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Sedimentology and multiple deformation of the Kittery Formation in southwestern Maine and southeastern New Hampshire.

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A4. SEDIMENTOLOGY AND MULTIPLE DEFORMATION OF THE KITTERY FORMATION, SOUTHWESTERN MAINE AND SOUTHEASTERN NEW HAMPSHIRE

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The purpose of this field trip is to examine the well-preserved sedimentary and structural features preserved in the Kittery Formation, a thick sequency of turbidite and contourite (?) deposits in southwestern Maine and southeastern New Hampshire. We will examine exposures of the Formation along the Marginal Way, a public shoreline footpath in the town of Ogunquit, Maine (Fig. 1), and exposures at several localities in the Kittery area (Fig. 1, Fig. 6). Emphasis at the Marginal Way locality will be on structural interpretation, and in the Kittery localities, on sedimentologic interpretation as to environments of deposition and direction of sedimentary transport. Hussey is responsible for the geologic mapping and interpretation at the Marginal Way, and Rickerich and Bothner for the Kittery area.

Geologic Setting

The Kittery Formation, the lowest unit of the Merrimack Group (Table I) crops out in a 5-10 km wide belt extending from near the Seabrook area, New Hampshire (Novotny, 1963) northward to the Biddeford Pluton in Kennebunkport, Maine (Hussey, 1962), and in the center of the Exeter anticline between Dover and Exeter, New Hampshire (Billings, 1956) (Fig. 1). The Kittery Formation is conformably overlain by the Eliot Formation, and is in ductile fault contact with the Rye Formation (Hussey, 1980 ; Carrigan, 1984).

The Kittery Formation consists of interbedded purplish gray calcareous and somewhat feldspathic metaquartzite, and very fine-grained dark gray phyllite or biotite schist (metapelite). Metaquartzite bed thicknesses are extremely variable normal to bedding and very uniform parallel to bedding. Metaquartzite beds range in thickness from 1 cm to about 3 meters, averaging about 25 cm; metapelite from 1 cm to a few meters, but are generally less than 10 cm thick. (Rickerich, 1983) Thicker metaquartzite beds commonly have basal zones of coarse sand to granule-sized grains including quartz (both milky and bluish) and minor feldspar.

In the exposures around Kittery studied by Rickerich (1983), a variety of sedimentary structures are present. The bases of many metaquartzites in this area are characterized by scour features and primary deformation features. Undulatory erosional surfaces are present at the bases of some metaquartzites, and often distinct metaquartzite beds are in erosional contact. Channeling less than 50 cm in width is occasionally present at or near the base

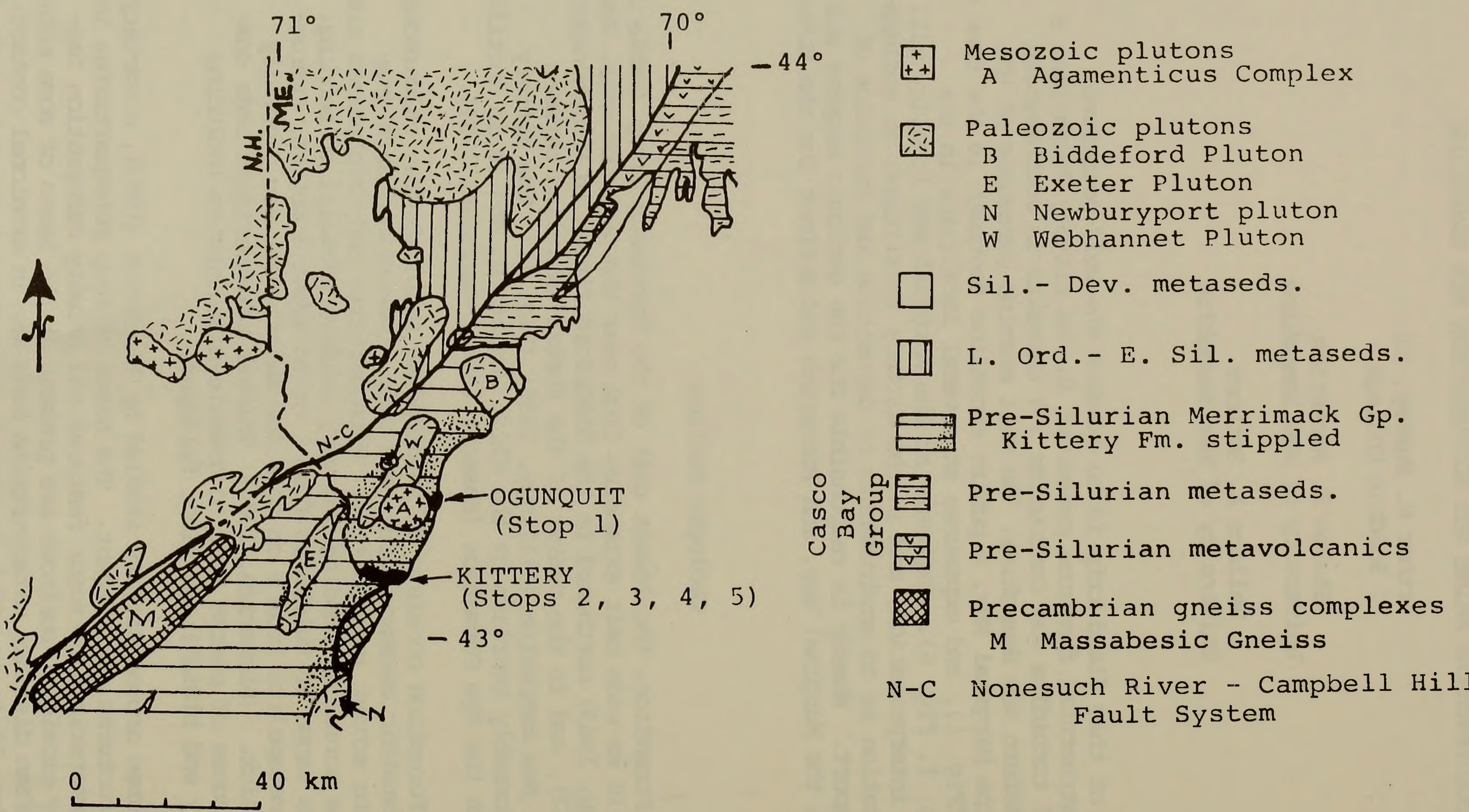

Fig. 1. Location map and generalized geologic map of southwestern Maine and southeastern New Hampshire (after Hussey and Pankiwskyj, 1975; and Lyons <u>et al</u>, 1982).

of some beds. Flute marks are rare, but both load and flow flames are frequently present in many metaquartzites.

Basal layers of some metaquartzites often contain thick, well-defined, laterally continuous parallel laminae; large-scale cross laminae; and dewatering or early cleavage structures. Thick parallel laminae tend to be spaced about 1 cm apart and usually occur in thick-bedded coarse-grained metaquartzites. Most large-scale cross-laminae are also restricted to coarse-grained thick-bedded metaquartzites and are frequently dunal in nature, although some large-scale antidunal cross-laminae are present. The dewatering or early cleavage structures are weak laminae that dip 10° to 26° in an upcurrent direction and are most often restricted to narrow laterally-continuous zones in mataquartzite beds. Basal layers of almost all metaquartzites are normally graded.

The basal layers of fine-grained metaquartzites, and the upper layers of coarse-grained metaquartzites frequently contain a range of delicate sedimentary structures. Thin (~1mm) usually close-spaced, laterally-continuous bed-parallel laminae generally underlie small-scale crossbedding. Small-scale crossbedding is most often plano-lenticular. Upward-steepening climbing ripple structures are occasionally present.

Each of these structures can be interpreted as having been deposited over a specific range of current flow conditions, i.e., velocity, duration, load, and competency. Specific suites of sedimentary structures, bedding characteristics, and grain size characteristics are helpful in identifying the nature of the current that deposited a particular bed. Thick-bedded medium to coarse-grained poorly-sorted normally graded metaquartzite beds with high metaquartzite/metapelite ratios, sharp upper and lower contacts, flame structures, thick parallel laminae, large-scale cross laminae and dewatering structures are indicative of high velocity deposition. Thinner-bedded, medium to fine-grained graded metaquartzites with low metaquartzite/metapelite ratios, often containing well-developed extremely thin parallel laminations and small-scale crossbedding are interpreted as having been deposited by low-velocity currents.

TABLE I

Stratigraphic Column,
Southwestern Maine and Southeastern New Hampshire

Siluro-Devonian	Shapleigh Group		Interbedded metapelite and metasandstone; rusty metapelite
E. Ordovician (?) to Precambrian (?)	Merrimack Group	Gonic Fm	Metapelite
		Berwick Fm	Medium-bedded to massive biotite and calc-silicate granofels and gneiss
		Calef M	Black phyllite
		Eliot Fm	Thin-bedded calcareous metapelite and metasiltstone
		Kittery Fm	Thin to thickbedded calcareous metasandstone, metasiltstone, and metapelite
Precambrian (?)		Rye Fm	Blastomylonitic calc-silicate gneiss, biotite gneiss, and metapelite gneiss

The apparent decrease in depositional energy upwards in each bed, the range of sedimentary features observed, the lateral continuity of parallel laminae, and the laterally constant thickness of each bed are all excellent evidence that the vast majority of beds in the study area were deposited by turbidity currents. In fact, most of the suites of structures observed in metaquartzite beds are analogous to specific turbidite suites discussed by Walker (1967, 1978), Ricci-Lucchi (1975), Mutti (1977), and Keith and Friedman (1977).

High velocity turbidity current deposits are often in close stratigraphic juxtaposition with low velocity turbidity current deposits. There are several possible sedimentologic explanations for this occurrance and the simplest explanations fit nicely within the context of a submarine fan model (Rickerich, 1983). Specifically, turbidite sequences in the Kittery area which contain evidence of rapid deposition have characteristics typical of the upper or central area of a submarine fan lobe (Walker, 1978). Turbidite sequences which contain evidence of low energy deposition are typical of the fringe area of a submarine fan lobe. Migration, switching or progradation of submarine fan lobes can account for stratigraphic variability of bedding styles. Temporal fluctuation in turbidity current magnitude can also explain stratigraphic variability.

The load flames, rip-up clasts, cross-bedded units, large and small-scale parallel laminae, and normal grading in the thick and thin-bedded metaquartzites near Fort McClary (Stop 2) are typical of the primary sedimentary features observed throughout the map area. A massive, thick-bedded metaquartzite near the Henry H. Cook Memorial School, Kittery (Stop 3) contains large-scale cross laminae and scour features that are less common in the map area, but are typical of high current velocity features observed in some beds in the Kittery Formation.

The range of bedding styles and sedimentary features at Fort McClary and the Cook Memorial School outcrops supports the likelihood that the Kittery Formation is a metaturbidite and demonstrates the stratigraphic diversity of bedding styles which led to the classification of the paleodepositional environment of the Kittery Formation as the lobe facies of a submarine fan (Rickerich, 1983).

Not all of the metaquartzites in the Kittery Formation are believed to be turbidites. The Squash Island outcrop (Stop 4) contains a unit which is tentatively identified as a contourite. This unit is thick-bedded, fine to medium grained, well-sorted, crossbedded and ungraded. Several possible contourites were observed in the Kittery area.

The paleocurrent azimuth mean for contourites in the study area is 308° with a standard deviation of 30°. In contrast, the paleocurrent azimuth mean for all turbidites in the area is 264° with a standard deviation of 60°, thus indicating an easterly source area for Kittery turbidites. It is not inconsistent for contourites and turbidites to be interbedded (Lonsdale and Hollister, 1979; Stow and Lovell, 1979).

Several important trends can be distinguished across the map area from southeast to northwest. The Pleasant Street outcrop (Stop 5) in South Eliot, Maine, is the most northwesterly and uppermost exposed section of the Kittery Formation in the study area. The average bed thickness at this outcrop is less than at the previous stops, the metaquartzite/metapelite ratio is lower, few high-velocity depositional features are present, and the metaquartzites are finer grained. These observations are representative of general trends from southeast to northwest across the map area and are also consistent with westward turbidity current flow.

The finer-grained, thinner-bedded more pelitic Eliot Formation is exposed a few hundred meters to the northwest of Stop 5. The contact between the Kittery and Eliot Formations is believed to be gradational.

The Kittery Formation has been regionally metamorphased from low Greenschist facies in the Wells Beach area to high Greenschist or possibly low Epidote Amphibolite facies in the Gerrish Island area. (See field trip B-4 by Swanson and Carrigan, this guidebook.)

Three major fold phases affect the Kittery Formation. The earliest, F_1, consists of SW-facing recumbent isoclines of possible regional extent. Parasitic mesoscopic scale recumbent F_1 isoclines are best observed along the Marginal Way in Ogunquit (Stop 1). F_2 folds are upright open to steeply overturned tight folds with plunges up to, but generally considerably less than, 30°; plunge reversals are common. Where tight, these folds have a well-developed axial plane cleavage (S_2) along which, in hinge zones, transposition of bedding is marked. F_3 folds are relatively open, overturned generally dextral fold sets with strongly developed strainslip cleavage, S_3, also involving significant bedding transposition in hinge zones. Cleavage to be seen along the Marginal Way (Stop 1) is correlated with S_3.

The Kittery Formation has been intruded by a great variety of magma types over a long period of time from Middle Ordovician (or perhaps earlier) to Cretaceous times. The oldest reported radiometric age for igneous rocks intruding the Kittery Formation is for the Newburyport pluton (Fig. 1) which intrudes the Kittery Formation in the Newburyport-Seabrook area. Zartman and Naylor (1984) report a zircon age of 450±15 Ma for this pluton. The Webhannet Pluton (Fig. 1) with a zircon age of 403±12 Ma and a Rb/Sr age of 390±10 Ma was intruded at the end of deformation of the Acadian Orogeny (Gaudette, et al, 1982). An early Mississippian age (341±12 Ma, Rb/Sr) is reported for the post-tectonic Biddeford Pluton (Fig. 1) (Gaudette, et al, 1982). Post-tectonic alkalic rocks of the Agamenticus Complex with a Rb/Sr age of 228±5 Ma (Foland and Faul, 1977) were intruded in Early Triassic time. These rocks are similar to, but somewhat older than, alkalic rocks of the White Mountain Magma Series in New Hampshire. Post-tectonic funnel intrusions and cone sheets of the Cape Neddick Complex (a small composite pluton in the town of York just southeast of the Agamenticus Complex) give a K/Ar age of 116±2 Ma (Foland and Faul, 1977) and is the youngest pluton, being emplaced during Cretaceous time. Between the time of injection of the Cape Neddick and Agamenticus Complexes two suites of basic dikes, with occasional felsic dikes, were emplaced. These are abundant in coastal zone exposures of southwestern Maine and southeastern New Hampshire, and will be well seen at Stop 1. The earlier suite of dikes may have been emplaced during Triassic to Jurassic time and the later suite in Jurassic to Cretaceous time (Swanson, 1982, p. 137).

The 450 Ma age for the Newburyport pluton places a minimum age of Middle Ordovician on the deposition, deformation, and possibly metamorphism of the Kittery Formation. Lyons, et al (1982) discuss relations of the

Berwick Formation and Massabesic Gneiss that suggest a possible late Precambrian age for the Merrimack Group as a whole, and thus for the Kittery Formation. Correlation of the Merrimack Group with the Vassalboro Formation of latest Ordovician to earliest Silurian age, despite the striking lithic similarity, now appears untenable.

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Road Log

Meeting Time and Place: Assemble in front of the Information Center at the Rest Area on the northbound lane of I-95 in Kittery at 8:00 a.m. sharp. People coming from the north should exit from the Maine Turnpike at the York tollbooth and proceed south on U. S. 1 for 3.2 miles then turn right into road marked "Rest Area." Please be prepared to consolidate into as few vehicles as possible--parking at Stop 1 may be quite limited or costly. We will return to the Rest Area to pick up vehicles before proceeding to Stop 2 (Lunch Stop).

From the Rest Area, exit to U. S. 1 around the north side of the Information Center. Road log begins at the junction with U. S. 1.

Mileage	
0	Junction Rest Area access road with U. S. 1. Turn left on U. S. 1.
1.4	Cross over York River.
2.8	Jcn, U. S. 1A. Stay on U. S. 1.
3.2	Jcn, I-95. Stay on U. S. 1.
6.4	Jcn, U. S. 1A. Stay on U. S. 1.
10.5	Ogunquit Square. Turn sharp right onto Shore Road.
11.3	Leave Shore Road. Proceed straight ahead to Perkins Cove.
11.5	Park in public parking lot. If full, park in pay lot ($2-$3).

Stop 1. Marginal Way. Walk northeast along the Marginal Way, a paved public footpath. We will proceed to the north end of rock exposures near the Ogunquit River (approximately 1/2 mile) and then work our way back to Perkins Cove.

The area seaward of the footpath is a nearly continuous exposure of the Kittery Formation, and abundant basic and felsic dikes that intrude it (Fig. 2). In general, bedding is not as well preserved here as a little further south and in the Kittery area. However, bedding styles, thicknesses, and metaquartzite/metapelite ratios vary greatly, probably reflecting the same variations in local submarine fan sedimentation as described for the Kittery area. Thicker beds commonly have coarse sand bases, and quick grades to thin metapelite tops. Thinner beds commonly have slower grades. Cross lamination is present, but relatively rare.

Bedding along this part of the Kittery exposures varies from vertical to gentle easterly dips, the latter predominating (Fig. 3).

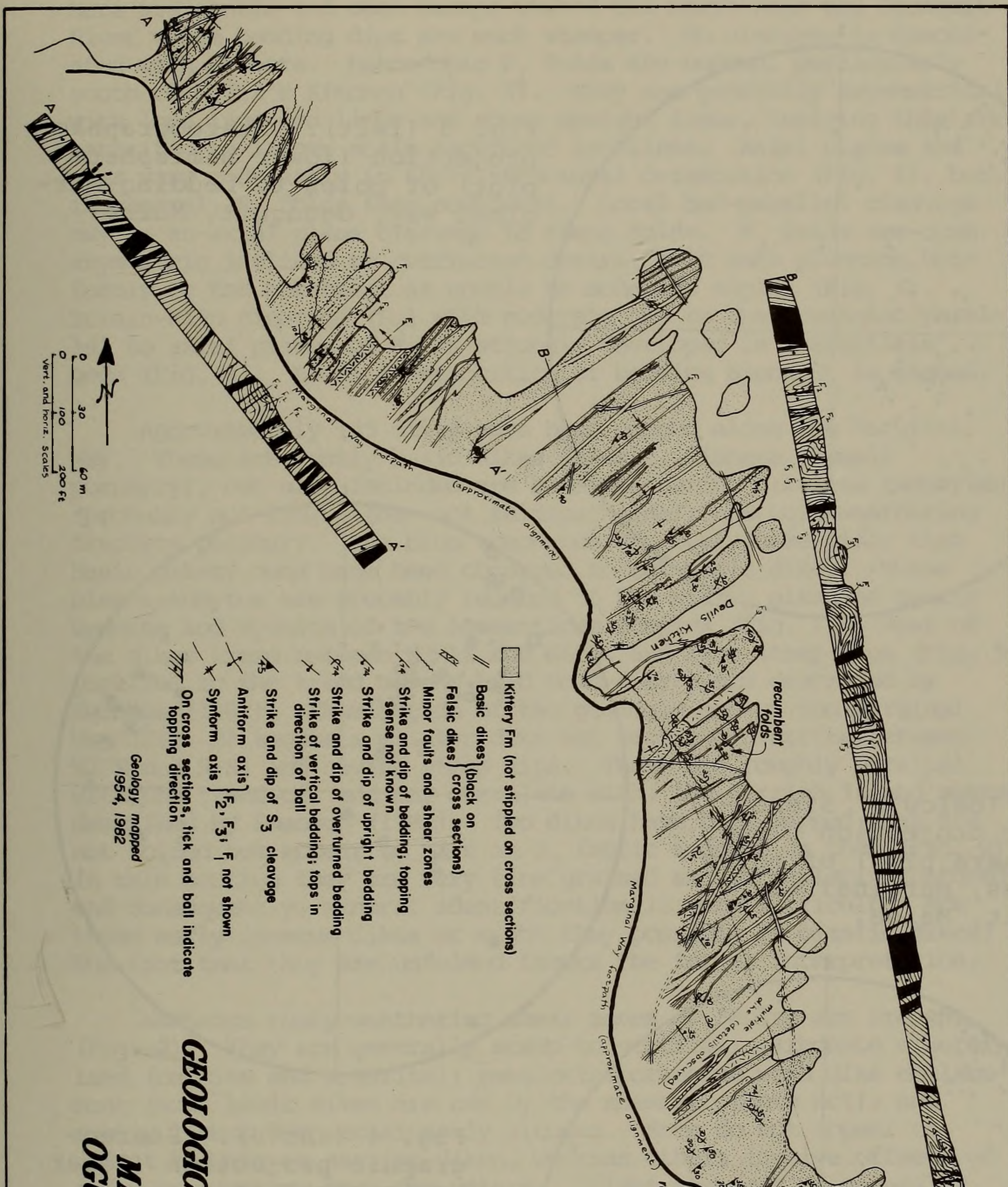


Fig. 2

GEOLOGIC MAP & CROSS SECTIONS OF THE MARGINAL WAY, OGUNQUIT, MAINE

By A. M. HUSSEY II

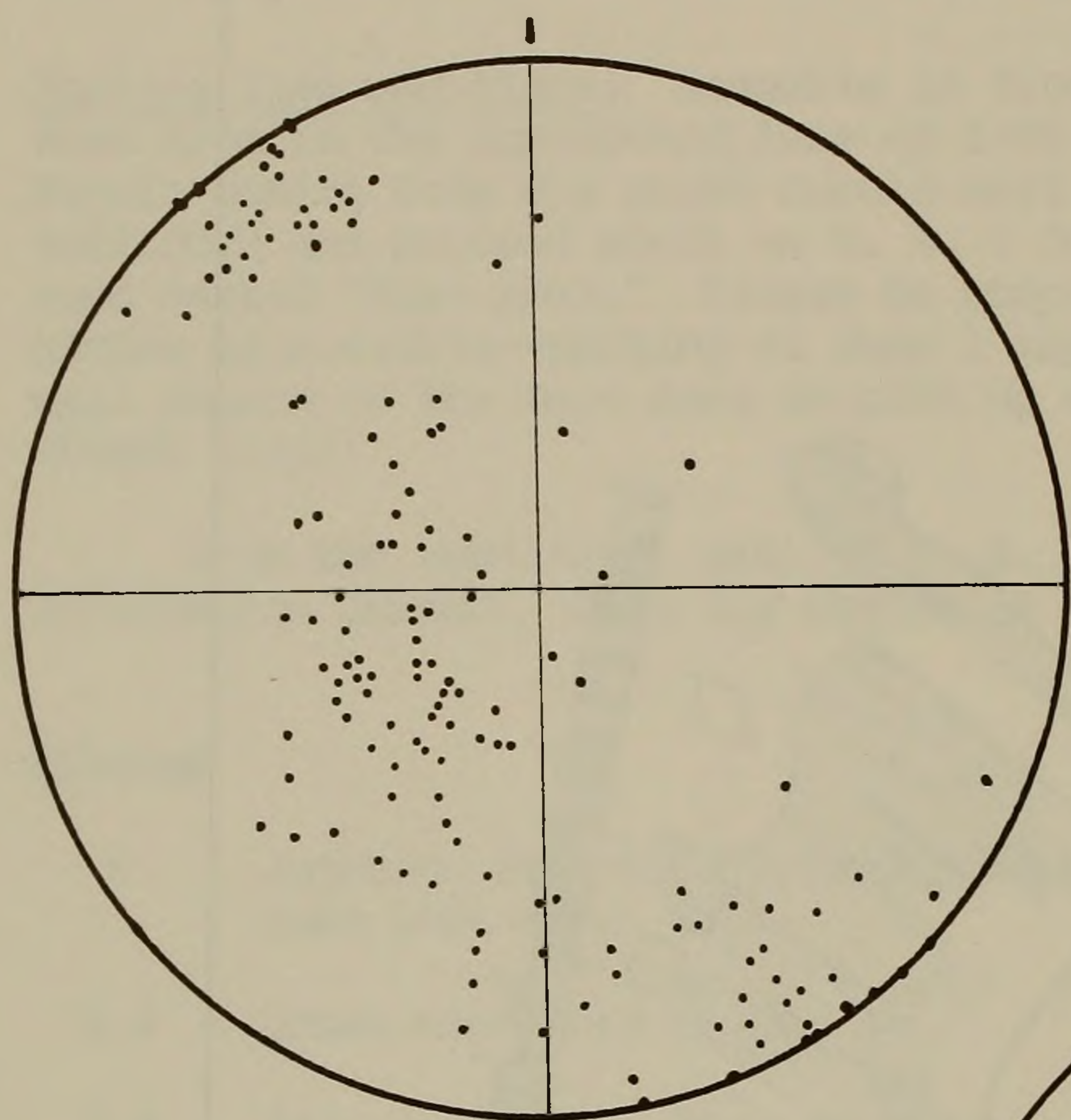


Fig. 3 (left). Stereographic projection (lower hemisphere plot) of poles to bedding, Marginal Way, Ogunquit, Maine.

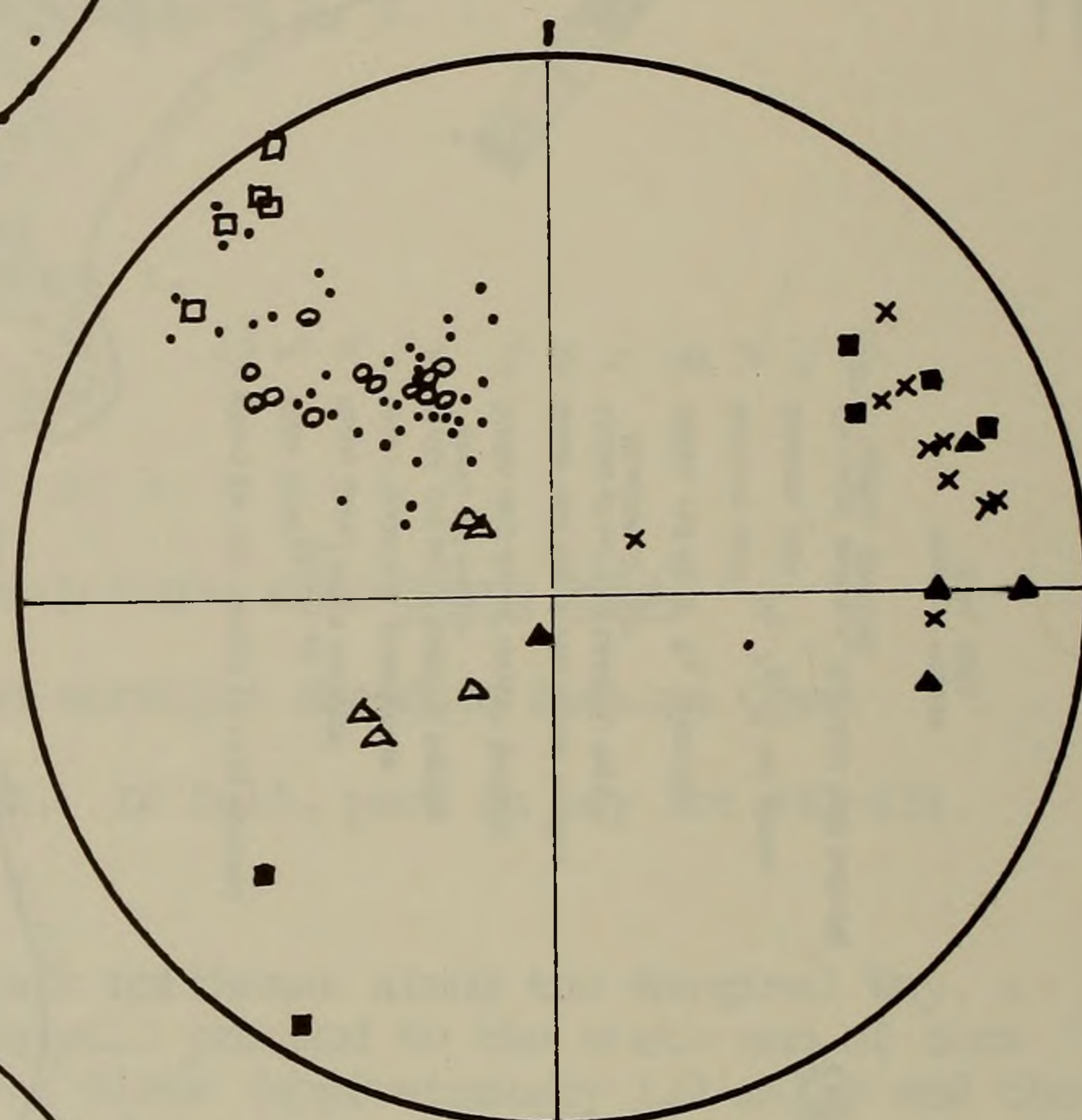
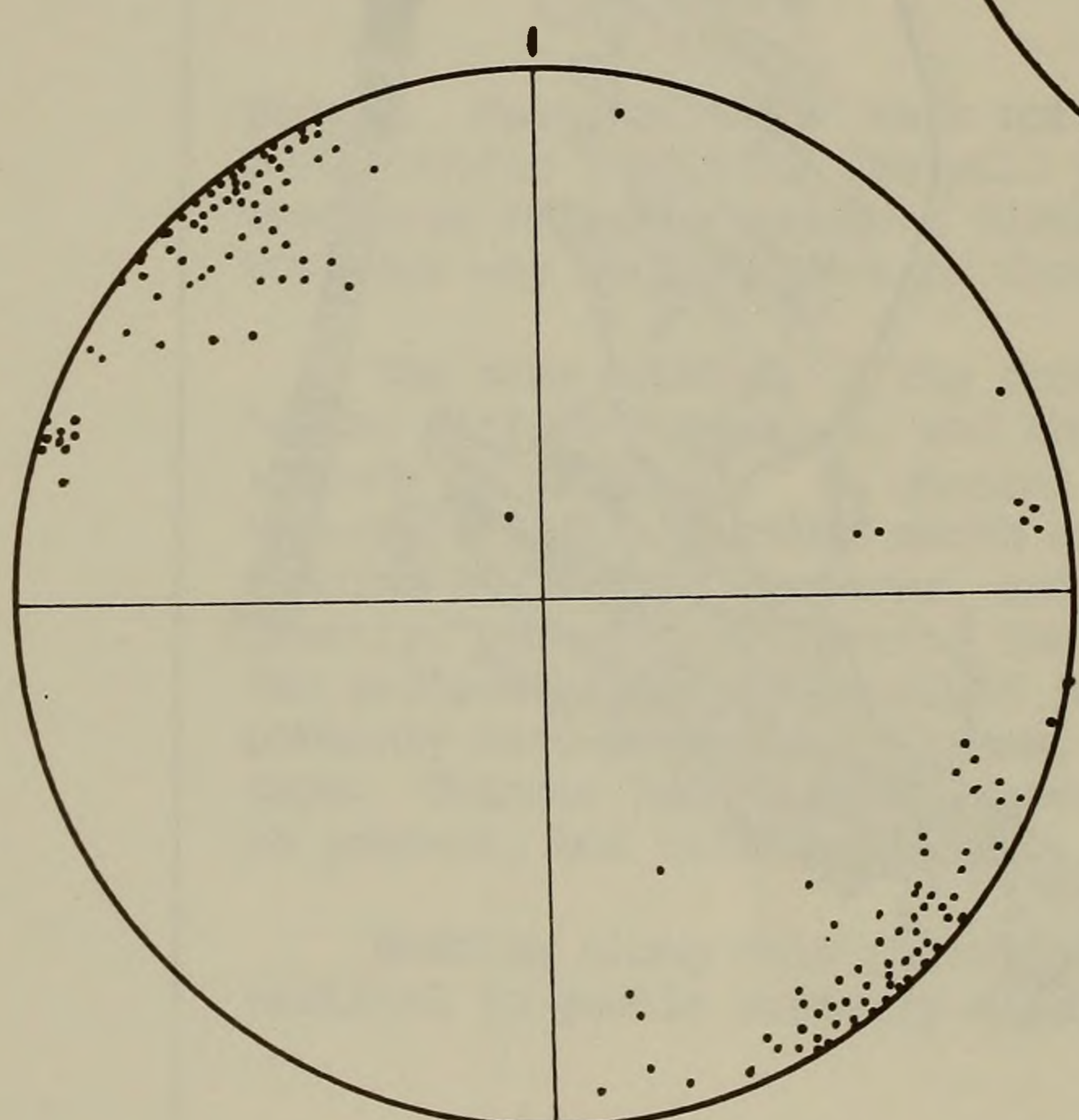


Fig. 4 (above). Stereographic projection (lower hemisphere) of:
- • poles to S_3 cleavage
- o poles to AP, F_3
- x axes, F_3
- □ poles to AP, F_2
- ■ axes, F_2
- △ poles to AP, F_1
- ▲ axes, F_1

Marginal Way, Ogunquit, Maine

Fig. 5 (below). Stereographic projection (lower hemisphere plot) of poles to dikes, Marginal Way, Ogunquit, Maine.



Low dips reflect the scarcity of tight upright F_2 folds. F_2 folds here are gentle and open except toward the north near the Ogunquit River where bedding dips are much steeper. No cleavage is associated with F_2 here. Mesoscopic F_1 folds are common, particularly south of Devil's Kitchen (Fig. 2). They are generally asymmetrical with long inverted limbs and short upright limbs, implying they are parasitic to larger scale recumbent isoclines. Axial planes and axes vary moderately in their structural orientation (Fig. 4), but, in general, F_1 folds face southwest. Local bed-parallel cleavage may be an axial plane cleavage to these folds. F_3 folds are open asymmetric inclined to overturned dextral fold sets plunging uniformly to the northeast at gentle to moderate angles (Fig. 4). Strain-slip cleavage (S_3) with moderate dip to the southeast parallel to axial planes of F_3 is strongly developed in metapelitic beds (Fig. 4). Local transposition of bedding along S_3 is marked.

Approximately 125 dikes have been mapped along the Marginal Way. These are mostly basic dikes (basalt, diabase, basalt porphyry), but also included are blue-weathering alkaline trachytes (probably not tinguaites--not feldspathoidal) and buff weathering trachyte porphyry. The blue trachytes are everywhere older than basic dikes; none have been observed to cut basic dikes. These blue trachytes are probably related to the nearby alkaline quartz syenite and syenite of the Agamenticus Complex (Fig. 1). Most of the dikes trend between N50E and N60E, and have steep dips (Fig. 5), parallel to the trend of the Bald Head dike swarm described by Swanson (1982). Examination of the geologic map of the Marginal Way (Fig. 2) suggests a later dike set varying in strike between N25E and N-S, and having steep dips. These are roughly parallel with the trend of, and may correlate with, the Gerrish Island swarm described by Swanson (1982). Two dikes have been mapped that are not folded but appear to have an S_3 fabric imposed on them (Fig. 2). In thin section they are very fine grained and irregularly textured, and consequently, mineral identification is very difficult. Are these early igneous dikes or might they possibly be clastic dikes? The fact that they are unfolded favors the former interpretation.

Numerous rusty-weathering shear zones or faults are present (Fig. 2). They are generally steep to vertical; carbonate mineralized (calcite and ankerite); penecontemporaneous with dike emplacement (some basic dikes are cut by the shears, others not); and mostly linear but occasionally sinuous. Some do not appear to offset bedding or earlier dikes, whereas others involve offsets of a few centimeters to a few meters. Offset movement is generally oblique or strike slip, both dextral and sinistral.

Return to vehicles at Perkins Cove not later than 11:45 a.m. Turn around and proceed back toward Ogunquit.

Mileage

11.7 Straight onto Shore Road

12.3 Turn left onto School Street. (Do not proceed to Ogunquit Square because left turn onto U. S. 1 is generally prohibited.)

Mileage

12.6 Left turn onto U. S. 1.

22.8 Turn right into Rest Area access road. Retrieve vechicles. Return to U. S. 1. Road log resumes at Junction with U. S. 1. Turn right (south) onto U. S. 1.

23.7 Turn left on Haley Road.

25.1 Norton Road to left. Stay on Haley Road.

26.6 Turn right on Maine Route 103 at stop sign.

27.3 Turn right into Fort McClary picnic area.

Stop 2. Lunch (Fig. 6). Lunch materials for those who have not brought it may be obtained at Bisbee's Market 1/4 mile towards Kittery.

After lunch we will walk west to parking lot at Fort McClary State Memorial for the following:

(1) Comparison of fold styles in parking lot exposures.

(2) SW of the Fort along shore of Portsmouth Harbor, beneath the stone turret in overturned beds, note load flames, rip-up clasts, normal grading, a strongly cross-bedded unit.

(3) Note bedding variability while walking west.

In westernmost outcrop note:

(a) coarse-grained medium-bedded metaquartzites, load structures, slow grades, large-scale parallel laminations (beds upright);
(b) preserved ripples (beds upright);
(c) extremely thin bedded metaquartzites (overlying (a) and (b), beds overturned) with low metaquartzite/metapelite ratio.

Turn right on Route 103 out of picnic area parking lot.

28.7 Pass Naval Shipyard on left.

28.9 At light, turn left on Whipple Road. (Stay on Route 103.)

29.0 Bear left onto Williams Avenue.

Stop 3 (Fig. 6).

29.1 Harry H. Cook Memorial School. West of the school on the shoreline in massive thick-bedded overturned metaquartzites, note large-scale cross-lamination, scour features, and small-scale cross beds in upper part of bed.

Backtrack to Route 103; bear left onto Route 103.

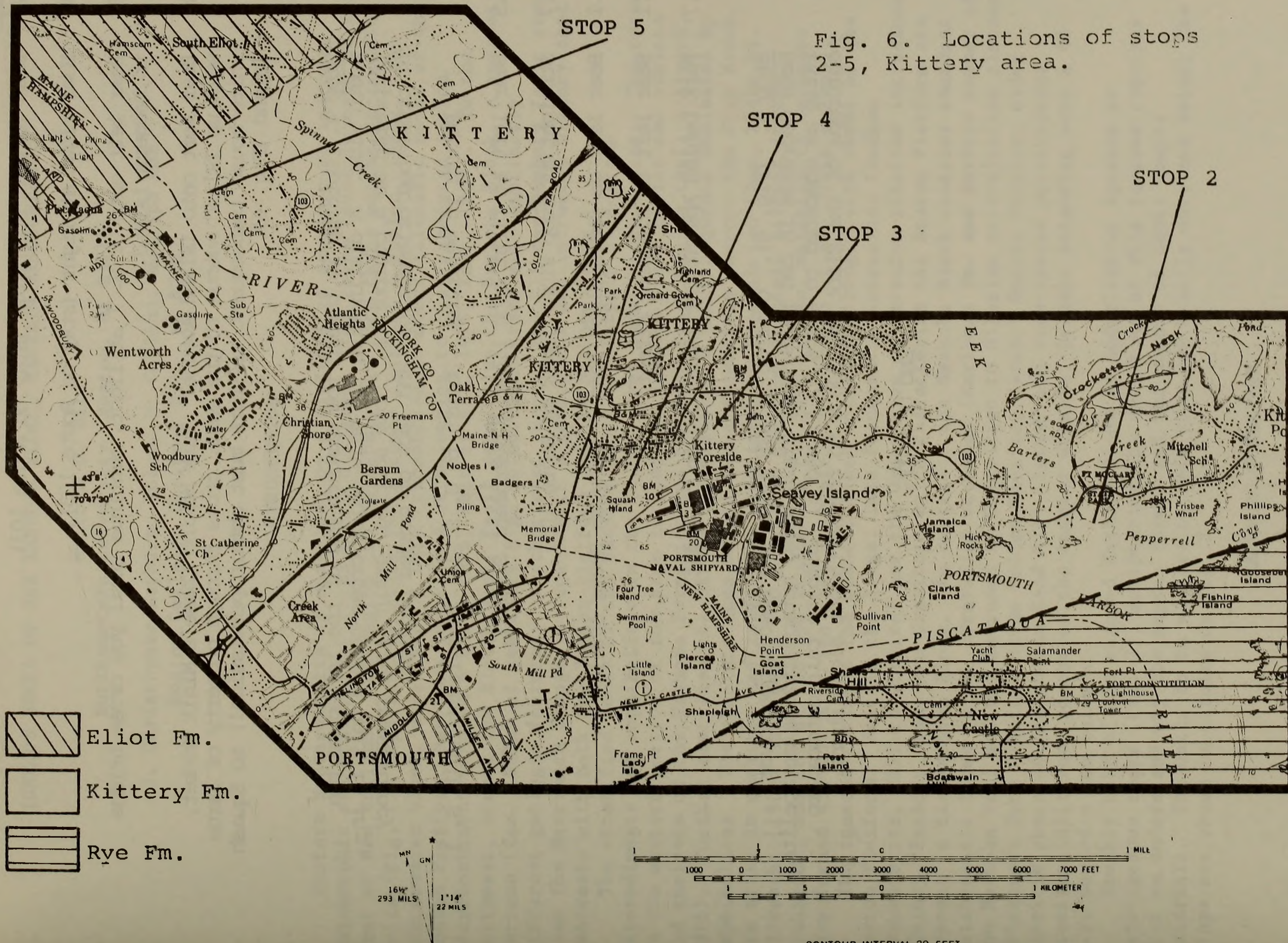


Fig. 6. Locations of stops 2-5, Kittery area.

Mileage

29.2 Bear left at stop sign (stay on Route 103).

29.4 Bear right at light (stay on Route 103).

29.8 Bear left onto U. S. 1 at light, continue until you cross bridge to Badgers Island.

30.2 Bear left onto Island Avenue. Park behind Chase's Minit Market, walk up Island Avenue to the east, cross through property of large white house (subsequent visitors must obtain permission!) to Squash Island (Fig. 6).

Stop 4. Outcrop is toward the eastern end of the island on the south side. A distinctive 2.5 mile-thick cross-bedded unit is interpreted as a contourite. Note sorting, grain size, consistency of cross-bed orientation, and lack of graded bedding.

Return to vehicles. Return to U. S. 1. Turn right on U. S. 1.

30.5 Bear left at first stop light (Government Street).

30.7 Straight at stop sign. Back on Route 103.

31.1 Bear left on South Eliot Road. (Stay on Route 103.)

32.1 Bear left on Pleasant Street.

32.7 Park behind Advent Christian Church on right.

Stop 5. (Fig. 6). Outcrop is SSE along the Piscataqua River. Note decrease in bed thickness, grain size, metaquartzite/metapelite ratio as compared to stops 3, 4, and 5. Compare this outcrop to outcrops of the Eliot Fm. 300 m to the northwest along shore.

-END OF TRIP-