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Title: *Bedrock Geology of the Waterboro 7.5-minute Quadrangle, York County, Maine*

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Chris Gusofski

ABSTRACT

Bedrock of the Waterboro quadrangle, southwestern Maine, was mapped as a project for the Maine Geological Survey. Recent studies of arsenic in ground water and its possible relationship with bedrock have led to an interest in better defining the geology of the Waterboro quadrangle.

The bedrock of the Waterboro quadrangle consists of metasedimentary rocks and igneous bodies. The metasedimentary rocks have previously been assigned to the Silurian-Ordovician Hutchins Corner Formation and the Devonian-Silurian Rindgemere Formation. These formations have been subdivided into 8 separate units in this study. From oldest to youngest the stratified rocks are as follows. The Hutchins Corner Formation consists of biotite granofels with calc-silicate lenses. The Rindgemere Formation includes units of quartz-rich schist with thick quartzite beds, andalusite-bearing schist and quartzite, calc-silicate-bearing granofels, rusty schist, schist and quartzite with calc-silicate lenses, granofelsic schist, and interbedded schist and quartzite. Two xenoliths of metasedimentary rock have been mapped within the Lyman pluton. They are of unknown age and include a unit of massive schist and a unit of migmatite that has been highly intruded by the surrounding igneous bodies.

A small unit of biotite-muscovite gneiss, presumably of igneous origin, is mapped in the southwest part of the quadrangle. Intrusive igneous bodies of Carboniferous(?) age include two-mica granite of the Lyman pluton along with dispersed minor granite plutons and scattered pegmatite bodies. The Lyman pluton dominates the southeastern quarter and eastern edge of the map. Mesozoic rocks include widespread northeast-trending mafic dikes and one trachyte sill occurrence.

The major deformational features are, from oldest to youngest: 1) recumbent to upright isoclinal folds with S_1 foliation; 2) asymmetric west-over-east antiforms and synforms with S_2 axial planar foliation; 3) broad warping macroscopic folds; and 4) jointing throughout the quadrangle. No evidence of a major thrust fault between the Rindgemere Formation and the Hutchins Corner Formation was recognized, as had been presented on the 1985 Bedrock Geologic Map of Maine (Osberg and others, 1985). To the contrary, clear evidence of interbedding between the Hutchins Corner Formation and the Rindgemere Formation was found. This suggests a more complex stratigraphic and structural history for the region than previously thought.

Editor's Note: Manuscript and geologic map were originally submitted in 1996.

INTRODUCTION

Purpose

The purpose of this study was to map the bedrock and structural geology of the Waterboro 7.5 minute quadrangle. Due to recent studies in arsenic-bearing ground water and its possible relationship to bedrock (Starer, 1995; Marvinney and others, 1995), the Maine Geological Survey has done detailed bedrock mapping projects in areas of concern. Rocks within the study area were described lithologically and mapped into stratigraphic units. This allowed for the subdivision of units within what was once mapped as a single formation. Field data was collected over the summer of 1995 and was analyzed to determine the structural geology and to create a detailed geologic map and cross-section. Brittle structural features were also analyzed.

Geography

The Waterboro 7.5 minute quadrangle is located in southwestern Maine (Figure 1). It encompasses the eastern portion of the town of Waterboro, the southwestern portion of the town of Hollis, the northeastern corner of Alfred, and the northwestern portion of the town of Lyman, including the Massabesic Experimental Forest. There are six major bodies of water, five of which are located in the south-southeast portion of the quadrangle. While lowlands and swamp make up the majority of the center of the quadrangle, the topography varies throughout the quadrangle with several higher hills in the west and low hills in the east. The lowest elevations are below 230 feet, in Cooks Brook, South Hollis, and Shaker Pond, Alfred. The highest elevation is near the west edge of the quadrangle on Ossipee Hill at 1028 feet above sea level. Two major highways cross the quadrangle, Route 5 running approximately east-west and Route 202 running approximately northeast-southwest. Secondary roads and maintained snowmobile trails, most of which are shown on the 1983 U.S. Geological Survey (USGS) 7.5-minute topographic map, are distributed throughout the quadrangle. Bedrock outcrops, on which this report is based, make up less than 5% of the quadrangle. Outcrops are generally located in areas of high elevation, road cuts, steep slopes, and stream exposures.

Glacial History

Surficial geology deposits within the quadrangle include till, glacial-stream deposits, wetland deposits, and stream alluvium (Meglioli, 1999). The source of the glacial deposits was a continental glacier which retreated through the area at about 14,000 yr B.P. The weight of glacial ice depressed the land surface, and seawater flooded lowland areas as the ice retreated. The Waterboro 7.5 minute quadrangle is near the upper limit of Late Pleistocene marine transgression (Weddle and others, 1993).

Previous Work

Stratigraphic relationships. The regional geology of southern Maine was originally mapped by Katz (1917). The

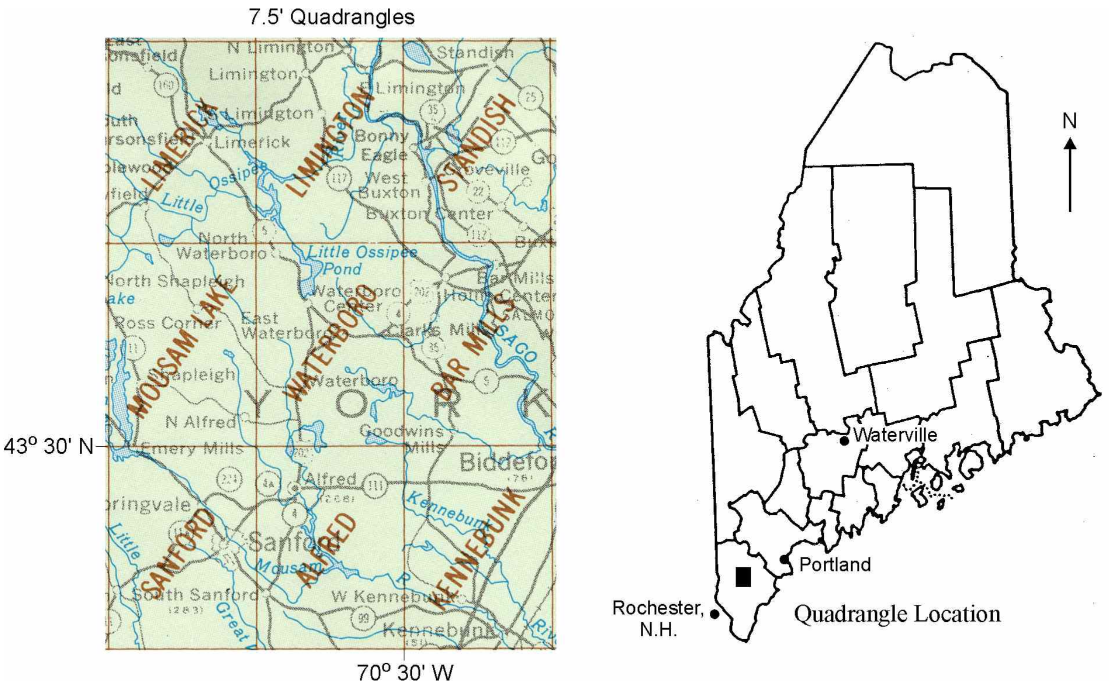

Figure 1. Location map showing the Waterboro 7.5' quadrangle, Maine.

Bath and Portland 2° sheets have been mapped by Arthur M. Hussey II (1985). On these regional maps, the Waterboro 7.5 minute quadrangle contains two formations, both part of the Central Maine Terrane and which are intruded by the Lyman pluton. The Central Maine Terrane is interpreted to have been a large Silurian to early Devonian depositional basin which was repeatedly deformed and metamorphosed during the Acadian and Alleghenian orogenies (Eusden and others, 1993). The Central Maine Terrane extends from Connecticut northeasterly to New Brunswick, bordered to the west by the Bronson Hill anticlinorium and to the southeast by the Norumbega-Nonesuch River fault zone (Lyons and others, 1982).

The two formations mapped by Hussey (1985) included the Vassalboro Formation (named by Perkins and Smith, 1925), and the Rindgemere Formation which is part of the Shapleigh Group (Katz, 1917). The name Vassalboro Formation has since been abandoned, replaced in part by the name Hutchins Corner Formation in the type area (Osberg, 1988) and by extension into southern Maine (Marvinney and others, 1995). This was due to correlations made by Newberg (1984, 1985) and Osberg (1988) that showed that the Vassalboro Formation included some rocks that could possibly be correlated with the Sangerville and Waterville Formations, while also containing rocks older than the Waterville Formation.

Structural relationships. The structural geology of the region has been characterized by a unique set of multiple phases of ductile deformation for each different stratigraphic group (Osberg, 1968, 1980; Hussey, 1985).

In the Waterboro area, the contact between the Vassalboro and Rindgemere Formations was mapped as a folded thrust fault, with the Vassalboro being the upper plate upon the Rindgemere Formation (Hussey, 1985; Osberg and others, 1985). The reason for postulating this fault was that the stratigraphic correlations did not allow for the two formations to contact each other. Hussey (1985) interprets this unnamed thrust fault as being a pre-metamorphic fault. It has been attributed to the Devonian Acadian orogeny because it juxtaposes stratigraphic units of Silurian and Devonian age, and is cut in turn by the Carboniferous(?) Sebago and Lyman plutons. Hussey (1985, his Plate II) shows four major F_2 folds that produce a ‘rabbit ears’ map pattern in the thrust fault between the Hutchins Corner Formation and the Rindgemere Formation in the Waterboro quadrangle.

In coastal New Hampshire and southern Maine, rocks of the Merrimack Group are reported as having three principle fold sets with the earliest folds (F_1) being south-facing recumbent isoclines that are parasitic to a larger fold structure (Hussey, 1985). F_2 folds are upright, open, to slightly overturned, tight folds with a common reversal of plunge, overturning of limbs, and a well-developed axial-plane cleavage (S_2). F_3 folds are characterized as open, overturned, generally dextral folds with strain-slip cleavage. These last folds refold the F_2 hinges.

In the Waterville area (Figure 1), within the Central Maine Terrane, F_1 folds are recumbent, west-facing isoclines whose existence is indicated by downward-facing F_2 folds (Osberg, 1980, 1988). F_2 folds are macroscopic-scale, upright to slightly overturned, tight to isoclinal, northeast-trending folds. Mesoscopic-scale F_3 folds within the area of the Lyman pluton refold F_2 folds, and may have originated due to the emplacement of the pluton (Hussey, 1985).

In the Rochester, New Hampshire area (Figure 1), the Shapleigh Group is interpreted to preserve an east-facing F_1 recumbent anticline, which is refolded by F_2 antiforms and synforms (such as the Lebanon antiformal syncline) (Eusden and others, 1984). This refolded nappe is said to have its major hinge on Blue Job Mountain in southeastern New Hampshire (Eusden and others, 1984). F_2 folds are characterized by tight to isoclinal, recumbent to inclined folds with northeast-trending axes and east-southeast vergence. In general, F_3 folds are broad, open, upright to inclined folds whose axes trend west to northwest.

METHODS

Field Methods

Approximately twelve weeks were spent in the field mapping the bedrock. The USGS 7.5-minute topographic map of the study area, at a scale of 1:24,000, was used as a base map. Each observed outcrop was located on the base map by estimating relation to known reference points or by pace-and-compass methods, assigned a station number, and described in a field notebook.

A total of 313 stations were recorded. These include stations where measurements of stratigraphic and structural features were taken, along with reconnaissance for visual recognition of outcrops that had similar measurements to previous outcrops.

Orientations of structural features were measured using a Brunton compass. The measured features include the strike and dip of bedding (S_0), schistosity (S_1), F_2 cleavage (S_2), crenulations (S_3), and the trend and plunge of fold axes from the first, second, and third phases of deformation (F_1, F_2, and F_3 respectively). Lineations (L_1) were also measured. Foliation in igneous rocks was measured, if present. Contacts of igneous dikes, veins and sills were also measured.

For each station, the major minerals were identified with the use of a hand lens. Sketches were drawn for features of interest, such as interesting structural features, or interesting formation characteristics. Graded beds and tops were recorded when recognized. Rock samples were taken from stations of interest for later microscope study or description.

The strike and dip of joints comprise the brittle structural data collected. This was carried out using the reconnaissance method, which involves the selective measurement of some of the major joint sets at each outcrop. This was done with the hope that it would allow characterization of major joint sets.

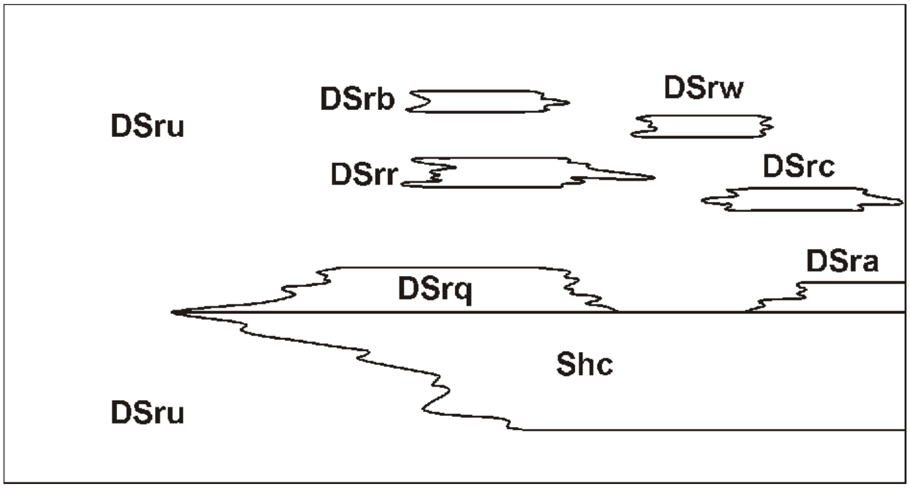

Figure 2. Proposed stratigraphic relationships showing lens-like nature of the units within the Waterboro quadrangle.

Unit	Thickness (meters)
DSrb	250
DSrw	250
DSrr	300
DSrc	250
DSra	300
DSrq	700
Shc	1200

Table 1. Approximate maximum thicknesses of units in the Waterboro 7 ½' quadrangle, estimated from the map.

Geologic Map and Cross Section

Data collected in the field was transferred to a copy of the USGS 7.5-minute topographic map and S_0, S_1, and S_2 were plotted. Contacts of rock units were then drafted on this topographic map. Subsequent mylar drafts were created with inferred locations of F_1 and F_2 fold axial traces. Orthographic projections were used to extend contacts and trace units through areas of limited outcrop.

To understand and visualize the subsurface geology and structure, cross section A-B was constructed. This cross section, presented on the geologic map sheet, extends west to east from Ossipee Hill in Waterboro, to Hollis. Stations where the strike is not perpendicular to the cross section were corrected for apparent dip to project correctly on the section. Stations that were not directly on the line of section were projected parallel to strike until they intersected the section line. Shapes of folds shown on the cross section were drawn using field observations and modeled after equal area projection plots.

Structural Analysis

Structural data were analyzed using the Macintosh version of **Stereonet 4.7A**. Separate equal area stereographic projections were created for S_0, S_1, and S_2. Planes were converted to poles and contoured by the method of Kamb (1959). Trend and plunge of linear fabrics (F_1, L_1, and F_2) were potted for map analysis and visualization. Mafic dike orientations were plotted on **Stereonet 4.7A** and as rose diagrams. Joints were also plotted on a rose diagram to show the major joint orientations.

Petrographic Study

Rock samples were first examined using a Spencer Forty microscope for major mineral composition. Then fifteen samples were cut perpendicular to foliation and parallel to lineation and were made into standard thin sections. A petrographic microscope was used to look at microstructures, textures, and mineralogy. A complete igneous and metamorphic petrologic study was beyond the scope of this project.

STRATIFIED ROCKS

The following description of stratified rock units in the Waterboro 7.5-minute quadrangle is arranged from the interpreted oldest unit to the youngest. This sequence was determined by graded beds recorded in the field and by previously existing stratigraphic models. A schematic stratigraphic diagram is presented in Figure 2. Maximum thicknesses of the lens-like units are given in Table 1. The ages assigned to the formations come from correlations with Eusden and others (1984), Osberg (1988), and Hussey (1985). Most of the Rindgemere Formation is thought to be Silurian, though the upper part may extend into the Devonian.

Hutchins Corner Formation (Shc)*

This formation is commonly well bedded and is a fine- to medium-grained biotite granofels with salt-and-pepper texture. The best location for viewing this formation is at the intersection of Route 202 and Route 5 in East Waterboro. The rocks weather purple and gray to light gray and are rarely rusty. Beds are be-

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* Letter symbols in **boldface** correspond to unit labels on the map.

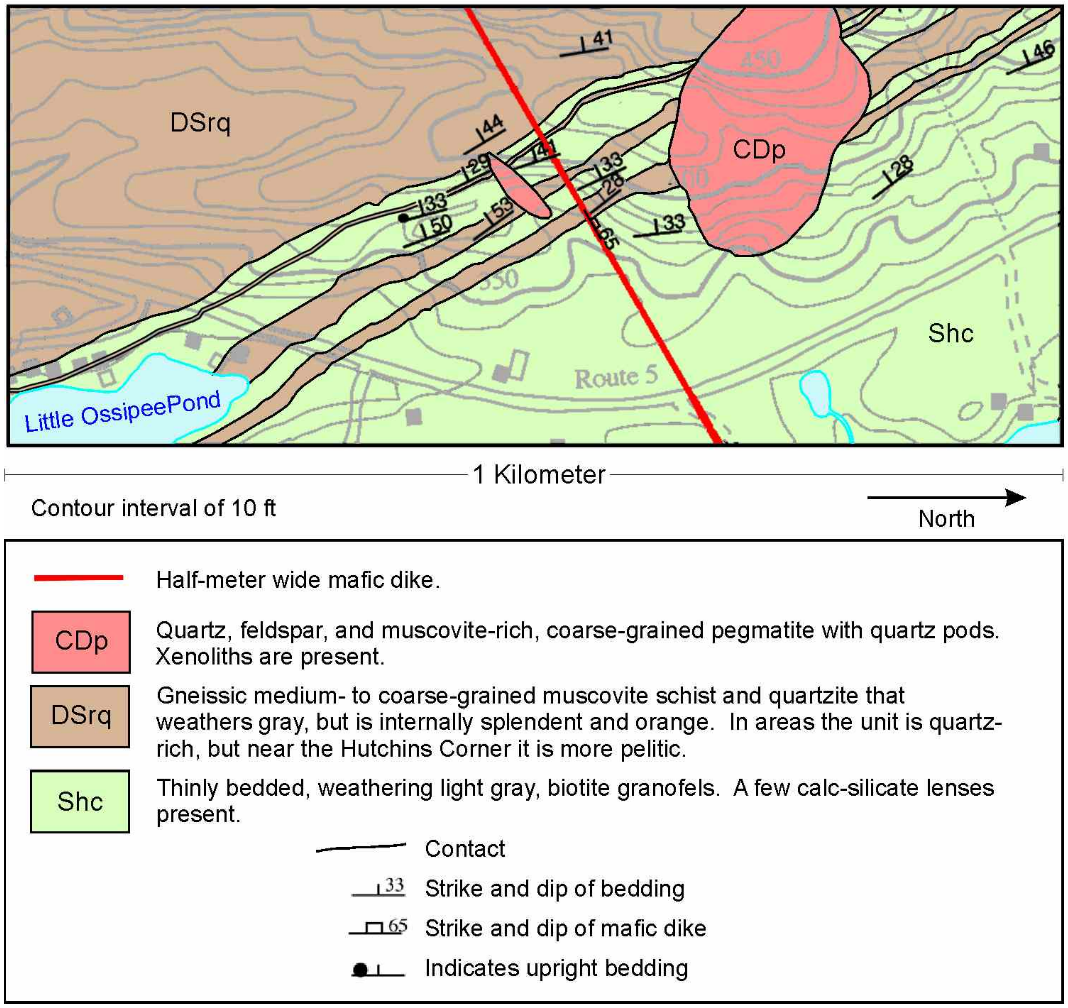

Figure 3. Geologic close-up map of the Herbert Knight Farm on Route 5 between North Waterboro and Waterboro Center. Interbedding between the muscovite schist and quartzite (**DSrq**) and the granofels and calc-silicate lenses of the Hutchins Corner Formation (**Shc**). No evidence of thrust faulting was observed.

tween 1 and 25 centimeters in thickness and include darker beds of biotite, plagioclase, garnet, and quartz, and lighter beds of biotite, quartz, and plagioclase. Typically, there are distinct breaks between the biotite and plagioclase-rich beds and the quartz-rich beds. Calc-silicate lenses that are 17-45 cm thick are commonly present, with the long axis lying within the bedding plane.

Truncated soft-sediment deformation is present in areas representing a steep depositional environment. Muscovite only occurs in certain sections of the quadrangle, where it is coarse-grained and easily visible on a fresh surface. This unit is interbedded with the adjacent muscovite-rich schist and quartzite. Outcrops showing this relationship are located behind the Herbert Knight Farm on Route 5 (Figure 3), where the Hutchins Corner Formation (**Shc**) is interlayered with the quartzite unit of the Rindgemere Formation (**DSrq**). No evidence for a thrust fault was observed between the Rindgemere and the Hutchins Corner Formation. Thus the interpretation of Hussey (1985) is not supported. At the single powerline west of Deering Ridge Road, graded beds along the contact show that the Hutchins Corner Formation (**Shc**) is older than the Rindgemere Formation (**DSru**). However, the Rindgemere is now structurally below the Hutchins Corner as part of an antiformal syncline. (See cross section.)

Another distinctive feature of this unit is metasomatically fused joints. These joints occur as raised ridges along the weathered surface of the outcrop. In some places these joint fillings appear to be quartz rich.

In the southwestern part of the map, a lens of Hutchins Corner Formation extends southward from Moody Pond for more than two miles, roughly following Federal Street. Within roadside outcrops, minor lineations (L_1) are noticeable. These lineations are distinct along the bedding plane and appear to be parallel to the axis of slight "wave-like" folds. However the age and cause of these lineations is unknown.

Rindgemere Formation

General Statement. This formation includes many subunits that have been mapped in various regions of southwest Maine and southeast New Hampshire. Hussey (1985) assigns unit #2 of Eusden and others (1984), containing andalusite pseudomorphed by muscovite, to part of the Lower Rindgemere Formation. Gilman (1991), however, assigns the same unit to part of the Upper Rindgemere Formation. Hussey (1985) and Gilman (1991) both include a rusty-weathering schist, calc-silicate schist, and plagioclase-biotite schist with granofels within the Lower Rindgemere, but these units are not considered to be the typical bedded schist and quartzite of the Rindgemere Formation. In the present study, rocks that were originally mapped as Lower Rindgemere have been subdivided into seven map units, described as follows.

DSru, undifferentiated. This unit is characterized by a dark gray to tan weathering, thin to thick, poorly bedded to well bedded schist (2 cm to 2 m) and granofels (2 cm to 1 m). This rock type is well exposed on the southern summit of Ossipee Hill, due west of Waterboro Center. The schist consists of fine- to medium-grained muscovite, biotite, garnet, tourmaline ± sillimanite and quartz. In places, the schist is more sandy and/or very micaceous, but these variations cannot be mapped into separate units due to their ubiquitous occurrence. This unit can be splendent on a fresh surface due to abundant micas, although it is also red to gray fresh. A well-developed foliation (S_1) is common and is shown by the parallel alignment of micas. Migmatization occurs in some areas and is accompanied by injected pegmatite. The granofels mineral assemblage is quartz, plagioclase, ± biotite, ± muscovite and garnet. Included within this formation in small amounts are beds of light gray weathering biotite granofels that are fine-grained and granoblastic. There are small, meter-wide, rusty lenses in this formation at scattered places in the quadrangle.

DSrq, quartzite and quartz-rich schist. This unit is characterized by thickly bedded quartzites up to 3 meters thick, and beds of quartz-rich schist 2 to 43 cm thick. The best exposure of this unit is on the hill west of the Herbert Knight Farm on Route 5 (Figure 3). The gray to tan weathered schists are fine- to coarse-grained, internally orange-yellow and gray to tan, and composed of quartz, muscovite, biotite and sillimanite. Within this formation are 1-3 cm thick layers of garnet and quartz coticule with the percentage of garnet ranging from 60%-100%. The coticule layers are often discontinuous. In some areas the coticule occurs as pink, garnet and quartz-rich pods rather than layers. These beds commonly interfinger with the Hutchins Corner Formation (**Shc**) that lies stratigraphically below this unit. This unit becomes more pelitic at that contact.

DSra, andalusite schist and quartzite. This member is only seen in the northeastern quarter of the quadrangle. It is nicely exposed in a new housing development 2.5 miles north from Route 202 along Deer Wander Road. It weathers dark to light gray and is a medium to thick, bedded schist (1- 26 cm thick) and quartzite (6-20 cm thick). The schist contains a mineral assemblage of medium-grained biotite, muscovite, plagioclase, sillimanite, and garnet. The quartzite contains quartz, plagioclase, ± muscovite, ± biotite, and garnet. It is characterized by 1 cm porphyroblasts of andalusite pseudomorphed by muscovite producing a nodular, lumpy appearance. These are referred to as "andalumps" (coined by Robinson, *in* Hatch and others, 1983). The long axes of the andalusite pseudomorphs are parallel to F_1 fold axes.

DSrc, calc-silicate-bearing granofels. This member is a distinctive calc-silicate-bearing gray biotite granofels in beds 2-12 cm thick. This unit is well exposed at the "Indian Caves," which are approximtely 500 meters north of Webber Road, north of Little Ossipee Pond. This unit is distinct from the Hutchins Corner Formation due to beds of tan- to gray- to purple-weathering calc-silicate granofels composed of quartz, plagioclase, garnet, diopside, actinolite and calcite. Contacts between this unit and other units are distinct and abrupt.

DSrr, rusty weathering schist. This member weathers to a distinctive rusty (creamy yellow, red to black and maroon) surface. It consists of poorly bedded, generally massive, fissile schist and rare quartzite beds with a thickness of 1 cm to 4 cm. Outcrops weather easily and are seen mostly in stream bed outcrops, although a fine exposure is located on the west side of Ossipee Hill Road, 500 meters along the H-framed power line. The fresh rock is silver to white or gray. The mineralogy includes fine-grained gray quartz, muscovite, plagioclase, graphite, and pyrrhotite.

DSrw, well-bedded schist and quartzite. This unit is made up of coarse- to medium-grained, well-bedded schist (1-8 cm thick) and quartzite (6-32 cm thick). The schist is often migmatized. The gray to tan weathered schist is internally dark gray and composed of muscovite, biotite, sillimanite, garnet, and quartz. Within this formation occur calc-silicate boudins or "footballs" that can be as long as 48 cm. The long axis of the boudins is within the bedding plane. The boudins have white cores with green and red spots of grossular and diopside and are resistant to weathering. This unit is limited to the southern portion of the quadrangle. The best exposure is on the hill to the east of Route 202 and northwest of Bunganut Pond, near where Lyman, Alfred, and Waterboro come together.

DSrb, biotitic schist. This member is light gray weathering, biotite granofelsic schist and quartzite. It weathers light gray and is well bedded, in beds up to 10 cm thick. The fresh color is light metallic gray. The mineral assemblage includes fine-grained biotite, garnet, quartz, and plagioclase. It is not correlative to any other unit and is isolated within the Lyman pluton. The best exposure is in the southern portion of the quadrangle along an unimproved road on the west side of Bunganut Pond.

Unnamed Units

DOus, unnamed schist. This unit consists of massive schist. It occurs within the southeast portion of the Lyman pluton. The best location for observing this unit is along South Waterboro Road, approximately 3.5 miles southeast of Waterboro. This unit weathers dark gray to black and is gray to brown fresh. This unit consists of a muscovite, biotite, and garnet schist. Because it is isolated within the Lyman pluton, the age of this unit and its stratigraphic relation to the other units is not known.

DOum, unnamed migmatite. This unit is made up of a migmatite which occurs within the southeastern portion of the Lyman pluton. The best location for seeing this unit is on an unnamed hill north of the West Outlet of Kennebunk Pond. This unit weathers dark gray to red and is dark to light gray fresh. Individual beds are only a few centimeters thick. The mineralogy of this unit is muscovite, biotite, quartz, plagioclase, ± garnet. Pegmatite bodies often intrude along the bedding planes. As with the unnamed schist unit (**DOus**), the age of this unit is not known. It is assumed that other xenolith bodies exist within the Lyman pluton, but they were not identified due to the limited bedrock exposure.

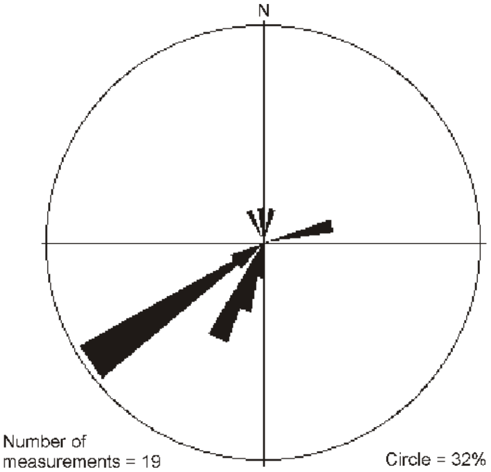

Figure 4. Rose diagram of the mafic dike orientations. This figure shows that the majority of the dikes within the quadrangle correspond with the NE to SW joint set reported in this and nearby quadrangles.

INTRUSIVE ROCKS

Gneiss (Dgn). Two small bodies of gneiss occur in the southwestern portion of the quadrangle. The rock weathers white to red to orange and is similar when fresh. Its mineralogy consists of muscovite, biotite, and feldspar. From the texture and mineralogy of this unit, it is interpreted to be igneous in origin and was later deformed. It is presumably younger than the enclosing stratified rocks and older than the undeformed Lyman pluton, suggesting a Devonian age, but its exact age is not known. The best location for seeing it is on top of an unnamed hill approximately 0.25 miles west from Federal Street, near bench mark BM 273.

Lyman pluton (CDg). This pluton consists of fine- to medium-grained, generally unfoliated granite containing biotite, muscovite, garnet, tourmaline, quartz, and feldspar. The granite weathers light gray to rusty orange, but is white on the fresh surface. Within the quadrangle there have been no direct contacts mapped due to extensive pegmatite intrusion occurring near the granite and metasedimentary rock contacts. This pluton underlies the entire southeast portion of the quadrangle and extends northward along the eastern edge. The Lyman pluton is thought to be Carboniferous based on Rb/Sr whole-rock analysis by Gaudette and others (1982).

Pegmatite plutons (CDp). These pegmatites weather white to yellow and are ubiquitous throughout the quadrangle, although they occur with greater frequency near the Lyman pluton. Their mineralogy includes coarse crystals of feldspar, quartz, tourmaline, garnet, ± biotite and ± muscovite. Rare foliation within the pegmatite, possibly related to D_2 deformation, is defined by parallel alignment of biotite. Near the contact with the surrounding metasedimentary rocks, the pegmatite is adjacent to zones of partial melting and/or migmatization of the country rock. Xenoliths of the country rock within pegmatite bodies are common in these areas. The pegmatites are folded by the second generation of folding (F_2). Pegmatite bodies occur as dikes of variable thickness, but are commonly up to several meters wide.

Mafic dikes. Dark brown to black basalt and diabase dikes contain plagioclase, hornblende, olivine, pyroxene, and biotite. Magnetite occurs in some of the basalts. Approximately 20 dikes were recorded which vary from 2 cm to 3 m in width. These dikes have chilled margins along the contacts with the country rock and do not significantly alter the intruded country rock. Starer (1995), Marvinney (1995), and Hussey (1985) have noted dikes of similar occurrence in the area. Most dikes strike NE to SW as shown in Figure 4. These dike swarms were most likely related to crustal extension and rifting leading to the formation of the Atlantic Ocean in the Late Triassic to Early Jurassic periods. These dikes most likely developed simultaneously with a joint set that also developed during the rifting and extension of crust (Swanson, 1989; Marvinney and others, 1995; Starer, 1995). At the northern edge of the quadrangle, west of Mansion Road, is a mappable, substantially thicker mafic dike (20-30 m wide) of basalt and diabase (**Md**) that extends northeast into the Limington quadrangle.

Trachyte sill. This rock is weathered rusty orange and is internally tan. Phenocrysts of potassium feldspar (30%) demonstrating Manebach twinning and hornblende (<5%) occur within a fine-grained groundmass of orthoclase, albite, hornblende, nepheline, and biotite. If the shallow-dipping joints within the trachyte are interpreted as columnar joints they can be used to approximate the orientation of the igneous body (Twiss and Moores, 1992). This analysis suggests that the one known occurrence is a sill rather than a dike. It is located in a tributary to Shaker Brook, in the northern part of Alfred. Trachytes similar to this are common in the Rattlesnake Mountain igneous com-

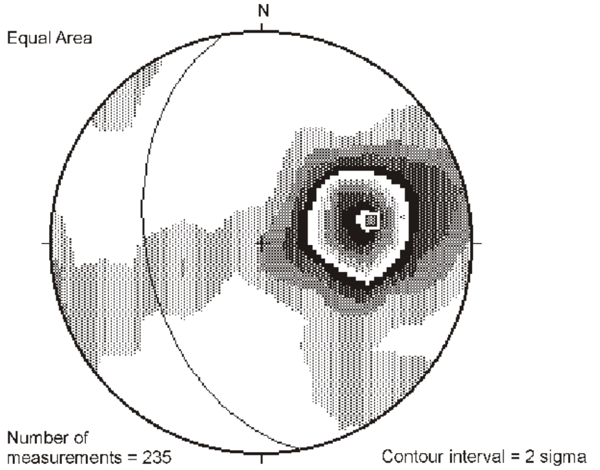

Figure 5a. Kamb contour plot of poles to bedding (S_0) for all units in the Waterboro quadrangle. Great circle shows average strike at 165°, dip 45° SW.

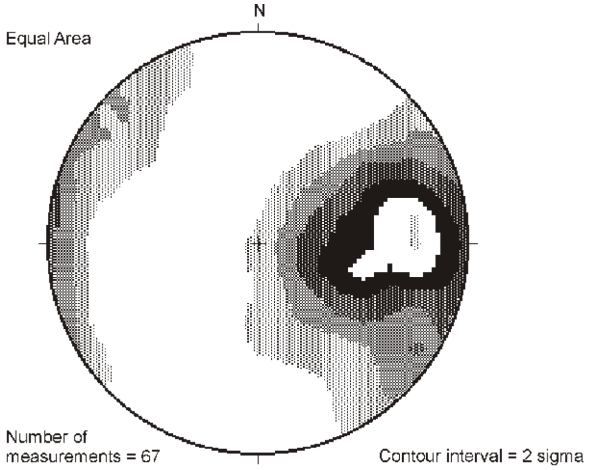

Figure 5b. Kamb contour plot of poles to bedding (S_0) in the Hutchins Corner Formation.

plex located approximately 50 kilometers northeast of Waterboro (Creasy, 1989).

DUCTILE STRUCTURAL FEATURES

The geologic map and cross section are based on the stratigraphy and field measurements of the structural fabrics. Equal area projections showing orientations of S_0, S_2, and F_2 are shown in Figures 5 and 6.

Bedding (S_0) and foliation (S_1) are well exposed throughout much of the quadrangle. These two features are parallel everywhere except within F_1 fold hinges which are quite rare. The strike and dip of the beds are different from place to place. This is somewhat different from the adjacent Bar Mills quadrangle to the east, in which bedding dips steeply eastward almost universally (Marvinney, 1995). In the Waterboro quadrangle, the Hutchins Corner Formation has a similar orientation to the other metasedimentary rocks within the quadrangle. This relationship can be seen by comparing the equal area projections of Figures 5a and 5b.

The average of all strike and dip measurements for bedding (S_0) in the quadrangle is 165°, 45° SW. Graded beds seen in some outcrops indicate the primary facing direction, which determines the relative ages of the formations and delineates areas within the quadrangle where units are structurally inverted.

Phases of Deformation

The first phase of deformation, D_1, is characterized by isoclinal, recumbent nappes. This folding event is represented by parasitic, mesoscopic folds. Good examples of this type of fold can be seen on the southern summit of Ossipee Hill. This deformation affected all the stratified units, since they all contain the S_1 fabric. A macroscopic fold axial trace below the southern summit of Ossipee Hill was determined by a reversal in the facing direction of graded beds. The parasitic folds related to this larger structure indicate that the nappe, possibly equivalent to the Blue Hills nappe (Eusden and others, 1984) has a fold axis with a WNW trend and a shallow plunge with an axial plane striking north and dipping west. These nappes show vergence to the southeast based on facing direction. Within these rare minor F_1 fold hinges of the nappe, bedding (S_0) and foliation (S_1) are oblique. In the northeast portion of the quadrangle, the orientation of andalusite pseudomorphs of **DSra** was taken to represent the orientation of the fold axis, as the long axes of the nodules are aligned along the F_1 axial trace.

According to Eusden and Lyons (1993), within southeast New Hampshire and southwest Maine, an early deformation characterized by a similar nappe style occurred during the Acadian orogeny. This ductile deformation was attributed to the closing of the proto-Atlantic, involving a collision with the microcontinent of Avalon.

S_1 orientations were not plotted on stereograms because they are commonly parallel to S_0.

The second phase of deformation, D_2, is characterized by numerous, mesoscopic, tight to close asymmetric folds. Generally, bedding is overturned in these structures, making the folds antiformal synclines and synformal anticlines. The antiforms have a shallow west-dipping limb and a steep east-dipping limb giving a west-over-east sense of rotation. Axial planar cleavage (S_2) is occasionally shown by the parallel orientations of micas within the fold hinge. This foliation can be seen within the Hutchins Corner Formation, although it has not been noted in neighboring quadrangles (Marvinney, 1995). The average orientation of S_2 is 184º, 54 º W (Figure 6a). F_2 fold axes have an average north trend and shallow plunge (Figure 6b).

The inverted graded beds and downward-facing F_2 folds have shown that the majority of the rocks within the quadrangle

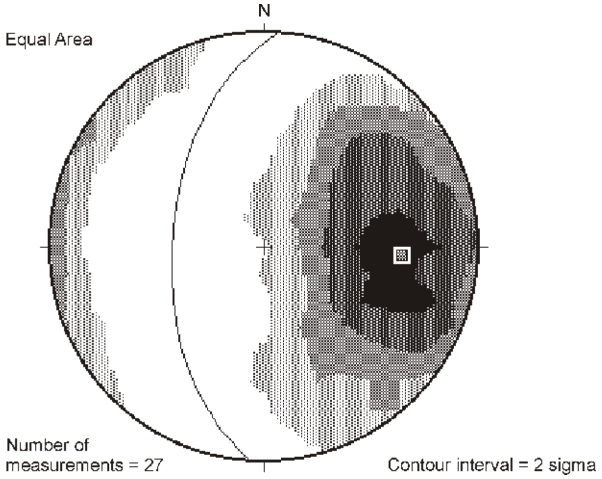

Figure 6a. Kamb contour plot of poles to axial planes (S_2). The plotted great circle shows the average orientation striking 184° and dipping 54° west.

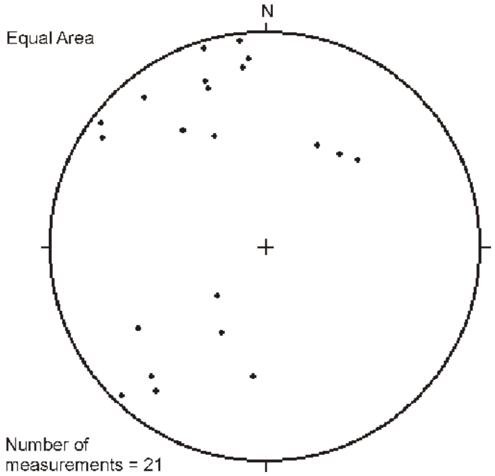

Figure 6b. Scatter plot of trends and plunges of fold axes (F_2).

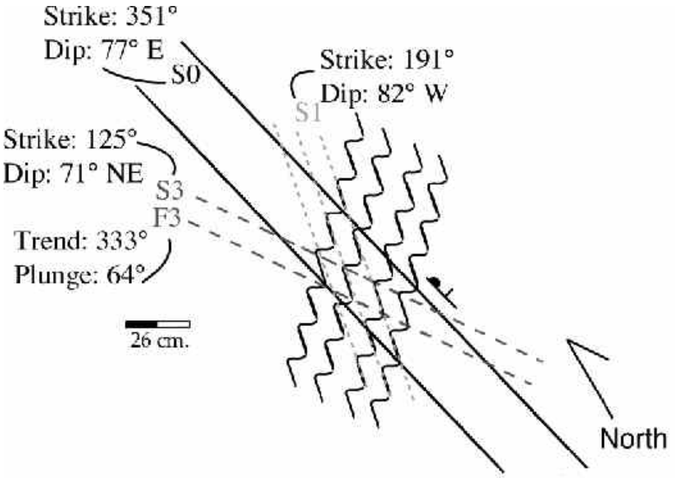

Figure 7a. Model of interaction of S_0, S_1, F_3 and S_3 as seen in the northeast corner of the quadrangle.

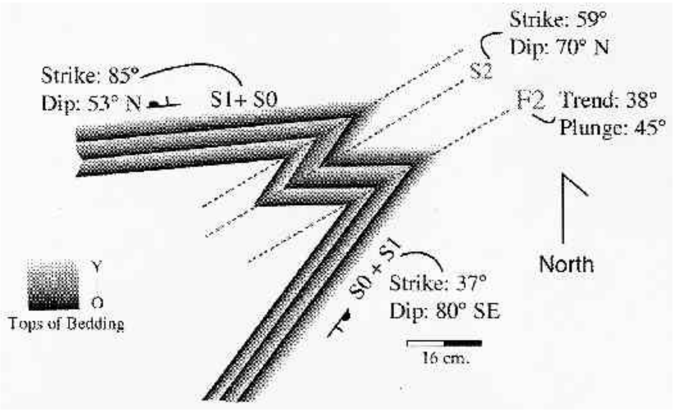

Figure 7b. F_2 anticline demonstrating interactions of S_0, S_1, F_2, and S_2.

lie on the inverted limb of a D_1 nappe, which was refolded during D_2. Pegmatite intrusions cut F_1 folds and are folded by F_2 folds, indicating that their intrusion occurred after D_1 but before D_2. There is commonly an S_2 foliation within the pegmatitic plutons related to D_2.

The third phase of deformation, D_3, is characterized by macroscopic broad warps. While some mild warping of bedding and foliation can be seen on large outcrops, this deformation is most commonly expressed mesoscopically by crenulations. Evidence for this deformation includes crenulations in much of the northeastern metasedimentary rocks. Hussey (1985) and Marvinney (1995) have mapped a foliation that they infer to be intrusion-related, expressed by crenulations within the metasedimentary rocks adjacent to the Lyman pluton. While the majority of the crenulations have been mapped near the contact of the Lyman pluton, they occur over a kilometer away from the contact and do not die out completely.

Figure 7 shows schematic relationships based on field observations of the structural elements related to each deformation. Figure 7a shows a sketch of S_1 intersecting S_0, and both being deformed by F_3 folds and cut by S_3 cleavage. Figure 7b shows an anticline under the single power line located to the west of Deering Ridge Road, where S_2 intersects S_1 and S_0.

BRITTLE STRUCTURAL FEATURES

132 joints from major joint sets were measured. Figure 8 shows the primary orientations of steeply dipping brittle fractures on a rose diagram. The dominant trends are similar to those found in the Buxton area by Starer (1995), who documented a

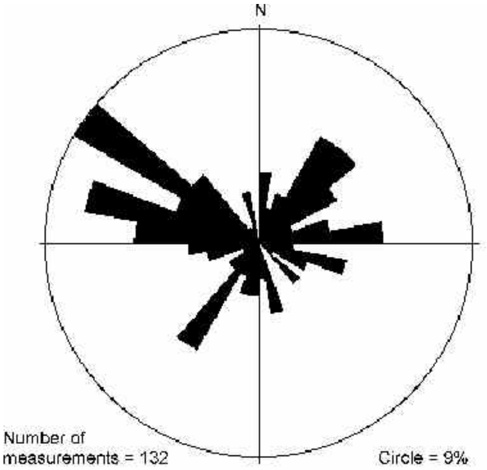

Figure 8. Rose diagram for major steeply dipping joints.

northeast-southwest set and an east-southeast – west-northwest set. In the Waterboro quadrangle, the only mineralization observed on brittle fractures was quartz veining, which occurred in less than 5% of the fractures, and the metasomatically fused joints common in granofels of the Hutchins Corner Formation.

CONCLUSIONS

The bedrock geology of the Waterboro 7.5 minute quadrangle was mapped in detail. The resulting stratigraphic and structural interpretation is that the contact between the Rindgemere and Hutchins Corner Formations is not a thrust fault, but a complex pattern of ductile polydeformation. Stratigraphic interbedding of these two formations was repeatedly observed which led to the conclusion that a new stratigraphic interpretation must be made.

From oldest to youngest, the revised stratigraphy includes the Hutchins Corner Formation and seven units of the Rindgemere Formation, each with distinctive composition and depositional characteristics. Separation of the different units was done to enable comparisons with other formations with similar lithologic characteristics, and to define with precision the geology of the area.

These rocks have undergone three phases of deformation that correlate to those described in New Hampshire by Eusden and Lyons (1993). The first phase, D_1, produced a southeast-verging nappe fold that is related to outcrop-scale isoclinal folds and repeated reversals in the facing direction of graded beds. Antiformal synclines and synformal anticlines of the second phase of deformation, D_2, are asymmetrical, with a west-over-east sense of rotation. The third phase of deformation, D_3, is represented by F_3 crenulations that occur within certain areas of the quadrangle.

To further understand the interaction and diversity of these rocks, neighboring quadrangles should be studied. While the contact between the Rindgemere and the Hutchins Corner Formation terminates southward within the Waterboro quadrangle at the Lyman pluton, it continues to the north for 25 kilometers (Hussey, 1985). By studying this contact zone, further evidence for a new stratigraphic correlation could be found. With this information, a better understanding of the structures and interactions between the lithologies found within southwestern Maine can be gained.

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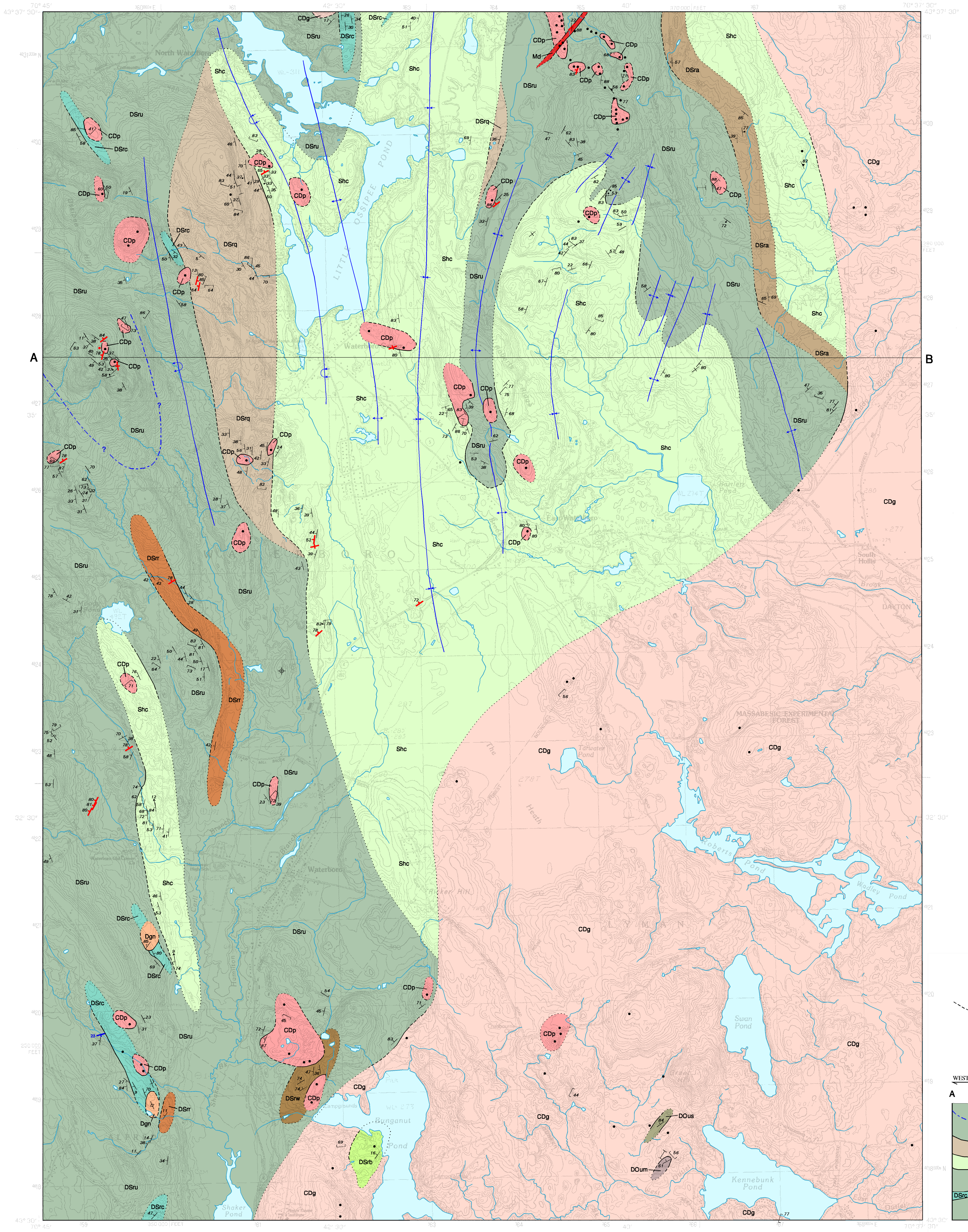

EXPLANATION OF UNITS

Intrusive Rocks

Mesozoic

Md	Thick mafic dike at north edge of map consisting of diabase and basalt with minor gabbro, probably from multiple injections. Mafic dikes too small to map are indicated by red symbols.

Carboniferous-Devonian

CDg	Granite of the Lyman pluton. Light gray to white, medium to coarse-grained biotite-muscovite ± garnet granite. Texturally heterogeneous at the outcrop scale.
CDp	White granitic pegmatite. Commonly contains muscovite, garnet, and black tourmaline. Only a few of the larger bodies are mapped separately; small bodies are common in schist of the Rindgemere Formation.

Devonian

Dgn	Unnamed muscovite-biotite-feldspar gneiss.

Stratified Rocks

Devonian-Silurian

DSru	**Rindgemere Formation.** Undifferentiated. Variably interbedded, coarse-grained quartz-mica-garnet schist and medium-grained quartz-feldspar-biotite granofels. Generally weathers dark gray to pale brown, but is locally rusty.
DSrb	Light gray, well bedded, fine-grained quartz-feldspar-biotite-garnet granofels to granular schist.
DSrw	Well bedded quartzite and schist. Muscovite-biotite-sillimanite-garnet-quartz schist is subordinate to thicker bedded quartzite. This unit also contains minor amounts of calc-silicate granofels shaped like flattened footballs.
DSrr	Rusty weathering, fissile, graphitic, sulfidic schist with minor thin quartzite beds.
DSrc	Light purplish gray, biotite-quartz-feldspar granofels with interlayered calc-silicate granofels.
DSra	Well-bedded gray quartzite and schist. Schist contains distinctive lumps of andalusite, or of sillimanite in pseudomorphs after andalusite.
DSrq	Thick bedded quartzite and subordinate light gray quartz-rich mica schist. Thin pink layers of garnet-quartz coticule occur sporadically.

Silurian

Shc	**Hutchins Corner Formation.** Medium gray, fine-grained to medium-grained biotite-quartz-plagioclase ± garnet granofels. Generally weathers to light gray, but locally somewhat rusty.

Devonian-Ordovician

DOus	Unnamed massive muscovite-biotite-garnet schist.
DOum	Unnamed migmatitic schist.

EXPLANATION OF SYMBOLS

⌖ 20 ✕ Bedding, tops unknown. (Horizontal, Inclined, Vertical)

20 20 Bedding with known topping direction. (Upright, Overturned)

20 Foliation. (Inclined)

20 Cleavage. (Inclined, Vertical)

20 Joint. (Inclined, Vertical)

20 ✕ ● Mafic dike. (Inclined, Vertical, Orientation unknown)

20 Trachyte dike. (Inclined)

20 Lineation. (Plunging)

● Outcrop without structural data.

Bedrock Geology of the
Waterboro Quadrangle, Maine

Bedrock geologic mapping by
Chris Guzofski
Geologic editing by
Henry N. Berry IV

Digital cartography by:
Bennett J. Wilson, Jr.
Susan S. Tolman

Robert G. Marvinney
State Geologist

Cartographic design and editing by:
Robert D. Tucker

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DEPARTMENT OF CONSERVATION
MAINE

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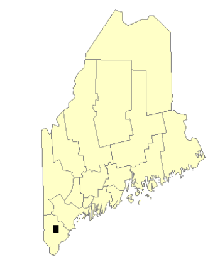
Open-File No. 04-15
2004

This map accompanied by 11p. report.


Quadrangle Location

TRUE NORTH

SCALE 1 : 24,000

1 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 0 1 KILOMETER

CONTOUR INTERVAL 10 FEET

SOURCES OF INFORMATION

Bedrock mapping by Chris Guzofski completed during the 1995 field season. Additional field work by Henry N. Berry IV in the northeastern corner of the quadrangle during the 1996 field season.

Topographic base from U.S. Geological Survey Waterboro quadrangle, scale 1:24,000 using standard U.S. Geological Survey topographic map symbols.

EXPLANATION OF LINES

Stratigraphic or intrusive contact between rock units.
- ——— Well located
- - - - - Approximately located
- ······· Inferred

Axial trace of F_1 recumbent anticline. Inferred from facing of graded beds.

Axial trace of F_2 antiform. Inferred from structural data.
- Upright
- Overturned

Axial trace of F_2 synform. Inferred from structural data.
- Upright
- Overturned

A ——— B Line of cross section.

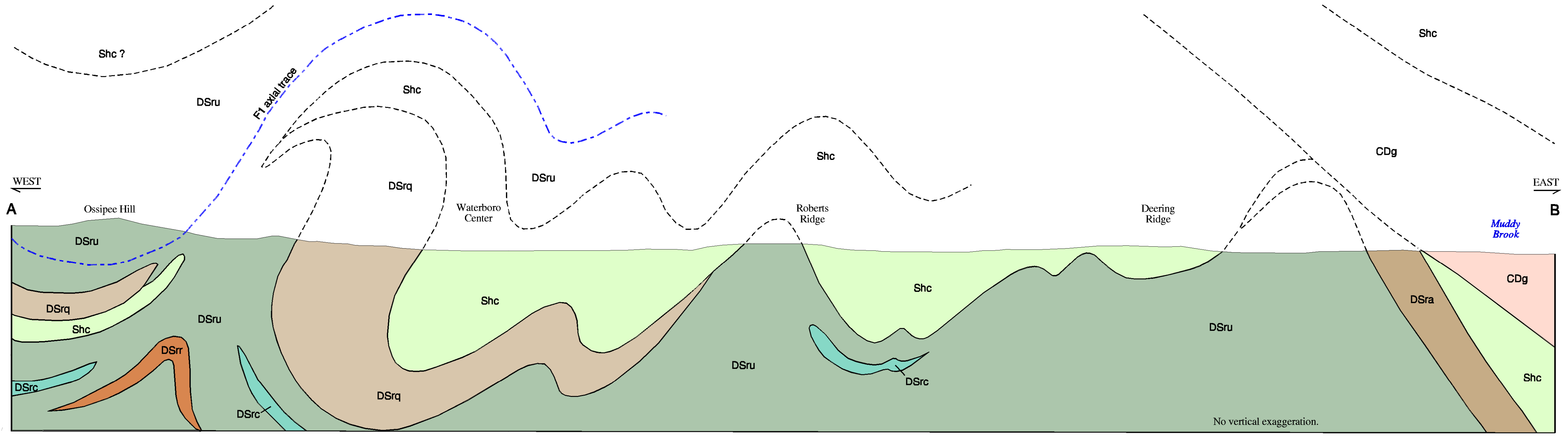
GEOLOGIC TIME SCALE

Geologic Age		Absolute Age*
Cenozoic Era		0-65
Mesozoic Era	Cretaceous Period	65-145
	Jurassic Period	145-200
	Triassic Period	200-253
Paleozoic Era	Permian Period	253-300
	Carboniferous Period	300-360
	Devonian Period	360-418
	Silurian Period	418-443
	Ordovician Period	443-489
	Cambrian Period	489-544
Precambrian time		Older than 544

* In millions of years before present. (Okulitch, A. V., 2002, Échelle des temps géologiques, 2002: Commission géologique du Canada, Dossier Public 3040 (Série nationale des sciences de la Terre, Atlas geologique) - RÉVISION.)

INTERPRETIVE CROSS SECTION

Units are colored below ground; contacts are dashed where projected above ground.



No vertical exaggeration.