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Title: *Bedrock Geology of the Wells 7.5-minute Quadrangle, York County, Maine*

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Bedrock Geology of the Wells 7.5-minute Quadrangle, York County, Maine

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INTRODUCTION

The Wells 7.5-minute quadrangle (Figure 1) lies along the Wells embayment of the southwest arcuate beach compartment of the coast of Maine (Belknap and others, 1989). The principal population centers of the quadrangle are Kennebunk Beach, Wells, Wells Beach, and Ogunquit. The land part of the quadrangle is characterized by low undulating to flat topography with the highest elevation just over 200 feet in the northwestern part of the quadrangle. The seaward edge of the land is a sequence of long sandy barrier beaches (Figure 2) that border extensive salt marshes up to a mile in width. Prominent points underlain by bedrock interrupt the continuity of the beaches. Drainage is dominated by relatively short east- to southeast-flowing postglacial streams, the principal ones of which are the Mousam, Merriland, Webhannet, and Ogunquit Rivers and Branch Brook. A broad variety of Pleistocene to Holocene glacial, glaciomarine, and marine sediments has been deposited as a relatively thin blanket over the bedrock (Smith, 1999). Bedrock beneath the surficial sediments includes Silurian age turbidites of the Kittery Formation, which is the upper unit of the Merrimack Group (Lyons and others 1997); Early to Middle Devonian gray and pink granites of the Webhannet pluton (Hussey, 1962); Triassic alkaline granite and syenite of the Agamenticus Complex; a variety

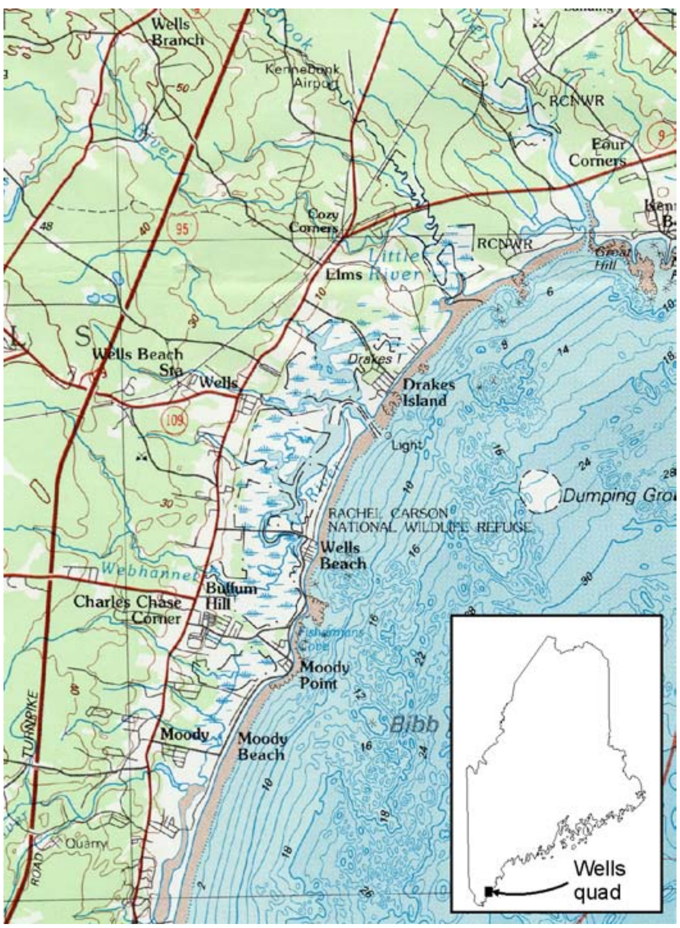


Figure 1. Location of the Wells 7.5-minute quadrangle, southwestern Maine.

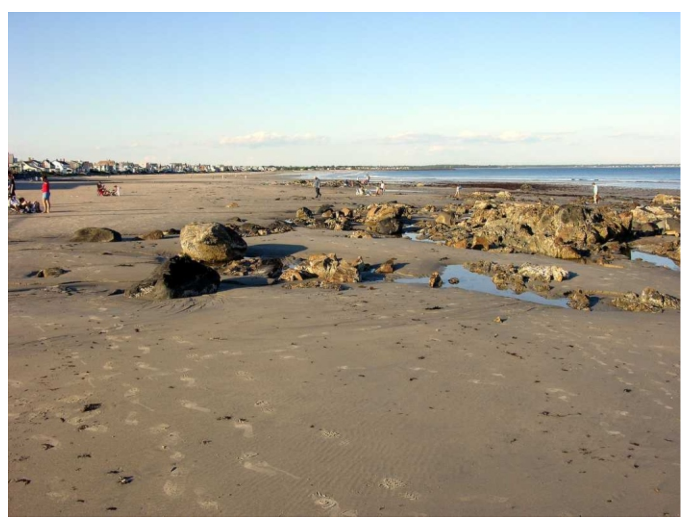


Figure 2. Wells Beach with exposure of the Kittery Formation on the foreshore, looking north from the vicinity of the beachfront parking area at the end of the Mile Road at Wells Beach.

Figure 3. Deeply-weathered gabbro near Wells Branch. Pit was excavated for "rotten rock" for path and driveway dressing.

Figure 4. Small knob of gabbro that has been produced by progressive weathering along joints in the gabbro. This knob, which is still attached to bedrock, will soon form a boulder from weathering like many others in the area. This locality is in a "rotten rock" pit north of the road near Wells Branch, as indicated on the geologic map.

of basalt and diabase dikes of presumed Triassic to Jurassic age; and gabbro of uncertain age. I have mapped the geology of the area intermittently over a period of time spanning my professional career in geology; and as a matter of note, this quadrangle has the first and (at the time of preparation of this report) the last of my field station numbers.

INTRUSIVE ROCKS

Gabbro (Klg)

Dark gray medium-grained highly weathered gabbro is exposed in two nearly adjacent rock pits (Figure 3) in the northwestern part of the quadrangle where weathered parts have been excavated for driveway and walkway dressing material. Depth of weathering of the gabbro is in excess of 2.5 meters in contrast to essentially no weathering of an exposure of the pink granite phase of the Webhannet pluton 60 meters to the east. Some surficial geology investigators have suggested that the weathering is preglacial (Bloom, 1960). Figure 4 shows a boulder of weathering of the gabbro still in place in the pit just north of the road leading west from its junction with Maine Highway 9A at Wells Branch. Minerals present include pyroxenes (both clinopyroxene and orthopyroxene), hornblende, biotite, plagioclase, and opaques. The full extent of this body is not known because of the scarcity of outcrop. It intrudes the pink phase of the Webhannet pluton. Based on coarse-grained texture and general mineralogy, this mafic rock is not correlated with the dikes noted below. It may correlate with Cretaceous-age igneous activity associated with intrusions in the Alfred Hills, Tatnic Hills, and Cape Neddick (Hussey, 1962; Hussey and others, 2008).

Diabase and basalt dikes

Basalt and diabase dikes are common throughout the area and intrude the Kittery Formation (Figure 5) and both phases of the Webhannet pluton. They are indicated on the accompanying geologic map by red symbols. Textures vary from basaltic to diabasic, and porphyritic to non-porphyritic. Inclusions of a variety of rock types are common, including digested fragments of the Kittery Formation, granite, and xenocrystic milky quartz (Figure 6). The dikes range from a few centimeters to greater than 10 meters. No radiometric ages are available from any of these dikes in the Wells quadrangle, but they probably correlate with similar dikes elsewhere along the shore for which radiomet-

Figure 5. Thin basalt dike cutting the Kittery Formation, same locality as Figure 2.

Figure 6. Angular quartz xenoliths in a 3+ meter wide diabase dike. Locality is shown on the geologic map.

Figure 7. Massive, non-foliated light pinkish gray mica-poor granite at Wells Branch, part of the Bald Hill granite of the Webhannet pluton.

ric ages ranging from Triassic to Jurassic have been reported (McHone and Butler, 1984). Similar dikes cut the Agamenticus Complex in York, Maine, for which a Triassic age is reported (Foland and Faul, 1977), and similar dikes are cut and contact metamorphosed by the Cretaceous age Cape Neddick Gabbro in York (Hussey, 1962, Foland and Faul, 1977).

Agamenticus Complex (TRag, TRas)

The Agamenticus Complex is an association of alkalic granite, alkalic quartz syenite, syenite, and biotite granite (Hussey, 1962) of Triassic age. Alkalic granite and alkalic syenite of this complex are inferred to occupy a small area in the very southwestern corner of the Wells 7.5-minute quadrangle. Alkalic syenite (**TRas**)is medium-grained olive gray, and composed predominantly of microperthitic alkali feldspar with soda-rich dark minerals such as arfvedsonite, riebeckite, aegirine, aegirine-augite, aenigmatite, hastingsite, and ferrohastingsite. Minor quartz, up to 2% of the mode, is present throughout the unit. Alkalic granite (**TRag**) is light buff gray and has mineralogy similar to the alkalic syenite, differing primarily in the relatively greater amount of quartz. Foland and Faul (1977) report a K/Ar age of 228 ± 5 Ma.

Webhannet pluton (Dwb, Dwg)

Gray and pink granite phases of the Webhannet pluton, a 30+ mile elongate composite intrusive body of Devonian age (Hussey, 1962) are exposed along the western edge of the quadrangle. The pink granite phase (**Dwb**), referred to informally as the Bald Hill granite (from the superior exposure at Bald Hill quarry just west of the quadrangle boundary), is medium-grained, non-porphyritic, non foliated, and light pink to light gray in color (Figure 7). The minerals present are microcline, quartz without undulatory extinction, plagioclase of composition An$_{12-20}$, biotite, and a minor amount of muscovite; accessory minerals include sphene, zircon, apatite, and opaque minerals (Hussey, 1962).

The gray granite phase (**Dwg**) (originally referred to as quartz monzonite in the Johannsen (1938) scheme of classification) is medium-grained to coarse-grained, light gray, non porphyritic, and massive to weakly-foliated. Minerals present are quartz with varying degrees of undulatory extinction, microcline, plagioclase of composition about An$_{25}$, and biotite, with minor amounts of hornblende, epidote, apatite, opaque minerals, and sphene. Sphene is notably more abundant than in the Bald Hill granite, and occasionally occurs as idiomorphic grains up to 2 mm long, readily recognizable in hand specimen. The ratio of potash feldspar to plagioclase is approximately 1:1, thus distinctly lower than in the Bald Hill granite. Near the Wells interchange of the Maine Turnpike, the granite is locally pinkish gray but is distinguished from the Bald Hill granite by the the greater amounts of biotite, epidote, and sphene.

Uranium-lead dating of zircon from both granite phases of the Webhannet pluton, as reported by Gaudette and others (1982), yields overlapping ages (404 ± 13 Ma), suggesting that both phases may have been emplaced synchronously. This agrees with a field observation at a location at the contact of the two approximately 1 km to the west of the Wells quadrangle where both both phases are intimately associated, and neither has any suggestion of chilling or contact alteration against the other.

Figure 8. Kittery hornfels, showing relict layering probably representing original bedding (near Ogunquit Village, southwest corner of the quadrangle).

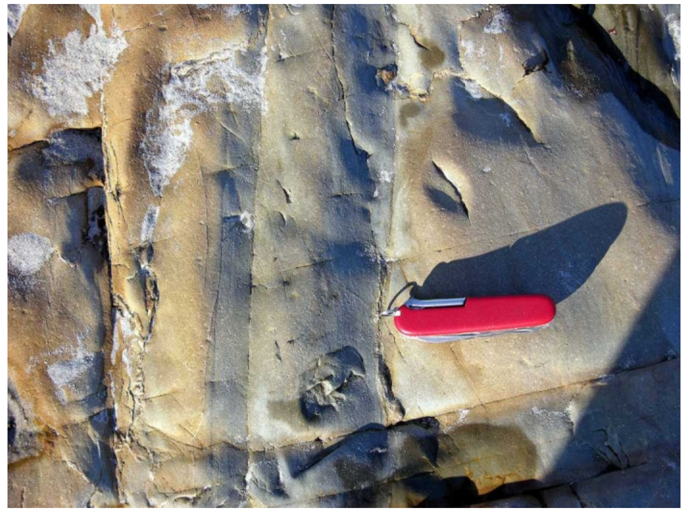


Figure 9. Graded beds (tops to the right) in relatively unaltered Kittery Formation at Wells Beach (same locality as Figure 2). The lighter buff-colored rock represents originally coarser-grained silty to sandy sediments and the darker rock represents clay. Note that the lighter colored rock grades to the right into the darker colored rock within a graded bed.

STRATIFIED ROCKS

Merrimack Group (SOk)

Most of the Wells quadrangle is underlain by one formation of the Merrimack Group, the Kittery Formation (**SOk**). The name, Merrimack Group, was first used by Hitchcock (1877) for the sequence of quartzites and quartzose slates and phyllites exposed along the Merrimack River valley near Salisbury, Massachusetts. In Maine and adjacent New Hampshire the Merrimack Group was divided into the Kittery, Eliot, and Berwick Formations (Katz, 1917; Freedman, 1950; Billings, 1956), and Billings (1956) established the stratigraphic order with the Kittery Formation at the base and the Berwick Formation at the top. Recent work in New Hampshire (Lyons and others, 1997) reverses the stratigraphic order of the Kittery and Eliot Formations, and Bothner and others (2004) suggest that the Berwick Formation may be in fault, not stratigraphic, contact with the Eliot Formation, an observation originally alluded to by Katz (1917).

Kittery Formation. In the Wells quadrangle the Kittery Formation consists of the following rock types:

1. Buff-weathering, very fine-grained, hard feldspathic ankeritic and/or calcareous quartz-rich granofels;
2. Dark gray chlorite phyllite.
3. Chocolate to purplish brown, fine-grained, hard, feldspathic and calcareous quartz-rich biotite granofels.
4. Dark brownish to purplish gray biotite phyllite.
5. Hard, flinty-textured, irregularly and thinly laminated quartz-plagioclase-biotite gneiss (Figure 8) with or without green calc-silicate minerals (hornblende, epidote, diopside).

Rock types 1 and 2 define the Kittery Fomation at low grade (ankerite-chlorite zone) of regional metamorphism, and types 3 and 4 define the Kittery at slightly higher regional grade (biotite zone). Rock type 5 represents a hornfels zone seen mostly in exposures within about one kilometer of the contact with the Webhannet pluton. Blocks or roof pendants of the Kittery Formation occur abundantly within the gray granite phase of the Webhannet pluton.

The Kittery Formation preserves excellent bedding, varying in thickness commonly from 1 to 25 cm, but occasionally up to 2 meters. Graded bedding (Figure 9) is common. Small scale cross-bedding has not been observed in the exposures in the Wells quadrangle, but is common in shoreline exposures to the south in the Ogunquit to Kittery area. One exposure at Moody Point in the Wells Beach area preserves flute casts (Figure 10). Some of the thicker beds, particularly as seen in the Moody Point area, have zones of relict detrital coarse sand-sized to fine granule-sized grains of quartz, feldspar, and possibly rock fragments in the basal 1-3 centimeter parts of beds. From sedimentological studies in the Portsmouth-Kittery area, Rickerich (1983) suggested that the Kittery Formation accumulated as turbidite and contourite deposits in a deep-sea submarine fan environment. He reports an average paleocurrent azimuth of 264º for turbidites based on cross-bedding. For the contourites he gives an average paleocurrent azimuth of 308º. The paleocurrent direction for turbidites indicates transport down a westerly-facing slope toward the present coast from an offshore land source to the east, thus ruling out derivation from the ancestral North American craton to the west.

The age of the Kittery Formation is constrained by the ages of plutons which intrude the formation, and by the ages of the youngest detrital zircons in the sediments. The oldest intrusive that cuts the Kittery Formation is the Newburyport quartz diorite in southern New Hampshire for which Fargo and Bothner (1995)

Figure 10. Well-developed, moderately deformed flute casts on the bottom of a 45 cm-thick bed of relatively unmetamorphosed Kittery granofels at Moody Point, Wells. The top of the bed lies to the right (southeast).

Figure 11. Plunging nose of steeply-overturned anticline in the Kittery Formation at Moody Point. Plunge of the fold is gently southwest.

report a Pb/U zircon age of 417±1 Ma. Wintsch and others (2007) indicate that the youngest age of detrital zircons from a sample of the Kittery Formation at Moody Point is approximately 460 Ma. This indicates a Late Ordovician to Silurian age for deposition of the formation.

Structural Geology

The rocks of the Kittery Formation have been deformed by two major folding events, the earlier producing recumbent folds for which there is no direct evidence in this quadrangle, but which are well displayed along the Ogunquit shoreline just south of the Wells quadrangle (Hussey, 2000). The younger folds are upright to moderately overturned and are well exposed at Moody Point (Figure 11). Similar upward-facing folds are indicated in other parts of the quadrangle by reversals of bedding facing directions as determined by graded bedding. Plunges of these upward-facing folds is gently to the southwest.

Major faults have not been mapped in this quadrangle. However, evidence of shearing with silicification is present in three zones:

1. In the vicinity of the scarp between Wells and Lower Landing there is one exploration (?) pit that originally exposed massive white bull quartz, in places with cavities filled with quartz crystals. Several other outcrops in the area expose highly silicified Kittery granofels. Upon reexamination of this locality in 2005, the pit could not be found, and is apparently the victim of burial by fill for a recreational trailer park that exists in the area today.

2. In a zone in the southwestern corner of the quadrangle near a large stone quarry, rocks of the Kittery Formation show extensive silicification with drusy quartz crystals in a narrow zone over about one half kilometer in length, extending in a north-northeast direction. This may possibly truncate the gray granite phase of the Webhannet pluton in that area as suggested in cross section A-A'.

3. Two large diabase dikes exposed more or less on strike with the first two localities carry abundant angular fragments of milky quartz (Figure 6) like that observed in the pit at locality 1. These may have been derived from the same silicified zone. Similar quartz xenoliths have not been seen in exposures of basalt and diabase dikes elsewhere in the quadrangle.

It is tempting to think that these zones may define a more significant through-going fracture zone or fault, possibly linked to one of the major faults in the Casco Bay area to the northeast, in particular, the Cape Elizabeth fault which has similar extensive silicification (Hussey, 2003).

Tectonic considerations

Early recumbent and later upright to overturned folds are a result of the Acadian orogeny, and both were produced prior to intrusion of the 417 Ma Newburyport pluton into the Kittery Formation in southern New Hampshire. This suggests that the Acadian orogeny occurred as early as Late Silurian time. The Early Devonian Webhannet pluton (ca. 404±13 Ma) is essentially undeformed, indicating that intrusion and cooling occurred after orogenic compression. Both deformation and intrusion may have resulted from the collision, in Late Silurian time, of a part of a peri-Gondwanan landmass (Avalonia?) with ancestral North America. The Kittery Formation likely was deposited as a continental rise apron bordering the North American side of Avalonia during Early to Middle Silurian time. During the latter part of the Paleozoic Era, other continental land masses accreted to form a supercontinent, Pangea. Evidence for this activity is not recognized in the rocks of the Wells quadrangle.

Intrusion of the Triassic Agamenticus Complex and the Triassic to Jurassic-age mafic dikes probably resulted from tensional fracturing of continental lithosphere that accompanied the breakup of Pangea to form the present Atlantic Ocean beginning in the Triassic Period.

REFERENCES CITED

Belknap, D. F., Shipp, R. C., Kelley, J. T., Schnitker, D., 1989, Depositional sequence modeling of Late Quarternary geologic history, west-central Maine coast, *in* Tucker, R. D., and Marvinney, R. G. (editors), Studies in Maine geology, Volume 5 - Quaternary geology: Maine Geological Survey, p. 29-46.

Billings, M. P., 1956, Geology of New Hampshire, Part 2: Bedrock geology: New Hampshire State Planning and Development Commission, Concord, N. H., 203 p.

Bloom, A. L., 1960, Late Pleistocene changes of sea level in southwestern Maine: Maine Geological Survey, 143 p.

Bothner, W. A., Laird, J., Escamilla-Casas, J., Kerwin, C. W., Schultz, J, Loveless, J. P., 2004, EDMAPS/newmaps in southeastern New Hampshire: Geological Society of America, Abstracts with Programs, v. 36, p. 57.

Fargo, T. R., and Bothner, W. A., 1995, Polydeformation in the Merrimack Group, southeastern New Hampshire and southwestern Maine: Geological Society of America, Abstracts with Programs, v. 27, no. 1, p. 42.

Foland, K. A., and Faul, H., 1977, Ages of the White Mountain intrusives - New Hampshire, Vermont, and Maine, USA: American Journal of Science, v. 277, p. 888-904.

Freedman, J., 1950, Stratigraphy and structure of the Mt. Pawtuckaway quadrangle, southeastern New Hampshire: Geological Society of America, Bulletin, v. 61, p. 449-492.

Gaudette, H. E., Kovach, A., and Hussey, A. M., II, 1982, Ages of some intrusive rocks of southwestern Maine, U. S. A.: Canadian Journal of Earth Sciences, v. 19, p. 1350-1357.

Hitchcock, C. H., 1877, The geology of New Hampshire part II - Stratigraphical geology: publisher unknown, Concord, New Hampshire, 684 p.

Hussey, A. M. II, 1962, The geology of southern York County, Maine: Maine Geological Survey, Bulletin 14 (Special Studies Series 4), 67 p.

Hussey, A. M. II, 2000, The Geological Story of Ogunquit, Maine: The Village Press, Freeport, Maine, 33 p.

Hussey, A. M. II, 2003, Bedrock geology of the Prouts Neck 7 1/2' quadrangle, Maine: Maine Geological Survey, Open-File Map 03-95, map (scale 1:24,000) and 8 p. report.

Hussey, A. M. II, Bothner, W. A., and Thompson, P. J., 2008, Bedrock geology of the Kittery 1:100,000 quadrangle, Maine and New Hampshire; Maine Geological Survey, Geologic Map 08-78, scale 1:100,000.

Johannsen, A., 1938, A descriptive petrography of the igneous rocks: Chicago University Press, 4 volumes.

Katz, F. J., 1917, Stratigraphy in southwestern Maine and southeastern New Hampshire: U.S. Geological Survey, Professional Paper 108, p. 165-177

Lyons, J. B., Bothner, W. A., Moench, R. H., and Thompson, J. B., 1997, Bedrock geologic map of New Hampshire: U.S. Geological Survey, Special Map, scales 1:250,000 and 1:500,000.

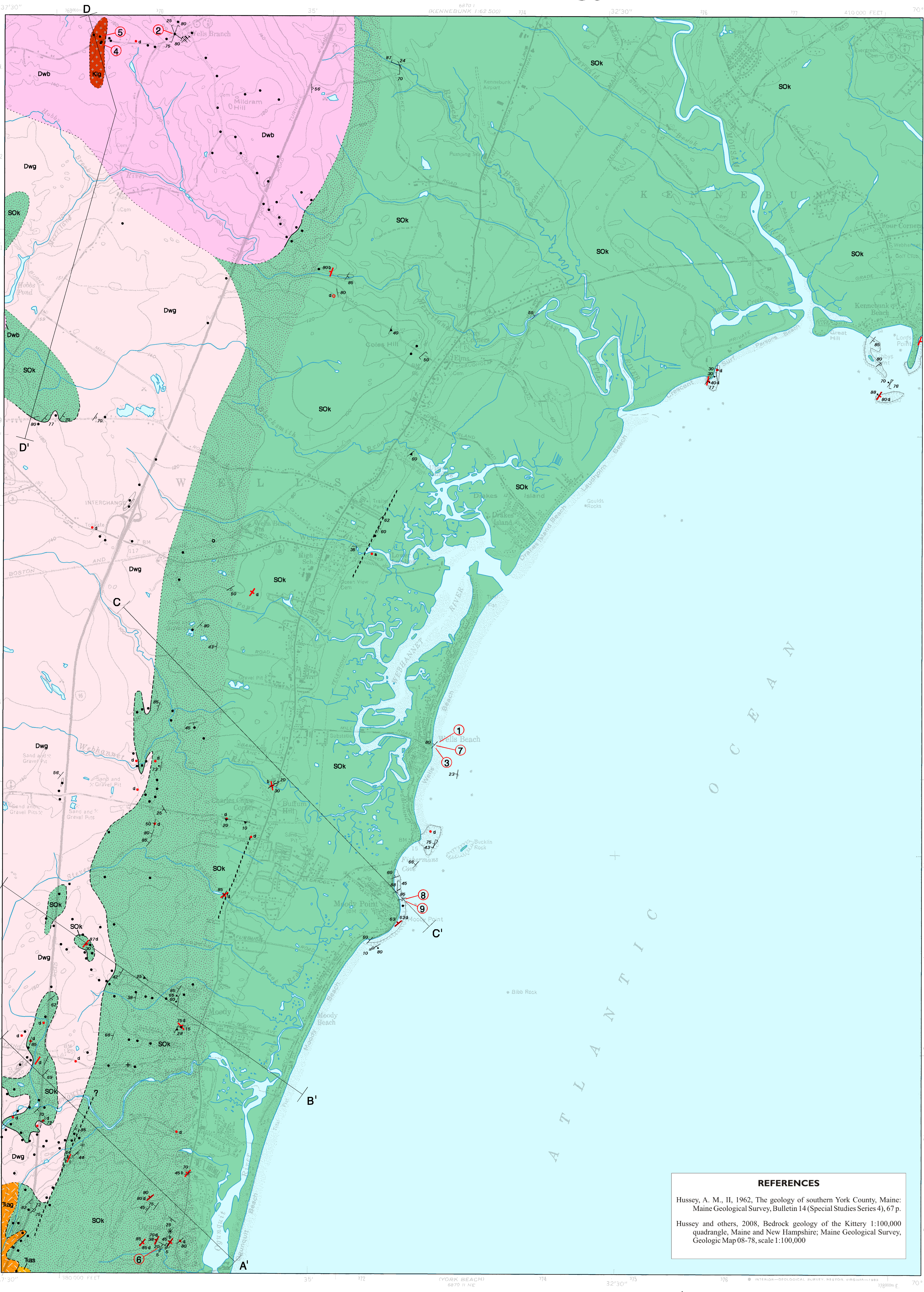
McHone, J. G., and Butler, J. R., 1984, Mesozoic ingeous province of New England and the opening of the North Atlantic Ocean: Geological Society of America, Bulletin, v. 95, p. 757-765.

Rickerich, S. F., 1983, Sedimentology, stratigraphy, and structure of the Kittery Formation in the Portsmouth NH area: M. S. thesis, University of New Hampshire, Durham, 115 p.

Smith, G. W., 1999, Surficial geologic map of the Wells quadrangle, Maine: Maine Geological Survey, Open File Map 99-104.

Wintsch, R. P., Aleinikoff, J. N., Walsh, G. 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, R. P. (editor), John Rodgers memorial issue; Part I: American Journal of Science, v. 307, no. 1, p. 119-167.

Bedrock Geology



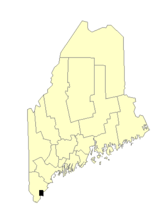
REFERENCES

Hussey, A. M., II, 1962, The geology of southern York County, Maine: Maine Geological Survey, Bulletin 14 (Special Studies Series 4), 67 p.

Hussey and others, 2008, Bedrock geology of the Kittery 1:100,000 quadrangle, Maine and New Hampshire; Maine Geological Survey, Geologic Map 08-78, scale 1:100,000

SOURCES OF INFORMATION

Field work by A. M. Hussey II (1970 - 2003).



Quadrangle Location

SCALE 1 : 24,000

1 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET

TRUE NORTH

Topographic base from U.S. Geological Survey Wells quadrangle, scale 1:24,000 using standard U.S. Geological Survey topographic map symbols.

The use of industry, firm, or local government names on this map is for location purposes only and does not impute responsibility for any present or potential effects on the natural resources.

EXPLANATION OF UNITS

INTRUSIVE ROCKS

Mesozoic, possibly Cretaceous (?)

Klg — **Gabbro at Wells Branch.** Dark gray gabbro with labradorite, pyroxene, hornblende, and biotite.

Triassic

Agamenticus Complex

Ꞧag — **Alkalic granite.** Medium to fine-grained buff granite of microperthite and quartz with a variety of sodium-rich and iron-rich amphiboles and pyroxenes.

Ꞧas — **Alkalic syenite.** Medium to dark olive gray, medium-grained to coarse-grained, alkalic syenite.

Devonian

Webhannet Pluton.

Dwb — **Pink granite.** Medium-grained mica-poor massive granite with microcline, plagioclase, and quartz, and minor biotite, muscovite, and accessory sphene. Sometimes called the Bald Hill granite.

Dwg — **Gray granite.** Medium-grained to coarse-grained, massive to very slightly foliated gray granite with microcline, quartz, plagioclase and biotite, and accessory sphene, epidote, apatite, and opaque minerals.

STRATIFIED ROCKS

Merrimack Group

Silurian - Ordovician

SOk — **Kittery Formation.** Thin-bedded to medium-bedded calcareous and feldspathic quartz-rich granofels with interbeds of dark gray chlorite phyllite or biotite schist depending on metamorphic grade. Some outcrops close to the Webhannet pluton have been baked to a streaky or laminated hard hornfels with green minerals (hornblende, epidote, and possibly diopside).

EXPLANATION OF LINES

Stratigraphic or intrusive contact (well located, approximately located, poorly located).

Shear zone.

A —— A' Line of cross section.

EXPLANATION OF SYMBOLS

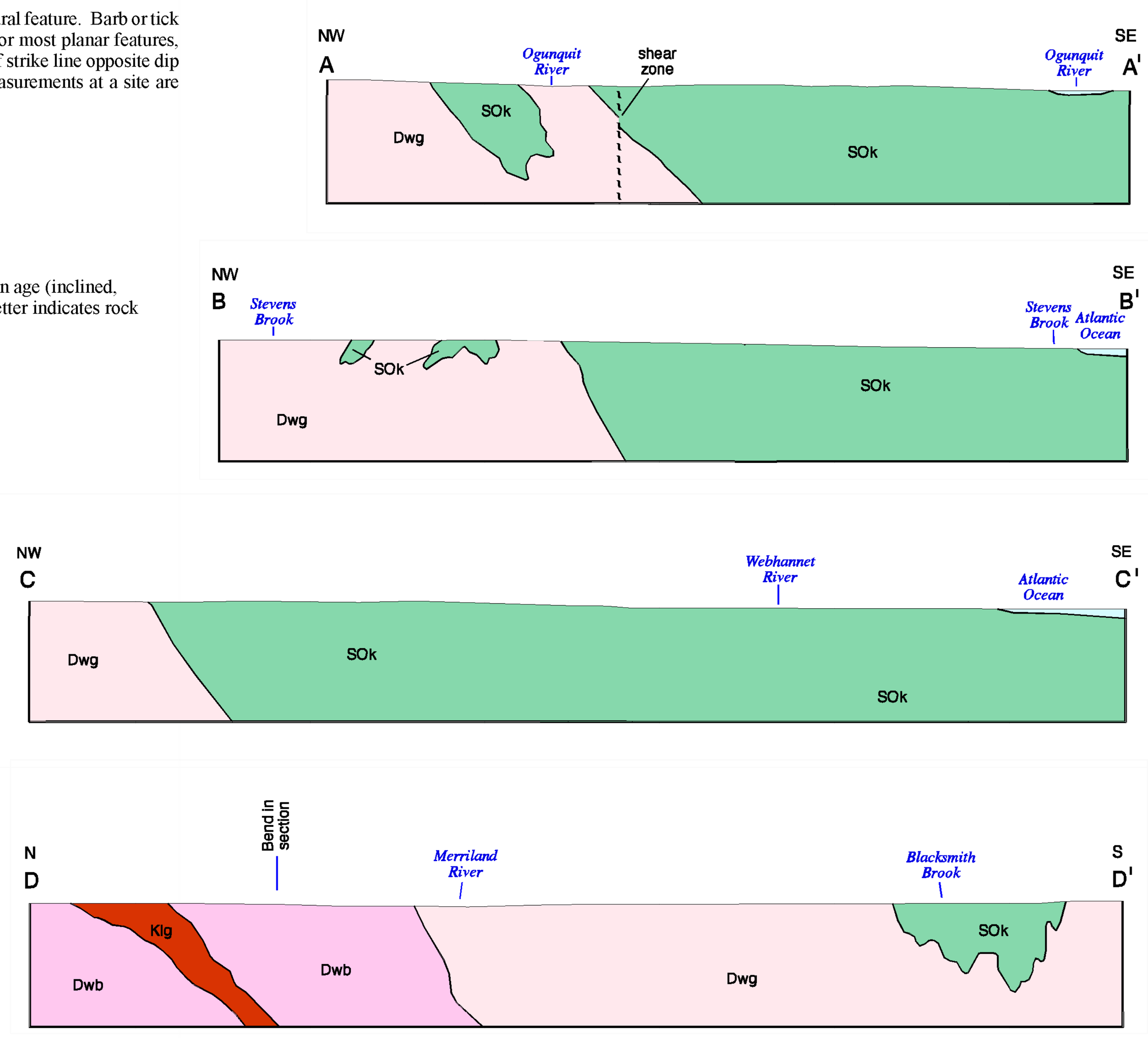
Note: Structural symbols are drawn parallel to strike or trend of measured structural feature. Barb or tick indicates direction of dip, if known. Annotation gives dip or plunge angle. For most planar features, symbol is centered at observation point; for joints, observation point is at end of strike line opposite dip tick. For linear features, tail of symbol is at observation point. Multiple measurements at a site are represented by combined symbols.

- Outcrop of mapped unit (small exposure, large area of exposure).
- Pegmatite.
- Blasted fragments from bedrock now unexposed.
- 20d, b, r, a — Dike or sill of fine-grained intrusive rock, probably Jurassic-Triassic in age (inclined, vertical, dip unknown, occurrence in outcrop, occurrence in float). Letter indicates rock type: a = andesite, b = basalt, d = diabase, r = rhyolite.
- 20 20 20 — Bedding (upright, overturned, tops unknown).
- 20 — Compositional layering (inclined, vertical).
- 20 — Foliation in igneous rocks.
- 20 — Schistosity.
- 20 — Cleavage.
- 20 — Axial plane of fold.
- 20 20 20 20 — Fold hinge (clockwise, counterclockwise, rotation sense unknown, anticline).
- 20 — Shear zone.
- 20 — Joint set.
- Quarry.
- (4) Location of photo shown in sidebar.

EXPLANATION OF PATTERNS

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

INTERPRETIVE CROSS SECTIONS



Wells Quadrangle, Maine

Bedrock geologic mapping by
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Cartographic design and editing by
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This map accompanied by a 6 p. report.

GEOGRAPHY

The Wells quadrangle is characterized by low gently rolling to flat topography that is bordered on the east by a series of marshes and sandy beaches (Photo 1), broken here and there by conspicuous points held up by either bedrock outcrops or exposures of glacial sediments. These beaches lie along the gently arcing Wells Embayment of the Gulf of Maine. Bedrock on land is buried by a thin veneer of glacial and marine sediments. Outcrops are relatively scarce throughout much of the area. The land is relatively well-drained by numerous east- to southeast flowing streams that commonly empty into lagoons and marshes behind the beaches.

THE BEDROCK MAP

On the geologic map, different bedrock units are indicated by colors, and identified by letter symbols that represent their assigned age and unit name. The following description summarizes the major rock types of each unit and gives a simplified geologic history by which they formed.

MAJOR ROCK TYPES

Rocks in the Wells quadrangle are of two general types: igneous intrusive rocks and layered metamorphosed sedimentary rocks of the Kittery Formation. The intrusive igneous rocks consist of granite, syenite, gabbro, diabase, and basalt. Granite is a coarse-grained igneous rock that consists primarily of quartz and feldspars (both potassium-rich microcline, and sodium and calcium-rich plagioclase). Syenite is similar to granite except that quartz is absent or present in amounts less than 2%. Gabbro is a coarse-grained dark rock with calcium-rich plagioclase and dark minerals (pyroxene, amphibole, and biotite mica). Diabase is simlar to gabbro except for finer grain size. Basalt is dark gray and so fine-grained that minerals are not readily observed except under a microscope.

The Webhannet pluton consists of two distinct granites, one gray and the other pink. The gray granite is characterized by about equal amounts of sodium-rich plagioclase feldspar and potassium-rich microcline feldspar, and has biotite (a dark brown flaky mineral) as the principal mica. Sphene, a brown calcium titanium silicate mineral, is common and forms well-shaped crystals that are readily detected with a hand lens. Epidote, a calcium-aluminum-iron-magnesium silicate is also present, but is most easily identified with the aid of a microscope. The pink granite (Photo 2) is pink to light gray in color, and like the gray granite consists of both plagioclase and microcline, the latter predominating over the former. Biotite is much less abundant than in the gray granite, and muscovite, a clear colorless mica, is present. Epidote and sphene are rare or absent. Both granite types in the Wells quadrangle are massive except for the systematic planar fractures known as joints which are present but not common. These rocks originated as molten silicate liquids known as magma that was produced by melting deep within the earth's crust, and then injected into the older stratified rocks of the Kittery Formation.

Two other coarse intrusive rocks bodies, exposed in the very southwestern corner of the map, are part of the Agamenticus Complex. These rocks are very rich in the element sodium and are referred to as alkalic granite and alkalic syenite. The alkalic granite is medium-grained and buff gray in color. It consists mostly of potassium-rich orthoclase feldspar that has abundant stringers of sodium plagioclase, and quartz. Dark minerals include a variety of sodium and iron rich pyroxenes and amphiboles such as riebeckite, arfvedsonite, aenigmatite, aegirine, and ferrohastingsite. These are distinguished only with the aid of a microscope. The syenite is olive gray in color and medium-grained to coarse-grained in texture. Its mineralogy is like that of the alkalic granite except that quartz is present only in amounts less than 2%.

Dark gray dikes of flinty-textured basalt and fine-grained diabase cut the Webhannet pluton, the Agamenticus Complex, and the stratified rocks of the Kittery Formation (Photo 3).

Dark gray, relatively coarse-grained gabbro forms an intrusive body that cuts the pink granite phase of the Webhannet pluton. This rock is deeply weathered and is exposed in two pits (Photos 4 and 5) originally excavated to provide granular rock dressing for driveways and walkways.

The stratified and layered rocks are all metamorphic rocks, including granofels, schist, phyllite, and hornfels. Granofels, made up mostly of the minerals quartz and plagioclase feldspar, has a fine grainy texture. Because of its fine texture, granofels is hard and tends to break into angular blocks and chunks. Schist consists mostly of thin flakes of mica which are arranged parallel to each other such that the rock breaks into thin sheets. Phyllite is similar to schist except the grains are very small and not readily seen without a microscope. Hornfels is a hard rock that has been recrystallized by the heat of nearby intrusive rocks (the Webhannet pluton and Agamenticus Complex). The hornfels may have relicts of the original bedding (Photo 6) or be massive. Green calcium silicate minerals (epidote, hornblende, or diopside) are commonly present.

ORIGIN AND DEFORMATION OF THE KITTERY FORMATION

The Kittery Formation preserves sedimentary structures (Photos 7 and 8) that indicate it accumulated in a deep ocean environment as a submarine fan deposit. These sediments formed a continental rise deposit on the edge of a landmass, commonly referred to as Avalonia, that once existed offshore to the east. Sediments were transported to the west away from Avalonia into the seaway that existed between that landmass and early parts of North America. This deposition took place during Silurian time. Avalonia gradually drifted westward during the later part of the Silurian Period as a result of the sliding of ocean crust under ancient North America. By the end of Silurian time, the westward drift caused Avalonia to collide with ancient North America, causing the deformation of the Kittery Formation. This episode of deformation is referred to as the Acadian orogeny. Early folds (not seen in the Wells quadrangle) are recumbent, that is, laying on their sides. Later folds (Photo 9) are upright to moderately overturned.

EMPLACEMENT OF THE IGNEOUS ROCKS

As a result of compression during the Acadian orogeny, deep burial of sediments of the Kittery Formation and older rocks not exposed at the surface in the Wells quadrangle led to melting and the production of large quantities of molten rock (magma) of the composition of granite. This was injected at considerable depth below the surface into the Kittery Formation and older rocks. There, slow cooling allowed large grains to crystallize forming granite. At the same time and place, due to the heat of the granite magma, the rocks of the Kittery Formation adjacent to the magma were baked into the hard hornfels. The fact that we see these deep-seated rocks today at the surface attests to the great amount of uplift and erosion that has occurred since Devonian time.

During the interval from Devonian to Permian time, most of the major continents around the globe accreted with North America to form a supercontinent known as Pangea. In Triassic time, Pangea started to break up into smaller landmasses that eventually became the continents of today. The tension that caused this break up may also have been responsible for injection of magma to form the rocks of the Agamenticus Complex, and still later during Triassic and Jurassic time, the injection of basalt magma that filled tension cracks in the Kittery Formation, producing dikes of basalt and diabase (Photo 3). These dikes also are found in the granites of the Webhannet pluton and the Agamenticus Complex.

Photo 1. Wells Beach with exposure of the Kittery Formation (**SOk**) on the foreshore, looking north from the vicinity of the beachfront parking area at the end of the Mile Road at Wells Beach.

Photo 2. Massive, non-foliated light pinkish gray mica-poor granite (Bald Hill granite) of the Webhannet pluton (**Dwb**) at Wells Branch.

Photo 3. Thin basalt dike (black) cutting the Kittery Formation, end of the Mile Road at Wells Beach.

Photo 4. Deeply-weathered gabbro (**Klg**) near Wells Branch. Pit was excavated for "rotten rock" for path and driveway dressing.

Photo 5. Small knob of gabbro that has been produced by progressive weathering along joints in the gabbro. This knob, which is still attached to bedrock, will soon form a boulder from weathering like many others in the area. This locality is in the "rotten rock" pit north of the road.

Photo 6. Kittery hornfels, showing relict layering probably representing original bedding (near Ogunquit Village, southwest corner of the quadrangle).

Photo 7. Graded beds (tops to the right) in relatively unaltered Kittery Formation at Wells Beach (same locality as **Photo 1**). The lighter buff-colored beds represent originally coarser grained silty to sandy sediments and the darker beds represent clay. Note that the lighter colored beds grade to the right into the darker colored beds.

Photo 8. Well-developed, moderately deformed flute casts on the bottom of a 45 cm-thick bed of relatively unmetamorphosed Kittery granofels at Moody Point, Wells. The top of the bed lies to the right (southeast).

Photo 9. Plunging nose of steeply-overturned anticline in the Kittery Formation at Moody Point. Plunge of the nose is gently southwest.

GEOLOGIC TIME SCALE

Geologic Age		Absolute Age*
Cenozoic Era		0-65
Mesozoic Era	Cretaceous Period	65-142
	Jurassic Period	142-200
	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	489-542
Precambrian time		Older than 542

* In millions of years before present. (Okulitch, A. V., 2004, Geological time chart, 2004: Geological Survey of Canada, Open File 3040 (National Earth Science Series, Geological Atlas) - REVISION.)