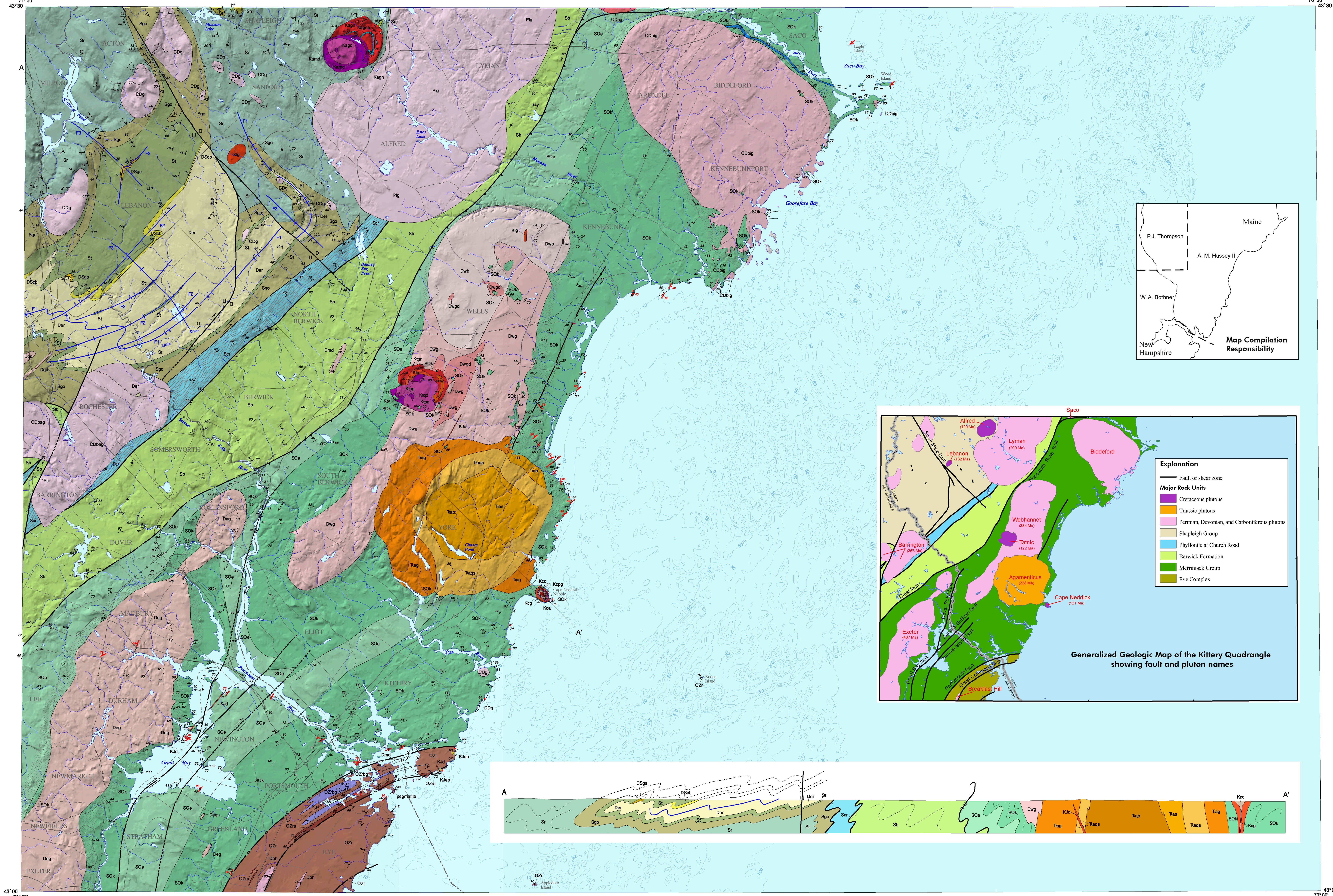
Bedrock Geology of the Kittery 1:100,000 Quadrangle, Maine and New Hampshire



Shaded relief base by Marc C. Loiselle using a digital elevation model with a 10-meter grid, sun angle of 315°, and sun elevation of 45°.

Miles (mi): 0 1 2 3 4 5 6 7 8 9 10 11 12

Map Scale
1:100,000

Kilometers (km): 0 2 4 6 8 10 12 14 16 18 20

National geodetic vertical datum of 1929.

Intrusive Rocks

Cretaceous

ALFRED COMPLEX

- **Kagd** — Fine to medium-grained gray granodiorite.
- **Kamd** — Medium-grained buff monzodiorite.
- **Kagn** — Dark brownish gray gabbronorite.
  - **Kagna** — Medium gray, medium-grained, anorthositic gabbronorite (as thin layers within **Kagn**).

TATNIC COMPLEX

Younger Funnel

- **Ktqd** — Medium olive-gray to light buff quartz diorite, commonly with abundant inclusions of dark gray porphyritic and aphanitic basalt.
- **Ktog** — Dark gray olivine gabbro with abundant hornblende and biotite.

Older Funnel

- **Ktpg** — Dark gray gabbronorite with large, elongate poikilitic hornblende phenocrysts.
- **Kta** — Medium gray coarse-grained anorthositic gabbronorite.
- **Ktgn** — Dark brownish-gray gabbronorite.
- **Ktv** — Volcanic breccia block within **Ktog**.

CAPE NEDDICK COMPLEX

Younger Funnel

- **Kcpg** — Poikilitic gabbro, gradational from **Kcc**.
- **Kcc** — Cortlandtitic gabbro: dark gray mafic-rich gabbro with large poikilitic hornblende phenocrysts.

Older Funnel

- **Kca** — Medium gray anorthositic gabbro.
- **Kcg** — Medium dark gray gabbro, commonly with thin lighter gray gabbro layers. Some layers are pegmatitic gabbro. Thin unit of breccia along south and east margins of the complex.

Cretaceous(?)

- **Klg** — **Gabbro.** Dark gray gabbro at Lebanon and Wells, commonly deeply weathered.

Cretaceous - Jurassic(?)

- **KJd** — **Diabase.** Large dikes are mapped to scale. Numerous smaller dikes, some of which are shown by symbols, intrude all stratified rocks and older intrusive rocks.
- **KJeb** — **Breccia.** Two areas of explosion breccia on Gerrish Island, Kittery. Includes fragments of the Rye Complex and older felsic and basalt dike rocks.

Triassic

AGAMENTICUS COMPLEX

- **Ŧab** — Fine- to medium-grained, pink biotite granite.
- **Ŧaqs** — Light buff, alkaline quartz syenite, with irregular texture.
- **Ŧag** — Light gray to light buff, fine- to medium-grained, alkaline granite.
- **Ŧas** — Medium to dark olive green, medium- to coarse-grained, alkaline syenite.

Permian

- **Plg** — **LYMAN PLUTON.** Biotite-muscovite-garnet granite and pegmatite.

Carboniferous - Devonian (?)

- **CDbig** — **BIDDEFORD PLUTON.** Light gray, medium-grained biotite granite, and rare pegmatite.
- **CDbag** — **BARRINGTON PLUTON.** Biotite-muscovite granite and pegmatite.
- **CDg** — **Granite and pegmatite.** Biotite-muscovite granite and pegmatite.

Devonian

WEBHANNET PLUTON.

- **Dwb** — Light gray to pink, biotite-muscovite granite and rare pegmatite.
- **Dwg** — Light gray, medium- to coarse-grained, biotite granite with sphene and epidote.
- **Dwgd** — Medium gray, fine-grained, porphyritic biotite-hornblende granodiorite and quartz diorite.
- **Dqd** — **ROCHESTER PLUTON.** Quartz diorite of the Rochester area.

Metamorphosed Intrusive Rocks

Carboniferous-Devonian(?)

- **CDsg** — **SACO PLUTON.** Dark greenish-gray, foliated and metamorphosed gabbro.

Devonian

- **Deg** — **EXETER PLUTON.** Medium gray, medium-grained, quartz diorite and diorite, minor gabbro.

Devonian (?)

- **Dmd** — **Metadiorite.** Medium-grained, foliated, gneissic metadiorite.
- **Dbh** — **BREAKFAST HILL GRANITE.** Foliated muscovite-biotite granite which intrudes the Rye Complex.

Stratified Rocks

SHAPLEIGH GROUP (revised)

Devonian

- **Der** — **EAST ROCHESTER FORMATION** (new name). Well-bedded muscovite-biotite-garnet-sillimanite (or andalusite)-staurolite schist and micaceous quartzite. Probably equivalent to the Littleton Formation (New Hampshire) and the Carrabassett Formation (Maine).

Devonian (?) - Silurian

- **DScb** — Unnamed calc-silicate and biotite granofels. Probably equivalent to the Madrid Formation (Maine) and the Warner Formation (central New Hampshire).
- **DSgs** — Unnamed quartz granule grit in rusty schist matrix, some blue quartz grains. Probably equivalent to the Wild Goose Grit, Strafford, New Hampshire (Eusden and others, 1987).

Silurian

- **St** — **TOWOW FORMATION.** Rusty schist and graphitic schist. Probably equivalent to the Smalls Falls Formation (Maine and New Hampshire).
- **Sgo** — **GULLY OVEN FORMATION** (Thompson, 2004). Well-bedded muscovite-biotite-staurolite-andalusite-garnet schist and micaceous quartzite with rare pink quartz-garnet granofels (coticule). Probably equivalent to the Perry Mountain Formation (Maine and New Hampshire).
- **Sr** — **RINDGEMERE FORMATION.** Poorly-bedded to moderately well-bedded biotite-muscovite-garnet-staurolite-andalusite (or sillimanite) schist. Probably equivalent to the Rangeley Formation (Maine and New Hampshire).
  - **Srr** — Rusty-weathering muscovite-biotite schist.
  - **Src** — Calc-silicate granofels and marble.

------------------------------ fault ------------------------------

Silurian(?)

- **Scr** — Phyllonite at Church Road. Silvery-gray muscovite-biotite-garnet-staurolite phyllonite with abundant deformed quartz veins. Schematic pattern of wavy lines in the map unit indicates the rocks are strongly sheared.

------------------------------ fault ------------------------------

Silurian

- **Sb** — **BERWICK FORMATION.** Medium-bedded, medium brownish gray, feldspathic quartz-biotite granofels, greenish calc-silicate granofels, and subordinate quartz-biotite schist.

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MERRIMACK GROUP

Silurian - Ordovician

- **SOk** — **KITTERY FORMATION.** Variably thin to thick bedded, buff-weathering feldspathic and calcareous metawacke. Characterized by well-developed primary structures including graded bedding, channel cuts-and-fills, small scale cross-bedding, flame structure, and flute casts.
  - **SOkr** — Rusty-weathering hornfels or granofels and phyllite.
- **SOe** — **ELIOT FORMATION.** Generally thin-bedded gray calcareous and ankeritic quartz-biotite-chlorite phyllite and metasiltstone, and dark gray biotite-chlorite-muscovite phyllite.

Strongly Deformed Rocks

Ordovician-Precambrian

- **OZr** — **RYE COMPLEX.** Strongly mylonitic, complex association of quartz-plagioclase-biotite gneiss, calc-silicate gneiss and biotite gneiss, biotite-muscovite-staurolite-sillimanite (or andalusite) gneiss; and extensively migmatitic equivalents of these rock types. Minor dark gray graphitic schist, and impure marble.
  - **OZra** — Amphibolite.
  - **OZrbg** — Blastomylonitic quartzofeldspathic gneiss.

Lines

- **Contact between mapped units.** Interpreted to be of stratigraphic or intrusive origin.
- **Fault or shear zone.** See inset map for location of named faults.
  - Projection of known fault into area of poor bedrock exposure.
  - Brittle, high-angle fault. Commonly marked by bull quartz, breccia, or offset map units. U = upthrown side, D = downthrown side, if known. Interpreted to be of Mesozoic age.
  - Ductile fault, ultramylonite present. Variably oriented. Last motion interpreted to be of Permian age.
  - Ductile fault, phyllonite present. Probably high-angle. Not well exposed. Arrows indicate sense of strike-slip motion, if known. Of Carboniferous-Devonian(?) age.
  - Thrust fault. Teeth on upper plate. Fault plane dips to NW at current level of exposure. Displays some late brittle displacement.
  - Fault inferred from stratigraphic relationships, existence and nature uncertain. Of presumed Carboniferous-Devonian(?) age.
  - Fault boundary between intensely sheared and less sheared rocks. Arrows indicate dextral shear within zone. Of Carboniferous-Devonian(?) age.
- **Fold axis.** Numbers distinguish F1,F2,F3. (Synform, Antiform)
- **Axis of overturned fold.** Numbers distinguish F1,F2,F3. (Synform, Antiform)

Symbols for Planar Features

Symbol is oriented parallel to strike of feature. Dip direction indicated by tick or barb. Dip angle given in degrees.

- Basalt, diabase, or mafic dike. (Inclined, Vertical, Orientation unknown)
- Bedding, tops unknown. (Inclined, Vertical)
- Bedding, tops known. (Upright, Vertical, Overturned)
- Compositional layering in metamorphic rock. (Inclined)
- Compositional layering in igneous rock. (Inclined, Vertical)
- Lamination. (Inclined)
- Igneous foliation. (Inclined, Vertical)
- Metamorphic foliation or schistosity. (Inclined, Vertical)
- Cleavage. (Inclined)
- Axial plane of fold. (Inclined)
- Shear zone. (Inclined, Vertical)
- Minor strike-slip fault. (Inclined dextral, Inclined sinistral)
- Joint. (Inclined, Vertical)

Symbols for Linear Features

Symbol is oriented parallel to trend. Plunge direction toward head of arrow. Plunge angle given in degrees.

- Intersection lineation. (Plunging)
- Mineral lineation. (Plunging)
- Fold hinge. (Rotational sense Clockwise, Neutral, Counterclockwise, Unknown)

Overprint Patterns

- Hornfels or granofels, in contact metamorphic aureole near a pluton.

ROCK UNIT	METHOD	AGE (Ma)	SOURCE
Published dates			
Alfred complex *Biotite in monzodiorite*	$^{40}Ar/^{39}Ar$	120.4 +/- 1.0	4,5
Cape Neddick Complex *Biotite in gabbro*	$^{40}Ar/^{39}Ar$	120.6 +/- 0.4	4,5
Tatnic Complex *Biotite in quartz diorite*	$^{40}Ar/^{39}Ar$	122 +/- 2	4,5
Tatnic Complex *Biotite in gabbro*	K/Ar	122 +/- 2	3
Lebanon diorite	$^{40}Ar/^{39}Ar$	132 +/- ?	4
Biotite	$^{40}Ar/^{39}Ar$	125 +/- 3	5
Agamenticus Complex	K/Ar	228 +/- 5	3
Barrington pluton *Monazite*	U/Pb	363 +/- ?	2
Berwick Formation *Detrital zircon*	U/Pb	425 (maximum)	6
Preliminary, unpublished dates			
Lyman pluton, granite	U/Pb	290 (with 320 Ma inheritance)	1
Webhannet pluton, granite	U/Pb	383.5	1
Webhannet pluton, granodiorite	U/Pb	382	1
Rye complex, biotite diorite	U/Pb	382	1
Rye complex, granitoid gneiss	U/Pb	380 (with 500-700 Ma inheritance)	1
Exeter diorite	U/Pb	407.7	1
Exeter biotite diorite	U/Pb	407.4	1

Sources

1) Bowring, S.A., 2008, unpublished data.
2) Eusden, J.D., and Barriero, 1988, The timing of peak high-grade metamorphism in central-eastern New England, *in* Lux, D. R., and Barr, S. M. (editors), Geology of coastal New England and New Brunswick east of the Kearsarge-central Maine synclinorium: Maritime Sediments and Atlantic Geology, v. 24, no. 3, p. 241-255.
3) Foland, K.A., and Faul, H., 1977, Ages of the White Mountain intrusives, New Hampshire, Maine, and Vermont, USA: American Journal of Science, v. 277, p. 888-904.
4) Hubacher, F.A., and Foland, K.A., 1991, $^{40}Ar/^{39}Ar$ ages for Cretaceous intrusions of the White Mountain magma series, northern New England, and their tectonic implications: Geological Society of America, Abstracts with Programs, v. 23. p. 47.
5) McEnroe, Suzanne A., 1996, A Barremian-Aptian (Early Cretaceous) North American paleomagnetic reference pole, Journal of Geophysical Research, B, Solid Earth and Planets, v. 101, no. 7, p. 15, 819-15, 836.
6) Wintsch, Robert P., Aleinikoff, John N., Walsh, Gregory J., Bothner, W. A., Hussey, A. M., II., and Fanning, C. M., 2007, SHRIMP U-Pb evidence for a Late Silurian age of metasedimentary rocks in the Merrimack and Putnam-Nashoba Terranes, eastern New England, *in* Wintsch, Robert P. (editor), John Rodgers memorial issue; Part I: American Journal of Science, v. 307, no. 1, p. 119-167.

GEOLOGY OF THE KITTERY 1:100,000 QUADRANGLE, MAINE

Rocks exposed in the Kittery 1:100,000 quadrangle include intrusive igneous rocks and metamorphosed sedimentary rocks. Intrusive igneous rocks are those rocks formed by the crystallization of masses of molten rock material (magma) that were entrapped within the Earth's crust. Sedimentary rocks are accumulations of particles of gravel, sand, silt, and clay in distinct beds, and precipitation of minerals from solution. Recrystallization of the sedimentary rocks by heat and pressure transforms them into metamorphic rocks, frequently developing minerals that are quite different from the originally deposited particles.

STRATIFIED ROCKS

Stratified rocks in the Kittery quadrangle are metamorphosed deposits of shale, siltstone, and sandstone that accumulated in two ancient ocean basins, the Central Maine basin on the west and the Merrimack basin on the east. Deposition occurred during latest Ordovician through Middle Silurian time in the Merrimack basin, and from latest Ordovician through Early Devonian time in the Central Maine basin. These rocks were derived from weathering and erosion from exposed landmasses surrounding those basins. Sedimentary rocks are separated into formations of closely similar rock types that can be mapped over a broad area. Within the Kittery quadrangle these include the Eliot and Kittery Formations deposited in the Merrimack basin, and the Berwick Formation, the source material for the phyllonite at Church Road, and formations of the Shapleigh Group (Rindgemere, Gully Oven, Towow, and East Rochester Formations) accumulated in the Central Maine basin.

The Eliot Formation consists of metamorphosed thin beds of alternating tan-weathering limy siltstone, and dark gray shale (**Photos 1 and 2**). The Kittery Formation consists of variably thin to very thick-bedded metamorphosed limy sandstone, siltstone, and shale that preserve a variety of sedimentary structures similar to those found today in deep-sea sediments that accumulate at the base of continental slopes. Graded bedding (**Photo 3**) and flute casts (**Photo 4**) are common and enable us to determine stratigraphic order and the direction from which the sediments were derived and transported, in this case, from a continental land mass lying to the east (in terms of present day orientation) of the Merrimack basin.

The Berwick Formation consists of metamorphosed calcareous sandstone, siltstone, and shale much like the Kittery Formation but of more medium- to massive-bedded character (**Photo 5**). The Rindgemere, Gully Oven, and East Rochester Formations consist of metamorphosed gray non-rusty-weathering shale, siltstone, and sandstone. Bedding of the Rindgemere Formation is weakly developed and variable, and primary sedimentary structures are rare. On the contrary, bedding in the Gully Oven (**Photo 6**) and East Rochester (**Photo 7**) Formations is characteristically well developed, with rhythmic alterations of shale and siltstone which are **commonly** graded (lighter colored siltstone grading up into darker colored shale followed by an abrupt break to the overlying siltstone, **Photo 6**). The Gully Oven Formation includes distinctive thin beds of reddish garnet-quartz granofels (**Photo 8**). The Towow Formation is a distinctive alternation of sulfidic, rusty weathering poorly bedded to massive metamorphosed shale and siltstone. Between the Towow and East Rochester Formations lies an unnamed thin, possibly discontinuous, unit of metamorphosed calcareous sandstone, and a thin rusty-weathering metasiltstone or metasandstone with granule-sized clasts up to 4 mm in size consisting of white and blue quartz, quartzite and rare metashale chips.

INTRUSIVE IGNEOUS ROCKS

The major intrusive bodies (called plutons) of the Kittery sheet include the following:

1) Biddeford pluton, a medium-grained evenly textured gray biotite granite (**Photo 9**).

2) Webhannet pluton, consisting of three principal phases. The youngest, forming the northern end of the pluton, is a pink to light gray medium-grained evenly textured biotite-muscovite granite; the intermediate-aged phase is medium- to coarse-grained, evenly textured to slightly foliated, light to medium gray biotite granite with moderate amounts of sphene and epidote; the oldest phase is fine- to medium-grained medium gray biotite-hornblende granodiorite.

3) Lyman pluton, a fine- to medium-grained, irregularly textured biotite and biotite-muscovite granite. Irregular masses of granite pegmatite are common in many parts of the pluton.

4) Exeter pluton, medium-grained variably textured quartz-biotite diorite with minor irregular masses of comagmatic gabbro to quartz monzonite.

5) Barrington pluton, medium- to coarse-grained biotite diorite.

6) Minor unnamed plutons mostly of biotite-muscovite granite with feldspar phenocrysts up to 3 cm long, commonly aligned with the foliation, which forms a swirled pattern in many outcrops. Pegmatite is common in the stratified units, especially in the Rindgemere Formation, as isolated bodies or migmatitic segregations.

7) Agamenticus Complex, consisting of four phases closely associated in space and time. The oldest is medium- to coarse-grained olive green syenite (a rock similar to granite but with very little quartz). The next younger phase is buff quartz syenite with very irregular texture. The next phase is a light gray to slightly pinkish gray, fine- to medium-grained granite. These three phases have a very unusual variety of dark minerals including riebeckite, arfvedsonite, enigmatite, aegirine-augite, and ferrohastingsite which reflect the sodium-rich nature of the magmas that gave rise to them. The youngest phase of the complex is fine- to medium-grained pinkish gray biotite granite.

8) Gabbro complexes. These are relatively small plutons (Cape Neddick, Tatnic, Alfred, and Lebanon plutons) that consist of a variety of iron- and magnesium-rich igneous rocks such as gabbro, cortlandtite, monzodiorite, and granodiorite. These are the youngest crustal rocks in the Kittery quadrangle, having been intruded about 120 million years ago.

In addition to these plutons, thin tabular igneous rock masses (dikes and sills) ranging from a few centimeters to 75 meters in thickness intrude all the metamorphosed stratified rocks and all the igneous plutons except the gabbro complexes. They are especially common in the exposures of the Kittery Formation in the coastal area from Kittery to Biddeford Pool (**Photo 16**). They are predominantly basalt and diabase (a coarser grained phase of basalt), approximately the same composition as gabbro.

DEFORMATION AND METAMORPHISM

The stratified rocks have been extensively folded and faulted. Two stages of folding are particularly well displayed in the Kittery Formation along the coast between Ogunquit and Kittery. Earlier folds are recumbent, that is, they are lying over on their side (**Photo 10**), whereas the later folds are upright (both sides of a fold dip steeply as illustrated in **Photo 11**). Major faults in the map sheet include: the Nonesuch River fault separating the Berwick and Eliot Formations, the Portsmouth fault separating the Kittery Formation and Rye Complex, the Great Commons fault cutting the Rye Complex, and a shear zone embodied as the phyllonite at Church Road (**Photo 12**) defining a boundary between the Berwick Formation and other members of the Central Maine basin. Old silver mines and prospect pits of the Acton Silver District are located along a zone of white bull quartz, apparently marking the trace of a Mesozoic fault (Silver Mine fault) in the Acton and Lebanon area.

Most of the large scale folding is probably the result of the Acadian orogeny a major period of middle Paleozoic crustal compression driven by plate tectonic movements. An additional effect of this event was the recrystallization of the stratified rocks to form schists out of shales and siltstones, and granofels and gneisses from sandstones. The degree of heating during this compression is expressed in the variety of new minerals that formed, particularly in the schists. Lower temperature, for example, is indicated by the presence of chlorite, medium temperature by garnet, and higher temperature by sillimanite, and andalusite.

GEOLOGICAL HISTORY

The oldest stratified rocks are those of the Rye Complex. They consist of layered metasedimentary rocks (**Photo 13**) that were once impure sandstones, shales (some carbonaceous), impure limestones, and perhaps a few volcanic rocks (**Photo 14**). Affected by at least two episodes of Paleozoic deformation, metamorphism (including partial melting), and intrusion, followed by such thorough, but variable, shear (**Photo 15**), they no longer preserve the primary structures that hint at source area. The major basin in which these rocks accumulated is unclear due to their separation from rocks of the Kittery and Eliot Formations by the Portsmouth fault.

The Eliot and Kittery Formations were deposited during Late Ordovician to Early Silurian time along the eastern edge of a deep seaway, the Merrimack basin, bordering an eastern landmass known as Avalonia. Primary sedimentary structures such as those shown in **Photos 2**, **3**, and **4**, indicate that sediments of the Kittery Formation came from an eastern source. Deposition in the Merrimack basin ceased by Middle Silurian time, followed shortly thereafter by deformation and metamorphism related to an early phase of the Acadian orogeny. The Berwick, Rindgemere, Gully Oven, and Towow Formations accumulated in a western part of the seaway (the Central Maine basin), with sediments derived from erosion of the Bronson Hill terrane, an island-arc complex of Ordovician age. However, by the time of deposition of the East Rochester Formation the source area shifted to the east, probably the uplifted and deformed rocks of the Merrimack basin. Deformation of the rocks of the Central Maine basin took place in early Devonian time as a result of a later phase of the Acadian orogeny.

Magmatic activity spans the middle Paleozoic to middle Mesozoic. The older intrusive rocks (e.g., 407 Ma Exeter pluton, and undated Rochester diorite) cut early Acadian folds in the seacoast area of New Hampshire and Maine. Granitic and granodioritic rocks of the Webhannet, Biddeford, Barrington and North Lebanon and related small plutons were intruded at about 380 Ma, close to the end of the Acadian deformation. Granite intrusion continued into the late Paleozoic (~280 Ma) and is represented here by the Lyman pluton. It is likely related to the Sebago batholith, just north of this map area, and one of the largest batholiths in the New England area. Some investigators relate the emplacement of these youngest Paleozoic granites to the Alleghanian orogeny, the terminal compressional event of the Paleozoic Era in the Appalachian Mountains.

The last major event in the geologic history represented on the Kittery sheet is the intrusion of rocks of the White Mountain Plutonic-Volcanic Series of Mesozoic age. The Agamenticus Complex is a ring complex of Triassic age (225 Ma), one of the oldest intrusive rock bodies of the series related to the opening of the Atlantic Ocean. It is part of a northwest-trending chain of eroded volcanic centers from the New England Seamounts across central New England and southern Quebec. This rift and drift-related magmatism spanned over 100 Ma. The last vestiges of this activity are reflected in the ~120 Ma age gabbroic complexes exposed in Tatnic Hill, Alfred, Cape Neddick, and Lebanon. In addition to these complexes, the area is crosscut by abundant basalt and diabase dikes (**Photo 16**), some of them tens of meters thick and traceable for tens of kilometers across the map area, and hundreds of kilometers to the northeast and southwest. They maintain an orientation roughly parallel to edge of the North American plate where it split and continues to separate from the Eurasian plate. A majority of these dikes are of Jurassic age (greater than 145 Ma and less than 205 Ma), intruded after the Agamenticus Complex but before the gabbroic complexes.

REFERENCES

Blomshield, R. J., 1975, Superposed deformations on the Isles of Shoals, Maine-New Hampshire: M.S. thesis, University of New Hampshire, Durham, 54 p.
Bothner, W. A., unpublished mapping.
Bothner, W. A., and Hussey, A. M., II, 1999, Norumbega connections: Casco Bay, Maine, to Massachusetts?, *in* Ludman, A., and West, D. P., Jr. (editors) Norumbega fault system of the northern Appalachians: Geological Society of America, Special Paper 331, p. 59-72.
Brooks, J. A., 1986, Bedrock geology of New Hampshire's inner continental shelf: M.S. thesis, University of New Hampshire, Durham, 127 p.
Brooks, J. A., 1990, The petrogenesis of the Agamenticus Complex and late Paleozoic and Mesozoic tectonics in New England: Ph.D. dissertation, University of New Hampshire, Durham, 317 p.
Carrigan, J. A., 1984, Geology of the Rye Formation: New Castle Island and adjacent areas of Portsmouth Harbor, New Hampshire and Maine: M.S. thesis, University of New Hampshire, Durham, 128 p.
Escamilla-Casas, Jose, 2005, Geology of the Exeter and Hampton 7.5 minute quadrangles, SE New Hampshire: Ph.D. dissertation, University of New Hampshire, Durham, 218 p.
Eusden, J. D., 1984, The bedrock geology of part of the Alton, New Hampshire and Berwick, Maine 15' quadrangles: M.S. thesis, University of New Hampshire, Durham, 114 p.
Eusden, J. D., Jr., Bothner, W. A., and Hussey, A. M., II, 1987, The Kearsarge-central Maine synclinorium of southeastern New Hampshire and southwestern Maine; stratigraphic and structural relations of an inverted section: American Journal of Science, v. 287, no. 3, p. 242-264.
Fargo, T. G., and Bothner, W. A., 1995, Polydeformation in the Merrimack Group, southeastern New Hampshire and southwestern Maine, *in* Hussey, A. M., II, and Johnston, R. A. (editors), Guidebook to field trips in southern Maine and adjacent New Hampshire: New England Intercollegiate Geological Conference, 87th Annual Meeting, p. 15-28.
Hussey, A. M., II, 1958-2004, field work.
Hussey, A. M., II, 1961, Petrology and structure of three basic igneous complexes, southwestern Maine: Ph.D. dissertation, University of Illinois, Urbana, 119 p.
Hussey, A. M., II, 1962, The geology of southern York County, Maine: Maine Geological Survey, Bulletin 14, 67 p., map scale 1:62,500.
Hussey, A. M., II, 1980, The Rye Formation of Gerrish Island, Kittery, Maine: A reinterpretation: Maine Geologist, v. 7, p. 2-3.
Lyons, J. B., Bothner, W. A., Moench, R. H., and Thompson, J. B., Jr., 1997, Bedrock geologic map of New Hampshire: U. S. Geological Survey State Map Series, scales 1:250,000 and 1:500,000 (2 sheets).
Novotny, R. F., 1969, The geology of the seacoast region, New Hampshire: New Hampshire Department of Resources and Economic Development, Concord, 46 p., scale 1:62,500.
Novotny, R. F., unpublished notes and field maps related to his 1964 dissertation: Bedrock geology of the Dover-Exeter-Portsmouth region, New Hampshire: Ohio State University, Columbus, 128 p.
Rickerich, S. F., 1983, Sedimentology, stratigraphy, and structure of the Kittery Formation in the Portsmouth, New Hampshire, area: M.S. thesis, University of New Hampshire, Durham, 115 p.
Thompson, P. J., 2004, Bedrock geology of the Milton quadrangle, New Hampshire-Maine: Maine Geological Survey, Open-File Map 04-77, scale 1:24,000.

Kittery Quadrangle
Maine-New Hampshire

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Geologic Map 08-78
2008

Photo 1. Thin, folded beds of the Eliot Formation at the type locality at Lee Five Corners, New Hampshire.

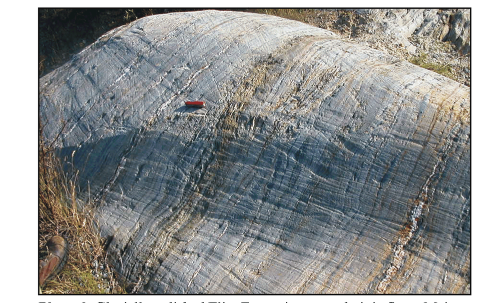
Photo 2. Glacially polished Eliot Formation, gravel pit in Saco, Maine.

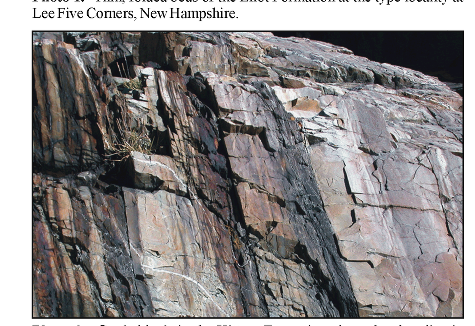
Photo 3. Graded beds in the Kittery Formation along the shoreline in York, Maine. A graded bed (two of which are well shown) has a light gray metasandstone lower part that grades upward into a dark metashale, the top of which is an abrupt break to the overlying metasandstone. These beds top to the right of the photo and are inclined because of folding that has affected these rocks. The conspicuous graded bed in the center of the photo is approximately eight centimeters thick.

Photo 4. Flute casts in Kittery Formation at Moody Point, Wells, Maine.

Photo 5. Berwick Formation at type location, South Berwick, Maine, Salmon Falls River. Note typical thick to thin bedded characteristic of the formation.

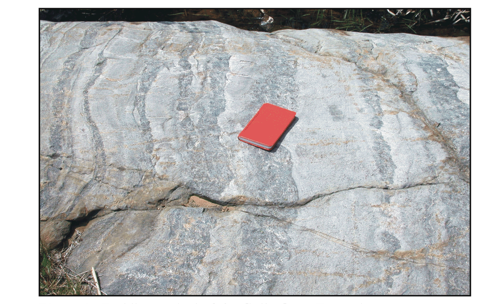
Photo 6. Bedding typical of the Gully Oven Formation at an exposure along Goding Road, Sanford, Maine. Note the conspicuous graded bed under the notebook (light colored metasiltstone grading upward into dark colored metashale. These beds are steeply inclined because of folding during the Acadian orogeny.

Photo 7. Bedding typical of the East Rochester Formation exposed in Little River, Lebanon, Maine. Arrow points to a graded bed, indicating that these beds are overturned.

Photo 8. Thin garnet-quartz granofels (coticule) bed in the Gully Oven Formation, Route 16 road cut, Rochester, New Hampshire.

Photo 9. Stringers of the Biddeford granite (light colored and massive) cutting the Kittery Formation (dark), Biddeford Pool, Maine.

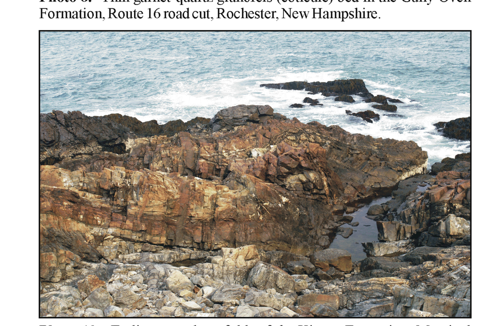
Photo 10. Earlier recumbent folds of the Kittery Formation, Marginal Way footpath, Ogunquit, Maine.

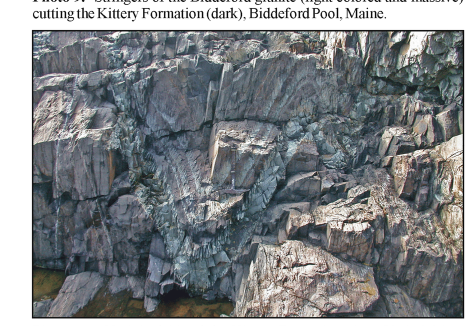
Photo 11. Upright folds of the Kittery Formation along York, Maine, shoreline.

Photo 12. Phyllonite at Church Road along Turkey Street, North Berwick, Maine

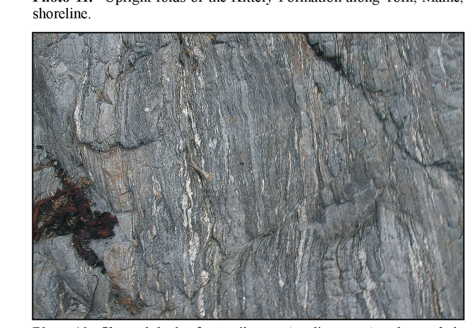
Photo 13. Sheared beds of metasiltstone (medium gray) and metashale (dark gray) typical of the Rye Complex at Fort Foster, Kittery, Maine.

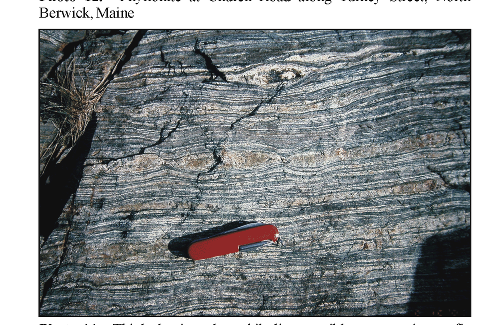
Photo 14. Thinly laminated amphibolite, possibly representing mafic volcanic rocks within the Rye Complex at Sewards Point, Kittery, Maine.

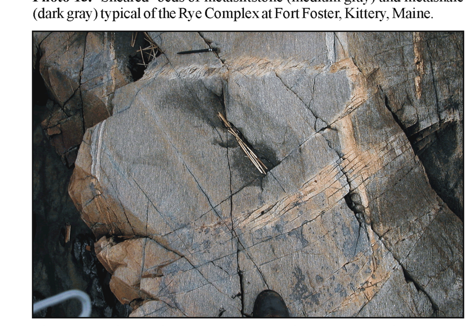
Figure 15. Quartz-feldspar gneiss, Rye Complex, New Castle, New Hampshire, Coast Guard station. The blastomylonitic texture in the gneiss is the product of extreme early shearing. This exposure also contains late pseudotachylite (frictional melt rock) in S-shaped gashes formed by late shearing.

Photo 16. A 2-meter-thick diabase dike cutting the Kittery Formation, in turn cut by a thinner basalt dike. Shoreline north of Bald Head Cliff, York, Maine.

GEOLOGIC TIME SCALE

Geologic Age		Absolute Age*
Cenozoic Era		0-65
Mesozoic Era	Cretaceous Period	65-145
	Jurassic Period	145-200
	Triassic Period	200-253
Paleozoic Era	Permian Period	253-300
	Carboniferous Period	300-360
	Devonian Period	360-418
	Silurian Period	418-443
	Ordovician Period	443-489
	Cambrian Period	489-544
Precambrian		Older than 544

* In millions of years before present. (Okulitch, A. V., 2002, Échelle des temps géologiques, 2002: Commission géologique du Canada, Dossier Public 3040 (Série nationale des sciences de la Terre, Atlas geologique) - RÉVISION.)