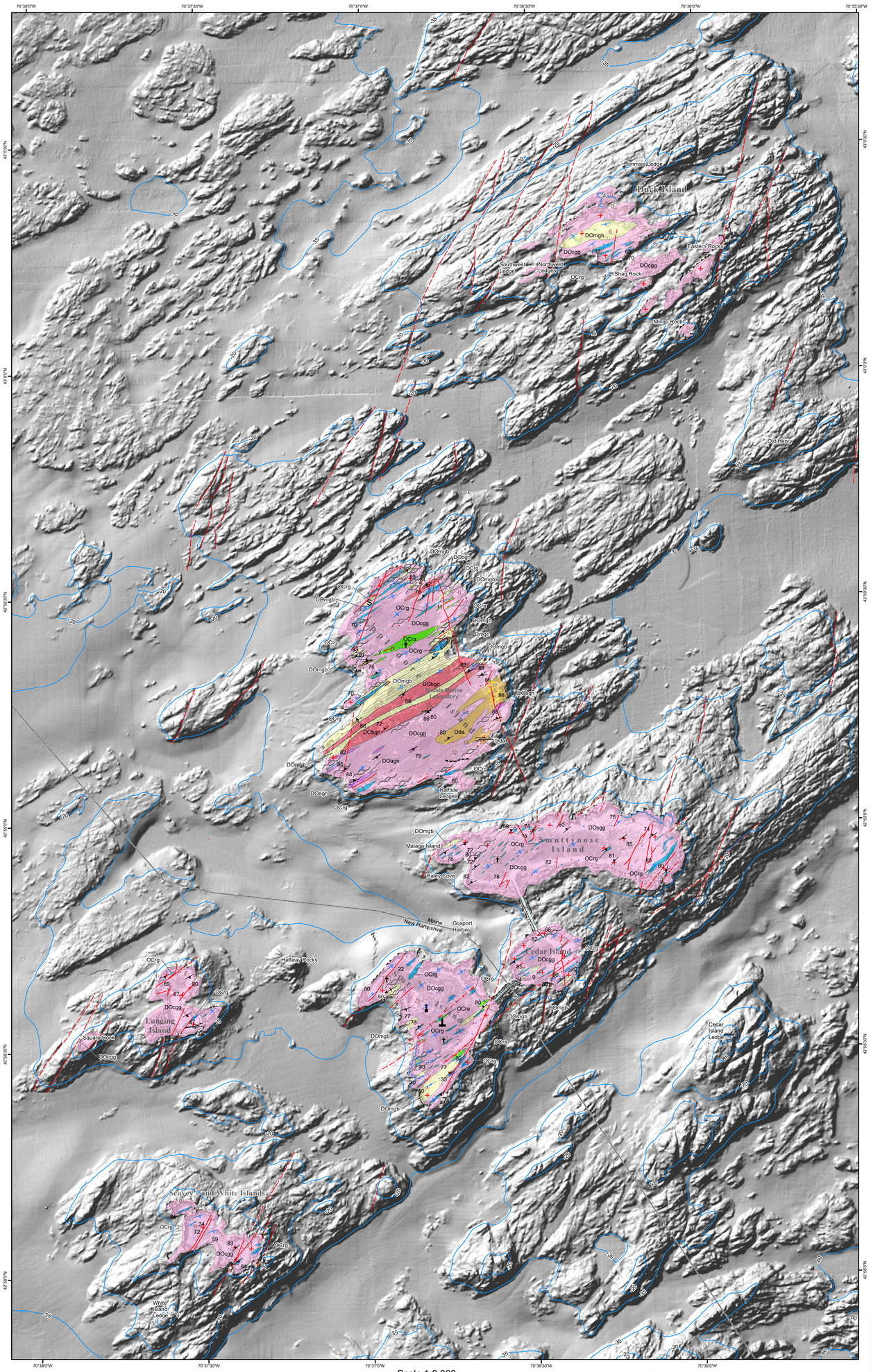
Bedrock Geologic Map of the Isles of Shoals, Maine and New Hampshire

Wallace A. Bothner, 2019

Geology modified and updated after Fowler-Billings (1959) and Blomshield (1975)



Scale 1:8,000

0 500 1,000 2,000 Feet

0 0.15 0.3 0.6 Miles

0 0.325 0.65 1.3 Kilometers

UTM GRID AND 2017 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

Topographic basemap developed from high resolution (1 meter) LiDAR data (hillshade and contours), National Hydrography Dataset and NHDOT roads data.

Bathymetry high resolution (1 meter) LiDAR data (hillshade and contours) provided by The Center for Coastal and Ocean Mapping at University of New Hampshire
Projection: North American Datum 1983 New Hampshire State Plane Feet.

EXPLANATION OF MAP UNITS

Igneous (and metaigneous)

Mesozoic

Diabase dikes: Triassic to Jurassic, typically subvertical tabular simple to multiple, fine to medium grained, sometimes porphyritic and occasional xenolithic diabase dikes ranging from a few centimeters to ~3-meters thick. Onshore where solid, offshore where dashed.

Diabase dike on Star, Cedar, and Smuttynose islands containing 3 – 5cm rounded light gray to black coarse-grained gabbroic xenoliths atypical of host lithologies. Onshore where solid, offshore where dashed.

Paleozoic – U/Pb zircon age control noted with *

Devonian and older

Felsic dikes – typically white to light gray, fine to medium grained 2-mica granite and aplite. Weakly foliated in part, sometimes folded, occasionally gradational with associated pegmatites (particularly on Smuttynose) * Preliminary date of ~384 Ma from small quarry on Star Island.

Coarse quartz-feldspar-muscovite pegmatite, some containing garnet and/or tourmaline up to 6cm long.

Dmgc Medium-grained, light gray to light brownish gray weathering, weakly to strongly foliated 2-mica gneissic granite. Biotite clots and xenoliths define intrusive breccia in two localities on Appledore. *awaiting date from Star and Appledore Islands

Dda Medium to coarse-grained, unfoliated to weakly foliated hornblende-biotite diorite. Intruded by several granitic dikes now expressed as fracture boudins and infolds. Xenoliths include augen quartzofeldspathic gneiss and a complex mixture (comagmatic?) of fine to coarse-grained granite. Published age of 361 Ma on fine grained diorite, analysis of coarse-grained diorite pending. *Maximum age on inter'mixed' granite yielded ~407 Ma

DOmgb Medium-grained, light-gray weathering variably porphyoblastic, protomylonitic gneissic granite; distinctive white felsic bands ½-1cm thick parallel to dominate foliation, may be gradational with Dmgc. *Preliminary maximum age from Star Island ~457 Ma. *awaiting additional date from Star and Appledore Islands

DOcgg Coarse-grained gneissic granite and pegmatite, variably foliated and sheared, commonly containing enclaves of older biotite granofels, amphibolite, and less common pelitic schist. Tentatively assigned to the Ordovician Rye Formation.

DObgn Coarse-grained banded quartzo-feldspathic gneiss distinguished by presence of infolded, frequently sheared biotite schist. Tentatively assigned to the Ordovician Rye Formation.

DOagn Fine to medium grained, well foliated pelitic quartzo-feldspathic augen gneiss with 1-3 cm, variably strained K-feldspar augen. Porphyroblasts often preserve shear fabric. Assigned to the Ordovician Rye Formation.

Metasedimentry/Metavolcanic(?) Rocks

Ordovician or older; Assigned to the Rye Complex

OCrg Well layered, blue gray to dark gray weathering, foliated biotite and biotite-actinolite granofels. May include intercalated rusty and non-rusty, sometimes spangled coarse muscovite sillimanite schist. Occurs as strike parallel,

OCra Fine grained green-black, well foliated hornblende and biotite-hornblende schist. Internal early isoclinal F1 folds are common. May be more broadly folded (as at the Thaxter cemetery on Appledore).

PRELIMINARY CORRELATION OF MAP UNITS (zircon U/Pb ages pending)

Modified after Hussey et al., 2016. *Intrusive ages. °Detrital zircon ages.

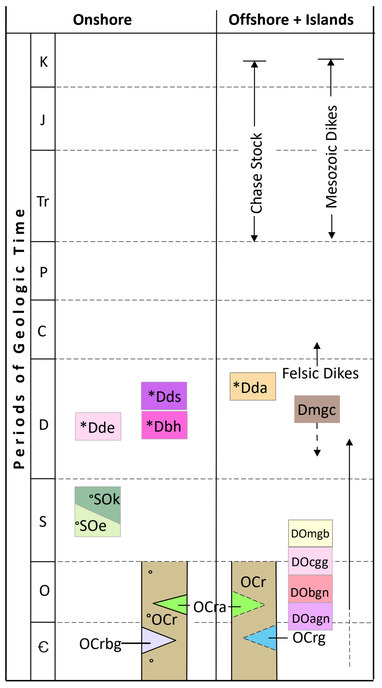
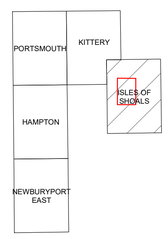


Table of pending zircon U/Pb ages to be inserted here

EXPLANATION OF MAP SYMBOLS

- 80 S1-2 Foliation (primary), showing dip and dip direction
- 74 S3 Foliation (secondary), showing dip and dip direction
- 86 Basalt dike, showing dip and dip direction
- 80 Basalt dike with gabbro clasts, showing dip and dip direction
- 7 Fold axis showing trend and plunge
- 65 Foliation; measured by RJB, showing dip and dip direction
- Foliation, vertical; measured by RJB
- 80 Shear zone point showing trend and plunge of fold axis
- Intrusive breccia
- Felsic dikes
- Diabase dikes, dashed where inferred and offshore; gabbroic xenoliths indicated by spaced crosses
- W.A. Bothner observation points
- R.J. Bloomshield observation points
- Pegmatite
- Right-lateral fault (vertical)
- Brittle faults
- Close-spaced shear folitation
- Shear boudins
- Onshore contours at 6, 12, and 18 meters above sea level
- Bathymetric contours at -5, -20, -35, and -60 meters below sea level
- Shoals/rocks
- Cemetery
- Tucke Monument
- Gosport Chapel
- Isle of Shoals Lighthouse
- S Zircon U/Pb sample location (ages pending)



NHGS Open-File Disclaimer: This map and the accompanying legend(s) are understood to be open-file products. They are draft versions of an unpublished report and represent mapping progress at the time of completion. Newer information may exist. If you have questions, please contact the New Hampshire Geological Survey (NHGS) at: geology@des.nh.gov or (603) 271-1976

Bedrock Geologic Map of the Isles of Shoals, Maine and New Hampshire, 1:8,000 scale

Wallace A. Bothner, 2019

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Bedrock Geology by Wallace A. Bothner
Digital Compilation by Wallace A. Bothner, Gregory A. Barker, and Joshua A. Keeley
New Hampshire State Geologist: Frederick H. Chormann, Jr.

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SHOALS SUMMARY AND PHOTOGRAPHS

The Isles of Shoals consist of seven islands and several smaller ledges about 10 kilometers southeast of Portsmouth, NH, and Kittery, ME, (Fig. 1). From the mainland the larger and most obvious ones, Appledore and Star, appear smooth and shield-like, but as roche moutonee, they are all asymmetric in NW-SE profile. Together they occupy some 10 km2 (~100 ha), but the shapes, orientation and principle northeast structural grain persist continuously beneath the sea surface as is obvious in the combined bathymetric/lidar bases used for this map.

Early geologic studies (Jackson, 1844; Hitchcock, 1877, Katz, 1917; Fowler-Billings, 1959) set the stage for remapping efforts on the islands using different base maps (aerial photographs used to update old topographic maps; Blomshield, 1975, and existing bathymetric maps for sea bottom bedrock mapping/sampling; Brooks, 1986). Those reexaminations identified many of the same rock units exposed on the New Hampshire and southwestern Maine coast (Hussey et al., 2016; Bothner et al., 2014) and confirmed the general correlation with the Cambro-Ordovician Rye Complex on mainland southeast New Hampshire and southwest Maine originally suggested by Fowler-Billings (1959).

The islands are underlain by variably deformed metasedimentary and metaigneous rocks. They are cross cut by Devonian (and younger?) granites and abundant Mesozoic diabase dikes. Gray coarse-grained quartzofeldspathic (granitic) gneisses and variably deformed pegmatite dominate the lithic assemblage. Intercalated biotite-rich lenses on Appledore Island are shown as banded gneiss with several areas of associated augen gneiss. Medium-grained, variably foliated, and in places, protomylonitic gneissic granite preserve evidence of significant shear, some expressed as dextral shear boudins up to 10 meters in length. Mildly metamorphosed and deformed Devonian diorite crops out only on Appledore (Dorais et al., 2014); it cross cuts and is cut but several generations of granite, granite dikes and diabase. Except for the diabase, all other units may include remarkably consistently NE-oriented bodies (enclaves) of biotite, biotite-actinolite, amphibolite, and lesser pelitic schist a few to 10's of meters thick and up to 100+ meters long. These latter units, based on cross-cutting relationships, represent the oldest mappable units on the islands.

Like much of the New England coast, the Isles of Shoals are cut by numerous diabase dikes of Mesozoic age up to 3-meters in thickness. Most are simple dikes, a few are multiple dikes, and some have porphyritic centers. Phenocrysts are mostly randomly oriented plagioclase up to 1 cm in length, sometimes clinopyroxene, and rarely olivine. They may contain xenoliths of country rock and one important diabase, continuous from Star Island to at least Cedar Island, contains a range of rounded coarse gray to black gabbroic rock fragments atypical of any local lithologies (from the lower crust?).

The ages of rocks and timing of events are based on cross-cutting relations, but the absolute ages remain somewhat equivocal. They have been constrained by correlation with dated rocks on the mainland (Lyons et al. 1997; Bothner and Hussey, 1999; Hussey et al., 2016, Bothner et al., 2019) but some of the newest U/Pb zircon ages yielded too large a spread to resolve a more absolute time sequence. Like the Rye Complex onshore, the host rocks on the Isles were metamorphosed and deformed prior to the emplacement of mid-Devonian diorite and granite, deformed again likely during Permian shear, and finally intruded during the initial stages of the opening of the Atlantic Ocean. The abundant diabase dikes attest to that stage of extension accompanied by widespread plutonic/volcanic activity preserved at nearby Mt. Agamenticus, Cape Neddick, and explosion breccia on the shore of Gerrish Island in Maine (Hussey et al., 2016).

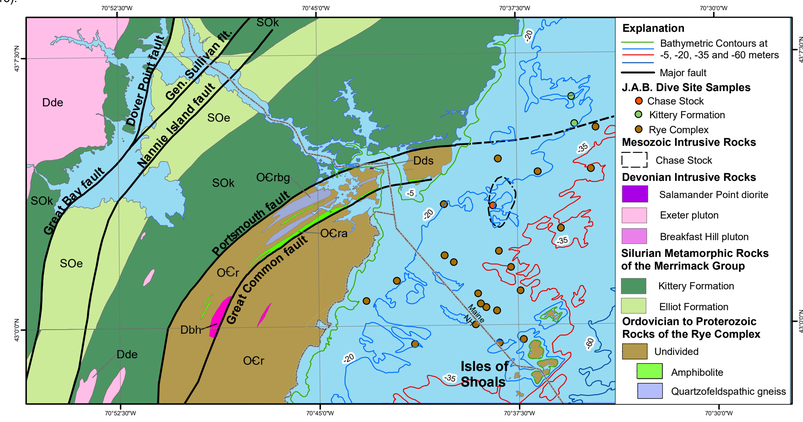

Figure 1. Simplified geologic map after Hussey et al. (2016) showing named faults and major geological formations of the Kittery 1:100,000 quadrangle. Note bathymetric contours at -5, -20, -35, and -60 meters depth. Contours at -5, -20, and -35 reflect post-glacial shoreline positions at approximately 10000, 8000-6000, and 4000 years before present when early indigenous peoples accessed the islands by foot and by canoe. J.A.B.– John A. Brooks.

Figure 2. Early isoclinal folds in amphibolite enclave, Babb's Cove, Appledore Island; outcrop of Star Island in granite contact with deformed dikes, and nearby intercalated with biotite granofels also at Star Island.

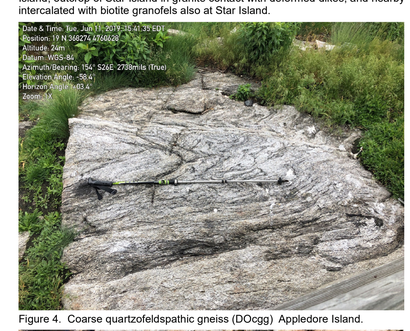

Figure 4. Coarse quartzofeldspathic gneiss (DOcgg) Appledore Island.

Figure 6. Multiple diabase with central zone xenolith choked with gabbroic xenoliths, Cedar Island. Inset shows character of xenoliths from same dike on Star Island

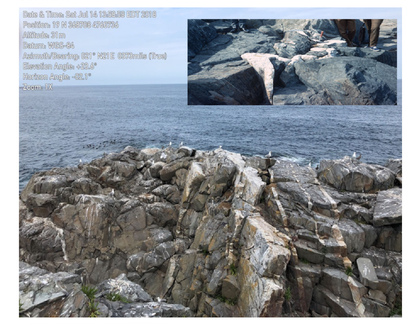

Figure 8. Appledore diorite (Dda) exposed on east and southeast shores showing cross-cutting, sometimes folded, granite dikes, dextral slip faulted granitic veins, and intermingled clasts in granite.

Figure 3. Banded gneiss and boudin shaped augen gneiss at Smith Cove, Appledore Island.

Figure 5. Biotite-actinolite granofels (OCrg) cut by Mesozoic diabase at Norwegian Cove, Appledore Island.

Figure 7. Augen gneiss with foliated cross cutting pegmatite offset by later granitic vein, Appledore Island

Figure 9. Medium grained gneissic granite with biotite granofels inclusion, intrusive breccia, shear boudins, one containing xenolith of coarser quartzofeldspathic gneiss and adjacent stretched augen gneiss boudin, Appledore Island.

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