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INTRODUCTION

The Fletcher Peak 7.5' quadrangle of eastern Maine was first mapped by Larrabee (1964) who described major rock types such as metasedimentary rocks and granites, and recognized through-going northeast-trending faults even though he did not realize their regional significance. The Bedrock Geologic Map of Maine (Osberg and others, 1985) considered these faults to be extensions of the Norumbega fault zone first mapped by Stewart and Wones (1974) north of Penobscot Bay in the south-central part of the state (Wones, 1978). This fault *system* is now known as one of the largest transcurrent fault systems in the Northern Appalachians (Figure 1; Ludman and West, 1994). Ludman's reconnaissance in eastern Maine from the early 1990's revealed three major high-strain strands of the Norumbega fault system (NFS) in eastern Maine: the Waite, Kellyland, and Codyville fault zones. Two of these, the Waite and Kellyland fault zones, pass through the Fletcher Peak 7.5' quadrangle.

The Norumbega fault system is an extensive but enigmatic regional structure, and its tectonic significance and deformation history are still hotly debated. Most previous work along the NFS was concentrated in the high-grade, mid-crustal segment in southwestern Maine (e.g. Swanson, 1992; West, 1993) where spectacular features characteristic of ductile shear are ubiquitous. Ludman (1994, 1998), Ludman and Gibbons (1995, 1999), and Ludman and others (1999) recently reported very different features in eastern Maine from those in southwestern Maine. The differences are due to the different crustal level exposed in the two regions. Ludman's regional mapping east of the Fletcher Peak quadrangle showed that strain in the shallow crustal segment of the NFS was concentrated in the three 2-5 km wide ductile and brittle zones mentioned above. Ludman (1994, 1998), Ludman and Gibbons (1995, 1999), and Ludman and others (1999) have also suggested a multi-episode, four-stage deformational history for the NFS in eastern Maine. Previous traverses in the area (Ludman, unpublished data) suggested that the Fletcher Peak quadrangle could provide an excellent section of the fault system and facilitate detailed exploration into the geometry, extent, spatial variations, deformation mechanics, displacement, and temporal evolution of the Norumbega system.

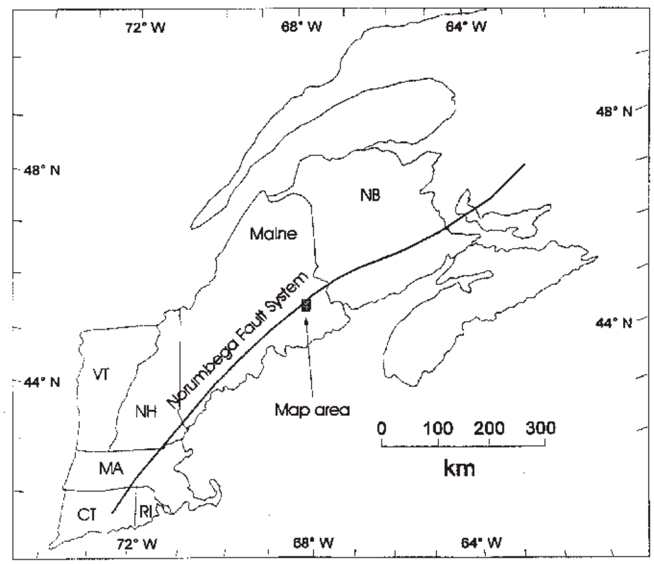

Figure 1. Schematic trace of the Norumbega fault system in the Northern Appalachians and the map area.

Thus the Fletcher Peak study area is essential to understanding the shallow-crustal segment of the system.

Because of its geometric complexity and multi-stage tectonic history, many details of the fault system remain unclear, so that more detailed mapping and research are required for complete understanding of the NFS in eastern Maine. The goal of this project was to decipher the fault history and mechanics through the detailed mapping of these two essential parts of the NFS, a complete transect across the Kellyland fault zone and part of the Waite fault zone. With petrographic, petrofabric, and thermochronologic studies, the sequence and nature of deformation in both granite and metasedimentary rocks could be identified. Coupled with Ludman's previous mapping, work in the Fletcher Peak quadrangle would permit more precise delineation of NFS history in eastern Maine than that accomplished by any previous workers anywhere else along the system.

This report summarizes the results of the mapping project supported by the USGS-EDMAP Program through the summers of 1998 and1999. Work was concentrated in the northern half of the quadrangle during the 1998 field season because previous mapping suggested (correctly, as it has turned out) that a particularly good transect through the Kellyland fault zone was present, with some road traverses and some woods traverses conducted in the southern half of the quadrangle. During the 1999 field season, the southern part of the quadrangle was mapped, the northern part was revisited and refined, and a combination of reconnaissance and detailed reconnaissance mapping was extended along strike to both northeast and southwest in order to improve understanding of the geometry of the fault system.

GEOGRAPHIC SETTING AND TOPOGRAPHY

The Fletcher Peak 7.5' quadrangle is located in eastern Maine between 45°00' and 45°07'30" north latitude and 67°52'30" and 68°00' west longitude. Most of the quadrangle lies within Washington County, although a small slice of the southwest corner is located in Hancock County. The quadrangle and its surrounding areas are situated in the Northern Appalachian orogen and have had a long and complex geologic history spanning most of the major orogenic events responsible for Paleozoic accretion along the eastern margin of the North American plate.

The area has been intensively glaciated and consists of a few prominent hills and ridges that reach elevations as high as 982 feet (the Lookout Tower on Washington Bald Mountain). Prominent hills and ridges include Washington Bald Mountain in the northern part of the quadrangle, Slewgundy Ridge in the central western segment, and Fletcher Peak, Knox Mountain, and Elwell Ridge in the south. Note that two features are named Fletcher Peak in this quadrangle: the prominent peak in the south-central part of the quadrangle, and a prominent cliff at the southwest end of Washington Bald Mountain. The lowest elevations in the quadrangle are occupied by several lakes such as Fifth Machias Lake, Third Machias Lake, and Second Machias Lake, and by several swamps. Dense woods cover most of the area except for some large cliffs and hilltops that have been clear-cut by paper and lumber companies. The quadrangle is very sparsely populated with only a few summer cabins around some lakes and a few winter cabins for hunting. An extensive network of unpaved gravel roads built by lumber companies provides access to almost the entire area.

Bedrock exposures comprise less than 1% of the total area and are mostly found on glacially-scoured hilltops and along lakeshores. Excellent outcrops have also been found on Fletcher Peak cliff and other hills, but these are rare. Interestingly, fault rocks produced by ductile shearing in the Kellyland fault zone are *more* resistant to erosion than their undeformed protoliths, and are ridge-formers. As a result, outcrop control of the Kellyland zone is remarkable compared with the remainder of the region.

GEOLOGIC SETTING

Tectonically, eastern Maine is composed of several different lithotectonic terranes. Ludman and others (1993) summarized six major belts; from east to west, these are the Coastal Volcanic belt, St. Croix belt, Fredericton belt, Miramichi belt, Aroostook-Matapedia belt, and Kearsarge-Central Maine belt respectively. The Fletcher Peak quadrangle is in the central part of the Fredericton belt, a thick pile of deep-water turbidites deposited from late Ordovician through middle Silurian times, and is separated by faults from Cambrian-Ordovician terranes to the northwest (Miramichi belt) and southeast (St. Croix belt).

Fredericton belt metasedimentary rocks have been divided into three formations: from oldest to youngest, these are the Pocomoonshine Lake, Digdeguash, and Flume Ridge Formations. The Flume Ridge Formation dominates in the belt and hosts the Norumbega fault system. The Fredericton rocks were tightly folded during the late Silurian to early Devonian Acadian plate collision and metamorphosed to only lower greenschist facies conditions (chlorite-zone). They were subsequently intruded in late Silurian and early Devonian times, first by mafic bodies to the southeast (e.g. Pocomoonshine gabbro-diorite) and then by large granitic plutons such as the Deblois and Bottle Lake plutons. The Deblois pluton is one of the largest granitoid bodies in Maine and underlies the entire southern part of the quadrangle. The NFS shearing began only after the intrusion of these plutons, but was reactivated at least twice – during Carboniferous and Mesozoic times (Ludman and Gibbons, 1995; Ludman and others, 1999).

Because of deformation partitioning, Norumbega shear strain was concentrated into at least two high-strain zones in the study area, the Kellyland and Waite fault zones, as named by Ludman (1994, 1998). The Kellyland fault zone forms the northwest contact between the Deblois pluton and Flume Ridge Formation in the northern half of the Fletcher Peak 7.5' quadrangle, and is the major structural feature in the quadrangle. Only a small segment of the Waite fault zone is exposed, in the northwestern corner of the study area.

MAPPING METHODS

Most of the mapping involved pace-and-compass traverses through the woods that cover most of the area, but odometer-and-compass traverses were also made along most of the drivable lumber roads in the quadrangle. Traverses were also made along lakeshores and islands in lakes, including the northeast and southwest sides of Third Machias Lake, the south side of Fourth Machias Lake, and Second Machias Lake. Most of the islands in Third Machias Lake and Fourth Machias Lake were also mapped by boat traverses. With extra financial support provided by the Maine Geological Survey in the 1999 field season, boat traverses were also made to the islands and lakeshores in Nicatous Lake and Gassabias Lake southwest of the Fletcher Peak quadrangle in order to reveal details of the Norumbega fault system on a regional scale.

A total of 422 bedrock outcrop stations were visited in the summer of 1998, most in the Fletcher Peak 7.5' quadrangle, and 204 additional stations were found during the 1999 field season, mostly outside the quadrangle along the strike of the fault system to the southwest. Sparse bedrock exposure meant that there were some traverses without any outcrops.

LITHOLOGY AND MAP UNITS

All previous workers have recognized two major bedrock categories in the quadrangle and surrounding areas: Fredericton belt metasedimentary rocks and plutonic bodies such as the Deblois granite and Bottle Lake igneous complex. The Fredericton belt, a thick pile of turbidites deposited from late Ordovician through middle Silurian times, has been classified into three formations: Pocomoonshine Formation (the oldest), Digdeguash Formation, and Flume Ridge Formation (the youngest; Ludman, 1986, 1987). Only the Flume Ridge Formation is exposed in the Fletcher Peak quadrangle.

The Flume Ridge Formation consists for the most part of medium to thick beds of variably calcareous, fine- to medium-grained quartzo-feldspathic wacke. It is by far the dominant unit in the Fredericton belt, accounting for approximately 75% of the total area. In the Fletcher Peak 7.5' quadrangle, however, it only occurs to the north of Washington Bald Mountain as sheared and faulted slices. Most of the bedrock in the quadrangle is Deblois granite, a mostly coarse to megacrystic pink K-feldspar hornblende-biotite granite. Besides these previously described rock units, mapping by this project identified a slice of ductilely sheared, coarse- to medium-grained biotite-granite between the Kellyland and Waite fault zones in the northern part of the quadrangle. This sliver is sandwiched between blocks of sheared Flume Ridge strata and is thus physically separated from the coarser grained main body of the Deblois granite in the quadrangle. This granite extends northeastward to Third Lake Ridge in the southern part of the Dark Cove Mountain 7.5' quadrangle which abuts the Fletcher Peak quadrangle to the north, and southwestward across the Gassabias Lake quadrangle to the west. We have also found a small stock of fine- to very-fine-grained granodiorite intruded into Flume Ridge wackes north of the Kellyland fault zone on the north side of Washington Bald Mountain.

Since the Flume Ridge Formation and much of the granitic rock in the quadrangle have been greatly involved in the Norumbega faulting (Figure 2), to show the bedrock geology and especially the geometry, extent, and strain variations of the Norumbega fault system in the quadrangle, we have applied the strain-intensity mapping method to the quadrangle. Therefore, rocks involved in the fault system have been classified into map units in terms of strain intensity or strain facies.

Stratigraphy

Flume Ridge Formation

The stratified rocks in the northern part of the quadrangle all belong to the Flume Ridge Formation of the Fredericton belt. Due to the early large-scale ductile shearing along the Norumbega fault system, much of the Flume Ridge Formation in the Fletcher Peak quadrangle is typically sheared to at least some extent. Shear strain facies, and the superimposition of later-stage brittle faulting, permit us to classify the Flume Ridge Formation in the quadrangle into three mappable units as follows.

SOf: undeformed to slightly sheared Flume Ridge Formation. This unit includes the slightly sheared and non-sheared Flume Ridge Formation. The rocks are a series of generally calcareous quartzo-feldspathic wackes with subordinate pelitic interbeds. Contact metamorphism took place around each granitic pluton and the granodiorite, its extent varying with the dip of the contact and types of rocks hornfelsed. In general, aureoles are more extensive in slate and metasiltstone than in wacke. The aureoles are marked by the appearance of biotite and locally actinolite, as well as by the presence of traces of chalcopyrite and pyrrhotite. Clastic texture is well preserved (Figure 3). Primary sedimentary features, such as bedding (S_0), graded bedding, and scour-and-fill features, are well preserved as well, as is the foliation caused by Acadian compressional folding (S_1). The regional metamorphic grade is lower greenschist facies (chlorite zone) although none of the Flume Ridge rocks in the Fletcher Peak quadrangle have escaped contact metamorphism to at least biotite grade.

SOf(p): strongly sheared Flume Ridge Formation (phyllonite). Primary sedimentary features are very poorly preserved in this unit, mostly obliterated by an intensively penetrative mylonitic foliation (S_2) due to intense ductile shearing in the earliest stage of Norumbega activity. The metasedimentary rocks were ductilely sheared to become phyllonite (Figure 4) which characterizes the zones of highest ductile shear strain in the Waite and Kellyland ductile shear zones. The phyllonite was formed under low-temperature shallow crustal conditions rather than the significantly higher temperatures associated with mid-crustal or deep-crustal realms along the NFS to the southwest. This is indicated by the production of muscovite (significantly) and biotite (locally) in the phyllonite, suggesting lower greenschist facies conditions during deformation. Foliation defined by the newly-formed muscovite and biotite typically anastomoses in phyllonite exhibiting the highest shear strain. Detrital quartz grains are plastically deformed, nearly to completely recrystallized, and elongated to develop grain shape-preferred fabrics. The lobe-shaped subgrains of quartz in quartz aggregates are aligned to define a continous foliation parallel to the major phyllonitic foliation. Quartz and feldspar (albite) are also present as larger individual porphyroclasts in highly micaceous phyllonite, and σ-type porphyroclasts have been observed that indicate dextral strike-slip shearing. Grain-size reduction due to dynamic re-

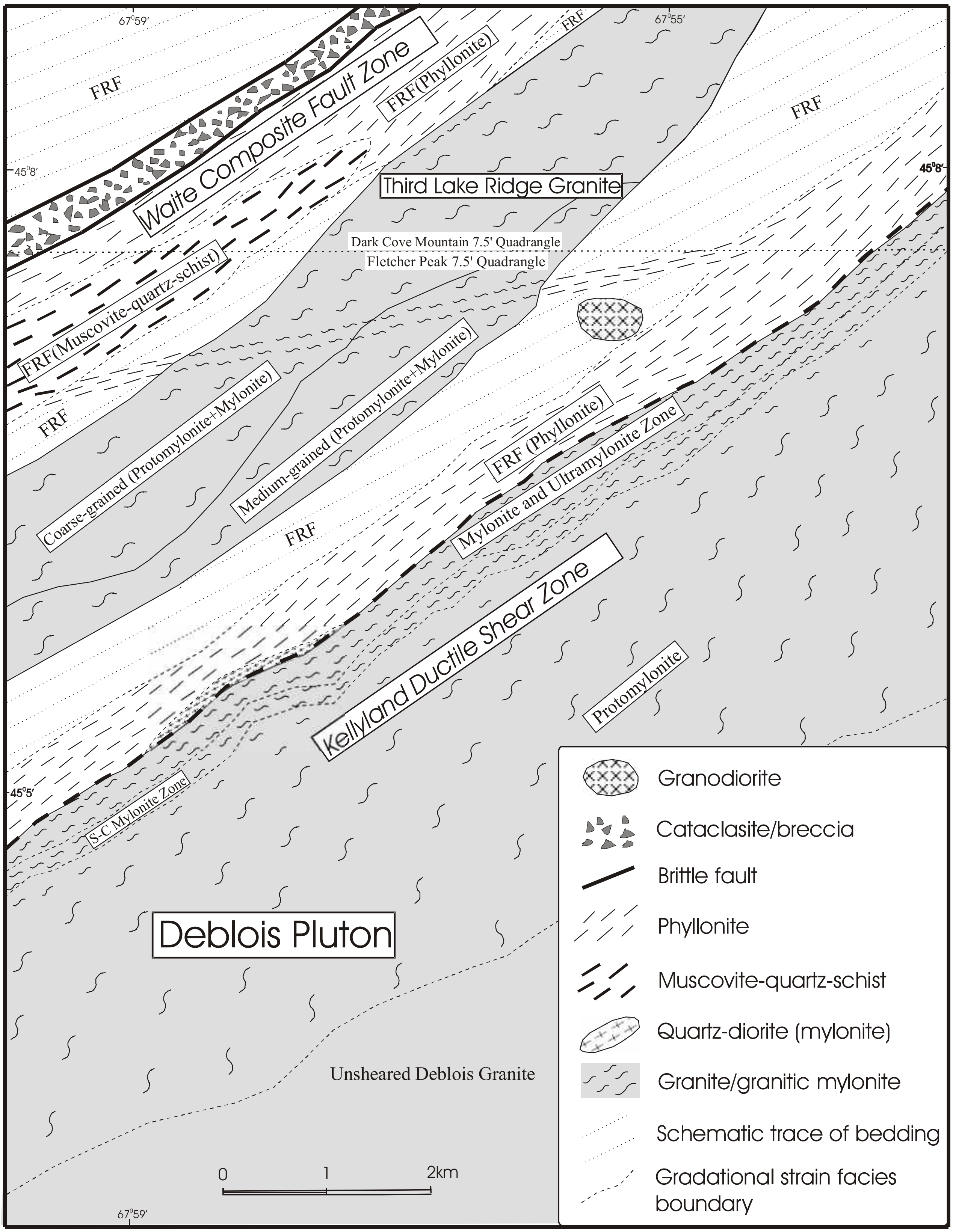

Figure 2. Structural map of the Norumbega fault system in the Fletcher Peak area. FRF = Flume Ridge Formation.

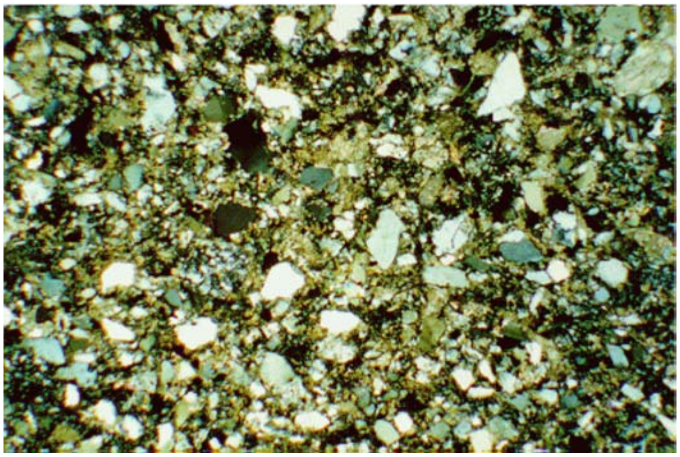

Figure 3. Photomicrograph of unsheared quartz-arenite with well-preserved clastic texture. (Width of field is 3.5 mm.)

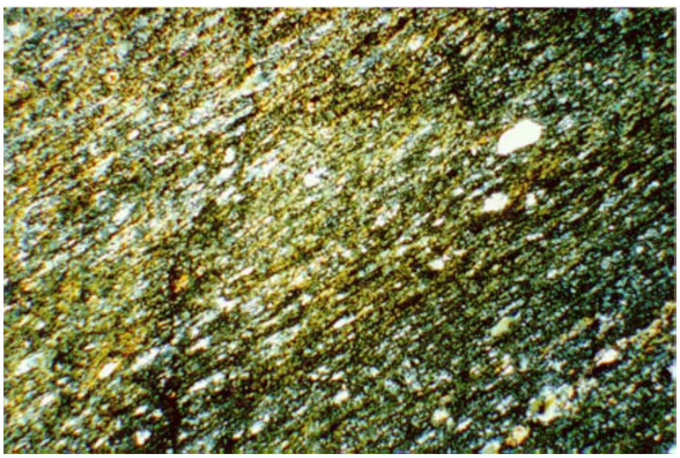

Figure 4. Photomicrograph of phyllonite. Quartz grains are completely recrystallized and elongated. (Width of field is 3.5mm.)

crystallization and sub-grain development are common, resulting in a remarkably fine-grained texture for all phyllonite (much finer grained than their protoliths). Microscopic s-c or s-c' structures are developed in more strongly sheared metasiltstones.

Synkinematic quartz veins are well developed, but are generally boudinaged to form foliation-parallel transgressive boudin strings and isolated asymmetric boudin lenses (Figure 5); these are converted to quartz mylonite in the zones of most intense shearing. The long axes of these quartz boudins (b-lineation) are perpendicular to near-horizontal stretching lineations, indicating near-horizontal shearing. Some aplite dikes (0.1 m - 5.0 m thick) intruded the metasedimentary rocks in this unit and are also strongly sheared to mylonite and ultramylonite. Small-scale drag folds are common in this unit. Some of them are synkinematic with the ductile shearing, but most of their hinges plunge gently to the southwest and are thought to have been generated by later stage brittle reverse faulting (see *Structural Geology* section for details).

SOf(s), strongly sheared Flume Ridge Formation (spangled muscovite-quartz-schist). In the central, highest strain zone of the Waite ductile shear zone in the northwest corner of the quadrangle, there is a belt of strongly sheared and mylonitized rock which is different from the phyllonite described above in that it is more *schistose* and has *larger* recrystallized grains than are found anywhere else in the sheared Flume Ridge Formation. This belt extends southwestward to at least the south side of Gassabias Lake and northeastward to just beyond the northern edge of the quadrangle. Primary sedimentary features are seldom preserved. Fabrics indicative of dextral shearing are abundant. The detrital grains are completely recrystallized and new coarse to very coarse phyllosilicate minerals (mostly muscovite with minor biotite) are present, hence the designation as spangled muscovite-quartz-schist. Some strain-free quartz grains have triple-junction boundaries, suggesting that grain-size enlargement was at least partly due to static recrystallization (Figure 6). Strain recovery is locally incomplete, so that an earlier

Figure 5. Boudinaged synkinematic quartz veins in phyllonite.

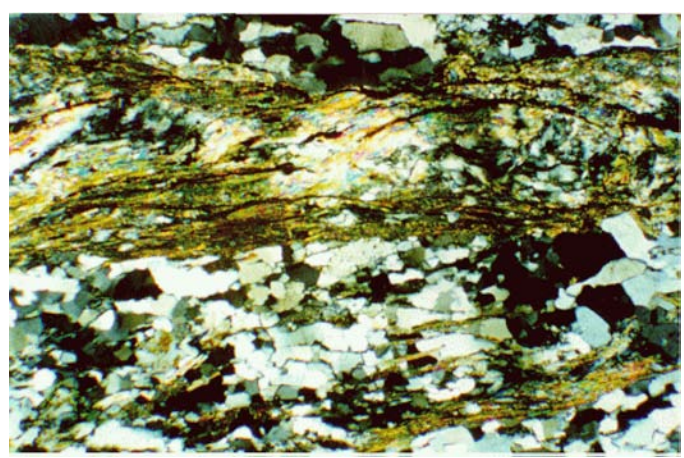

Figure 6. Photomicrograph of muscovite-quartz-schist and static recrystallization. (Width of field is 3.5 mm.)

Figure 7. Fault breccia in Waite fault zone. Light colored areas are broken quartz veins.

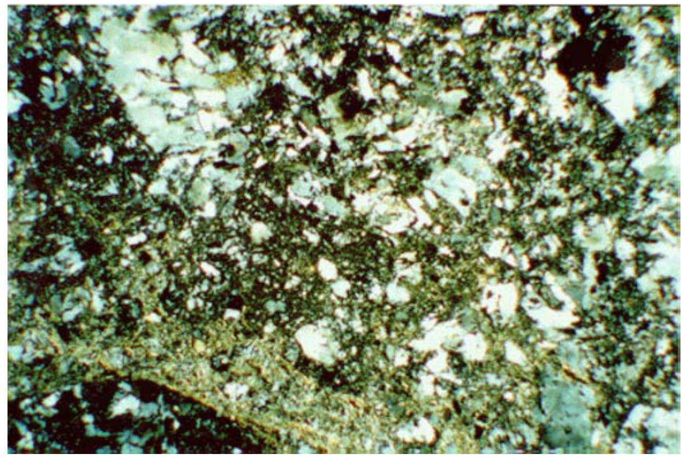

Figure 8. Photomicrograph of cataclasite in meta-wacke in Waite fault zone. (Width of field is 3.5 mm.)

dynamic recrystallization event comparable to that in the phyllonite is well preserved. Obviously, this lithology was generated by high-strain ductile shearing instead of regional metamorphism. Strain heating may have been responsible for the static recrystallization, but this cannot be proven. The remarkable feature of this "schist" is the presence of voluminous quartz veins (15% of the rock volume) and quartzo-feldspathic segregations. This suggests that the static recrystallization was due to the addition of hot, Si-rich fluids into the protolith during ductile deformation.

SOf(c): cataclasized, brecciated, and fractured Flume Ridge Formation (cataclasite and breccia). The rocks in this unit include coarse fault breccia (Figure 7), fine-grained cataclasite (Figure 8), and intensively fractured/jointed metasedimentary rocks and phyllonite. These are restricted to the northwest corner of the quadrangle where late-stage brittle faulting was superimposed on the earlier ductile fabrics of the Waite fault zone. This late brittle faulting overprinted mylonitic Flume Ridge Formation (SOf(p)) in the high-strain parts of early ductile shear zones and was also locally devloped in only slightly sheared Flume Ridge metasedimentary rocks. Late cataclasite and breccia are distributed continuously along the Waite fault zone, indicating that the Waite ductile shear zone was reactivated during later brittle activity. In contrast, only minor cataclasis and brecciation are found along the Kellyland fault zone.

The central part of this unit is a cataclasite/breccia zone about 50 meters wide that represents the greatest brittle strain in the Waite fault zone. The texture ranges from cataclastic to chaotic with all previous bedding and foliation completely destroyed (Figures 7 and 8). Joints and/or small-scale faults associated with even later brittle faulting are developed throughout this unit (see *Structural Geology* section). Intensively fractured/jointed Flume Ridge strata are symmetrically distributed on both sides of the central cataclasite/breccia unit. Within these the previous bedding and foliation have been well preserved but significantly cut by joints. The transition from the central belt to the fractured/jointed belts is gradual, and within the transition zone, compressional tectonic lenses and boudins have been well developed. Calcite veins and minor chlorite veins cut early foliation and filled in the cracks and fissures, suggesting that they are associated with the cataclasis.

More detailed mapping and study shows that this unit of cataclasite/breccia and closely-spaced fractures and joints are products of stage-1 reverse faulting (see *Structural Geology* section for details).

Igneous rocks

Granite of the Deblois pluton underlies the entire quadrangle south of Washington Bald Mountain. A sliver of granite between the Kellyland and Waite fault zones previously mapped as part of the Deblois pluton (Osberg and others, 1985) has proved to be completely separated from that pluton. We have therefore mapped it as a separate unit here named the Third Lake Ridge granite. A small, previously unknown granodiorite stock was also discovered in unsheared Flume Ridge Formation (SOf) north of the Kellyland fault zone near Farm Cove Mountain.

Deblois granite

The Deblois pluton is the largest igneous intrusion in the coastal Maine magmatic province. It extends north from the Sullivan granite in south-central Maine to the Grand Lake Stream 7.5' quadrangle, adjacent to the Fletcher Peak quadrangle on the northeast. This batholith has two lobes extending northward, termed the west lobe and east lobe in this discussion. Its northeastern extension in and around the study area, or northern part of the east lobe, was first mapped as the "Wabassus Lake pluton" by Larrabee (1964) and then remapped and modified by Ludman (1986, 1987). It is characterized by an extremely coarse-grained appearance, distinctive pink potassic feldspar megacrysts, pau-

Figure 9. Horizontal exfoliation in Deblois granite and happy Brian, Knox Mountain.

Figure 10. Slightly foliated coarse/megacrystic granite. Pen is pointing to north.

city of pegmatites indicative of the low volatile content of the melt, and metaluminous composition. Rapakivi albite rims are common on microcline megacrysts. The batholith has intruded several lithotectonic belts/terranes including the St. Croix, Coastal Volcanic, and Fredericton belts. A well-developed intrusive contact aureole is present in Fredericton belt strata around the batholith everywhere except along its northwestern contact where the Kellyland ductile shear zone is located. Granite in the western lobe of the pluton was dated at 393 ± 17 Ma by Rb/Sr whole-rock methods (Loiselle and others, 1983), but a more precise age of 384 ± 5 Ma was determined recently by Ludman and others (1999; U/Pb methods on zircon) for granite at Wabassus Mountain, just east of the study area. The large-scale ductile deformation along the Norumbega fault system took place along the northwestern margin of the pluton – in this quadrangle, along the northwestern slope of NE-trending Washington Bald Mountain. Variations due to this tectonic overprint are mapped separately, essentially as estimates of strain facies in the Kellyland fault zone first described by Ludman (1994, 1998). As discussed here, four map units are now recognized in terms of the shear strain facies of the deformed Deblois granite within the quadrangle.

As mentioned above, there is only minor brittle faulting outside the Waite fault zone in the Fletcher Peak quadrangle. Thus brittle faulting is manifested in the Deblois and other granites by only small cataclasite and breccia zones at outcrop and thin-section scales. They are for the most part products of conjugate jointing or outcrop-scale faulting overprinted on previous ductilely sheared and/or mylonitized granites in the Kellyland fault zone and in the area between the Kellyland and Waite zones. Chlorite is abundant in the fractures and cracks, again suggesting association with much later brittle faulting.

Dg: undeformed Deblois granite. Undeformed Deblois granite has normal granitic to megacrystic texture with the typical appearance of coarse to megacrystic varieties. It is most commonly a K-feldspar-rich, two-feldspar, hornblende-biotite granite. Sodic plagioclase occurs locally as euhedral crystals, inclusions in perthitic microcline, and as rapakivi rims outlining microcline megacrysts. The pluton is mineralogically quite homogeneous within the study area and adjacent quadrangles. Two minor variations include slightly more mafic zones found on the northeastern side of Slewgundy Ridge and the southwestern side of Elwell Ridge. In these more mafic zones, there are more than twice the typical percentages of hornblende and biotite, resulting in a higher color index. The increased abundance of these ferromagnesian phases is largely at the expense of quartz. Since the relative ease of quartz deformation controls shearing in the granite, the more mafic granitic rocks prove more competent than the typical granite and thus accommodated little shear strain. They are barely foliated.

Primary flow foliation has been locally developed within undeformed granite. The foliation is defined by alignment of euhedral feldspars. No plastic deformation has been noticed in quartz grains in these rocks. Exfoliation (Figure 9) has been observed on tops of several mountains and hills such as Knox Mountain and Fletcher Peak. The exfoliation planes are flat and obviously caused by non-tectonic agents.

Dg(pm): foliated to slightly foliated Deblois granite (protomylonite). The zone of foliated Deblois granite, here termed the protomylonite unit, is about 3.5 km wide in the Fletcher Peak quadrangle. Due to dextral simple shearing, the feldspars in this unit are rotated and oriented to form shape-preferred fabrics and foliation (Figure 10). Feldspar grains themeslves are barely deformed, either plastically or brittlely. Quartz grains, however, are plastically deformed and dynamically recrystallized. The intensity of recrystallization increases progressively northward from undeformed granite at the intrusive contact with metasedimentary rocks on the south toward

Figure11. S-C structure in s-c mylonite. Pen is pointing to north.

Figure 12. Photomicrograph of imbricated feldspar porphyroclasts indicating dextral shear sense. (Width of field is 3.5mm.) Note quartz ribbon along upper edge of porphyroclast.

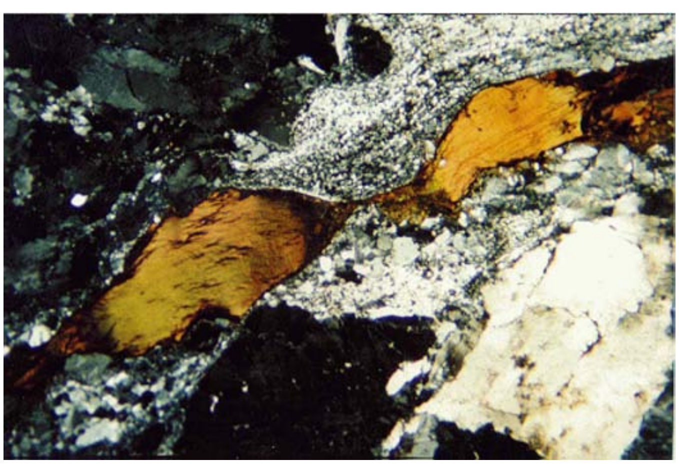

Figure 13. Photomicrograph of mica-fish in s-c mylonite. (Width of field is 9mm.)

zones of intense shear strain near the fault contact on the northwest. The foliation intensifies and s-c structure begins to appear locally near the next higher strain facies (the s-c mylonite unit). Grain size reduction is not significant in this foliated granite unit. The foliation strikes around 355°-000° in slightly foliated granite adjacent to undeformed Deblois rocks on the south and swings gradually to 020°-035° in the contact with the s-c mylonite unit. This sigmoidal pattern, shown clearly on the accompanying bedrock geologic map, is consistent with the dextral shear deduced from megascopic and microscopic shear indicators.

Dg(s-c): mylonitized Deblois granite with typical s-c structure (s-c mylonite). Between the zone of highest shear strain and the protomylonite granite unit (Dg(pm)) is a mylonite zone characterized by well-developed s-c structure (Figure 11). S-bands are mostly defined by arrangement of feldspars and sigmoid quartz ribbons consistent with the foliation in the protomylonite granite unit. The formation and appearance of c-foliation is indicative of higher shear strain, and the shear (simple shear in this case) is more concentrated in C-domains. It has been noted that the c-foliation begins to appear when the foliation in protomylonite strikes at 030°-035° or the angle between this foliation and the shear zone boundary (or shear direction) reaches 10°-15°, or the shear strain γ reaches 3.464-5.495. Grain-size reduction by dynamic recrystallization and sub-grain rotation becomes significant in this unit and is also propagated from C-domains. Toward the zone of highest ductile shear associated with the Kellyland fault zone (the mylonite and ultramylonite zone), s-bands are rotated and more closely approach orientations comparable to the dominant c-foliation. In other words, the angle between s-bands and c-foliation gets smaller and smaller toward the highest shear zone, the central zone of the Kellyland fault zone.

In this unit, all quartz grains have been dynamically recrystallized and smeared to form quartz ribbons (Figure 12). Abundant features of crystal-plastic deformation are developed in quartz, such as core-mantle structure, sub-grain development, and deformation bands. Plagioclase and potassic feldspars, however, are only brittlely fractured and broken into smaller porphyroclasts that are sandwiched between quartz ribbons (Figure 12). Some porphyroclastic feldspars are fractured and imbricated to form domino structures (Figure 12) and occur as textbook asymmetric sigma and delta shear indicators. Some plagioclase feldspars show twin-lamellae kinking. Biotites are generally kinked. Some are present as mica-fish (Figure 13). The s-c structure itself and all these shear-sense indicators consistently suggest a dextral simple shearing.

The s-c mylonite zone is about 200-300 m wide. Some lenses of lower strain domains were preserved within the s-c mylonite unit because of the heterogeneous nature of the shear strain. Unfortunately, only one of these is mappable at 1:24,000 map scale – in the middle of Washington Bald Mountain on the accompanying map.

Dg(m/u): mylonitized and ultramylonitized Deblois granite (mylonite and ultramylonite). This unit represents the highest

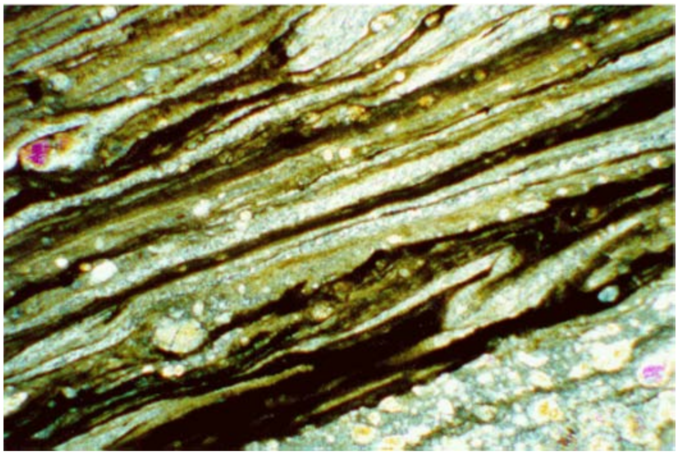

Figure 14. Photomicrograph of extremely fine-grained ultramylonite and ultramylonitic bands. The micro-fold shows dextral shear sense. (Width of view is 3.5mm.)

Figure 15. Mylonitic coarse-grained granite in Third Lake Ridge granite. Compass points to north.

ductile strain facies in the Fletcher Peak quadrangle derived from a granitic protolith. The s-c structure may persist locally, but the angle between s-bands and c-foliation is typically so small that they are almost parallel to one another. The intensive c-foliation – the mylonitic foliation – dominates. It strikes mostly at 045° and is representative of the strike of the whole Kellyland ductile shear zone. Grain-size reduction is much more significant in this zone due to the extremely high strain. Quartz grains are completely recrystallized and individual quartz ribbons are sheared to as much as 10 cm long. All large quartz grains have been converted to complex sub-grain assemblages by dislocation and recrystallization, and are extremely fine-grained in the ultramylonite sub-zones (Figure 14). Porphyroclastic feldspars are fractured and broken into progressively smaller and mostly round and elliptic grains (Figure 14) as one approaches the fault contact with the Flume Ridge Formation to the northwest. Because of the lack of fluids during mylonitization, the mineral compositions of the mylonite and ultramylonite are quite simple and there is little alteration except for a few chlorite veins found in some thin sections.

The ultramylonite might be mistaken for mylonitized Flume Ridge Formation since both are fine to very fine-grained and felsic. However, the granitic ultramylonite is more "glassy" and in thin sections it has micro-porphyroclastic potassic feldspars (Figure 14). This unit is adjacent to the mylonitized Flume Ridge Formation (SOf(p)), and the two units together define the central, highest strain portion of the Kellyland fault zone. The granitic mylonite and ultramylonite zone (Dg(m+u)) also preserves lower-strain domains (such as s-c grade coarse mylonite) due to the local heterogeneity of shear strain. This zone is about 250-700 m wide.

Some aplite dikes have been found around the contact between the granite and Flume Ridge Formation at Fletcher Peak cliff at the southwestern end of Washington Bald Mountain. These dikes are strongly mylonitized in the mylonite and ultramylonite zone and parallel to the mylonitic foliation.

Third Lake Ridge granite

The sliver of granite between the Kellyland and Waite fault zones, as introduced earlier, is completely separate from the Deblois pluton in the quadrangle. It extends northeastward as far as the eastern side of Wabassus Lake and southwest as far as the south side of Nicatous Lake where it is believed to be connected to the west lobe of the Deblois pluton through our extended mapping in that area. We have identified and subdivided two units of the granite, a coarse-grained unit (Dg(pm+m)) and a medium-grained unit (Dmg(pm+m)). Both are more or less ductilely sheared. The northern half of the sliver consists of coarse to megacrystic, pink microcline-rich, two-feldspar, hornblende-biotite granite nearly identical to typical Deblois granite. Rapakivi texture is also common in this granite. The southern half of the slice of granite between the Kellyland and Waite fault zones is, however, medium-grained, much finer than either the coarse-grained variety just described or the main body of the Deblois pluton. It is also a pink microcline-rich, two-feldspar, hornblende-biotite-granite. The elongated shape and the large ductile shear strain of the whole sliver of the Third Lake Ridge granite suggest that it has been deeply involved in the Norumbega shearing (Figure 2).

Dg(pm/m): foliated and/or mylonitized coarse-grained granite (protomylonite and mylonite). This unit of coarse-grained granite is ductilely sheared/foliated and locally mylonitized and ultramylonitized to become protomylonitic and mylonitic granite (Figure 15). Typical s-c structures are common in higher strained zones. Quartz grains are plastically deformed and dynamically recrystallized. Feldspars are rotated to define the foliation and fractured to become porphyroclasts (Figure 15). All deformation features of minerals are similar to the ones within the sheared and mylonitized Deblois granite. Several-meter-wide narrow mylonite and ultramylonite zones have been found mostly on the northwest contact zone with the Flume Ridge Formation metasedimentary rocks. The mylonite and ul-

Figure 16. Mylonitic medium-grained granite and s-c structure in Third Lake Ridge granite. Pen is pointing to north.

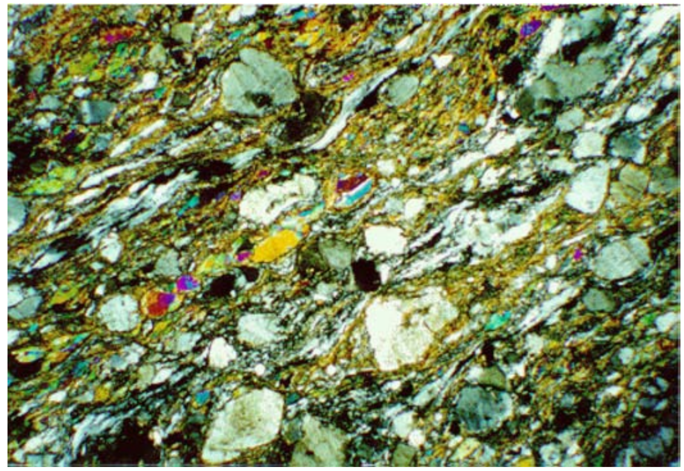

Figure 17. Photomicrograph of mylonitized and foliated quartz-diorite. (Width of view is 3.5mm.)

tramylonite zones strike more easterly than those in the Deblois granite, however. Shear-sense indicators all suggest dextral simple shearing.

Dmg(pm/m): foliated and/or mylonitized medium-grained granite (protomylonite and mylonite). Most of this unit of granite is also ductilely sheared and foliated. Quartz is smeared and dynamically recrystallized and s-c structures (Figure 16) are also seen in higher strain belts. All shear-sense indicators such as sigmoid shear patterns, s-c structures, and asymmetric feldspar porphyroclasts also suggest a dextral simple shearing which is probably coeval with the shearing within the coarse-grained granite. Higher-strain mylonite and even ultramylonite belts are developed locally with strikes around 075°-090° (Figure 16). Combined with the more easterly striking foliation within the coarse-grained part and the dextral simple shearing, this pattern suggests a second-order or synthetic shear system between the Waite and Kellyland ductile shear zones.

Dqd(m): Strongly sheared quartz-diorite

A narrow slice of strongly sheared fine-grained quartz-diorite has been identified and mapped as a single unit around the Fletcher Peak cliff at the southwestern end of Washington Bald Mountain. It intruded between the Deblois granite and Flume Ridge metasedimentary rocks and later was intensively sheared and elongated into a mylonite and ultramylonite zone. The zone is about 40 m wide at the Fletcher Peak cliff. It contains several aplite dikes, and the dikes are also mylonitized and ultramylonitized. The quartz-diorite is composed of quartz, hornblende, and plagioclase feldspar. Quartz grains are dynamically recrystallized and ribboned. Some hornblende grains are sheared and altered to fine-grained biotite. Some remain as elliptical porphyroclasts with their longer axes parallel to the foliation. The foliation is defined by quartz ribbons and biotite flakes (Figure 17). Feldspars are fractured and some are broken into smaller pieces. Most feldspar grains remain as elliptical or irregular-shape porphyroclasts. (Figure 17). Because this quartz-diorite intrusion was ductilely sheared and coeval with the major ductile shearing event that generated the Kellyland ductile shear zone, it predated the ductile shearing event and is very likely a Devonian intrusion as is the Deblois pluton.

D(?)gd: Unnamed granodiorite

A small stock (~0.25km^2) containing fine to very fine-grained granodiorite was found in a lowland on the northern side of Washington Bald Mountain.The stock is massive, lacking foliation, and has created a contact aureole at least several tens of meters wide in the surrounding Flume Ridge metawackes. The granodiorite is composed of feldspar, hornblende, and some quartz grains. Relationships between this lithology and other igneous rocks in the quadrangle are unknown, but may be revealed when samples collected for radiometric dating are processed. Because it intruded rocks of the Flume Ridge Formation that had already been ductilely sheared, it is unlikely that the stock is coeval with the Deblois and other granites. It is probably younger than the post-Acadian granitic magmatism and the ductile shearing in the Kellyland fault zone.

STRUCTURAL GEOLOGY

The major structural features in the Fletcher Peak quadrangle are the Kellyland and Waite fault zones (Ludman, 1994, 1998; Ludman and others, 1999; Figure 2), the two southernmost high-strain strands of the Norumbega fault system. Both strike at about 045°. These fault zones were clearly developed after the emplacement of the Deblois pluton. The Kellyland zone is a dominantly ductile shear zone and exhibits little evidence of brittle faulting, but the Waite zone first underwent ductile shearing and later experienced multiple brittle faulting episodes with measurable displacement.

Ductile shear zones and associated structures

Ductile shearing is coeval in the Kellyland and Waite ductile shear zones. In the Kellyland fault zone, maximum shear took place along the contact between the Deblois granite and the Flume Ridge Formation, and the sheared rocks are mappable as strain facies units as described above. The progressive change from protomylonite to mylonite to ultramylonite toward the highest strain zone within the Deblois granite, observed with increasing strain, clearly involved a reduction in the mineral grain size and in the number of K-feldspar and plagioclase porphyroclasts. Due to inferred shear heating, the metamorphic grade in sheared Flume Ridge Formation is higher than in unsheared hornfelses. An ^{40}Ar-^{39}Ar thermochronologic study on hornblende and biotite samples recently collected from Wabassus Mountain in the nearby Grand Lake Stream quadrangle by Ludman (1998), Ludman and others, (1999) and Idleman and others (1998) showed that this ductile shearing event began around 380 Ma years ago, only a few million years after emplacement of the Deblois granite.

Foliation. The foliation (S_2) formed by this ductile shearing in both Waite and Kellyland ductile shear zones and in the Third Lake Ridge granite sliver is unique and pervasive and readily distinguished from the axial-plane cleavages (S_1) developed in Flume Ridge Formation metasedimentary rocks during Acadian upright folding. The foliation is defined by platy minerals such as muscovite and biotite in the sheared metasedimentary rocks and by alignment of feldspars, quartz ribbons, and biotite flakes in sheared granites. In sheared Deblois granite in the Kellyland ductile shear zone, this foliation is sigmoidal and intensifies toward the central highest strain zone (Figure 2).

Stretching lineations. Stretching lineations defined by stretched and elongated minerals such as quartz ribbons and feldspars (Figure 18) have been observed on foliation planes both in sheared Flume Ridge Formation metasedimentary rocks and in granites throughout the quadrangle. Most of them are near horizontal or plunge gently to the northeast at 10°-15° (Figure 19), proving the strike-slip nature of the ductile shearing.

Small-scale folds. Small-scale or sample-size scale folds are locally developed within the ductile shear zones. Three types of folds have been identified, each generated by a different structural event. The earliest folds were parasitic to the conventional Acadian upright folds in the Flume Ridge Formation metasedimentary rocks. The second set, though not as common, was synkinematic with the dominant ductile shearing. Most folds of this set are dextrally asymmetric and plunge very steeply to vertically. Within the sheared metasedimentary rocks with abundant synkinematic quartz veins and boudins, the quartz veins are also folded locally. Similar asymmetric folds have been seen at thin-section scale. These folds might be the product of progressive deformation during the ductile shearing, and the asymmetric feature of the folds is associated with the dextral simple shearing.

Figure 18. Stretching lineation in granitic mylonite.

Boudinage. Boudinage features have been observed in the sheared metasedimentary rocks with interbedded quartz arenite layers or syntectonic quartz veins (Figure 5). The more competent quartz arenite beds or quartz veins were ductilely sheared and boudinaged to form foliation-parallel transgressive boudin strings and isolated boudin lenses. The long axes of the boudin lenses (b-lineations) are mostly perpendicular to the near-horizontal stretching lineation, also indicating a near horizontal or strike-slip shearing.

Shear strain and displacement estimate. Shear strain is the function of the angle between the shear bands, i.e. the major foliation or s-foliation in sheared granites, and the shear zone boundary or shear direction, $\gamma = 2 / \tan 2\theta'$, and could be easily

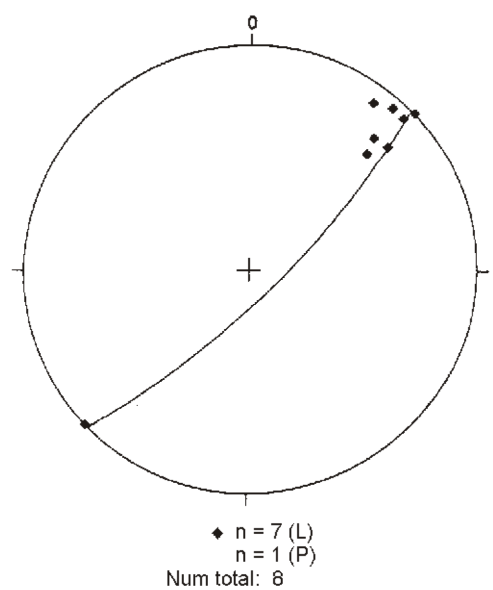

Figure 19. Equal angle stereonet showing stretching lineation.

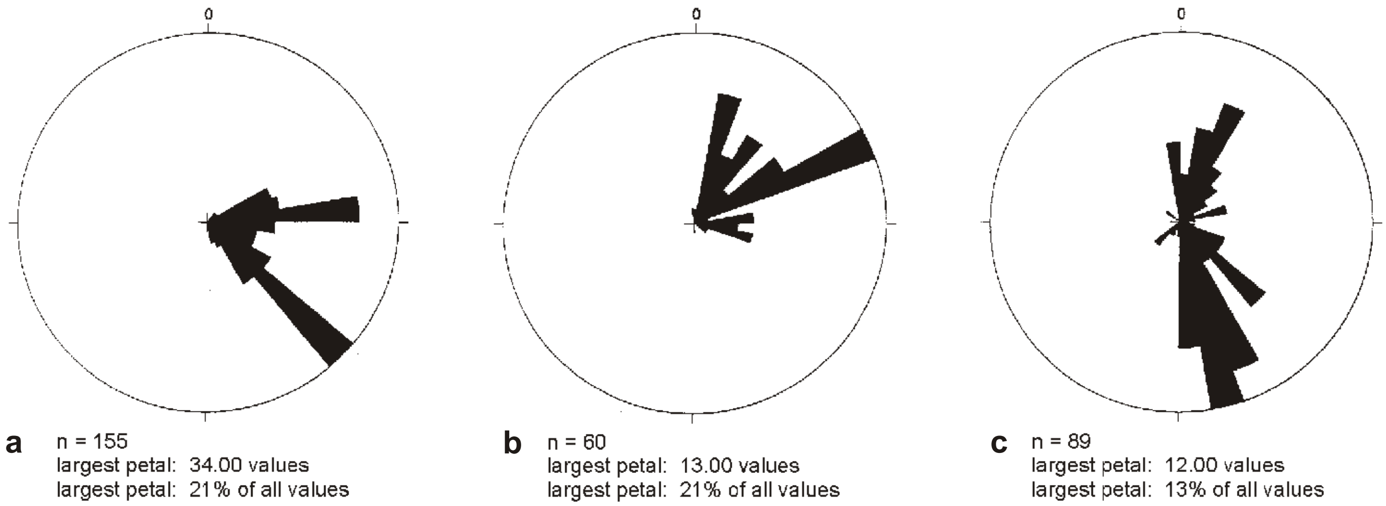

Figure 20. Rose diagrams for conjugate faults/joints. Strike direction. 10° classes.

calculated with the measurement of this angle. However, since the shear strain is heterogeneous in the shear zones, the angle changes from about 45° at the shear zone margin to near 0° in the highest strain zone where the s-bands nearly parallel the c-foliation. For example, when c-foliation begins to develop in the transition from the protomylonite to s-c mylonite, θ' ranges from 15° to 10°, and therefore the shear strain is 3.464-5.495.

A reconnaissance and detailed reconnaissance study from Grand Lake Stream to the Great Pond area suggests that the Third Lake Ridge granite was dextrally dragged/sheared from the west lobe of the Deblois pluton, and that the Morrison Ridge granite southwest of Nicatous Lake was derived/dragged from the Lucerne pluton by the ductile shearing as well. The estimates of the displacement of the Third Lake Ridge granite and Morrison Ridge granite both yield a minimum displacement of 25km (Wang and others, 2000).

Multiple brittle faulting episodes

Multiple brittle faulting episodes have been recently identified and reported by Ludman (1998) and Ludman and Gibbons (1999) in the Kellyland and Wabassus Mountain areas northeast of the Fletcher Peak map area. Several senses of motion have been described, including reverse and normal dip-slip as well as strike-slip, but no previous studies of the Norumbega system have analyzed the change of fault dynamics and stress fields with time. This mapping project is thus the first effort to interpret not only the multiply episodic nature of faulting, but also the dynamics and stress fields for each faulting event along the Norumbega fault system in eastern Maine.

All brittle faulting recognized in the Fletcher Peak quadrangle and adjacent areas was superimposed on early ductile shear zones in either granitic or metasedimentary rocks. Intense brittle faulting resulting in significant rupture, cataclasis and brecciation, and measurable displacement is concentrated mostly along the Waite zone (Figure 2). In contrast, the Kellyland zone in the study area has only experienced secondary, very small-scale brittle faulting which generated very local cataclasites – most less than 5 cm thick. The small-scale structures associated with the late brittle faulting, especially conjugate small-scale faults and joints, were analyzed carefully because they reflect changing stress fields late in the history of Norumbega faulting. The study has thus far identified stress fields related to three separate significant brittle faulting events, each characterized by different directions of the maximum principal stress (i.e. $\sigma 1$) along the Norumbega fault system.

Stage-1 reverse faulting. Stage-1 brittle faulting caused the large-scale cataclasis and brecciation distributed continuously along the pre-existing Waite ductile shear zone. Pre-existing phyllonite and metasedimentary rocks are brecciated (Figure 7), cataclasized (Figure 8), boudinaged, and fractured/jointed with obvious strain-related zonation described above (see *Lithology and Map Units*). The small-scale drag folds caused by this reverse faulting have well-developed axial-plane cleavage (S_3) with new minerals such as muscovite and minor biotite overgrowing the cleavages, suggesting a relatively deep level in the shallow crust where there was a reducing environment. These drag folds are asymmetric and mostly gently plunge 10°-20° to the southwest, indicating a reverse motion. Related slickensides on some faulted surfaces also indicate dominantly dip-slip movement. Compressional tectonic boudin lenses with near-horizontal long axes are developed within the transition zone from cataclasite/breccia to intensively fractured/jointed rock. These and other kinematic indicators consistently suggest an episode of reverse brittle faulting along the fault system.

Two sets of conjugate small-scale faults/joints, one around 80° and the other 130° in strike (Figures 20a and 21), have been

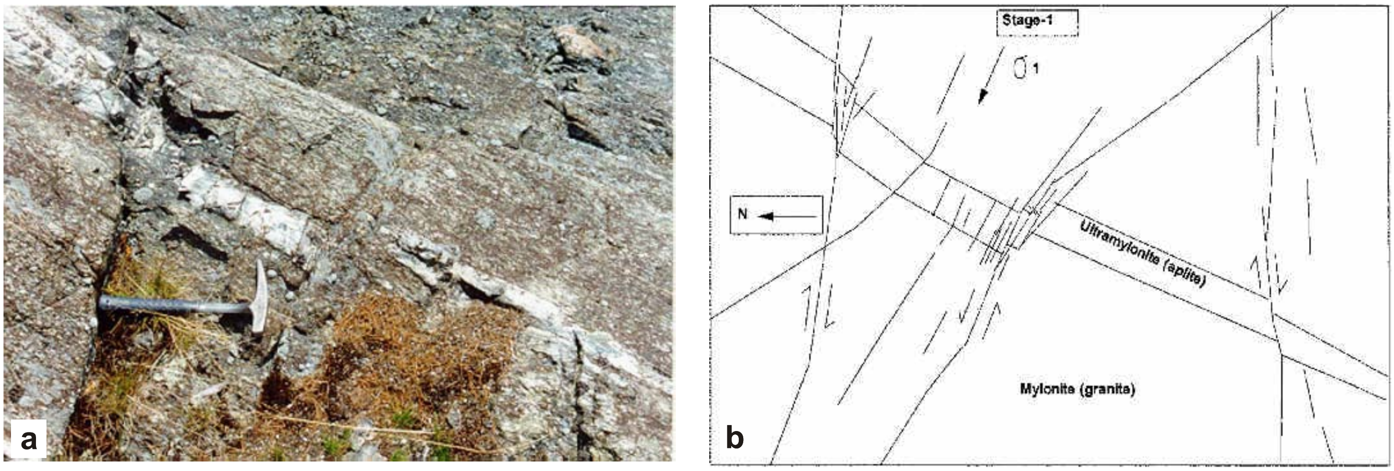

Figure 21. (a) Stage-1 conjugate small-scale faults in granitic mylonite at Fletcher Peak cliff. Hammer points to north. (b) Line drawings of (a) and explanation (map view).

observed within metasedimentary and granite rocks along the fault system. Development of some small valleys or streams was obviously controlled by these two joint sets (Figure 22), e.g. on the north side of Washington Bald Mountain and cliffs such as Fletcher Peak cliff and parts of Slewgundy Ridge, Knox Mountain, and Fletcher Peak. These are interpreted as the oldest brittle features because they are cut by all other small-scale faults/joints (Figure 23). Cataclasite zones less than 5 cm thick were generated within these conjugate faults/joints. Some faults/joints in granite are filled by epidote veins. Most slickenlines on these fault surfaces plunge gently to the southwest at 10°-15°(Figure 24a), confirming that the motion was likely reverse and east-side-up. These conjugate faults/joints are products of the major reactivated faulting along the fault system, and are thus second-order to the master faulting. The direction of the maximum principal stress ($\sigma 1$) for Stage 1 brittle faulting is interpreted from these faults/joints throughout the study area to be about 100°-125° (Figure 24a).

Stage-2 transtensional faulting. A second (Stage-2) brittle faulting event overprinted Stage-1 joints and small-scale structures with a second conjugate set of small-scale faults/joints (Figure 20b) throughout the extended study area. The maximum principal stress ($\sigma 1$) deduced from these conjugate structures is oriented 065°-085° (Figure 24b), and the associated faulting was in a dextral strike-slip sense. This is very likely due to early Carboniferous oblique movement between former Avalon and North America plates that had accreted during the Acadian orogeny. Stage-2 faulting is thus transtensional and might have accompanied the opening of Pennsylvanian pull-apart redbed basins along the Waite zone.

The pull-apart mechanism for the redbed basins along the Waite zone has not been addressed by previous workers. Two possible models are consistent with the results of this study.

Model 1 – Pull-apart basins originated from linked R shears: From our observation of Stage-2 conjugate faults/joints along the fault system – especially on the segments where the

Figure 22. Development of a stream valley on north side of Washington Bald Mountain is controlled by Stage-1 conjugate faults/joints. Brian is facing east. Hammer aligned along $\sigma 1$.

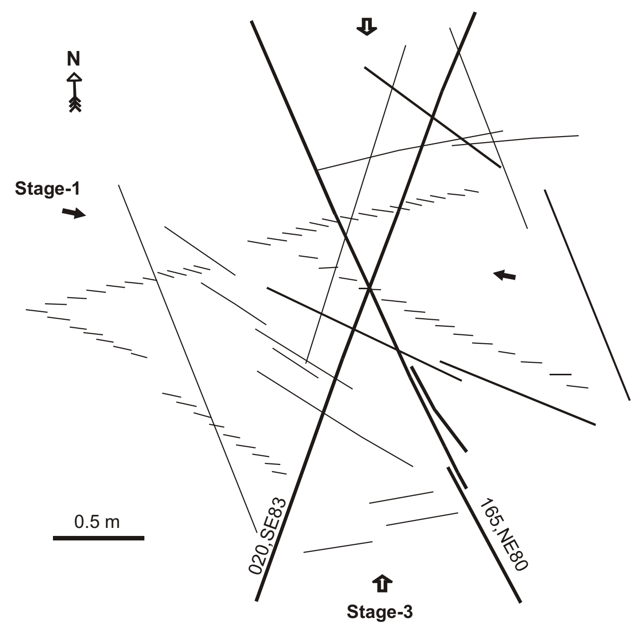

Figure 23. Stage-1 and -3 conjugate joints in granite and their $\sigma 1$ directions (map view).

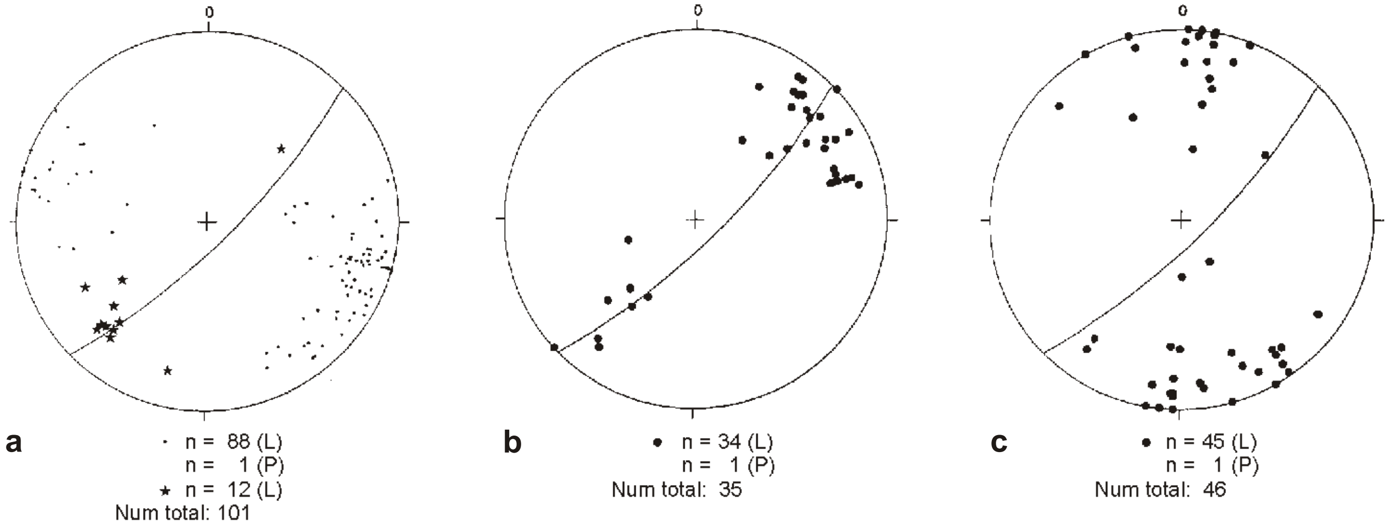

Figure 24. Stereonets of maximum principal stresses deduced from conjugate faults/joints for (a) Stage-1 (stars for slickenlines on fault surfaces), (b) Stage-2, and (c) Stage-3.

redbeds are located in eastern Maine – faults and joints oriented around 050° are locally extensively developed with obvious displacement and cataclasis. Slickensides on the fault surfaces are generally subhorizontal. In the Stage-2 dextral transtension faulting regime, this set of second-order faults/joints makes a smaller angle with the master fault than the other set and are also interpreted as synthetic R shears. In this model, because of dextral strike-slip motion, these 50°-trending R-shears were pulled apart and linked to form narrow pull-apart basins. The right-hand-stepped en-enchelon redbed basins in the area of Nicatous Lake to Gassabias Lake could be explained with this model.

Model-2 – Pull-apart basins originated at small releasing bends: Since the fault zone is not always straight but curves, bends, and anastomoses locally in some segments, the dextral movement could cause narrow depressions or basins to form extensionally at the releasing bends. Some redbed basins formed in the area north of Amazon Mountain and near Waite might be explained with this model. The very poorly-sorted thick layers of conglomerate with clasts from multiple sources within the redbed basins imply short transportation and rapid deposition.

Stage-3 reverse-sinistral faulting. A third brittle faulting episode along the NFS took place after deposition of the redbeds. This event juxtaposed the redbeds against Fredericton belt rocks and was responsible for the current steep dip of the red conglomerates and sandstones. Second-order conjugate faults/joints (Figure 20c) associated with Stage-3 faulting cut the small-scale Stage-1 and -2 faults/joints and cataclasites (Figure 23). The maximum principal stress deduced from the Stage-3 conjugate faults/joints is in the direction of 135°-155°(Figure 24c), suggesting that the master faulting was compressional and had a component of sinistral strike-slip motion. The related breccia, though minor, is red in color and indicative of a very shallow oxidizing environment. Its relative age may represent Alleghenian reactivation of the Norumbega fault system.

GEOLOGIC HISTORY

The Fredericton belt turbidite suite was deposited from late Ordovician through middle Silurian times in what may have been an ocean basin separating a composite North American terrane from an equally complex Avalonian continent (Ludman and others, 1993). Closing of the Fredericton depositional trough occurred during the Acadian orogeny (Ludman and others, 1993), producing the tight regional folding, (S_1) axial-plane cleavages, and the lower greeschist facies metamorphism seen in the Flume Ridge Formation and other rocks of eastern Maine.

The granitic plutons were emplaced after the Acadian orogeny, and most of their ages cluster around 380 Ma – generally slightly earlier. Roof pendants, miarolitic cavities, and the low regional metamorphic grade outside the contact aureoles all indicate that the Deblois and other post-Acadian plutons in eastern Maine and adjacent New Brunswick were emplaced at shallow crustal levels.

Shortly after emplacement and crystallization of the granites, at about 380 Ma, the large-scale ductile Norumbega shearing event took place, producing ductile shear zones oriented in a 045° direction from at least southwestern Maine to central New Brunswick. The Norumbega fault system broadens northeastward from Great Pond and strain was partitioned into the two strands described in this report plus the Codyville fault zone (Ludman, 1998). The Kellyland ductile shear zone developed along the contact between the Deblois granite and the Flume Ridge Formation, and the Waite ductile shear zone, just a few miles across strike to the northwest, truncates the southeastern part of the Bottle Lake pluton.

A regional study of the whole fault system from the Great Pond area to easternmost Maine shows that the dextral simple shearing in these fault strands accounted for most of the dextral strike-slip offset along the entire Norumbega fault system, and the minimum displacement in this area is about 25 km (Wang and others, 2000). Rocks in the Flume Ridge Formation, in most of the Deblois pluton in the quadrangle, and all the unnamed granite slices between the two high-strain zones, are ductilely sheared and foliated.

Three significant stages of brittle faulting followed the early ductile shearing and were focused mostly along the Waite fault zone. Stage-1 brittle faulting was dip-slip and compressional and responsible for the large-scale cataclasis and brecciation along the Waite fault. It probably took place in late Devonian times. Future dating of the biotite formed in the secondary axial-plane cleavages (S_3) may yield a more precise age. Transtensional Stage-2 brittle activity was dextral oblique-slip and is believed to have been responsible for opening the Pennsylvanian redbed depocenters as pull-apart basins along the fault system. The Stage-3 brittle activity, mostly dip-slip but with a sinistral component, indicates a return to a compressional regime. It juxtaposed the Carboniferous redbeds against Fredericton belt metasedimentary rocks, perhaps during the late Paleozoic Alleghenian orogeny.

CONCLUSIONS

This USGS-EDMAP project has led to significant improvements in our understanding of the bedrock geology in the Fletcher Peak 7.5' quadrangle, including:

• A more accurate bedrock geologic map has been compiled for the quadrangle and for the shallow crustal segment of the Norumbega fault zone in eastern Maine than was hitherto available.

• Use of map units based on strain intensity has helped to clarify the extent, strain variation, and internal structure of the Norumbega fault system in eastern Maine, especially the Kellyland ductile shear zone. This map vastly improves the best previous picture of the Kellyland ductile shear zone in this part of eastern Maine.

• The spatial distribution and extent of the Third Lake Ridge granite, a sliver sandwiched between the Waite and Kellyland zones, have been revealed. The granite is physically separated from the eastern lobe of the Deblois pluton in the quadrangle, but mapping in the Gassabias Lake and Nicatous Lake quadrangles suggests that it was derived from the western lobe of the pluton. Two phases of granite have been identified: coarse to megacrystic K-feldspar hornblende-biotite granite on the north side of the sliver, and medium-grained biotite granite on the south. Both were affected by the major Norumbega ductile shearing event. Secondary or synthetic dextral simple shears have been found within the granite sliver, suggesting that the dextral simple shear responsible for displacement along the fault system includes not only shear within the Waite and Kellyland ductile shear zones, but also these synthetic simple shears between the two ductile shear zones. This will help future ductile shear modeling for the fault system in eastern Maine.

• The multi-stage deformation history of the Norumbega fault system in the area has been detailed, including its extent, geometry, and internal structure in both homogeneous granite and heterogeneous metasedimentary rocks. The (earliest) dextral ductile shearing event began after the emplacement of granitic plutons ~380 Ma years ago and branched into two big strands in the study area – the Waite and Kellyland fault zones. The accompanying map provides a refined picture of the Kellyland ductile shear zone in this part of eastern Maine.

• Shear strain facies have been mapped within Deblois granite deformed in the Kellyland ductile shear zone. Plastic deformation within quartz grains (with associated microstructures such as dynamic recrystallization by sub-grain rotation with curved grain boundaries, core-mantle structures, and deformation bands) accompanied by fractures, only, within adjacent feldspars, demonstrate that the deformation temperature is probably below 350° based on the experiments by Hirth and Tullis (1992).

• Three distinct subsequent multiple brittle faulting events have been identified, and the changing stress fields associated with each event were reconstructed for the first time from small-scale cross-cutting structures. Almost all the brittle faulting was concentrated in the pre-existing Waite ductile shear zone with only minor very small-scale secondary jointing/faulting distributed along the Kellyland zone. Stage-1 reverse faulting, with its maximum principal stress in the direction of 100°-125°, caused large-scale cataclasis and brecciation along the Waite zone. Stage-2 transtensional faulting, with its maximum principal stress in the direction of 065°-085°, is believed to be responsible for the opening of narrow pull-apart Pennsylvanian(?) redbed basins along the Waite zone. The R-shears, one of two sets of conjugated secondary faults, might have been pulled apart and linked to form narrow pull-apart depressions (then basins) under a dextral transtension regime. Extension at some releasing bends may also have formed small and very narrow redbed basins. Stage-3 reverse-sinistral-faulting, with its maximum principal stress in the direction of 135°-155°, juxtaposed the redbeds against Fredericton belt rocks and was responsible for tilting the redbeds to their current steeply dipping attitudes.

Because of the complexity of the fault system, and the generally poor bedrock exposure, some issues remain uncertain. Also because of the regional scale of the fault system, more work should be done along the southwestward extension of the Norumbega fault system to resolve large-scale geologic issues such as the origins of the granitic slivers between the Waite and Kellyland zones and the branching mechanism of the fault system. The complexly sheared granitic slivers (Third Lake Ridge granite is one of these slivers) between the Kellyland and Waite fault zones from Great Pond to the Amazon Mountain area may provide a key to understanding the evolution of the NFS in an area where these two strands appear to converge. This will finally help to build a shear model for the early ductile Norumbega shearing system in eastern Maine. The three-stage brittle-faulting model proposed by this project also needs additional work southwestward along the fault system for comparison and refinement.

ACKNOWLEDGMENTS

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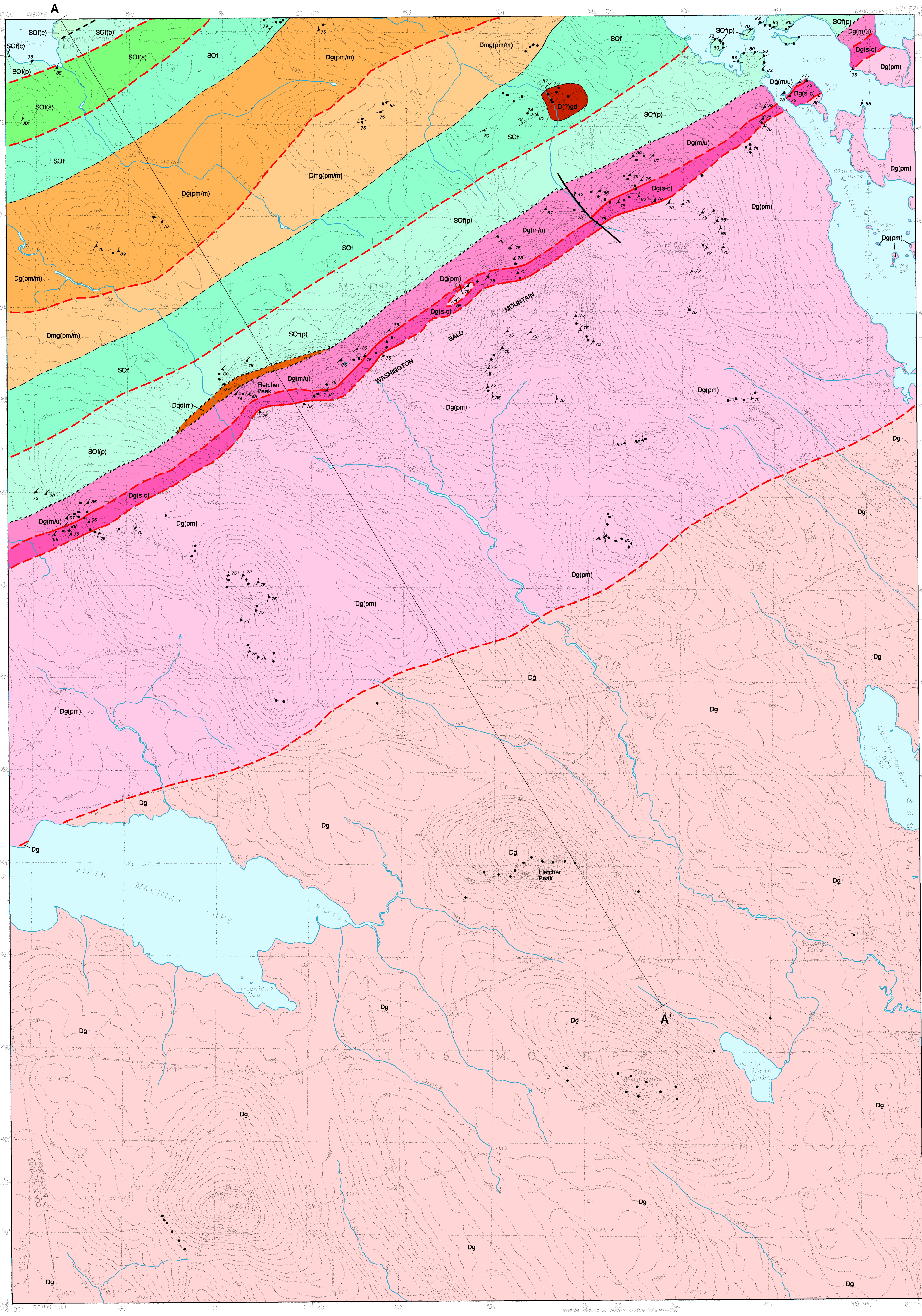

EXPLANATION OF UNITS

INTRUSIVE ROCKS

Devonian and Devonian (?)

Unit	Description
D(?)gd	Unnamed granodiorite. Fine to very fine-grained hornblende granodiorite.
Dqd(m)	Mylonite derived from quartz-diorite.

Third Lake Ridge granite

Unit	Description
Dmg(pm/m)	Medium-grained biotite granite. Typically foliated or mylonitized (protomylonite-mylonite).
Dg(pm/m)	Coarse to megacrystic K-feldspar hornblende-biotite granite. Typically foliated or mylonitized (protomylonite-mylonite).

Deblois pluton

Unit	Description
Dg	Coarse to megacrystic K-feldspar hornblende-biotite granite. Undeformed with normal granitic texture.
Dg(pm)	Foliated to slightly foliated coarse to megacrystic granite (protomylonite).
Dg(s-c)	S-C mylonite developed in coarse to megacrystic granite.
Dg(m/u)	Mylonite and ultramylonite derived from Deblois granite.

STRATIFIED ROCKS

Silurian-Ordovician

Flume Ridge Formation

Unit	Description
SOf	Flume Ridge Formation (unsheared). Variably calcareous turbiditic quartzofeldspathic wacke, typically hornfelsed to biotite facies.
SOf(p)	Phyllonite derived from Flume Ridge Formation.
SOf(s)	Spangled muscovite-quartz-schist produced by intense ductile shearing of Flume Ridge Formation
SOf(c)	Cataclasite and coarse breccia produced by brittle shearing of Flume Ridge Formation.

EXPLANATION OF SYMBOLS

- Bedrock outcrop with no structural data
- Strike and dip of foliation (20)
- Strike and dip of bedding (20)

EXPLANATION OF MAP LINES

- Intrusive contact modified by shearing (well located, inferred).
- Brittle fault (well located, inferred).
- Ductilely sheared contact between Flume Ridge and igneous rocks (well located, inferred).
- Gradational ductile strain facies boundary (well located, inferred).

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 géologique) - RÉVISION.)

Bedrock Geology of the Fletcher Peak Quadrangle, Maine

Bedrock geologic mapping by
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Digital cartography by:
Susan S. Tolman

Robert G. Marvinney
State Geologist

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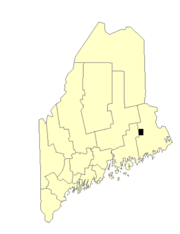
Open-File No. 07-143
2007
This map accompanied by a 16 p. report.


Quadrangle Location

SCALE 1 : 24,000

1 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET

TRUE NORTH

SOURCES OF INFORMATION

Bedrock geologic mapping by Chunzeng Wang completed during the 1998 and 1999 field seasons; funding for this work provided by the U. S. Geological Survey STATEMAP program.

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

The use of industry, firm, or local government names on this map is for location purposes only and does not impute responsibility for any present or potential effects on the natural resources.