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Title: Bedrock Geology of the Palermo 7.5-minute Quadrangle, Maine

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INTRODUCTION

The Palermo 7.5-minute quadrangle is the northwest quarter of the Liberty 15-minute quadrangle (see Figure 1). It is thus located on the Norumbega Fault Zone and is an area in which rocks of the Central Maine Sequence are juxtaposed against the older rocks of the Casco Bay Group.

The Palermo quadrangle has not previously been mapped although several studies have included reference to rocks in the area. For example, Perkins and Smith (1925) refer to the Branch Pond gneiss in their discussion of the relationship between the Vassalboro sandstone and the Waterville shale. Exposures of the Vassalboro Formation west and south of Branch Pond are presumably at sillimanite grade and as a result appear different from the lower grade outcrops of similar lithology to the west -- hence the different name. Perkins and Smith suggested that "...the sudden change... from unmetamorphic to metamorphic rock suggests a break of some kind" (1925, p. 224). The Dearborn Brook Fault, named by Pankiwskyj (1976), is such a break. It offsets Acadian metamorphic isograds.

Pankiwskyj (1976) began to map the Liberty 15-minute quadrangle, which includes the Palermo quadrangle, but did not complete this work. He considered the rocks, which outcrop in the northwestern half of the quadrangle, to include 5 lithic types (1976, p. 1), all of which were assigned by him to the Vassalboro Formation. They were:

1. feldspathic biotite granofels with minor interbeds of biotite schist
2. biotite granofels with abundant interbeds of biotite schist
3. rhythmically layered biotite granofels and calc-silicate granofels
4. sulfide-rich metasandstone and metasiltstone
5. mica-rich metapelite.

In the mapping upon which this report is based, lithic types 1-3 were not separately identified. Type 4, however, is considered a separately mappable lithology. Type 5 is assigned to the Waterville Formation.

In addition to the Dearborn Brook Fault discussed above, Pankiwskyj named the Jose Pond and Hackmatack Pond faults. There is no good evidence of the existence of the Jose Pond Fault. However, the Hackmatack Pond Fault which Pankiwskyj (see Figure 2) considered to separate rocks of the Central Maine Sequence from rocks of the Casco Bay Group is an important folded pre-metamorphic thrust.
Figure 1. Location of the Palermo Quadrangle relative to major structural features of the Casco Bay - Lower Androscoggin River area of Maine (modified from Figure 1 of Newberg, 1983b).
Figure 2. Figure 2 of Pankiwskyj (1978).
STRATIGRAPHY

ROCKS OF THE CASCO BAY SEQUENCE

Cushing Formation

Much of the southeastern third of the Palermo quadrangle is underlain by rocks of the Cushing Formation. The predominant lithology is a buff weathering mica-poor granofels which has a flaggy to angular and blocky break and contains scattered large garnet porphyroblasts and patches of magnetite. Good exposures of this lithology occur northeast and southwest of Dow and Hackmatack Ponds and on the hill between Prescott Pond and Nutter Pond. Additional outcrops can be seen just west of Saban Pond. Because of the similarity of these exposures to rocks in the northwest part of the Wiscasset quadrangle (see Newberg, 1984, p. 5, 29) they are considered to represent the Nehumkeag Pond Member of the Cushing. Included within the Nehumkeag Pond Member are an impure marble (and/or amphibolite and calc-silicate granofels) unit and a metapelite unit. It seems apparent that Pankiwskyj considered these to comprise his Sandy Pond Member, which he described as "...composed of aluminous leucocratic staurolite-garnet-kyanite granofels and schist, coarsely garnetiferous amphibolite, biotite-rich staurolite schist, calc-silicate granofels, and minor marble" (Pankiwskyj, 1976).

Along U.S. Route 3 at Greely Corner on the south boundary of the quadrangle, as well as on the hill immediately east of Beech Pond, other lithologies are present within the Nehumkeag Pond Member. The outcrop of Greely Corner has previously been described by Pankiwskyj (1978, p. 8). It includes amphibolites and lenses which contain diopsidic augite, plagioclase, biotite, and garnet.

In the southeast corner of the quadrangle, the Wilson Cove Member of the Cushing Formation is assumed to be present on the basis of float observed along the road east of Sandhill Cemetery. The Cape Elizabeth Formation, which unconformably overlies the Cushing, is also assumed to be present on the basis of relationships in adjoining quadrangles. Like the Wilson Cove it does not outcrop within the Palermo quadrangle.

ROCKS OF THE CENTRAL MAINE SEQUENCE

Rocks of the Kearsarge-Central Maine Sequence (Lyons et al., 1982) include the Sangerville, Waterville, and Vassalboro Formations. Graptolite faunas found in these rocks are not sufficiently diagnostic as to clearly resolve the question of their relative ages. In addition, each formation, although characterized by a distinctive lithology, contains intervals essentially indistinguishable from one or both of the other formations. For example, poorly graded, thick beds of coarse sand to clay-sized material can be found in both the Sangerville and Waterville Formations. When metamorphosed to sillimanite grade, beds of this sort do not reveal the original sedimentary top from particle size grading and sillimanite is scattered throughout sedimentation units that have a round, rubbly appearance on the weathered surface. Similarly, intervals of the Waterville and Vassalboro Formations can be indistinguishable where
regional metamorphism has produced a sequence of banded biotite and calc-silicate granofels from sediments which presumably were calcareous siltstones with little or no clay.

Presently -- as reflected in the new State geologic map -- the Vassalboro is considered the oldest and the Sangerville the youngest of the three formations. However, at other times (e.g. Osberg, 1968), the sequence has been reversed. Also, Ludman (1976) suggested that the Rangeley, Sangerville, and Waterville Formations could be related in a facies model in which they are, respectively, proximal, intermediate, and distal sediments deposited relative to a sediment source to the west. The Vassalboro Formation was considered younger -- Late Ludlow to Devonian in age.

What appears most likely is that these rocks are part of a conformable sequence of sediments deposited in closely related but spatially and temporally distinct environments. The depositional basin was a tectonically unstable and rapidly subsiding one which existed after the close of the Taconic Orogeny. Possibly a highlands along the present axis of the Bronson Hill-Boundary Mountain Anticlinorium shed sediment eastward, developing a sequence of poorly sorted and weakly graded turbidity current deposits and grain flows. These characteristics typify the Sangerville Formation along Route 23 between Dexter and Guilford, Maine. The instability of the Sangerville Formation depositional environment is evidenced by soft-sediment slump features, sedimentary decollement surfaces, rip-up clasts, and other features (Griffin, 1973; Newberg, 1983a). The Waterville Formation includes lithologies suggestive of a more stable environment that may not have been interrupted by repeated faulting and slumping of sediment. It is finer grained, thinner bedded, much better sorted, and much more aluminous than the Sangerville Formation. Impure ribbon limestone is interbedded with shale in the Waterville Formation. The Vassalboro Formation includes a sequence of calcareous feldspathic siltstones and silty sandstones which typically are moderately well graded and show an abrupt transition to a minor (+10%) amount of clay at the tops of beds. The rocks are typically thick bedded. However, transposition of layering during primary soft-sediment deformation has resulted in much of the Vassalboro Formation -- particularly where metamorphosed to alternating biotite schist and calc-silicate granofels -- having a thin bedded appearance. The Vassalboro Formation is correlated with the Madrid Formation of Northwestern Maine. If the two lithologies are time-correlative as well, and the Vassalboro Formation is of easterly derivation while the Madrid Formation is of westerly derivation, the paleogeographic implications are interesting. Basically a very large area existed in which environmental conditions were similar, as were the sediment source areas and mode of sediment transport (?). The idea that the Kearsarge-Central Maine Synclinorium sediments accumulated in a two-sided basin has been proposed previously by Roy (1980). The basin may have been located between proto-North America with its accreted arc and Armorica (see Perroud et al., 1984).

In addition to the questions concerning the stratigraphy of the Central Maine Sequence, there is also the question of their relationship to the rocks of the Casco Bay Group. Radiometric dating (Brookins and Hussey, 1978) indicates that the latter sequence is distinctly older. On a
regional scale, units of the Vassalboro and Waterville Formations are in contact with different units of the Cushing Formation. Hence the contact is clearly not conformable. The assumption of a pre-metamorphic thrust contact between the two groups of rocks is based in part upon the lack of conglomerates, or meta-conglomerates, at the contact.

In the absence of conclusive data conflicting with the facies model of Ludman (1976) and the relative ages he assigned to the formations, the author prefers his sequence to that generally accepted. Hence the Waterville Formation is here considered to be older than the Vassalboro Formation. The Sangerville Formation -- or its correlative -- is absent in the Palermo quadrangle.

Waterville Formation

Osberg (1968, p. 13) describes the Waterville Formation as consisting of greenish gray pelite, quartz wacke, gray limestone, minor black phyllite and their metamorphic equivalents.

At Sennetts Corner in the north-central portion of the Palermo quadrangle a finely laminated calcareous phyllite is exposed on the northeast side of the road. Additional outcrops of this lithology can be found to the northeast, east of the road to Albion. The phyllite fizzes vigorously with dilute HCl, is rust-spotted, and is flecked with biotite porphyroblasts. This lithology is poorly exposed along strike to the southwest, but, along the Negro Ridge Road 3600 ft north of its intersection with the Parmeter Hill Road, a narrow (30 ft wide) interval of impure marble crops out. The marble is contained within an interval of non-rusty weathering non-calcareous metapelite. These two lithologies are considered facies equivalents of the calcareous phyllite to the northeast. All three are considered Waterville Formation on the basis of their similarity to type Waterville Formation.

At several places, notably 65°, 2200 ft from Carrs Corner, as well as along the ridge east of Center Cemetery, massive fine-grained pyrrhotite occurs as pods and lenses within impure marble. Outcrops of this lithology are rare and small.

Vassalboro Formation

The Vassalboro Formation in the northwest part of the quadrangle consists of calcareous sands and silts in beds of variable thickness. An outcrop just west of the Palermo quadrangle boundary and approximately 0.8 mi east of the village of China contains gritty sands in beds up to 1.5 ft thick which contain internal laminations interpreted to represent cross-bedding. In other outcrops near China, as well as at the quarry at Twitchell's Corner 3 mi east of Burnham, early transposition of bedding is clearly shown. A thin section taken from the quarry contains sub-angular to sub-rounded < 0.4 mm grains of quartz, feldspar, calcite, muscovite, and rock fragments in a poorly sorted sandstone with carbonate cement.
Osberg (1968, p. 22) describes the Vassalboro Formation as consisting of "...heavy bedded, light bluish gray, slightly calcareous wacke...with thin (interbeds of) medium gray phyllite." There is in excess of 100 ft of Vassalboro Formation exposed in the Waterville quadrangle 0.15 mi east of Paine's Corner on the north side of State Route 137. The rocks are purplish gritty siltstones with or without thin pelitic "tops" which are muscovite rich, silvery, and biotite flecked. Bed thickness is highly variable: 3 ft - 0.5 in.

Most of the exposures of the Vassalboro Formation in the Palermo quadrangle are at considerably higher metamorphic grade than the rocks described above. They are best described as a monotonous sequence of compositionally layered biotite granofels, biotite schist, and calc-silicate granofels. Deformation and recrystallization has masked the thick bedded character of the Vassalboro Formation except for a few localities (see, for example, the outcrops in the gravel pit just north of the intersection of the Western Ridge and Parmeter Hill Roads). Also the internal cross laminations are rarely recognized at higher grade. However, fine examples can be seen 2000 ft east of the intersection noted above, in the clearing just south of the road. Sedimentary top can be determined here and indicates the relationship between rusty and non-rusty intervals of Vassalboro Formation, which, unfortunately, is of no value in understanding the basic stratigraphy of the larger area.

The Vassalboro Formation contains an unknown number of rusty-weathering intervals. While a few of these are also pelitic and locally graphitic, most are simply intervals where sufficient pyrite is present to drastically change the weathering character of the rock. Outcrops approximately 0.5 mi north of Dirigo Corner in the Vassalboro quadrangle and along Western Ridge Road in the north-central part of the Palermo quadrangle illustrate this lithology well. In the Palermo quadrangle a number of these intervals have been mapped. All are considered stratigraphic and their pattern suggests that they represent several stratigraphic horizons and cannot be relied upon as "marker beds." Furthermore, their lateral continuity is suspect.

IGNEOUS ROCKS

Few igneous rocks outcrop in the Palermo quadrangle except for pegmatites, confined largely to the area underlain by the Cushing Formation, and a large body of biotite granite gneiss. The latter is massive to strongly foliated, and the foliation is tightly folded in outcrops at the north end of Sheepscot Pond south of U.S. Route 3. In thin section the rock contains perthitic microcline-plagioclase-quartz-biotite-muscovite. The name Sheepscot Pond pluton is informally proposed. The intrusive is a syntectonic Acadian granite.

METAMORPHISM

The Casco Bay Group rocks (Cushing and Cape Elizabeth Formations) which outcrop in the southeastern third of the quadrangle are at sillimanite or higher metamorphic grade on the basis of a few locations
that contain diagnostic mineral assemblages. These rocks have been 
metamorphosed at least twice, but the rather complex sequence of 
deformational and metamorphic events demonstrated elsewhere (see Hussey, 
1981) cannot be resolved here. There is, however, a very interesting 
pattern of Acadian isograds within the Merrimack Group rocks (Figure 3). 
Generally the metamorphic grade increases from west to east and from north 
to south. Although the control is not as good as it might be, the data 
suggest that the metamorphic isograds are displaced to the north on the 
east side of the Dearborn Brook Fault. Assuming shallow northward dips for 
the isogradic surfaces this offset is consistent with left-lateral strike-
slip motion. However, it is also consistent with east-side-up oblique slip 
along the fault surface with a component of right-lateral strike-slip 
motion. Minor folds observed in outcrop just west of Tobey's General Store 
on the north side of U.S. Route 3 have axes whose trend and plunge are 
200°, 43°. The displacement sense is east-side-up, and, assuming motion 
perpendicular to the fold axes, the oblique slip in the fault surface would 
have been inclined 47° from the horizontal. The sillimanite isograd is 
offset 10,000 ft along the trace of the fault. Figure 4 summarizes these 
relationships.

Unfortunately, neither the slip along the fault surface nor the dip of 
the sillimanite surface are known. However, to illustrate how one might 
quantitatively determine one of these assuming the other were known, we can 
make a simple calculation. Pratt (1985) in a gravity study of the Blinn 
Hill granodiorite calculated 400-600 ft of dip-slip post-emplacement motion 
along a fault transecting the body. If we use 500 ft for simplicity in 
this example, the dip of the sillimanite surface is determined to be 3°N 
(see Figure 4).

Retrograde metamorphism is associated with motion along several of the 
recognized faults. This is best seen just west of Carrs Corner along a 
splay of the Palermo School Fault which is not shown on the map. The rock 
is a metapelite in which pseudomorphs of cordierite after staurolite 
porphyrroblasts have been retrograded to sericite and chlorite. Guidotti 
(pers. comm.) has suggested that this metapelite (which Pankiewskij mapped 
as the Sandy Pond Member of the Cushing Formation and which I include as a 
unit within the Nehumkeag Pond) records two metamorphic events. In a pre-
Acadian metamorphism the assemblage kyanite-staurolite-sillimanite was 
formed. During Acadian metamorphism sillimanite again developed and the 
staurolite was pseudomorphed by cordierite. The cordierite has then been 
"pinnitized" in association with post-Acadian brittle faulting. To the 
south along the trace of the same fault, an outcrop on the north side of 
U.S. Route 3 shows numerous slickensided surfaces along which biotite is 
altered to chlorite.

STRUCTURE

The stratigraphic uncertainties discussed above make resolution of the 
structures in the Palermo quadrangle very difficult. For example, the two 
bands of Waterville Formation including calcareous phyllite, and its facies 
equivalent pelite and limestone, might be assumed to occupy two limbs of a 
large upright fold. However, the lack of symmetry of the units suggests 
that this is not the case. In Figure 5, a schematic NW-SE structure
Figure 3. Acadian metamorphic isogrids and post-metamorphic faults of the Palermo area, Maine.
Figure 4. Calculated dip of Acadian isogradic surface.
section drawn approximately through Branch Pond presents a hypothetical resolution of this problem. A soft-sediment slide of major proportions truncates the Waterville through Vassalboro stratigraphy, placing transported Vassalboro Formation of much younger age in contact with older Waterville Formation units just east of the Dearborn Brook Fault. Evidence for such a slide consists of a zone of very curious disrupted bedding which is exposed just north of the Albion town line on the Western Ridge Road. Similar structure is seen in Vassalboro Formation outcrops near the village of Freedom.

The structure section shown in Figure 5 indicates that this zone should also outcrop to the west. No analogous structures in the Vassalboro Formation near the contact with the Waterville Formation metapelites exposed to the west have been found. The metapelite occupies the core of an anticline in this interpretation, rather than a syncline as was previously proposed. It plunges very gently to the southwest, closing in the adjacent Vassalboro 15-minute quadrangle.

The compositional layering in the rocks -- which is assumed to represent transposed bedding and not true bedding in most instances -- is steeply inclined. Northwest of the Dearborn Brook Fault the dips are southeast, whereas to the southeast the dips are to the northwest. The reason for this change is unknown. It seems possible, but unlikely, that rotation of the structures due to movement on the fault could account for this.

The tight isoclinal folds, with gentle north plunges outlined by the impure marble and calc-silicate granofels unit of the Nehumkeag Pond Member of the Cushing Formation between Dowe and Beek Ponds illustrate the structure well. These, as well as the problematic structure discussed above, are Acadian folds. They are probably F-2 structures more or less coaxial with early recumbent folds that are possibly related temporally to the sedimentary slide shown on Figure 5. These F-2 folds also deform the Hackmatack Pond Fault which is interpreted as a west-over-east thrust separating the Casco Bay Sequence rocks from the rocks of the Merrimack Sequence. Finally, high-angle faults cut all earlier structures. They are evidenced by mylonitic and/or cataclastic textures. Good examples may be seen along U.S. Route 3 approximately 0.25 mi north of Palermo School and just west of Tobey's General Store, as well as in the Liberty 7.5-minute quadrangle 0.50 mi northwest of Thurston's Corner.
Figure 5. Schematic northwest-southeast structure section drawn through Branch Pond, Palermo, Maine.
REFERENCES


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