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Front Cover: Fall color highlights the banks of South Branch Ponds Brook where it flows over exposures of the Black Cat Member of the Traveler Rhyolite in Baxter State Park, Maine (Site 64). Here gently dipping surfaces on the right bank of the stream are roughly parallel to a compaction foliation (eutaxitic texture) in the ash-flow tuff. Crude columnar joints are perpendicular to the foliation. (Photo by D. C. Roy)

Structure and stratigraphy of the Central Maine Turbidite Belt in the Skowhegan-Waterville region

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LOCATION

The site consists of eight stops in the Kingsbury, Skowhegan, and Waterville Quadrangles of central Maine (Fig. 1). A current roadmap and geologic maps of these quadrangles (Osberg, 1968; Ludman, 1977, 1978) are recommended for navigation and for a more complete geologic description than can be given here. Stop locations follow, along with driving instructions for travel between stops.

Stop 1. NW Kingsbury Quadrangle at intersection of Maine 16 and 151 (45°06′12″N, 69°41′27″W). Drive south on Maine 151 to Athens and turn left (east) onto Maine 150. Drive 3.75 mi (6 km) to large roadcuts on south side of road at Lords Hill.

Stop 2. Skowhegan Quadrangle, series of outcrops on Maine 150 between Lords Hill and Harmony town line. Drive west on Maine 150 through Athens, park just west of Wesserunsett Stream, and walk north up long driveway to ask permission at the house. Stop 3 is in the stream east-northeast of the house.

Stop 3. Skowhegan Quadrangle in Wesserunsett Stream 800 to 1,000 ft (250 to 300 m) north of Maine 150 (44°55′28″N, 69°40′22″W. Follow Maine 150 south to Skowhegan and turn east onto U.S. 2. Park east of Coburn Park on south side of the Great Eddy of the Kennebec River.

Stop 4. SW Skowhegan Quadrangle at Great Eddy of Kennebec River and along U.S. 2 to the east (44°46′19″N, 69°42′30″W). Take U.S. 2 through Skowhegan and follow Maine 201 south to I-95, exiting at Exit 33 in Waterville. Turn left onto Kennedy Drive at stop sign and drive 0.9 mi (1.6 km) to outcrops on north side of road.

Stop 5. Waterville Quadrangle, road cut at intersection of Kennedy Drive and First Rangeway (44°32′N, 69°39′45″W). Continue east 0.6 mi (1 km). Pass light, cross bridge, and bear right onto Grove Street. After 0.5 mi (0.8 km) turn left onto Water Street. Travel 0.8 mi (1.4 km) and turn left onto Maine 201. Cross Kennebec River and turn left at traffic light. Drive 3.8 mi (6.8 km) north, cross Routes 100/139/11 at Benton Station, and continue north. Park at railroad crossing and walk tracks to the northeast.

Stop 6. Waterville Quadrangle, railway cut 1,200 ft (370 m) from River Road (44°35′47″N, 69°34′49″W). Retrace route to Maine 201 and take it south. After 0.2 mi (0.4 km) park in lot on right.

Stop 7. Waterville Quadrangle on Maine 201 1,000 ft (325 m) south of Waterville-Winslow bridge; exposure is over steep bank at river's edge (44°37′42″N, 69°37′32″W). Continue south on Maine 201 0.4 mi (0.75 km) and turn left onto Maine 137. Drive 2.5 mi (4.5 km) and park at junction of Patten Pond Road.

Stop 8. Waterville Quadrangle, roadcut at junction of Maine 137 and Patten Pond Road (44°31′24″N, 95°35″W).

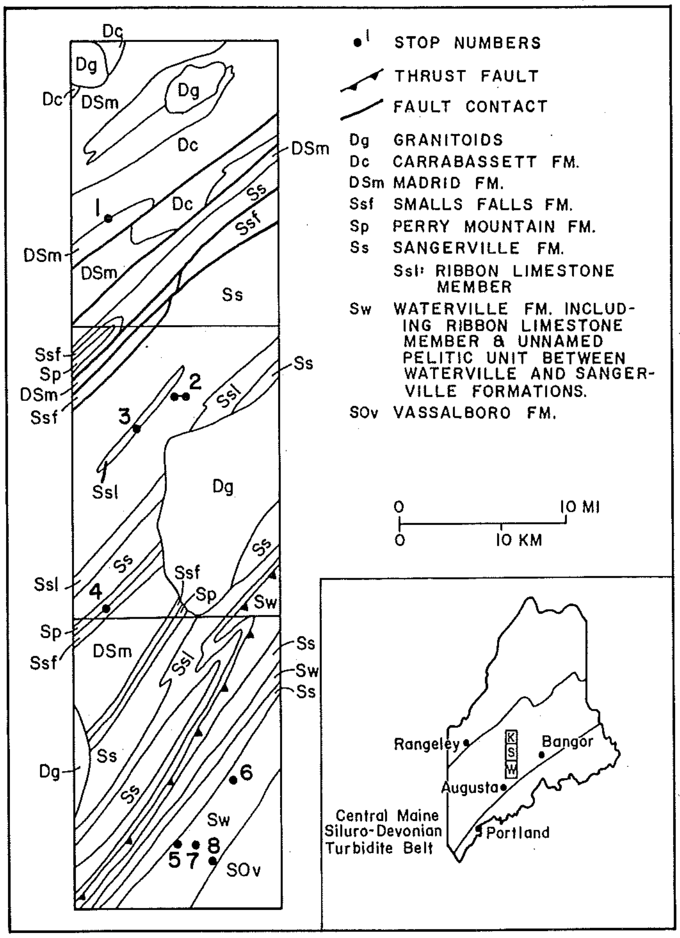

Figure 1. Simplified geologic map of the Kingsbury-Skowhegan-Waterville area. Inset shows location of Kingsbury (K), Skowhegan (S), and Waterville (W) Quadrangles.

SIGNIFICANCE

Siluro-Devonian turbidites underlie the Kearsarge–Central Maine Synclinorium (previously the Merrimack Synclinorium) in a belt 75 mi (120 km) wide across strike in Maine (inset, Fig. 1). This belt narrows rapidly to the south, but its rocks can be traced into the high-grade, complexly deformed terrain of northern Connecticut. In contrast, the sequence in central Maine is widely exposed at chlorite grade. As a result, primary sedimentary features are generally well preserved and graptolites have been collected from several localities. Two major contributions to the geology of the Northern Appalachians have come from the Central Maine Turbidite Belt, and particularly from the quadrangles covered in this site: (1) an understanding of a complex stratigraphy, complete with faunal age control, that is used to postulate post-Taconian facies relationships in eastern New England and to date rocks as far south as Connecticut; and (2) a multiphase deformation history that serves as a model for the Early Devonian Acadian orogeny. This site presents evidence for both structural and stratigraphic interpretations.

SITE DESCRIPTION

This site consists of eight outcrops that provide a traverse across the turbidite belt (Fig. 1) illustrating the lithologies and the styles and sequence of folding events. Several formation and intraformational member contacts are included so that detailed evidence is also presented for the interpreted stratigraphic sequence.

Stratigraphy. The stratigraphy of central Maine has been reconstructed from two continuous but geographically and structurally disjointed sections. The outcrops at Stops 1 through 4, in the Kingsbury and Skowhegan Quadrangles, define the upper part of this sequence whereas at Stops 5 through 8 in the Waterville area, they fix the lower part (Figs. 1, 2). A thrust fault probably separates the two parts of the section; thus they may have been more widely separated during deposition than present locations suggest. The upper part of the sequence is very similar to the section in the Rangeley area of western Maine (Moench and Boudette, 1970), and fossils from rocks in the Skowhegan-Kingsbury area have been used to pinpoint the ages of these western Maine correlatives. The lower part of the central Maine sequence, however, is less convincingly comparable to that of western Maine, and some stratigraphic problems remain. The central Maine Silurian rocks are interpreted as intermediate (and distal?) equivalents of the proximal rocks of western Maine (Pankiwskyj and others, 1978). The basin is thought to have been filled mostly from the west during Silurian times, but a shift to an eastern source during the Early Devonian has been suggested by Hall and others (1976).

Structure. Three episodes of folding are recognized in these Siluro-Devonian rocks: early recumbent folds (F_1), an intermediate set of upright folds (F_2), and late asymmetrical folds (F_3).

No large-scale folds attributable to the youngest event have been identified, although a well-developed S_3-cleavage is found throughout the region. Axial surfaces of F_3-folds strike within 10° of north and dip steeply. Bedding and earlier cleavages/schistosities are deformed, so that plunge and asymmetry of F_3-folds vary according to the attitude of the surface that has been deformed. These asymmetrical folds deform small dikes and aplites associated with the Hallowell Pluton (Osberg and others, 1985), and

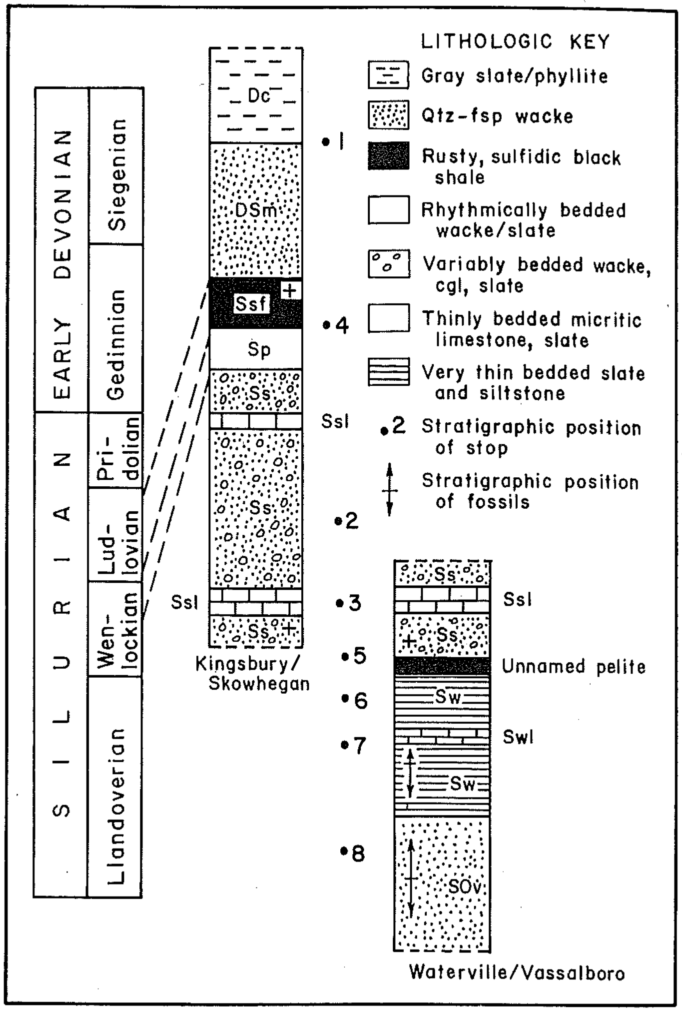

Figure 2. Stratigraphy of Kingsbury-Skowhegan-Waterville area. Formation symbols as in Figure 1.

that pluton has been dated as 387 ± 11 Ma by Dallmeyer and van Breemen (1978). Muscovite and sillimanite have grown in the axial plane cleavages of these folds. This metamorphic event (M_2 of Holdaway and others, 1982) has been dated by $^{40}Ar/^{39}Ar$ methods on hornblendes as ca. 360 Ma (Dallmeyer and van Breemen, 1978). The F_3-event is thus latest Devonian or Earliest Carboniferous in age.

The F_2-upright folds are recognized on both mesoscopic and regional scales, and control the regional map pattern (Osberg and others, 1985). The F_2-folds range from relatively open to highly flattened isoclinal structures, with form depending on the competence of the rocks affected. F_2-axial surface strike northeast and dip steeply. Pressure solution cleavage in low-grade rocks and a strong schistosity at higher grades parallel these axial surfaces. Plunges are generally less than 25° but some reach 45°. These folds face upward throughout some areas, but downward in others, indicating the presence of earlier folds. F_2-folds affect rocks as young as Siegenian, or possibly Emsian (Osberg and others, 1985), and are cut by plutons as old as 400 Ma (D. R. Lux, personal communication, 1984). F_2 is thus clearly associated with the Acadian orogeny. A weak Acadian metamorphism (M_1 of Holdaway and others, 1982) is synchronous with F_2-folding but is overprinted by the younger M_2-metamorphism.

Evidence for the F_1-recumbent folds is largely indirect. Local map patterns, downward-facing upright folds, and stratigraphic relationships have been used to infer early recumbent axial surfaces. Only at a single outcrop (see Stop 7) do minor folds display evidence of this episode of deformation. Little can be said about the form or vergence of F_1-folds, but the regional extent of downward-facing structures indicates that they are large-scale features. F_1-folds are probably of early Acadian origin but may represent large sedimentary slump structures.

STOP DESCRIPTIONS

Stop 1: Contact between the Carrabassett and Madrid Formations. Begin at the north side of Maine 16 at the culvert and walk west. Thick, massive beds of pale purplish gray, calcareous biotite-bearing wacke exposed at the culvert are typical of the Madrid Formation in this area. These pass westward into well-graded sandstones, siltstones, and very subordinate phyllites typical of the top of the formation. Calc-silicate pods, layers, and stringers are abundant here and throughout the entire Madrid. The beds thin and the amount of pelite gradually increases over about 250 ft (75 m) toward the west, until sandstone comprises only 60 percent of the outcrops. A consistent northwest facing is indicated here by graded beds, cross-bedding, flame, and cut-and-fill structures.

Cross to the south side of Maine 16 at the break in outcrop (the exposures are continuous in the woods to the north). The first exposures here are of the basal Carrabassett Formation: medium gray "clean" phyllite with very sparse, light gray siltstone laminae. A few believable graded beds indicate continued northwest facing, confirming that the Carrabassett is younger than the Madrid. Farther west, siltstone laminae become thicker and more abundant but remain subordinate to the phyllite.

Although no folds are visible here, S_2- and S_3-cleavages are well developed in the Carrabassett phyllites. They are characteristically only poorly exhibited by the Madrid sandstones. S_2 is dominant here and is nearly vertical. The phyllitic sheen parallel to S_2 is defined by aligned muscovite and biotite, and is attributed to the earliest metamorphic event (M_1). Small chloritoid and garnet porphyproblasts were also caused by M_1. A very steep north-trending cleavage (S_3) cuts S_2 in the pelites, and steep S_2/S_3-intersection lineations are prominent. Retrogradation of chloritoid to biotite and chlorite here is noted in thin section and is attributed to M_2.

Stop 2: Typical Sangerville Formation lithologies. Most of the Sangerville Formation consists of variably bedded calcareous, ankeritic quartzofeldspathic wackes interbedded with medium gray slates. Graded bedding is common, as are several other primary features associated with turbidites. The rocks here are typical of the finer grained, graded Sangerville sandstones and exhibit sole markings and cross-laminations. A gradual darkening of color related to original grain size and clay mineral content clearly denotes facing direction and is best seen on the glacially polished top of the exposure. S_2-cleavage is again dominant here, but the north-trending S_3 is also visible. A problematic subhorizontal cleavage is also present and has been assigned to a later deformational phase by Griffin (1973).

Drive east and park on the south shoulder at the power substation. Cross to the north side of the road and walk west to the outcrops. Several distinctive subordinate rock types occur within the Sangerville, two of which are well exposed here. Granule conglomerate containing abundant feldspar and lithic clasts is found locally in the lower part of the formation. The granule conglomerates occur either at the bases of Bouma sequences (as along Carson Hill just north of this outcrop), or as they do here—as massive beds with little sign of grading. Highly carbonaceous pyritiferous pelites commonly occur with these rocks, as is the case here. Two generations of pyrite are visible: early grains are flattened in S_2, but a younger set occurs as undeformed cubes. Graptolites from the black shales at this locality include two monograptid species that suggest a Wenlock age for this exposure.

Stop 3: Ribbon limestone member of the Sangerville Formation showing typical rock types and superb F_2 folds. These ribbon limestone exposures consist of gray micrite intercalated with noncalcareous medium gray slates and buff weathering calcareous sandstones. The micrite is dominant and occurs in beds 0.4 to 6 in (1 to 15 cm) thick. Sandstones range from 0.4 to 3 in (1 to 8 cm) thick and slates tend to be very thin. Sandstone and slate are less soluble than the micrite and stand out as ribs, whereas the limestone beds form narrow troughs. Crinoid columnal segments have been collected from this outcrop but have not provided useful age control.

These outcrops form a natural block diagram in which F_2-folds are magnificently displayed. They are very tight, with sharp hinges and small interlimb angles typical of F_2-folds in incompetent rocks. Plunges are gentle to the south. Cross-beds in some of the thicker sandstone beds indicate that the folds face upward, and are thus on the upright limb of an inferred F_1-fold.

Stop 4: Contact between the Perry Mountain and Smalls Falls Formations, with well-developed F_2-folds. Rocks exposed close to U.S. 2 are typical of the Perry Mountain Formation: rhythmically interbedded wackes and light gray phyllite in graded beds 1 to 4 in (2.5 to 10 cm) thick. Sandstone dominates over phyllite in all beds and cross-laminations are well developed. A few elliptical calcareous pods up to 12 in (30 cm) long are present in the wackes. Small, equant porphyroblasts best seen in the phyllite but also present in the wacke, are prograde pseudomorphs of biotite, muscovite, and quartz after ankerite. Nearly isoclinal F_2-folds are prominent, and primary facing features show that all face upward. A vertical north-trending S_3 cleavage is weakly developed in the phyllites.

Thin-bedded carbonaceous sulfidic slates of the Smalls Falls

Formation crop out at the river's edge and are in sharp contact with the Perry Mountain. A few thin sandstone beds separate the slates, but thicker bedded Smalls Falls rocks are well exposed along U.S. 2 just east of the Eddy and upsection from the river outcrops. These roadcuts are massive sulfidic quartzose sandstones in beds 4 in to 3 ft (10 cm to 1 m) thick, separated by rusty weathering sulfidic slates 1 to 12 in (2.5 to 30 cm) thick. The sequence here is almost identical to that described by Moench and Boudette (1970) at Smalls Falls in western Maine (and in this volume), and is critical in establishing regional correlations.

Stop 5: Contact between Sangerville Formation and an unnamed pelite unit, establishing relationships between Waterville area sequence and that of Skowhegan/Kingsbury. Rusty weathering, dark gray quartz-mica phyllite interbedded with dark gray quartzose layers typical of the unnamed unit is exposed at the east end of the outcrop. Pyrite is abundant. Crystals have a common orientation and do not have associated quartz-filled pressure shadows. Beds range from 0.5 mm to 1.5 cm in thickness.

The unnamed unit is in contact with the Sangerville Formation at the middle of the outcrop. The Sangerville here consists of light gray, slightly calcareous wacke and quartz-mica phyllite. Beds are 6 to 20 in (15 to 50 cm) thick and commonly grade from arenaceous bottoms to phyllite tops. Sandstone-phyllite ratios range from 1:1 to 8:1. Rip-up clasts and small feldspar grains are visible at the bases of some beds. Graded beds are best viewed at the top of the exposure and indicate that the Sangerville overlies the unnamed unit. Both units face west.

Because outcrops of the Waterville Formation can be seen in a drainage ditch that protects the airport runway just south of Kennedy Drive, the relationships here set the stratigraphic sequence: Sangerville Formation/unnamed phyllite/Waterville Formation.

Beds strike northeasterly and dip steeply. Schistosity cuts bedding at a low angle, and the traces of graded beds in schistosity indicate that the stratigraphic section is upright. Small F_2-isoclinal folds, some of which are sheared, can be seen to deform bedding on the vertical face. Quartz pods form boudin fillings, and other veins visible here are late features.

Stop 6: Evidence for F_1, F_2, and F_3 in Waterville Formation phyllites. This exposure is wholly within phyllites of the Waterville Formation. Although most of the formation is gray, the rocks here are light purplish to greenish gray quartz-mica phyllites interbedded with quartzite and ankeritic quartzite. Bed thickness ranges from 0.2 to 8 cm, but apparent thicknesses on cleavage faces are greater because of the small angle between bedding and cleavage. Quartzite beds have sharp boundaries, but color gradations in some pelitic beds reflect compositional differences thought to be due to original grading.

A prominent S_3-cleavage surface on the south wall of the cut strikes N12°E and is nearly vertical. The trace of bedding on this surface defines an open, somewhat symmetrical fold form. A joint nearly perpendicular to this cleavage displays a tight symmetrical fold form in the same bedding surface, so that the three-dimensional properties of the fold are readily observed. Its axial plane strikes N37°E and is nearly vertical; the fold plunges gently to the northeast. This structure is typical of F_2-folds in pelitic rocks, and the cleavage that cuts both of its limbs is S_3.

Directly across the cut on the north wall is a steeply dipping S_2-cleavage surface that strikes N35°E. The trace of bedding on this cleavage plunges gently to the northeast in harmony with the plunge of the upright fold. Color gradation in the beds suggests that they are upside down in the cleavage, and that these F_2-folds face **downward**. The local stratigraphy is thus upside down on the inverted limb of an F_1-recumbent fold.

About 165 ft (50 m) to the east, on the north wall of the cut, bedding and S_2-cleavage are essentially parallel. Dendroid graptolites and the trace fossils *Nereites* and *Phyllodacites* have been collected here. These are long-ranging forms, but are particularly common in the Silurian of Wales.

Stop 7: Relationships between all three fold episodes in and near the limestone member of the Waterville Formation. The rocks here belong to the limestone member and adjacent phyllites of the Waterville Formation. The pelitic rocks consist of gray quartz-mica phyllite intercalated with white to buff quartzite in graded beds 6 mm to 8 cm thick. The limestone member consists of gray, slightly micaceous micrite interbedded on a 6-mm to 12-cm scale with rusty weathering, buff-colored quartz-mica phyllite or micaceous quartzite. The contact between the two members here is sharp.

Four areas of this outcrop are particularly important (inset, Fig. 3). In Area 1, a northeast-trending F_2-isoclinal fold plunges gently to the north and displays a well-developed axial plane cleavage. Graded bedding near the hinge of this fold is tentatively interpreted to indicate that these folds face downward and that the stratigraphy here is inverted. This outcrop is thus on the inverted limb of a recumbent F_1-fold. Both limbs of the upright F_2-folds are cut by a steeply dipping S_3-cleavage. Right-handed asymmetric F_3-folds with axial surfaces parallel to this cleavage are found on both limbs of the upright folds.

In Area 2, an isoclinal F_2-synform deforms an earlier isoclinal fold (Fig. 3). The F_2-synform has an axial surface that strikes northeasterly and dips steeply; its axis plunges gently toward the southeast. Beds on the limbs of the earlier fold can be traced around the F_2-hinge, and the early cleavage can be seen only in the F_1-hinge. The plunge of this early fold has not been ascertained. Small-scale F_1-folds such as this are very rare.

At Area 3, beds of the limestone member are folded by gently plunging isoclinal F_2-folds. These have nearly plane flanks, sharp hinges, and northeast-striking axial surfaces. S_3 cleavage, best preserved in phyllite beds, cuts both limbs of F_2-folds.

In Area 4, a dike of light gray plagioclase-quartz-muscovite-chlorite-calcite-epidote granofels (meta-dacite?) strikes N33°E and cuts bedding at a low angle. Similar dikes elsewhere have been shown to cut F_2-folds (Osberg, 1968). This dike is cut by a faint S_3-cleavage, and is also broken into a "rotated" boudinage in which boudin lines plunge steeply. These relationships show

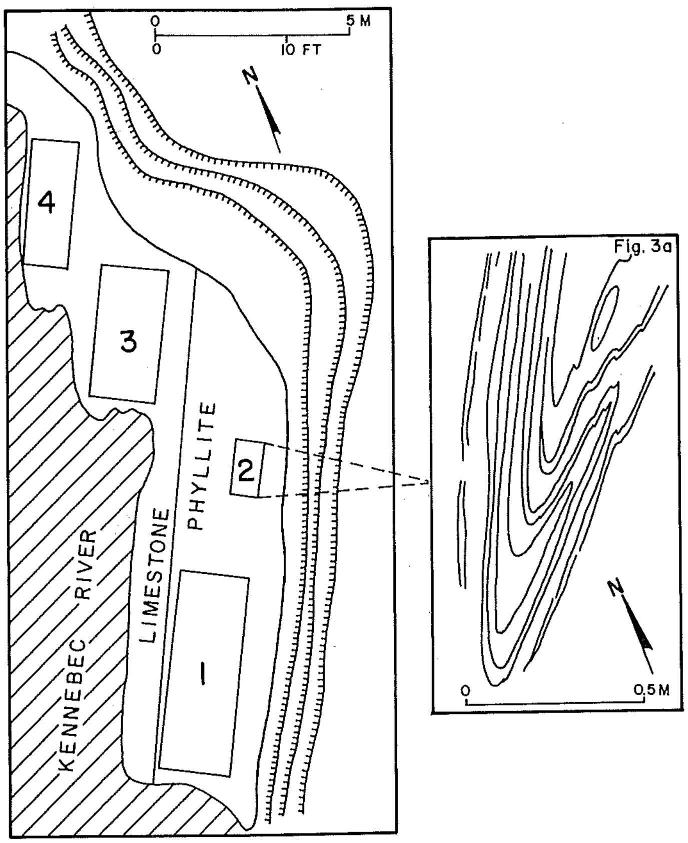

Figure 3. Map showing important structural features at Stop 7. 3a, refolded fold in Area 2.

that the dike intruded after the F_2-event but prior to F_3-folding and M_2-metamorphism.

Stop 8: F_2- and F_3-fold styles in sandstones of the Vassalboro Formation. (No Hammers, please!) Rocks here belong to the Vassalboro Formation and include light gray quartz-mica phyllite interbedded with blue-gray, slightly calcareous quartzwacke. Possible grading and cross-beds may be seen at the west end of the outcrop.

Open to isoclinal F_2 folds are visible at the west end of the outcrop. Their axial surfaces strike northeast and dip steeply, and their axes plunge to the southwest. The "openness" of these folds is controlled by the thick quartzose beds exposed on the south side of the road, and is typical of F_2-folds in the thicker bedded rocks of the region. In less competent rocks like those seen at Stops 3 through 7, F_2-folds are more nearly isoclinal. Primary sedimentary features here indicate that the folds face upward.

Cleavage parallels the axial surfaces of the upright folds. In competent beds it is a pressure solution cleavage, but in the more pelitic layers it is close-spaced with micas in the plane of cleavage. Cusp-shaped cross sections of thin quartzite beds interlayered with phyllite may be due to competency differences between the two rock types.

A set of north-trending F_3-folds deforms the F_2-structures, and S_3-cleavage is well developed. F_3-fold plunges vary, depending on the orientation of the surfaces that were folded. An interference pattern produced by F_2/F_3-interaction is beautifully displayed 100 ft (30 m) from the west end of the outcrop on the north side of the road.

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