Stratigraphic Notes, 1992

U.S. GEOLOGICAL SURVEY BULLETIN 2060

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Four short papers propose changes in stratigraphic nomenclature in Vermont, Virginia, Maryland, and the District of Columbia

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1994

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
GORDON P. EATON, Director

For sale by U.S. Geological Survey, Information Services
Box 25286, Federal Center, Denver, CO 80225

Published in the Eastern Region, Reston, Va.
Manuscript approved for publication August 20, 1993.

Stratigraphic Notes, 1992
ISSN 1071–7102

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[Plates are in pocket]

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METRIC CONVERSION FACTORS

Multiply	By	To obtain
	Length	
millimeter (mm)	0.0394	inch
centimeter (cm)	0.3937	inch
meter (m)	3.281	foot
kilometer (km)	0.6214	mile
	Area	
square centimeter (cm^2)	0.1550	square inch
square meter (m^2)	1.196	square yard
	Volume	
cubic centimeter (cm^3)	0.06102	cubic inch
liter (L)	1.057	quart

1. Changes in Stratigraphic Nomenclature in the Eastern Cover Sequence in the Green Mountain Massif from Ludlow to West Bridgewater, Vermont

By Nicholas M. Ratcliffe

ABSTRACT

Detailed mapping of the cover sequence rocks overlying the Green Mountain massif from Ludlow north to West Bridgewater in Vermont indicates that the presently accepted concept of a continuous easterly topping section from the Tyson Formation to the Pinney Hollow Formation is incorrect. Instead, two similar sequences as defined herein, the Tyson Formation and the Plymouth Formation, are in thrust fault contact, which creates a structural repetition of the two sections. Each section rests on Middle Proterozoic rocks, and each passes upward into quartzite and beds of dolostone and black carbonaceous schist or phyllite. The Tyson Formation contains beds typical of the Hoosac Formation, which replaces the Tyson to the south. It is proposed that the Plymouth Formation consists of deeper water, finer grained and better laminated sediments than those of the Tyson and part of the Hoosac, consistent with west- to east-deepening condition of deposition. In addition, rocks previously assigned to the base of the Tyson Formation or Saltash Formation by previous authors are shown to belong to the Middle Proterozoic Mount Holly Complex.

INTRODUCTION

Metasedimentary cover rocks on the eastern flank of the Green Mountain massif north of Ludlow, Vt., are thought to consist of an east-dipping and easterly topping succession of rocks of Late Proterozoic(?) and Early Cambrian (pl. 1.1*A*) rocks. Where best exposed, in the Plymouth, Killington Peak, and Ludlow quadrangles, rocks assigned to the cover sequence belong to the Tyson and Hoosac Formations, as illustrated on the Bedrock Geologic Map of Vermont (Doll and others, 1961) or in the Plymouth quadrangle report (Chang and others, 1965). Recent geologic mapping in this area suggests that the section is not continuous but is broken by important thrust faults (pl. 1.1*B*). These faults juxtapose two similar but recognizably different stratigraphic sequences, here called the Tyson and Plymouth Formations, which probably are, in part, lateral facies equivalents. Both sections, which contain beds of shallow-water shelf-sequence carbonate rocks near their tops, probably are the extension of the Cambrian miogeoclinal shelf east of the Green Mountain core as suggested by Perry (1929), Keith (1932), and Thompson (1972). The existing stratigraphic nomenclature (Doll and others, 1961) does not describe adequately the rock bodies present, nor does it unambiguously relate them to correlative units along strike.

The stratigraphic sequences discussed here rest with angular discordance on Middle Proterozoic rocks of the Mount Holly Complex. Locally preserved basal conglomerates, often very coarse grained, contain fragments of the Mount Holly as described by Perry (1929). The lower part of the section contains gritty feldspathic quartzite, black phyllite, and quartzite originally assigned to the Mendon series of Perry (1929) or to the Saltash Formation of Brace (1953). Brace mapped an overlying sequence of conglomeratic quartzite and dolostone that he believed lay unconformably on the older Saltash. He applied the term Tyson Formation to these younger beds, following the newly adopted usage of Thompson (1950), in the Ludlow area immediately to the south. However, in producing the State geologic map, Doll and others (1961) abandoned the term Saltash, mapped all of Brace's Saltash as Tyson, and eliminated the angular discordance between the Saltash and Tyson previously suggested by Brace. In the usage of Doll and others (1961) and in that of Chang and others (1965), the dolostone at the top of the Tyson is conformably overlain by black albitic schists, feldspathic quartzite, a second dolostone, and an uppermost black phyllite all assigned by them to the Hoosac Formation. Brace assigned these same albitic rocks to the Grahamville Formation following Thompson's (1950) usage to the south, which was not followed in Doll and others (1961) or in Chang and others (1965). The upper part of the Hoosac, represented by rocks above the albitic schists, was assigned to the Plymouth Member of the Hoosac Formation by Doll and others (1961), thus establishing continuity with a previously used name, the Plymouth Marble, as proposed by Keith in 1932, and the name Plymouth Marble was adopted by the U.S. Geological Survey.

The term Plymouth marble, as originally used by Keith (1932), was incorrectly applied by him to two belts of dolostone, one that crops out in the Black River Valley and the other exposed near the village of Plymouth. However, the two belts differ, as shown by Perry (1929), Brace (1953), Chang and others (1965), and by this study. It is proposed here that the upper quartzite, dolostone, and black phyllite previously assigned to the Plymouth Member of the Hoosac be assigned as members to a new formation, the Plymouth Formation. These members contain rocks atypical of those of the Hoosac Formation in southern Vermont and Massachusetts (Ratcliffe and others, 1993; and Ratcliffe, 1993), and the name Hoosac for these rocks is not appropriate. Therefore, the name Plymouth Member of the Hoosac Formation is not recommended for use. The name Saltash, as proposed by Brace, is not here adopted. The term Tyson Formation, however, is. Notably, revisions in areal distribution of the Tyson from that shown by Doll and others (1961) are made herein, as not all of Brace's Saltash is thought to be part of the cover sequence; much of what was mapped as Saltash is severely deformed and retrograded gneiss of the Mount Holly Complex.

The Plymouth Formation, as used here, is overlain by the greenish phyllite and greenstone of the Pinney Hollow Formation. The contact of the Plymouth Formation and the Pinney Hollow may be a fault, although evidence for this is not convincing in this area.

Since preparation of this report for publication, details of the geology have been released in Walsh and Ratcliffe (1994). Readers interested in the geology of the area discussed as well as areas immediately to the east are referred to this Open-File Report.

MAP RELATIONS

The Mount Holly Complex crops out in the western part of the area shown (pl. 1.1*B*), where it forms the eastern edge of the Green Mountain massif. A variety of rock types, including granite gneiss, quartzite, diopside-calcite marble, calc-silicate rocks, amphibolite, and a complex variety of garnetiferous schist and gneiss, make up the Mount Holly. General structural trends for the Middle Proterozoic gneisses of the Mount Holly Complex are east-west to north (pl. 1.1*B*). These trends commonly are documented by relict, steeply dipping compositional layers. Near the edge of the massif, in a zone approximately 2 km wide, north- to northwest-striking, east-dipping Paleozoic foliation, either Taconic, Acadian, or both, transects Proterozoic rocks and fold patterns and virtually transposes the earlier Proterozoic layering. Because the regional metamorphism is biotite grade, lower greenschist-facies minerals are ubiquitous in the basement rocks. The combination of retrograde minerals and intense structural overprinting makes recognition of Proterozoic protoliths difficult and mapping of the contact with Paleozoic rocks challenging.

From the central part of the Ludlow quadrangle north to a point just north of the center of the Killington Peak quadrangle and along the eastern border of the massif, the contact with cover rocks is a thrust fault (pl. 1.1*B*). North and south of this fault, a well-defined unfaulted unconformity is mapped. A small inlier of cover rock exists at Tiny Mountain in the western part of the Ludlow quadrangle.

East of the Green Mountain massif, gneisses of the Mount Holly reappear in the cover sequence at two places. One occurrence at Dry Hill is produced by an anticline that is mantled by conglomeratic rocks of the Tyson Formation. The second but more equivocal exposures appear between albitic schist of the Hoosac below and quartzite of the Plymouth Formation above, in the steep cliffs above Black Pond. The lower contact with the Hoosac from Plymouth Union north to Mission Chapel is interpreted as a regionally important thrust fault that separates rocks of the Tyson Formation from the Hoosac. The Pinney Hollow overlies the upper member of the Plymouth Formation along the eastern edge of the map area and in a faulted synform north of Plymouth.

The one dolostone unit previously mapped as one unit by Keith (1932) is actually two separate units. One, the Tyson dolostone, crops out in the western and lower Black River Valley, whereas the other crops out in valleys flanking the synformal ridge of Pinney Hollow Formation at Plymouth and in scattered small exposures to the south.

SALTASH FORMATION

The Saltash Formation as proposed by Brace (1953) (pl. 1.1*A*) crops out on Saltash Mountain and over broad areas on the slopes that extend down to the Black River Valley. According to Brace, the lowermost unit in the Saltash is largely massive albite-magnetite grit (his unit *A*). This unit is overlain by a black carbonaceous phyllite (his unit *B* of the Saltash), and this in turn is overlain by more gritty quartzite and quartzose dolostone (his unit *C*). Unit *C* is locally overlain by a reasonably persistent quartzite, as shown by Perry (1929), which Brace placed in the Tyson Formation. Near the southern end of Amherst Lake, Brace mapped quartzite and dolostone of the Tyson truncating units *B* and *C* of the Saltash. These map relations were used to support the idea of the unconformity at the base of the Tyson (Brace, 1953, pl. 2, section *H–H'*).

Remapping of the rocks on Saltash Mountain and on a series of peaks extending northward from that point in the Killington Peak quadrangle shows that much of what Brace placed in his unit *A* of the Saltash is actually highly retrograded salt-and-pepper-textured actinolite gneiss and associated calc-silicate gneiss of the Mount Holly Complex. Rocks Brace assigned to the Saltash in the Killington Peak quadrangle, which extend from Saltash Mountain on the south to Smith Peak on the north, consist of a mixture of "dioritic" gneiss, aplite, magnetite felsic gneiss, and aplite, as well as multiple zones of calc-silicate gneiss, quartzite, and marble. Minerals seen in thin section are chlorite (after biotite), tremolite-actinolite, talc, magnetite, albite, epidote, and quartz. Albite from unit *A* of the Saltash belt of Brace contains abundant inclusions of epidote. These epidote inclusions bespeak an original Na-Ca plagioclase rather than the pure albite so characteristic of the Hoosac Formation.

Although the rocks of Brace's Saltash are albite studded and in places resemble some rocks in the Hoosac Formation, distinctive zones of dark rusty-brown dolomitic rock, aplite, quartzite, and ligniform quartz-poor gneiss, as well as biotite-quartz-plagioclase gneiss, can be mapped and extend eastward down to the floor of the Black River Valley. These rocks cut across the outcrop belts of Brace's units *A*, *B*, and *C*.

These data indicate that the rocks contained in Brace's unit *A* of the Saltash, which are the same as the rocks at the base of the Mendon series as shown by Perry (1929) as well as those shown by Chang and others (1965) as basal Tyson, are in fact highly retrograded Na-rich gneisses rather than metasedimentary rocks of the cover sequence. Because of the extensive retrogression, magnetite, muscovite, and albite are so widespread as to suggest erroneously that these rocks are part of the cover sequence that contains similar but prograde minerals.

A series of photographs (fig. 1.1*A–D*) illustrates the relict textures of these rocks, although the rocks are exceptionally strongly foliated in most exposures. Faint relict gneissic layers and rare pegmatite suggest that the rocks are Proterozoic. Owing to intense shearing associated with thrust faults, pegmatitic segregations that originally existed as 1- to 2-cm-thick seams in the Proterozoic rocks are stretched and pulled apart to produce zones of pseudoconglomerate. In some cases, thin migmatitic seams, only one to two crystals thick, are sheared in the crossing Paleozoic foliation, to produce "granular" feldspathic clasts in thin layers that resemble layers of feldspar-rich grit. Undoubtedly this pseudoconglomeratic texture misled Brace to classify unit *A* of his Saltash as part of a cover sequence that is younger than the Mount Holly. A sample of pseudoconglomerate derived from a biotite-quartz-plagioclase gneiss is shown in figure 1.1*D*.

Chemical analyses of a series of gneisses from Bruce's unit *A* of the Saltash are given in table 1.1. Locations are shown in plate 1.1*A* and 1.1*B*. Sample 1 is taken from typical salt-and-pepper-textured magnetite-biotite-epidote-chlorite-albite quartz gneiss of the Mount Holly on Bissell Hill, west of Brace's unit *A* of the Saltash. Felsic gneisses like this are common throughout the northern Green Mountains and are especially abundant in a belt extending from the southern half of the Killington Peak quadrangle westward into the Rutland quadrangle. Where not retrograded too highly, these rocks contain relict biotite, well-twinned oligoclase, minor amounts of microcline, abundant quartz, and ubiquitous magnetite. Similar rocks are widespread in the Weston quadrangle where they are closely associated with calc-silicate rocks and migmatitic biotite-magnetite felsic gneiss. I believe the rocks belonging to Brace's unit *A* of the Saltash in the Killington Peak and Ludlow quadrangles are highly retrograded and carbonated variants of these rock types. Samples 3083B through 3148 (table 1.1) are albitic and other gneisses collected from the outcrop belt of Brace's unit *A* of the Saltash. Photographs of some of these rocks are shown in figure 1.1.

In figure 1.2, the normalized rare earth element patterns for two samples from unit A of the Saltash (table 1.1, samples 2 and 3) and one from gneiss of the Mount Holly Complex (table 1.1, sample 1) are seen to coincide almost exactly and to exhibit the same negative europium anomalies. Hf abundances of all samples agree at 3.59 to 3.60±3 percent. The normative An-Ab-Or composition of the albitic gneisses from the Mount Holly Complex of the Weston quadrangle are compared to those from the Killington Peak and Plymouth quadrangles in figure 1.3. Anorthite contents are lower in several cases for the Killington Peak and Plymouth samples, in part, because of the assignment of a large amount of CaO to form calcite in the normative calculations. The proper proportioning of CaO-MgO to the carbonate to form dolomite in the rocks increases CaO assigned to normative anorthite to that illustrated in figure 1.3. Introduced nonfoliated veins consisting of quartz-dolomite and albite are widespread in the Saltash near the eastern margin of the massif, thus supporting the introduction of the dolomite and possibly some of the albite.

Rocks mapped by Brace (1953) as units *B* and *C* of the Saltash Formation are metasedimentary rocks belonging to the cover sequence and are here assigned to the Tyson Formation. A reasonably sharp contact between very phyllonitic, dark-gray to green phyllite of the Tyson (Brace's unit *B*) here placed in the Tyson Formation, and the sheared gneiss (Brace's unit *A*) here assigned to the Mount Holly Complex, can be mapped but only with extreme difficulty. Along the western slope of the Black River Valley from the northern end of Woodward Reservoir south to Dry Hill, the contact between Middle Proterozoic gneisses of the Mount Holly and the overlying Tyson Formation or Hoosac Formation is marked by extensive shearing and widespread development of mylonite. Many different rocks in the hanging wall strike east-west into the fault zone (pl. 1.1*B*). These relations are best seen in the numerous small east-draining unnamed brooks located north and south of Plymouth Union. In these exposures, greenish-gray and dark-gray phyllonitic rock derived from phyllite or albitic granofels in the Tyson are in contact with quite similar-appearing

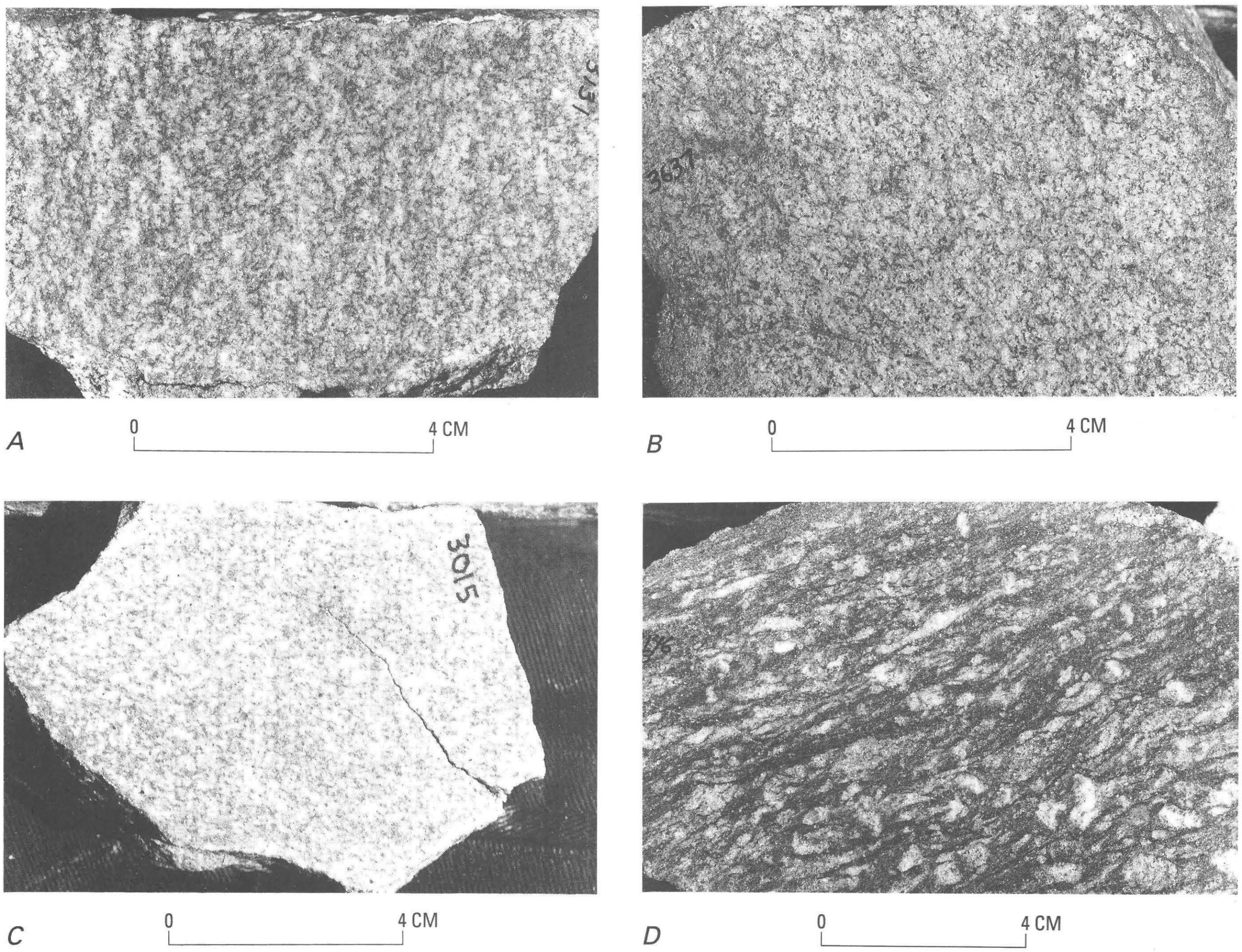

Figure 1.1. Rock samples from the Mount Holly Complex and the Saltash Formation of Brace (1953). *A*, Salt-and-pepper-textured gneiss of the Mount Holly Complex (table 1.1, sample 1). *B*, Salt-and-pepper-textured albitic gneiss from Smith Peak, Brace's unit *A* of the Saltash. C, Albitic gneiss from U.S. Route 100 road-cuts (table 1.1, sample 3). *D*, Pseudoconglomerate (porphyro-clastic gneiss in table 1.1, sample 7).

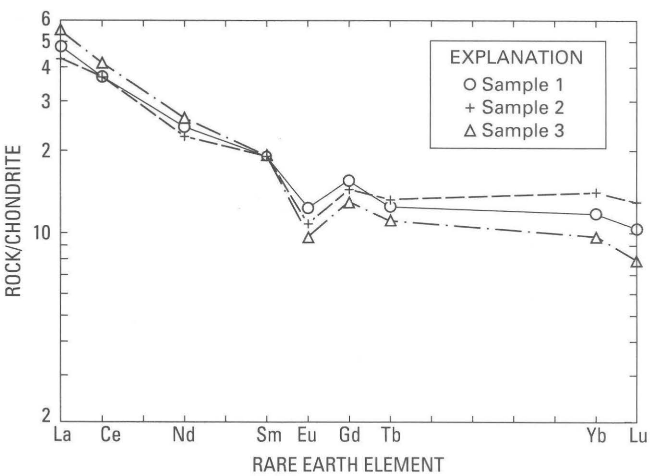

Figure 1.2. Chrondrite normalized rare earth element diagram of samples of albitic gneisses from Brace's unit *A* of the Saltash Formation (table 1.1, samples 2 and 3) compared to similar salt-and-pepper-textured gneiss from the Mount Holly Complex (table 1.1, sample 1) (INAA analysis by J. Grossman, U.S. Geological Survey).

phyllonites derived from quartz biotite-magnetite-plagioclase gneisses, calc-silicate gneiss, and marble. The actual contact zone, which consists of phyllonites derived from Proterozoic rock and from the Tyson, is as much as 50 m thick. In this zone, distinguishing one protolith from the other is virtually impossible. Below this sheared zone, ghost, relict Proterozoic layers become more and more evident as the penetrative fault fabric decreases. Along the entire length of the fault relict, Proterozoic layering in the footwall strikes at high angles into the fault. Conglomerate

Table 1.1. Major-element compositions of gneiss and altered gneisses near the eastern margin of the Green Mountain massif in the Killington Peak and Ludlow quadrangles, Vermont.

[All samples are from Brace's (1953) unit *A* of the Saltash Formation, except for sample 1, which is from gneiss on Bissell Hill in the Killington Peak quadrangle mapped as gneiss of the Mount Holly Complex by Brace (1953). H. Smith, C.L. Prosser, J. Taggart, A. Bartel, and D. Siems, U.S. Geological Survey analysts]

Major oxide	Sample[1] (weight percent)							
	Mount Holly Complex	Brace's unit *A* of the Saltash Formation						
	3131 1	3083B 2	3105 3	3095 4	3139 5	3082A 6	3146B 7	3148 8
SiO_2	64.8	56.0	75.6	54.2	69.7	71.2	70.3	67.3
Al_2O_3	12.0	9.67	11.2	23.5	13.6	12.7	11.7	14.8
Fe_2O_3	1.30	1.38	1.98	3.35	1.19	1.99	3.45	2.38
FeO	4.3	3.2	1.3	4.1	2.4	2.4	2.6	2.6
MgO	2.32	3.76	1.08	1.65	1.16	1.32	2.04	2.14
CaO	3.67	8.84	1.42	.81	2.37	1.75	1.56	2.39
Na_2O	2.66	1.89	2.41	4.13	3.70	2.64	3.12	3.60
K_2O	1.99	2.20	2.09	3.81	1.85	2.21	2.57	2.34
H_2O^+	1.9	1.2	1.4	3.3	1.8	1.8	1.3	1.7
H_2O^-	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	0.03	<0.01
TiO_2	0.61	0.32	0.42	1.06	0.43	0.44	0.44	0.51
P_2O_5	0.08	0.12	<0.05	0.15	0.07	0.06	<0.05	0.09
MnO	0.11	0.28	0.04	<0.02	0.04	0.03	0.06	0.05
CO_2	4.3	11.6	1.0	0.22	1.9	1.3	0.73	0.15
Total	<100.05	<100.47	<100.00	<100.34	<100.22	<99.85	<99.95	<100.06

[1]Description of samples:

1. Light-gray, medium-grained, massive weakly foliated epidote-chlorite [biotite]-magnetite-muscovite-albite-quartz gneiss. Roadcut eastern flank of Bissell Hillin Killington Peak quadrangle, in rocks mapped as gneiss of Mount Holly Complex by Brace.
2. Light yellow-gray, medium-grained, well-foliated rutile-magnetite-chlorite [biotite]-muscovite-quartz-epidote-albite [oligoclase] gneiss, impregnated with veinlets of secondary dolomite-albite and quartz, contains as much as 7 percent introduced carbonate. Roadcuts south of Great Roaring Brook in Plymouth quadrangle, 400 m east of Killington Peak quadrangle border.
3. Light pinkish-gray, fine-grained, well-foliated magnetite-chlorite [biotite]-muscovite-epidote-albite quartz gneiss. Associated with marble roadcuts, western side of U.S. Route 100, opposite southern end of Black Pond, Killington Peak quadrangle.
4. Medium-gray, medium-grained ilmenite-epidote-chlorite muscovite-quartz-albite granofels, consisting of 40 to 50 percent clear albite having abundant inclusions of epidote and flakes of ilmenite. Roadcut 2,000-foot elevation on road up to Ingalls Hill west of Black Pond, Killington Peak quadrangle.
5. Light-gray, well-foliated epidote-chlorite-muscovite-quartz-albite gneiss. At 1,580-foot elevation in small unnamed brook 1.6 km southwest of Plymouth Union in Plymouth quadrangle.
6. Light-gray, medium-grained magnetite-chlorite-epidote-muscovite-albite-quartz gneiss in outcrop veins as much as 20 cm thick of nonfoliated quartz-dolomite and albite that crosscut the gneiss; tiny veinlets of dolomite permeate the rock along the joints. At 2,240-foot elevation, western side of ridge, 2 km northeast of Bear Mountain Killington Peak quadrangle.
7. Strongly sheared, porphyroclastic, gray chlorite [biotite]-quartz-albite-epidote [plagioclase] gneiss; rock contains sheared dikes of pegmatite. In stream at 1,680-foot elevation on southern border of Killington Peak quadrangle.
8. Medium-dark-gray chlorite [biotite], epidote-muscovite-quartz-plagioclase-gneiss; contains relict biotite, twinned oligoclase, and abundant scattered epidote. In same stream as sample 7, but at 1,480-foot elevation.

that is so prominent elsewhere along the base of the Tyson is strikingly absent along this fault. Unfaulted contacts having abundant and coarse-grained conglomerate are present from Cherry Knoll northward and on Dry Hill.

From a point west of Woodward Reservoir south to Dry Hill, all units of the Tyson and green albitic schist of the Hoosac in the hanging wall are truncated. This discordance was mapped by Brace (1953) and is supported by this study; however, here it is interpreted as a fault rather than an unconformity.

Thus the original distribution of the Saltash Formation of Brace (1953), which Doll and others (1961) equated on a 1:1 basis with their Tyson Formation, has been greatly reduced in areal extent because much of what Brace referred to as unit *A* of the Saltash is now regarded to be part of the Mount Holly Complex. Much of the contact of the Mount Holly with the Tyson is a fault rather than an unconformity. Following Chang and others (1965), the name Saltash Formation is not adopted, but the eastern upper units roughly equivalent to Brace's units *B* and *C* are assigned to the Tyson Formation (see fig. 1.4).

TYSON FORMATION

Unconformable contacts of conglomerate and grits of the Tyson Formation resting on the Mount Holly Complex

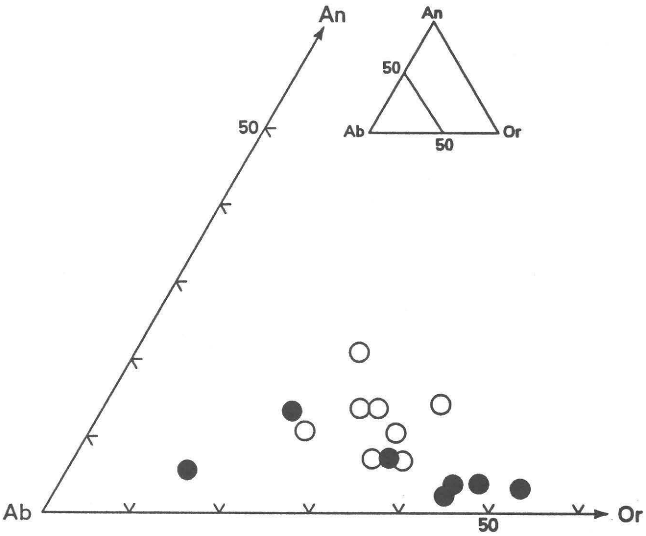

Figure 1.3. Normative An-Ab-Or plot of samples of gneisses in table 1.1 from the Mount Holly Complex in the Killington Peak and Plymouth quadrangles (open dots) compared to similar felsic gneiss (solid dots) in the Weston quadrangle. The diagram illustrates the similarity between rocks previously assigned to the Saltash Formation (Brace, 1953) or basal Tyson Formation by Doll and others (1961) to rocks in the Mount Holly Complex. Saltash samples are corrected for introduced dolomite and have one-half of the molecular proportion of CO_2 subtracted from the proportion of CaO, thus increasing An content over calculations that assign only CaO to CO_2 to make normative calcite.

are present in four areas: (1) from the vicinity of Cherry Knoll north to the northern border of the Killington Peak quadrangle, (2) at Dry Hill in the Ludlow quadrangle, (3) along the eastern flanks of Ludlow Mountain, and (4) at the small faulted syncline at Tiny Mountain.

No complete sections of the Tyson Formation are known in which all units up through the upper dolostone are exposed in one continuous unfaulted exposure. Therefore, the section must be pieced together by correlation of the faulted sequences. This can be done most readily and completely in the area from West Bridgewater to the southern end of Woodward Reservoir.

Conglomerate and grit exposed at Cherry Knoll and on the eastern flank of Hadley Hill overlie basement rocks in numerous exposures in small east-draining streams. Here the contacts can be closely defined. The beds of conglomerate and grit are as much as 150 m thick and contain lenses of dolomitic quartzite and feldspathic grit near the top. A thin zone, as much as 50 m thick, of greenish-gray magnetite-albite-granofels overlies the basal beds of grit.

In the area north and west of Woodward Reservoir, a prominent zone of black carbonaceous phyllite, and interbedded dolostone as much as 100 m thick, is present. Beige- to tan-weathering beds and pods of dolostone increase in abundance near the top where they pass into punky weathered dolomitic and feldspathic quartzite. Along the base of the slopes west of Woodward Reservoir several lenses of feldspathic and vitreous quartzite are present. A prominent vitreous quartzite as much as 15 m thick forms the top of this clastic section. At or near the western shore of Woodward Reservoir, massive white or cream-colored dolostone overlies this quartzite. The dolostone, which is as much as 20 m thick, contains distinctive channels of crossbedded dolostone marked by rounded, suspended grains of white quartz as much as 2 mm in diameter. The pinkish-white dolostone exposed in the quarry at the southern end of Woodward Reservoir contains beds of bluish-gray oolitic dolostone. Dolostones of the Tyson commonly contain abundant detrital quartz, crossbeds, climbing ripples, and oolites all of which suggest shallow-water, perhaps near-shore, deposition. By contrast, dolostones of the Plymouth Formation, described below, contain thinly laminated dolostone, dark laminated phyllite, and intraformational conglomerate and are suggestive of deeper water conditions of deposition.

South of Dry Hill and in the Ludlow area, the Tyson, as defined here, contains beds of dark-gray to brown, slightly albitic schist/phyllite (€ts), which locally contains pods of beige-weathering dolostone (€td) as much as 2 m thick. Three belts of dolostone crop out on the eastern, southern, and western slopes of Dry Hill (pl. 1.1*B*); a fourth is found at the base of Ludlow Mountain. In the area between Ludlow and Dry Hill, the schist of the Tyson is locally albitic and resembles beds typical of the Hoosac elsewhere. These albitic beds were referred to as the Grahamville Formation by Thompson (1950). They are overlain by a discontinuous black carbonaceous phyllite (€tbs) similar to that found west of Woodward Reservoir, described above. The highest beds of the Tyson in the Ludlow area are green lustrous magnetite-chlorite-muscovite quartz phyllite and schist (€tg) which is locally albitic. West of Dry Hill, dark-green and gray albitic schists assigned to the Hoosac Formation conformably overlie schist of the Tyson. From this point west of Dry Hill south to Ludlow, the thick quartzite and dolostone seen at Woodward Reservoir are absent, and either they are faulted out beneath the Plymouth or they thin to a feather edge southward.

Along the eastern margin of the Green Mountain massif, gritty beds of quartz-pebble conglomerate and grit typical of the Tyson are present as far south as Simonsville in the southwestern corner of the Andover quadrangle (see Doll and others, 1961). From this point south, albitic schist and granofels of the Hoosac largely replace the Tyson, although pods of dolostone and vitreous quartzite occur irregularly as far south as the Wilmington area within the Hoosac (Ratcliffe, 1993). Facies relations indicate that beds typical of the Tyson laterally replace typical Hoosac from south to north along the eastern margin of the Green Mountain massif.

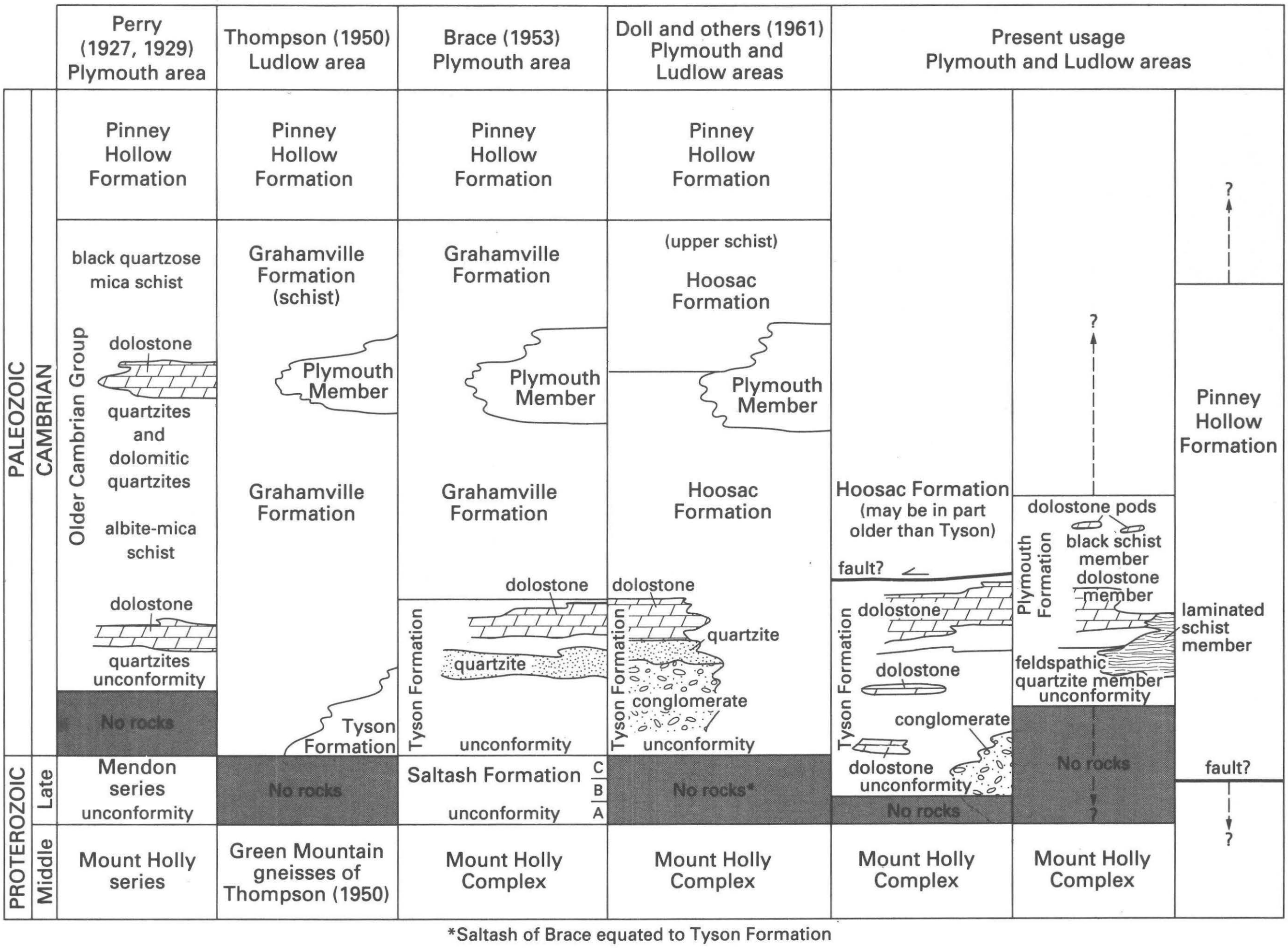

Figure 1.4. Correlation chart of previous usage and present interpretation.

HOOSAC FORMATION

Along the eastern side of the Black River Valley from near the southern border of the Plymouth quadrangle north to Mission Chapel, 0.5 km north of West Bridgewater, green-gray to black albitic granofels of the Hoosac Formation overlies the dolostone of the Tyson Formation. Contacts are exposed near Mission Chapel and at Plymouth Union where sharp contacts are visible. At Mission Chapel the contact is faulted. A tectonic breccia, consisting of blocks of dolostone in a ductily deformed finer grained dolomite matrix is present at the contact. At the abandoned iron mine 60 m north of Plymouth Union, the contact is also exposed and appears to be sharp. Interbedding is not present; however, direct evidence of faulting is not displayed either. At both localities mentioned above, the immediate contact is a punky weathered, dark rusty-brown hematitic rock, which Chang and others (1965) interpret as a terra rosa formed by weathering at the top of the dolostone. Equally valid interpretations would be a mineralized fault zone or a subsurface alteration of the magnetite-rich schist of the Hoosac by groundwater flow along the contact.

At the southern end of Woodward Reservoir, where the dolomite belt is about 200 m wide, a peculiar, highly tectonized greenish-gray to black quartz knotted schist, containing pods and stringers of pegmatite, overlies the dolostone along what is a probable fault contact. The distinctive albitic rocks of the Hoosac are absent. The hanging wall of the fault, from the eastern shore of Black Pond to an altitude of 1,900 ft on the eastern side of the ridge, consists of intensely sheared dark-gray to light-pinkish-gray mylonitic microcline-rich biotite gneisses that largely transpose into a gently east-dipping mylonite and rodded tectonite. These gneisses are interpreted as part of the Mount Holly Complex that tectonically overlies albitic rocks of the Hoosac. The thrust faults, which separate rocks of the Tyson Formation from either the Hoosac or other rocks, belong to the Black Pond fault zone (pl. 1.1*B*). A photograph of gneiss from

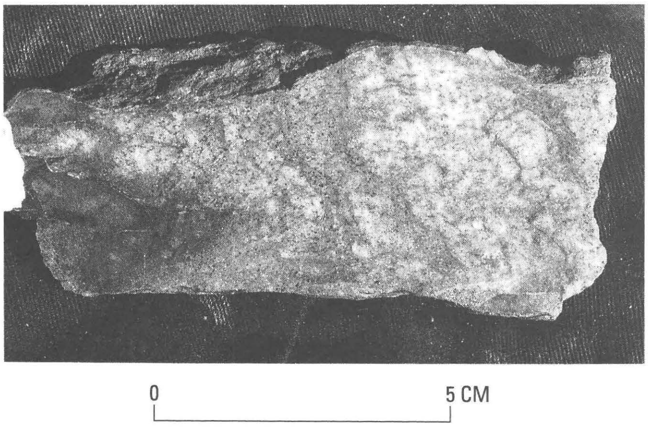

Figure 1.5. Hand specimen of typical gneiss exposed at cliffs in the Plymouth quadrangle east of Black Pond. Gneissic layers strike east and dip vertically. Axial surfaces of folds dip gently to the east, parallel to foliation and bedding in overlying cover rocks in the area.

cliffs above Black Pond is given in figure 1.5. The above observations indicate that it is not likely that the Tyson and Hoosac sections in and west of the Black River Valley are stratigraphically continuous at any point with rocks appearing to the east of the Black Pond fault zone.

PLYMOUTH FORMATION

The name Plymouth Formation is here proposed for a series of feldspathic and dolomitic quartzites, dolostones, and black phyllites that overlie the probable Middle Proterozoic gneisses in the hanging wall of the Black Pond thrust zone. The formation derives its name from exposures in and near the village of Plymouth, Vt., where various members crop out. Rocks assigned to the Plymouth Formation most recently were referred to as the Plymouth Member of the Hoosac Formation by Doll and others (1961) and by Chang and others (1965).

From a point on the small ridge above Mission Chapel (see pl. 1.1, northern edge of the map) south to Mount Tom and on Soltudus Mountain, a nearly continuous belt of very regularly layered (tectonically layered) gray and pinkish-gray feldspathic quartzites and possibly admixed mylonitic gneiss crop out. All contain the same distinctive pin-striped structure and strong tectonic lineation that plunges east down the dip of the foliation. The foliation is parallel to a well-developed transposition structure. As previously stated, some of the rocks in this belt appear to be microcline gneiss or other gneissic rocks that contain shredded pegmatites. These rocks are believed to be Middle Proterozoic and are not part of the Plymouth Formation as defined here.

Other less microcline rich rocks clearly are gray or tan quartzite or gray silty-textured phyllite that has thin but transposed siliceous layers, which are 0.1 to 0.5 cm thick. These rocks are interpreted as metaquartzites and metasiltstones of the Plymouth Formation (shown on pl. 1.1*B* as (Єpfq). The contact with the Proterozoic rocks is difficult to map, but a sequence of dolomitic quartzite or thinly bedded quartzite appears to mark the contact. Well-bedded feldspathic quartzite and siliceous phyllite can be seen in the roadcut exposure north of U.S. Route 100A, east of Plymouth Union, and are well exposed in abandoned quarries at the 1600 foot altitude on the southern slope of hill 1796 at Plymouth Notch. On Soltudus Mountain, dark laminated silty phyllites (Єpl) laterally replace the more feldspathic quartzites. In the Plymouth area, dark-gray schistose quartzite and more massive vitreous quartzite or dolomitic quartzite passes upward to the east into well-bedded cream-weathered light-gray dolostone breccia that contains irregular fragments of a darker gray dolostone. Associated with these lower beds is light-gray and black ribbon dolostone, in layers 3 to 10 cm thick, that passes into distinctive intraformational edgewise-conglomerate in which the lighter gray dolostone forms fragments in a darker blue-gray matrix. An interbedded zone of light-blue-gray or white fissile dolostone passes upward into massive medium-grained white dolostone. The dolostone unit exposed west of Plymouth is as much as 300 m thick. A similar section of dolostone is exposed in a small stream south of the road leading east from Moore's Pond; the stream crosses the road about 600 m east of bench mark 1829. In this section, darker gray dolostone and mottled dolostone change upward, over a thickness of about 150 m, to light-whitish-gray cream-weathered dolostone. Mottled blue-gray dolostone breccia and associated white dolostone, and quartzite of the Plymouth Formation, crop out to the south in the abandoned quarry east of Lake Amherst.

The dolostone member of the Plymouth Formation, as described above, is distinct from the dolostone of the Tyson Formation in that it contains abundant sedimentary breccia, intraformational conglomerate, and thin ribbony dolostone. The light-colored dolostone near the top of the member superficially resembles the light-colored white dolostone of the Tyson, but it lacks the coarse gritty beds and suspended quartz grains common in the dolostone of the Tyson. Numerous crossbeds and cut- and fill-structures indicate that the section tops from the quartzite up into the dolostone.

The upper member of the Plymouth Formation is a black graphitic and siliceous phyllite or schist (Єpbs) that contains 1- to 3-cm-thick layers of dark-gray ferruginous quartzite, dolomitic quartzite, and ribbony beds of dark blue-gray dolostone (Єpd). Glistening black to dark-gray vitreous quartzite in beds as much as 10 cm thick are present locally. Where the lower contact is exposed, for example at the western foot of East Mountain, blue-gray dolostone of the dolostone member passes, through interbedding of black phyllite, upward into the phyllite; the contact is gradational over a distance of approximately 10 m.

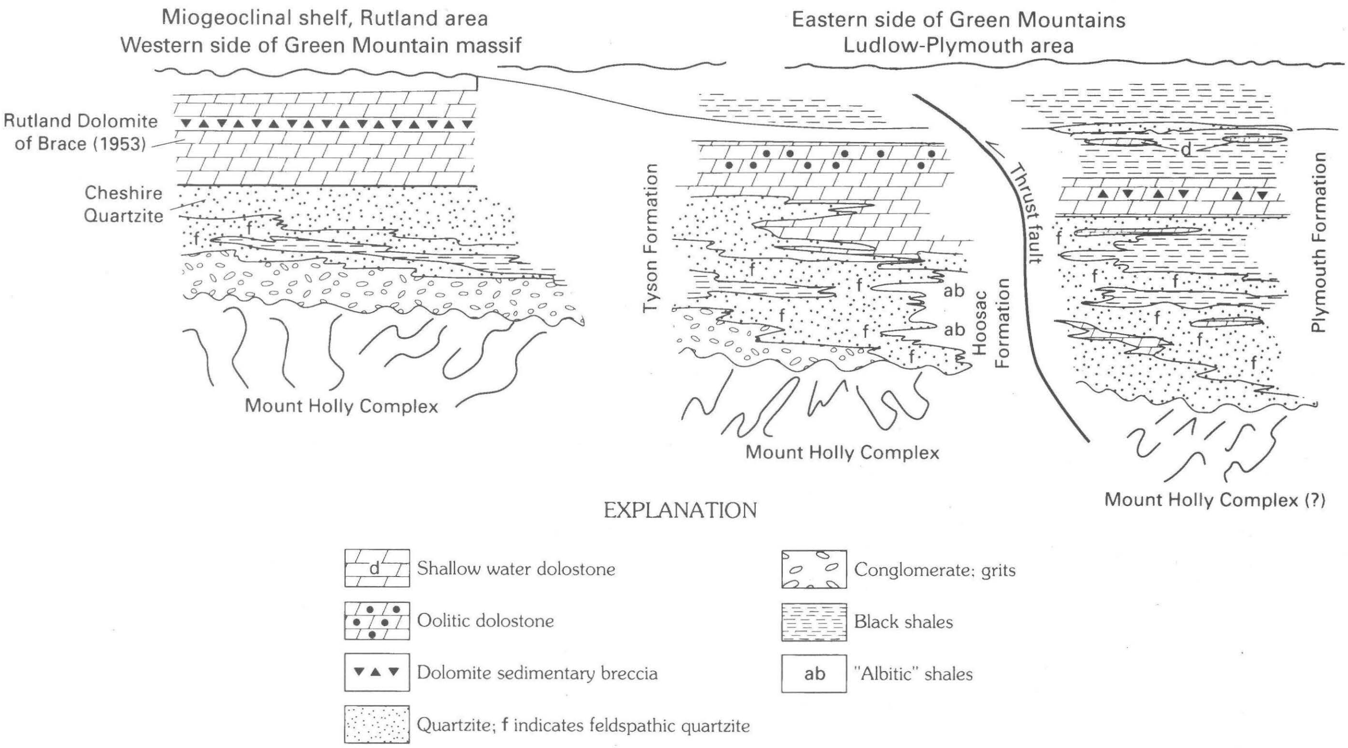

Figure 1.6. Diagrammatic west-to-east section showing inferred depositional relations of basal cover sequence rocks west and east of the Green Mountain basement rocks in Early Cambrian time.

At other localities, for example east of Woodward Reservoir, black phyllite is in contact with white dolostone and shows no evidence of interbedding, although the phyllite does contain lenses of blue-gray dolostone. At West Bridgewater, at the base of Morgan Peak, on Wood Peak, and from Blueberry Hill south to Ludlow, lenses of light-gray to tan and yellow feldspathic quartzite or vitreous quartzite appear irregularly near the upper part of the member, as do pods of dolostone (€pd). These dolostones are in a different stratigraphic position from the main belt of dolostone and quartzite that makes up the middle member of the Plymouth Formation. The upper contact of the Plymouth Formation is placed at the first occurrence of light-silvery-green magnetite-muscovite-quartz knotted phyllite of the Pinney Hollow Formation. The contact is sharp and in many places expressed by strong development of a second generation mylonitic foliation that transposes an earlier schistosity. Fold axes and lineations plunge down the dip of the foliation in a fashion identical to structures found in the thrust faults at the Tyson contact west of Woodward Reservoir and in the Black Pond thrust system. The contact appears to be a fault. This interpretation is, however, not entirely defensible, as pods of a very distinctive, deep reddish-brown-weathered pyritic dolostone as much as 2 m thick occur at or near the Pinney Hollow contact at several localities north and south of Blueberry Hill (€pd on pl. 1.1*B*), suggesting a stratigraphic contact. However, evidence of interbedding is not present, and the map relations suggest low-angle truncation of mapped units within the upper part of the Plymouth Formation.

CONCLUSIONS

Detailed mapping of the cover sequence rocks overlying the Green Mountain massif from Ludlow north to West Bridgewater indicates that the currently accepted concept of a continuous eastwardly topping section from the Tyson Formation to the Pinney Hollow Formation is incorrect. Instead, two similar sequences as defined herein, the Tyson Formation and the Plymouth Formation, are in thrust fault contact, which creates a structural repetition of the two sections. Each section rests on Middle Proterozoic rocks, and each passes upward into quartzite and beds of dolostone and black carbonaceous schist or phyllite. The Tyson Formation contains beds typical of the Hoosac Formation, which replaces the Tyson to the south. It is proposed that the Plymouth Formation consists of deeper water, finer grained and better laminated sediments than do the Tyson and part of the Hoosac; this proposal is consistent with a west- to east-deepening condition of deposition (fig. 1.6).

The age of the Tyson and Plymouth Formations is unknown; no fossils are present. However, inasmuch as both sequences rest on Proterozoic rocks and the dolostone member of the Plymouth contains sedimentary breccia similar to those found in the Rutland Dolomite, a Cambrian age is likely (Thompson, 1972). The basal rocks in each section may be as old as Late Proterozoic; however, this is conjectural. The upper age limit of both sequences is constrained only by the probable Middle to Late Ordovician age of the Taconic orogeny as they were deformed during that event. An age of Late Proterozoic(?) to Cambrian is favored for these rocks.

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2. The Wilcox Formation of Vermont Assigned to the Mount Holly Complex

By Nicholas M. Ratcliffe

ABSTRACT

Mapping of the type locality of the Wilcox Formation in the Rutland area of the Green Mountain massif, Vt., indicates that the schists, quartzites, and related gneisses in and around Wilcox Hill in the Rutland 7.5-minute quadrangle are part of the Middle Proterozoic Mount Holly Complex. Previous workers assigned these phyllitic but highly diaphthoritic rocks to either a Proterozoic or lower Paleozoic cover sequence that is younger than the Mount Holly. Reexamination shows that these rocks can be mapped, to the east and to the west, into the Mount Holly Complex and, therefore, are an integral part of that unit. These results eliminate the need for a complex series of thrust and normal faults used by previous workers to account for the presence of cover rocks within the Mount Holly Complex in this northwestern part of the Green Mountain massif of Vermont. The name Wilcox Formation is herein assigned as a formation within the Mount Holly Complex.

INTRODUCTION

The Wilcox Formation was applied by Brace (1953, p. 21) to "a group of schists, dolomite and gneiss about 3,000 feet thick," exposed in the western part of the Rutland 15-minute quadrangle. The type locality is near Wilcox Hill and on the slopes south of the town of Cold River (fig. 2.1). Brace described the unit as occupying a syncline. As described by Brace (1953), the eastern overturned limb is in unconformable contact with rocks of the Mount Holly Complex. The western contact is a poorly defined, west-dipping, high-angle reverse fault (Brace, 1953, pl. 2, sec. *D–D'*). Brace described three units of the Wilcox in ascending order as, A, a lower unit of gray, green, and black schist containing beds of buff dolomite and pebbles of quartz; B, a middle unit of pegmatitic gneiss; and C, an upper unit of schist similar to the lower unit. Brace's Wilcox Formation was adopted by Doll and others (1961) as shown in figure 2.1. Karabinos (1987, fig. 2) reinterpreted Brace's geology and assigned much of the middle unit of Brace's Wilcox Formation to the Mount Holly Complex. He also assigned the schistose units of Brace's Wilcox Formation to the Tyson Formation, a Late Proterozoic(?) and Cambrian unit in the cover sequence rocks above the Mount Holly. This interpretation was followed by Thompson and others (1990). Their interpretation (fig. 2.2) included a combination of unconformities and faults. They mapped a high-angle, east-dipping normal fault along the western margin of the Tyson where Brace had mapped a west-dipping thrust fault. They showed this fault to extend 45 km along strike. Two faults, one an east-dipping thrust fault and another high-angle fault of unspecified dip, bound the Tyson belts on the east. Neither the earlier interpretations of Brace (1953) nor those of Karabinos (1987) satisfies the field relations that I have observed. Geology, shown on plate 2.1, was mapped from 1991 to 1992.

MAP DISTRIBUTION AND ROCK TYPES

My mapping in the Rutland and adjacent Killington Peak quadrangles does confirm Brace's original observation that the schist and dolomite units of his Wilcox Formation contain abundant lens of pegmatite, an attribute that Brace noted is more in keeping with a Proterozoic than Paleozoic age for the Wilcox. He suggested that the Wilcox was somewhat older than the Saltash Formation, which does not, according to him, contain pegmatite. He assigned a Late Proterozoic age to the Saltash, which crops out along the eastern margin of the massif (see Ratcliffe, Note 1, this volume, for a discussion of the Saltash). Mapping in the Cold River area, on Wilcox Hill and near Shrewsbury (pl. 2.1), suggests that the distribution of these problematic schists and gneisses was more accurately shown by the mapping of Brace than by the subsequent mapping of Karabinos (1987). The structural-stratigraphic interpretation presented here however differs from that of Brace (1953) and Karabinos (1987) and that of Thompson and others (1990). The geology in the area of Wilcox Hill in the Rutland and Killington Peak quadrangles is shown on plate 2.1.

The most prominent rock type in the Wilcox Formation (Yw) is a dark-gray to brownish-gray, muscovite-rich, chlorite-quartz schist. Closely spaced foliation and rusty-weathering phacoidal cleavage surfaces give the rock a distinctive shredded, schistose appearance. A local variant is a

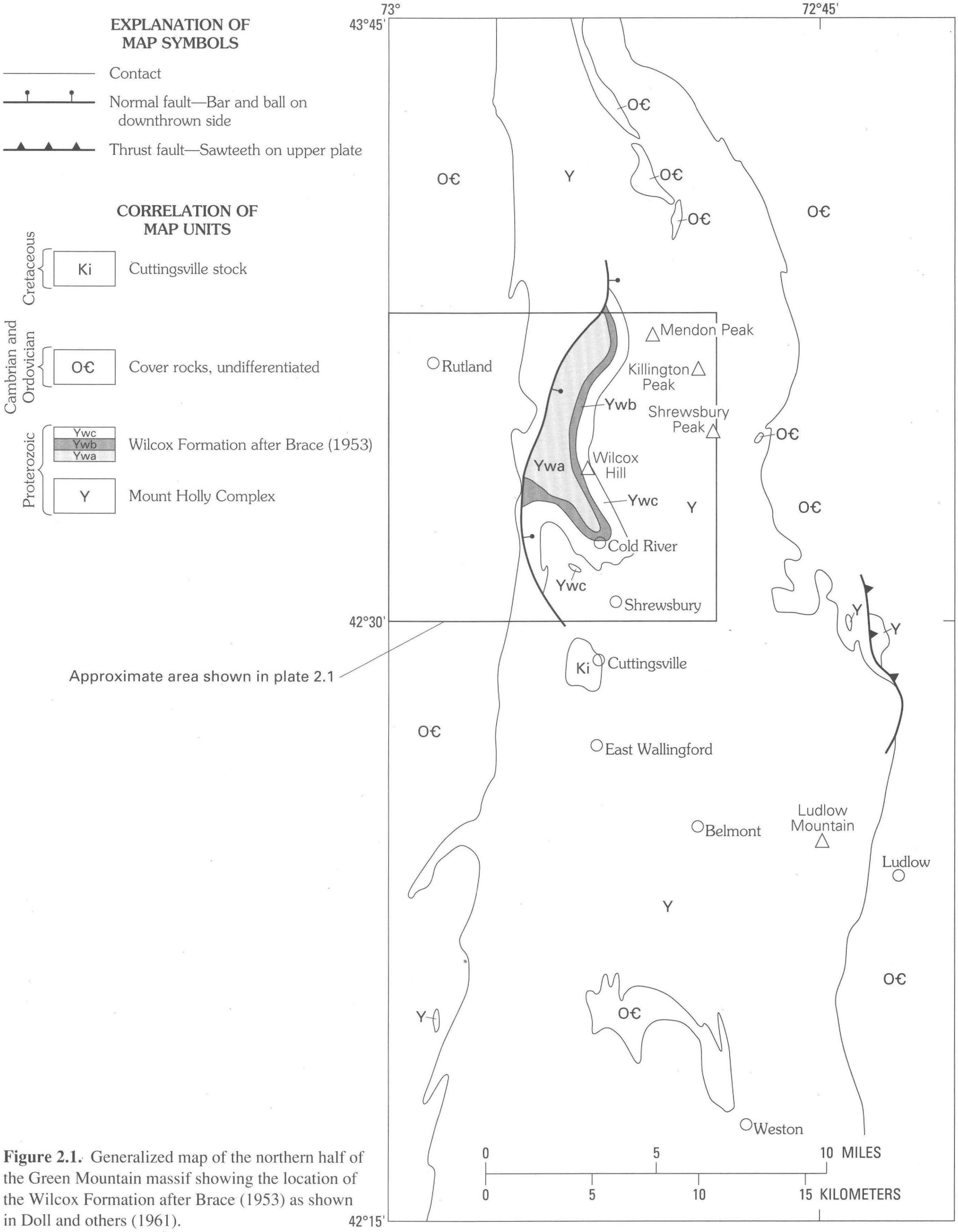

Figure 2.1. Generalized map of the northern half of the Green Mountain massif showing the location of the Wilcox Formation after Brace (1953) as shown in Doll and others (1961).

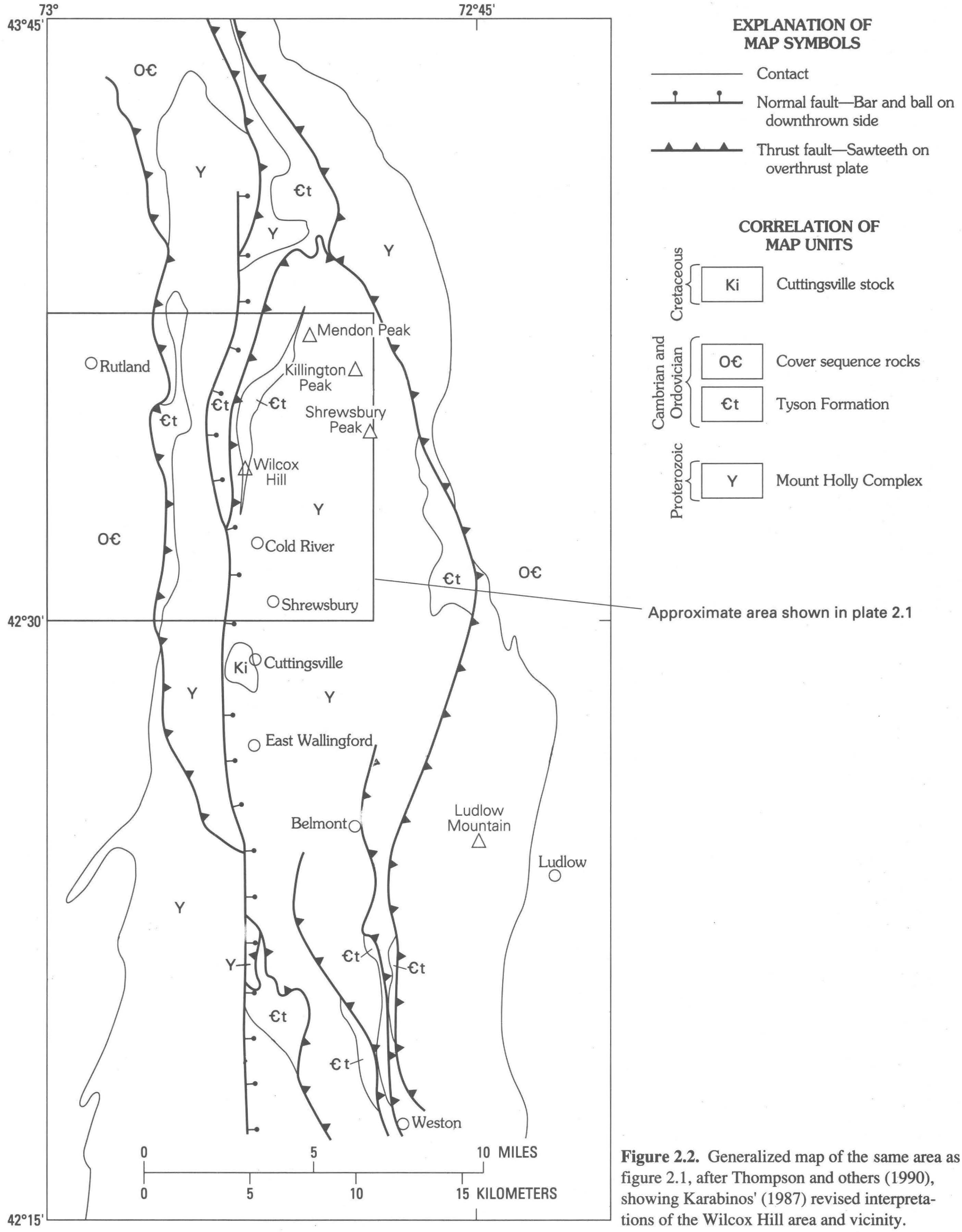

Figure 2.2. Generalized map of the same area as figure 2.1, after Thompson and others (1990), showing Karabinos' (1987) revised interpretations of the Wilcox Hill area and vicinity.

greenish, quartz-knotted, chlorite-muscovite phyllite that has associated quartzite. Magnetite is abundant in this rock. Beds of chlorite-spotted vitreous quartzite too small to map are greenish, quartz-knotted, chlorite-muscovite phyllite that common, and prominent beds of vitreous quartzite (Ywq) as much as 10 m thick are interbedded in the Wilcox. Less commonly, zones of yellow sulfidic weathering, sooty-black quartzite and phyllite are also found in the Wilcox. Many of these quartzites are located at or near the contact with biotite-quartz-plagioclase gneiss (Yb) where they are associated with calc-silicate rocks (Ycs) or are found entirely within the Wilcox.

The quartzites pass into chlorite-spotted quartz gneiss. The chlorite spots are as much as 1 cm in diameter, contain opaque inclusions, and are clearly pseudomorphs after garnet. Mapping of quartzite or calc-silicate units within the Wilcox shows a parallelism between the contact of the schists of the Wilcox and the biotite-quartz-plagioclase gneiss as shown in plate 2.1, thus establishing concordance of the Wilcox and the Mount Holly.

At the type locality on Wilcox Hill and on the slopes south of Cold River (Brace, 1953, p. 21), the schists of the Wilcox contain pods of aplitic gneiss and veins rich in tourmaline. Near its border calc-silicate gneiss (Ycs), such as diopside-actinolite-knotted granofels, beds of white graphite-dolomite marble, and retrograded deep-orange- to tan-weathering dolostone is common. These calc-silicate rocks and carbonate rocks are generally found elsewhere at or near the contact of the Wilcox with the surrounding gneisses and are designated Ycs on plate 2.1. All of these rocks and the schists contain pods of pegmatite (Yp). In areas where pegmatite is abundant, for example in cliffs beneath the powerline exposures 3 km northwest of Cuttingsville (pl. 2.1, loc. 1), a second generation of fine-grained, buff to deep-orange- brown dolomite crosscuts the coarse dolomite marble and forms veinlets within the pegmatite in association with veins of quartz. The second generation of mobilized dolomite appears to have originated in zones of hydrothermal activity caused by intrusion of pegmatite. The buff dolomite superficially resembles dolomite found within the Tyson, Hoosac, and Plymouth Formations that lie unconformably on the Mount Holly Complex. Unlike these rocks, the dolomite in the Wilcox contains or is spatially associated with pegmatite and other coarse-grained marble and calc-silicate rock, which are common constituents of the Mount Holly Complex. Such calc-silicate rock and pegmatite are not present in the biotite-grade cover rocks.

The eastern contact of the Wilcox according to Brace (1953) is an overturned east-dipping unconformity. He cites truncation of units of the Mount Holly from Mendon Peak south to Wilcox Hill as evidence for this interpretation. Examination of this eastern contact (pl. 2.1) reveals a different relation. Instead of a truncation of units, numerous exposures on the hills south of the Cold River, on Wilcox Hill, and on the hills north of Wilcox Hill show the interlayering of quartz-knotted, green-muscovite-chlorite schist or of pale-gray to whitish-tan phyllitic rocks and quartzite (Yw and Ywq) within gray biotite-quartz-plagioclase gneiss (Yb) of the Mount Holly Complex. Near the contact of the phyllitic rocks or included within the phyllite are beds of vitreous quartzite that contains pegmatite and white, medium-grained aplitic gneiss (Yap). In addition, calc-silicate rocks, such as coarse-grained, gray, phlogopitic marble, dark-green, fuchsite-quartz-plagioclase bearing gneiss, and diopside-calcitic marble, are spatially associated with belts of phyllitic rocks. The units described above occur within the greenish phyllites of the Wilcox (Yw) as well as in gray biotite gneisses (Yb) at the eastern contact of the Wilcox. From these relations it is clear that the phyllites of the Wilcox are conformable with, and indeed, interfinger with biotite-quartz-plagioclase gneisses of the Mount Holly Complex.

The western contact of the Wilcox according to Brace (1953) is a west-dipping, high-angle fault. This contact is not well exposed in much of the area north of the Cold River (see below), but data there suggest that the foliation generally dips east rather than west, and there are no indications of west-dipping structure. This foliation is the diaphthoritic foliation in the Mount Holly and is marked by strongly developed isoclinal reclined folds, the axes of which plunge from S. 70° E. to due east. South of the Cold River in Shrewsbury, the contact with the biotite-quartz-plagioclase gneiss (Yb), amphibolite (Ya), and hornblende-plagioclase gneiss (Yhd) is well exposed and is highly sinuous (pl. 2.1). The map relations rule out a north-trending fault along this contact, as the outcrop belts trend east-west across the trace of the faults proposed by Brace (1953), Doll and others (1961), and Thompson and others (1990). Relations here duplicate those seen on the eastern border of Brace's Wilcox, namely that distinctive rocks of the Mount Holly occur within phyllites of the Wilcox, and units in the adjoining gneisses parallel those within the Wilcox and the contact of the Wilcox.

On the eastern slopes of Bald Mountain north of the Cold River, excellent exposures of rusty muscovitic and chloritic quartz-ribbed schist typical of the Wilcox were mapped to the east where they cross the North Branch of the Cold River at a high angle to Brace's contact. In these outcrops, on both sides of the river, the diaphthoritic foliation strikes east-west and is not oriented north-south. A prominent zone of pegmatite (Yp) marks the southern contact of the schist with biotite-quartz-plagioclase gneiss (Yb) and the Wilcox (Yw). Where the rocks are diaphthoritically deformed, vein quartz is segregated into isolated knots and ellipsoidal masses resembling pebbles. This pseudoconglomeratic texture is common in the Mount Holly Complex, particularly where thin pegmatite veinlets intruded schistose host-rocks and where subsequent multiple deformation separated and deformed them. Brace (1953, p. 26) noted that garnet quartzites of the Mount Holly commonly have this pseudoconglomeratic texture, an observation with which I agree.

The data cited above, therefore, rule out the north-trending fault contacts east or west of the Wilcox belts as shown by Brace (1953). In addition, the schistose rocks of the Wilcox, which were assigned to the Tyson Formation by Karabinos (1987) and Thompson and others (1990), can be shown to map into the Mount Holly Complex both to the east and to the west.

PROTOLITH FOR THE PHYLLITES OF THE WILCOX FORMATION

Before discussing the protolith of the phyllites of the Wilcox Formation, it is necessary to understand the extensive alteration that all the rocks of the Mount Holly Complex were subjected to during remetamorphism in the Taconic and Acadian orogenies. Throughout the northern part of the Green Mountain massif (from about Weston northward) (fig. 2.1), little if any of the original Middle Proterozoic mineralogy is preserved in the Mount Holly. Exceptions include some exposures of coarse hornblende-garnet amphibolite, microcline-garnet-biotite-augen gneisses, pegmatites, and locally preserved diopside-calcite and calcite-scapolite marbles.

Extensive retrograde (diaphthoritic) dynamothermal effects were produced during the development of a regional schistosity mapped here as the Paleozoic S_2 schistosity of Taconic age, which is the second generation foliation developed in Paleozoic cover rocks both to the east and to the west of the massif. Along the eastern margin of the massif and within the massif (Ratcliffe and others, 1988; Ratcliffe, 1992, in press), this S_2 foliation is spatially associated with inclined to low-angle thrust faults that imbricate basement and cover rocks. Extension lineations in fault-zone mylonites, both in cover and basement rocks, commonly plunge S. 65°–70° E. on southeast-dipping shear surfaces. This fabric is penetrative in nearly all exposures of basement rocks. Diaphthoritic minerals that define this lineation are chlorite, muscovite, actinolite-tremolite, and reconstituted quartz-albite and strands of epidote and quartz.

Where strain is high or where rocks are highly susceptible to diaphthoresis, all original Middle Proterozoic minerals are totally replaced. Brace (1953) clearly recognized the extensive alteration and noted (p. 26–27) that the mineralogy of the Mount Holly was largely the same as that of the Paleozoic cover rocks. However, to the south of Weston, relict garnet-microcline-sillimanite-biotite-quartz assemblages have been found in the Mount Holly, attesting to hornblende granulite or higher grade metamorphism in the Middle Proterozoic. In the northern part of the massif, calcite marbles contain knots of tremolite and talc suggestive of the replacement of fosterite-diopside marble. Distinctive quartz-plagioclase gneisses of the southern part of the massif contain well-twinned relict oligoclase (An_{25}), distinctive large anhedral quartz, and sparse grains of deep-reddish-brown biotite. Similar rock in the north contains abundant epidote and muscovite and untwinned albite or in the extreme case porphyroblasts of pellucid albite and abundant epidote and muscovite in a phyllitic appearing semischist.

Because of the mineralogic and petrographic similarity of the Mount Holly and the cover rocks, mineralogy is essentially useless in distinguishing basement from cover rocks. The key, however, is recognition of textural and structural relicts of the prior high-grade metamorphism. To illustrate this point, three examples of the Wilcox, which exhibit the transition from rocks having Middle Proterozoic gneissic structure into phyllonitic rocks, are discussed below.

Example 1 (pl. 2.1, loc. 2) is a chlorite-spotted, blue-quartz-plagioclase gneiss from the Mount Holly Complex, as mapped by Brace, immediately east of the Wilcox Hill at the eastern margin of the Rutland quadrangle. The rock has a coarse gneissic texture produced by 1- to 3-cm-thick potassium feldspar and quartz-rich layers alternating with darker plagioclase-quartz layers. Both layers contain 0.5-cm-sized splotches of chlorite, some of which retain the dodecahedral outlines of the original garnet (about 15 percent original garnet). The thin-section mineralogy of this rock is chlorite, muscovite, albite, epidote, quartz, and minor amounts of relict biotite. Although foliated, the development of S_2 is moderately weak. A typical rock (fig. 2.3) contains coarse chlorite clots in a feldspathic matrix.

Example 2 (pl. 2.1, loc. 3) is from the center of the Wilcox phyllitic unit (Yw) on Wilcox Hill, within Brace's upper schist unit (C) (fig. 2.4). This rock is enclosed within distinctive greenish, chlorite-muscovite-quartz phyllite (Yw) having intensely developed S_2 and a strong tectonic rodding. This rock (fig. 2.4) contains the same kind of inclusion-filled chlorite pseudomorphs after garnet as are found at locality 2.

Example 3 (pl. 2.1, loc. 4) is from cliff exposures between the elevations of 2,200 and 2,350 ft, 2 km south of Eddy Brook along the eastern border of the Wilcox as identified correctly by Brace (1953) (see pl. 2.1 for location). In these cliffs, zones of highly foliated gneiss contain lenses of green magnetite-muscovite-chlorite-quartz-knotted phyllite typical of the Wilcox. The phyllitic rocks, in zones 1 to 5 m thick, have transitional upper and lower contacts with rocks clearly recognizable as chloritic (garnet) quartz-plagioclase gneiss containing thin 3- to 5-cm-thick seams of pegmatite. Within 10 to 20 m of the center of the phyllitic zones, the gneiss becomes disharmonically folded and faulted and develops crosscutting veins of white quartz as much as 5 cm thick. These quartz veins become disrupted and are highly folded in the more ductily deformed phyllonite. The final product is a fine-grained, muscovite-chlorite-quartz-knotted

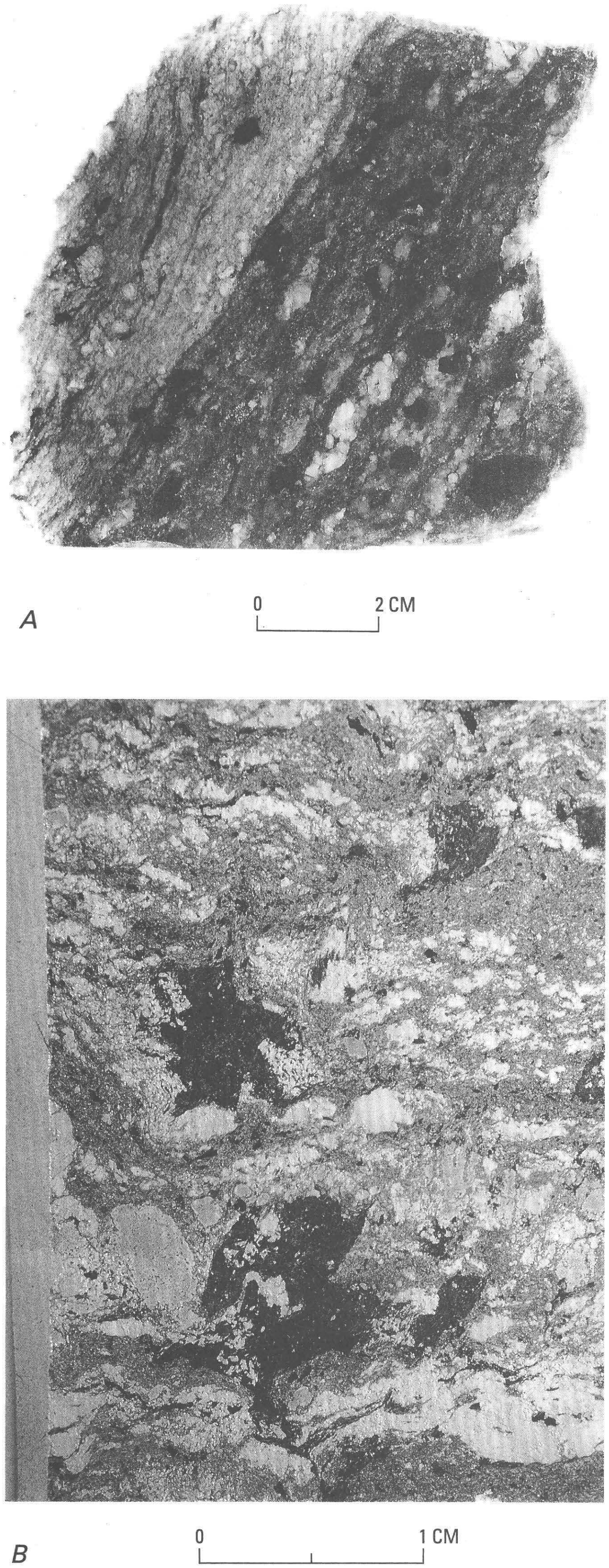

Figure 2.3. *A*, hand specimen of chlorite-spotted garnet quartzite and, *B*, photomicrograph of gneiss from locality 2 (pl. 2.1), 3 km north of Wilcox Hill.

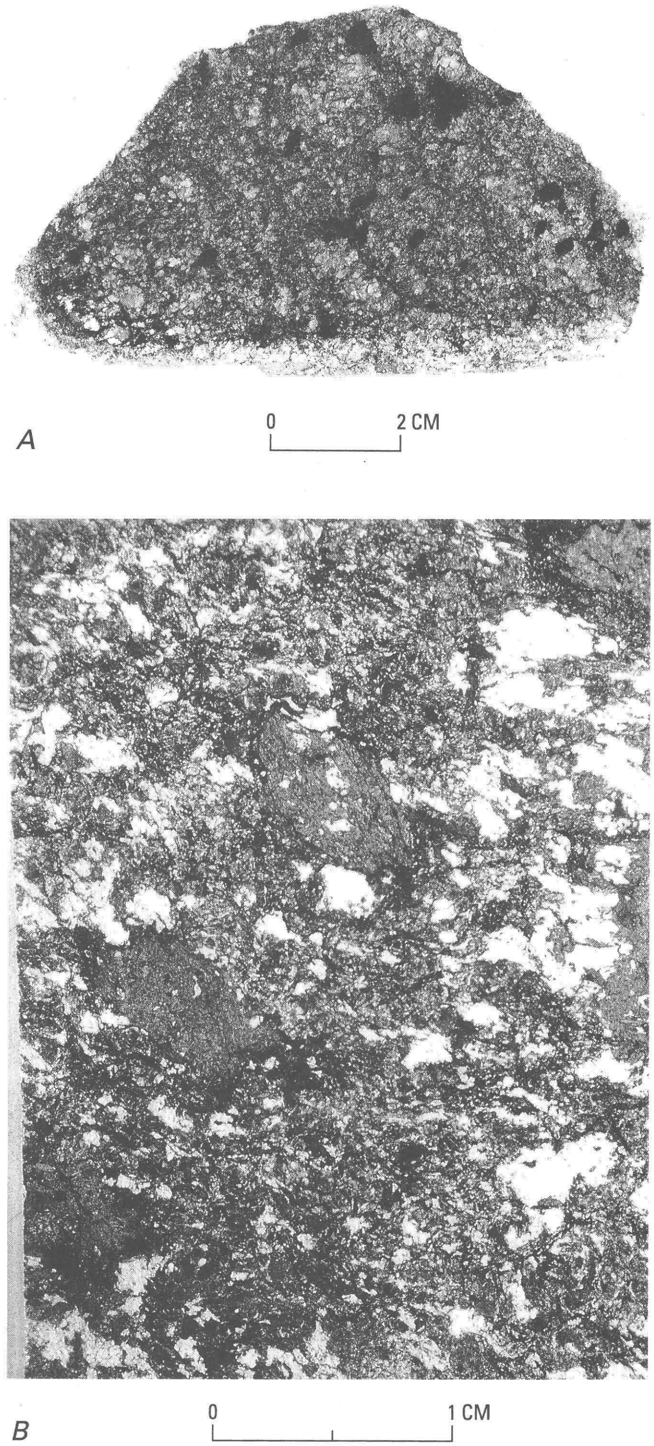

Figure 2.4. *A*, hand specimen and, *B*, photomicrograph of chlorite-spotted retrograded garnet gneiss from locality 3 (pl. 2.1) on Wilcox Hill.

schist (phyllonite). The relations show clearly that "phyllite" typical of the Wilcox, as described by Brace (1953) and subsequently assigned to the Tyson Formation by Karabinos (1987), was produced within rocks of the Mount Holly Complex by intense diaphthoric mylonitization.

Similar transformations include (1) coarse hornblende amphibolite altered to fine-grained, needle tremolite-actinolite-epidote-quartz schist or (2) biotite-quartz-plagioclase gneiss altered to gray, finely laminated chlorite-muscovite-epidote-quartz schist or semischist. These rocks are common throughout the Mount Holly Complex on the Green Mountain massif. The mineralogy and structure of the Wilcox at its type locality differs in no significant way from other phyllites mapped throughout the Green Mountains as parts of the Mount Holly Complex. For example, the schist and quartzite unit mapped by Brace (1953) on Shrewsbury Peak and on Little Killington (pl. 2.1) and the schist and quartzite units on Ludlow Mountain in the Mount Holly and Ludlow quadrangle are identical to schist at the type section of the Wilcox Formation. On Ludlow Mountain these schists and phyllites are intruded by coarse- to fine-grained granite gneiss and by abundant pegmatite (Ratcliffe, 1992) that is possibly as old as 1.2 Ga (based on U-Pb zircon ages; John Aleinikoff, U.S. Geological Survey, written commun., 1992). On Ludlow Mountain, chloritoid-chlorite-muscovite quartz phyllonite derived from coarse-grained (as much as 4 cm in diameter) garnet schist older than 1.2 Ga closely resembles phyllite of the Wilcox. Likewise, phyllite associated with garnet-quartz schist and pegmatite on College Hill and elsewhere in the Jamaica quadrangle (Ratcliffe, in press) closely resembles that in the Wilcox. On College Hill these schists are intruded by granites dated at 1.24 Ga (Ratcliffe and others, 1991). In short, phyllite that Brace mapped as distinctive of the Wilcox Formation is found throughout the Green Mountain massif as parts of the Mount Holly Complex and is demonstrably of Middle Proterozoic age. All of these schistose rocks (pl. 2.1) are assigned to the Wilcox Formation, as amended, in this report. Similar schists that occur within the core of the Chester dome, and that were previously assigned to the Cavendish Formation of Doll and others (1961), may also belong to the Mount Holly Complex based on my current mapping in the Cavendish quadrangle. However, it is not recommended that the name Wilcox be extended to include rocks of the Chester dome because of the lack of continuity among the rocks of the Green Mountains and the core rocks of the Chester dome.

CONCLUSIONS

On the basis of the new map data and the observations above, the schistose rocks of the Wilcox Formation (Brace's units A and C) are considered to be units of the Mount Holly Complex of Middle Proterozoic age. The middle unit (B) of the Wilcox Formation of Brace (1953) appears to be well-layered biotite-quartz-plagioclase gneiss (Yb) that is indistinguishable from other such gneisses in the Mount Holly as concluded by Karabinos (1987). On the basis of these data, the type Wilcox Formation is identified as schist, quartzite, and dolomite marbles developed in the vicinity of Wilcox Hill and southwest of Cold River in the Rutland and Killington Peak quadrangles. The Wilcox Formation is Middle Proterozoic, as suggested by Brace (1953). However, no evidence for an unconformity between the Wilcox and the Mount Holly Complex has been found; indeed they are interlayered. The Wilcox Formation, as here amended, is defined to be an integral part of the Mount Holly Complex.

At present, it is unclear whether all belts of schist similar to the Wilcox in the Green Mountains are the same units or are stratigraphic repetitions of similar rock intercalated throughout the Mount Holly Complex. However, within the area on plate 2.1, the five areas of schistose rocks in the Mount Holly Complex are all sufficiently similar and have comparable associations with surrounding rocks to be considered structural repetitions of the Wilcox. The large central annular belt (pl. 2.1) appears to be continuous with the rocks at the type locality.

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3. Definition and Nomenclature of the Robertson River Igneous Suite, Blue Ridge Province, Virginia

By Richard P. Tollo[1]

ABSTRACT

Detailed field mapping and results from petrologic, geochemical and isotopic analyses indicate that the herein designated Robertson River Igneous Suite (formerly Robertson River Formation) includes at least eight petrologically related intrusive bodies composed of syenite, granite and felsite with emplacement ages that span an interval of at least 30 million years. The suite includes a main, dike-like batholith, at least two satellite bodies, extrusive rhyolite, and numerous, petrologically related dikes enclosed within the surrounding Grenville-age country rocks. Type localities are defined for each of the eight major lithologic units of the suite based on field, petrographic and geochemical criteria. The youngest unit includes aegirine ± reibeckite-bearing granitoids and felsites that collectively define the hypabyssal portion of the former Battle Mountain peralkaline volcanic center. Newly recognized, compositionally similar rhyolites and volcanoclastic deposits occur 8 km southwest of the volcanic center and are intercalated with metasedimentary rocks correlated with the Mechum River Formation. These volcanic rocks are interpreted as derived from the Battle Mountain volcanic center and are included within the Battle Mountain lithologic unit.

INTRODUCTION

This paper is intended to complement the detailed 1:100,000 scale geologic map of the Robertson River Igneous Suite (Tollo and Lowe, 1994). Formal nomenclature is proposed for each of the eight lithologic units of the suite, geological field relations are briefly described, and type localities are defined. In addition, newly discovered rhyolite and rhyolitic volcanogenic deposits interlayered with metasedimentary rocks related to the Mechum River Formation are described and correlated with subvolcanic units of the Robertson River, indicating that Mechum River sedimentation and the final stages of Robertson River magmatism were contemporaneous. Geology, shown on plate 3.1, was mapped from 1985 to 1992.

This research was supported by grants from the National Science Foundation (award EAR89–16048) and the George Washington University.

ROBERTSON RIVER IGNEOUS SUITE

Rocks associated with the previously designated Robertson River Formation occur in the core zone of the Blue Ridge anticlinorium in northern Virginia and form an elongate, dikelike body extending nearly 100 km from Charlottesville north-northwest to Ashby Gap (Allen, 1963; Lukert and Nuckols, 1976; Lukert and Halladay, 1980; Clarke, 1984; Gathright and Nystrom, 1974; Tollo and others, 1991) (pl. 3.1). Field evidence, including dikes of granite cutting gneiss and inliers (xenoliths) of gneiss within granite, indicates that the Robertson River is intrusive into the surrounding Middle Proterozoic (Grenville) gneisses (Allen, 1963; Lukert and Nuckols, 1976; Lukert and Halladay, 1980; Clarke, 1984; Arav, 1989). Both field evidence and the results from recent provenance studies (Hutson, 1992) indicate that much of the Robertson River is older than most of the adjacent Late Proterozoic metasedimentary rocks (Mechum River Formation); however, contacts separating these units are typically fault-bounded where observed.

Recent detailed mapping and petrologic analysis indicate that rocks previously assigned to the Robertson River Formation include a series of granitoids, syenitoids, felsites, and rhyolites that were emplaced episodically during an extended period of magmatism lasting more than 30 million years (Arav, 1989; Hawkins, 1991; Lowe, 1990; Tollo and others, 1991; Tollo and Aleinikoff, 1992; Tollo and Arav, 1992; Tollo and Lowe, 1994). These studies demonstrate that the Robertson River includes at least eight units that are distinguished by characteristic mineral composition, texture, bulk chemical composition, and age as determined by U-Pb isotopic analysis. Each lithologic unit can be mapped in the field at a scale of 1:24,000 or smaller (for example, Arav, 1989; Hawkins, 1991; Lowe, 1990); crosscutting or other mutual field relationships indicative of independent

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intrusion can be observed locally. I propose that each of these predominantly intrusive, nonstratiform bodies represents a lithodemic unit. Furthermore, mineralogic and geochemical analyses demonstrate that all of the Robertson River lithologic units are petrologically similar to A-type granitoids recognized from other localities (Loiselle and Wones, 1979; Whalen and others, 1987; Eby, 1990; Tollo and Arav, 1992). All of the Robertson River rocks were emplaced in a rift-related continental setting and collectively define a large, dikelike mass formed by intrusion in a predominantly extensional regime. I propose that this occurrence of multiple lithodemic units of related origin indicates that the Robertson River Formation should be redesignated as the Robertson River Igneous Suite.

Rocks exposed within the Robertson River outcrop belt were first described by Theismeyer (1938) who referred to exposures located near Cresthill in Fauquier County as the "Crest Hill Granite." The name Robertson River Formation was given by Allen (1963) in reference to prominent outcrops of granite exposed along the Robinson River in Madison County, Va. As noted by Lukert and Banks (1984), the discrepancy in the formation name apparently was due to the incorrect spelling of the stream on the 1933 edition of the Madison 7.5-minute quadrangle. These exposures provide an informative cross section through the southern portion of the suite and surrounding gneissic rocks and are collectively an important locality. However, although the spelling of the stream is correct on the most recent edition of the Madison map, a corresponding change in the spelling of this often-cited formation would cause considerable confusion and is therefore unwarranted.

The following lithodemic units are defined for the Robertson River Igneous Suite. The type localities were selected as the most representative of the rock type characteristic of each unit on the basis of field, petrographic, and geochemical criteria. The overall age of the Robertson River Igneous Suite is Late Proterozoic; the individual lithologic units are described below in order of decreasing age as determined by U-Pb isotopic analysis of zircons (Tollo and Aleinikoff, unpub. data).

RIVANNA GRANITE

The Rivanna Granite (nomenclature after Le Maitre and others, 1989) is a white, medium-grained, fluorite-bearing granite to alkali feldspar granite characterized by low (typically <5) color index. This lithologic unit occurs in a narrow (generally less than 1 km in width), elongate belt (8.4 km in length) located at the southernmost termination of the Robertson River batholith and in three small (less than 0.5 km^2 each) patches located northwest of Brightwood. The type locality is chosen as the exposures south of Rivanna on the south side of the spillway north of the filtrationg plant on the south fork of the Rivanna River in the Charlottesville East 7.5-minute quadrangle (lat 38°06'40"N., long 78°28'08"W.). Contacts separating the Rivanna Granite from adjacent rock units are not exposed.

LAUREL MILLS GRANITE

The Laurel Mills Granite is a gray, ubiquitously coarse-grained, amphibole-bearing granite locally displaying abundant, outcrop-scale shear zones. This lithologic unit occurs primarily as an elongate body that varies in width from 1 to 5.4 km and extends for nearly 38 km along the western edge of the Robertson River outcrop belt from the vicinity of Delaplane southward to the near Castleton. Laurel Mills Granite also occurs as two small (less than 1 km^2 each), irregularly shaped bodies located west and northwest of Novum and as a small (about 1 km^2), satellite pluton located at Naked Mountain northeast of Markham. The type locality for this lithologic unit is the roadcut on Virginia Highway 618, approximately 1.4 km south-southwest of Laurel Mills in the Massies Corner 7.5-minute quadrangle (lat 38°38'17"N., long 78°05'48"W.). The Laurel Mills is separated from basement gneiss along the western border of the Robertson River outcrop belt by both fault-bounded and intrusional contacts (Lukert and Nuckols, 1976; Lukert and Halladay, 1980). The Laurel Mills is cut by felsite dikes of Battle Mountain Alkali Feldspar Granite and by dikes of the Amissville Alkali Feldspar Granite, Cobbler Mountain Alkali Feldspar Quartz Syenite, and the Hitt Mountain Alkali Feldspar Syenite.

ARRINGTON MOUNTAIN ALKALI FELDSPAR GRANITE

The Arrington Mountain Alkali Feldspar Granite is a gray, medium-grained, equigranular, biotite-bearing alkali feldspar granite characterized by typically prominent euhedral to subhedral mesoperthite grains. This lithologic unit occurs as a series of four variably sized (1–18 km^2, irregularly shaped bodies exposed discontinuously for nearly 25 km from near the Hazel River in the central portion of the Robertson River outcrop belt southward to Haywood. The bodies range from elongate to irregular in shape and are typically less than 6 km) in the longest dimension. The type locality for this unit is the large outcrop on the west side of the southernmost crest of Arrington Mountain adjacent to the trail from Virginia Highway 603 in the Brightwood 7.5-minute quadrangle (lat 38°27'48"N., long 78°14'45"W.). Contacts separating the Arrington Mountain from adjacent rock units are not exposed.

WHITE OAK ALKALI FELDSPAR GRANITE

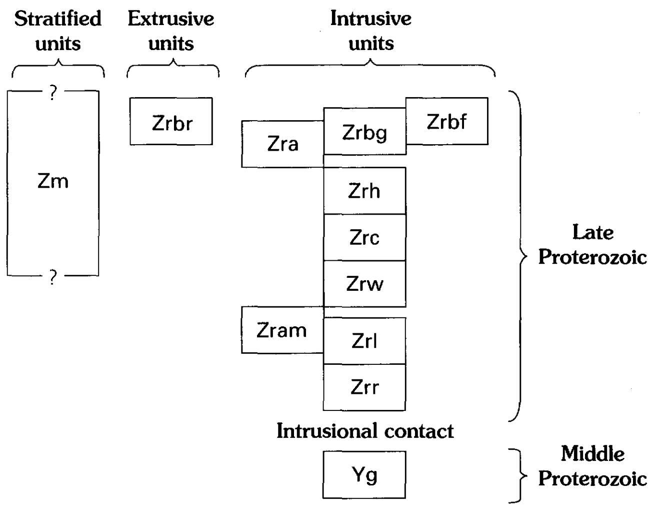
The White Oak Alkali Feldspar Granite is a white to light-gray, coarse-grained, amphibole-bearing alkali feldspar granite closely associated with light-gray, fine-grained, amphibole-bearing alkali feldspar granite. This unit occurs as an narrow, elongate body (12.8 km in length) located along the eastern edge of the Robertson River outcrop belt west of Rochelle and as a smaller, elongate body (4.8 km in length) located near Madison. Both bodies are less than 2 km in width. The finer grained alkali feldspar granite typically cuts the coarser grained variety (Lowe, 1990). The type locality is the large roadcut on the east side of Virginia Highway 638 approximately 0.24 km northeast of the bridge crossing the Robinson River, 0.6 km northeast of the confluence of Glebe Run and White Oak Run in the Brightwood 7.5-minute quadrangle (lat 38°24'18"N., long 78°14'20"W.). Contacts separating the White Oak Alkali Feldspar Granite from adjacent rock units are not exposed.

COBBLER MOUNTAIN ALKALI FELDSPAR QUARTZ SYENITE

The Cobbler Mountain Alkali Feldspar Quartz Syenite is a dark-gray, medium-grained, alkali feldspar quartz syenite typically displaying an interlocking network of abundant, subhedral to euhedral mesoperthite grains on weathered surfaces. This lithologic unit occurs as an elongate body (1.6–6.1 km in width) extending nearly 30 km (18 mi) from Ashby Gap at the northern end of the Robertson River outcrop belt southward to the Rappahannock River. The type locality is selected as the roadcut north of Little Cobbler Mountain on the north side of Virginia Highway 55, 1.4 km west of the intersection with U.S. Highway 17 in the Upperville 7.5-minute quadrangle (lat 38°54'12"N., long 77°55'53"W.). Dikes of Cobbler Mountain Alkali Feldspar Quartz Syenite cut the Laurel Mills Granite west of Cobbler Mountain and intrude basement gneiss located east of the Robertson River outcrop belt along Goose Creek near Upperville (Arav, 1989).

HITT MOUNTAIN ALKALI FELDSPAR SYENITE

The Hitt Mountain Alkali Feldspar Syenite is a light-gray, coarse-grained, amphibole-bearing alkali feldspar syenite locally associated with darker gray, fine-grained, amphibole-bearing alkali feldspar syenite. This lithologic unit occurs as a narrow (2.8 km maximum width), elongate body stretching nearly 32 km southward from Madison and as an irregularly shaped, elongate body (12 km in length) located west of Brightwood. The type locality is a series of small outcrops on the southwest slope of Hitt Mountain west of Virginia Highway 607, approximately 1.4 km northeast of the intersection of Virginia Highways 607 and 606 in the Brightwood 7.5-minute quadrangle (lat 38°29'59"N., long 78°10'42"W.). Dikes of fine-grained Hitt Mountain cut the Laurel Mills Granite near Novum.



EXPLANATION

Zm, Mechum River Formation.
Zrbr, Battle Mountain Alkali Feldspar Granite, ryholite
Zrbf, Battle Mountain Alkali Feldspar Granite, felsite
Zrbg, Battle Mountain Alkali Feldspar Granite, granite
Zra, Amissville Alkali Feldspar Granite
Zrh, Hitt Mountain Alkali Feldspar Syenite
Zrc, Cobbler Mountain Alkali Feldspar Quartz Syenite
Zrw, White Oak Alkali Feldspar Granite
Zram, Arrington Mountain Alkali Feldspar Granite
Zrl, Laurel Mills Granite
Zrr, Rivanna Granite
Yg, Basement gneiss and granitoid

Figure 3.1. Age correlation diagram for the constituent lithologic units of the Robertson River Igneous Suite and Mechum River Formation. Relative ages compiled from U-Pb analyses of zircons (Tollo and Aleinikoff, 1992 and unpub. data).

AMISSVILLE ALKALI FELDSPAR GRANITE

The Amissville Alkali Feldspar Granite is a light-gray, medium-grained, porphyritic, aegirine ± reibeckite-bearing alkali feldspar granite for which small prisms of green aegirine and black reibeckite are particularly diagnostic field criteria. This lithologic unit occurs as a narrow (1.4 km average width), elongate body stretching 8.1 km along the eastern edge of the Robertson River outcrop belt from the Rappahannock River southward to the vicinity of Battle Mountain and as a small (less than 1 km^2), equidimensional body located south of Castleton Mountain. The Amissville type locality (fig. 3.1) is chosen as the series of roadcuts on U.S. Highway 211 at the intersection with Virginia Highway 640, 4.3 km west of Amissville in the Massies Corner 7.5-minute quadrangle (lat 38°41'35"N., long 78°80'04"W.). The Amissville is in fault contact with basement gneiss along the eastern border of the Robertson River outcrop belt (Lukert and Halladay, 1980). Dikes of fine-grained Amissville cut Cobbler Mountain Alkali Feldspar Quartz Syenite and Laurel Mills Granite in the northern portion of the Robertson River outcrop belt, and the

Amissville is cut by felsite dikes of the Battle Mountain Alkali Feldspar Granite near Massies Corner (Arav, 1989; Hawkins, 1991).

BATTLE MOUNTAIN ALKALI FELDSPAR GRANITE

The Battle Mountain Alkali Feldspar Granite is a composite unit including alkali feldspar granite, felsite, and rhyolite, each of which has been mapped separately. The alkali feldspar granite is the most abundant subunit and is typically cut by numerous felsite dikes that cannot be distinguished at 1:24,000 map scale (Hawkins, 1991). The alkali feldspar granite is typically blue gray, medium grained, and aegirine bearing, whereas the felsite (lithologic term used herein for light-colored, fine-grained, igneous rocks that are not demonstrably of volcanic origin) is typically blue gray, aphanitic to sparsely porphyritic, aegirine bearing, and locally flow banded (Hawkins, 1991). Within the main Robertson River outcrop belt, the alkali feldspar granite occurs as an elongate body (as much as 2 km in width) that stretches 10 km from the area north of Little Battle Mountain southward to the southern flank of Castleton Mountain. The alkali feldspar granite also occurs east of the main Robertson River belt as an elongate body stretching 15 km from near Orlean southward to the vicinity of Viewtown. The felsite occurs as a small (1 × 3.3 km), elongate body located at Little Battle and Battle Mountains and as a narrow (less than 0.5 km in width), elongate body stretching 7.4 km from Blackwater Creek southward to the Hazel River. The type locality of this composite unit is the roadcut near the south end of Battle Mountain on the north side of Virginia Highway 729, located 0.55 km east of the intersection with Virginia Highway 618 in the Massies Corner 7.5-minute quadrangle (lat 38°38'57"N., long 78°04'06"W.) where weakly flow-banded felsite is in contact with medium-grained alkali feldspar granite. Battle Mountain Alkali Feldspar Granite is in fault contact with basement gneiss along the eastern border of the Robertson River outcrop belt (Lukert and Halladay, 1980; Hawkins, 1991). Dikes of Battle Mountain (felsite) cut the Laurel Mills Granite and Amissville Alkali Feldspar Granite in the vicinity of Battle Mountain (Arav, 1989; Hawkins, 1991).

White, aphanitic to sparsely porphyritic (feldspar phenocrysts) rhyolite that is similar in composition to the felsite of the Battle Mountain Alkali Feldspar Granite is intercalated with metasedimentary rocks (including pale-green phyllite, meta-arkose, and metaconglomerate herein correlated with the Mechum River Formation) throughout a distance of 3.6 km between Castleton Mountain and Blackwater Creek in the Castleton 7.5-minute quadrangle (Hutson, 1992). These volcanic and volcanoclastic rocks occur as a series of discontinuous layers interbedded with less abundant metasedimentary strata and are considered to be part of the Battle Mountain unit. Metaconglomerate stratigraphically overlying the rhyolite layers typically contains clasts of lithologically identical rhyolite indicating that the contacts are unconformable. The type locality is chosen as the abandoned quarry on the north side of Virginia Highway 615, located 1.7 km south of the intersection with Virginia Highway 617 in the Castleton 7.5-minute quadrangle (lat 38°35'30"N., long 78°6'8"W.). The rhyolite and volcanoclastic rocks comprise at least three discontinuous layers, separated by metasedimentary strata, with a total minimum thickness of 100 m. The rhyolite and volcanogenic deposits are interpreted to have been derived from the Battle Mountain volcanic center (informal name) located 8 km to the northeast.

SUMMARY

The Robertson River Igneous Suite includes a main dikelike batholith, at least two satellite bodies, and numerous fine-grained dikes that intrude Grenville-age (1.1–1.0 Ga) gneisses and granitoids within the core zone of the Blue Ridge anticlinorium in northern Virginia. The suite is composed of at least eight lithologic units defined on the basis of field, petrographic, and geochemical criteria and that range in composition from alkali feldspar syenite to granite. U-Pb isotopic analyses of zircons (Tollo and Aleinikoff, 1992 and unpub. data) indicate that the suite was emplaced episodically throughout an interval of at least 30 million years. The older (735–722 Ma; Tollo and Aleinikoff, 1992) group of rocks (Rivanna Granite, Laurel Mills Granite, Arrington Mountain Alkali Feldspar Granite, White Oak Alkali Feldspar Granite, and Cobbler Mountain Alkali Feldspar Quartz Syenite) includes biotite- and (or) calcic amphibole-bearing rocks and collectively constitutes most of the main batholith (pl. 3.1). The younger (706–702 Ma; Tollo and Aleinikoff, 1992) group includes amphibole-bearing alkali feldspar syenite (Hitt Mountain), exposed only in the southern portion of the main batholith, and aegirine ± reibeckite-bearing alkali feldspar granites and felsites (Amissville and Battle Mountain) that together define the hypabyssal portion of the former Battle Mountain volcanic center, located in the central section of the main batholith. Aphanitic to sparsely porphyritic rhyolite that is similar in composition to the felsite of the Battle Mountain volcanic center is intercalated with metasedimentary rocks correlated with the Mechum River Formation in a small (5.5 × 0.2 to 0.6 km) graben structure located 8 km southwest of the Battle Mountain area (Hutson, 1992). The rhyolite and associated volcanogenic deposits are interpreted, on the basis of the close correspondence in chemical composition, to be ultimately derived from the nearby volcanic center and are considered to be part of the Battle Mountain unit. The intercalated nature of these rocks with strata correlated with the Mechum River Formation indicates that rift-related sedimentation and volcanism were contemporaneous at about 700 Ma (Hutson and Tollo, 1992).

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4. The Dalecarlia Intrusive Suite and Clarendon Granite in the Potomac Valley, Washington, D.C., Virginia, and Maryland

By Avery Ala Drake, Jr., and Anthony H. Fleming

ABSTRACT

Intrusive Early Ordovician rocks are abundant in the District of Columbia and adjacent Virginia and Maryland. Current geologic mapping has recognized two new intrusive sequences, the Dalecarlia Intrusive Suite and the Clarendon Granite. The Dalecarlia Intrusive Suite consists of abundant biotite monzogranite and lesser leucocratic muscovite-biotite monzogranite, muscovite trondhjemite, and muscovite-biotite tonalite. The Clarendon Granite is muscovite-biotite monzogranite.

These rocks are part of an Early Ordovician magmatic arc that was formed on the margin of the Laurentian craton during the late stages of the Penobscot orogeny. The monzogranite and tonalite of the Dalecarlia Intrusive Suite are interpreted to be the result of the melting of metasedimentary rock, whereas the trondhjemite of the Dalecarlia Intrusive Suite may have resulted from the partial melting of tonalite of the older Georgetown Intrusive Suite. The trondhjemite appears to have been partly contaminated by earlier emplaced monzogranite.

INTRODUCTION

Intrusive Early Ordovician rocks are abundant along and just west of the Fall Line in the central Appalachian Piedmont (Drake and others, 1989, p. 117–134). These rocks include bodies of unnamed trondhjemitic metatonalite and plagiogranitic metatonalite in the Fredericksburg, Va., area (Pavlides, 1981), the Occoquan Granite (Seiders and others, 1975; Drake and Froelich, 1986) and Falls Church Intrusive Suite (Drake and Froelich, 1986, in press) of northern Virginia, and the Georgetown Intrusive Suite and Kensington Tonalite (Hopson, 1964; Drake and Froelich, in press) and Norbeck Quartz Diorite of Hopson (1964) in the District of Columbia and adjacent Maryland and Virginia. The Norbeck is actually tonalite in today's petrologic nomenclature. It contains lesser amounts of gabbro and ultramafic rocks. Recent geologic mapping in the Washington West 7.5-minute quadrangle by A.H. Fleming and A.A. Drake, Jr., and the Falls Church and Kensington 7.5-minute quadrangles by Drake has delineated two additional intrusive units, the Dalecarlia Intrusive Suite and Clarendon Granite. The purpose of this paper is to describe these new units and to speculate on their role in the tectonic history of the Potomac Valley. Geology, shown on plate 4.1, was mapped from 1976 to 1991.

REGIONAL GEOLOGY

The geology of the Piedmont part of the Potomac Valley was recently summarized by Drake (1989). In the study area of this paper, metasedimentary and transported intrusive rocks occur in a thrust sheet-precursory sedimentary mélange pair termed a "tectonic motif" (Drake, 1985a, 1985b). The precursory mélange element of the motif is characterized by olistoliths of its overlying thrust sheet. This motif consists of a thrust sheet containing rocks of the Mather Gorge Formation and the underlying sedimentary mélange, the Sykesville Formation. Only the Sykesville element of the motif stack is shown on plate 4.1. The Sykesville contains olistoliths of metagraywacke, migmatite, and phyllonite of the Mather Gorge Formation as well as transported intrusive rocks. The rocks of the Sykesville Formation are at biotite±garnet grade (Drake, 1989). In the area under consideration in this paper, the Sykesville is intruded by rocks of the Georgetown Intrusive Suite, Kensington Tonalite, Dalecarlia Intrusive Suite, Clarendon Granite, and leucocratic granitoids of uncertain affinity. All of these intrusive rocks have been metamorphosed.

GEORGETOWN INTRUSIVE SUITE

Rocks of the Georgetown Intrusive Suite are the oldest intrusive rocks in this part of the Potomac Valley because they are intruded by the Kensington Tonalite and rocks of the Dalecarlia Intrusive Suite. Most of these rocks are mafic biotite-hornblende tonalite. Here, and throughout this paper, mineral prefixes of intrusive rocks are listed in ascending order as recommended by Streckeisen (1973). Smaller plutons of biotite tonalite and quartz gabbro as well as bodies of pyroxenite and garnetiferous biotite-hornblende tonalite also belong to this suite. All these rocks have clear intrusive relation with the metasedimentary rocks as the metasedimentary rocks are contact metamorphosed and contain inclusions and probable roof pendants (Fleming and others, 1994) of metasedimentary rocks. At most places, the tonalite has a well-developed igneous flow structure that parallels contacts with wall rocks and pendants and swirls around inclusions. This structure is overprinted by a tectonic foliation and lineation. Rocks of the suite were described by Fisher (1963), Hopson (1964), and Drake and Froelich (in press). Chemical analyses of Georgetown rocks are given in Hopson (1964), Drake and Froelich (in press), and Fleming and others (1994). Normative data from samples collected in the Washington West 7.5-minute quadrangle (Fleming and others, 1994) appear in figure 4.1. Hornblende tonolite of the Georgetown Inrusive Suite has a U-Pb upper intercept age of 466±3 Ma and a single zircon crystal age of 465±5 Ma (J.N. Aleinikoff, U.S. Geological Survey, written commun., 1994). Tonalites of the Georgetown Intrusive Suite are identical to those of the Falls Church Intrusive Suite (Drake and Froelich, 1986, in press) and Norbeck Quartz Diorite (tonalite) of Hopson (1964). These rocks probably result from separate pulses from a common magma stem. The Norbeck Quartz Diorite (tonalite) of Hopson has a ^{207}Pb–^{206}Pb age of 570 Ma (Hopson, 1964). More recently, A.K. Sinha (written commun., 1992) found that zircons from the unit give such discordant relations that dating is impossible. Tonalite from the Falls Church Intrusive Suite has a single crystal U-Pb age of 481±11 Ma (J.N. Aleinikoff, U.S. Geological Survey, written commun., 1993).

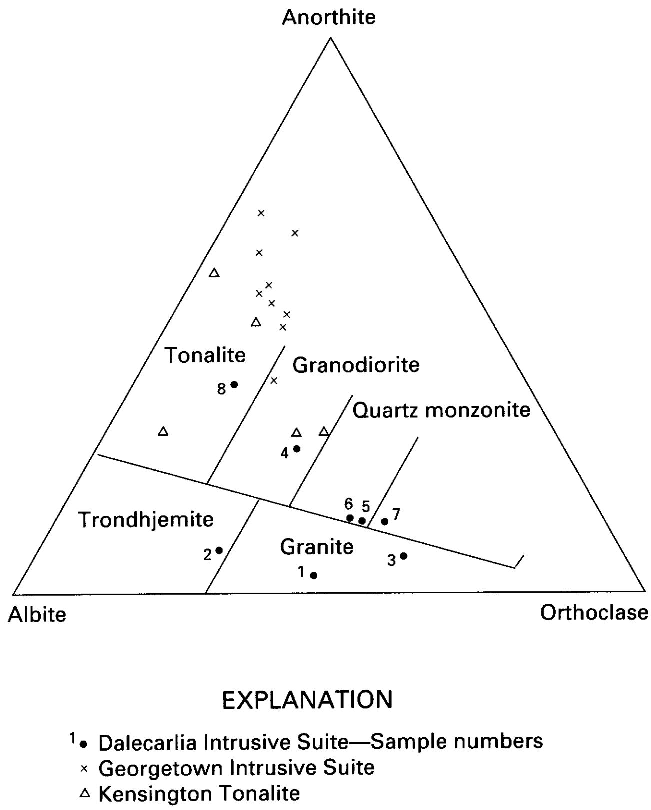

Figure 4.1. Normative feldspar plot (O'Connor, 1965) comparing rocks of the Dalecarlia Intrusive Suite, solid circles, with those of the Georgetown Intrusive Suite, x, and the Kensington Tonalite, Δ. Numbered points refer to samples in table 4.1. Data for the Georgetown Intrusive Suite and Kensington Tonalite from Fleming and others (1994).

KENSINGTON TONALITE

The Kensington Tonalite is a moderately to well-foliated plutonic rock composed chiefly of oligoclase, quartz, biotite, and muscovite. The primary igneous fabric is, at most places, strongly overprinted by a tectonic foliation. In the northern part of the Washington West 7.5-minute quadrangle (Fleming and others, 1994) and the adjoining Kensington quadrangle (A.A. Drake, Jr., unpub. data), the rock becomes sheared and metamorphic muscovite and microcline augen appear. There, the unit is granodioritic in composition. Textural and structural relations suggest that the rock was altered by potash metasomatism during a shearing event in a manner like that described by Kano (1991). The Kensington body shown on plate 4.1 is uniform in appearance and consists of well-foliated, medium- to coarse-grained muscovite-biotite tonalite. Chemical analyses of Kensington Tonalite appear in Hopson (1964), and normative data from samples from the Washington West 7.5-minute quadrangle (Fleming and others, 1994) appear in figure 4.1. The Kensington has recently been found to have a single crystal zircon age of 460±4 (J.N. Aleinikoff, U.S. Geological Survey, written commun., 1994). It intrudes the metasedimentary rocks as well as the rocks of the Georgetown Intrusive Suite as well shown by crosscutting relations.

DALECARLIA INTRUSIVE SUITE (HERE NAMED)

The Dalecarlia Intrusive Suite is here named for exposures near Dalecarlia Reservoir and along Dalecarlia Parkway in the Washington West 7.5-minute quadrangle, District of Columbia, where it intrudes the Sykesville Formation (pl. 4.1). It consists of subequal parts of biotite monzogranite and leucocratic muscovite-biotite monzogranite, lesser muscovite trondhjemite, and much lesser tonalite. Rocks of the Dalecarlia Intrusive Suite are abundant in the northwestern part of the Washington West 7.5-minute quadrangle and immediately adjacent Falls Church 7.5-minute quadrangle. This unit has been traced a short distance north into the Kensington 7.5-minute quadrangle (A.A. Drake, Jr., unpub. data). It has not been recognized elsewhere. Most of the rocks are only weakly deformed, and many are massive. Much of the unit was mapped as Kensington Tonalite by previous workers (Cloos and Cooke, 1953; Fisher, 1963; and Johnston, 1964). Some of the more leucocratic rocks were mapped as Bear Island Granodiorite by Cloos and Cooke (1953) and Johnston (1964). Wall rock inclusions are sparse, but exposed contacts clearly show that rocks of the suite intrude both the Sykesville Formation and rocks of the Georgetown Intrusive Suite. The typical weak foliation suggests that the rocks are late kinematic.

BIOTITE MONZOGRANITE

Biotite monzogranite is medium- to coarse-grained and is composed of potassium feldspar, quartz, plagioclase, and biotite. Samples 4 through 8 in table 4.1 are of this rock type. It forms three large, elongate plutons and numerous smaller bodies largely west of Wisconsin Avenue (pl. 4.1). The best exposure is on a hill at the southeastern corner of Dalecarlia Reservoir (pl. 4.1, loc. 1). This is on U.S. Government property, and access, unfortunately, is prohibited to the general public. This is the location of sample 7 (table 4.1). Other good exposures are east and west of Little Falls Parkway north of Massachusetts Avenue (pl. 4.1, locs. 2 and 3).

Typically, the biotite monzogranite contains between 15 and 20 percent biotite, but more leucocratic phases are common. There appears to be a complete gradation between biotite monzogranite and leucocratic muscovite-biotite monzogranite, which can be seen in some outcrops. The rock in some outcrops is porphyritic; the plagioclase phenocrysts are as much as 1.5 cm in length. Chemically, the rock is predominantly quartz monzonite (fig. 4.1), although sample 4 is granodiorite and sample 8 plots in the tonalite field. The monzogranite has a single crystal zircon age of 465±4 Ma (J.N. Aleinikoff, U.S. Geological Survey, written commun., 1994).

LEUCOCRATIC MUSCOVITE-BIOTITE MONZOGRANITE

Leucocratic muscovite-biotite monzogranite forms separate plutons as well as lenses and irregular bodies within biotite monzogranite plutons. It is composed of potassium feldspar, quartz, plagioclase, biotite, and muscovite. Biotite typically forms small books intergrown with lesser muscovite and forms 1 to about 10 percent of the rock. Other muscovite is probably of metamorphic origin. Typically the rock is coarse grained. In some outcrops the rock has a strong flow lineation marked by aligned, coarse euhedral feldspar crystals. The one analyzed sample is chemically granodiorite (table 4.1, sample 4).

MUSCOVITE TRONDHJEMITE

Muscovite trondhjemite is a leucocratic, massive to weakly foliated rock composed of oligoclase, quartz, muscovite, and, at places, minor amounts of potassic feldspar. The muscovite probably is not a primary mineral but results from metamorphic reactions. The trondhjemite has a fine- to medium-grained aplitic texture. It crops out in small plugs and forms sheets within biotite monzogranite and the Sykesville Formation, as well as in thin dikes that fill joints within the monzogranite. The plugs lie in a northwest-trending zone within the Sykesville Formation north of Dalecarlia Reservoir (pl. 4.1). Intrusive relations between the trondhjemite and monzogranite can be seen just east of the Dalecarlia Parkway (pl. 4.1, loc. 4), as well as in outcrops along the parkway. These relations are not shown on plate 4.1 because the different rocks occur in bodies too small to be represented at that scale. The field relations show that the trondhjemite crosscuts the monzogranite.

Chemically, samples 1 and 3 (table 4.1) plot as granite (fig. 4.1) although they are similar in appearance to other specimens of trondhjemite from the Dalecarlia Intrusive Suite. They contain more K_2O than typical trondhjemite defined by Barker (1979), and they contain less than 3 percent total FeO+MgO and much less MgO than the 2 to 3 percent common to trondhjemite (Barker, 1979). In any case, these rocks are here called trondhjemites because they more nearly resemble those rocks than any other. The trondhjemites are muscovite rich, and the high K_2O content may be the result of postemplacement metasomatic alteration such as that described for similar rocks in the Falls Church quadrangle by Drake and Froelich (1986), or perhaps by wall-rock assimilation by magma flow through dikelike conduits (Huppert and Sparks, 1985).

GEOCHEMISTRY

Rocks of the Dalecarlia Intrusive Suite are siliceous (table 4.1), corundum normative (table 4.1), and peraluminous (fig. 4.2). They are calc-alkaline (fig. 4.3) and are highly oxidized, much more so than the type magnetite granites of Japan (figs. 4.4 and 4.5). The monzogranite differs from the trondhjemite in its much higher content of ferromagnesian elements and high-valence cations excepting Ta, Ba, and Sr (table 4.1).

Rare earth element (REE) patterns for rocks of the Dalecarlia Intrusive Suite are given in figure 4.6. Some of the samples of biotite monzogranite (fig. 4.6, samples 5, 7, and 8) have a calc-alkaline trend and an enrichment of light rare earth elements with respect to heavy rare earth elements (HREE). Compared to chondrite, they have a 60- to 100-fold enrichment of La and a 4- to 15-percent enrichment of Lu. Samples 5 and 7 have negative Eu anomalies, whereas sample 8 has a positive anomaly.

Table 4.1. Chemical analyses, C.I.P.W. norms, and trace and rare earth element abundance of rocks of the Dalecarlia Intrusive Suite.

[—, no data. Major oxides X-ray spectrographic analyses, J. Taggart, A. Bartel, and D. Siems, U.S. Geological Survey, analysts. FeO, H_2O+, H_2O–, and CO_2 by rapid rock analysis, H. Smith, C.L. Progger, J.M. Allingham, and J.W. Marinenko, U.S. Geological Survey, analysts. Trace and rare earth elements by instrumental neutron activation analysis, J. Grossman, U.S. Geological Survey, analyst. Rb by ion exchange separation, M.W. Doughten, U.S. Geological Survey, analyst]

Major oxide	Sample[1] (weight percent)							
	1	2	3	4	5	6	7	8
SiO_2	75.4	75.0	74.0	72.2	69.9	71.1	69.5	69.1
Al_2O_3	14.3	15.1	13.9	14.0	14.7	14.6	14.9	15.1
Fe_2O_3	.35	—	1.0	1.5	1.4	1.22	1.35	.99
FeO	.16	.72	.32	.84	1.9	1.3	2.1	2.1
MgO	.19	.27	.49	1.06	1.58	1.2	1.54	1.86
CaO	.42	.79	.63	2.87	1.4	1.33	1.37	4.46
Na_2O	3.43	3.69	2.22	2.61	2.43	2.81	2.24	3.39
K_2O	4.29	2.34	4.88	2.53	4.25	4.4	4.31	1.36
H_2O^+	.63	1.1	.70	.57	1.0	.87	.92	1.2
H_2O^-	.09	.09	.22	.09	.1	.07	.08	.04
TiO_2	.06	.07	.15	.31	.46	.35	.48	.39
P_2O_5	.09	.19	.11	.06	.21	.21	.20	.14
MnO	.03	—	.03	.04	.07	.07	.07	.05
CO_2	.01	.01	.01	.28	.01	.01	.01	.01
Total	99.45	99.37	98.66	98.96	99.41	99.54	99.07	100.19
Mineral	**C.I.P.W. norm (weight percent)**							
Quartz	38.6	43.3	41.6	41.2	34.6	33.9	35.1	31.5
Orthoclase	25.7	14.1	29.5	15.2	25.6	26.4	26.0	8.1
Albite	29.4	31.8	19.2	22.5	20.9	24.1	19.3	29.0
Anorthite	1.4	2.7	2.4	12.3	5.6	5.2	5.5	21.4
Corundum	3.4	5.6	4.2	2.6	4.2	3.4	4.7	.3
Hypersthene	0.5	—	1.3	2.7	5.7	4.0	6.0	7.2
Magnetite	.2	2.0	.7	2.0	2.1	1.8	2.0	1.4
Apatite	.4	.5	.3	.1	.5	.5	.5	.3
Ilmenite	.1	.1	.3	.6	.9	.7	.9	.8
Hematite	—	—	.6	.2	.2	.8	—	—
Calcite	—	—	—	.6	—	—	—	—
Total	99.7	100.1	100.1	100.0	100.3	100.8	100.0	100.0
Trace element	**Abundance (parts per million)**							
Sc	—	4.47	4.48	6.96	10.04	—	9.81	4.67
Ti	—	<1	<0.9	<0.9	<1	—	<0.9	<1
Cr	—	3.0	9.6	24.9	28.7	—	28.7	24.9
Co	—	.86	2.46	5.55	8.7	—	9.09	18.4
Ni	—	<9	<9	12	18	—	27	<18
Zm	—	8.4	18.3	31	50.5	—	57.6	81.4
As	—	<0.5	<0.6	.69	2.02	—	.93	2.73
Rb	—	72.9	126	135	159	—	153	61.3
Sr	—	104	107	135	159	—	163	322
Zr	—	<90	67	170	175	—	190	157
Mo	—	<0.3	.4	—	<0.5	—	—	3.4
Sb	—	<0.08	.53	.211	<0.08	—	.091	1.6
Cs	—	2.95	2.09	3.45	5.8	—	2.83	2.76
Ba	—	90	96	479	602	—	656	319
Hf	—	1.46	2.14	4.3	5.11	—	4.7	5.67
Ta	—	3.04	.993	1.2	1.51	—	1.44	.508
Th	—	1.12	4.61	12.4	11.98	—	11.27	7.64
U	—	1.45	1.32	2.81	2.01	—	2.17	1.31

Table 4.1. Chemical analyses, C.I.P.W. norms, and trace and rare earth element abundance of rocks of the Dalecarlia Intrusive Suite—Continued.

Rare earth element	Abundance (parts per million)							
	1	2	3	4	5	6	7	8
La	—	3.98	6.07	40.3	36.1	—	19.6	27.4
Ce	—	5.98	28.8	77.8	75.6	—	54.6	45.4
Nd	—	4.1	6.5	25.1	34.7	—	19.3	13.7
Sm	—	1.34	1.73	4.4	8.15	—	4.83	1.98
Eu	—	.235	.363	.838	1.34	—	.796	.937
Tb	—	.354	.338	.510	1.13	—	.761	.230
Yb	—	1.98	2.57	1.49	3.41	—	2.79	.77
Lu	—	2.52	.367	.220	.464	—	.397	.119

[1]Description of samples:

1. Medium-grained muscovite trondhjemite from an outcrop along Spring Valley Run, 150 m upstream (east) of Dalecarlia Parkway (lat 38°56'45"N., long 77°06'02"W.). Chemically, the rock is granite (fig. 4.1).
2. Fine- to medium-grained muscovite trondhjemite from an excavation 100 m south of Spring Valley Run and 125 m east of Dalecarlia Parkway (lat 38°56'40"N., long 77°06'05"W.). Chemically, the rock is trondhjemite (fig. 4.1).
3. Medium-grained muscovite trondhjemite from an outcrop about 1 m east of a wooden gangway along the Little Falls Branch recreational trail, 250 m southwest of Massachusetts Avenue and Little Falls Parkway (lat 38°57'18"N., long 77°06'31"W.). The trondhjemite appears to grade into leucocratic muscovite-biotite monzogranite near the top of the outcrop. Chemically, the rock is granite (fig. 4.1).
4. Medium- to coarse-grained leucocratic biotite monzogranite from a building excavation on the northwestern corner of the intersection of Wisconsin Avenue and Bradley Boulevard (lat 38°58'40"N., long 77°05'30"W.). The monzogranite intrudes the Sykesville Formation at this locality, which is on the western contact of a large, elongate monzogranite pluton. Chemically, the rock is granodiorite (fig. 4.1).
5. Coarse-grained, moderately foliated biotite monzogranite from a large outcrop on the northwestern side of Little Falls Branch, 250 m northeast of Massachusetts Avenue (lat 38°57'31"N., long 77°06'26"W.). Chemically, the rock is quartz monzonite (fig. 4.1).
6. Coarse-grained, massive biotite monzogranite from an abandoned quarry 125 m west of an abandoned railroad line and 400 m south of River Road (lat 38°57'40"N., long 77°06'20"W.). Chemically, the rock is quartz monzonite (fig. 4.1).
7. Coarse-grained, massive biotite monzogranite from an outcrop on a ridgetop on the Dalecarlia Reservoir grounds, 150 m east of the reservoir and 600 m due north of the intersection of Loughboro Road and Dalecarlia Parkway (lat 38°56'26"N., long 77°06'24"W.). Rock is characterized by numerous coarse quartz hobnails and sparse plagioclase phenocrysts. Chemically, the rock is monzogranite (fig. 4.1).
8. Coarse-grained biotite monzogranite from an outcrop 180 m west of Massachusetts Avenue and 90 m north of Van Ness Street (lat 38°56'35"N., long 77°05'45"W.). This exposure was destroyed during construction of a housing addition in 1985. The rock in this immediate area is choked with xenoliths and roof pendants of biotite hornblende tonalite, quartz gabbro, and rocks of the Sykesville Formation, which appear to have reacted with the monzogranite and modified its chemical composition. Chemically, the rock is tonalite (fig. 4.1).

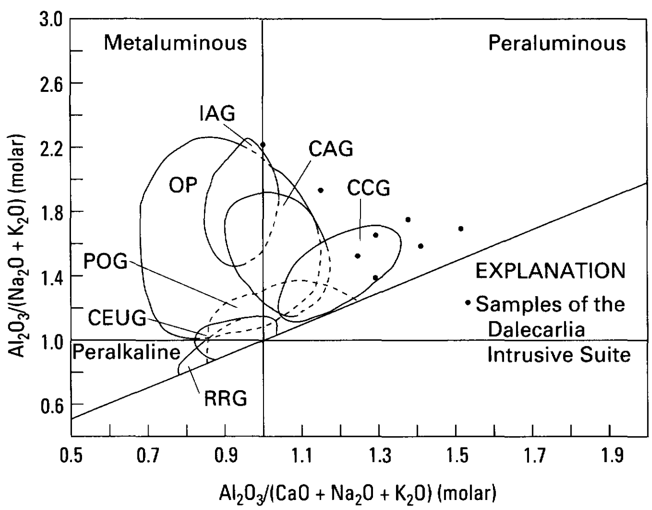

Figure 4.2. Shand's index showing different tectonic environments of granitoids (after Maniar and Piccoli, 1989). IAG, island arc granitoids; CAG, continental arc granitoids; CCG, continental collision granitoids; POG, postorogenic granitoids; RRG, rift-related granitoids; CEUG, continental epeirogenic uplift granitoids; and OP, oceanic plagiogranites.

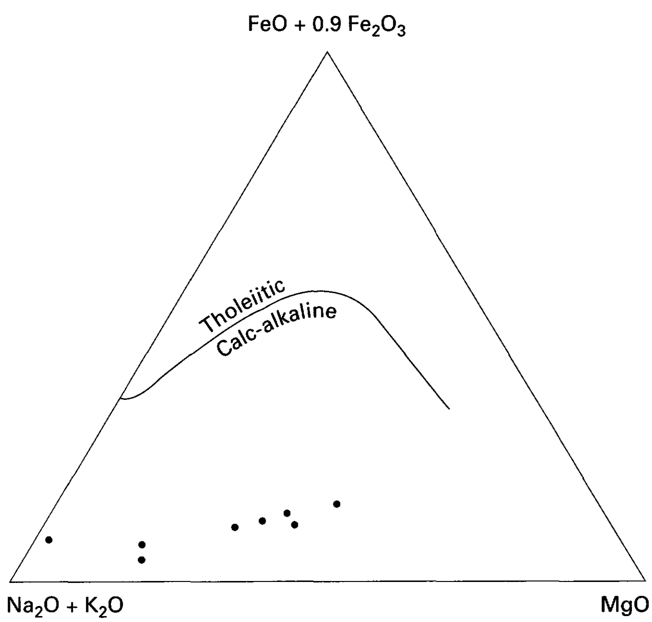

Figure 4.3. AFM diagram for samples (solid circles) from the Dalecarlia Intrusive Suite. Boundary between tholeiitic and calc-alkaline from Irvine and Baragar (1971).

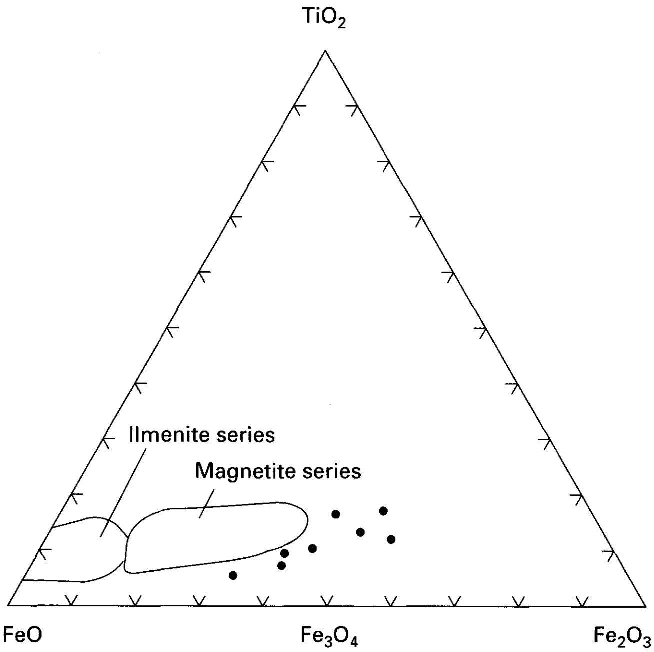

Figure 4.4. TiO_2-FeO-Fe_2O_3 (mole percent) diagram for samples (solid circles) from the Dalecarlia Intrusive Suite showing their oxidation state. Magnetite and ilmenite series fields from Jin and others (1981).

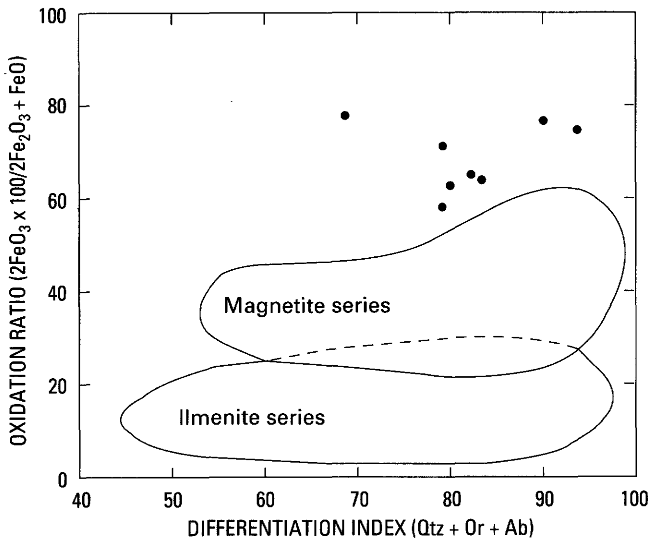

Figure 4.5. Oxidation ratio (mole percent) (Chinner, 1960) versus differentiation index (Thornton and Tuttle, 1960) of samples (solid circles) from the Dalecarlia Intrusive Suite. Magnetite and ilmenite series fields from Jin and others (1981).

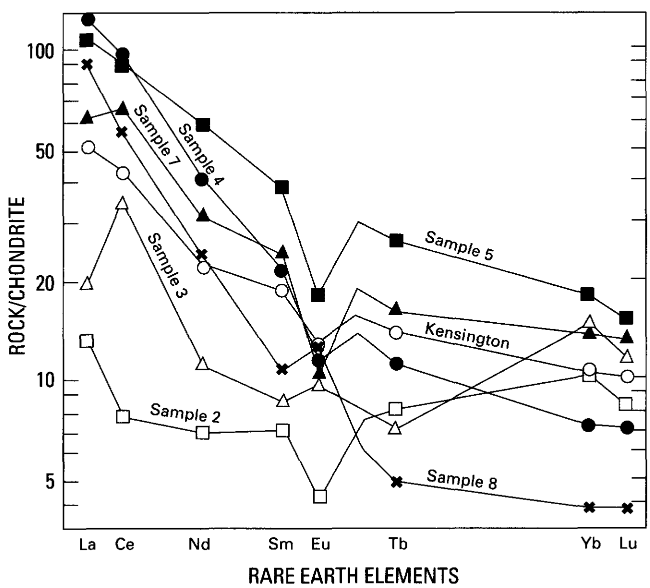

Figure 4.6. Chondrite-normalized plots of samples from the Dalecarlia Intrusive Suite.

Leucocratic muscovite-biotite monzogranite (fig. 4.6, sample 4) has a REE pattern similar to those of the biotite monzogranites, but those of the trondhjemite (fig. 4.6, samples 2 and 3) differ. The trondhjemites have relatively flat patterns and are enriched in HREE. Sample 3 is enriched in Ce and has a weak positive Eu anomaly, whereas sample 2 has a strong negative Eu anomaly, which is not characteristic of trondhjemites.

These data suggest that the monzogranite and trondhjemite may have had different sources. The peraluminous monzogranite has the characteristics of an S-type granitoid produced from the melting of a metasedimentary source (Chappell and White, 1974). We suggest that the trondhjemite may have been produced by the partial melting of I-type tonalites (Chappell and White, 1974) of the Georgetown Intrusive Suite in the manner described by Hamilton (1989). Such a process has been documented in the New Jersey Highlands by Drake (1969, 1984) and Puffer and Volkert (1991) and particularly by Size (1985) in the southern Appalachians. The low content of ferromagnesian elements in the trondhjemite is compatible with the concept that it is a leucocratic melt from old tonalite. The spatial relations of the two rock types described above supports the idea of two separate magmas and that the later trondhjemite filled open space in the monzogranite.

CLARENDON GRANITE (HERE NAMED)

The name Clarendon Granite was informally used by Huffman (1975) for monzogranite that intrudes the Sykesville Formation in the Clarendon area, Arlington County, Va. (pl. 4.1). In addition to the Clarendon locality, the unit was mapped at two places in the Falls Church quadrangle (pl. 4.1). The intrusive relations are obvious because the Clarendon contains xenoliths of Sykesville (Huffman, 1975, fig. 34). Johnston (1964) mapped other small bodies of granite within the Sykesville Formation in Fairfax County, Va. None of these could be found during the present study, but they may well be Clarendon Granite.

Currently, the Clarendon Granite is exposed only in saprolite, but Huffman (1975) describes the unit from drill core taken at the Clarendon Metro Station. This sample contains 40 percent quartz, 15.5 percent oligoclase, 13.5 percent potassic feldspar, 17.7 percent muscovite, 9 percent biotite, 1.2 percent epidote, and much less of accessory minerals. No chemical data are available. The rock obviously has been metamorphosed. Johnston's (1964) samples collected from what is now the CIA compound (the northern body on pl. 4.1) are identical to the sample described by Huffman. The unit is considered to be Early Ordovician in age.

UNDIFFERENTIATED LEUCOCRATIC GRANITOIDS

Small bodies of leucocratic granitoids are widespread in the Washington West 7.5-minute quadrangle (Fleming and others, 1994). Most of these bodies have a fine- to medium-grained aplitic texture and are composed largely of quartz, perthitic microcline, oligoclase, and muscovite. Some bodies are clearly associated with rocks of either the Georgetown Intrusive Suite or the Kensington Tonalite. Others, such as the two bodies shown on plate 4.1, have no clear relation to any of the other intrusive rocks. No chemistry is available for these rocks. They are considered to be Early Ordovician in age.

TECTONIC ENVIRONMENT

Trace element discrimination diagrams have been used for some time to attempt to fingerprint the tectonic setting of mafic igneous rocks. More recently Pearce and others (1984) extended this technique to granitoid rocks. There are problems with these techniques, but they appear to give consistent results for the data considered herein. These data apply only to rocks of the Dalecarlia Intrusive Suite as there are no chemical analyses of Clarendon Granite or of undifferentiated leucocratic granitoids.

All samples plot in the volcanic arc granite field on the Rb-(Yb+Ta) diagram (fig. 4.7) and the Rb-(Y+Nb) diagram (fig. 4.8). All but one sample plot in the volcanic arc granite field on the Ta-Yb diagram (fig. 4.9), and all samples plot in the combined volcanic-arc, syncollision granite field on the Nb-Y diagram (fig. 4.10). Taken at face value, these diagrams suggest that rocks of the Dalecarlia Intrusive Suite are volcanic arc granitoids, which, as used here, include granitoids generated from a calc-alkaline arc, whether oceanic or continental. These rocks most likely stemmed

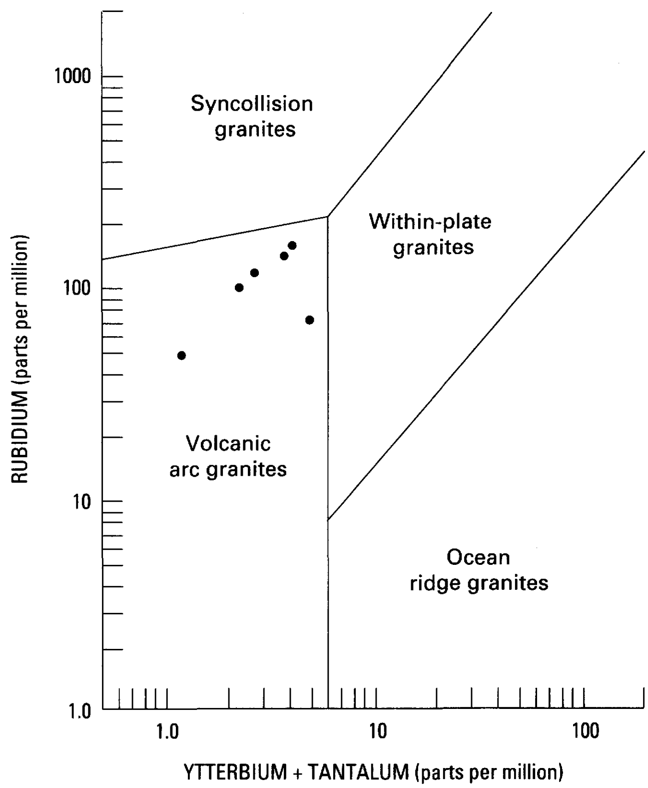

Figure 4.7. Rb-(Yb+Ta) discriminant diagram (Pearce and others, 1984) for samples (solid circles) from the Dalecarlia Intrusive Suite.

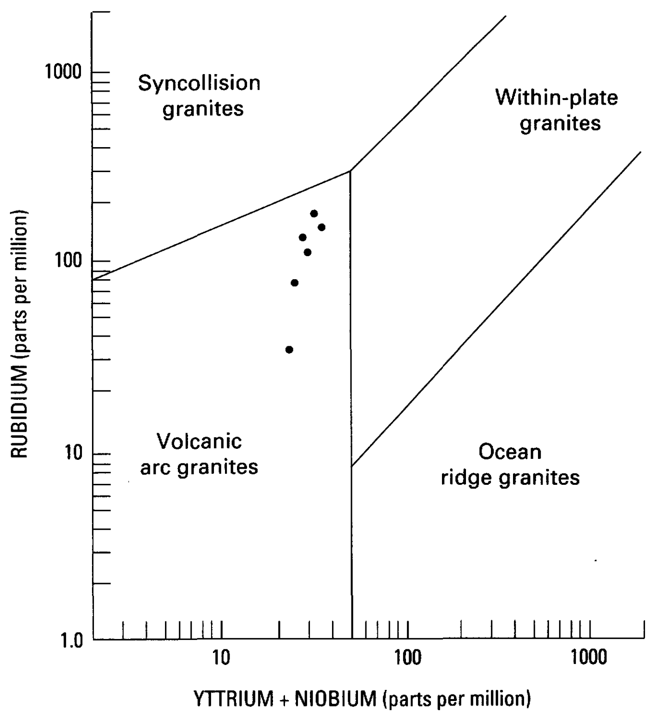

Figure 4.8. Rb-(Y+Nb) discriminant diagram (Pearce and others, 1984) for samples (solid circles) from the Dalecarlia Intrusive Suite.