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Preliminary Bedrock Geologic Map of the Milford Quadrangle, Massachusetts
Sheet 2: Brittle Structural Data Analysis

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DRAFT

OMSG Open File Report. 07-01
Preliminary Bedrock Geologic Map of the Milford Quadrangle
Sheet 2: Brittle Structural Data
2007

Topographic Base Information:
Topographic base scanned and georeferenced from paper base U.S. Geological Survey, 1969
Polyconic projection. 1983 North American Datum

Shaded relief from MassGIS (http://www.mass.gov/mgis/img_shdrel5k.htm), produced with an illumination azimuth of 315° with an altitude of 45° and a vertical exaggeration of 1.5, without the effects of local shadows.

15½
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1999

SCALE 1:24 000
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER
CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

QUADRANGLE LOCATION

Data Sources:

Map produced from digital structural database of the Milford quadrangle.

-Structural data collected by Joseph P. Kopera with assitance from Stephen B. Mabee and Rick Ponti (2006-2007)

-Additional foliation and lineation measurements for southern portion of quadrangle from Shaw (1966).

-Contoured Stereonets (Figures 1 to 8) produced with Daisy 3.53, by Francesco Salvini

EXPLANATION OF MAP SYMBOLS

Structural data

- Station where data was collected
- Strike and dip direction of steeply dipping fracture set (dip > 60°) which is part of a major map-scale fracture set
- Moderately to steeply dipping fracture set (dip > 60°) which is part of the northwest-striking, lineation-orthogonal set
- Strike and dip direction of foliation. For dip values see sheets 1 and 3
- Strike and dip direction of fracture parting parallel to foliation. For dip values see sheets 1 and 3
- Strike and dip direction of shallow to moderately dipping (dip < 60°) fracture that is not part of major map-scale fracture set.

Faults and zones of sheared rock

Ductile Fault (shear zone / gneissic mylonite)
Long dashed where approximate, short dash where inferred

Brittle Fault
Location approximate- inferred from nearby brittle structural data

Zone of intense foliation development / gneissic character in plutonic rocks

Hydrostructural Domains
(see discussion to right)

- Rocks with strong tendency to part parallel to foliation
- Rocks with moderate tendency to part parallel to foliation
- Poorly foliated to massive rocks
- Permiable overburden overlying bedrock

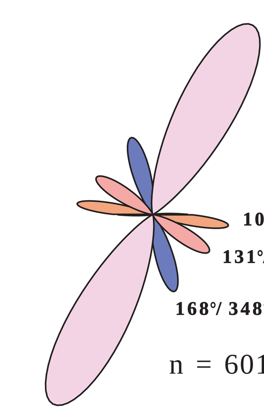

Figure 9 - Major families of steeply dipping fractures
Rose diagram of gaussian distribution of major families of fractures with dips > 60°. Length of petal of rose denotes relative abundance of fracture set relative to the total population. Width of petal roughly denotes one standard deviation of the mean from that set.

Photo 1 - Example of fracture sets at an outcrop of sheared granitic rock.
This photo shows excellent parting parallel to foliation in sheared coarse grained granite-gneiss (Zcg; see sheet 1). Also present are fracture zones which are part of the NNE (22°/202°) major set of fractures (the set of fractures facing the viewer), and the NNW (168°/348°) lineation-orthogonal set (looking downstrike from viewer).

INTRODUCTION AND DISCUSSION

This map sheet is a summary and analysis of 2639 structural measurements collected at 375 outcrops across the Milford quadrangle i. Information gathered at each outcrop included strike and dip of joints, faults, joint and fault zones, foliation, bearing and plunge of linear features, trace length of planar features, spacing (perpendicular distance between fractures having the same trend), width of joint zones, mineralization, and observations on water flow and the openness of planar features. 1680 structural measurements were collected as of this publication. 541 foliation and lineation measurements collected by Charles E. Shaw (1966) are also included in these analyses. This data has been tabulated in a digital database which is provided on an accompanying DVD to this map. As of the date of this publication, brittle structural data are still being collected for rocks of the Blackstone Group in the southeastern portion of the map (see sheet 1; area delineated on map to left), and are not included on this map, in the database, or in the discussion below.

Major Fracture Sets
The large map to the left, in part, summarizes the distribution of the major families of fractures across the quadrangle. Data are summarized as radiating strike and dip symbols of each major fracture set present at an outcrop. The data are coded as to fracture type and dip family (see legend). Major fracture sets are defined as those observed in the field to be the dominant sets at outcrop scale, and which form statistically significant populations within the entire fracture data set for the quad (Figs. 1 and 9). A rose diagram showing the major fracture families with dips > 60° in the quadrangle is presented in Figure 9.
In general, there are five major fracture can be observed in the Milford quadrangle based on field observations, stereonet analysis, and statistical analysis of the dataset. They are listed in order of prominence:

1. **Subvertical north-to-northeast trending fractures (~020°, 86°) and fracture-zones.** Such fractures are associated with similarly trending faults, vein sets, and Mesozoic-age diabase dikes. This set occurs in both foliated and massive rocks primarily as zones of closely-spaced fractures one to several meters in width (Figure 8; Photo 1). This is the most prominent fracture set observed throughout the entire Milford quadrangle (Figures 1 and 9). This set is roughly parallel to a major set of outcrop scale faults (see below; Figure 5; sheet 3).
2. **Moderate to shallow-northeast-dipping partings parallel to foliation.** These are shallow to moderately dipping (~26°), northwest striking (310°) fractures that predominantly occur in strongly foliated to sheared rocks (Figures 2 and 3; Photo 2) . At a regional scale, these fractures generally follow the trend of foliation (see Sheet 3), but are more predominant and intensely developed in the highly sheared rocks in the northwest portion of the Milford quadrangle (see Sheet 3).
3. **Moderate to steeply-southwest-dipping, northwest striking (127°, 62°) cross joints.** This fracture set is primarily orthogonal to partings parallel to foliation, and perpendicular to lineation in strongly foliated rocks (Figures 1, 2, and 4). set occurs throughout all rocks in the quadrangle.
4. **Subvertical east-west striking (270°, 86°) fractures and fracture zones.** set occurs throughout all rocks in the quadrangle.
5. **Subvertical north-south striking (000°, 84°) fractures and fracture zones.** set occurs throughout all rocks in the quadrangle.

Hydrostructural Domains
The map to the left also shows hydro-structural domains. The hydrostructural domains and overlay zones shown on the map define regions that contain attributes thought to be important in influencing groundwater availability and flow in the bedrock. These attributes include bedrock type, the presence or absence of layering (foliation) in the rocks, the degree of development of transmissive partings parallel to the layering, the intensity of sub-horizontal sheeting development, the number and distribution of regional joint systems and outcrop-scale faults, and the distribution of permeable surface materials.

Three hydrostructural domains have been delineated in the Milford quadrangle, and have a direct correlation with the presence and strength of ductile structural features in the rock. The domains are generally delineated based on the presence and strength of partings parallel to foliation in the rock. All other major fracture families are present in all domains. In general, the steeply dipping fracture families may provide an excellent opportunity for vertical recharge and communication to fractured bedrock aquifers from the surface.

1.) **Strongly foliated rocks with well developed fracture partings parallel to foliation.** The dominant fracture set in these domains are shallow- to moderately-dipping fractures that are parallel to foliation. These domains are associated primarily with strongly sheared granitic rocks in the northwestern portion of the quadrangle. These partings are evenly distributed throughout the rock mass with spacings varying from 2-3 centimeters to 10 or more meters, do not terminate against other fracture sets or within the rock mass, and their trace lengths generally exceed the width of the outcrop being studied ("through-going"). The partings may serve as a conduit for lateral flow between more steeply dipping fractures.

2.) **Foliated rocks with moderately developed fracture partings parallel to foliation.** Partings parallel to foliation are not the dominant fracture set in these domains, but are still present. The partings are generally not evenly distributed throughout the rock mass, and tend to terminate within the rock mass or against other fracture sets. The other major fracture families are more dominant in this domain.

3.) **Poorly foliated to massive rocks.** Partings parallel to foliation are uncommon to generally absent in these domains. All other major fracture sets are present. This domain is characterized by a near-orthogonal lattice-work of the major steeply dipping fracture sets, providing the possibility for good local vertical recharge. Subhorizontal sheeting joints near the tops of hills that roughly follow topography provide the opportunity for lateral flow of groundwater.

Permeable Overburden: The map also shows areas of permeable overburden (e.g., stratified glacial drift) that lie on top of the fracture domains. Such deposits may serve as reservoirs of groundwater that could recharge fractured bedrock aquifers via steeply dipping fracture sets. Conversely, such deposits could be drained of groundwater via vertical communication with the fracture sets they overlie.

Major observations and interpretations from fieldwork and stereonet analysis:

- Foliation and lineation exert a fundamental control on the development of fractures, veins, and faults in the Milford quadrangle. Nearly all the fractures in the quadrangle that are not partings parallel to foliation, or are part of the above mentioned fracture sets, are orthogonal to foliation, and/or parallel to lineation (Figures 1 through 5). Very few fractures in the Milford quadrangle cut foliation at an oblique angle.
- Sub-horizontal sheeting joints are generally poorly developed in the Milford quadrangle, except in massive rocks or where foliation exceeds roughly 50 degrees in dip. This phenomenon has been observed in both the Marlborough and Hudson quadrangles to the north (Mabee and Salamoff, 2004; Mabee, 2005).
- Vein sets are primarily developed roughly perpendicular to lineation, or parallel to north-northeast trending, subvertical faults.
- In poorly foliated and massive rocks the north-south / east-west subvertical fracture sets rotate into parallelism and orthogonal with local features such as diabase dikes, xenoliths of country rock, outcrop-scale brittle faults, geologic contacts, etc...
- Heterogeneities in the rock, such as outcrop-scale brittle faults, xenoliths, or diabase dikes, tend to have feature-parallel fracture zones extending outward for several meters from them.
- Fractures and their relation to topographic lineaments: The intersection of partings parallel to foliation and fracture sets oriented perpendicular to local lineation and foliation tend to form local topographic lineaments, or troughs, parallel to the strike of foliation, noteably in the western portion of the quadrangle. Such local topographic lineaments are more common in areas where foliation is more strongly developed, and partings parallel to foliation are more dominant. Cross-joints to foliation-parallel partings also tend to form hill-slopes where foliation is shallowly dipping into the slope of the hill. All other steeply dipping fracture sets tend to have prominent topographic lineaments associated with them (see sheet 3).

Faults

- Three major families of faults exist in the Milford quadrangle (Figure 5; sheet 3):
  - Moderate to shallow north-dipping, east-west trending ductile faults (shear zones) generally parallel to regional foliation, and concentrated in the northwestern corner of the quadrangle.
  - North-to-northeast trending, subvertical outcrop-scale brittle to semi-brittle faults. As of this writing, few major faults with this orientation could be delineated at map scale.
  - A smaller family of east-west, sub-vertical ductile faults exists in the Milford granite (see sheet 1) in the eastern portion of the quadrangle.
- Where there is a great concentration of outcrop-scale brittle faults (usually near a larger brittle fault) and or xenoliths, the fracture orientations and distribution tend to be chaotic and not mirror the major fracture sets observed across the quadrangle.
- Zones of intensely sheared rock locally have well developed partings parallel to foliation within them.

NOTE: This Open-File map is a progress report of ongoing mapping in this area, and is preliminary in nature. It has not been peer reviewed or edited to conform with editorial standards of the Massachusetts State Geologist or with the North American Stratigraphic Code. A final, edited, reviewed version of the map will be published at a later date.

This research was supported by U.S. Geological Survey, National Cooperative Geologic Mapping Program, under assistance Award No. 06HQAG0012. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government, the Commonwealth of Massachusetts, or the University of Massachusetts.

Citation:
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A digital copy of this map, including GIS datalayers, is available at **http://www.geo.umass.edu/stategeologist**. Additional paper copies can also be obtained from the Office of the State Geologist for a small fee.

Figure 1 - All fractures
Equal area projection of poles to all fractures

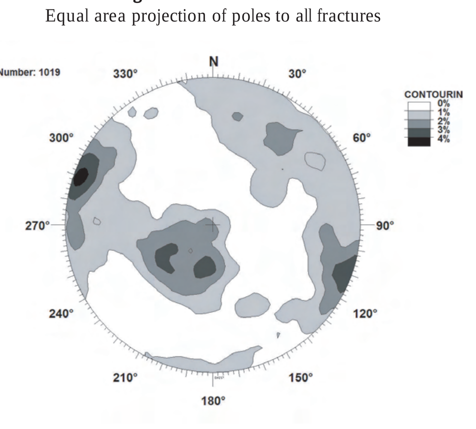

Figure 2 - Foliation-parallel partings
Equal area projection of poles to all partings parallel to foliation

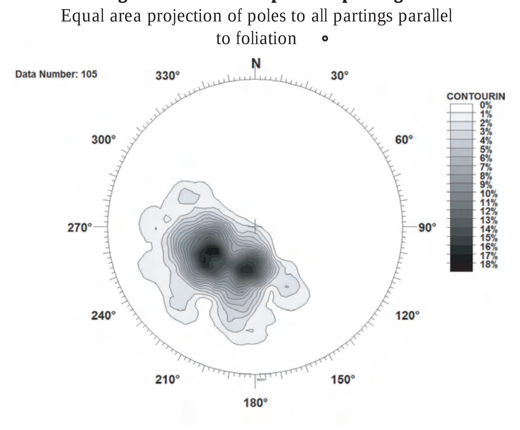

Figure 3 - Foliations
Equal area projection of poles to all foliations

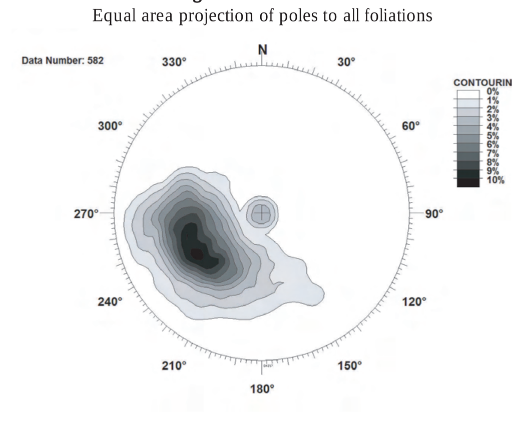

Figure 4 - Lineations
Equal area projection of all lineations

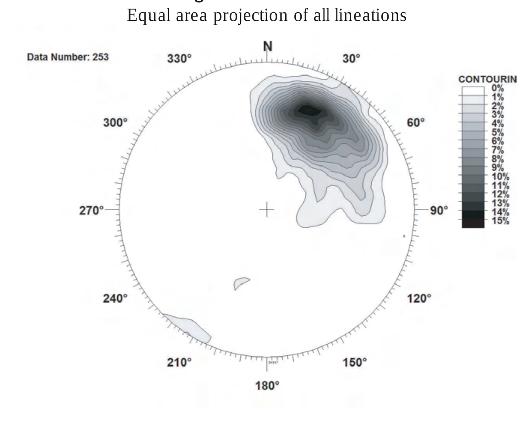

Figure 5 - Faults
Equal area projection of poles to all ductile and brittle faults

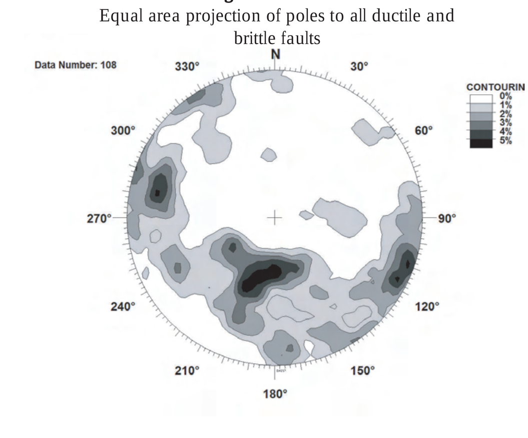

Figure 6 - Sheeting Joints
Equal area projection of poles to all subhorizontal sheeting joints

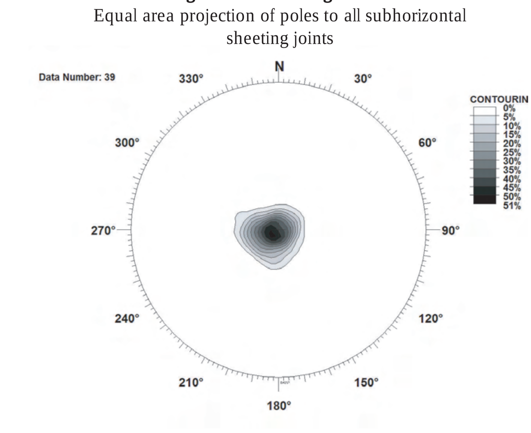

Figure 7 - Veins and Dikes
Equal area projection of poles to all veins and dikes

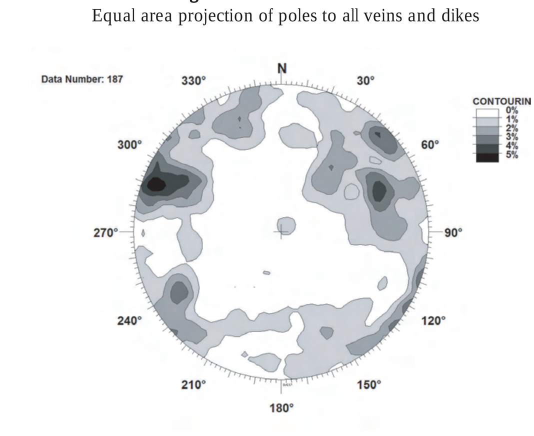

Figure 8 - Fracture Zones
Equal area projection of poles to all fracture zones