bedded tuffs on Green Island and Green Ledge.

Spcr — White-weathering, vitreous, black rhyolite.

Spca — Hornfelsed siliceous argillite and calc-silicate. A bedded quartz grit lens rests unconformably on the Calderwood Formation.

UNDIFFERENTIATED SILURIAN ROCKS

Su — Stoped blocks of contact metamorphosed unfoliated bedded argillite and siltstone in Dcg and Dg. Block labeled Su(f) on Greens Island has Silurian brachiopods.

Sur — Rhyolite intruding Sut argillite on Roberts and Hay Islands.

Sut — Tuff and argillite on Roberts and Hay Islands.

Sub — Basalt, diabase, and basaltic breccias on Brimstone Island.

Sup — Flow-banded plagioclase porphyry on Brimstone Islands.

Cambrian?

These formations are not listed in stratigraphic order as their stratigraphic relations to each other are not known.

CALDERWOOD FORMATION

Foliated blastomylonitic rocks metamorphosed to epidote amphibolite grade. The mineralogy and textures of the original rocks have been mostly obliterated. In thin section many of the rocks resemble recrystallized mylonites perhaps part of a broad shear zone.

Cca — Quartz amphibolite. Includes a foliated gabbro.

Ccs — Quartz-biotite-actinolite schist. Augen of granular quartz and actinolite in granular quartz matrix. Originally chert, argillite, and siliceous volcanic rocks. Locally pyritic.

Ccl — Metalatite sill with sheared margins. Plagioclase phenocrysts in matrix of fine-grained granular quartz, K-feldspar, biotite.

Ccb — Sheared pillow basalt. Nesting and vesicular tops suggest younging to northwest.

Ccp — Foliated plagioclase porphyry on Widow Island. Assigned to the Calderwood Formation based only on its foliation and geographical position.

NORTH HAVEN GREENSTONE

Cnh — Pillow basalts, basaltic tuffs, carbonaceous schist, conglomerate. Highly altered to clays, chlorite, calcite, actinolite, tremolite, leucoxene, iron ores. Only ghosts of original textures remain. Strongly sheared with flattened pillows. Mineral streaking and pillow elongation plunge steeply southwest. Most dips are to the south and southeast. The North Haven Greenstone underlies Oak Island and Grass Ledge northeast of the map area. The following rock types of inland outcrops too sparse to map with continuity and shoreline exposures too small to differentiate are designated by letter symbols: (g) greenstone, undifferentiated; (p) pillow lava; (a) granular quartz veins common in fault zones; (ac) quartz-carbonate-pyrite veins; (rp) "rotten" pyritic rock, most commonly associated with sheared rocks; (se) sheared diabase and gabbro.

- **a** — Argillite.
- **cg** — Polymict rhyolite, latite, basalt pebble conglomerate lenses.
- **gb** — Gabbro, some unsheared.
- **sc** — Black, mylonitic schist.
- **sd** — Sheared diabase and gabbro.

Cnh' — Latite and rhyolite tuff-breccias, chloritic tuffs, and pillow lavas at Pulpit Harbor and Bartlett Harbor and as lenses in €nh elsewhere.

FISH POINT FORMATION (new name)

Cfp — Slightly foliated recrystallized graywacke, devitrified rhyolite, conglomerate of rhyolite pebbles, and sheared limestone on Fish Point, Fish Point Ledge, and Kent Ledge, and highly sheared pyritic feldspar porphyry on the west shore of Waterman Cove.

UNDIFFERENTIATED PRE-SILURIAN ROCKS

pSs — Crinkly mica schists with quartz lenses and veins, foliated amphibolite, and minor quartzite resembling rocks of the Ellsworth Formation.

MAP SYMBOLS

- Attitude of bedding. Ball indicates younging direction, if known (inclined, vertical).
- Attitude of pillow lavas. Dot indicates younging direction, based on nesting or vesicular pillow tops (inclined, vertical).
- Attitude of foliation (inclined, vertical).
- Attitude of flow-banding (horizontal, inclined, vertical).
- Trend and plunge of lineation.
- Trend and plunge of fold axis, with rotation sense indicated (clockwise, counterclockwise, neutral).
- Spherulite locality in the Vinalhaven Rhyolite.
- 4 — Location of photo shown in sidebar.
- Attitude of major joints in quarries.

MAP LINES

- Dip-slip fault; upthrown (U) and downthrown (D) blocks indicated. (located, approximately located, inferred).
- Strike-slip fault, arrows indicate sense of motion (located, approximately located, inferred).
- Fault; motion uncertain (located, approximately located, inferred).
- Contact (located, approximately located, inferred).
- Approximate trace of anticline axial plane.
- Approximate trace of syncline axial plane. Arrowhead indicates direction of plunge.
- A — B: Line of cross section.

STRUCTURAL GEOLOGY

Faults within the North Haven Greenstone are delineated by lenses of mylonite, and by zones of intense shearing rich in pyrite and locally bull quartz veins. They are vertical or nearly so (cross section A-B). Offsets of the latite member suggest a left-lateral component of displacement. Other workers have suggested that another northeast-striking fault may lie just off the northwest coastline. Most northeast-striking faults in the North Haven Greenstone may be pre-Silurian. The Southern Harbor fault, however, appears to cut the Cox Cove fault, which is Devonian or younger.

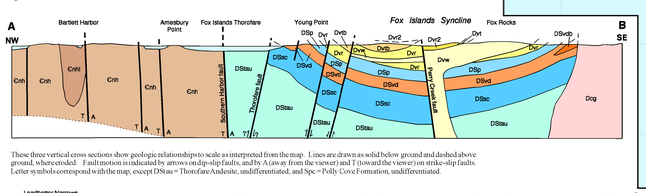
Waters of the Fox Islands Thorofare cover the critical contacts south of the Waterman Cove fault. The dotted faults and contacts show a speculative reconstruction of the hidden geology based primarily on the requirement that the geology make a reasonable sense.

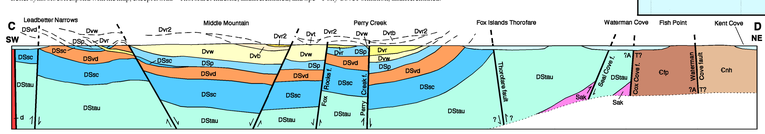
The Silurian-Devonian volcanic rocks occupy two fault blocks, separated by the inferred Cox Cove fault. One block contains a large, open syncline here named the Fox Islands syncline (cross sections A-B, C-D) and the other block contains the Fish Point Formation and the Thorofare Andesite north of the Little Thorofare (cross section E-F). The Waterman Cove fault is the principal fault bringing the Silurian - Devonian volcanic section and the Calderwood Formation to the south against the North Haven Greenstone to the north.

In the Fox Islands syncline block, the Calderwood and Polly Cove faults accommodate uplift of the Calderwood Formation along the east side of the syncline (cross section E-F). Relationships along the southwest side of the Fox Islands syncline suggest a fault that may be an extension of the Polly Cove fault. If so, that fault must be younger than the syncline. Another fault, the Thorofare fault, may exist beneath the Thorofare, north of the Fox Islands syncline, accounting for the apparent omission of part of the Seal Cove Formation (cross section C-D).

According to this speculative reconstruction, the Waterman Cove and Cox Cove faults are merging dextral strike-slip faults bounding the wedge-shaped Little Thorofare block, which was tilted down to the east (cross section E-F). This strike-slip faulting occurred after formation of the Fox Islands syncline and associated faults along its eastern and perhaps northern side. Sinistral movement on the Southern Harbor fault then displaced the North Haven Greenstone on the west side of Southern Harbor to the southwest. Accordingly, the Waterman Cove and Cox Cove faults and the Fox Islands syncline should be somewhere southwest of Crabtree Point. East Penobscot Bay hides the eastward extent of the strike-slip faulting and the geologic relations of the Silurian-Devonian volcanic sections to other rocks of coastal Maine.

These three vertical cross sections show geologic relationships to scale as interpreted from the map. Lines are drawn as solid below ground and dashed above ground, where eroded. Fault motion is indicated by arrows on dip-slip faults, and by A (away from the viewer) and T (toward the viewer) on strike-slip faults. Letter symbols correspond with the map, except DStau = Thorofare Andesite, undifferentiated; and Spc = Polly Cove Formation, undifferentiated.





GEOLOGIC HISTORY

The rocks of North Haven and Vinalhaven islands were formed by a series of geologic events during the Cambrian, Ordovician, Silurian, and Devonian geologic time periods, which span from about 545 million years ago to 360 million years ago. Though a long time, it is but a minute fraction of the 3.8 billion years of earth history recorded in the oldest known Precambrian rocks. The following story, as every geologic history, is incomplete due to the imperfect preservation of geologic features. Still, a complex sequence of events is required to explain the origin of the most significant rocks on the geologic map. These events are described from oldest to youngest. Letters in parentheses refer to units on the geologic map. Photo locations are on the map.

CAMBRIAN TIME

North Haven Greenstone (€nh). The history of the two islands began with lava erupting from a volcano on an ancient ocean floor, of which the present outcrop area of North Haven Greenstone represents only a tiny preserved fragment. The type of lava was basalt, which originates by partial melting of the earth's upper mantle, below the 6-18 mile thick outer layer called the crust. When the hot, molten rock rose to the surface and erupted into cool sea water, it quickly chilled at its outer edge, forming solid rock tubes from which still-molten basalt extruded like toothpaste from its tube. These new extrusions in turn quickly chilled, forming a pile of elongated rock tubes (Photo 1) that, when viewed end-on, look somewhat like pillows (Photo 2). Seawater circulating through the hot pillow lava reacted with the rock and formed the dark green mineral chlorite, converting the basalt into greenstone. Between eruptions of basalt, minor amounts of mud were deposited, now converted to schist (**sc**), as well as rhyolite lava and volcanic debris (**€nh'**), best seen at Pulpit Harbor. In contrast to basalt lava, which originates in the mantle and is relatively poor in silicon and rich in iron, most rhyolite lava is melted earth's crust which has more silicon, sodium, and potassium, accounting for the different volcanic rock types.

Calderwood Formation (€cs). Most rocks of the Calderwood Formation were probably originally volcanic rocks also, but this is not entirely clear. They have been so severely sheared that the original minerals and volcanic fragments have been almost obliterated (Photo 3). Some volcanic structures are still recognizable, such as lava pillows near Ash Tree Point (**€cb**), but most rocks have been converted to schist. Schist forms when heated rocks are compressed and sheared, a process similar to pushing the top of a stack of paper. Each sheet moves past the adjacent sheet so that the shape of the entire stack is changed, or deformed. During shearing, existing minerals are broken down and new ones form. Sheet-like micas commonly grow parallel to the shears along which the rock splits easily, a rock property called cleavage. It is not known whether the Calderwood Formation and North Haven Greenstone were produced in the same episode of volcanic activity or in two separate episodes.

ORDOVICIAN TIME

Careful examination of the map reveals an absence of rocks that formed in the Ordovician Period, a time span encompassing over 50 million years. Features of the Cambrian rocks help explain this gap in time. Outcrops of the North Haven Greenstone show that once-horizontal rocks have been tilted to the southeast. Large blocks of rock have moved relative to one another along faults. In both the North Haven Greenstone and Calderwood Formation pillows have been flattened and elongated, and rocks have been cleaved into thin sheets. These structural features indicate that the Cambrian sea floor was highly distorted by pressure and movements within the earth's crust after its formation, a transformation process known as metamorphism. The younger rocks of the Silurian Period were not affected by this geologic activity. It is inferred that an episode of deformation and uplift, perhaps forming mountains, occurred in late Cambrian or Ordovician time. A time of erosion followed, gradually removing any Ordovician rocks that may have formed, and some of the Cambrian rocks by Silurian time.

SILURIAN TIME

Ames Knob Formation (Sak). These rocks, first studied in 1892, are a key to the geologic history of coastal Maine. In contrast to the folded, sheared, and metamorphosed rocks of the North Haven Greenstone, sedimentary rocks of the Ames Knob Formation are well preserved, unmetamorphosed, and rich in Silurian fossils. The beautifully layered rocks (Photo 4) originated as sediment accumulated in the shallow water of Silurian seas, including muds, sands, and gravel in which shellfish thrived. The layers of sediment were draped across the older metamorphic rocks and faults (see Schematic Diagram below). Eventually the sediments were hardened into rock to become gray and maroon shale, sandstone, and conglomerate that today comprise the Ames Knob Formation. Silurian rocks with similar shelly faunas are preserved in a few areas in Massachusetts, eastern Maine, New Brunswick, and Nova Scotia indicating that Silurian seas once flooded a large contiguous area.

LATE SILURIAN - EARLY DEVONIAN TIME

Thorofare Andesite. Lava erupted through the fossiliferous muds and sands (**Sak**) on the floor of the Silurian sea and built a volcano whose gray, green, and maroon volcanic rocks now line the north shore of the Thorofare and the shores of Calderwood Point. Coarse volcanic breccias (**DStab**) consist of large angular blocks of andesite embedded in a mass of smaller volcanic fragments (Photos 5 and 6). Andesite lava, which contains more silicon than basaltic lava, produces some of the most explosive volcanoes in the world, such as Mount St. Helens, Pinatubo, and Vesuvius. The original andesitic volcanic pile, built on the Ames Knob Formation, consisted of lava flows (**DSta**), breccias from explosive eruptions (**DStab**), avalanches and debris flows of mud and rock fragments down the volcanic slopes, deposits of volcanic ash (**DStnr**), and siltstones and sandstones deposited by streams on the volcanic lower slopes (**DSst**). Volcanic gases and hot ground water fed by rain percolated through the volcanic pile, altering original minerals and oxidizing iron to form maroon staining. Faulting and landsliding accompanied the eruptions as the volcanic rocks accumulated on slopes of a fault basin. A reconstruction of the volcano is shown in the Schematic Diagram.

Seal Cove Formation (DSsc). After the volcanic eruptions ceased, sluggish streams spread sand, silt, and mud, across the land surface, now preserved as sedimentary rocks of the Seal Cove Formation. The area was then tilted up to the northwest causing much of the Seal Cove Formation and some of the underlying Thorofare Andesite to be eroded so that the Seal Cove Formation now has a wedge shape, thicker to the southeast and thinner to the northwest.

Perry Creek Formation (DSp). Streams eroding the maroon andesite spread maroon sand and silt across the surface of the Seal Cove wedge. This stream erosion was followed by the beginning phase of the Vinalhaven rhyolitic volcanism. Nearby explosive eruptions contributed volcanic ash and rock fragments from eruption clouds, including blocks of rhyolite lava (Photo 7). Streams eroded these materials and re-deposited them locally as stream-washed deposits of volcanic silt, sand, and pebbles (Photo 8). These continued to be mixed with deposits of maroon sand and silt, deposited by airfalls from eruption clouds and by steep streams eroding a rhyolitic volcano somewhere nearby. The resulting rocks, transitional to the Vinalhaven Rhyolite, make up the Perry Creek Formation.

Vinalhaven Diabase (DSvd and DSvdb). After some, but perhaps not all, of the Perry Creek Formation had been deposited, molten basalt intruded at a shallow depth, more or less along the contact between the Seal Cove and Perry Creek formations before their sediments had been hardened into rock. The molten basalt cooled slowly enough so that small interlocking crystals grew, forming a rock called diabase. The Vinalhaven Diabase is composed of several such intrusions of varying thickness injected at about the same level.

Vinalhaven Rhyolite. The Vinalhaven Rhyolite is a remnant of a volcanic center, the youngest volcanic activity preserved on the two islands. Rhyolite lava, like molten glass, does not flow far because it is rich in silicon and extrudes at lower temperatures than do basalt or andesite. Rhyolite forms stubby lava flows with steep sides or mushroom-shaped domes over a central conduit (as shown in the left side of the Schematic Diagram). The top, sides, and bottom of a flow or dome cool to form a crust of solid blocky fragments, within which the still-molten rhyolite continues to move. Within this slowly flowing mass, layers may glide over one another to produce flow bands (Photo 9). The Vinalhaven Rhyolite includes such flows and domes that are complex mixtures of flow-banded rhyolite with broken rhyolite fragments (**Dvr**). After rhyolite flows solidify and as they cool, small, round masses of crystals (spherulites) may form by crystals growing outward from a central point (Photo 10). Other units in the Vinalhaven Rhyolite were produced in a different type of eruption, which occurs when the molten rhyolite contains a small amount of water vapor. As the pressure of water vapor builds up, it may force open a crack to the surface, or blow out the overlying rock in an explosive eruption. The sudden release of pressure allows water vapor to escape from the molten rhyolite to make a froth (pumice) or to blow the pumice apart to make glass shards of fingernail size. The expanding mixture of shards and pumice fragments may shoot up the conduit into the air to form an eruption cloud from which they settle to form tuffs (**Dvt**, **Dvtb**) that may blanket thousands of square miles. Alternatively the hot mixture of pumice, shards, and gas may run along the ground, racing down the volcano slope, down valleys, or spreading across relatively flat land. It may remain so hot that the sticky mass of shards and pumice collapses and becomes welded together to form a welded tuff (**Dvw**).

Photo 1. A pile of bulbous lava tubes formed in a submarine eruption. (*North Haven Greenstone, northeast shore of North Haven*)

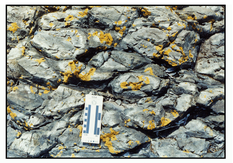


Photo 2. End-on view of stacked lava tubes showing why geologists call these rounded forms "pillows". (*North Haven Greenstone, Kent Cove*)

Photo 3. Heat and pressure have flattened this rock. Thin white streaks may have been volcanic fragments. (*Calderwood Formation, Calderwood Neck*)

Photo 4. Sedimentary rock of the Ames Knob Formation. Light and dark layers of sandstone, siltstone, and mudstone, though tilted on edge, can be followed across the outcrop. (*Calderwood Island, Little Thorofare*)

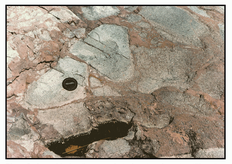


Photo 5. Large blocks of green andesite lava in red matrix. (*Thorofare Andesite, west of Iron Point*)

Photo 6. Breccia composed of angular volcanic rock fragments. (*Thorofare Andesite, west of Iron Point*)

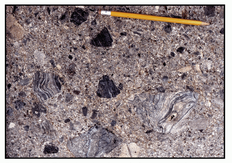


Photo 7. Tuff-breccia. Angular rock fragments of rhyolite were deposited from an eruption cloud. (*Perry Creek Formation, Browns Head*)

Photo 8. Volcanic debris that has been washed by streams and deposited in layers of differing particle size. (*Perry Creek Formation, Browns Head*)

Photo 9. Flow-banded rhyolite. Streaks were caused by flow in the lava before it solidified. (*Vinalhaven Rhyolite, north of Middle Mountain*)

Photo 10. Spherulites up to an inch across are rounded lumps of small crystals that grew as the hot rhyolite rock cooled. (*Vinalhaven Rhyolite, by Crockett Point*)

EARLY DEVONIAN TIME

After an unknown interval, following rhyolitic volcanism but before the granite had formed, the rock layers were warped into a syncline (a down-fold) and broken by faults including the Cox Cove, Waterman Cove, Southern Harbor, and other faults. The Schematic Diagram shows the relationships of the rocks before this faulting occurred.

MIDDLE TO LATE DEVONIAN TIME

In middle to late Devonian time, the folded and faulted rocks were intruded by a large mass of molten rock, or magma, that solidified deep in the earth's crust, perhaps several miles below the surface. This mass, roughly circular in outline, included magmas of compositions equivalent to basalt and rhyolite, but instead of erupting to form volcanic rock, it cooled slowly to form rocks with relatively large, interlocking crystals. The resulting rocks, gabbro (**Dg**) and granite (**Dgr** and **Dfg**), are the coarse-grained equivalents of basalt and rhyolite, respectively.

The main mass of the intrusion is made up of two kinds of granite of about the same chemical composition, the generally pink coarse-grained granite (**Dcg**) of the Sands and Swenson's quarries and the fine-grained gray to white granite (**Dfg**) of the East Boston and Lawson quarries (Photo 11). Gabbro intruded schist in the Coombs Neck area and, except for a gap at Roberts Harbor, continues around the shore to Old Harbor. This rock was quarried as "black granite" on Norton Point. Commonly along the shore there is a mingling zone of gabbro, granite, and inclusions of blocks of schist and Silurian rocks. In this zone, vertical sheets of granite cut already crystallized gabbro. Some of these sheets, however, are composed of ellipsoidal masses of black basalt separated by a mortar of granite (Photo 12) as can be seen from the ferry along the north shore of The Reach. In these places, molten gabbro and granite mingled with each other, the hotter gabbro magma being rapidly cooled against the cooler granite magma to form pillows with fine-grained margins; the heavier gabbro sank, squeezing out most of the molten granite to leave a thin mortar; and then the remaining magma crystallized to rock.

EPILOGUE - BEDROCK GEOLOGY SINCE THE DEVONIAN

Erosion has removed the rock record of the past 370 million years of the islands' geologic history, since the intrusion of the gabbros and granites in the Devonian Period. We know from younger rocks preserved in New Brunswick, Nova Scotia, and the Bay of Fundy that miles of younger rock were probably also deposited in coastal Maine, rocks since removed by erosion. Greenstone, schist, granite, and gabbro, known to form at depth, are now at the ground surface, attesting to the significant thickness of overlying rock that must have been eroded. The latest chapter of the erosion history on the islands, the advance of continental glaciers that retreated about 14,000 yrs. ago, has yet to be studied in detail. The shape of the modern shoreline is controlled by the bedrock geology.

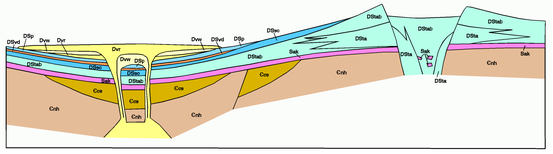
The 19th century human history on the two islands was influenced by their geology. The greenstone of North Haven makes rich soils that sustained a farming community. The granites of Vinalhaven provided excellent building stone that sustained a granite quarrying industry.

Photo 11. Lawson Quarry is one of several quarries in the light gray, fine-grained granite (**Dfg**). (*north of Carvers Pond*)

Photo 12. Interesting patterns were created when dark (basaltic) magma commingled with light (granitic) magma while they were still molten. (*mingling zone, Vortons Point along The Reach*)

Geologic Time Scale (Lower Paleozoic portion)

	Age in millions of years before present
Devonian Period	360-415
Silurian Period	415-443
Ordovician Period	443-495
Cambrian Period	495-545

Schematic Diagram

Hypothetical cross-section illustrating the presumed relationships of Silurian and Devonian sedimentary and volcanic rocks before faulting and erosion. The Ames Knob Formation was deposited across the partly eroded North Haven Greenstone and Calderwood Formation. The Thorofare Andesite erupted through the Ames Knob Formation forming the volcano shown on the right. The Vinalhaven Rhyolite erupted later, forming a broad dome as shown on the left. Letter symbols correspond with the map. (not to scale)