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PRECAMBRIAN ROCKS OF SEVEN HUNDRED ACRE ISLAND AND DEVELOPMENT OF CLEAVAGE IN THE ISLESBORO FORMATION

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Introduction

Islesboro is a low-lying island, 10 miles long and nowhere more than 2 1/2 miles wide, with a deeply indented shoreline. This island, together with structurally related islands (see Fig. 1) that extend southward another 4 miles, will be referred to as the Islesboro block.

The field trip will focus on three geological features of the Islesboro block. The first is the stratigraphy and lithology of the chlorite-grade metamorphic rocks that compose most of the block and constitute the Islesboro Formation. These rocks are different in several aspects from those immediately adjacent on the surrounding mainland, and compose a structural block which I interpret to be bounded by large north-trending faults along which miles of right-lateral strike-slip motion has occurred. Details of the structural blocks of northern Penobscot Bay are given in trip B-7, this volume.

The second feature is a horst of Precambrian medium-grade metamorphic rocks within the Islesboro block. These rocks were the first of Precambrian age to be recognized in Maine and have many implications that bear on the nature of basement rocks along the northeastern Maine coast and of the faulting in the region.

The third feature is the relation between large faults and cleavage and foliation in chlorite-grade rocks. Outcrops are spectacular and should provide valuable background for geologists who will later work with deformed higher grade metamorphic rocks with chlorite-bearing protoliths.

The rocks to be seen were most recently mapped mostly by Paul C. Bateman and Harvey E. Belkin of the U.S. Geological Survey in 1968 as part of my mapping project on the Castine and Blue Hill 15-minute quadrangles. This map is reproduced (Fig. 1), with few changes except for the omission of hundreds of structure symbols. D.G. Brookins, now of the University of New Mexico, and I established the age of the Precambrian rocks. I am responsible for postulating boundary faults of large displacement on either side of Islesboro. Another interpretation based on the same map was given by Osberg in Poitras and others (1972).

The field trip will necessarily be hurried to meet the ferry schedule. Additional problems can be caused by a trip by charter boat necessary to see important outcrops on Spruce and Seven Hundred Acre Islands. Bad sea or tide conditions may force the order of stops to be changed or may prevent access to some stops. Swimming in Penobscot Bay in October can be hazardous to your health and is at best marginal in August.

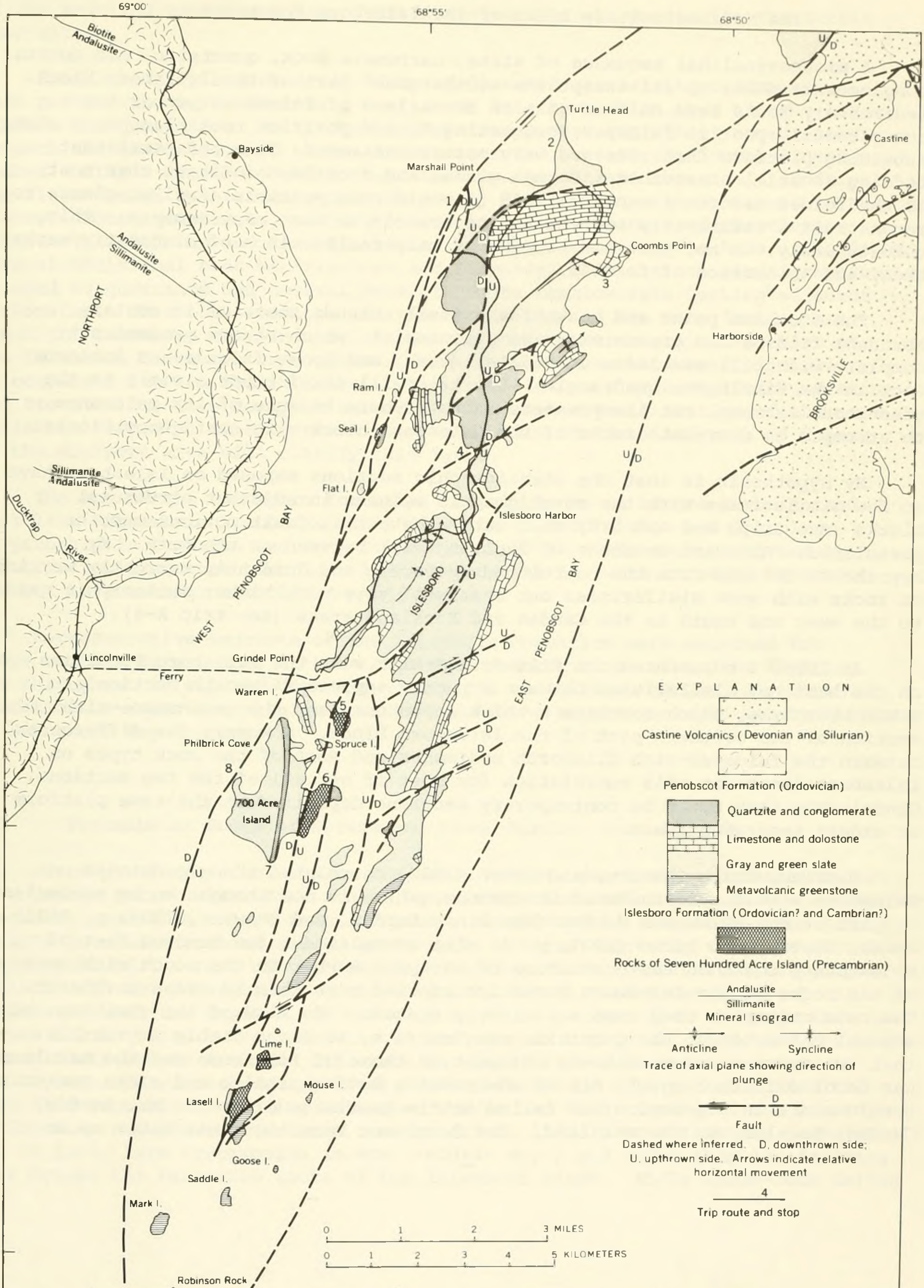

Figure 1. Geologic map of Islesboro and vicinity.

The Metasedimentary Rocks of the Islesboro Formaticn

A miogeosynclinal sequence of slate, carbonate rock, quartzite, and quartz conglomerate makes up all except the southernmost part of the Islesboro block. Sedimentary rocks seen on this trip on the island of Islesboro proper are conspicuously poor in feldspar, suggesting that deposition took place on a slowly subsiding platform that received only mature sediment. Thin and persistent bedding is still observable. Common graded and crossbeds indicate that most of the folded section is upright, and it would seem possible at first glance to reconstruct a sedimentary section and separately to name many members. This, unfortunately, is not possible because of many faults, lack of diagnostic marker beds, and an absence of fossils.

The southern point and most of the small islands south of it contain abundant feldspathic greenstones and greenschist, which become predominant, complete with pillowed lavas on Saddle, Mouse, and Goose Islands and Robinson Rock in the Vinalhaven quadrangle. The trip will not include a visit to the greenstone terrane, but its presence is noted here because of its relevance to attempts to correlate rocks of the Islesboro block with contiguous blocks.

My hypothesis is that the stratigraphic sections exposed on Islesboro have so few similarities with the stratigraphic columns in adjacent structural blocks (see trips A-4 and B-7) that very substantial fault motions must be postulated. Abundant evidence of faulting will be seen on the trip. My hypothesis differs from one postulated by Osberg and Guidotti, currently working on rocks with some similarities but mostly of very much higher metamorphic grade to the west and south in the Camden and Rockland areas (see trip A-4).

In 1956, I correlated the Ellsworth Schist with the Islesboro Formation, on the basis of similarities between a poorly exposed Ellsworth section at North Deer Isle, which contains a thick dolostone, and the greenstone-rich section of the southern part of the Islesboro block. However, the differences between the feldspar-rich Ellsworth sediments and most of the rock types on Islesboro discredit this correlation for most if not all of the two sections. Conceivably they could be contemporary sections deposited on the same platform at widely separated areas.

Earlier, Smith, Bastin, and Brown (1907) correlated the greenstones on Islesboro with the North Haven Greenstone, which is now thought to be equivalent to part of the Ellsworth Schist (Brookins, Berdan, and Stewart, 1973, p. 1621). Smith, Bastin, and Brown (1907, p. 3) also correlated a few hundred feet of sedimentary rocks on the east shore of Rockport Harbor to the south with some of the rocks of the Islesboro Formation exposed more than 10 miles northeast. The main criterion they used was clearly stated: "In view of the striking and unusual character of the quartzite conglomerate, it seems highly improbable that two occurrences so closely adjacent as those of Islesboro and the mainland can be of different age." All of the massive buff quartzite and clean quartzite conglomerate in the region was called Battie Quartzite after the Mt. Battie, Camden, locality on the mainland. The Penobscot Formation that makes up most of the mainland west and north of Islesboro was thought to overlie the Battie Quartzite.

Smith, Bastin, and Brown (1907, p. 1-3) named the Islesboro Formation that part of the metasedimentary section on Islesboro which they thought lay beneath the quartzite. Their Coombs Limestone Member was almost immediately beneath the quartzite, and their slate member was beneath the Coombs Limestone Member. Stop 3 is the locality they cited to demonstrate these relationships. The slate member was recognized to be mostly slates, but also contained calcareous slates, impure quartzites, carbonate beds, and small amounts of pyroclastic rocks. The 1907 map and text discussion and the recent mapping have established several additional beds of dolostone and limestone that are not stratigraphically related to quartzite and several beds of quartz conglomerate lacking adjacent carbonates. These observations and the recognition of the many faults that break the Islesboro section assure that the correct stratigraphic section of the Islesboro Formation is complex and is not now known because of inability to correlate between fault blocks. Thus, the old correlation by Smith, Bastin, and Brown of the thin Rockport Harbor section with a small section of the Islesboro Formation must be questioned. Possibly the detailed work of Osberg in the Rockport area will clarify this issue.

The age of the Islesboro Formation is only known to be pre-Devonian and post-late Precambrian. On the basis of style of deformation and lithology it probably is Cambrian and (or) Ordovician. Rb/Sr whole-rock isochrons by Brookins (written communication, 1971) are compatible with an early Paleozoic age but have a large associated error band.

Representative sections of the Islesboro Formation were selected for stops on this trip. Most of them also show deformations related to faulting, but throughout it will be emphasized that the correlation of the Islesboro Formation is a problem with profound implications to the geologic interpretation of Penobscot Bay country.

Precambrian Rocks of Spruce and Seven Hundred Acre Islands

Outcrops of splendent coarse muscovite schist, garnet-bearing amphibolite, retrograded garnet-andalusite schist, quartzite, and banded gray marble containing muscovite pegmatite can be seen on Spruce, Seven Hundred Acre, Lime, and LaSell Islands in a horst; these medium-grade rocks contrast markedly with the chlorite-grade rocks of the rest of the Islesboro block and are nowhere in stratigraphic contact with the Islesboro Formation. Smith, Bastin, and Brown (1907, p. 9) speculated that the regional deformation might be younger than the pegmatite on Spruce Island because the muscovite it contains is highly deformed, and the pegmatite is remote from and different in composition from other granites in the region. They concluded, however, that deformation more probably resulted from differential flow during intrusion. K/Ar and Rb/Sr dating of the muscovite by Brookins and Stewart (written communication, 1972) proves that the pegmatite is, in fact, late Precambrian in age (~600$\pm$20 m.y.) and older than the faulting that breaks the Paleozoic rocks of the Islesboro block. Rb/Sr whole-rock dating with a large error band also indicates that the medium-grade metamorphic rocks are older than the pegmatite. The medium-grade rocks have been extensively retrograded and are more foliated than the pegmatite. No migmatite has been observed, and the deformation style is simple.

The closest known Precambrian rocks are the gneisses in the Passagassawakeag block 12 miles northwest of the Precambrian rocks of Islesboro. Mapping of these gneisses by Wones and Bickel (see trips A-1 and B-7) has shown three deformations older than Late Ordovician, multiple intrusion of granitic rocks, abundant migmatite, and higher metamorphic grade (to second sillimanite) throughout the Passagassawakeag block. The apparent contrast in Precambrian basement rocks in the Islesboro and Passagassawakeag blocks is one possible consequence of an early Paleozoic plate collision (Trip B-7).

The Precambrian rocks of Seven Hundred Acre Island have many similarities to the Green Head Formation Precambrian of southwestern New Brunswick. The finely laminated dolomitic limestone of Lime Island is virtually identical in appearance with dolomitic limestone at Green Head, St. John, New Brunswick. Thin beds of varied composition are common to both of these Precambrian terranes. The Precambrian rocks of Seven Hundred Acre and nearby islands are therefore tentatively correlated with the Green Head Formation. If the Precambrian rocks of the Islesboro block were originally contiguous with the Green Head Formation of New Brunswick, more than 100 miles of strike-slip motion would have been required to bring them to their present positions.

Development of Cleavage and Schistosity near Large Faults

The Islesboro block is bounded on both sides by major regional fault zones. Both fault zones are probably branches of a single fault zone, here called the Turtle Head fault zone; south of the Islesboro block this zone strikes nearly north; north of the block, it strikes N.35°E. Condidered in this way, the entire Islesboro block is a fault sliver caught in a bend of the large fault zone. The great differences in regional stratigraphy across both West and East Penobscot Bays can be explained by this model. The mile-long sliver of Islesboro rocks found outside the area of Fig. 1, 1 mile southwest of the South Penobscot crossroad and 5 miles northeast of the northern tip of the Islesboro block, and the small area of Castine Volcanics south of Marshall Point on northwestern Islesboro indicate right-lateral strike-slip motion on this fault. The fault pattern within the Islesboro block, the many minor structures along the western border of Islesboro and on Ram, Seal, Flat, Warren, and Seven Hundred Acre Islands, and the abrupt and great contrast in metamorphic grade across West Penobscot Bay, also all indicate large right-lateral fault motion.

The Turtle Head fault zone cannot be observed directly on Islesboro as the zone is under water. Breccia zones along the fault trace have been observed in Penobscot Township to the north. Intensely cleaved rocks make up the western shore of Seven Hundred Acre Island, the west shore of Warren Island,

and all of Flat, Seal, and Ram Islands to the north. These localities form a line that transects bedding and minor faults and indicates the approximate trace of the fault zone. The intensity of the cleavage measured by the spacing of slip planes and the amount of mineral reorientation in the schist decreases away from the fault trace, as will be demonstrated by several stops, suggesting that cleavage and faulting formed in response to the same forces.

The fault zone on the east side of Islesboro either is further offshore, or the Islesboro rocks there have not been so highly deformed. Both alternatives probably are true, indicating that more of the fault motion occurred along the western branch of the zone.

Cleavages mapped in the Islesboro block are everywhere very steep to vertical. Only one shallow-dipping cleavage has been observed. This is a relict cleavage and is cut by strong steep cleavage. It can be observed at Stop 7. Close to the trace of the fault zone in West Penobscot Bay, cleavage strikes strictly parallel to the fault trace. Eastward from the fault trace, the strike of the cleavage becomes more divergent, ranging from N.20°W. to N.45°E., but it varies only approximately 25° within each of the small fault blocks.

The strong first cleavage is subparallel to the axial planes of gently plunging folds. Within the strongly cleaved western zone, muscovite and chlorite grew parallel to the trace of the fault zone, oblique to the first axial-plane cleavage in many places, including Stops 2 and 8. This recrystallized muscovite and chlorite may be parallel to the axial planes of steeply plunging folds, which are relatively common close to the western fault trace and are uncommon to the east away from it. I hypothesize that the steep folds and second cleavage formed during fault movement and that the attitude of the cleavage indicates the attitude of the fault zone. Accordingly, the fault zone may be nearly vertical.

The age of movement along the Turtle Head fault zone is known very closely. The fault breaks Castine Volcanics of Late Silurian and Early Devonian age (Brookins, Berdan, and Stewart, 1973) and the South Penobscot pluton (Lower Devonian), which metamorphosed the Castine Volcanics, is intruded by the unbroken Lucerne pluton (Middle Devonian). The Turtle Head fault is thus known to be post-Early and pre-Middle Devonian in age.

The Turtle Head fault zone appears as a low on the aeromagnetic map by Taylor and others (1968) and can be traced southward by this means through the Gulf of Maine until it reaches shore again at Newburyport, Mass., where it separates a Baltic Silurian and Devonian volcanic terrane on the southeast from higher grade metamorphosed rocks of the Merrimack synclinorium to the northwest. Its trace toward the northeast is less certain, but probably it crosses the Canadian border north of St. Stephen, New Brunswick, and extends into New Brunswick at least as far as the St. John River. It may be comparable in scale and rate of movement to the San Andreas fault of California.

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Itinerary

The trip begins at the State of Maine Ferry Service dock at Lincolnville, Maine. Participants must consolidate into as few vehicles as possible so that adequate space will be available on the ferry BOTH ways. Very early arrivals should attempt to see the highly metamorphosed Penobscot Formation typical of the mainland west of Islesboro. Outcrops can be seen north of Lincolnville along Route 1, or west of Lincolnville along Route 173 to Slab City. The outcrops south of Lincolnville are the Megunticook Formation of Osberg (Trip A-4), which reputedly lies beneath the Penobscot Formation. An excellent outcrop of Penobscot Formation containing 3-cm andalusite crystals occurs on the north shore of the mouth of Ducktrap River, about 1 mile north of the ferry landing.

Mileage	
0.0	Board ferry at Lincolnville
0.01	Depart ferry at Grindle Point, Islesboro - Drive northeast on paved road.
1.2	Stop sign. Turn left on tarred road.
2.7	Pass access road to airport on right, meeting late arrivals and first class guests.
3.1	Stop sign. Turn left on tarred main road.
5.6	Pass Shell station and Islesboro fire station on right.
6.25	Fork in road, take left road.
7.3	At curve in road, note abandoned paved road on left. Make sharp left U-turn, go 100 yards, and turn right onto dirt road.
8.0	Park in small lot with care. Proceed on foot to shore outcrops north and west of lot.

<u>Stop 1</u>. As the shoreline is reached, massive buff quartzite of the Islesboro Formation intruded by greenstone dikes is visible on the left. DO NOT try to descend to the shoreline here, as this unit will be seen later on the trip. The cove is caused by erosion along a fault that strikes northeast inshore.

Along the right-hand trail from the parking lot, highly sheared gray pelitic rocks can be seen. The cleavage is N.10°E., dipping 80°E. A weakly developed second cleavage is N.10°W., and vertical.

Another 100 meters along the shore trail, a second fault is crossed, and highly cleaved Castine Volcanics are encountered These are purple and green andesitic tuff, breccia, and agglomerate and are typical of substantial thicknesses of rocks in the Castine section. The cleaved clasts show that strong cleavage may involve only small displacements. No other Castine rocks occur in the Islesboro block. These Castine outcrops are interpreted as a sliver dragged along the fault as much as 13 km from the northeast.

Return to cars, and drive out the same road, recrossing the quartzite terrane.

8.7 Turn left onto main road.

9.7 Outcrop of quartzite on left side of road is the northernmost outcrop of this lithology before it is cut off by faults.

10.1 Park on right side of road by beach. DO NOT TRESPASS on grounds of house on beach side of road. Walk directly from the main road to the tidal part of the beach, and proceed north (right) along the west shoreline of Turtle Head. Take your camera, as this stop is a beauty for future lectures!

Stop 2. A sequence of thin-bedded gray siltstone and sandstone beds has been folded, refolded, and cleaved several times. Gradual northward increase in the intensity of deformation is interpreted to indicate that the fault along the west side of the Islesboro block converges northward on the shoreline. Axial-plane cleavage becomes highly developed, spectacular cleavage refraction is seen across sandy and silty beds, and extensive chemical migration has formed new mineral layering parallel to cleavage. The minerals are chlorite, muscovite, quartz, opaque minerals, and a little albite. Original bedding is increasingly obscured northward, and at the end of the traverse, the extensive development of a second, and even of a third, cleavage makes its recognition very difficult. In view of the limited time for movement along the Turtle Head fault zone, I hypothesize that the sequence of cleavage orientations probably results from rotations of compression axes during fault motion rather than recrystallization during epochs of deformation widely separated in time.

Return to car and drive east on road.

11.4 Water wells in this area pass through 36 meters of glacial till!

11.8 Sarpola residence on left. Turn left down dirt road to end of road.

12.3 End of road, park cars. Proceed past house toward flagpole on point.

Stop 3. This outcrop was cited by Smith, Bastin, and Brown (1907) as best showing the quartzite and quartzite conglomerate (which they called the Battie Quartzite) resting on an impure marble (which they called the Coombs Limestone Member of the Islesboro Formation). Approximately 45 meters of quartzite is exposed, resting on 2 meters of slaty pelite. At least 6 meters of contorted dolomitic marble is separated by 45 meters of beach from the quartzite, but north along the beach at Coombs Point, outcrops of quartzite are within a few meters of outcrops of dolomite.

The section is upright. Top criteria at this stop include sandy beds with siltstone tops and crossbedding. Although many of the clasts in the conglomerate are quartzites, a few gray, black, or red clasts of jasper or chert are present. The axis of the open syncline plunging northeast is sub-parallel to the axis of a larger syncline to the southeast and an anticline 0.6 km to the west.

Return to cars, retrace route to tarred road.

12.8 Tarred road, turn left.

14.5 Rejoin original route at junction.

14.9 Pass Shell station and Islesboro fire station.

16.3 Stop on right side of road by road.

Stop 4. Yeaton D. Randlett property. The outcrop is directly over the bank toward the shore from the back (sea) side of this house. Permission for entry should be sought before going to the outcrop.

The section of green slate and greenstone between the cars and the outcrop contains several impure carbonate beds containing shaly beds. The rocks are tightly folded about nearly vertical axes, and some shearing has occurred. Of special interest is a shaly bed in the carbonate that has been plastically sheared and rotated by a left-lateral couple toward the axial plane. Contortionists can take a beautiful picture here.

Return to cars, and proceed in same direction along the main road.

17.2 Turn right on paved road.

19.2 Turn right at sign pointing toward ferry landing.

20.5 Arrive at ferry landing and park cars. Take only essential field gear and adequate clothing (it's at least 10° colder in a boat). Proceed by chartered small craft to Stop 5, northeast side of central point on Spruce Island, on shore immediately below 'A' frame camp.

Stop 5. Muscovite pegmatite in impure marble. This is the Precambrian pegmatite, noted by Smith, Bastin, and Brown (1907, p. 9), that has been isotopically dated. Two independent K/Ar dates on the muscovite are 594 ± 18 and 599 ± 15 m.y. A Rb/Sr mineral isochron yields 620 ± 18 m.y. (Brookins and Stewart, oral communication, 1971).

The impure marble is more coarsely laminated than is typical at Lime Island. Garnet-bearing schist crops out on the eastern shore of the cove southeast of the dolomite but will not be visited. Similar rocks will be seen at the next stop.

Reboard boats and proceed to next stop, the landing of the Dark Harbor Boat Yard Corporation at Cradle Cove, Seven Hundred Acre Island.

Stop 6. Walk west past the boathouses along the shoreline to examine rocks in the Precambrian section. Individual beds approximately 10 meters thick differ greatly in composition. The presence of thin beds of quartzite and carbonate suggests miogeosynclinal sedimentation. However, feldspathic gneiss, greenstone, and amphibolite indicate some igneous activity in the same area. Medium-grade metamorphism is indicated by large garnets. Equally large andalusites (chiastolite) are visible at low tide in pelitic rocks west of the point beyond the boat yard. Extensive retrograding has almost obliterated most andalusite and some garnets, but characteristic shapes remain.

The age of this Precambrian terrane can only be estimated from scattered Rb/Sr data as approximately 750 ± 100 m.y. (Brookins, written communication, 1972).

Reboard boats and proceed to next stop.

Stop 7. Southern point of Seven Hundred Acre Island. Good photos for camera fans.

The rocks of the Islesboro Formation at this stop are chlorite-grade pelite and grit that contrast strongly in grade and metamorphic style with the nearby Precambrian rocks. Original bedding is easily seen with graded beds and bedding-cleavage intersections showing that several 10- to 15-meter folds are present and some are overturned. Pebble beds like those in this outcrop can be traced northward across to the northernmost point of the island.

West along the beach 150 meters, two cleavages can be seen in the steeply dipping west-facing strata. Chlorite bands a centimeter apart mark a relict cleavage that strikes N.60°-80°W. and dips northward at about 45°. The relict cleavage is cut by a younger vertical cleavage that strikes N.10°C. The older cleavage is enigmatic as it cannot be related to folds, and elsewhere on the Islesboro block only vertical or steeply dipping cleavage has been observed. The closest flat-lying cleavage known is at Rockport, 11 km southwest of this locality (Osberg, oral communication, 1970), where axial-plane cleavage occurs in over-turned folds at much higher metamorphic grade.

The younger cleavage is parallel to the large western fault zone and is spaced at centimeter intervals. This spacing should be remembered for comparison with that at the next stop, which probably is only about 100 meters stratigraphically from this horizon but approximately 0.6 km closer to the fault zone.

Return to boats. Proceed to point on west side of Philbrick Cove.

Stop 8. Cameras should be taken ashore. The greenish-gray slates of the Islesboro Formation close to the major fault zone show a remarkable development of cleavages and mineral migration. Old quartz veins crossing the slates show ptygmatic folds with right-lateral shear sense, although younger quartz veins are little deformed. Secondary cleavage at small angles to a first cleavage almost obliterates it. The spacing of both cleavage planes is much closer than at the last stop, being 1 to 2 mm. Intensely cleaved rocks like these make up the western shore of the northern point on Seven Hundred Acre Island, the west shore of Warren Island, and all of Flat, Seal, and Ram Islands to the north and mark the inferred trace of the major fault zone.

Return to boats for trip to ferry landing. On the way, note the highly cleaved rocks of the western shores of Seven Hundred Acre and Warren Islands. The Islesboro Formation along this shoreline is a green or gray slate some parts of which contain many ferruginous and calcareous claystone concretions. These resist weathering, and together with the intense cleavage and differential weathering yield a rasplike outcrop surface that needs to be treated with respect by geologists and stranded seamen.

Trip ends at ferry landing. Line up cars for next ferry to Lincolnville. If time remains, a visit to the museum in the lighthouse at Grindel Point or a walk along the shore would be informative. Walk through the spruce grove past the brick shed northwest of the toll booth. A series of thin to 6-meter thick ferroan dolomite beds, pelites, and greenstones is exposed on the shore. The carbonates are hardly cleaved, with schistosity parallel to bedding. Nearby gray pelites and psammites are cleaved, and greenstone dikes, though broken into blocks, are hardly sheared internally. Although this area is only a few hundred yards from the projected strike of the highly cleaved rocks on Warren Island, it has not been strongly affected. Possibly the Grindel Point-Islesboro Harbor sub-block moved southwestward into the fault zone, and the cleaved rocks were scraped off shortly before fault motion ceased.

Drive carefully up Route 1 to Stockton Springs, la to Bangor, and 95 to Orono.