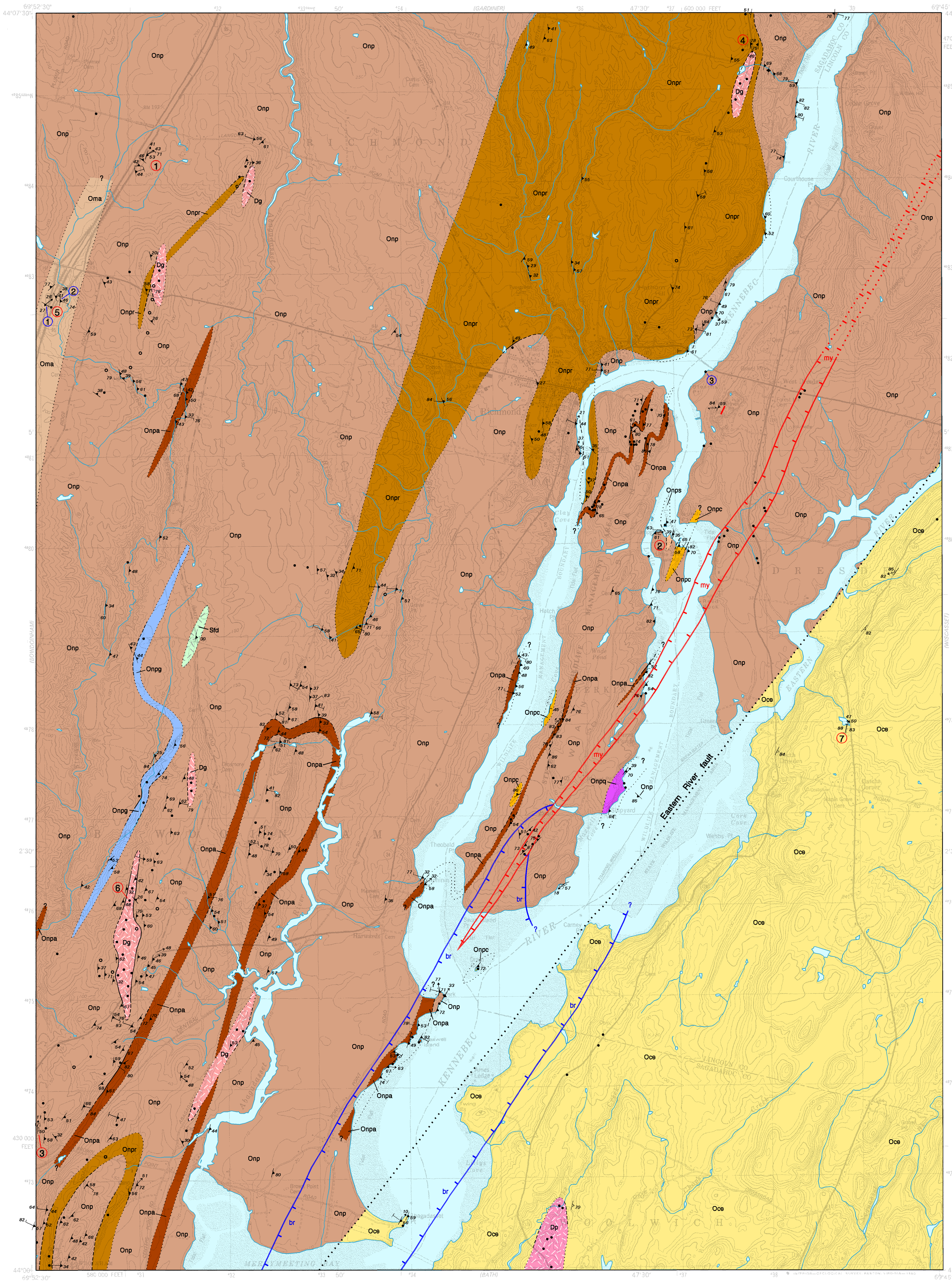
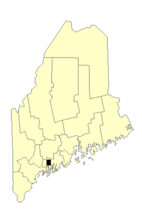
Bedrock Geology



SOURCES OF INFORMATION

Field work by D. P. West, Jr., and L. B. Corbett, 2008; field work by H. N. Berry IV, 2008-2009.



Quadrangle Location

SCALE 1 : 24,000

1 MILE — 0 — 1; 1000 0 1000 2000 3000 4000 5000 6000 7000 FEET; 1 0 1 KILOMETER

CONTOUR INTERVAL 10 FEET

TRUE NORTH

Topographic base from U.S. Geological Survey Richmond 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.

Richmond Quadrangle, Maine

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EXAMPLES OF BEDROCK TYPES AND NOTABLE FEATURES

Note: These photographs are included for illustration only. Public access to the locations is not implied. Any locations on private property require permission of the landowner before being visited. In particular, stopping on the Interstate highway is dangerous and prohibited. Special permission from the State Police was obtained by the geologist for access to the Interstate highway localities shown here.

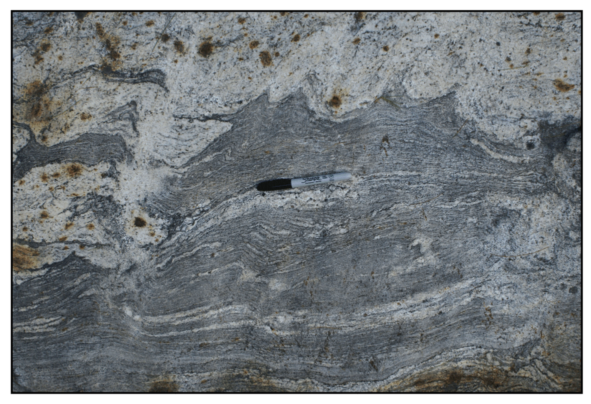

Photo 1A. Light colored gneiss of the Nehumkeag Pond Formation (**Onp**). The light and dark streaks running through the rock in the lower portion of the photo are caused by an alignment of minerals called **foliation**, a characteristic of gneiss produced by deformation and metamorphism. The lighter colored rock in the upper part of the photo is igneous rock (granite) that was once molten and which flowed into the gneiss and solidified. *(Locality 1: Road cuts along I-295, north-bound lane, approximately 1 mile north of the Route 197 exit, Richmond.)*

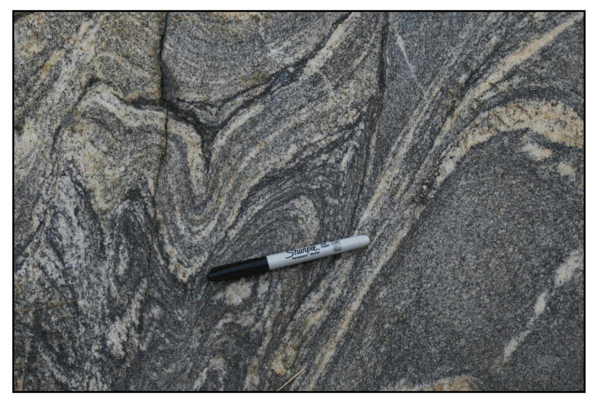

Photo 1B. Folded layers in gneiss of the Nehumkeag Pond Formation (**Onp**). The rock was deformed, somewhat like putty, when the rocks were hot and under pressure in the earth. This probably occurred during the Devonian Period of geologic time. *(Locality 1.)*

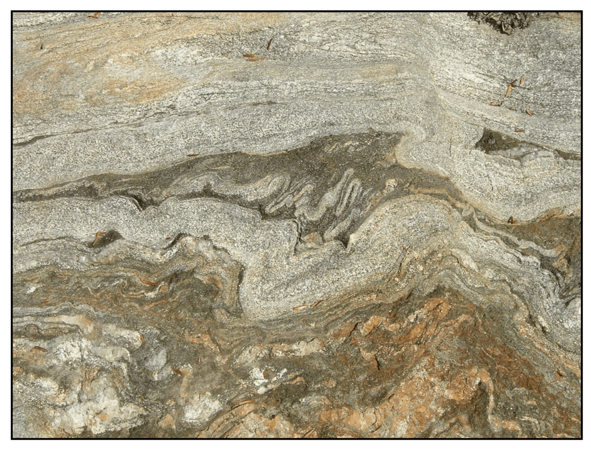

Photo 2A. Folded layers in the Nehumkeag Pond Formation (**Onp**). Not all layers were deformed in the same way, producing a complicated rock structure. Darker layers are rich in biotite, a black mica. The darker layers had less strength during deformation than did the lighter layers. *(Locality 2: Northwest shore of Little Swan Island, Kennebec River. Field of view approximately three feet across.)*

Photo 2B. Gneiss of the Nehumkeag Pond Formation (**Onp**). In the upper center is a white quartz vein that was folded and pulled apart during the rock deformation. This indicates the rocks were internally sheared as well as folded. *(Locality 2.)*

Photo 3. Natural woods outcrop of gneiss in the Nehumkeag Pond Formation (**Onp**), displaying a broad fold. The eroded upper surface of the outcrop follows the shape of the foliation within the rock. The fold shape, an anticline with a steep west (left) limb and a shallow east (right) limb, is described as being overturned to the west. This shape could form during top-to-the-west shear. *(Locality 3: Southwest part of the quadrangle, approximately 1000 feet northwest of the intersection of Brown Point Road and the Maine Central Railroad, Bowdoinham.)*

Photo 4. Rusty weathering schist and granofels of the Nehumkeag Pond Formation (**Onpr**). The rust is produced by weathering of iron sulfide minerals (such as pyrite or pyrrhotite) in the rock. Rocks of this sort, with a relatively high sulfide content, occur in mapped units. (*Road cut along Route 24 approximately 500 feet north of the Pitts Road intersection, Richmond.)*

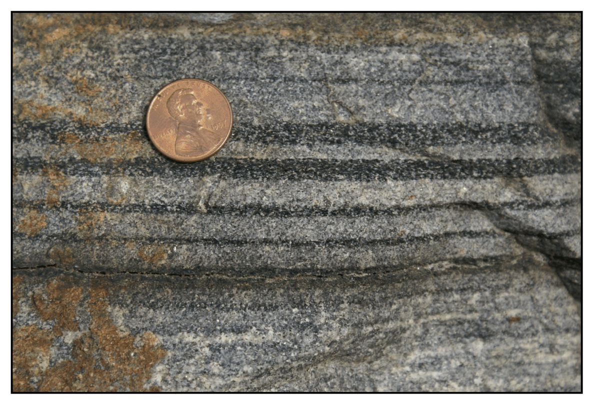

Photo 5A. Fine-scale layering within gneiss representative of the Mount Ararat Gneiss (**Oma**). The light and dark layers have differing mineral content and may represent layers of volcanic ash erupted during the Ordovician Period. Such ash layers of differing composition would have been transformed subsequently by heat and pressure (metamorphism) into the minerals we see today, probably during the Devonian Period. *(Locality 5: Road cut along I-295, south-bound lane, south of the Route 197 exit, Richmond.)*

Photo 5B. Folded, dark colored gneiss of the Mount Ararat Gneiss (**Oma**). The dark colored rock contains dark green to black hornblende, an amphibole mineral, and the rock is called amphibolite. The folds formed during the metamorphic process. *(Locality 5.)*

Photo 5C. Light colored igneous rock (granite) cutting across dark colored rocks of the Mount Ararat Gneiss (**Oma**). The granite formed when fluid magma flowed up through cracks in the gneiss deep underground, and then solidified. The dark colored rocks were originally deposited during the Ordovician Period and the granite magma intruded more than 50 million years later, in the Devonian Period. *(Locality 5.)*

Photo 6. Representative close-up view of granite (**Dg**) in the Richmond quadrangle. The rock is composed primarily of cream-colored feldspar with lesser amounts of translucent gray quartz, and black biotite (mica). *(Locality 6: Southwest part of the quadrangle, approximately 1500 feet northwest of the intersection of Route 24 and White Road, Bowdoinham.)*

Photo 7A. Folded pegmatite dike in the Cape Elizabeth Formation (**Oce**). Stratified rocks of the Cape Elizabeth Formation consist of interbedded mica-rich schist and quartz-feldspar granofels. Originally deposited as layers of mud and sand on a sea floor, the layers are now folded metamorphic rock. The hammer rests on a layer of pegmatite, an igneous rock with large mineral grains, which intruded the Cape Elizabeth Formation before being folded itself. *(Locality 7: Outcrop in field west of Route 127, approximately 2100 feet north of Hatchs Corner, Dresden.)*

Photo 7B. Crenulated foliation, Cape Elizabeth Formation (**Oce**). The metamorphic foliation in this rock is defined mainly by micas arranged in parallel planes. The rock is called schist, and this type of foliation is called schistosity. The pencil point is against a grain of the mineral sillimanite, a metamorphic mineral which forms at high temperature. The small crinkle folds, or crenulations, formed after the metamorphic event which produced the sillimanite and the schistosity. *(Locality 7.)*

EXPLANATION OF UNITS

INTRUSIVE ROCKS

Devonian (?)

Dp — Light gray to white muscovite pegmatite.

Dg — Biotite granite and pegmatite. Light gray, medium-grained to pegmatitic, moderately foliated to non-foliated, biotite ± muscovite ± garnet granite.

Silurian (?)

Sfd — Foliated hornblende diorite. Medium to dark gray, medium- to coarse grained, porphyritic, strongly foliated, hornblende diorite. This rock was only observed at a single locality.

STRATIFIED ROCKS

Ordovician

Falmouth-Brunswick Sequence

Oma — **Mount Ararat Gneiss.** Interlayered light gray, quartz-plagioclase-biotite gneiss and dark gray, plagioclase-hornblende ± biotite gneiss and amphibolite. Layers are generally 2 to 15 cm thick, but are thicker in some places. In addition to these layered rock types, relatively massive amphibolite and hornblende gneiss (meter-scale thickness) are present locally. Subordinate rock types include calc-silicate bearing amphibolite, and rusty-weathering biotite ± garnet sillimanite schist.

Onp — **Nehumkeag Pond Formation.** The predominant rock type is light gray, medium to coarse-grained, non-rusty to slight rusty-weathering, plagioclase-quartz-biotite ± garnet gneiss. The gneiss is commonly migmatitic, and pegmatite dikes, sills, and boudins are common. Subordinate rock types include amphibolite, and slightly to moderately rusty-weathering, quartz-plagioclase-biotite ± garnet ± sillimanite schist and gneiss.

Onpr — Rusty schist and gneiss. Light to medium gray, medium-grained to coarse-grained, moderately to deeply rusty weathering, sulfidic, quartz-muscovite-biotite ± sillimanite ± garnet schist and gneiss. Occasional non-rusty weathering felsic gneiss is interlayered with the above rock type. A large area of this unit is shown in the northern part of the quadrangle. Alternatively, this area might contain more than one rusty unit separated by belts of more typical gray gneiss. There is not enough bedrock exposure in this area to discriminate between these possibilities.

Onpa — Amphibolite. Dark gray, fine-grained to medium-grained amphibolite and hornblende gneiss, locally containing biotite and/or garnet. Discontinuous thin layers (< 2 cm thick) of greenish gray, fine-grained to medium-grained calc-silicate rock are locally abundant. Occasional layers up to a few meters in thickness of rusty and/or non-rusty weathering felsic gneiss may be found within this rock unit. It is likely that there are several amphibolite units at at different stratigraphic levels within the Nehumkeag Pond Formation.

Nehumkeag Pond Formation (continued).

Onpg — Dark gray to greenish gray, fine-grained to medium-grained, amphibole-bearing, plagioclase-quartz-biotite carbonate granofels. Amphibolite and rusty weathering schist are locally abundant. At most exposures these rocks are massive and lack distinctive layers.

Onps — Sulfidic schist and gneiss. Very rusty-weathering quartz-feldspar-biotite ± garnet gneiss and red rusty-weathering quartz-feldspar-biotite-muscovite-garnet schist. Small area at north end of Little Swan Island that appears to be separate from **Onpr**.

Onpc — Calc-silicate granofels and gneiss. Several small units of light greenish gray, medium-grained to fine-grained quartz-plagioclase-diopside ± garnet ± biotite ± tremolite ± calcite granofels. Thinly layered, with various proportions of interlayered light gray to pale violet-gray quartz-feldspar-biotite ± garnet granofels or gneiss.

Onpq — Feldspathic quartzite. Snow white feldspar-muscovite quartzite with thin partings of fine-grained muscovite-biotite-quartz schist; ivory-weathering, light gray biotitic quartzite, locally sulfidic. Minor calc-silicate granofels. Exposed on southeastern shore of Swan Island.

Casco Bay Group

Oce — **Cape Elizabeth Formation.** Light gray to medium gray, medium-grained, quartz-plagioclase-muscovite-biotite ± garnet ± sillimanite schist interlayered with light gray, fine-grained, quartz-plagioclase micaceous granofels. Layering is typically in the range of 3 to 15 cm thick.

EXPLANATION OF LINES

my — Area of mylonitic deformation. Rocks to the hachured side of this line contain notable mylonitic features such as porphyroclastic rocks, augen gneiss, s-c fabrics, asymmetric boudinage, and low-angle shear surfaces. Asymmetric features commonly indicate a dextral sense of shear. These features are interpreted to comprise a Late Paleozoic ductile shear zone, perhaps related to the Flying Point or South Harpswell faults of Hussey and Berry (2002).

br — Area of brittle deformation and retrograde metamorphism. Nearly all outcrops to the hachured side of this line contain numerous structural features characteristic of post-metamorphic brittle deformation, such as cataclasite or steeply-dipping small-scale faults with slickensided surfaces. In addition, retrograde metamorphic effects are common, including minerals such as chlorite and epidote, and fine grain size. These features may reflect a period of post-Devonian, perhaps Mesozoic, brittle faulting with accompanying alteration by hydrothermal fluids.

Contact between mapped units. (Well located, approximately located, poorly located.)

Inferred high-angle fault. (Poorly located)

EXPLANATION OF SYMBOLS

- Outcrop of mapped unit.
- Large or abundant float blocks interpreted to represent underlying bedrock.
- Strike of fine-grained diabase dike, dip unknown.
- Inactive mine or prospect.
- 20 — Strike and dip of compositional layering. May approximate bedding in some cases.
- 20 — Strike and dip of metamorphic foliation. (Inclined, vertical)
- 20 — Strike and dip of schistosity.
- 20 — Strike and dip of crenulation cleavage.
- 20 20 — Trend and plunge of lineation. (Mineral lineation, crenulation lineation)
- 20 20 20 — Trend and plunge of fold hinge. (Clockwise, counterclockwise, unknown asymmetry.)
- 20 — Strike and dip of fold axial plane.
- 20 20 — Strike and dip of brittle fault. (Dextral motion, unknown motion.)
- 20 — Strike and dip of prominent joint or joint set (Inclined, Vertical).
- 4 — Photo locality.
- 4 — Geochronology location.

GEOCHRONOLOGY

Numbered locations are shown on the map.

Location	Method	Mineral	Age (Ma)	Reference
1	Ar-Ar	Hornblende	282 ± 3	West et al., 1988
2	Ar-Ar	Muscovite	246 ± 2	West et al., 1993
2	Ar-Ar	Biotite	241 ± 2	West et al., 1993
2	Ar-Ar	K-feldspar	227 ± 3	West et al., 1993
2	Fission Track	Apatite	124 ± 15	West et al., 2008
3	Fission Track	Apatite	121 ± 20	West et al., 2008

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West, D. P., Jr., Roden-Tice, M. K., Potter, J. K., and Barnard, N. Q., 2008, Assessing the role of orogen-parallel faulting in post-orogenic exhumation: Low temperature thermochronology across the Norumbega fault system, Maine: Canadian Journal of Earth Science, v. 45, p. 287-301.

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.)