Geology, Geochemistry, and Mineral Resource Assessment of the Big Branch and Peru Peak Wildernesses and the Wilder Mountain Roadless Area, Rutland and Bennington Counties, Vermont

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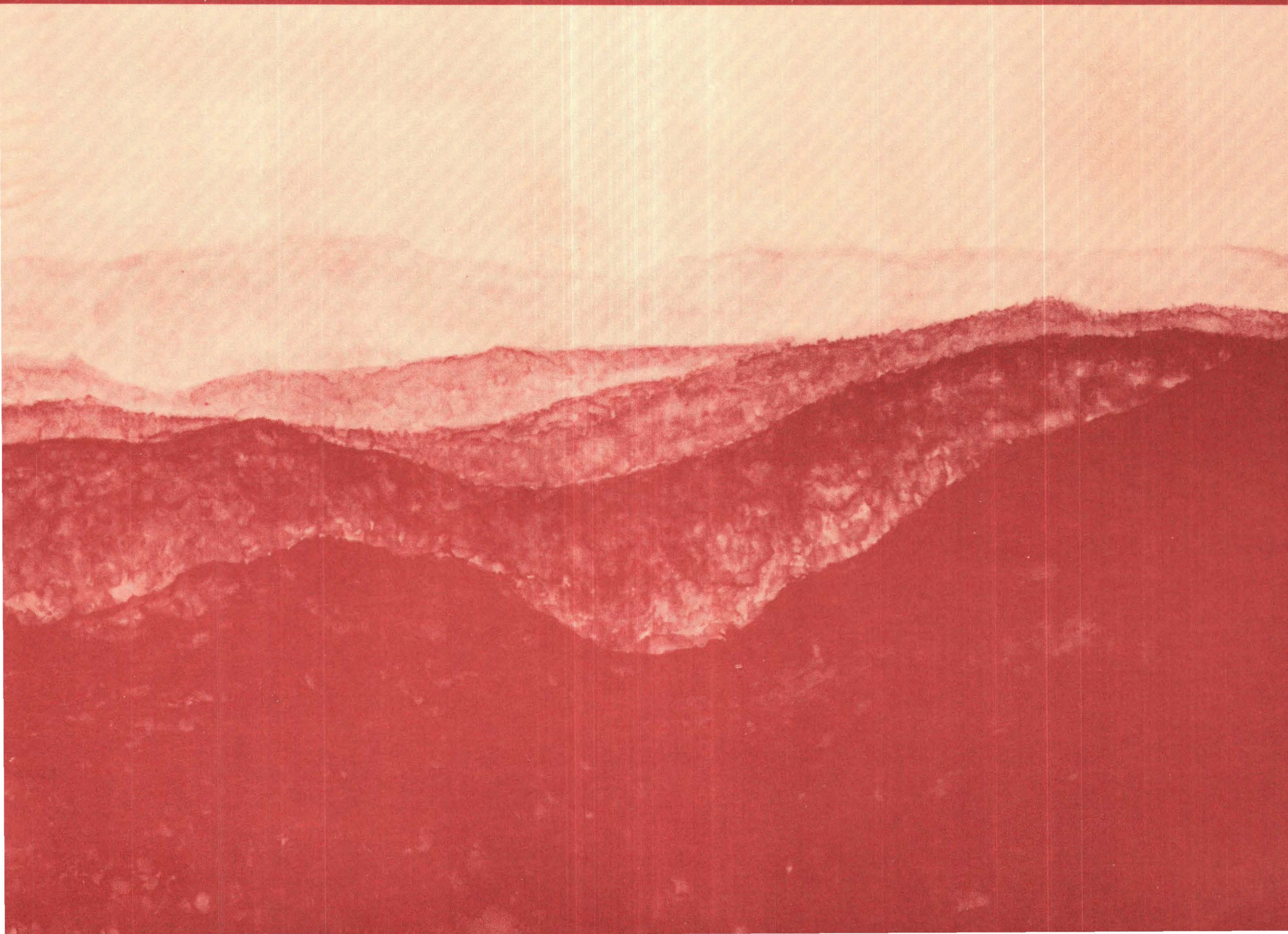

Geology, Geochemistry, and Mineral Resource Assessment of the Big Branch and Peru Peak Wildernesses and the Wilder Mountain Roadless Area, Rutland and Bennington Counties, Vermont

By JOHN D. PEPER and ELIZABETH A. DOWNIE

As assessment of the mineral resources and mineral resource potential based on geologic mapping, a geochemical survey, and consideration of the derived data in the regional context of metallogeny and appropriate ore deposit models

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Studies Related to Wilderness

The Wilderness Act (Public Law 88–577, September 3, 1964) and related acts require the U.S. Geological Survey and the U.S. Bureau of Mines to survey certain areas on Federal lands to determine the mineral values, if any, that may be present. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a geologic, geochemical, and mineral resource survey of the Big Branch and Peru Peak Wildernesses and the Wilder Mountain Roadless Area in Vermont. The Wilder Mountain Roadless Area, and the former Griffith Lake Roadless Area to the south, were classified as non-Wilderness during the Second Roadless Area Review and Evaluation (RARE II) conducted by the U.S. Forest Service, January 1979. Land in the Wilder Mountain Roadless Area was included in the area designated the White Rocks National Recreation Area by Congress (Public Law 98–322, June 19, 1984). This same law designated the Big Branch and Peru Peak Wildernesses, formed mostly from land earlier classified as the Griffith Lake Roadless Area.

CONTENTS

PLATES

[Plates are in pocket]

FIGURES

Geology, Geochemistry, and Mineral Resource Assessment of the Big Branch and Peru Peak Wildernesses and the Wilder Mountain Roadless Area, Rutland and Bennington Counties, Vermont

By John D. Peper *and* Elizabeth A. Downie

SUMMARY

The Big Branch and Peru Peak Wildernesses and the nearby Wilder Mountain Roadless Area are in the White Rocks National Recreation Area in the Green Mountain National Forest, east of the town of Danby, Vt. Strongly metamorphosed, but retrograded and polydeformed gneiss, schist, thick quartzite, and lesser amounts of marble of the Grenville (1.1 Ga (billion years)) Mount Holly Complex make up the eastern and central parts of the study areas. The outcrop patterns of map units of the Mount Holly Complex rock units reflect an early phase of isoclinal folding that preceded deposition of the Late Precambrian and Early Cambrian Dalton Formation and the Early Cambrian Cheshire Quartzite. These younger units, in upright folds, form ridges at the western margins of the study areas. Surficial deposits include a widespread blanket of glacial till, deposits of sand and gravel in kames, kame terraces, and kame deltas, and organic-rich deposits in swamps. Geologic considerations and geochemical sampling suggest little or no potential for mineral resources other than rough stone, some permeable fill, and some organic-rich materials. Marbles are impure and thin. The potential for uranium and thorium in small segregation deposits, and for lead-zinc in sandstone deposits, is believed to be low; no potential for other metals is recognized. The potential for oil and gas at depth is unknown, but is believed to be low.

Character and Setting

The Big Branch Wilderness, the Peru Peak Wilderness just to the east, and the Wilder Mountain Roadless Area just to the north make up most of the steep, west-facing slope east of the Vermont towns of South Wallingford and Danby, as well as the rugged upland north and south of U.S. Department of Agriculture (USDA) Forest Service Route 10 (road east of Mount Tabor Village, east of Danby (pl. 1, fig. 1)). The Big Branch Wilderness (pl. 1, fig. 1) encompasses about 6,720 acres, the Peru Peak Wilderness about 6,320 acres, and the Wilder Mountain Roadless Area more than 7,000 acres. The study areas include many craggy, scenic peaks near 3,000 ft (feet) in elevation: Mount Tabor, and Peru and Styles Peaks, in the southeast; and Wilder Mountain, Homer Stone Mountain, and Green Mountain in the north. Grenville-age rocks in the Green Mountain core include polydeformed and multiply metamorphosed units of gneiss, schist, quartzite, granite gneiss, and calc-silicate gneiss and marble. Mostly greenschist-grade metasedimentary rocks of the Dalton Formation (phyllite, arkosic metasandstone, and some basal quartz-pebble and polymict conglomerate) overlie the Grenvillian rocks with pronounced angular unconformity. The Dalton, and the Early Cambrian Cheshire Quartzite (quartzite, muscovite-quartz schist, feldspathic quartzite), in tight upright folds of complex internal structure, form the steep slope at the western perimeters of the Big Branch Wilderness and Wilder Mountain Roadless Area. Most bedrock exposures are reached by mountain trail in rugged terrane. Rock forms the higher ridges; glacial till covers most lower areas and slopes. Sand and gravel are present only sparsely in widely scattered kame terrace deposits or thin terraces perched above streambeds. Stream courses are steep, and streams flow mostly over till near bedrock.

Mineral Resource Assessment

The U.S. Geological Survey (USGS) carried out geologic studies and made a geochemical survey to evaluate the potential resources of the study areas, and to look for geochemical halos or anomalies that might indicate the presence of important mineral deposits on the surface or at depth.

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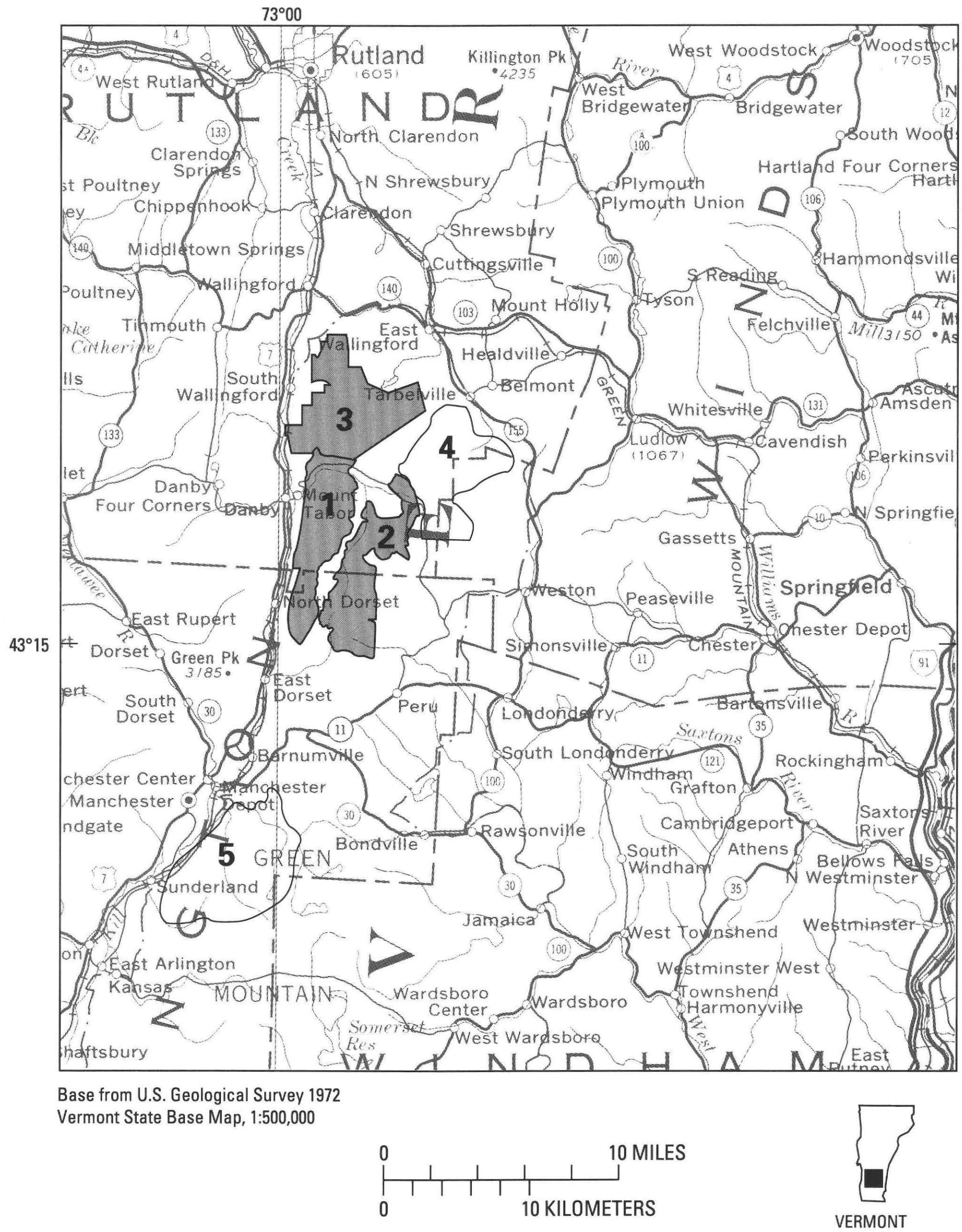


Base from U.S. Geological Survey 1972
Vermont State Base Map, 1:500,000

EXPLANATION

Study area

3 **Area name—1**, Big Branch Wilderness; **2**, Peru Peak Wilderness; **3**, Wilder Mountain Roadless Area (09082); **4**, Devils Den Roadless Area (09083); **5**, Lye Brook Wilderness (U.S. Forest Service identification number in parentheses)

Figure 1. Index map showing locations of wildernesses and roadless area in south-central Vermont.

The Big Branch and Peru Peak Wildernesses and the Wilder Mountain Roadless Area contain the following identified commodities: rough stone, minor sand and gravel, sandy till, and organic-rich muck and peat. Some quartzites, quarried and crushed, might be a suitable source of high-silica rock. Sparsely distributed dolomitic marble is present in thin beds but is impure and typically is not exposed. Although these materials are considered resources, the difficulty of reaching them over large parts of the study areas, and their low economic value, render them more or less unprofitable at this time.

Metals specifically looked for and discussed in the regional geologic context of the study areas were gold, lead, tin, zinc, copper, uranium, and thorium. The potential for deposits of uranium and thorium, and for pegmatite minerals, in the basement rocks is considered low. The potential for lead and some zinc, in sandstone-lead deposits in the clastic cover-rocks, also is considered low. There is no potential for gold, copper, or other metals based on existing data. The potential for oil and gas at depth is unknown, but is believed to be low, by analogy with the potential determined for the southern Blue Ridge province.

INTRODUCTION

Location, Access, and Physiography

The Big Branch and Peru Peak Wildernesses, and the Wilder Mountain Roadless Area (fig. 1, pl. 1), are partly adjacent to one another in the Green Mountain National Forest east of Danby in south-central Vermont. The Big Branch Wilderness, an elongate rectangular area 1–2 mi (miles) wide and 8 mi long, spans the Rutland and Bennington County line. The northern part of the wilderness is in Mount Tabor township, the southeastern part is in Peru township, and the southwestern part is in northeastern Dorset township. The Peru Peak Wilderness is a wider and somewhat longer rectangular block of land, about 10 mi by 4 mi, just east of the Big Branch Wilderness, in the townships of Peru and Mount Tabor. The Wilder Mountain Roadless Area is an irregularly shaped, 4.5-mi by 6-mi area in the form of a flattened "V." It lies north of the two wildernesses in the northern part of Mount Tabor township and the south-central part of Wallingford township.

The Big Branch Wilderness (pl. 1) encompasses about 6,720 acres. It includes most of a north-south elongate, 1,200- to 2,000-ft-high escarpment on the west, as well as four prominent peaks and some tableland just east of the escarpment. The western edge of the wilderness lies about 0.5 to 1 mi east of Vermont Route 7, east of the village of Danby, Vt., and northeast of the village of East Dorset, Vt. Access from the west is by the Lake Trail, which leads steeply up McGinn Brook, and then continues eastward toward Griffin Lake or climbs northward to scenic Baker Peak (fig. 2). Access from the north is by Long Trail (pl. 1, Appalachian Trail), which descends southward from the road east of Mount Tabor Village (Forest Service Route 10). Forest Service Route 30 leads southwestward from Forest Service Route 10 and provides added access to both the Appalachian Trail and to hiking trails along Forest Service Corridor 7. Corridor 7, which extends from just northeast of Mt. Tabor, northward through Long Hole, and along Lake Brook, (pl. 1), acts as a transportation easement between the wildernesses. From the northwestern part of the village of Peru, Mad Tom Notch Road crests the steep ridge and, descending, forks right and winds northwestward to Forest Service Corridor 7.

The highest elevations in the Big Branch Wilderness are Mount Tabor (3,043 ft) in the south, and South Buckball Peak (2,839 ft) and Baker Peak (just over 2,850 ft) in the north. The lowest elevations are about 900 ft near the base of the west-facing escarpment south of the village of Mount Tabor. Most tableland areas are openly wooded. The craggy higher ridges and peaks are largely covered by dense thickets of scrubby spruce, and many of the lower areas between crags contain numerous small bogs. The wilderness is drained eastward and northward via Lake Brook to the westward-flowing Big Branch Brook. To the west, a few established streams flow into McGinn Brook; otherwise, in wet weather, many small streams scamper randomly down the steep west-facing escarpment. In a small area in the southernmost part of the wilderness, a few small streams head south to flow down Mad Tom Brook.

The Peru Peak Wilderness (pl. 1) encompasses about 6,320 acres, most of them on the high ground between Forest Service Corridor 7, on the west, and Forest Service Route 22 north of the Hapgood Pond Camp and Picnic Grounds, on the southeast. An additional part of the wilderness is the high ground south of Forest Service Route 30, on the north, and west of Forest Service Route 10, on the east. The wilderness includes Pete Parent Peak and Big and Little Mud Ponds in the northeast, and a scenic part of the Appalachian Trail (fig. 3, Staples Trail on pl. 1) across Peru and Styles Peaks in the southernmost part of the wilderness. No maintained trails traverse the steeper eastern side of this wilderness. Access from the north and south is essentially similar to that for the Big Branch Wilderness. Peru Peak is the high point in the Peru Peak Wilderness (3,429 ft). Styles Peak to the south is somewhat lower, and Pete Parent Peak to the northeast is several hundred feet lower. The lowest point in the wilderness, about 1,900 ft above sea level, lies along its northern edge. Most of the wilderness is drained northward and westward to Lake Brook by streams such as Three Shanties Brook. Drainage to the east is by many steep streams that flow into Griffith Brook, Jones Brook, Styles Brook, and other tributaries to south-flowing streams that are about 1 or 2 mi to the east.

The Wilder Mountain Roadless Area (Forest Service Area 09082) encompasses more than 7,000 acres of mostly high ground south of White Rocks and Wallingford Pond,

Figure 2. Baker Peak. View, about N. 22° W., shows blocks of coarsely recrystallized vitreous quartzite of the Mount Holly Complex (foreground, lower right), a long spur of an unnamed ridge west of Buckball Peak that extends down to Big Branch (near-midground, right), and the long crest of Green Mountain (near-midground, right-center). Village of Danby, Vt., valley along Otter Creek (Vermont Valley), and Vermont State Highway Route 7 are in near-midground, left and left-center; ridge west of Danby is in far-midground. High Taconic Mountains are on the horizon. Long axis of the large block of quartzite is about 3 feet. Site of photograph shown on plate 1. Photograph courtesy of R. Lopez, U.S. Geological Survey.

in the south-central part of Wallingford township and in the north-central part of Mount Tabor township, north of Forest Service Route 10. The area includes, on the west, the scenic and steep-sloped Green Mountain (fig. 2), the ridges south of White Rocks and west of Little Rock Pond (fig. 8), and Homer Stone Mountain. To the east are Wilder Mountain and part of Willard Mountain.

The highest point in the Wilder Mountain Roadless Area is the crest of Wilder Mountain (2,784 ft). Willard Mountain to the east is nearly as high. The lowest points (along the western perimeter at about 1,000 ft above sea level) are part way up the steep slope northeast and southeast of the town of South Wallingford. Most slopes are openly wooded, but locally the slopes are crowded with scattered patches of dense spruce. Numerous small bogs and some larger swamps are present in the basinal area of the gentle slope that extends eastward from the uppermost reaches of Big Black Brook. Some swamps dot the valley extending southwestward for about a mile from Fifield Pond.

The roadless area is reached from the west by the Homer Stone Trail, which ascends the brook of the same name from South Wallingford. From the south, several hiking trails reach the interior of the area from points along Forest Service Route 10. These include, from west to east, (1) the Green Mountain Trail, which wends southwestward from the Big Branch Picnic Grounds, then north along Green Mountain, (2) the Appalachian Trail, which snakes along Big Black Brook northward from the parking lot, and (3) Forest Service Route 60, which heads northeastward, from about 1.5 mi east of the parking lot on Route 10, along Corridor 7 trails to the Fifield Pond area. From the north, the roadless area is reached by a trail wandering southward from the bend in Forest Service Route 20 west of Wallingford Pond, or by the Appalachian Trail, which extends southward from White Rocks.

The roadless area spans a tripartition of stream drainage. The northern part of the area is drained mostly westward by Homer Stone Brook. A northeasternmost fraction of the area drains northwestward into Wallingford Pond. Central and southern parts are drained southwestward by Big Black Brook and Little Black Brook. Numerous small, steep, intermittent streams scamper down the broad

Figure 3. Styles Peak and Peru Peak, from left to right on horizon; the eastern perimeter of the Peru Peak Wilderness is in the midground. View is west-southwest from 2,300-foot elevation on an unnamed spur southeast of Pete Parent Peak at the boundary of the Peru Peak Wilderness. Peaks are about 1.8 miles apart. Site of photograph shown on plate 1.

west-facing slopes south of White Rocks and across Green Mountain, flowing directly into Otter Creek.

Regional Geologic Setting and Previous Work

The wilderness and roadless study areas lie on the western flank of the Green Mountain anticlinorium (anticline of Whittle, 1894a, who credits Adams (C.B. Adams, a director of the Vermont Geological Survey and professor at Middlebury College) and Hitchcock (Edward Hitchcock, professor, Amherst College) for knowledge of the structure as early as 1846–47). The anticlinorium is a broadly westward overturned, folded massif of basement gneiss and schist of Precambrian age (Thompson, 1972). The massif extends from near the Massachusetts-Vermont border northward through southern and central Vermont to northeast of Rutland, Vt. The metasedimentary rocks of the basement complex are probably correlative with the Grenville-aged (Middle Proterozoic) gneisses and schists of the Adirondack Mountains. They were metamorphosed to upper amphibolite and granulite facies before the deposition of Late Proterozoic rift-facies clastic rocks along the axis of the Appalachian orogen (Williams, 1978). Stanley and Ratcliffe (1985), as evidence of the Middle Proterozoic age, remarked on the ubiquitous presence within the metamorphosed basement gneisses of probably intrusive granitic gneisses similar to the Tyringham Gneiss or Stamford Granite Gneiss. The intrusive gneisses in the Berkshire massif to the south were dated radiometrically at about 1 Ga by Zartman (Ratcliffe and Zartman, 1976). Green Mountain gneisses were generally assigned to the Mount Holly Complex (Doll and others, 1961; Osberg, 1952; earlier the Mount Holly series of Whittle, 1894b).

The basement rocks are overlain by a lithologically complex series of Late Proterozoic and Early Cambrian rocks of contrasting depositional facies. Along the western flank of the massif the sequence includes weakly metamorphosed graywacke, arkose, micaceous quartzite, minor polymict pebble- and boulder-conglomerate, and pink marble of the Late Proterozoic and Early Cambrian Dalton Formation. The lower part of the sequence was called Nickwaket Graywacke, and was combined with Cheshire

Quartzite on an earlier geologic map (Thompson, 1959). The Dalton is overlain by quartzite, micaceous quartzite, minor quartz-pebble conglomerate, and dark phyllite of the Cheshire Quartzite of Early Cambrian (Ollenelus) age (Doll and others, 1961). The Cheshire Quartzite is overlain by the Early Cambrian Dunham Dolomite of Doll and others (1961) west of the study areas (mapped as the Rutland Dolomite by Thompson, 1972).

Geologic mapping and studies in and about the wildernesses and roadless area have been conducted since before the turn of the last century. Early on, T.N. Dale (1894) studied the geologic structure of the Pine Hill-Danby ridge west of Otter Creek Valley. His geologic map depicts the lithology and structure mostly west of the study areas, but includes a small segment along McGinn Brook in the Big Branch Wilderness. Dale (1915) later described marbles east of the area. J.B. Thompson, Jr., studied the stratigraphy and structure of the Vermont Valley (Thompson, 1959) and did reconnaissance mapping for the 1:250,000-scale Centennial Geologic Map of Vermont (Doll and others, 1961). In the decade or so of mapping preceding the State map, J.P. Osberg (1952), working at the northern end of the anticlinorium in the Rochester and East Middlebury area, worked out the detailed stratigraphy of dissimilar eastern and western sequences of cover rocks. Studies by W.F. Brace (1953) in the Rutland area, and by J.W. Skehan (1961) in the Wilmington and Woodford areas, emphasized the character of the separate sequences and further defined a deformation history for the area, as documented in the complexly developed sequence of minor structures. More recently, Thompson investigated the complex facies relations and their correlations in the lower Paleozoic cover seqence of rocks flanking the Green Mountains in south-central Vermont (Thompson, 1972) and, with others, described their metamorphism and tectonic history (Ando and others, 1984; Karabinos and Thompson, 1984; Downie and others, 1986). Elizabeth A. Downie mapped and studied the stratigraphy, metamorphism, and deformation of the basement rocks in the Wallingford, Vt., 15-minute quadrangle. Her stratigraphic units within the Mount Holly Complex are shown on plate 1. With others (Downie and others, 1986), she noted that the high-grade Precambrian basement rocks initially were remetamorphosed to staurolite-kyanite grade. This was followed by ductile recumbent folding and thrust faulting of deeply buried basement and cover rocks during Early Paleozoic time. A later Paleozoic (Taconian or Acadian?) greenschist-facies metamorphism (chlorite, epidote-actinolite) accompanied the generation of crenulation and fracture cleavage during a phase of mostly upright folding after the rocks had been transported to shallower crustal levels. Most recently, Paul Karabinos and John N. Aleinikoff (Karabinos and Aleinikoff, 1988) identified tabular bodies of microcline- and muscovite-bearing augen gneiss near the northern end of the Green Mountain massif which they dated at about 1,120 Ma (million years), and obtained a date of about 960 Ma for the Stamford Gneiss near the southern margin of the Green Mountain massif. In addition, recent work has identified an older sequence of metatrondhjemite, dated at about 1,300–1,500 Ma (Aleinikoff and others, 1990), that may form a basement for younger metasedimentary rocks in the massif sequence (Ratcliffe and others, 1988; Karabinos and Aleinikoff, 1990).

Surficial deposits in the study areas have been portrayed on a regional-scale map (1:250,000) by D.P. Stewart and Paul MacClintock (1969). These authors have also described the general glacial and postglacial framework of the region.

Several mineral resource studies have recently been done in the Green Mountain region. Slack and Sabin (1983) described the mineral potential, and Slack and others (1985) described the geochemistry of the adjacent Devils Den Roadless Area (fig. 1). Sabin and Jones (1981) and Slack and Sabin (1983) reported on the mineral resources of the same area. Ayuso and Robinson (1984) summarized the geology of the Lye Brook Wilderness, southwest of the Big Branch Wilderness (fig. 1); in addition, Ayuso and Harrison (1983) evaluated the mineral resource potential, Ayuso and Day (1985) reported on a geochemical survey, and Harrison (1981) described the mineral resources. Slack and others (1988) described the geology and geochemistry of the Bristol Cliffs Wilderness, which is about 50 mi north of the study areas of this report and contains some similar rock units. Slack and Mory (1983) assessed the mineral resources of the Bristol Cliffs Wilderness. Watts (1990) described the results of a regional geochemical survey, based mainly on heavy-mineral concentrates, that included data for the general region in and surrounding the study areas (data given in Day and others, 1986). The studies of specific metal deposits, occurrences, and paleogeochemical systems in nearby areas (Slack, in press) provided invaluable aids to the targeting of specific aspects of the geology of the areas of this report in the search for mineral deposit potential.

Present Work and Acknowledgments

J.D. Peper, assisted by E.D. Peper and C.M. Phipps, sampled rock, stream sediment, and soil, collected structural data, and did selective geologic mapping of bedrock and surficial units to amplify the detail of previous mapping in the Big Branch and Peru Peak Wildernesses in August 1984. E.A. Downie met with the senior author in the field. Her mapped Precambrian units formed the basis for the initial rock sampling scheme and interpretation. Additional reconnaissance geologic mapping in conjunction with the geochemical sampling was carried out by J.D. Peper to better define contacts and to more precisely locate and define lithologic units within the broad framework of the quarter-million-scale mapping of the bedrock and surficial maps of Doll and others (1961) and Stewart and MacClintock (1969). Peper, assisted by Dina M. Demichales and Debbie Kay, did reconnaissance mapping and sampling of parts of the Peru Peak Wilderness and the Wilder Mountain Roadless Area in September 1984. Additional geochemical sampling, specifically of some basal conglomerates of Middle and Late Proterozoic units, and two areas of granitic gneiss, was completed by J.D. Peper, assisted by Ricardo Lopez, in October 1985.

Gilpin R. Robinson, Jr., visited the authors in the field, and discussed units and the nature of the Dalton Formation-Mount Holly Complex contact. He showed the authors sulfide mineralization at Copperas Hill, and nearby Mesozoic alkalic rocks, both in the town of Cuttingsville (fig. 1). John F. Slack discussed the geology and sampling of the Devils Den Roadless Area, and Slack and Robert A. Ayuso described the nature of uranium occurrences in rocks of the Green Mountain massif. Sandra H.B. Clark discussed her sampling and studies of stratabound zinc-lead deposits of the early Paleozoic shelf sequence of the adjacent Vermont Valley.

Enlargements of the Wallingford 15-minute quadrangle, modified for the USDA Forest Service, with overprints of roads and trails at 1:24,000 scale, were used as topographic bases for the field compilation of data. These quadrangles, the Wallingford SW and the Wallingford NW, are available for purchase at Forest Supervisors Headquarters, Green Mountain National Forest, Federal Building, 1501 West Street, Rutland, VT, 05701.

Samples collected for chemical analysis included 189 rocks, 24 soils, and 86 fine-grained stream sediments. Semiquantitative spectrographic analyses of all samples were done in USGS laboratories, Denver, Colo., by D.E. Detra. In addition, each sample was analyzed quantitatively by atomic-absorption techniques for gold and zinc, in USGS laboratories in Denver. Atomic-absorption analyses of initial rock and soil samples were performed by Thomas Huyck and M.A. Porkony in July 1985, and on stream-sediment samples by E.P. Welsch and D.L. Kelly in September 1985. Additional rock samples were analyzed by L.S. Laudon, and by Laudon and R.J. Fairfield, in February 1986. Previously reported values for gold in samples from the study areas of this report, and in samples from the Devils Den Roadless Area collected by J.F. Slack, were reanalyzed in May 1986. Complete analytical results and descriptions of the samples are given in Detra and others (1990). The analyses are grouped in tables 1–7 (on pl. 4) in this report.

Petrologic examination of thin sections and of crushed rock and mineral fragments, as well as studies of rock slabs with a binocular microscope, augmented the outcrop and hand-sample description of rock units.

Verifications of tin anomalies in two samples of Mount Holly Complex conglomerate were checked by X-ray fluorescence analyses by J.C. Jackson in USGS laboratories in Reston, Va.

GEOLOGY

Distribution, Stratigraphy, and Lithology of Basement Rocks of the Mount Holly Complex

The five informal rock units of the Mount Holly Complex mapped on plate 1 are, from oldest to youngest, hornblende gneiss, schist (enclosing lenses of calc-silicate rock), granite gneiss, and vitreous quartzite. These originally high grade rocks were remetamorphosed at middle amphibolite-facies grade and then retrograded. Staurolite, garnet, and relict kyanite occur in some schists, and chlorite and epidote of the retrograde greenschist metamorphism are abundant. Late crenulation cleavage and crinkle folds are best developed in the schist. Feldspathic rocks are coarse grained, and evidence variable deformation by the degree of development of schistosity and augen texture. In addition, many gneisses were more or less metamorphically differentiated into feldspathic and micaceous layers, probably at high grade and before the later deformation (fig. 4). The gneisses are intruded by thin sills and dikes of granite and pegmatite. The thicker quartzites have been coarsely recrystallized. In some places, thin ribbon beds of quartzite have been so strongly recrystallized and deformed as to be indistinguishable from vein quartz. Sound facing criteria such as graded bedding or cross bedding are mostly lacking in these rocks. Reconstruction of the original stratigraphic succession is therefore somewhat interpretive, as is the location of the axes of some early isoclinal folds. Both the structural reconstruction and the location are inferred together from the distribution of similar lithologies in conformity with local structural elements.

The hornblende gneiss unit crops out in a band across Styles Peak and across the western side of Peru Peak; another band forms the ridges and slopes on the eastern side of the Peru Peak Wilderness. Most of the unit is white-weathering to light-gray-weathering, medium-grained quartz-plagioclase-biotite-hornblende-(garnet) gneiss with a dark-colored mineral content of 5 to 25 percent. Most of the gneiss is banded with thinner and thicker, darker and lighter layers. Some of the layers in the gneiss are hornblende-plagioclase-(garnet) amphibolite; locally the gneiss is medium to fine grained and schistose. Coarse augen gneiss is present in some areas. The felsic gneiss is interlayered with amphibolite on a scale of 1 to 2 in (inches) on the eastern side of Styles Peak, in the valley at the upper reach of Three Shanties Brook (fig. 4), and on the low slopes east of Pete Parent Peak. Thick intervals of coarse amphibolite occur in the gneiss on the unnamed ridge northeast of Big

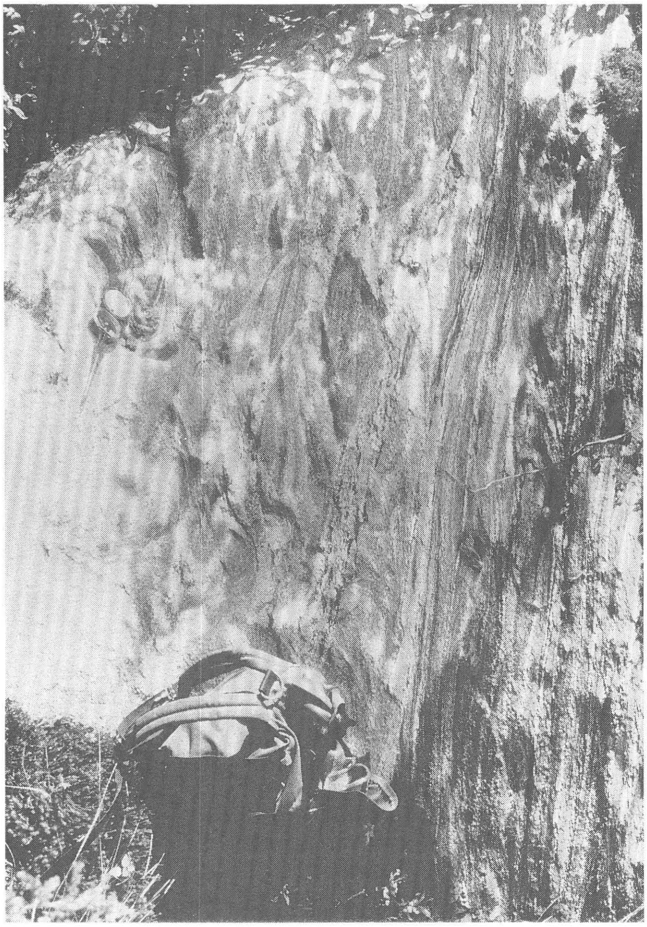


Figure 4. Mount Holly Complex hornblende gneiss, showing thinly interlayered dark- and light-colored layers. Outcrop is in the valley that forms the headwaters of Three Shanties Brook. Note thick layer of augen gneiss inclined toward pack, at a low angle to foliation and compositional layering. Gneiss layers pinch and swell about axes of early isoclinal folds in banded layers in upper left and center of photograph. Discordant, gently folded, thin band of late pegmatite cuts gneiss in lower left center of photograph. Pack is about 2 feet wide at base. Site of photograph shown on plate 1.

Mud Pond and in the valley at the upper reach of Three Shanties Brook. Finer grained, schistose amphibolite occurs on the spur southeast of Pete Parent Peak.

The schist unit is composed mostly of biotite-chlorite-muscovite schist and schistose gneiss (fig. 5), but it includes diverse rock types. It underlies much of the Wilder Mountain Roadless Area. South of the latitude of Willard Mountain, the schist unit forms wide western and narrower eastern bands. Here it lies on either side of a band of the hornblende-gneiss unit that follows the axis of an early, north-plunging antiform. The antiform has been refolded by southwest-plunging folds that cross the high ground west of Pete Parent Peak. Beds of quartzite are common in the schist unit near the contact with the quartzite unit on Buckball Peak, and on the western slope of Homer Stone Mountain. Beds of graphitic, pencil-lead-gray biotite-garnet-staurolite schist are common in the schist unit across the peak of Homer Stone Mountain, on the northern peak of Willard Mountain, and on the lower parts of the ridge south of Three Shanties Brook (fig. 6). Thin (1 ft) layers of hornblende-plagioclase amphibolite in thick (30 ft) lenses of biotite gneiss are common in the schist unit across Wilder Mountain, on the ridge east of Elbow Swamp, and on the slope northwest of Little Mud Pond (pl. 1).

The calc-silicate gneiss and impure marble unit includes gneiss, schist, quartzite, and marble that contain calc-silicate minerals. These rocks occur as lenses within the schist unit (pl. 1). Two thick lenses occur in the southern part of the study areas, one across Mount Tabor to the west of Long Hole and the other southeast of Baker Peak. These consist mostly of gray, quartzose calc-silicate granofels but include tremolite-actinolite rock and some pink marble. Farther north, two lenses are exposed in Big Branch Brook. The easternmost lens includes gray, layered calc-silicate gneiss and minor quartzite, as well as two thick pods of strongly deformed tremolite-actinolite-talc schist with enclosed pods of pink calcite marble. Thin to thick layers of white and pink calcite marble occur in gray- and brown-weathering calc-silicate gneiss in the lens to the west. The thick, folded lens in the northern part of the area through Fifield Pond includes mostly medium- to coarse-grained, light-gray-weathering plagioclase-quartz-(biotite) gneiss with green amphibole and rare diopside.

The granite gneiss unit forms a thin band below the quartzite unit in the Big Branch Wilderness (pl. 1) and occurs in two large areas in the Wilder Mountain Roadless Area. These large areas contain (1) a mass of granite gneiss, in the core of a southwest-plunging isoclinal anticline across the northwestern slope of Green Mountain, that extends in narrow bands west of the schist unit to the north and east of Little Rock Pond, and (2) a mass along the axis of an early northeast-plunging isoclinal synform between Wilder and Willard Mountains, where the gneiss has been infolded with the schist unit. The gneiss is mostly poorly exposed in the latter area. The medium-grained and schistose gneiss forms mostly low, rounded outcrops that are fairly homogeneous in composition. Distinctive aspects in the field include augen of pale-pink potassium-feldspar (0.25–0.5 in; up to 5 percent of rock) in a matrix of chiefly microcline, oligoclase, and quartz. In many outcrops a biotite pencil-lineation is intensely developed. Granite contacts are sharp and conformable with underlying quartzites and quartz-schist where exposed on the western slope of Homer Stone Mountain and on the ridge north of Little Rock Pond. The gneiss is broadly compositionally homogeneous, and may be an early conformable subporphyritic quartz-monzonite, intrusive into the basement sequence, that has been deformed and recrystallized.

The vitreous quartzite unit, with some thin quartz-pebble conglomerate at its base (fig. 7), is exposed above the schist unit across Buckball Peak. The quartzite occupies

Figure 5. Mount Holly Complex feldspathic schist in an outcrop of the schist unit (Ys) on the unnamed hill about 1 mile northeast of Little Rock Pond. Note early isoclinal fold transected by late fracture cleavage. Early isoclinal fold with asymmetric nose plunges to the left about an axis that is somewhat steeper than the long axis of the marker. Early foliation parallels compositional layering in schist, except in fold nose. Schist shows some metamorphic differentiation into lighter and darker bands, which outline the fold nose. Late fracture cleavage dips away from observer to the right. Fracture cleavage cuts early foliation outlined by thin septa of crinkled biotite in the nose, and on the limbs, of the fold. Marker is about 5 inches long. Site of photograph shown on plate 1.

the core of an isoclinal syncline, overturned to the east. Assignment of the vitreous quartzite to the Mount Holly Complex rather than to the western cover sequence in this area is somewhat problematic. The quartzite might be a Cheshire or Dalton quartzite that is repeated by a narrow, sinuous fault that would be unexposed in the area of sparse outcrop on the western slope of Buckball Peak. The quartzite unit is generally conformable with the underlying schist, however, and farther south the quartzite comformably overlies granite gneiss. Across Baker Peak (fig. 2), the quartzite unit consists of vitreous quartzite interlayered with quartz-muscovite schist. This schist is extensively cut by concordant and discordant muscovite-bearing pegmatite.

Distribution, Stratigraphy, and Lithology of Cover-Sequence Rocks

Greenschist-facies metasedimentary rocks of the western Vermont cover sequence, including the Early Cambrian Dunham Dolomite and underlying Cheshire Quartzite, and the Late Proterozoic and Early Cambrian Dalton Formation, are exposed in a series of lenses and arcuate bands (pl. 1) along and within the westernmost part of the study areas. These units occupy the cores and limbs of isoclinal and upright major folds of several generations. Late Proterozoic and Early Cambrian rocks of the eastern cover sequence are exposed to the east in the Devils Den Roadless Area (Slack and Sabin, 1983). There, greenschist-facies quartz-muscovite-paragonite-chloritoid schist of the Pinney Hollow Formation(?), as well as quartz-plagioclase-mica schist with albite porphyroblasts, and some dolomite of the Hoosac Formation, are exposed in a trident-shaped area in which the cover rocks have been complexly folded into the basement gneisses.

The Dunham Dolomite of Doll and others (1961), not exposed in the study areas, crops out in Mad Tom Brook to the southwest in East Dorset Village, 1.5 mi southwest of the Big Branch Wilderness. From these exposures and from those in the Vermont Valley, the Dunham is inferred to overlie the Cheshire Quartzite along the very westernmost margins of the study areas (see Doll and others, 1961).

The Cheshire Quartzite (figs. 8, 9), which is as much as 700–800 ft thick, forms a band from one-quarter to one mile wide in the western part of the study areas. The quartzite has been thickened in fold cores and drastically

Figure 6. Deformed and retrograded schist in an outcrop of the schist unit (Ys) of the Mount Holly Complex on the unnamed ridge south of Three Shanties Brook. Note deformed and refolded quartz-feldspar laminae in biotite-garnet schist. Feldspar rim surrounds 0.8-inch altered garnet core of mostly chlorite, below the cross fracture in right-center of the photograph. Site of photograph shown on plate 1.

Figure 7. Mount Holly Complex vitreous quartzite, showing folded bed of quartzite at the base of the unit (Yq) (above marker tip). The quartzite bed outlines a small anticline with an intensely fracture-cleaved core of schist of the underlying Mount Holly schist unit (Ys). Fracture cleavage is parallel to the marker on the outcrop face and parallel to the axial plane of the anticline. Marker is about 5 inches long. Site of photograph shown on plate 1.

thinned on the limbs of folds. Moderately to steeply dipping layers of quartzite form a steep escarpment. More gently dipping layers near fold hinges make up the ridges and crags of the high ground. The outcrop pattern of the Cheshire forms broad simple bands, but the internal structure of the unit is exceedingly complex. In numerous exposures, original bedding has been largely obscured or completely obliterated by tight buckle-folding and shearing along foliation. Locally, several generations of recrystallization and annealing of fractures have formed coarse, massive quartzite. Contacts of the Cheshire with the underlying Dalton Formation, well exposed west and east of Black Pond, are gradational over 10–30 ft. Thin-bedded, medium-grained quartzite with schist partings of the Cheshire (fig. 9) grades downsection into micaceous quartzite, arkosic metasandstone, and some phyllite of the Dalton Formation.

The Dalton Formation, possibly 100 to 200 ft thick, is mapped (pl. 1) as a narrow, sinuous, "S"-shaped band that truncates a variety of units in the underlying Mount Holly Complex. The base of the Dalton Formation is a profound unconformity, but it is difficult to locate in the field in places where distinctive Dalton lithologies such as gray quartz-granule conglomerate or polymict conglomerate (figs. 10, 11) are absent, and Dalton feldspathic sandstones and quartzites rest on Mount Holly feldspathic gneisses and quartzites. Dalton rocks, however, are generally finer grained and better layered, and lack the pods and lenses of pegmatite so characteristic of the Mount Holly feldspathic gneisses.

Structural Fabrics and Minor Folds

Rocks on the western flank of the Green Mountain anticlinorium in the Big Branch and Peru Peak Wildernesses and the Wilder Mountain Roadless Area have been affected by several episodes of deformation. Basement

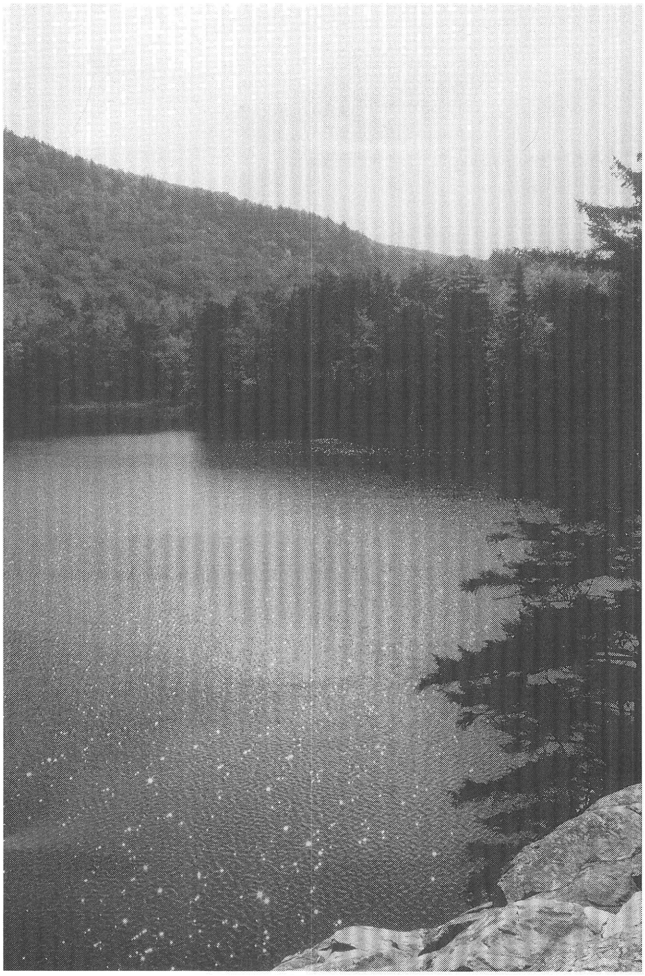


Figure 8. Little Rock Pond, in the Wilder Mountain Roadless Area. View is south-southeast toward the head of Little Black Brook (midground). The southern ridge of Homer Stone Mountain is on the horizon. Relict thick bedding(?) in mostly massive recrystallized Cheshire Quartzite (foreground, lower right) dips moderately to the west-northwest (to right in photograph). Spruce tree (right edge) is 18 feet tall. Site of photograph shown on plate 1.

units were recumbently folded into a series of tight isoclinal folds (figs. 4, 5). This early folding was concurrent with high-grade metamorphism, so that most foliation and compositional layering in the basement gneisses dip northwest, subparallel to the axial planes of the early basement folds. This deformation was followed by shearing and the development of augen gneiss in the basement units. The lenses of augen gneiss (fig. 4) are generally subparallel to foliation and compositional layering, but some cross cut the foliation at low angles. A later major deformation, accompanied by greenschist-grade metamorphism of the cover rocks and more or less retrogradation of the basement rocks (fig. 6), resulted in locally intense shearing in basement and cover rocks alike, and in the development of west-dipping slip cleavage (figs. 7, 9) parallel to the axial planes of overturned major folds. This younger folding was in large part accompanied by intrafolial buckling and shearing and the formation of numerous sympathetic drag folds at minor and meso-scales. The buckling and intrafolial and bedding-plane shearing is most obvious in large outcrops of the thicker masses of quartzite, whereas outcrops of the finer grained schistose units are marked by intense crenulation cleavage and resulting crinkle-lineation. Schist contacts with quartzite, (fig. 7) or with gneiss, commonly are intensely deformed by this folding, so that complex interdigitation of lithologies, at a small scale, occurs along the strike of the contacts in most parts of the study areas.

The statistical distributions of planar and linear features in the Big Branch and Peru Peak Wildernesses are shown in figures 12 and 13, respectively. For reference, these can be compared with the field measurements shown on the geologic map (pl. 1). Although not abundant, and distributed too widely for detailed fold analysis, the data nevertheless emphasize the intensity of the different deformations and augment description of the geologic structure. The gross structure of the wildernesses is dominated on the west by an early isoclinal syncline through quartzite of the Mount Holly Complex (Yq, pl. 1). On the east, an early isoclinal antiform trends through the western belt of Mount Holly hornblende gneiss (Yh, pl. 1). The axial traces of these early folds trend generally north to north-northeast. They are offset where they have been refolded by a series of intensely developed younger folds whose axial traces trend south-southwest through the general area around Elbow Swamp southeastward to Swale Meadow (pl. 1). The orientation of the statistically most prevalent planar features (fig. 12) seems to reflect the intensity of the late folding. Most planar features dip moderately to the northwest (9-percent contour interval), and their poles spread out in a great circle (circle I, fig. 12). A line perpendicular to the plane of the great circle I defines a theoretical fold axis (beta axis). It has a shallow plunge to the south-southwest. The other weaker concentrations of planar features (along circle II and possibly circle III) are not well understood. Those along circle II may represent a foliation of the early isoclinal folds refolded about later axes. Most lineations plunge moderately to the south-southwest (5 percent concentration, blackened area in fig. 13), reflecting the dominant southwestward plunge of major and minor late folds in the wildernesses. The lineations spread through the horizontal and into the north-northeast quadrant, suggesting some "porpoising" of the major fold axes (that is, plunging alternately to the south-southwest and north-northeast).

GEOCHEMISTRY

Geochemical Survey

The U.S. Geological Survey made a reconnaissance geochemical survey of the study areas to test for mineralized rock and to look for indistinct or unexposed mineral deposits that might be detected by associated

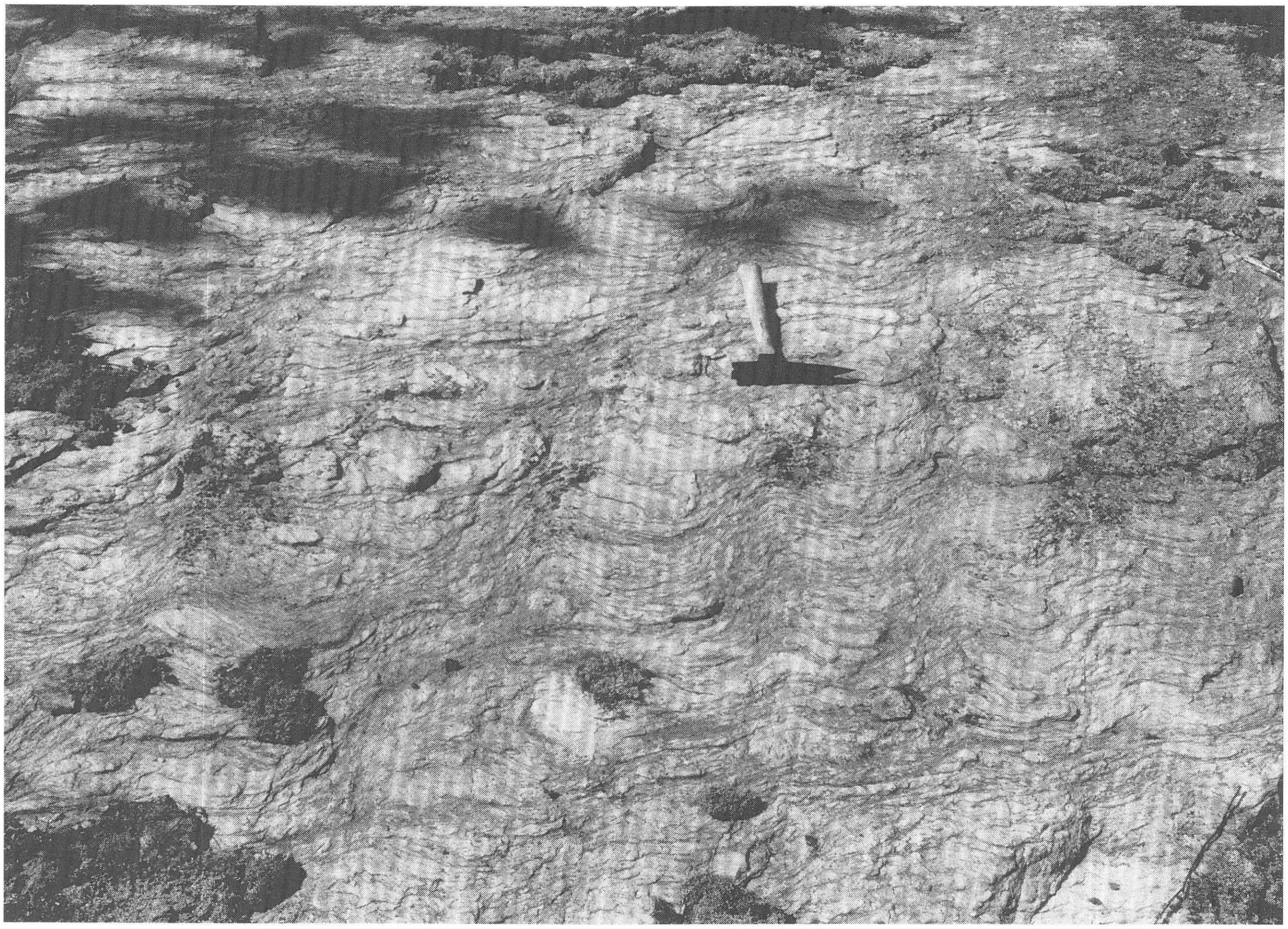


Figure 9. Cheshire Quartzite, showing interlayered quartzite and quartz-muscovite schist in an outcrop northwest of the crest of Green Mountain. Relict bedding is folded and offset along regularly spaced zones of late fracture cleavage that trend from lower right to upper left in photograph. Hammerhead is about 8 inches long. Site of photograph shown on plate 1.

chemical halos. Systematic patterns formed by the distribution of trace elements, either directly in the bedrock, dispersed in overlying soil, or dispersed as sediment within a drainage basin, were also sought.

Chemical analyses suggest that the study areas have low potential for the presence of deposits of uranium and thorium, and possibly for sandstone-lead deposits. No potential for deposits of gold or precious metals is evident. The metal contents of most rock, stream-sediment, and soil samples are near or below average crustal abundances, including rock samples from geologic horizons considered most favorable for mineralization; no significant or systematic anomalous concentrations are present in potentially economic amounts. Low concentrations of gold (0.05–0.5 ppm (parts per million)), reported initially for 27 rock samples, were not confirmed by further detailed resampling of the rock localities; splits of the original samples, when reanalyzed, were found to lack detectable amounts of gold at detection limits as low as 0.05 ppm. In addition, splits of samples containing similar low concentrations of gold from the nearby Devils Den Roadless Area (Slack and others, 1985) were reexamined and found to contain no detectable gold (D.M. Detra, pers. commun., 1986).

Sampling Procedures

The individual study areas are till covered and upland centered, with many expanses of deranged (Thornbury, 1954, p. 124 and fig. 5.14) drainage. The many small basins in the uplands are drained by intermittent streams on steep flanking slopes. Most of the small streams draining these basins and some larger streams (pl. 2) were sampled by gathering at random a bagfull (a few handfuls) of the finest material available in the stream. After removal of visible organic materials such as root, cone, and leaf fragments, the sampled material consisted mostly of silt and clay mixed with variable amounts of finely comminuted peat, muck, and forest litter. The samples were dried in the laboratory, sieved to −80 mesh (0.007 in), and then pulverized to −140 mesh (0.004 in) for analysis.

Most soil-sample sites were on till-covered flats and low mounds in areas barren of rock exposures. The soil

Figure 10. Dalton Formation quartz-pebble conglomerate on the northwestern slope of Green Mountain. Note white and light-gray subrounded clasts of mostly quartz in finer grained matrix of quartz and feldspar and massive bedding. Eyeglasses are about 5 inches wide. Site of photograph shown on plate 1.

Figure 11. Dalton Formation polymict conglomerate, showing flattening and elongation of the pebbles and cobbles (5–10:1) in the plane of the fracture cleavage. Extension fractures are developed across the long axis of a cobble of hornblende gneiss to left of hammer. Outcrop is on the unnamed ridge south of White Rocks. Hammerhead is about 8 inches wide. Site of photograph shown on plate 1.

samples (pl. 3) consisted of grab samples collected from the A2 or upper B soil zone, just below the dark, organic-rich surface soil (A1 zone). Soils were dried, sieved to −80 mesh, and then pulverized to −140 mesh for analysis.

The rock samples consisted of chips taken across a measured thickness (6 ft) of bedding or layering of relatively homogeneous rock, or of grab samples of individual veins. These samples included reasonably fresh rock, coherent and well indurated, taken from glaciated natural outcrops and more rarely from a few fresh rock surfaces along roadcuts. Rocks were crushed to about 0.25 in and pulverized to −140 mesh in a vertical grinder with ceramic plates prior to analysis.

Analytical Techniques

Each sample was analyzed semiquantitatively for 31 elements by means of a six-step direct-current arc, optical-emission spectrographic method (Grimes and Marranzino, 1968) in the USGS laboratories in Denver, Colo. In addition, most of the samples were analyzed quantitatively by atomic-absorption techniques for zinc (Ward and others, 1969) and for gold (Thompson and others, 1968). The semiquantitative spectrographic values are reported as six steps per order of magnitude (1, 0.7, 0.5, 0.3, 0.2, 0.15, or multiples of 10 of these numbers) and are the approximate midpoints of geometric brackets whose boundaries are 1.2, 0.83, 0.56, 0.38, 0.26, 0.18, 0.12, and so forth (see histograms, pl. 4, for a graphic example of boundaries). The expected precision is within one adjoining reporting interval on each side of the reported value 83 percent of the time, and within two adjoining intervals 96 percent of the time (Motooka and Grimes, 1976). References to the complete analytical data set, as well as to descriptions of the rock types sampled, are given in Detra and others (1990).

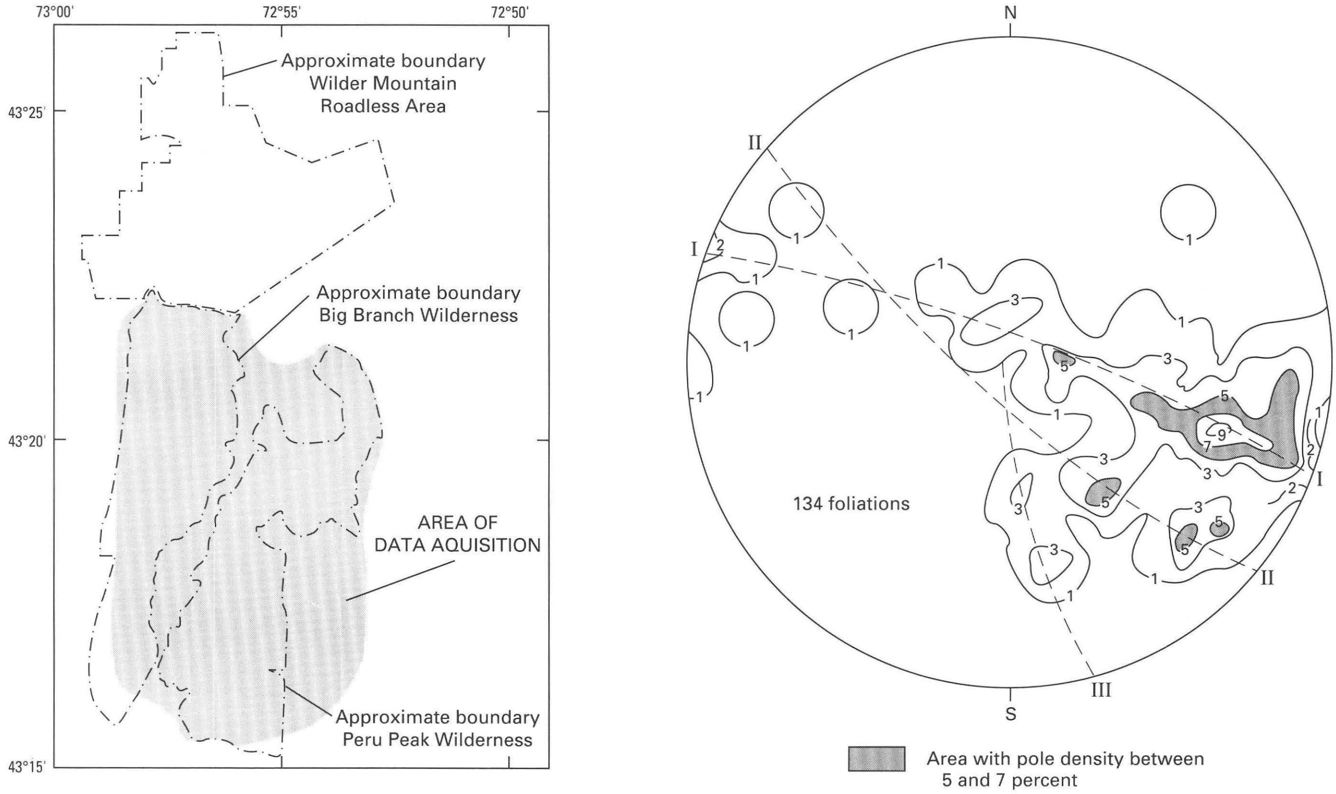


Figure 12. Planar features in the Big Branch and Peru Peak Wildernesses. Lower hemisphere equal-area stereographic projection showing the orientation of planar features (that is, foliations and compositional layers) in the southern parts of the study area. Contours show the density (number of poles per 1 percent of stereographic projection area) of poles to the planar features. Maxima and contour shape suggest that these poles lie mostly along three great circles—I, II, and III. Poles to the planes defined by these great circles (beta axes) have the following plunges: I, 6° S. 21° W.; II, 10° N. 41° E.; and III, 6° N. 84° E. (see text discussion).

Analytical Strategy

The highest values (highest concentrations of an element) were determined for each element by inspection of the distribution of elemental concentrations in the various sample media and among rock types (see histograms, pl. 4). The highest, or higher, values among high values were identified as worthy of consideration as a possible indicator of important mineralization. These values were evaluated further as to (1) geographic correspondence that might indicate areas of important mineralization, (2) association with visible sulfide mineralization, or with an obvious silicate mineral host (for example, boron in tourmaline in the rock sample), (3) permissible and possibly preferred zones of mineralization dictated by lithology and stratigraphy (conglomerates, metasandstones, unconformities, pegmatites, and so forth), and (4) gross structural features (fold cores, zones of intense foliation or well-developed cleavages that might provide pathways and traps for ore-forming fluids). The elemental values (concentrations) were sorted by rock type and (or) stratigraphic position. These are compared with values for similar rocks in nearby areas, and with values for average rocks, in tables 1–7 (on pl. 4). The average rocks are the types of rocks that were the *probable* protoliths of the metamorphic rocks with which they are compared, for example, shale with schist, sandstone with quartzite, granite gneiss with high- and low-calcium granites, and so forth. Inasmuch as these types of rock comparisons cannot be made to be exact because of uncertainties and some degree of speculation concerning the metamorphic rock parentage of the rock samples, additional average rocks (that is, rocks that *may have been* protoliths of the metamorphic rock, as well as rocks that *may have contributed significant components* to the metaclastic rocks) are included for comparison where appropriate.

Discussion

The analytical data do not verify the existence of areas of potential metallic resources. The median values for most elements in the various rock samples (tables 1–7 on pl. 4) are comparable to the median values for similar rock types, in similar stratigraphic position, in nearby areas, or are comparable to the median values for average crustal rocks. The distributions in the various sample media of elements commonly associated with massive sulfide and other stratabound mineral deposits, including boron,

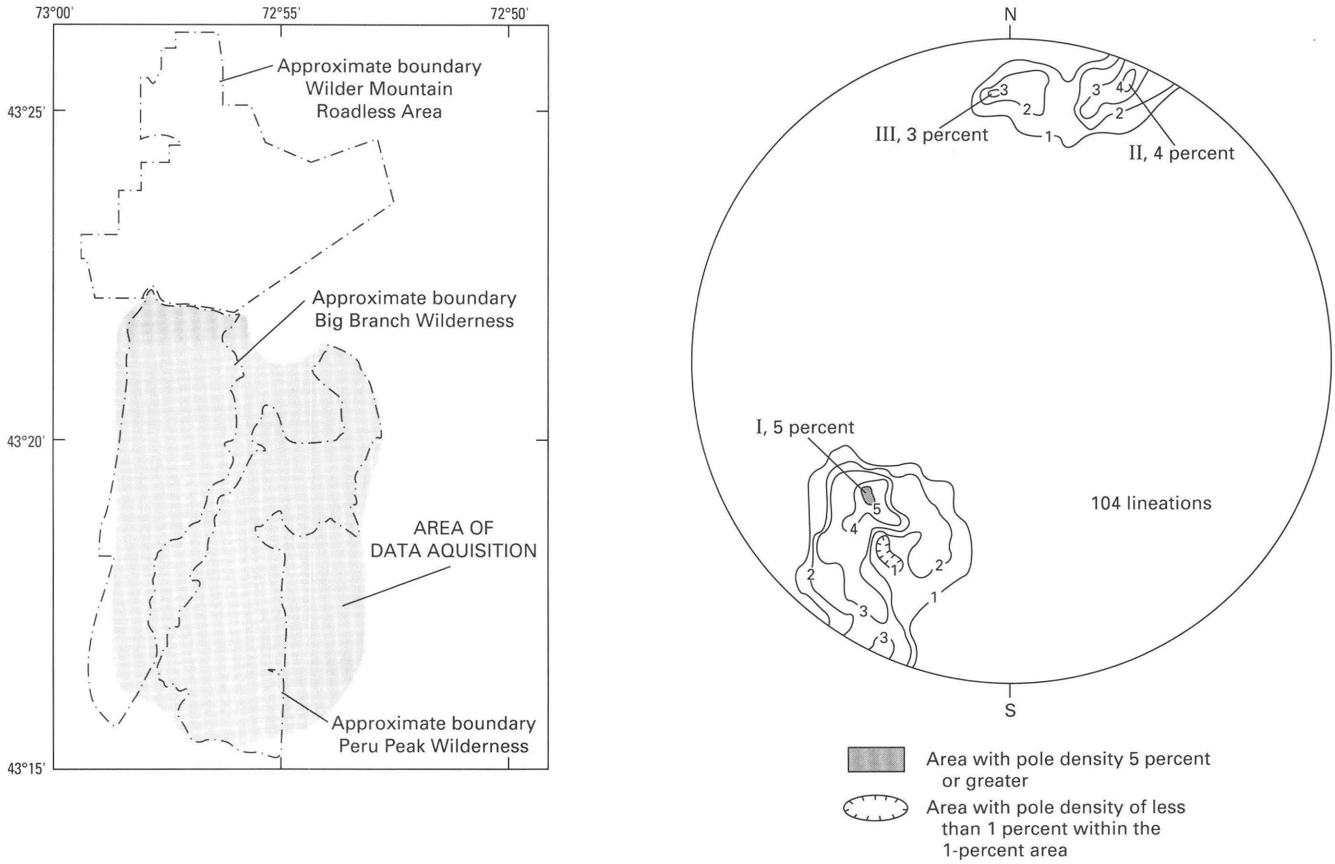


Figure 13. Lineations in Big Branch and Peru Peak Wildernesses. Lower hemisphere equal-area stereographic projection showing the orientation of mineral lineations and minor fold axes in the southern study area. Contours show density (number per unit projection area) of mineral lineations, and minor fold axes. Individual maxima and corresponding plunges are as follows: I, 5 percent, 40° S. 48° W.; II, 4 percent, 5° N. 22° E.; and III, 3 percent, 18° N. 3° W. (see text discussion).

barium, cobalt, manganese, copper, lead, and zinc (Slack, 1982; Hutchinson, 1983, p. 34), as well as nickel and chromium, are normal (pl. 4). These elements occur in expected amounts in the rock types of the study areas. The higher values of these elements associated with massive sulfide and other stratabound mineral deposits do not occur in rock samples with visible sulfide mineralization. Silver, molybdenum, niobium, tin, and thorium are detectable in low amounts in some rock samples, but the resulting scattered distribution is not considered anomalous for the basement rocks. High values for zinc in stream sediment and lead in pan concentrates might outline areas of sandstone-lead deposits in the cover-sequence clastic rocks.

Boron

Values for boron in stream sediments and soils in the study areas are distributed bimodally (pl. 4) and range from 10 to 500 ppm and from 20 to 200 ppm, respectively. The median value for stream sediments (70 ppm) is the same as that for Devils Den, lower than that for Bristol Cliffs, and higher than the mean value for Lye Brook (table 1 on pl. 4). Boron is present in the mineral tourmaline. In the study areas, three samples of tourmaline-rich schist of the Mount Holly Complex contain boron in concentrations of 2,000 ppm or more. Many samples of tourmaline quartzite and schist contain more than 500 ppm of boron. Median values for boron in rocks are highest in quartzite and schist within quartzite of the Mount Holly Complex, in schist of the Dalton Formation, and in Cheshire Quartzite (tables 3 and 4 on pl. 4). These highest median values, 50–30 ppm, are near the value for average sandstone, somewhat lower than the value for average shale, somewhat higher than the values for Cheshire Quartzite from Lye Brook and Mount Holly quartzite from Devils Den, and somewhat lower than the value for Cheshire Quartzite from Bristol Cliffs.

Barium

The barium contents in rocks, stream sediments, and soils of the study areas are within the range of concentrations for rocks, stream sediments, and soils collected from nearby areas (tables 1–7 in pl. 4). The highest values for barium in stream sediments (table 1 on pl. 4; fig. 16) are 1,000–1,500 ppm and are from basins that drain areas underlain by the upper part of the Mount Holly Complex schist unit and lenses of calc-silicate gneiss and impure marble. The highest values in rock (1,000–2,000 ppm) are from feldspathic schists (table 4 on pl. 4) and feldspathic Cheshire quartzite (table 3 on pl. 4), and median values are highest (500 ppm) for Dalton schist (table 4 on pl. 4). The median value for barium in stream sediments from the study areas is lower than those from Devils Den and Bristol Cliffs. The median value for barium in both stream sediments and soils is somewhat higher than the mean value from Lye Brook (tables 1 and 2 on pl. 4).

Cobalt, Chromium, and Nickel

The values for cobalt, chromium, and nickel for rocks from the study areas are within normal limits for average rocks, soils, and stream sediments. Median values for these elements in rocks from the study areas are low to negligible in quartzites (Co, N-5 ppm; Cr, 10–15 ppm; Ni, N-5 ppm; table 3 on pl. 4) and highest in Mount Holly Complex schist (table 4 on pl. 4). Individual samples of hornblende schist and amphibolite have contents comparable to those of average basalt. Median values for cobalt and chromium in the mafic rocks (table 5 on pl. 4) are consistently lower than average basalt values, and higher than values for average compositionally intermediate volcanic rocks. Median values for nickel in these mafic rocks are much less than average basalt and average intermediate rocks (table 5 on pl. 4). Isolated higher values for chromium in a sample of Cheshire quartzite are thought to be related to low concentrations of chromite, a resistate mineral. The chromite occurs in rare laminae, and is not indicative of important mineralization. The high values for Co, Cr, and Ni in some rocks of the Mount Holly calc-silicate gneiss and impure marble unit Ym (relative to average shelf carbonate or deep-sea carbonate, table 7 on pl. 4) suggest the possibility of a mafic or intermediate volcaniclastic component in some of the rocks in the unit.

In stream sediments and soils (tables 1 and 2 on pl. 4), cobalt, chromium, and nickel show normal or near-normal distributions. Ranges and median values for individual elements are only slightly higher, or slightly lower, than in soils and stream sediments from Lye Brook, Bristol Cliffs, and Devils Den, and values among the various areas are reasonably comparable.

Silver, Molybdenum, and Tin

Silver (fig. 14) and molybdenum (fig. 15) were detected at low parts-per-million values in a very few rocks, stream sediments, and soils in the study areas (pl. 4). The few samples that contain detectable silver and molybdenum form a patchy pattern of distribution. Silver was detected at the 2-ppm level in one sample of quartzite in the Cheshire Quartzite (fig. 14). This value, though clearly anomalous for this area, does not indicate important silver mineralization, as no other nearby samples showed anomalous values. One soil sample (figs. 14, 15, sample 809), over granite gneiss, contains detectable molybdenum and silver at values of less than 5 ppm. However, no other rock or soil sample from the granite areas border zone contains detectable amounts of these elements, and there is no pattern of mineralization associated with the granite. In the Devils Den Area, Slack and others (1985) noted anomalous values of 5 ppm for silver in pan-concentrate samples. Low values for molybdenum in many different rock types in Devils Den, typically 5–10 ppm, were considered high but not anomalous by Slack and others (1985). Somewhat lower values for molybdenum form a patchy distribution in the present study areas. Samples of rock and soil containing detectable amounts of silver and molybdenum are not in drainage basins where detectable amounts are found in stream sediment. The scattered values do not appear to outline any important mineralized areas.

Tin was detected in two samples (samples 138 and 143, pl. 3) from the Mount Holly Complex quartzite unit on the northern flank of Buckball Peak, at 50 ppm and 30 ppm, respectively. The mineralogy of the tin is not known. However, this mode of occurrence, in quartz-pebble metaconglomerate and conglomerate with schist matrix near and at the base of the unit, Yq, is suggestive of the presence of cassiterite, a resistate mineral. No other Mount Holly Complex quartzites in the study areas contain detectable tin; nor do any other samples of rock. However, similar values for tin (10–50 ppm) were detected in a few samples of rock from the Mount Holly Complex (mostly quartzites) in the nearby Devils Den Roadless Area by Slack and others (1985). Those values, together with the occurrences in the present study areas, suggest possible paleo-placer accumulations of tin, and have implications for an older period of possible tin (and (or) silver and molybdenum) mineralization in the basement rocks, either as epithermal vein associations with the basement volcanic units or possibly in association with the older metatrondhjemite-younger granite igneous evolution of basement intrusives. Tin anomalies have not, however, been identified with any of these specific rock types. Much younger igneous sources for possible tin mineralization, such as in geographic association with Mesozoic alkalic rocks (Watts, 1990), seem unrelated to the spatial distribution of tin occurrences in rock in the present study areas and in the Devils Den Roadless Area. Tin was found in low values (20–50 ppm) in the nonmagnetic fraction of heavy mineral panned concentrates from two drainage basins along the eastern side of the Devils Den Roadless Area by Slack and others (1985), and also from a sample net of much larger basins both south and west of the present study areas by Day and others (1986). Slack and others (1985) noted that these occurrences of tin, in the nonmagnetic fraction of panned heavy mineral concentrates from the basins in the Devils Den Roadless Area, probably indicated that the tin was in the mineral cassiterite. The low values of tin detected in the probable paleo-placer accumulations of tin in the basement metaclastic lithologies imply that the paleo-placers have little economic importance.

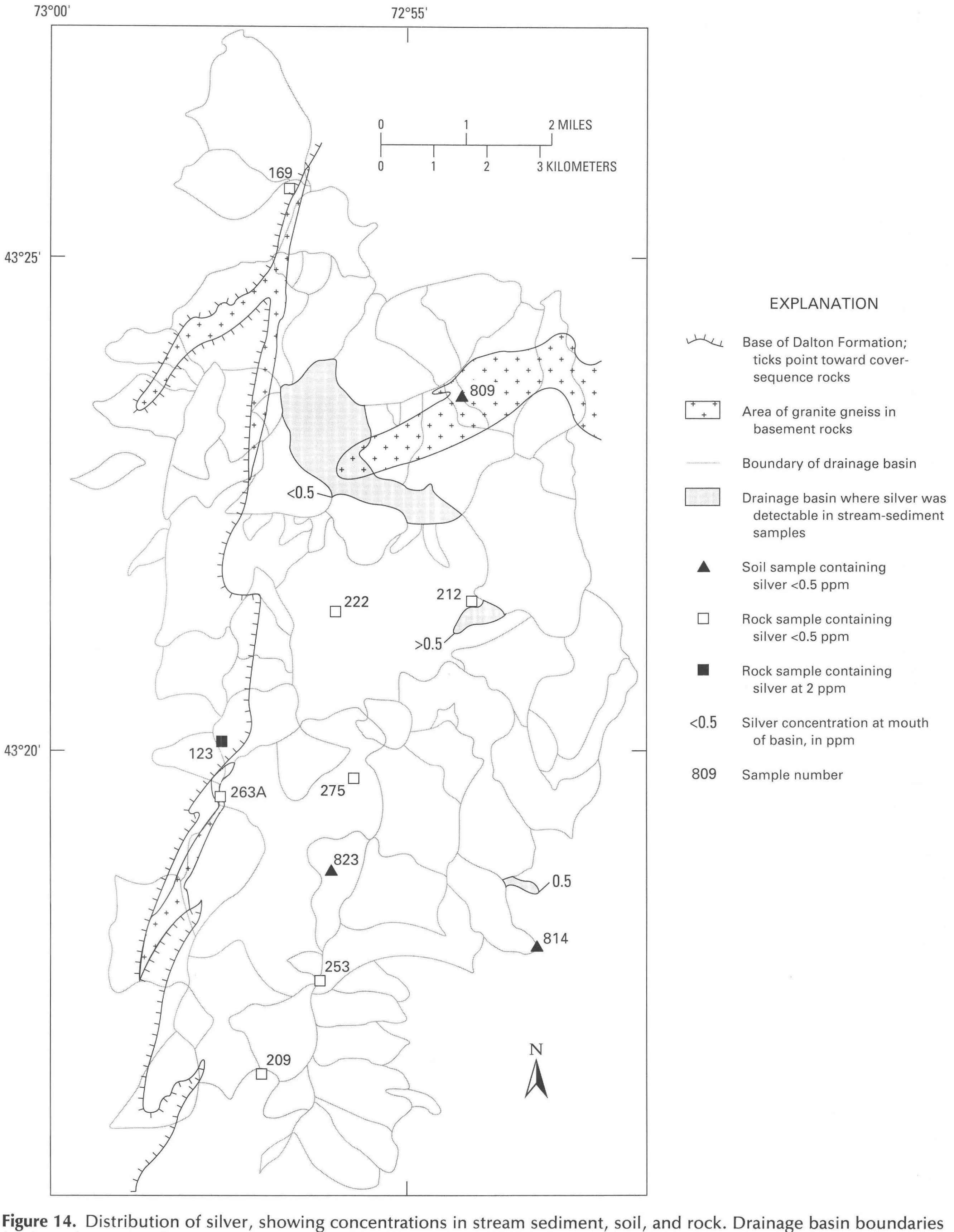
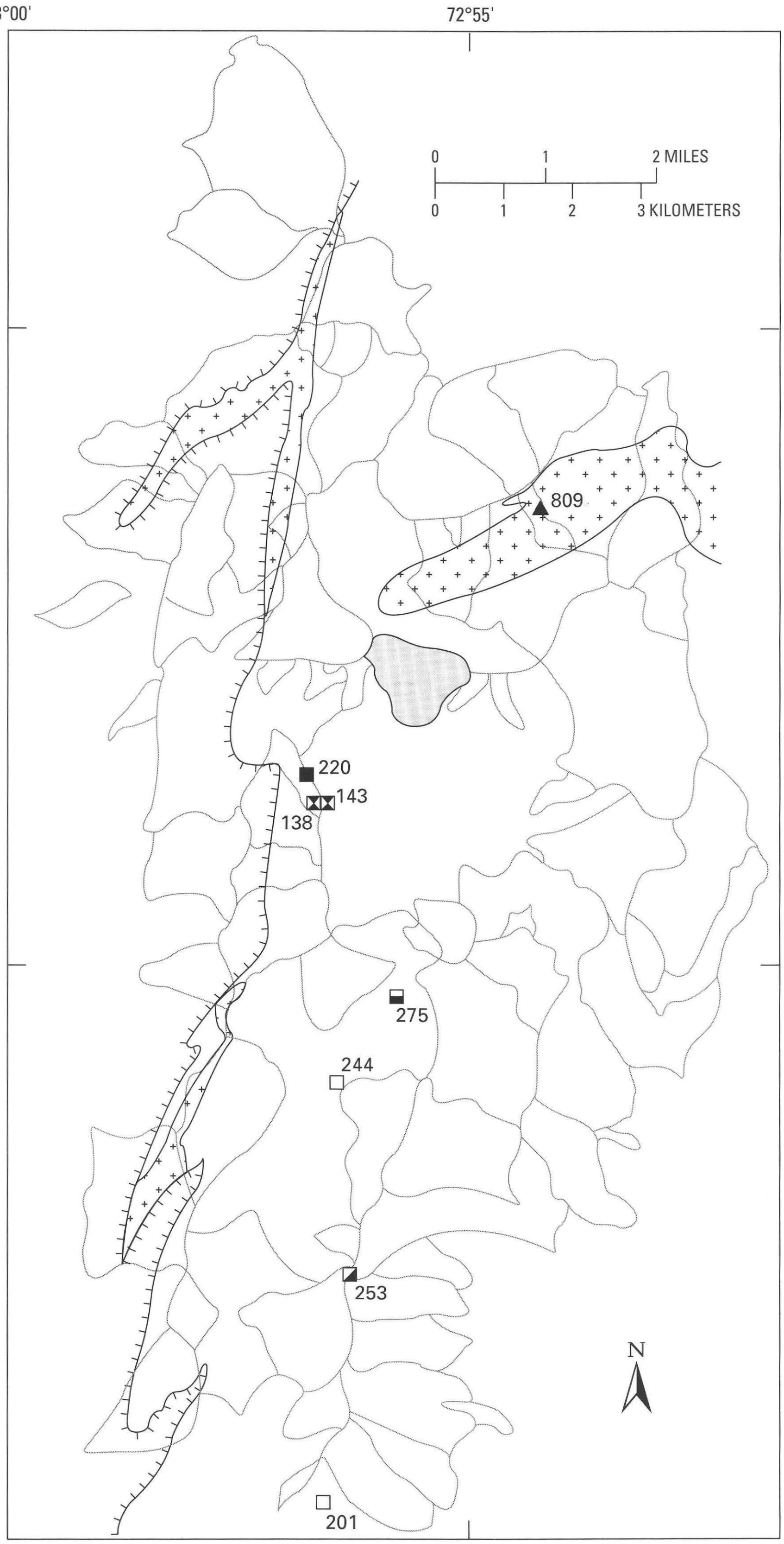


Figure 14. Distribution of silver, showing concentrations in stream sediment, soil, and rock. Drainage basin boundaries (net), and associated stream-sediment sample sites, are located on plate 2. Location of rock and soil samples shown in detail on plate 3.



EXPLANATION

Base of Dalton Formation; ticks point toward cover-sequence rocks

Area of granite gneiss in basement rocks

Boundary of drainage basin

Drainage basin where molybdenum was detectable (5 ppm or greater) in stream-sediment samples

▲ Soil sample containing molybdenum <5 ppm

□ Rock sample containing molybdenum <5 ppm

Rock sample containing molybdenum at 5 ppm

Rock sample containing molybdenum at 7 ppm

■ Rock sample containing molybdenum at 10 ppm

Rock sample containing detectable tin

809 Sample number

Figure 15. Distribution of molybdenum in stream-sediment and soil samples, and of molybdenum and tin in rock samples. Drainage basins (net), and associated stream-sediment sample sites, are located on plate 2; rock and soil sample sites shown in detail on plate 3.

Copper, Lead, and Zinc

The base metals copper, lead, and zinc (and cobalt) are commonly associated with stratabound sulfide deposits. In stream sediments, soils, and rocks, these metals are present in normal amounts in the study areas (histograms on pl. 4). Except for some isolated, marginally elevated concentrations, the values are similar to those in lithologically similiar rocks in similar stratigraphic positions nearby (tables 3–7 on pl. 4). Many rock samples in the study area, including quartzite and schist, contain meager amounts of visible sulfide. There is, however, no correlative increase in copper, lead, or zinc in these samples. Instead, the iron values are distinctly elevated, suggesting that the sulfide is pyrite or pyrrhotite. Lead is distributed normally in stream sediments, soils, and rocks, whereas copper and zinc show isolated occurrences of somewhat elevated values in all sample media. The geographic distribution and rock association of these elevated values, including copper up to 200 ppm in schist, and zinc up to 230 ppm in stream sediment and muscovite-chlorite schist, are shown in figure 16. High values for barium, and a single high value for lead in the nonmagnetic fraction of a heavy-mineral pan-concentrate sample reported by Day and others (1986), are also shown (fig. 16) for reference.

A striking north-south pattern of stream-sediment basins containing high zinc, lead, and (or) barium concentrations is evident along the western parts of the study areas. The pattern here is a subset of a regionally established pattern of lead anomalies closely associated with the cover-sequence rocks as discussed by Watts (1990). A similar pattern was noted in association with potential for sandstone-lead deposits in the Bristol Cliffs Wilderness, by Slack and Sabin (1983), and with the potential for sandstone-lead deposits more broadly in the Cheshire Quartzite (Slack, 1990).

Medially in the Big Branch Wilderness, and along the western part of the Wilder Mountain Roadless Area, two types of element associations are evident. Basins containing high barium, or high barium and zinc, concentrations mostly drain areas of basement rock. Basins in which stream sediments contain high concentrations of lead and (or) zinc, but no or low concentrations of barium, are clearly associated with streams that drain the Dalton Formation and Cheshire Quartzite. These are clastic units overlying a granitic basement source area of some relief, so that a possible source of the lead-zinc might be sandstone-lead mineralization in favorable clastic horizons. No bedrock sample of the Dalton or Cheshire was noted to contain lead or zinc mineralization, and local trace sulfide in the Dalton evidently is pyrite or pyrrhotite. The source and rock association for these high values in drainage basins are unknown.

Copper values are low in the stream-sediment samples from the study areas, but higher, although normal, concentrations occur in the basement rocks. Many of the higher values in the basement rock are in metamorphosed mafic rocks that might have been basalts, and the values for copper in these rocks are near values considered normal for basalts (table 5 on pl. 4). In one sample of schist from the northeastern corner of the area (fig. 16, sample 305), relatively high values for copper are associated with relatively high values for barium. The absolute value for copper in this rock is not very high, however, and no other schist sample shows this elemental association. In the area of the basement rocks, none of the higher values for these elements in soil or rock correspond with higher values in associated stream sediments. None of the higher values in rocks and soils are associated with elevated values for barium (fig. 16) or other elements potentially indicative of stratabound sulfide deposits. It is unlikely, therefore, that these relatively high values for copper and zinc outline areas of important mineralization in the basement.

Thorium

Thorium was detected at 100 ppm in two schist samples from the Wilder Mountain Roadless Area: sample 522, of Dalton Formation muscovite schist, and sample 114, of muscovite schist in the Mount Holly Complex quartzite unit. Although these two values clearly are anomalous for rocks of the area, they are in metasediments, and no other samples of rock, including nearby rocks, contain detectable thorium. Thorium occurs in the detrital minerals monazite and zircon. High values of thorium, in association with high values of uranium, are in pegmatite vein occurrences, or biotite-rich schist, and may constitute important thorium and uranium mineralization in Green Mountain basement gneisses (Ratté and Vaneck, 1980). The rock associations found here are muscovite schists of the cover sequence, and of the basement, and are not with pegmatite veins. The few relatively high thorium values are not thought to be indicative of important mineralization.

Manganese

Manganese is normally distributed in the sample media (pl. 4), ranging from 50 to +5,000 ppm in stream sediment, from 15 to 3,000 ppm in soil, and from 10 to +5,000 ppm in rock. Distribution of the highest values for manganese are shown in figure 17. The high values for manganese in quartzites are somewhat unusual. Thesesamples (sample 102, from the Dalton Formation quartzite, and sample 106, from quartzite from the Mount Holly Complex schist unit) are from jointed and fractured outcrops, many of which have visible thin dendrites of pyrolucite (MnO_2) on joint surfaces. These high values probably represent secondary enrichment in manganese of the sample surfaces and are not indicators of manganese mineralization of any economic importance.

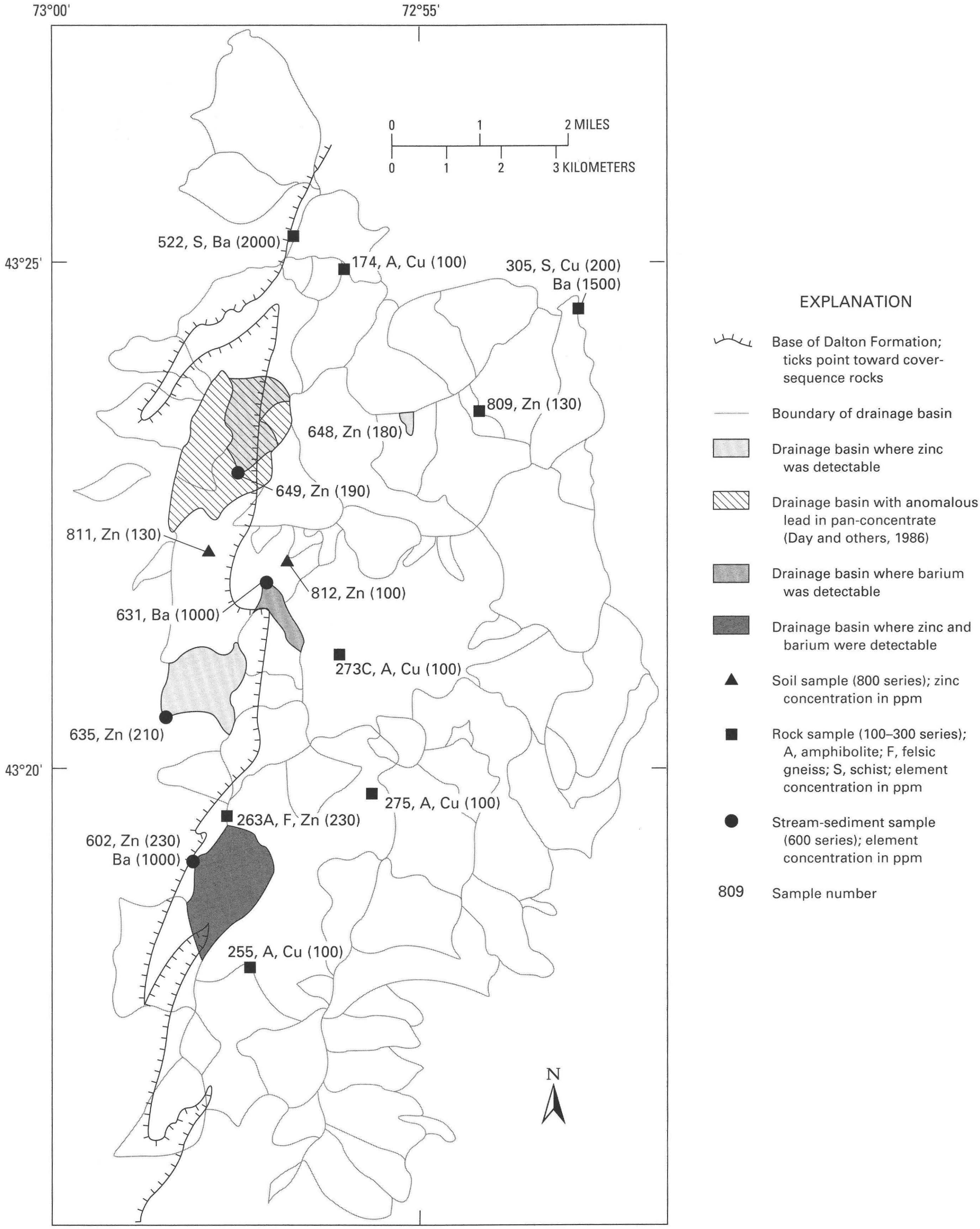


Figure 16. Distribution of copper, lead, zinc, and barium, showing highest concentrations in stream sediment, soil, and rock. Drainage basin boundaries (net), and associated stream-sediment sample sites, are located on plate 2; location of rock and soil samples shown on plate 3.

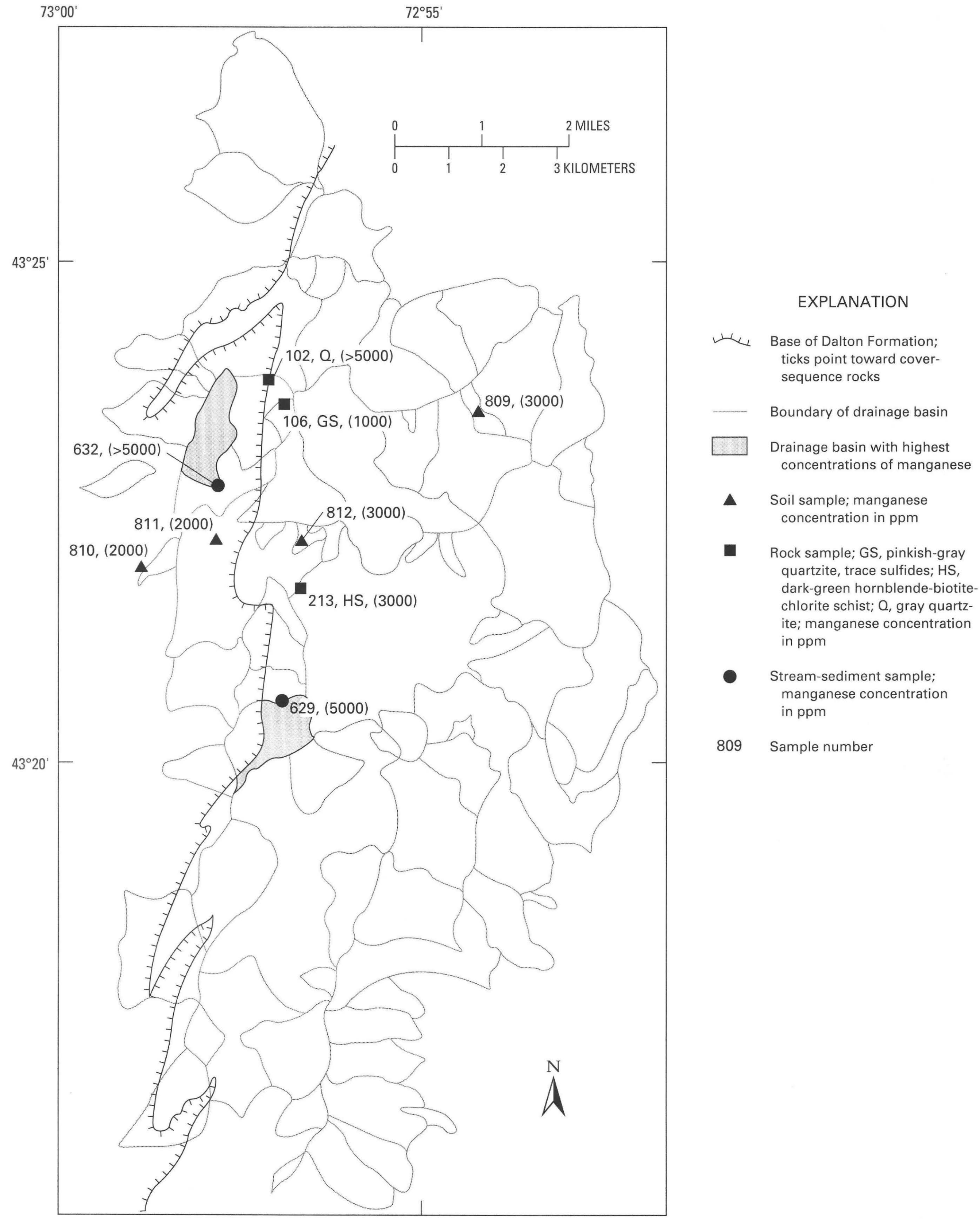


Figure 17. Distribution of manganese, showing highest concentrations in stream sediment, soil, and rock. Drainage basin boundaries (net), and associated stream-sediment sample sites, are located on plate 2; location of rock and soil samples shown on plate 3.

MINERAL RESOURCE ASSESSMENT

The Big Branch and Peru Peak Wildernesses and the Wilder Mountain Roadless Area contain commodities with only industrial or agricultural applications. These include rough stone, minor sand and gravel, fill, and organic-rich deposits of muck and peat. Some quartzites, suitably crushed, might be useful as a high-silica source. Marble, in thin beds associated with calc-silicate rock, is dolomitic but is contaminated with silicate minerals. Although these materials constitute a resource, their distant location from potential markets, their difficult access, and their low economic values render them more or less unprofitable under current economic conditions. Local anomalous concentrations of certain metals, considered in the context of regional metallogeny and ore deposit models, are not believed to indicate the presence of important ore deposits. Gold, lead, zinc, uranium, and thorium were specifically considered because they occur in mineral deposits nearby in similar geologic terranes. The potential for uranium and thorium and for lead-zinc mineralization is judged to be low. There seems to be no potential for gold, copper, or other metals based on existing geologic data and the geochemical survey. The potential for oil and gas at depth remains unknown, but is considered low based on interpretations of comparable hydrocarbon accumulations beneath similar basement terrane in the southern Blue Ridge province (Hatcher, 1982).

Commodities with Industrial or Agricultural Applications

Stone

Stone suitable for rough building stone or for road metal is abundant in the wildernesses and roadless area but is mostly inaccessible. Thin-bedded parts of the Cheshire Quartzite might be suitable for hearthstone or flagstone. Quartzite layers are highly variable in iron content, but with suitable site selection, and crushing, a high-silica aggregate might be obtained. Similar sources of stone are present outside the boundaries of the study areas. Rough stone was quarried locally along Forest Service Road 10 (the road east of Mt. Tabor Village, pl. 1) at the foot of Green Mountain, probably for local use in road building.

Sand and Gravel

Sand and gravel, perched in scattered, small, glaciofluvial deposits (Qg, pl. 1; kame terraces and dissected kame deltas 5–15 ft thick), might supply small amounts of permeable fill for road building or local use in construction. Most deposits, however, are not near roads. Similar material in terraces along major streams (Qst, pl. 1) is inaccessible and of small potential volume, because the mountain-stream gradients are steep and most streams flow on or near till or bedrock surfaces. Larger deposits of permeable fill are being worked outside the study area in the Vermont Valley to the west, and in Weston to the northeast. More abundant deposits of sandy till blanket low-lying hummocky areas, and could be used as local sources of semipermeable fill.

Organic Litter and Muck

Organic litter and muck suitable for use as top-dressing for new lawns or as soil conditioners are present in the swamp deposits (Qs, pl. 1).

Peat

Peat in larger swamps such as Elbow Swamp may reach thicknesses of 5–10 ft, but the quality of this peat (for example, the ash content) has not been evaluated.

Marble

Marble in the study areas is thin, poorly exposed, impure, and more difficult to access compared with the much thicker early Paleozoic marbles that are being quarried in the nearby Vermont Valley.

Metals

Uranium and Thorium

Uranium and thorium are present in small stratabound deposits in the southeastern part of the Green Mountain anticlinorium, and rocks of the Mount Holly Complex are known regionally to be relatively favorable hosts for uranium and thorium. Mineralization consists generally of segregations in granite pegmatites or in Mount Holly quartz-muscovite schists or tourmaline quartzites (Grauch and Zarinski, 1976). A large anomaly (18 ppm uranium) was noted in biotite schist of the Mount Holly Complex about 4 mi south of the study areas (Ratté and Vanecek, 1980). A significant stratabound uranium deposit is present in the Okemo Mountain area, about 8 mi east of the study areas (Ayuso and Ratté, 1990). Regional studies, including investigation of airborne radioactivity (Popenoe, 1964), and hydrogeochemical and stream-sediment sampling (Koller, 1979), have suggested the locations of possible uranium and thorium deposits in the Green Mountains. Data bearing on their occurrence have been summarized by Ratté and Vanecek (1980). Somewhat elevated values of uranium in stream waters were found in Koller in the northwestern part of the Wilder Mountain Roadless Area. Thorium values of 100 ppm were found in two rock samples in this study. However, none of the other samples, including nearby samples, contain detectable thorium. The anomalous values are not considered indicative of important radioactive mineral deposits. Granite pegmatites are small and relatively rare in lithologies of the Mount Holly Complex in the study areas. Thus, the potential for metal deposits associated with these rocks, and for pegmatite minerals, is considered low. Although the amount of exposed bedrock is small, and although stream sediment and soil materials have been affected by glacial transport (see Watts, 1990), the chemical analyses available for streams, soil, and rock suggest a low potential for uranium and thorium deposits in Proterozoic basement rocks of the study areas.

Gold

Gold, reported in low values (0.05–0.3 ppm) for some rock and stream-sediment samples from the adjacent Devils Den Roadless Area (Slack and others, 1985), prompted attention to the possible presence of gold in the areas studied for this report. Gold targets, including gold-bearing massive pyrrhotite and gold in quartz-carbonate-pyrite stockworks associated with an alkalic Mesozoic stock, occur 4 to 6 mi north of the study areas in Cuttingsville, Vt. (Doll, 1969; Robinson, 1990). The gold-bearing Cuttingsville pyrrhotite deposit is a stratabound body associated with marble and calc-silicate gneiss of the Mount Holly Complex, as in the study areas. Additional attractive targets for gold are quartz-pebble conglomerates along unconformities at two stratigraphic horizons: (1) at the base of the Dalton formation; and (2) along the base of the Mount Holly quartzite unit. These rocks might host paleo-placers of gold that was shed off an emergent Grenville terrane. Neither the reconnaissance sampling nor specific target sampling, however, detected gold at levels of 0.05 ppm or greater. On this basis it is concluded that the study areas lack potential for bedrock or paleo-placer deposits of gold.

Lead, Zinc, and Copper

Lead and zinc and some copper were noted to form base-metal sulfide occurrences in rocks of the cover sequence, generally in the Vermont Valley west of the Big Branch Wilderness and the Wilder Mountain Roadless Area (Clark, 1987). Mineral deposits in these rocks include stratabound accumulations of sulfides, galena and sphalerite, and some copper-bearing sulfide, chalcopyrite. These sulfide deposits are hosted mainly by siliciclastic rocks within the carbonate-siliciclastic shelf-facies interval of western cover-sequence rocks that includes the Monkton Quartzite and the Dunham Dolomite of Doll and others (1961). The dolomite-quartzite contact is a favored horizon for accumulation (Clark and Slack, 1988; Clark, 1990). The stratigraphic position of this contact is above the youngest rocks in the study areas, and the contact does not crop out in the study areas.

A pattern of anomalously high lead and (or) zinc values in stream-sediment and pan-concentrate samples from streams draining areas underlain by the Dalton Formation and Cheshire Quartzite on the western side of the study areas (see section on "Geochemistry," this report) may outline areas of sandstone-lead (Bjoerlykke and Sangster, 1981) mineralization in these rocks. These kinds of deposits (Laisvall-type deposits) are typically hosted by sandstones over granitic basement rocks of the Baltic Shield in Sweden, and over granitic basement rocks elsewhere. None are known to exist in the Cheshire Quartzite or Dalton Formation or correlative rocks along the length of the U.S. Appalachians, but galena- and sphalerite-cemented sandstones of Cambrian age have been reported from the Canadian Appalachians (Schreiver and Beaudoin, 1987).

Several samples of quartzite of the western cover sequence (dark-gray Dalton quartzite) contain visible trace sulfides. Spectrographic analyses of these Dalton samples show them to be rich in iron, with only normal amounts of lead, zinc, and copper. The Dalton sulfide is probably pyrite or pyrrhotite, and not indicative of any base-metal mineralization in these rocks. In addition, the quartzites in the cover sequence here are typically well exposed in surface outcrop, and no lead or zinc mineralization was noted in any of the exposures during fieldwork for this study. On these bases, it is believed that there is only low potential for sandstone-lead deposits in these rocks in the study areas.

In the basement rocks, one sample of schist was noted to contain relatively high values of copper in association with relatively high values of barium. However, no other schist contained this association, and no pattern indicative of stratabound massive-sulfide mineralization is present within the area of the basement rocks in the studied areas. On this basis, the basement rocks, including sulfidic schists in the basement, are believed not to host massive sulfide deposits in the study areas.

Trace chalcopyrite mineralization was noted in association with calc-silicate rocks and marble of the Mount Holly Complex in the study areas. Marbles in the Mount Holly are thin units, less than 8–10 ft thick, and are poorly exposed. Many are impure, with masses of tremolite-actinolite, or talc and chlorite where they were extensively retrograded by late greenschist-facies metamorphism. Spectrographic analyses of samples of these rocks show only background concentrations of lead, zinc, and copper. The chalcopyrite mineralization seems local and not indicative of any important deposits.

Copper and zinc show only somewhat elevated values in some basement rock, and in stream-sediment and soil samples derived from a basement-rock source. The elevated values in the different sample media are not systematically distributed, and are not related to a specific rock type, stratigraphic interval, or structural zone. Rock samples containing high concentrations of metal are not from basins in which concentrations in stream sediment are high. Based on these relationships, it is concluded that there is no potential for deposits of lead, zinc, or copper in the basement rocks in the study areas.

Tin, Molybdenum, and Silver

Tin, molybdenum, and silver are present in low concentrations in some rocks in the study areas (see "Geochemistry" section). Molybdenum and silver are present in a variety of rock types and form a patchy distribution that is not understood, but is not believed indicative of any significant mineralization. Tin, in the study areas and in the nearby Devils Den Roadless Area (Slack and others, 1985), occurs in Mount Holly quartzites in concentrations of 10–50 ppm. The tin is probably in cassiterite, in minor paleo-placer accumulations. These occurrences imply an earlier period of tin mineralization, in association either with basement volcanic rocks or with evolved basement granite intrusives. None of the spectrographic analyses of the basement metavolcanics or granite, however, document a tin association. The low concentrations of tin detected in the paleo-placer accumulations suggest that the paleo-placers in the metamorphosed basement rocks have no economic value in the study areas.

Oil and Gas

Some deep seismic studies (Cook and others, 1979; Ando and others, 1984) suggest that crystalline basement rocks in the Blue Ridge of the southern Appalachians and in the Green Mountains of Vermont may lie in allochthonous sheets of transported rock that have been thrust over a thick succession of younger Paleozoic rocks. Although the crystalline rocks exposed in these far-traveled sheets at the surface are devoid of hydrocarbons, it is possible that a wedge of younger sedimentary rocks trapped at depth below the crystalline rock sheet might be favorable for the accumulation of oil and (or) gas. Speculation on the thermal evolution and history of the sedimentary rocks in the southern Blue Ridge trapped at depth suggests that only gas may be present at depth there, along the western edge of the overthrust belt (Hatcher, 1982, p. 980).

The study areas lie in the broadly defined, so-called Eastern Overthrust belt, an area within which large tracts of land were actively being leased by industry in the several years preceding 1984 (McCaslin and Sumpter, 1981; Bigelow, 1982) in anticipation of a search for oil and gas. Additional seismic studies and deep exploratory drilling are needed to evaluate the hydrocarbon resource potential, if any, that might be present. Currently, interest in such exploration seems to be lacking. A recent maturation study of the Ordovician black shales to the west suggests that only gas would be present in those Paleozoic rocks (Wallace and Roen, 1989).

The potential for oil and gas below the study areas is unknown. That these speculative northern overthrust traps may have had a thermal history similar to that of the southern Blue Ridge can be inferred from broadly based terrane models such as that of Williams and Hatcher (1983). If so, the potential for economic concentrations of oil and gas in the subsurface below the study areas would probably be low.

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