INTRODUCTION

The Belvidere Mountain area is located within the serpentine belt in the towns of Eden, Eden Mills, and Lowell, Vt. The rocks in the area were previously mapped as part of a normal stratigraphic sequence, from oldest to youngest, eastward from the core rocks of the Green Mountain anticlinorium (Albee, 1957; Doll and others, 1961; Cady and others, 1963; Chidester and others, 1978). The sequence consists of, from base to top, schist and gneiss of the Cambrian Hazens Notch Formation (Cady and others, 1963), greenstone, amphibolite, and muscovite schist of the Belvidere Mountain Complex (Belvidere Mountain Formation of Chidester and others, 1978), and schist and phyllite of the Ottauquechee Formation (Perry, 1929). The ultramafic rocks were most recently interpreted as solid mantle material which intruded into continental crust and eugeosynclinal sediments during rifting. The rock was transported to high levels in the eugeosynclinal pile during subsequent uplift in Early Ordovician time (Chidester and others, 1978).

In contrast with the earlier views, (Cady and others, 1963; Chidester and others, 1978) detailed mapping of tectonic stratigraphy at a scale of 1:20,000 offers evidence for fault emplacement of the ultramafic rocks, and questions previous age assignments. The geology reflects a history of faulting and folding which results in a severely disrupted sequence of metasedimentary rocks, mafic meta-igneous rocks having ocean-floor characteristics (Gale, 1980), and serpentinized ultramafic rocks. There is little evidence for establishing a stratigraphic sequence in the area: primary sedimentary features are not present in the multiply deformed rocks; consistent contact relationships are not present; most contacts are not exposed; units are repeated and truncated by folds and faults.

The rocks in the area are mapped as 13 units grouped into three litho-tectonic packages that coincide with the previously mapped formations: schist and gneiss (wgn, rs, ss, agn) of the Hazens Notch Formation, the Belvidere Mountain Complex (Gale, 1980) consisting of a transported association of serpentinized ultramafic rocks (oud, outc) and the underplated amphibolites (bac, baf) greenstone (bgs), and fault breccia (mus); schist and phyllite (grp, bcp, gp, pgw) of the Ottauquechee Formation (Perry, 1929). However, the contacts between these packages are fault contacts, and the stratigraphy within some of the packages is fault constructed. The geology represents an imbricate fault zone in which a variety of lithic packages are juxtaposed.

STRUCTURE

Four fold generations (F_1, F_2, F_3, F_4) are recognized in the area. The three most recent fold events (F_2, F_3, F_4) postdate the faults. The relationship of the faults to the early fold event (F_1) is less clear, and F_1 is considered synchronous with faulting. Faults and early folds are suggested as part of a long history of transport and emplacement of the Belvidere Mountain Complex onto Lower Cambrian and Cambrian clastic rocks of the continental margin.

Folds and Minor Structures

Definition of four fold generations in the Belvidere Mountain area is based on superposition of minor folds and foliations as well as consideration of style, orientation, and systematic change in orientation. Primary sedimentary features were not recognized in the multiply deformed, polymetamorphosed rocks.

F_1 folds are east-northeast- to northwest-striking, isoclinal overturned folds. A finely spaced (<1 mm) cleavage, parallel to compositional layering in thinly banded rocks, is the S_1 foliation associated with F_1. The compositional banding is believed to result from metamorphic differentiation and to occur parallel to the F_1 axial surfaces. However, because F_1 folds are isoclinal, the compositional banding may also parallel bedding(?) except in the hinges of F_1 folds.

F_1 and S_1 are deformed by F_2 northeast- to northwest-striking, tight to isoclinal, southeast- to southwest-plunging folds. S_2 is a closely spaced (1–2 mm) schistosity parallel to the F_2 axial surfaces. Due to the isoclinal nature of F_2 folds, S_1 and S_2 are nearly parallel except at F_2 fold hinges where S_1 is at a high angle to and truncated by S_2.

F_3 folds are superposed on all earlier structures. F_3 folds are tight to open, northeast-trending folds having variable northeast, southeast, and southwest plunge. S_3 is a poor to well-developed crenulate foliation axial planar to F_3.

F_4 folds are northeast-trending gentle folds recognized by a slight warping of all earlier structures. No foliation is associated with F_4.

F_2, F_3, and F_4 folds are superposed on all faults and F_1 folds. The relationship of the faults to F_1 is variable (see section on thrust surfaces).

Thrust Surfaces

Fault contacts in this area are defined by truncated units on both sides of a common surface, truncated fold structures, and physical features such as slivers of structurally higher units incorporated along successively lower fault surfaces, breccia, slickensides, and discontinuous talc zones.

Five fault surfaces are delineated in the Belvidere Mountain area. Three faults, best documented near the summit of Belvidere Mountain, are confined to the Belvidere Mountain Complex, are folded by F_1, and truncate some F_1 minor structures (fig. 1, faults A, B, C). F_1 folding is thus considered synchronous with faulting, and together these events constitute the earliest recognized deformation (D1).

Fault surface A (fig. 1) is the contact between the serpentinite (oud) and the underlying units of the Belvidere Mountain Complex. The serpentinite truncates the muscovite schist (mus)-greenstone (bgs) contact (loc. 1), the greenstone (bgs)-fine-grained amphibolite (baf) contact (loc. 2), and the fine-grained amphibolite (baf)-coarse-grained amphibolite (bac) contact (loc. 3). In addition, at the serpentinite (oud)-fine-grained amphibolite (baf) contact (loc. 2) the amphibolite contains rounded pods of extremely coarse grained chlorite-actinolite rock. The serpentinite (oud)-greenstone (bgs) contact is marked by a discontinuous talc zone (loc. 4) and a sliver of coarse-grained amphibolite (loc. 5).

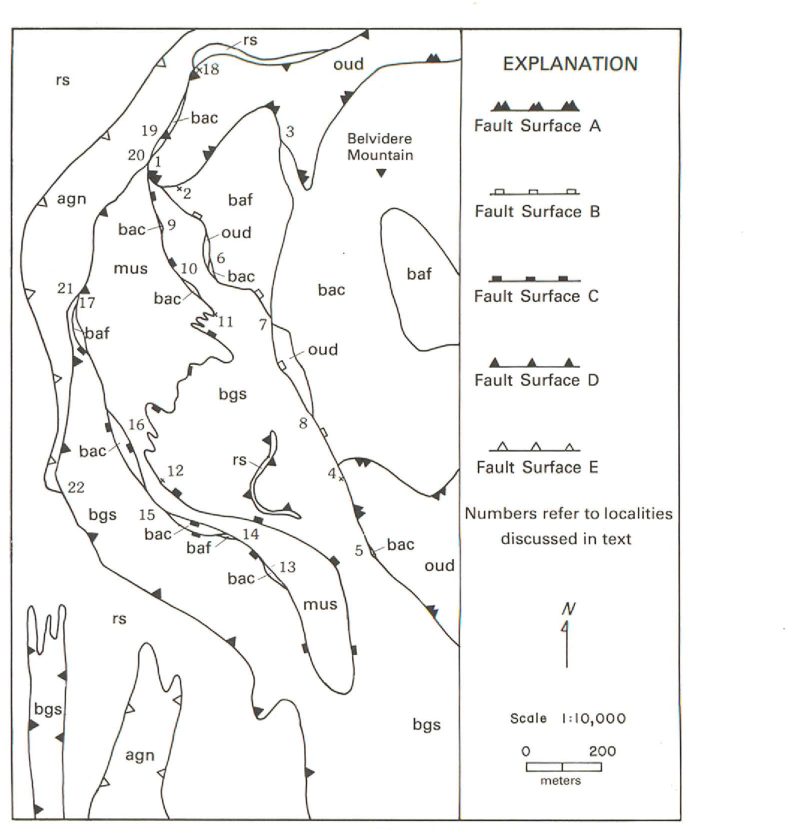


FIGURE 1.—Summit area of Belvidere Mountain.

Fault surface B (fig. 1) is the contact of the fine-grained amphibolite (baf) and coarse-grained amphibolite (bac) with the underlying greenstone (bgs). The fault is exposed for approximately 15 m along strike (loc. 6), and is marked by a sliver of schistose serpentinite (oud), a sliver of coarse-grained amphibolite (bac), chlorite-actinolite pods within the fine-grained amphibolite (baf), and a 2 mm- to 15 mm-thick sheet of contorted talc-carbonate rock containing numerous bent and broken amphibole laths. The fine-grained amphibolite (baf)-coarse-grained amphibolite (bac)-serpentinite (oud) contact (loc. 7) is truncated by the greenstone (bgs), and the coarse-grained amphibolite (bac)-serpentinite (oud) contact is truncated by the greenstone (loc. 8). The serpentinite (oud) is thus interpreted as a fault sliver. Fault surface B joins fault surface A at localities 2 and 4.

Fault surface C (fig. 1) is the folded (F_1) fault contact between the greenstone (bgs) and the underlying muscovite schist (mus). The contact is marked by several slivers of coarse-grained amphibolite (bac) (locs. 9, 10, 13, 15, 16), fine-grained amphibolite (baf) (locs. 14, 17), and discontinuous zones of talc-carbonate rock and talc-rich phyllite (locs. 11, 12). The fault contact is well exposed at locality 16 where greenstone (bgs) is below the muscovite schist (mus) because of F_1 folding.

The fault contacts within the Belvidere Mountain Complex (litho-tectonic package 2) are characterized by truncated units and the presence of slivers of the upper units incorporated along successively lower fault surfaces.

Fault surface D (fig. 1) is the contact between the Belvidere Mountain Complex and the underlying schists and gneisses of litho-tectonic package 1. This contact is not folded by F_1, but does predate F_2, F_3, and F_4 folds. The serpentinite (oud) truncates the rusty schist (rs)-albite gneiss (agn) contact (loc. 18), and the fault is marked by slickensides, a 0.3-m-thick discontinuous layer of green and gray banded phyllite, and discontinuous talc zones. To the south, a coarse-grained amphibolite (bac) sliver (loc. 19), the serpentinite (oud), and the muscovite schist (mus) are truncated by the albite gneiss (agn) (loc. 20). The folded (F_1) fault contact of the greenstone (bgs) and the muscovite schist (mus) is truncated by the albite gneiss (agn) at locality 21, and the rusty schist (rs)-albite gneiss (agn) contact is truncated by the greenstone (bgs) at locality 22. The southern continuation of fault surface D is inferred on the basis of isolated bodies of talc-carbonate rock, talc-steatite, and quartz-carbonate rock present along the contact of the greenstone (bgs) with both the rusty schist (rs) and the sericite schist (ss). In addition, the greenstone (bgs) is in contact with three different units (rs, agn, ss) of litho-tectonic package 1 suggesting that the underlying stratigraphy is truncated by the greenstone (bgs). An additional fault surface may be present at the albite gneiss (agn)-rusty schist (rs) contact as evidenced by the isolated occurrences of serpentinite (oud) and talc-carbonate along this contact (fault surface E).

Documentation of a fault contact between the Belvidere Mountain Complex (litho-tectonic package 2) and litho-tectonic package 3 is poor due to the paucity of outcrop. However, a fault contact is suggested by isolated occurrences of black carbonaceous phyllite (bcp) along the greenstone (bgs)-phyllite graywacke (pgw) contact. In addition, different units such as serpentinite (oud), and greenstone (bgs) of the Belvidere Mountain Complex are in contact with three different units of litho-tectonic package 3 (bdp, pgw, grp) suggesting truncated units on both sides of a common surface.

SUMMARY AND DISCUSSION

The structural and stratigraphic relationships document a tectonic stratigraphy of the Belvidere Mountain area. The 13 mapped units are grouped into three litho-tectonic packages depicted in figure 2. Figure 2 also illustrates the fault relationships within packages and the fault relationships between the litho-tectonic packages. Construction of litho-tectonic package 2 by a series of thrust faults is followed by transport of litho-tectonic package 2 over the rocks of litho-tectonic packages 3 and 1. Litho-tectonic package 3 is later thrust over litho-tectonic package 2. This inferred relationship of litho-tectonic package 3 to litho-tectonic package 2 is, however, preliminary.

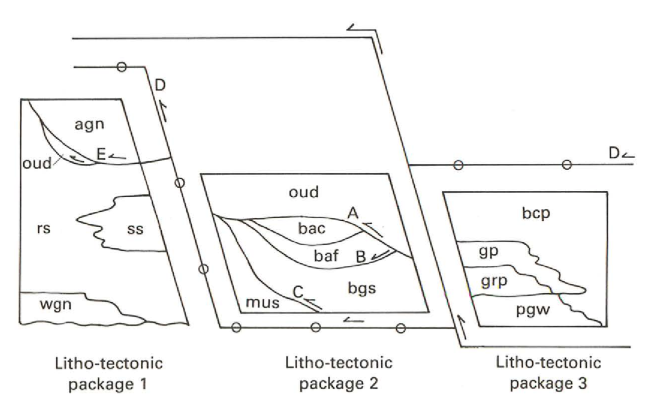


FIGURE 2.—Summary of stratigraphic relationships. Letters A-E refer to fault surfaces discussed in text and depicted on figure 1. Not drawn to scale.

Construction of the Belvidere Mountain Complex (litho-tectonic package 2), its emplacement onto clastic rocks of litho-tectonic package 1, and the relationship of the faults to F_1 folds is shown schematically in figure 3. Initial transport of the serpentinite (oud), formation of fault surface A (fig. 1), and underplating of the amphibolites (bac, baf) is depicted in figure 3a. Continued faulting of the serpentinite (oud) plus the underplated amphibolites (bac, baf) onto the greenstone (bgs), and the development of fault surface B (fig. 1) are shown in figure 3b. Complete construction of the Belvidere Mountain Complex (litho-tectonic package 2) is illustrated in figure 3c where serpentinite (oud), the two amphibolites (bac, baf), and greenstone (bgs) are faulted onto the muscovite schist (mus) along fault surface C (fig. 1). Blocks of the overriding units (oud, bac, baf, bgs) are thought to be incorporated into the muscovite schist (mus) during this final stage of development.

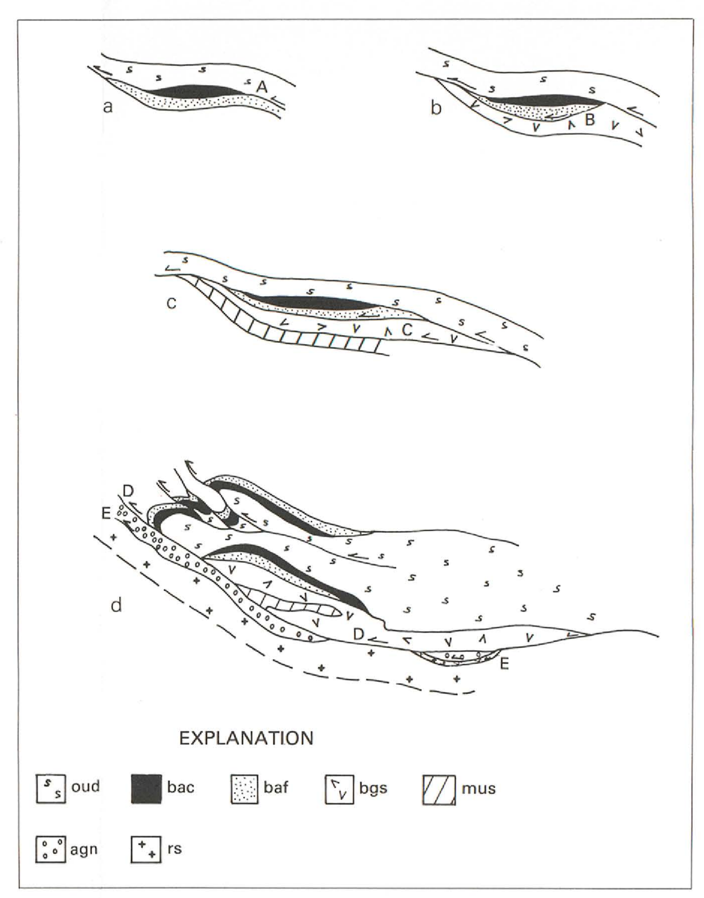
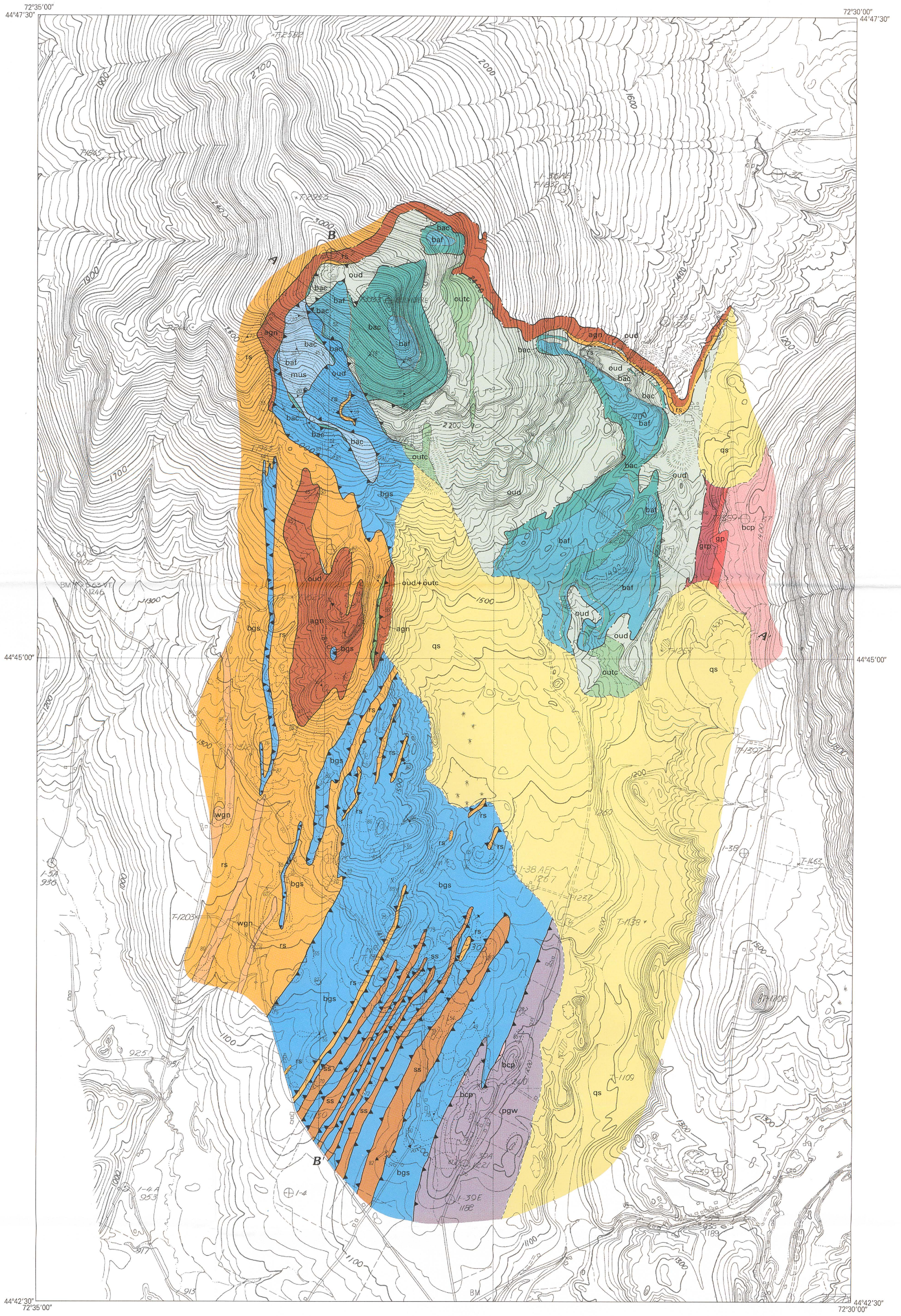


FIGURE 3.—Schematic diagram of emplacement of the Belvidere Mountain Complex (litho-tectonic package 2). Letters A-E refer to fault surfaces discussed in text and depicted on figure 1. (a) Initial transport of serpentinite and underplating of amphibolites (bac, baf) along fault surface A. (b) Faulting of serpentinite and amphibolites onto greenstone along fault B. (c) Faulting of serpentinite, amphibolites, and greenstone onto muscovite schist along fault C, thus completing construction of the Belvidere Mountain Complex. (d) Folding (F_1) of the Belvidere Mountain Complex, followed by fault emplacement onto metasedimentary rocks of litho-tectonic package 1 along fault D. Not drawn to scale. All stages are pre-F_2.

In Figure 3d, major F_1 folding of the Belvidere Mountain Complex (litho-tectonic package 2) is followed by, or associated with, fault emplacement of the Belvidere Mountain Complex onto the metasedimentary rocks of litho-tectonic package 1 (agn, rs) along fault surface D (fig. 1). The upper, overturned limb of the F_1 fold corresponds to the geology in the lower quarry area of Belvidere Mountain. The lower limb of the F_1 fold corresponds to the geology mapped at the summit area of Belvidere Mountain and to the south. All developmental stages depicted in figure 3 are pre-F_2.

As discussed by Gale (1980), the rocks in the area exhibit a metamorphic history which is correlative with, and helps to define, the deformational history. No changes in the metamorphic mineral assemblages are associated with the F_3 and F_4 fold events. Metamorphism in the biotite zone of the greenschist facies is associated with the F_2 fold event. The effects of this metamorphism vary from partial to complete overprinting of the earlier mineral assemblages associated with D_1. On the basis of textural and mineralogical criteria, the metasedimentary rocks reflect two metamorphic events, while the mafic rocks reflect at least three metamorphic events. In the metasedimentary rocks, the pre-F_2 mineral assemblages are not diagnostic of metamorphic grade, although they are consistent with Barrovian type greenschist facies assemblages.

In the rocks of the Belvidere Mountain Complex, any difference in metamorphic grade is due to the survival of an earlier assemblage (epidote-amphibolite facies) in the coarse- and fine-grained amphibolites (bac, baf). The variation in metamorphic mineral assemblages (epidote-amphibolite facies to greenschist facies) follows the fault contacts of the amphibolites (bac, baf) and greenstone (bgs). It also reflects cataclasis and retrograde metamorphism in the greenschist facies during shearing associated with transport and emplacement of the mafic metaigneous rocks at the base of the serpentinite. Epidote-amphibolite facies metamorphism (bac, baf, bgs) and subsequent retrograde metamorphism of the greenstone (bgs) to greenschist facies assemblages are all associated with D_1/F_1 folds and faults, and predate both the incorporation of these units (bac, baf, bgs) as blocks in the basal muscovite schist (mus) of the Belvidere Mountain Complex and the final emplacement of the Belvidere Mountain Complex onto the continental margin. An additional greenschist facies overprint is associated with F_2.



Base from U.S. Geological Survey Unpublished Jay Peak special map, 1:20,000, 1953

SCALE 1:20 000

1 ½ 0 1 MILE

1 .5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

APPROXIMATE MEAN DECLINATION 1986

QUADRANGLE LOCATION

Geology of the ultramafic rock and VAG (Vermont Asbestos Group) quarry area from Cady and others, 1963; Chidester and others, 1978; and Gale, 1980

DESCRIPTION OF MAP UNITS

The rocks in the Belvidere Mountain area are divided into 13 mapped units. These units are assigned to three distinct litho-tectonic packages principally on the basis of observed fault relationships. The litho-tectonic packages correspond to previously mapped formations; however, age and formation designations are omitted from the map because of the uncertainty of stratigraphic relationships.

qs — **Surficial deposits**

LITHO–TECTONIC PACKAGE 1

The lowest litho-tectonic package in the Belvidere Mountain area consists of a variety of schists and gneisses. These units correspond to rocks previously mapped as the Hazens Notch Formation (Cady and others, 1963). Isolated bodies of serpentinite and talc-steatite occur along the rusty schist (rs)-albite gneiss (agn) contact and suggest a fault contact between these units.

wgn — **Fine-grained gneiss**—White- and gray-green-banded, quartz-sericite-albite-chlorite gneiss; 3–5-mm quartzo-feldspathic bands alternate with 1-mm-wide sericite-chlorite-rich bands

rs — **Rusty schist**—Fine-grained, gray- and rusty-banded, slightly graphitic, quartz-albite-sericite-chlorite schist containing minor amounts of epidote, calcite, garnet, biotite, and sphene; includes coarser grained (1–3-mm) schist containing albite porphyroblasts

ss — **Sericite schist**—Fine-grained, silvery-gray-green phyllitic schist composed of quartz, sericite, albite, chlorite, and magnetite; finely laminated (1–2 mm) due to alternate sericitic and quartzo-feldspathic bands; estimated maximum thickness is 65 m

agn — **Albite gneiss**—Fine- to medium-grained, massive, light-gray- and green-banded (0.5–3 cm) quartz-albite-muscovite gneiss containing minor amounts of epidote, chlorite, sphene, and magnetite; estimated maximum thickness is 80 m

LITHO-TECTONIC PACKAGE 2

Litho-tectonic package 2 is the Belvidere Mountain Complex (Gale, 1980). The ultramafic rock structurally overlies the other units in the Complex. Fault contacts between these units area common, and the entire complex is in fault contact with the underlying litho-tectonic package 1. The maximum estimated thickness of the Belvidere Mountain Complex is 500 m

Because of its complexities and extent, the name Belvidere Mountain Formation is herein changed to Belvidere Mountain Complex.

oud, outc, oud + outc — **Ultramafic rocks**—Massive, brown- to white-weathering, green, moderately to fully serpentinized dunite and peridotite and schistose serpentine (oud); rusty-weathering, medium-grained, talc-carbonate rock and carbonate quartz (magnesite) rock (outc). Ultramafic rocks in the quarry area mapped by Cady and others (1963) and Chidester and others (1978) include partly serpentinized peridotite and dunite (oud), talc-carbonate rock and steatite (outc) and carbonate-quartz rock (ouc). X—Isolated outcrop of ouc

bac — **Coarse-grained amphibolite**—Coarse-grained, dark-gray amphibolite composed of hornblende, epidote, garnet, actinolite, albite, chlorite, sphene, sericite, biotite, and calcite; includes banded amphibolite in which layers are defined by slight variation in grain size and the presence or absence of garnet; maximum estimated thickness is 60 m

baf — **Fine-grained amphibolite**—Fine- to medium-grained, blue-gray to dark-gray rock composed of actinolite, epidote, hornblende, and albite with lesser amounts of garnet, chlorite, quartz, and sphene; maximum estimated thickness is 35 m

bgs — **Greenstone**—Fine-grained, green rock composed of chlorite, actinolite, albite and epidote and lesser amounts of biotite, calcite, sericite, quartz, sphene, pyrite, and magnetite; includes a homogeneous, schistose greenstone, an albitic greenstone, and a light- and dark-green-banded greenstone; maximum estimated thickness is 80 m

mus — **Muscovite schist**—Medium-grained, silver-blue schist composed almost entirely of muscovite and minor amounts of chlorite, epidote, albite, and tourmaline; contains discontinuous layers and lenses of greenstone, coarse-grained amphibolite, and talc phyllite; contains rounded to subrounded blocks (3 mm to 20 cm in diameter) of greenstone, coarse-grained amphibolite, and fine-grained amphibolite; maximum estimated thickness is 25 m

LITHO-TECTONIC PACKAGE 3

Litho-tectonic package 3 consists of phyllite, schist, and phyllitic graywacke. These units were previously mapped as the Ottauquechee Formation (Perry, 1929; Albee, 1957; Cady and others, 1963). The rocks are in fault contact with the Belvidere Mountain Complex (litho-tectonic package 2), and although litho-tectonic package 3 is considered to structurally overlie the Belvidere Mountain Complex, this relationship is not adequately documented. The areal extent of litho-tectonic package 3 is limited to a narrow belt of poorly exposed outcrop east of Belvidere Mountain, and the work here is preliminary.

bcp — **Black carbonaceous phyllite**—Black, rusty-weathering, graphitic, quartz-sericite phyllite containing pyrite

gp — **Gray phyllite**—Dark gray, quartz-sericite phyllite having quartz veins; distinguished from black carbonaceous phyllite (bcp) by its lighter gray color, lower carbon content, and lack of pyrite

grp — **Green phyllite**—Light-green, rusty-brown-weathering, quartz-sericite-chlorite phyllite

pgw — **Phyllitic graywacke**—Tan to gray rock composed of round to angular grains of quartz, blue quartz, and albite in fine-grained matrix of quartz, sericite, and chlorite

EXPLANATION OF MAP SYMBOLS

Limit of outcrop

Contact—Long dashed and dotted where taken from Cady and others (1963); short dash indicates approximate contact of qs with units

Thrust Fault—Teeth on upper plate; open teeth where inferred; long dashed and dotted where taken from Cady and others (1963)

20 — **Trend and plunge of F_2 fold axis**—(May be combined with strike and dip symbol)

Strike and dip of S_1—Finely spaced (<1mm) cleavage defined by alignment of platy (mica, chlorite) and elongate (amphiboles) minerals. Parallel to the axial surfaces of isoclinal F_1 folds. Parallel to compositional layering in thinly banded rocks, except locally in rusty schist (rs) and sericite schist (ss) where S_2 slip cleavage transposes layering

45 — Inclined

Vertical

Strike and dip of S_2 spaced (1-2 mm) schistosity—Parallel to axial surfaces of isoclinal F_2 folds. In rusty schist (rs) and sericite schist (ss) S_2 is closely spaced (<1 mm) slip cleavage that transposes layering

45 — Inclined

Vertical

Strike and dip of S_3 crenulate cleavage—Parallel to the axial surfaces of tight to open F_3 folds

45 — Inclined

Vertical

REFERENCES

Albee, A. L., 1957, Bedrock geology of the Hyde Park quadrangle, Vermont: U.S. Geological Survey Geologic Quadrangle Map GQ–102, scale 1:62,500.

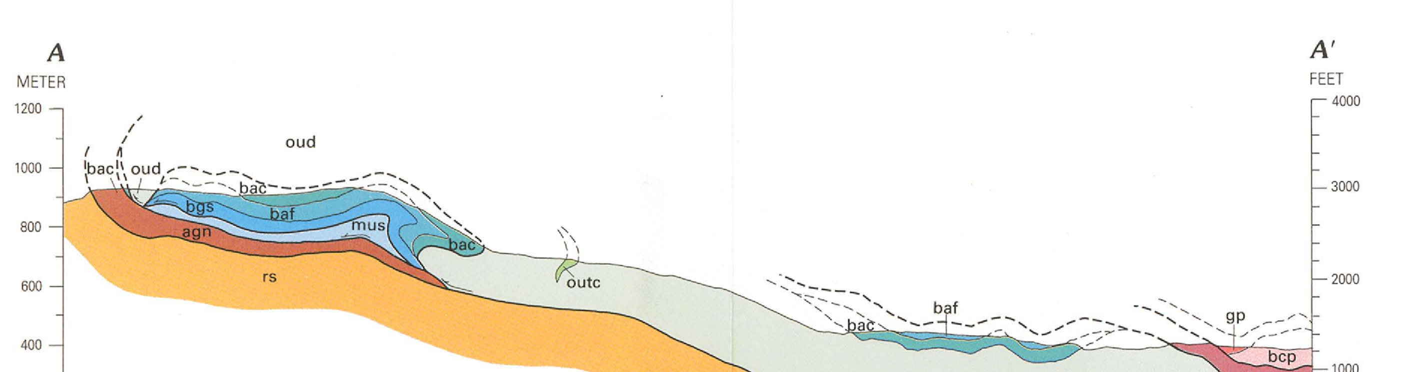
Cady, W. M., Albee, A. L., and Chidester, A. H., 1963, Bedrock geology and asbestos deposits of the upper Mississquoi Valley and vicinity: U.S. Geological Survey Bulletin 1122–B, 78 p.

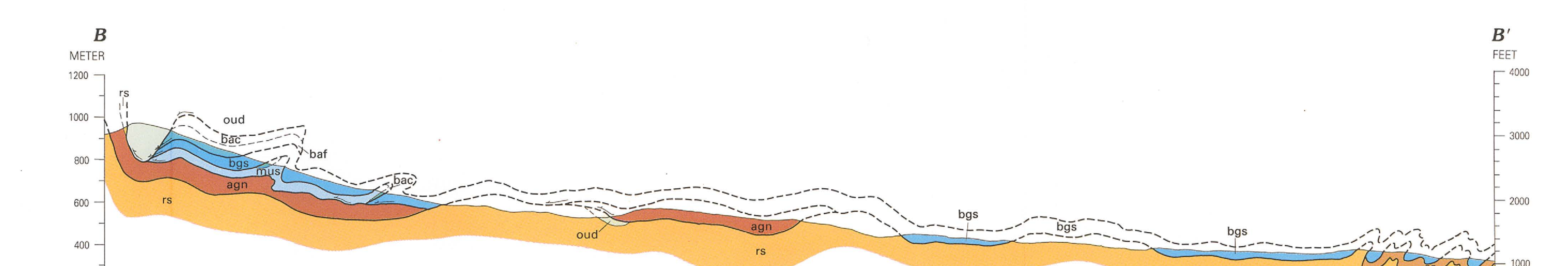
Chidester, A. H., Albee, A. L., and Cady, W. M., 1978, Petrology structure, and genesis of the asbestos-bearing ultramafic rocks of the Belvidere Mountain area in Vermont: U.S. Geological Survey Professional Paper 1016, 95 p.

Doll, C. G., Cady, W. M., Thompson, J. B., Jr., and Billings, M. P., 1961, Centennial geologic map of Vermont: Montpelier, Vermont Geological Survey, scale 1:250,000.

Gale, M. H., 1980, Geology of the Belvidere Mountain Complex, Eden and Lowell, Vermont: U.S. Geological Survey Open-File Report 80–978, 169 p.

Perry, E. L., 1929, The geology of Bridgewater and Plymouth townships, Vermont: Vermont State Geologists 16th Biennial Report 1927–1928, p. 1–64.





GEOLOGIC MAP OF THE BELVIDERE MOUNTAIN AREA, EDEN AND LOWELL, VERMONT

By
Marjorie H. Gale
1986

For sale by Branch of Distribution, U.S. Geological Survey, Box 25286, Federal Center, Denver, CO 80225