Title: Preliminary Report on the Bedrock Geology of the Tenants Harbor 7 1/2' Quadrangle and a portion of the Friendship 7 1/2' Quadrangle, Maine.

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This report is preliminary and has not been edited or reviewed for conformity with Maine Geological Survey standards.

Contents: 12 page report and map
Introduction

This report and the accompanying maps are based on two to three weeks of field mapping during each of the summers of 1976, '77, '78, and '79. This mapping was undertaken in order to extend the mapping carried out previously by the writer in the Rockland and Thomaston 7 1/2' quadrangles. That mapping work is presently on open file status with the Maine Geological Survey and has also been summarized in Osberg and Guidotti (1974).

Osberg and Guidotti (1974) described the stratified rocks in terms of three sequences of units, the Benner Hill Sequence, the Megunticook Sequence, and the Rockport Sequence. Each sequence consists of several units, the relative ages of which could be established by means of graded beds etc. However, the relative age relations of each sequence with respect to the other two sequences could not be established.

Starting near the town of Thomaston and trending southwest down the St. George River, the writer mapped (See Fig. 1 of Osberg and Guidotti (1974)) a large anticline involving the three units of the Benner Hill Sequence. Three questions which arose were: (1) How far to the south did this structure and associated strata extend? (2) Did the Benner Hill unit undergo some facies changes along strike as proposed by Osberg and Guidotti? (3) Did any units of the Megunticook Sequence occur along strike to the south of the large granite body shown by Osberg and Guidotti along the southern border of the Thomaston quadrangle?

STRATIGRAPHY

Benner Hill Sequence

All three of the units of this sequence are clearly present in the map area and are describable essentially as done by Osberg and Guidotti
Hence, there is little doubt that this sequence extends to the south along the St. George River but then swings to the east along the south side of the large granite pluton in the southern part of the Thomaston and northern part of the Tenants Harbor quadrangles. However, the geologic map shows that the sequence "noses" out in an ENE plunging anticline in the vicinity of Hart Neck. Then it swings to the SSW again and trends out to sea toward the islands in the south-central part of the Friendship quadrangle.

Descriptions of the three units in the sequence are given on the geologic map. The relative ages implied by the sequence of units given in the legend of the map are based on the mapping results given in Osberg and Guidotti.

As seen on the geologic map, in many localities the strata of this sequence are intimately mixed with intrusive material. In most cases this intrusive material is granitic but near the diorite bodies it commonly involves diorite also. Moreover, especially for the quartz-rib unit along the southern shorelines (eg. Marshall Point and Hoopers Island) there is a progressive recrystallization and intermixing with granitic material on a small scale. The result is a gradual, progressive transformation into a rock looking approximately like a granite with just wispy inclusions of metamorphic rocks. In many cases these inclusions of wispy metamorphics seem to remain in essentially the same orientation as the on-strike, less recrystallized metamorphic rocks.

Benner Hill Unit (See map for lithologic description)

It is of particular interest that both of the lithologic varieties described in this unit by Osberg and Guidotti are present in this area. Moreover, they clearly grade into and interbed with each other on a small
scale. For example, the northern outcrops of this unit on the St. George River are free of any garnet bedlets and are much like the rocks exposed at the Prison Farm in the Thomaston quadrangle. However, these same outcrops are directly traceable along strike about .5 km into outcrops with abundant garnet bedlets. Or also at Southern Island (at the mouth of Tenants Harbor) there is spectacular development of the garnet bedlets but there are also some zones that are more like the exposures at the Prison Farm. Furthermore, some of the garnet-rich Benner Hill unit near Deep Cove on the St. George River is interbedded with metavolcanics, some of which may have pillow structures.

It seems clear that the observations made in this study completely confirm the facies variations in the Benner Hill Unit which were suggested by Osberg and Guidotti. Also confirmed is the suggestion that the garnet-rich Benner Hill lithology is an intimate part of the sequence involving the quartz-rib unit. This is an important feature because the mapping covered in the report of Osberg and Guidotti was not able to establish this point.

Because the Benner Hill Unit has rusty weathering surfaces, it was a fairly easy matter to distinguish it in outcrop from the other two units of the sequence. Moreover, its contact with the underlying Biotitic-Unit is fairly sharp as seen in some of the outcrops in the vicinity of the village of Tenants Harbor. Only in the case of the rusty weathering outcrops on Mosquito Island is there much doubt on whether or not the strata are part of the Benner Hill Unit.

**Biotitic Unit:** (See map for lithologic description)

Some of the quartzose pelites in this unit contain thin, light colored laminae of quartzo-feldspathic material. In such cases it becomes difficult
to distinguish rocks of this unit from those in the Quartz-rib Unit. However, in most cases the light colored laminae are much thinner and less pronounced than those in the Quartz-rib Unit. Moreover, the pelites in the Biotitic Unit are almost always intimately associated with biotite granulites and grits - both of which are almost non-existent in the Quartz-rib Unit. Hence, only at small, isolated outcrops in the woods (especially if associated with abundant, small granitic intrusives) was much difficulty encountered in distinguishing the Biotitic Unit and the Quartz-rib Unit.

An especially distinctive, though quantitatively minor lithology in the Biotitic Unit is quartz-pebble conglomerate. The pebbles are mainly quartzite and vein quartz, ranging up to 10 cm in diameter and set in a biotitic quartzite matrix. These conglomerates are best developed as two to three meter thick bands in a ten meter thick zone that trends along much of the east-central shoreline of Hart Neck. Very good exposures are present on the northern lip of the locally popular site known as "the roaring spout". This conglomerate also occurs as a few one-half meter thick beds on the shores of the St. George River just south of Turkey Cove.

Very good exposures of this unit are present just south of Turkey Cove and truly spectacular outcrops of it are present along virtually all of Hart Neck. In general the Biotitic-Unit has conformable, gradational contacts (over about 50 meters) with the underlying Quartz-rib Unit. The contact relations are especially well shown just south of Turkey Cove.

Quartz-rib Unit: (See map for lithologic description)

This unit is characterized by the light and dark banding described in the legend of the geologic map. Only very minor amounts of any other
lithologic type are present in this unit. One of these other lithologic
types that is especially noteworthy is flaggy bedded amphibolite. It is
similar in appearance to the quartz-rib schist except that the mica schist
portion is made up of dark green amphibolite. This flaggy bedded
amphibolite seems to become more abundant in the western part of the
area — especially on Hooper Island. It is almost never found associated
with the other units of the area.

Very good exposures of the Quartz-rib Unit are present at the road
cuts on Rte. 131, just east of Port Clyde and also along the eastern
shores of Mosquito Harbor.

Megunticook Sequence

Based upon the regional strike of this sequence as seen on the map
of Osberg and Guidotti (1974, Fig. 1) one would expect it to be present
in the Tenants Harbor quadrangle (ie. to the south of the large granite
body). However, because the Benner Hill Sequence swings to the east on
the south side of the granite pluton, none of the Megunticook Sequence
was found in the expected localities. The question now becomes whether
or not it is present offshore to the east of Southern Island and Hart Neck.

Reconnaissance of most of the islands in the northern part of the
Hewett Island quadrangle (eg. Graffam, Bar, Hewett, and Andrews Islands)
suggests that they are all granite. However, Two Bush Island is underlain
by rusty weathering metamorphic rocks that could be the Owls Head Unit of
the Megunticook Sequence. Obviously it will be necessary to go ashore
there and look at the rocks in detail.

On the other hand, Metinic Island (~10 km to the SSW of Two Bush
Island) is clearly underlain by the Owls Head Unit of the Megunticook
Sequence. The rocks there are virtually identical with the strata at Owls Head. Some question remains about the correct assignment for the rusty weathering strata on Mosquito Island. They look most like the Benner Hill Unit and seem to be on strike with the good exposures of that unit on Southern Island. However, uncertainty arises because there is some suggestion of a NE trending fault on the NNW corner of Mosquito Island. This suggested fault seems to separate the grey-weathering Biotite Unit from the rusty-weathering strata on the remainder of the island. Some additional field work on Mosquito Island should resolve these questions.

It should be noted in conclusion, that the 1967 Geologic Map of Maine incorrectly shows the rocks on Mosquito, Metinic, and Two Bush Islands as granite.

**STRUCTURE**

The geologic map and attitudes of bedding map shows a major anticline that trends ESE from the St. George River into the central part of the Tenants Harbor quadrangle. This anticline which is cored by quartz-rib schist bifurcates into one anticline that plunges out (≈35°) to the ENE over the northern end of Hart Neck and into another anticline trending SW out to sea through the village of Port Clyde. These two anticlines may in fact be part of the same structure, the south limb of which is at sea to the WSW of Mosquito Island.

The overall structure thus appears to be half of a saddle with the seat of the saddle over Turkey Cove. It is not known now how this structure relates to the structures to the west across the St. George River. A. M. Hussey (MGS, in house report) shows NE trends for the strata immediately across the St. George River and this is corroborated by more detailed but unpublished mapping by D. Newberg.
The structures discussed above are based upon map patterns and attitudes of bedding. In general, the structures implied by the map pattern and attitudes of bedding coincide quite closely. This is especially well shown in the vicinity of Hart Neck. However, in a few localities the attitudes of bedding do not seem to occur in coherent patterns. Most of these cases seem to be associated with extensive mixing with small intrusive bodies or involve outcrops near the contacts with larger intrusives—especially some of the diorite plutons. On the other hand, in numerous localities where intrusive material is even the dominant material, the attitudes of inclusions of metamorphic rocks retain attitudes consistent with those in adjacent outcrops consisting wholly of non-intrusive material.

In most outcrops, the dip of the metamorphosed strata is very steep—commonly nearly vertical. The only major exception to this generalization is on the ENE plunging "nose" of the Hart Neck anticline.

Most of the minor folds observed are tight isoclinal structures plunging in both directions parallel to the trends of bedding. In many cases they have very steep plunges—commonly near vertical. In a few cases these tight folds appear to deform an earlier set of tight minor folds.

A distinct axial plane cleavage can be seen in many of the better exposed minor folds, but it is always strongly recrystallized. The folding and cleavage developments appear to be either previous to or synchronous with the intense metamorphism which has affected the strata.

Some late, postmetamorphic shear zones have been observed. They are relatively minor features in that they are only 0.5 to 1.0 meter thick and do not appear to offset any of the map units. They always have steep dips and commonly trend about N60°E. These features clearly represent some late fracturing. However, they are very much less common than was the case
in the Rockland quadrangle. In that area many of the outcrops are greatly jointed and cut by postmetamorphic shear zones.

**Igneous and Metamorphic Petrology**

*(based on field observations only)*

All of the stratified rocks were at one time at sillimanite grade or higher. Based on the absence of migmatites and fewer small granitic intrusives, it would appear that the stratified rocks in the eastern part of the area are the lowest grade. In contrast, the rocks in the west and southwest portions of the area show spectacular development of migmatites and are intruded by a multitude of small granitic to dioritic bodies. Many such outcrops (e.g. at Marshall Point) range from intimate mixtures of schist and igneous rocks to just inclusions of schist in granite. Also, there are spectacular examples of the Quartz-rib and Biotitic Units progressively "developing" small wisps of granitic material and gradually undergoing a transition into a rock looking much like a granite. In such transitions the bedding progressively becomes more disrupted and is finally obliterated. These latter features are especially well displayed just north and south of the village of Port Clyde and on Hooper Island.

All of the metamorphic rocks are now at least somewhat retrograded. This is indicated by the prominent development of muscovitic pseudomorphs after andalusite and sillimanite and irregular biotite (and chlorite?) aggregates after some presumably Fe-Mg mineral. The pseudomorphs after andalusite consist of medium-grained muscovite plates and form euhedra up to 4 cm long. They are well displayed on weathered surfaces along portions of Hart Neck.

The long directions of the "andalusite prisms" are randomly oriented
but lie within the plane of foliation. These relations suggest that the initial andalusite may have formed while the rocks were being subjected to some regional stress but the pseudomorphing occurred under essentially static conditions.

The igneous petrology of the area is extremely complex. Many different types of igneous plutons have been emplaced in a sequence of events. On the geologic map only the three especially abundant lithologic types are shown. However, there are many other less prominent varieties which are intermediate to the three main groups. In general it has been found that the dark colored varieties are oldest and the lighter colored types are progressively younger.

The contacts of the diorite bodies are quite indistinct and almost gradational in the sense of outcrops of metamorphic rocks with many small diorite intrusives ranging to outcrops which are mainly diorite with just inclusions of the metamorphics. The contact relations of the granitic rocks are commonly similar to those of the diorite bodies except in the vicinity of the village of Tenants Harbor. There the contact of the granite body seems to be more distinct and sharply defined.

The diorite bodies and especially the gabbro body clearly appear to have been affected by a metamorphic event. Because of the intrinsically less reactive mineralogy in the granitic rocks it is difficult (based only on field observations) to determine whether they have suffered any metamorphism. However, it should be noted that especially in the vicinity of the village of Tenants Harbor, Southern Island, Hart Neck, and Mosquito Head, there are sharply bounded granitic dikes, sills, and irregular plutons that at the very least have not suffered any deformation. Again however, it is not yet possible to tell if they have been subjected to any meta-
morphic events.

The igneous petrology of the area is sufficiently complex and interesting that it would be worthy of a specific, detailed study. Moreover, the area has numerous granite quarries and therefore very good, fresh exposures are available for such a study.

**Summary and Proposed Further Work**

Mapping of the peninsula portion of the area is essentially complete and seems to interrelate well with mapping by the writer in the Rockland and Thomaston quadrangles. This new work serves to expand the "geologic picture" of coastal Maine both in terms of stratigraphy and geologic structures. The only remaining field work is some minor re-checking of the offshore geology on Mosquito Island and Hooper Island.

This mapping project has resulted in the recognition in the area of a rather interesting structure. The special interest arises because E-W trending structures are not common in the geologic belt along coastal Maine. The orientation of the structure which has been mapped seems clearly related in a spatial sense to the distribution of igneous plutons. However it is not clear yet whether the unusual orientation is directly due to bowing aside by the intrusives or whether it results from some interaction between the fold-causing stresses and the presence or emplacement of the plutons.

It is evident that in the case of some of the smaller plutons (e.g. the diorites) there seems to be truncation and direct re-orientation of the metamorphosed strata on a local scale. But in the case of the larger granitic bodies the relationships are less clear. For example, near the village of Tenants Harbor along the southern border of the large granite
body, the bedding of the metamorphosed strata dips steeply toward the pluton. In general however, the commonly indistinct contacts and spatial relations between the metamorphic rocks and the distribution of plutons suggests that intrusion, deformation and high grade metamorphism (sillimanite and/or andalusite) were roughly contemporaneous, but with recrystallization possibly outlasting deformation.

The fact that the metamorphic rocks in the west and southwest are much more intimately intermixed with granitic material whereas those in the east do not involve small scale intermixing with granitic material and have sharp contacts with the granites present suggests that the rocks in the east represent higher tectonic levels than those in the west. This suggestion is in harmony with the observation that andalusite pseudomorphs are present only in the east whereas the remnant sillimanite observed was in outcrops from the western and southwestern part of the area. In turn, these observations tend to lend support to the suggestion that intrusion, deformation and metamorphism are roughly synchronous.

Subsequent to the above described events the area was subjected to another metamorphism under static conditions. This metamorphism appears to have been lower grade than the first event. Possibly it may have affected the granitic rocks also but the petrography required to establish this point has not yet been done. Indeed, considerable thin section petrography will have to be done in order to get further information on the geologic history of the area and to refine the proposed interrelationship between the E-W trending geologic structures and the areal distribution of plutonic bodies.

In terms of possible additional field mapping to expand and check the models developed herein, two routes seem to hold promise.
(1) Extending mapping to the east and southwest: Basically this mapping would entail a couple of weeks of island geology. To the east it would include the islands at the southern end of Two Bush Channel (previously noted as being underlain by rusty-weathering metamorphic rocks) and Little Green plus Large Green Islands. In essence, this work would complete the mapping of the Hewett Island 7 1/2' quadrangle. It would provide some control on whether the Megunticook Sequence underlies much of the southwest corner of Penobscot Bay. It would also provide information on what probably lies immediately east of the Benner Hill Sequence in the Tenants Harbor quadrangle.

To the southwest this proposed work would include the islands in the south-central part of the Friendship quadrangle and the north-central part of the Monhegan quadrangle. It would provide some idea of how far out to sea in a southwesterly direction the Benner Hill Sequence might extend. "Binocular reconnaissance" from Marshall Point suggests rusty weathering rocks on Allen and Burnt Islands. Hence, it is an obvious question as to whether the rocks there are part of the Benner Hill Unit or the Owls Head Unit.

(2) Extending mapping across the St. George River into other parts of the Friendship quadrangle. This work would presumably be done in conjunction with D. Newberg who has done considerable detailed mapping there already. Such work would be oriented toward solving the problem of the interrelationship between the WNW strikes on the east side of the river and the NE strikes on the W side of the river.

References