U.S. DEPARTMENT OF THE INTERIOR
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TECTONIC LITHOFACIES, GEOPHYSICAL, AND MINERAL-RESOURCE APPRAISAL MAPS OF THE SHERBROOKE-LEWISTON AREA, MAINE, NEW HAMPSHIRE, AND VERMONT, UNITED STATES, AND QUEBEC, CANADA

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INTRODUCTION

Coordinated geologic, geophysical, and geochemical studies by the U.S. Geological Survey in cooperation with the Maine Geological Survey and the Office of the State Geologist of New Hampshire were begun in 1979, under the Conterminous United States Mineral Assessment Program (CUSMAP). The focus of this work was to define the metallic mineral resources of the United States portion of the Sherbrooke and Lewiston 1°x2° quadrangles. Most of these studies were completed by the end of the 1984 field season, and a public meeting was held in September 1984, in Littleton, N.H., at which the preliminary results of the project were presented as posters and a preliminary geologic map was made available (Moench, ed., 1984). Reports published since then include stream-sediment and heavy-mineral-concentrate maps (Nowlan and others, 1990a, b, c), a map of potential tin resources associated with the White Mountain Plutonic-Volcanic Suite (Cox, 1990), and a detailed geologic map (Moench and others, 1995). Map A of this report is simplified, with important local modifications, from Moench and others (1995), and provides the geologic base for maps B, C, and D.

In 1985, R.H. Moench was asked to map the geology of the Mount Cube 15' quadrangle, New Hampshire and Vermont, in order to extend the newly mapped metamorphic stratigraphy in the western part of the Lewiston 1°x2° quadrangle southwestward into the Glens Falls 1°x2° quadrangle, where another CUSMAP project was in progress (Slack, ed., 1990). This new mapping in the Mount Cube quadrangle showed that rocks of an extensive belt previously considered to be Ordovician or older in age, largely devoid of metavolcanic rocks, and autochthonous, are actually mainly Silurian, contain variably abundant metavolcanic and volcaniclastic rocks having potential for the occurrence of volcanogenic massive-sulfide deposits, and are allochthonous. Publication of the products contained in this report and in Moench and others (1995) was delayed until the allochthonous body, termed the Piermont-Frontenac allochthon, was delineated sufficiently well for presentation at a scale of 1:250,000.

In this report, the locations of named plutons are shown on figure 2 and are referenced in the texts by index number (for example, index 63). The locations of unnamed small plutons or small bodies of stratified metamorphic rocks are referenced by map grid coordinates (for example, grid 4F–5F is at the boundary between the Old Speck Mountain and Milan 15-minute quadrangles, Maine and New Hampshire).

Abbreviations of tectonic lines and belts used throughout are: BHA, Bronson Hill anticlinorium; BHBMA, Bronson Hill–Boundary Mountains anticlinorium (BHA+BMA); BMA, Boundary Mountains anticlinorium; CMT, Central Maine trough; CVT, Connecticut Valley trough; M-F-T, Monroe–Foster Hill–Thrasher Peaks line; P-F allochthon, Piermont-Frontenac allochthon; TMO, Towns Mountain outlier of the P-F allochthon; CuRW, Coppermine Road window through the P-F allochthon; SLR, magmatic axis of Second Lake rift; STH, Silurian tectonic hinge. Stratigraphic names in Appendix I and in the pamphlet are from Moench and others (1995).

TECTONIC LITHOFACIES (MAP A)

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INTRODUCTION

The purpose of this map is to provide a relatively simple but meaningful substrate for the geophysical maps (maps B and C), and the mineral-resource appraisal (map D) of the area. On map A, the major age groupings of stratified rock assemblages are shown by color; the map also shows selected primary stratified metamorphic and plutonic rock types by means of patterns. The "Correlation and interpretation of map units" also provides a numbered guide to the following summary of tectonic history. Color and the correlation diagram are not reproduced on maps B–D.

With the exception of the Ordovician Period, the nomenclature of Palmer (1983) is used in this report for the major divisions of Paleozoic and Mesozoic time. For the Ordovician Period, North American nomenclature recommended by Ross and others (1982) and an unpublished Ordovician time scale furnished by R.J. Ross, Jr. (written commun., 1993) are used here, and by Moench and others (1995). Ross also recommended informal usage of the terms Early, Middle, and Late Ordovician (written commun., 1993), which in this report correspond to the Ibexian (Early Ordovician), Whiterockian plus Mohawkian (Middle Ordovician), and Cincinnatian (Late Ordovician). The scale of Tucker and McKerrow (1995) was published too recently for extensive revision of this report, but pertinent refinements or revisions are incorporated in the body of the following text and in Appendix I. Additionally, North American and British nomenclature for the Ordovician are shown on the correlation diagram.

SUMMARY OF PLATE-TECTONIC HISTORY

As shown on figure 1, the Sherbrooke and Lewiston quadrangles span the core of the northern Appalachians from the Laurentian craton almost to the Norumbega fault system, within and southeast of which are the peri-Gondwanan or Avalonian lithotectonic belts that form composite terrane T3. The terrane nomenclature shown on figure 1 is modified and simplified according to our preferences from many sources (for example, Williams and Hatcher, 1983; Lyons and others, 1982; Zen, 1983, 1989; Stewart and others, 1993; Rankin, ed., 1993; Rast and Skehan, 1993; Ludman and others, 1993; Thompson and others, 1993; Dubé and others 1996). Because published geographic terrane nomenclature among the cited references is complex and frequently conflicting, we prefer a simplified numerical nomenclature (T1, T2, and T3, fig. 1).

The following narrative is tied to the rock assemblages that are numbered on the "Correlation and interpretation of map units" and, for Paleozoic accretionary events, to the terranes of figure 1.

Early Paleozoic Penobscottian and Taconian accretions

[Rock assemblages numbered 1 and 2 on correlation diagram, and terranes LC, T1, and T2 (fig. 1)]

The Laurentian craton (LC)

The LC contains the Grenvillian crystalline basement, about 1 Ga old, and late Proterozoic to early Paleozoic rift and miogeoclinal deposits that accumulated off the southeastern margin of the craton when Iapetus opened. Miogeoclinal slope-rise deposits are represented on figure 2 by the parautochthonous internal nappes (Ꞓin) and the allochthonous external nappes (OꞒen) of St. Julien and Hubert (1975). According to St. Julien and Hubert's model, deposits of the external nappes accumulated more seaward than those of the internal nappes, and were transported to their present position on the craton during the Middle Ordovician Taconian collision. As shown on profiles of the Quebec–Maine–Gulf of Maine transect (Stewart and others, 1993), Grenville basement extends at depth southeastward from the LC approximately to the STH, below the western side of the CMT. The STH also approximately marks the southeastern boundary of Ayuso and Bevier's (1991) northern group of plutons, which have relatively nonradiogenic lead-isotope signatures (in feldspar) that suggest melting sources in Grenville basement. In the area of the Chain Lakes massif, the upper surface of the Grenville is at a depth of about 5 km.

Far to the south, in Massachusetts, the probable peri-Gondwanan Dry Hill Gneiss (fig. 1, DHG), now only 50 km east of the LC, may have been thrust over the eastern margin of Grenville basement (Thompson and others, 1993, section A–A'). Alternatively, Stewart and others (1993, p. 6) suggested that the Dry Hill Gneiss, which contains metavolcanic rocks dated at 613±3 Ma (Tucker and Robinson, 1990; U-Pb zircon), is Grenvillian granulite whose isotopic systems were reset during late Proterozoic Iapetan crustal rupture. This alternative seems unlikely, however, because the common occurrence of isotopic inheritance in zircons from plutonic rocks indicates that U-Pb zircon systems in ancient crust commonly (if not always) survive younger magma-generating conditions.

Baie Verte–Brompton line (BBL) and terrane 1 (T1)

The BBL, which marks the southeastern margin of the LC at the present erosion surface, is widely interpreted as the trace of the principal suture produced by the Taconian collision (Williams and St. Julien, 1982; Stanley and Ratcliffe, 1985). Zen (1989, p. 13) has suggested that the BBL (his Brompton-Cameron line) might represent the surface of obduction of a minor piece of ocean floor that formed close to the LC margin. His suggestion is supported by the recent studies in Quebec by Whitehead and others (1993), who cited a U-Pb zircon age of 479±3 for plagiogranite at Mont Ham (part of Thetford Mines ophiolite), and reported $^{40}Ar/^{39}Ar$ hornblende ages of 480±5 or 483±5 Ma for amphibolite in shear zones at the base of the Thetford Mines and Asbestos ophiolite bodies. On their assumption that the plagiogranite actually is slightly older than the amphibolite, Whitehead and others (1993) concluded that ocean crust formation and sole accretion were virtually synchronous. On the basis of later U-Pb zircon studies, Whitehead and others (1996) inferred that the oceanic Thetford Mines ophiolite, which crystallized at 480±2 Ma, was ramped over the Laurentian margin no more than 3–15 m.y. later.

Cawood and Suhr (1992) have offered a similar interpretation for the obduction of the Bay of Islands ophiolite complex, western Newfoundland, onto the LC. According to their generalized model (Cawood and Suhr, 1992, p. 895), subduction of old (cold, dense) oceanic crust results in trench rollback, and extension accompanied by generation of new (hot, buoyant) oceanic lithosphere in the overriding plate; when the old lithosphere is entirely consumed, extension ceases, collision occurs, and the new ophiolite is thrust onto the continental margin. Ophiolites generated by this process "***only form during subduction of old oceanic lithosphere trapped in small ocean basins along irregular continental margins***" (Cawood and Suhr, 1992, p. 895). Applied to the Northern Appalachians, the Ordovician Quebec and Newfoundland ophiolites of the BBL were generated within the Quebec and Newfoundland reentrants, on opposite sides of the St. Lawrence promontory (Cawood and Suhr, 1992, fig. 6).

Although evidence cited above indicates that the Ordovician ophiolites of the BBL formed near the LC margin, close enough to have acquired a sparse Laurentian fauna (van Staal, 1994, p. 946, and references therein), Cawood and Suhr's model is consistent with the interpretation that the BBL represents the leading edge of a terrane derived from well within Iapetus and is the trace of the principal suture produced by the Taconian collision.

The Quebec portion of the BBL marks the deformed but *originally* southeast-dipping sole of the leading side of T1 (fig. 1). Although shown to dip steeply northwest at the northwest side of the Thetford Mines ophiolite (St. Julien, 1989, fig. 1), Tremblay and Pinet (1994, p. 1175–1177, figs. 3–6) showed that the ophiolite and associated units are deformed by Acadian (F_4) folds in a manner reasonably interpreted to indicate that the original dip of the sole was to the southeast, possibly gentle. On the interpretive cross section of Stewart and others (1993) (who have a different interpretation), a likely place for the sole is at a depth of about 5 km at the crest of the broadly arched Chain Lakes–Grenville boundary in the BMA.

The principal recognized components of T1 are: (1) the Thetford Mines and other Lower Ordovician ophiolitic complexes of Quebec (fig. 2, Oo); (2) accretionary melange mapped as the St. Daniel Formation (Om); (3) diamictite and associated metasedimentary and plutonic rocks of the Chain Lakes massif (ЄPc); and (4) rocks similar to the Chain Lakes found within the melange near Beauceville, Quebec (Cousineau, 1991), and at the eastern tip of the Gaspé Peninsula (Boone and Boudette, 1989, p. 31). For the following reasons, the area of T1 shown on figure 1 is somewhat smaller than the area of the Boundary Mountains terrane of Boone and Boudette (1989, fig. 4A). The southeastern border of T1 is exposed only at the Boil Mountain line (BML), on the south side of the Chain Lakes massif; extensions from that locality are conjectural, as shown on figure 1. From there to the eastern tip of the Gaspé Peninsula, the T1-T2 boundary is drawn on figure 1 so that all melange correlated with the Hurricane Mountain Formation lies to the southeast of the BML, as it does southeast of the massif.

West of the Chain Lakes massif, the BML is tentatively shown to intersect the BBL at a point just north of the Cambrian Orford ophiolite, which is about 30 km north of the Vermont-Quebec border (see Laurent, 1975, fig. 1). Whereas most ophiolite complexes of the Appalachian-Caledonian orogen have yielded Early to Middle Ordovician isotopic ages (Cawood and Suhr, 1992, fig. 7, and references therein), trondhjemite from the Orford and Boil Mountain Complexes have yielded Cambrian U-Pb zircon ages of 504±3 Ma and 520±12 Ma, respectively (David and others, 1993; Eisenberg, 1981, 1982). Although the Boil Mountain Complex needs more isotopic study, these data permit a model whereby the Boil Mountain and Orford ophiolites represent the intitial stages of an accretionary event that was significantly older than the event represented by the Ordovician Quebec ophiolites.

Although Boone and Boudette (1989) have interpreted the Chain lakes massif as an allochthonous 1.5-Ga-old microcontinent, other interpretations have been offered (Trzcienski and others, 1992; Stewart and others, 1993), and the Chain Lakes rocks might be no older than about 571 Ma, as shown by single-grain U-Pb zircon studies (Dunning and Cousineau, 1990). An age of about 570 Ma is late Proterozoic, however, according to Tucker and McKerrow (1995), and is not incompatible with the 580- to 630-Ma numbers that have been obtained from recognized peri-Gondwanan plutonic and volcanic rocks in Massachusetts and southeastern New Hampshire (Aleinikoff and others, 1995; Tucker and Robinson, 1990; Goldsmith and Secor, 1993, p. 423–425). Trzcienski and others (1992) have contended that the Chain Lakes body does not form a massif, but their observation (p. 513) that the body is most deformed near its margins indicates that it behaved as a structurally resistant buttress (by definition a massif) against Ordovician and younger deformations. Additionally, we find no support for their proposal (p. 526, 527) that the Boil Mountain Complex was emplaced onto Chain Lakes rocks after crystallization of the Attean pluton (index 2), dated at 443±4 Ma (Lyons and others, 1986; U-Pb zircon). Trzcienski and others (1992) were misled by the apparent agreement of a single U-Pb monazite metamorphic age of 468±3 Ma from the Chain Lakes (Dunning and Cousineau, 1990) and a U-Pb zircon age of about 470 Ma, by L.T. Silver, from the Attean, cited long ago (Boone and others, 1970, p. 19) but supplanted by the much younger age cited above. Moreover, the sample that yielded the cited monazite age was obtained from a wide, extensive, probably high temperature fault zone recognized by E.L. Boudette and G.M. Boone; accordingly, 468 Ma might represent the age of fault-related metamorphism, rather than the age of regional metamorphism of the massif; or it might be disturbed. However, we emphasize the need for further monazite studies throughout the massif, and for completion of study of the fault zone.

Pending the results of future studies, we favor a model by which the rocks of the Chain Lakes massif were consolidated and metamorphosed at high grade before they were overramped by rocks of T2, and subsequently incompletely retrograded. Although this interpretation has been disputed (Trzcienski and others, 1992), it is strongly supported by evidence of sillimanite-zone metamorphism in the matrix of diamictite in large blocks of Chain Lakes rocks embedded in greenschist-facies melange of the St. Daniel Formation, in Quebec (Cousineau, 1991). Features described by Boudette (1982) and Boudette and others (1989, p. 111) indicate that the Boil Mountain Complex was emplaced over the Chain Lakes massif by ductile faulting, while the ophiolite was still hot and not long after the ophiolite formed, in accord with the model of Cawood and Suhr (1992). The Chain Lakes rocks might either be part of a small upper Proterozoic sialic plate of Gondwanan affinity, or part of an intra-oceanic melange formed at the leading edge of T2.

Alternatively, Stewart and others (1993, p. 5) speculated that the Chain Lakes rocks were deposited upon Grenville crust. While their proposal is favored by lead isotope data from Grenville and Chain Lakes rocks (Ayuso and Bevier, 1991, figs. 2, 3), it is disfavored by the absence of recognized Grenville lithologies among the clasts, and by the fact that known or suspected Chain Lakes rocks are entirely caught *between* the BBL and BML sutures.

Boil Mountain line (BML) and terrane 2 (T2)

The BML is the fault at the sole of the Boil Mountain Complex (fig. 2, Єop), or the Jim Pond Formation (Єovs) where the Boil Mountain is absent. These units comprise the leading side of T2, which also contains (1) euxinic melange (Єem) mapped as the Hurricane Mountain Formation, (2) Late Proterozoic(?) sialic basement of indeterminate character shown by Stewart and others (1993) as the lowermost layer of their Central Maine and Nashoba-Casco-Mirmachi composite terranes, and (3) oceanic flysch (O€f) mapped as the Dead River and Aziscohos Formations, deposited on the melange and on the indeterminate basement before the Taconian collision. Upper Proterozoic rocks of the Massabesic Gneiss Complex (fig. 1, MG) and the Dry Hill Gneiss (DHG), dated respectively at 623±8 Ma (Aleinikoff and others, 1995) and 613±3 Ma (Tucker and Robinson, 1990; U-Pb zircon), might be exposures of the indeterminate basement. If so, because both occurrences are out of sequence with far younger surrounding rock assemblages, some mechanism (such as thrusting, diapirism, or deep erosion before deposition of the Ammonoosuc Volcanics of that area) must be devised to account for their presence.

Boone and Boudette (1989) proposed that the T1-T2 collision was a late Cambrian to early Ordovician Penobscottian event. According to their model, Penobscottian accretion along the BML produced a composite terrane, T1+T2, that subsequently collided with the Laurentian craton along the BBL, resulting in the Middle Ordovician Taconian orogeny. Ophiolites of both belts have geologic and petrochemical characteristics of ophiolites that formed in suprasubduction settings [(Shaw and Wasserburg, 1984, and others (BBL); Boudette, 1982; Coish and Rogers, 1987 (BML)], not far from the edges of sialic basement, and the process of obduction in both belts was probably according to the model of Cawood and Suhr (1992), but at different times.

Available isotopic age data suggest that the Boil Mountain Complex is the oldest ophiolitic body in the Quebec-Maine Appalachians. Eisenberg (1981, 1982) reported a U-Pb zircon upper intercept age of 520±12 Ma from trondhjemite of the Boil Mountain Complex. Although his data are strongly discordant and were analyzed at two separate laboratories (see Boone and Boudette, 1989, p. 29, and Moench and others, 1995, site E-1, for discussions), they are tentatively supported by an age of about 520 Ma obtained from three of five zircon size fractions separated from weakly metamorphosed fragmental sodarhyolite of the Jim Pond Formation (Aleinikoff, *in* Moench and others, 1995, site M-4); the other two fractions showed evidence of an older component of undetermined age. Tentative support for a Cambrian age for the Boil Mountain Complex and Jim Pond Formation is provided by primitive sponges recovered from the overlying Hurricane Mountain Formation (Harwood, 1973) for which R.M. Finks (oral commun. to Moench, 1983, and to G.M. Boone, 1986) preferred a Cambrian age, although he did not rule out an Ordovician age. [The oft-cited age of about 500 Ma reported for the Jim Pond Formation (Aleinikoff and Moench, 1985) was obtained from probable detrital zircon in Silurian felsic schist (tentatively but incorrectly correlated to the Jim Pond when sampled) exposed 60 km southwest of the type belt of the Jim Pond Formation (see Moench and others, 1995, site M-5).]

Although we emphasize the need for further study, the best available age for the Jim Pond Formation and Boil Mountain Complex is about 520 Ma. As already discussed, the BML was drawn on figure 1 to include the Orford Ophiolite Complex, dated at 504±3 Ma (David and others, 1993), in T2 near the postulated junction of the BML and BBL. These data indicate that the Boil Mountain and Orford are the two oldest known ophiolites in the Appalachian-Caledonian orogen (Dunning and Pedersen, 1988).

Mapped lithologic sequences, graptolite occurrences, and U-Pb zircon age data indicate that ophiolitic melange assemblages that occur above the BBL and those that occur above the BML are unrelated. As described by Cousineau and St. Julien (1992), the St. Daniel Formation contains a sequence of lithologic types correlated to the Frontiere, Etchemin, Beauceville, and St. Victor Formations (ascending order) of the Magog Group. The Beauceville and St. Victor Formations contain Ordovician graptolites (St. Julien and Hubert, 1975, p. 350) that correspond respectively to the *Nemagraptus gracilis* and *Diplograptus multidens* Zones of Riva (1968, 1974). Berry (1962) also recognized graptolites corresponding to his *Climacograptus bicornis* Zone in the Magog, and (Harwood and Berry, 1967) in black slate now mapped as the Partridge Formation (Moench and others, 1995), shown as unit Oe on this map. The lithologically similar Partridge and Beauceville Formations are therefore coeval; in our view, they are euxinic sedimentary expressions of the Bronson Hill magmatic arc, discussed later (event 3 on the correlation diagram). The cited graptolite zones correspond to latest Whiterock to middle Mohawk (late Llandeilo to middle Caradoc) time (Ross and others, 1982, sheet 12), which correspond to numerical ages of about 460–453 Ma (Tucker and McKerrow, 1995).

In contrast, the Cambrian(?) Hurricane Mountain Formation is conformably overlain by the unfossiliferous flysch sequence (O€f; Dead River and Aziscohos Formations), which in the region between Oquossoc, Maine, and Littleton, N.H. (grids 4D to 8G) is conformably overlain by the Ammonoosuc Volcanics (Olv) or, locally, by the Partridge Formation (Oe). As shown by ages of 467±3 Ma and 469±2 Ma obtained respectively from the Chickwolnepy intrusions and Joslin Turn pluton (indexes 39, 57), emplaced across and near the Dead River–Ammonoosuc contact, the uppermost beds of the Dead River Formation are no younger than about 470 Ma (see Moench and others, 1995, sites O-7, O-13). According to Tucker and McKerrow (1995), 470 Ma corresponds to the Arenig-Llanvirn boundary (early-middle Whiterock time of Ross and others, 1982). Evidence summarized by Boone and Boudette (1989, p. 27, 28, table 1) for northern Maine exposures of the Dead River Formation suggest that its uppermost beds are no younger than middle Arenig, or about 475–480 Ma (Tucker and McKerrow, 1995). These relationships indicate that Pinet and Tremblay (1995) have incorrectly correlated the Magog Group to the Dead River Formation, and the Thetford Mines and related Ordovician ophiolites above the BBL to the Boil Mountain Complex and Jim Pond Formation.

Summary

The Boil Mountain–Jim Pond ophiolite formed above a southeast-dipping subduction zone near the Boundary Mountains terrane, possibly in early Middle Cambrian time (if correctly dated at about 520 Ma), somewhere in the middle of Iapetus. The ophiolite and oceanic crust to the southeast were backed farther southeast (present direction) by indeterminate Upper Proterozoic(?) basement of T2, possibly represented by the Massabesic Gneiss Complex in southeastern New Hampshire, and the Dry Hill Gneiss of western Massachusetts (fig. 1, MG, DHG). While still hot, almost certainly before the end of Cambrian time, the ophiolite and associated melange at the leading edge ramped northwestward over T1 forming a composite terrane (T1+T2) that continued northwestward, above a second southeast-dipping subduction zone. Beginning about 480 Ma (Whitehead and others, 1993, 1996) T1+T2 collided with the LC and ramped several tens of kilometers over the Grenvillian basement, but, because of Silurian extension, discussed later, probably a considerably shorter distance than implied by the profiles of Stewart and others (1993). The earlier T1-T2 collision occurred in an oceanic setting and was followed by abyssal flysch sedimentation that continued to about 470 Ma, when Bronson Hill arc and back-arc magmatism and sedimentation began. Whereas southeast-dipping subduction best explains the northwestward obductions represented by the BBL and BML, the occurrence of younger Ordovician rocks of the Bronson Hill arc on or marginal to the Taconian margin of the Laurentian craton probably requires a reversal of subduction polarity.

Middle to Late Ordovician magmatism and sedimention related to the Bronson Hill arc

[Rock assemblage numbered 3 on correlation diagram]

The Sherbrooke-Lewiston area contains the type localities or type areas of the principal named volcanic and sedimentary components of the Bronson Hill magmatic arc, including the Ammonoosuc Volcanics (Olv), the euxinic sedimentary Partridge (Ole) and Quimby Formations (Oue), and the volcanic and euxinic sedimentary members of the Quimby Formation (Ouv, Oue). As already cited, the earliest Ammonoosuc eruptions occurred at about 470 Ma. U-Pb zircon ages for metavolcanic rocks include 461±8 Ma for felsic metatuff in the Ammonoosuc, and 444±4 Ma for the basal felsic metatuff of the volcanic member of the Quimby Formation (Aleinikoff, *in* Moench and others, 1995, sites M-9, M-10). Also reasonably included are (1) small remnants of the Ordovician (Cincinnatian) Lobster Mountain Volcanics (in Ouv), whose type locality is a short distance northeast of the report area and (2) exposures of several named and unnamed Ordovician volcanic units in northern Maine (see Winchester and van Staal, 1994, and references therein). Petrochemical studies by several researchers indicate that the middle Whiterockian through Cincinnatian (Lanvirnian through Ashgillian) metavolcanic rocks that we include in the Bronson Hill magmatic arc were generated in arc, back-arc, or possibly fore-arc tectonic settings (Leo, 1985; Schumacher, 1988; Hollocher, 1993; Winchester and van Staal, 1994). The Chickwolnepy intrusions (index 39) and associated basaltic rocks in the lower part of the Ammonoosuc Volcanics of the Milan area, New Hampshire, probably represent supra-subduction ophiolite (Fitz and Moench, 1996; Fitz, 1996a, b). The Chickwolnepy ophiolite formed by incipient sea-floor spreading at an angle of about 60° to the orogenic trend (Fitz and Moench, 1996), probably in a setting of low-angle oblique sinistral subduction. The Chickwolnepy and early Ammonosuc magmas evolved to arc-type magmas of felsic and mixed composition represented by the upper part of the Ammonoosuc Volcanics. Also arc-type magmas are the predominantly felsic plutons of the Oliverian and Highlandcroft Plutonic Suites, discussed below. Lead isotope studies indicate that Highlandcroft plutons, but not Oliverian plutons, were generated from Grenville (or Chain Lakes) basement (Ayuso and Bevier, 1991; Aleinikoff and Moench, 1987). Accordingly, the Highlandcroft and Oliverian plutons might occur above opposite sides of the Grenville margin below T2. Alternatively, if the southeasternmost Grenville basement is southeast of the Oliverian belt, as shown by Thompson and others (1993, section A–A'), the Oliverian magmas might have been generated in a rift that penetrated the Grenville.

We interpret the Ascot Formation and Magog Group, a Middle to Late Ordovician volcano-sedimentary sequence northwest of the CVT in Quebec (fig. 2), as a remnant of the Bronson Hill arc that was left behind when the majority of the arc was split from the Laurentian margin during Silurian extension, and migrated southeastward to form what is now the BHBMA. This interpretation is supported by reported U-Pb zircon ages of 460±3 and 440+6/−8 Ma obtained recently from the Ascot Formation (David and others, 1993); these ages are respectively comparable to those of the Ammonoosuc Volcanics and Quimby Formation, already cited.

In addition to the Joslin Turn pluton (index 57; 469±2 Ma) and Chickwolnepy intrusions (index 39; 467±3 Ma), intrusive components of the Bronson Hill arc in the map area include the many bodies of the predominantly calc-alkalic Highlandcroft (Ohu, SOha) and Oliverian (Oou, SOoh) Plutonic Suites, all but one of which are dated in the range of 458–441 Ma (Aleinikoff, *in* Moench and others, 1995, sites S-3, O-1 to O-6, O-8 to O-12). The exception is pink biotite granite of the Cambridge Black pluton (index 38), dated at 468±3 Ma (J.N. Aleinikoff, written commun., 1997), which intrudes metadiabase dikes of the Chickwolnepy intrusions. On the basis of their proximity and similar age, the Cambridge Black granitic magma is reasonably interpreted to have formed by partial melting of sialic crust, or of Dead River or older deposits, by heat that was introduced by Chickwolnepy gabbroic magma. Although the Highlandcroft and Oliverian Plutonic Suites are mainly felsic and calc-alkalic in composition, the central part of the Oliverian Jefferson batholith (index 63; SOoh) contains mildly alkalic hornblende granite, quartz syenite, and syenite; the syenite and quartz syenite have yielded an earliest Silurian age of 441±15 Ma (Foland and Loiselle, 1981; Rb-Sr whole rock).

Sevigny and Hanson (1995) have recently obtained U-Pb zircon ages of 453±3 Ma and 446±2 to 436±2 Ma, respectively, for intrusive rocks of the informally named Brookfield plutonic series and Newtown gneiss, exposed in southwestern Connecticut, west of the CVT. These intrusions can be included in the Bronson Hill magmatic arc on the same basis as the volcanic rocks of the Ascot Formation of Quebec.

Stratigraphic relationships and isotopic age data permissively suggest that a volcanic hiatus occurred between about 460 and 445 Ma, during the time of sedimentation of the euxinic Partridge Formation (Oe), after eruption of the Ammonoosuc Volcanics and before eruption of the volcanic member of the Quimby Formation. This apparent volcanic hiatus is partly bridged by metavolcanic rocks of the southern part of the Bronson Hill arc, western Massachusetts, where Tucker and Robinson (1990) dated felsic metavolcanic rocks from the Ammonoosuc Volcanics and the Partridge Formation at 453±2 Ma and 449+3/−2 Ma, respectively. When one considers plutonic as well as metavolcanic rocks, the 460- to 445-Ma gap is closed by the many cited ages obtained for the Highlandcroft and Oliverian Plutonic Suites. All these data indicate that no important magmatic hiatus occurred between 470 and 440 Ma.

Although none of the Highlandcroft and Oliverian plutons are known to have breached the surface, at least some are high-level intrusions. The Lost Nation and Highlandcroft plutons (indexes 53, 58), for example, are chilled against the country rocks, which are locally converted to fine-grained hornfels. The Catheart Mountain pluton (index 3) must be a near-surface intrusion in order to host the Catheart copper-molybdenum porphyry deposit. The Attean pluton (index 2), dated at 443±4 Ma (Lyons and others, 1986; U-Pb zircon), is overlain by probable remnants of the fossil-dated, latest Ordovician (Cincinnatian and Ashgillian) Lobster Mountain Volcanics (Neuman, 1973); these rocks might indeed be comagmatic.

The bottommost metavolcanic rocks of the Ammonoosuc Volcanics in the Littleton area (grid 8G) are felsic. Here, fine-grained, variably altered, and locally sparsely copper-mineralized felsic metatuff is intruded by the Joslin Turn pluton (index 57), composed of weakly metamorphosed tonalite that locally displays granophyric texture, noted by Rankin (1995, 1996) and Moench and others (1995). The pluton is lenticular and semiconcordant. Near the north end of the pluton, where it is about 4 m thick, the pluton intrudes strongly altered, abundantly pyritic, silicified, and sparsely copper-mineralized metarhyolite of the Ammonoosuc Volcanics. Here, the pluton lies 50–75 m west of and stratigraphically above the contact of the Ammonoosuc with underlying pyritic slate and graded quartzwacke of the Dead River Formation, also hydrothermally altered. Although Rankin (1996, fig. 1) has mapped a thrust fault at this contact, Moench believes that he confused the probable pluton-generated alteration features for evidence of a fault. According to recent mapping (Moench, 1996a, fig. 4; unpub. mapping, 1996), several small offshoots of the Joslin Turn pluton occur just above or just below the same contact. This contact is folded, however, so that not all of the offshoots are directly on strike with the main body. [See Moench (1996a, fig. 4), and Rankin (1996, figs. 1, 5) for alternative mapping in the vicinity of the Joslin Turn pluton; also see the following section for discussion of the relevance of granophyric textures to the P-F allochthon controversy, as emphasized by Rankin (1995, 1996).]

Moench (1995) interpreted the main pluton as the upturned edge of a high-level laccolith that generated the hydrothermal system that altered and locally mineralized the tuffs. As such, the 469±2 Ma age of the pluton can be considered to date some of the earliest Ammonoosuc eruptions.

In summary, plutonism and volcanism represented by rocks of the Bronson Hill magmatic arc occurred on and marginal to the Taconian margin of the LC, during and after Taconian accretion of T1+T2 to the LC. Accretion probably began shortly after 480 Ma, when the Thetford Mines ophiolite originated (Whitehead and others, 1996), and culminated in locally medium-high-pressure metamorphism at 465±10 Ma (Laird and others, 1993, p. O-17). Armstrong and others (1992) have proposed that peak high-grade to low-grade metamorphic conditions occurred at about 475–445 Ma from east to west in the Taconian hinterland to foreland. Northwest-vergent Taconian thrusting and folding continued through Middle and Late Ordovician time. Oceanic flysch sediments (O€f) that accumulated above T2 ended at about 470 Ma, during the Taconian accretion, and Bronson Hill arc magmatism began. The earliest magmas, of basaltic and tonalitic composition, were generated in a supra-subduction setting (Fitz and Moench, 1996; Fitz, 1996a, b), and they evolved to mixed and abundantly felsic compositions later in Ordovician time, represented by the upper members of the Ammonoosuc Volcanics, the volcanic member of the Quimby Formation, and the Oliverian and Highlandcroft Plutonic Suites. The Highlandcroft and predominantly felsic Ascot magmas of the LC margin were probably generated from Grenville basement, mainly after Taconian accretion. To judge from the disconformity and major unconformity mapped recently at the base of the Quimby Formation, shoaling that preceded major Silurian uplift began in latest Ordovician time. This event is dated by the U-Pb zircon age of 443±4 Ma obtained from the basal felsic metatuff at Bath, N.H.

The earliest eruptions of Bronson Hill magmas probably occurred far from the LC shore, possibly due to continuing southeastward Taconian subduction. As Iapetus closed, however, arc polarity probably reversed and arc magmas of more continental character were generated on or just off the LC margin, above a northwest-dipping subduction zone. This model approximately accords with the model proposed by van Staal (1994, fig. 8) for the Brunswick subduction complex (fig. 1, BSC). Tentatively, the sole of the Brunswick subduction complex, shown as the New Brunswick line on figure 1 (NBL), might be considered the subduction zone that generated all but the earliest Bronson Hill magmas.

The BHBMA is truncated on the west by faults of the M-F-T line (fig. 1) and probably represents one of possibly five eastern remnants (now represented by the BHBMA, LMA, M-WA, W-LA, and MA, fig. 1) of a major landmass that emerged in latest Ordovician to earliest Silurian time. This emergence accompanied the termination of magmatism associated with the Bronson Hill arc, and represents the beginning of a major extensional tectonic regime, discussed in the next section.

Late Ordovician and Silurian sedimentation and magmatism related to synconvergent extension

[Rock assemblage numbered 4 on correlation diagram]

In this report, Silurian history is emphasized over earlier and later histories because it has been treated less adequately elsewhere.

The Silurian Period, possibly beginning in Late Ordovician (Cincinnatian or latest Caradoc and Ashgill) time, was a time of block faulting, basin formation, sedimentation, and strongly bimodal magmatism produced by rifting. In the Sherbrooke-Lewiston area, extension occurred approximately normal to the orogen, as described herein, but was probably dextral-oblique to the orogen (transtensional) in the Gaspé Peninsula (Malo and Borque, 1993, p. 119). According to Moench (1996b), extension was driven by rapid retreat, or rollback, of a northwest-dipping subduction zone inferred by Ludman and others (1993) and van Staal (1994) to have been active in latest Ordovician and Silurian time in the boundary between T2 and T3 (fig. 1). Rollback processes are described by Royden (1993a, b). Evidence for extension follows.

Central Maine and Aroostook-Matapedia troughs (CMT, AMT)

Ludman and others (1993, fig. 7) have recently interpreted the AMT and the adjacent W-LA and MA as a Late Ordovician and Silurian horst-graben-horst structural complex. Their argument is based largely on the distribution of conglomeratic debris-flow deposits and associated clastic turbidites, derived from the adjacent anticlinoria, along both margins of the AMT. These deposits grade basinward to more distal, siliciclastic and calcareous turbidites. This facies pattern defines the paired Silurian tectonic hinges (STH) that are shown on oppposite sides of the AMT (fig. 1), along and west of the Maine–New Brunswick border.

As shown on figure 1, the western STH of that area extends southwestward along the northwest margin of the CMT, where Moench (1996b) has proposed a similar model for the CVT, BHBMA, and CMT. Here, conglomerate-bearing, proximal turbidite sequences of Llandoverian age on both sides of the STH likewise grade southeastward to more distal siliciclastic and calcareous turbidites of approximately the same age in the southeastern part of the CMT (**Sbe**). Unlike the paired hinges that bound the AMT, no mirror-image equivalent to the STH of western Maine can be defined in southeastern Maine, possibly because of truncation by the Norumbega fault system (fig. 1, NFS).

The stratigraphic basis for the STH of western Maine is shown on figure 3, and is best demonstrated by the southeastward transition from the Upper Llandoverian Clough Quartzite (of **Sns**) to far thicker, conglomerate-bearing facies of the Llandoverian Rangeley Formation (of **Sbw**). [See unit descriptions in Appendix I, and Moench and others (1995), and discussions in Moench and Pankiwskyj (1988a), and Moench and Boudette (1987).] Briefly, thin lenses of Clough Quartzite (quartzite and quartz conglomerate) are exposed in a narrow belt that crosses the north end of Kennebago Lake (grid 3D). These lenses are interpreted to mark the northwestern depositional edge of the basal portion of member C of the Rangeley Formation. Below the lenses is a thin layer of member B (mainly dark-gray slate) that is unconformably underlain by the Dead River Formation (of **O€f**). Above the lenses is the upper part of member C (600 m of dark-gray slate and feldspathic quartzite), which is conformably overlain by the Perry Mountain Formation (pale-green slate, feldspathic quartzite, and minor felsic volcanic rocks), of unknown thickness in the Kennebago Lake area.

Near the south end of Kennebago Lake (grid 3D) are basal rocks of member C, composed of fossil-bearing, upper Llandoverian quartz conglomerate and metalimestone, a few tens of meters thick. These rocks represent approximately the same sedimentary level as the Clough Quartzite. Below the fossil-bearing beds, however, is a thin, conformable sequence, in descending order: (1) member B of Rangeley Formation (dark-gray slate); (2) member A of Rangeley Formation (about 10 m of massive polymictic conglomerate); (3) the Greenvale Cove Formation (of **Ste**; probably less than 200 m of calcareous feldspathic siltstone and sandstone); and (4) the euxinic metashale and metagraywacke member of the Quimby Formation (of **Oue**; about 700 m of black slate and volcaniclastic graywacke).

The Quimby and Greenvale Cove Formations (of **Oue** and **Stw**) continue southeastward, with little change, into the Rangeley Lake area (grid 3E). Here, however, the polymictic conglomerate of member A becomes a 1,200-m-thick body of upward-coarsening, southeastward-fining subaqueous fanglomerate; and member B becomes an additional 1,200 m of commonly slump-folded, euxinic turbidites, and southeastward-fining, quartz-rich polymictic debris-flow deposits. Member C becomes a more distal turbidite, relative to its exposures near

Kennebago Lake, again about 600 m thick, having a southeastward-fining basal unit of interstratified dark-gray schist, sandstone, and quartz conglomerate (coeval with the Clough Quartzite), and an upper unit of dark-gray schist and feldspathic quartzite.

To complete the Silurian sequence, member C of the Rangeley is gradationally overlain by the Perry Mountain Formation (about 600 m of more distal and more mature, noneuxinic turbidites), succeeded by the Smalls Falls Formation (as much as 750 m of strongly euxinic schist, quartzite, and calcareous deposits), and the Madrid Formation (300 m of calcareous sandstone, siltstone, and gray pelitic schist). The Madrid is considered to be the deep-water equivalent of the Fitch Formation (of Sns), of Pridolian and upper Ludlovian age. Facies relationships consistently point to a northwestern source for the entire Rangeley to Smalls Falls sequence, but the provenance of the overlying Madrid Formation probably shifted to the coastal volcanic belt (fig. 1, CVB) to the east. Conformably above the Madrid are typically dark-gray, mud-silt-sand turbidites of the Lower Devonian cover sequence (Dc), which coarsens upward and southeastward, probably in response to encroachment of T3, just before the Acadian T2-T3 collision.

These relationships demonstrate that the STH is a boundary between regions that underwent uplift to the northwest and subsidence to the southeast. The earliest Silurian(?) Greenvale Cove sediments were shed from the emerging western source area, which, in Llandoverian time, very quickly became a mountain range. The range shed the enormously thick, conglomeratic Rangeley deposits. As differential uplift and subsidence slowed, the range was worn down, and shed the progressively more mature, more distal, upper Rangeley and Perry Mountain deposits. In Ludlovian time, renewed subsidence produced a closed, anoxic basin that received black sulfidic deposits now represented by the Smalls Falls Formation.

The vertical movements that produced the STH were probably controlled by one or more normal master faults that were active through Silurian and into Early Devonian time. One of the faults is probably represented by the premetamorphic Mahoosuc fault (MF), which displaces Lower Devonian and Silurian deposits of the CMT (Dc, Sbw) against Ordovician and older rocks of the BHBMA. Where seen in outcrops, the fault dips 80° SE.; faulted conglomerate of the Rangeley Formation contains granitic, volcanic, and plutonic boulders that are extremely rodded almost directly down dip. The northeastern terminus of the MF is probably represented by the Hill 2808 fault (2808F), mapped at Rangeley Lake (grid 3E). As described elsewhere (Moench, 1970; Moench and Pankiwskyj, 1988b), this fault probably originated during Silurian sedimentation as a southeast-dipping, normal, listric, growth fault, bordered to the southeast by a back-tilted syncline-rollover anticline pair. Acadian compression only tightened and amplified the whole fault-fold structure. Although Bradley (1989) reinterpreted the 2808F as a rotated thrust fault, he did not address the three-dimensional, fault-fold relationships that form the basis of the interpretations of Moench (1970) and Moench and Pankiwskyj (1988b). Shown on map A is a family of other premetamorphic extensional faults mapped along the northwest side of the CMT.

The STH and the MF are here interpreted as expressions of a deeply penetrating normal fault that was controlled by the southeastern margin of Grenville basement of the LC. This view is suggested by the fact that the STH approximately coincides with the Grenville margin at depth, as shown by seismic studies (Stewart and others, 1993), and by the lead-isotope data of Ayuso and Bevier (1991). According to Ayuso and Bevier (1991), Ordovician and younger plutons exposed northwest of the STH have a Grenville-like lead-isotope signature that is less radiogenic than plutons to the southeast. These data indicate that the Grenville margin extends laterally approximately along the trend of the STH at least from northeastern Maine to the Maine–New Hampshire border just north of the Jefferson batholith (indexes 63, 64).

Farther southwest, however, seismic, U-Pb zircon, and lead-isotope feldspar data suggest that the Grenville margin diverges from the STH, to an alignment that lies between plutons of the Oliverian and Highlandcroft Plutonic Suites, respectively east and west of the Grenville margin (Lyons and others, 1996, p. 881; Aleinikoff and Moench, 1987). According to these data, the Highlandcroft plutons were generated from Grenville-like basement, whereas the Oliverian plutons were not. However, the Oliverian magmas may have been generated in a rather narrow, Grenville-free rift, because the garnet-bearing Kinsman Granodiorite crops out in a belt that lies southeast of the Oliverian belt. Garnet (almandine)-bearing magma requires a depth of origin of at least 50 km (Stewart, 1989, p. 706, and references therein). Such a depth would be satisfied by a slice of Grenville-like crust between the Oliverian belt and the STH south of the 44th parallel.

The Grenville margin was probably underthrust to its present inferred position below the STH of western Maine by latest Ordovician time. This interpretation is based on the fact that the Attean pluton (index 2), dated at 443±4 Ma (Lyons and others, 1986), has a Grenville-like lead-isotope signature (Ayuso and Bevier, 1991), and probably formed by partial melting of Grenville-age basement. Although the Attean pluton intrudes rocks of the Chain Lakes massif (€Pc), which also has a Grenville-like lead isotope signature, the Chain Lakes is a much less likely melting source because it is no thicker than 5 km, whereas the underlying Grenville basement is at least an additional 40 km thick (Stewart, 1989; Stewart and others, 1993; Rankin and Tucker, 1995).

It follows that the bouyancy of the thick, predominantly felsic Grenville (plus Chain Lakes) crust is a likely cause of Silurian uplift northwest of the STH, and that the Grenville margin a likely site of Late Ordovician to Early Silurian rupture that initiated subsidence southeast of the STH. The rupture probably penetrated to mantle depths, and probably was active into Early Devonian time. The basis of this interpretation is the fact that the Flagstaff–Sugarloaf–Pierce Pond–Moxie group of Early Devonian gabbroic plutons (indexes 19A, 24, 20; Osberg and other, 1985) approximately coincides with the STH for a distance of about 125 km from near Rangeley, western Maine, to the Katahdin batholith, north-central Maine (Osberg and others, 1985).

Connecticut Valley trough (CVT)

The CVT is bounded by major faults. The northwest side is marked by the Guadeloupe fault (GF) in Quebec, which is coextensive with a rupture widely called the "Richardson Memorial Contact" or RMC (Thompson and others, 1993, fig. 4, p. 24) in Vermont. In the area of figure 2, the GF displaces Silurian and Early Devonian deep-water deposits of the CVT (DSs) against Ordovician volcanic and sedimentary deposits and plutonic rocks, and unconformably overlying Silurian near-shore deposits exposed northwest of the CVT. Studies by Cousineau and Tremblay (1993) indicate that the GF is a northwest-directed Acadian thrust fault. The GF might, however, have a Silurian ancestry as a deep-penetrating, basin-margin normal fault that was reactivated as a relatively minor Acadian thrust fault. This interpretation is suggested by the character of the GF at depth, according to published interpretations of the Quebec-Maine seismic profile (Spencer and others, 1989; Stewart and others, 1993). As depicted in the interpretive cross section of Stewart and others (1993), the GF dips southeast at a moderate angle, and extends to a depth of about 13 km, where it flattens slightly and penetrates the Grenville basement. As shown, the basement is broken and thinned below the central part of the CVT.

The southeast margin of the CVT is marked by the Monroe–Foster Hill–Thrasher Peaks line (M-F-T), which, as defined by Moench (1993), sharply marks the northwestern limit of known near-shore Silurian deposits of the BHBMA. The M-F-T combines three faults of very diverse character: (1) the Thrasher Peaks fault (TPF) northeast of Magalloway Mountain (grid 5D); (2) the strongly folded Foster Hill fault (FHF) from Magalloway Mountain southwest to near Fairlee Vermont (in grid 9I); and (3) the Monroe fault (MNF) farther south.

The MNF and its correlatives extend at least 450 km from northern Massachusetts into northwestern Maine. The type locality of the MNF is near Monroe, N.H., and the name "Monroe" is currently applied to the fault from Springfield, southeastern Vermont, to where the fault is cut by the Jurassic Gore Mountain plutons (index 43). South of Springfield, the same structure is informally known as the "Chicken Yard line," (Thompson and others, 1993, p. 24), and north of the plutons it is shown on map A and figure 2 as the Perry Stream, Victoria River (as now located by Tremblay and Pinet, 1994), and Marie Petuche faults (PSF, VRF, MPF). Northeast of the Gore Mountain plutons, the MNF extensions form a northwest-vergent thrust fault that dips steeply southeast (Jahrling, 1983; Jahrling and Bothner, 1983; Tremblay and Pinet, 1994; Marvinney, 1989). In this area, the fault displaces the Silurian Frontenac Formation (Srw, Srwv) over metasedimentary rocks of the same formation and, locally, Lower Devonian rocks tentatively shown as the Ironbound Mountain and Compton Formations (of Dp, Dc). Marvinney (1989) estimated a thrust displacement of about 1 km for exposures of the MPF in grid 1A. A short distance south of the Gore Mountain plutons, the MNF is cut, deformed, and contact metamorphosed by the Devonian Maidstone and Victory plutons (indexes 50, 52). Between the Gore Mountain plutons and the area of Fairlee, Vt. (in grid 9I), the MNF is similarly a southeast dipping thrust fault (Rankin, 1996, p. 21) that displaces Silurian rocks of the Frontenac Formation and the Piermont sequence (Srw, Srp) over Lower Devonian sequences (Dp?, Dc); two sheeted dike bodies (indexes 93, 99) also were thrust northwestward. [See Rankin, 1996, for an alternative interpretation]. South of Fairlee, the MNF displaces known Ordovician rocks of the BMA over Silurian and Lower Devonian rocks of the CVT. Near Fairlee and farther south (Moench, 1996a, fig. 5; Thompson and others, 1993, sections A–A', B–B'), the MNF is strongly folded by major, southeast-dipping, northwest-vergent nappes. These north-to-south changes express the more intense effects of Acadian deformation that are displayed in the deeper crustal levels represented toward the south. Although the surface expressions of the MNF and its continuations are compressional, available evidence does not rule out an extensional ancestry.

The FHF is mapped from its intersection with the MNF near Fairlee, Vt., to its intersection with the TPF near Magalloway Mountain (grids 9I to 5D). Typically, it is a knife-sharp, strongly folded, premetamorphic fault that has a sinuous trace, and outlines the Towns Mountain outlier (TMO) and the Coppermine Road window (CuRW). It is consistently a younger-over-older fault that displaces rocks of the Piermont sequence over Ordovician and older rocks of the BHBMA. The FHF marks the sole of the P-F allochthon, and is interpreted to have been, prior to Acadian compression, a gently west-dipping surface of gravity sliding that carried the Piermont sequence into the CVT from its site of deposition between the inferred Bronson Hill and Somerset Islands (fig. 2, BHI, SI). Displacement probably ended no later than about 410 Ma, because rocks of the Piermont sequence are cut by the Fairlee pluton (index 94), dated at 410±5 Ma (Aleinikoff, *in* Moench and others, 1995, site D-9). Because basal Emsian rocks have been recently dated at about 408–409 Ma (Bradley and others, 1996), transport probably occurred during marine sedimentation earlier in Devonian time. The Gedinnian(?) Ironbound Mountain Formation (of Dp), which is cut by the FHF, is thought to have accumulated on the allochthon during transit.

As shown on map A and figure 2, the Thrasher Peaks and Deer Pond faults (TPF, DPF) closely follow the southeastern margin of the CVT. In Quebec literature, the TPF is named the Woburn fault; the same fault was named the western Boundary fault by Spencer and others (1989), and the northwest boundary fault by Westerman (1983). The DPF was named the Sandy Stream fault by Spencer and others (1989).

The TPF marks the actual CVT-BMA boundary; it juxtaposes a narrow belt underlain by the Lower Devonian (Gedinnian?) Ironbound Mountain Formation (Dp) against the Chain Lakes massif (ЄPc) and overlying Cambrian to Lower Devonian stratified rocks of the BMA and the Ordovician Attean pluton (index 2), as shown on map A. The DPF marks the northwest side of the Ironbound Mountain belt, northwest of which are the Frontenac Formation and the Piermont sequence. Mapping indicates that the DPF and probably the TPF are cut by the Spider Lake pluton, dated at 367.7±1.3 Ma (Heizler and others, 1986, $^{40}Ar/^{39}Ar$ hornblende).

The rock assemblages exposed southeast of the TPF contain thin sequences of commonly fossiliferous Silurian near-shore deposits (Sns) that lie unconformably above Ordovician rocks of the BMA. In contrast, northwest of the TPF, the Ironbound Mountain Formation (Dp) is conformably underlain by the Madrid Formation or, where the Madrid is absent, by the Smalls Falls Formation (both of Srp). A possible exception is where thin lenses of Silurian limestone (Sns) occur along the TPF (Westerman, 1983; Albee and Boudette, 1972) along the northwestern boundary of the Attean pluton (index 2). Here, Westerman (1983) described breccias involving rocks of Dp, Sns, and the pluton, and common northwest-plunging lineations along the TPF (his "northwest boundary fault"). According to our interpretation, the limestone lenses are slices within the TPF zone, and are remnants of Sns beds now exposed at the northern tip of the pluton; we believe that the principal segment of the TPF lies between the Dp exposures and Sns lenses, rather than between the Sns lenses and the Attean pluton (Westerman, 1983, fig. 2).

R.H. Moench (unpub. field observations, 1981) has observed northwest-dipping cataclastic foliation and northwest-plunging lineations where the TPF cuts the Dead River Formation near Magalloway Mountain (grid 5D). Marvinney (1989), however, has recognized subhorizonal lineations and granitic clasts derived from the Attean pluton at exposures of the TPF where the Ironbound Mountain Formation is faulted against other units of the Seboomook Group in grids 2A and 2B; he proposed that at least 8 km of right-lateral displacement occurred along the TPF in that area.

Although the TPF is difficult to trace far northeast of the area of map A, and southwest of Magalloway Mountain (grid 5D), seismic reflection and refraction data indicate that the TPF is a major crustal feature where it cuts the Chain Lakes massif. The TPF, DPF, and GF are the only faults exposed within or bounding the CVT that are visible in the seismic profile (Spencer and others, 1989; Stewart and others, 1993). As shown in the profile, the TPF dips northwest at steep to moderate angles, and flattens with increasing depth; it cuts the Grenville basement at depths of 10–20 km. The DPF likewise dips steeply northwest, but converges downward with the TPF (Spencer and others, 1989, figs. 6, 11). As shown on the interpretive cross section of Stewart and others (1993), the TPF and GF are listric and dip inwardly toward the center of the CVT. Although Stewart and others (1993, p. 6) suggested that the TPF is a normal fault of late Paleozoic or Mesozoic age, evidence already cited indicate that the principal movements on the DPF and TPF occurred no later than the Late Devonian age of the Spider Lake pluton.

In summary, available evidence obtained from surface exposures and from the seismic profile (Spencer and others, 1989; Stewart and others, 1993) are consistent with the interpretation that the GF and TPF are deeply penetrating listric normal faults of Silurian ancestry that were reactivated during Acadian compression. The TPF-DPF companions appear in the profile to define a minor Silurian to Early Devonian graben, subsequently rotated, on the southeast side of the CVT.

The Second Lake rift (SLR, SLRA) is defined by metamorphosed Silurian sedimentary and bimodal volcanic rocks, and predominantly mafic dike swarms and sheeted dike bodies that extend for a distance of 300 km along the southeast side of the CVT. They lie between the MNF and FHF south of the Gore Mountain plutons (index 43), and between the northern continuation of the MNF (PSF, VRF, MPF) and the DPF-TPF pair of faults northeast of the plutons. Petrochemical data for the metabasalts and some of the mafic dikes indicate compositions that are characteristic of regions undergoing extension (see Moench and others, 1995, Note 7, p. 46–47, and references therein; Hafner-Douglass, 1986, 1987; Chevé, 1990; Chevé and others, 1983; Eisenberg, 1983; Desjardins and others, 1994).

The Silurian Standing Pond Volcanics, in the southern Vermont portion of the CVT, also have within-plate, rift-like petrochemical characteristics (Hepburn, 1991), as do Silurian to Early Devonian volcanic rocks of the Gaspé Peninsula (for example, Bedard, 1986), where Silurian block faulting and basin formation probably accompanied dextral transtension (Malo and Borque, 1993, p. 119). Readers are referred to Borque and others (1995) for a detailed discussion of Late Ordovician to Early Devonian sedimentation and tectonism of the Gaspé belt. Additionally, hypersaline sedimentary conditions, common in rift basins, are locally expressed in the southern Vermont portion of the CVT by sodium chloride crystals in fluid inclusions described by Rich (1979), and interpreted by him to indicate the former presence of evaporites.

The principal stratigraphic units of the SLR and SLRA are the Frontenac Formation (of Srw, Srwv) and the Piermont sequence (SOp, Srp, Srpv). As described later, the SLRA (mainly grids 5D to 6E) probably represents an incipient submarine spreading ridge that, according to Moench and others (1992), Moench (1993), and Marvinney and others (1994), separated a sub-basin of Frontenac deposition on the northwest from a sub-basin of Piermont sequence deposition. Eruptive equivalents of the mafic dikes and sheeted dike bodies of the SLR are probably represented by the commonly pillowed basaltic greenstone or amphibolite units in the Frontenac Formation (Srwv). Additionally, much of the lava erupted from the dikes might have flowed westward into deeper parts of the CVT, where they are now represented by the predominantly basaltic Standing Pond Volcanics of southern Vermont (Hepburn, 1991), and amphibolite bodies that occur in the Waits River and Gile Mountain Formations, west of the MNF (Srwv, Dcv). This interpretation is supported by U-Pb zircon ages of 423±4 Ma for a felsic dike in the Standing Pond Volcanics (Aleinikoff and Karabinos, 1990), 419.8±2.6 Ma for pegmatitic metadiorite in the Waterford sheeted dikes (R.D. Tucker, written commun., 1996), and 418±4 Ma for a felsic dike of the swarm in grid 6E (Lyons and others, 1986).

The magmatic axis of the rift (SLRA) is represented in northwestern Maine (grid 1A), where Marvinney (1986) has mapped a thick sequence of abundantly pillowed basalt (of Srwv) that tongues laterally into sedimentary rocks of the Frontenac Formation (Srw). These Silurian sedimentary and basaltic sequences are conformably overlain by the Ironbound Mountain Formation (of Dp).

The principal magmatic center of the SLRA, however, is farther southwest, between the south end of Lac Mégantic, Quebec, and Second Connecticut Lake, N.H. (grids 4C to 5D). Results of a recent study by Cousineau (1995) are incorporated in the Quebec portion of the belt. The metavolcanic rocks of this area are intruded by the high-level, granitic East Inlet pluton (index 12), dated at 430±4 Ma (Eisenberg, 1982; Lyons and others, 1986), and by the Marble Mountain bimodal sheeted dike body (index 11). Both intrusions are interpreted to be comagmatic with the metavolcanic rocks of the belt, which have yielded U-Pb zircon ages in the range of 418–432 Ma (Moench and others, 1995). Additionally, this part of the SLRA coincides with the Mount Bon Durban geophysical anomaly, described in the "Complete Bouguer gravity and aeromagnetics" section by Bothner and others (maps B, C).

Structurally, this belt is broadly anticlinal, forming the Second Lake anticline of Harwood (1969), but it is "creased" parallel to its length by a faulted syncline. The several volcanogenic massive-sulfide deposits (VMS) of the Clinton River district, Quebec, and at Ledge Ridge, Maine, occur within the syncline (map D). When the effects of Acadian compression are removed, the faulted anticline has the appearance of a spreading ridge with an axial half-graben that contains VMS deposits distributed along the graben-valley floor, much as shown by Franklin (1986, fig. 8) for modern spreading ridges.

The Moose Bog fault (MBF), which follows the west limb of the faulted axial syncline of the SLRA, probably originated as a Silurian ridge-crest normal fault; it might have been slightly reactivated as a thrust fault during Acadian compression. During compression, the several small bodies of Devonian(?) diapiric serpentinite (Du) that occur along or near the MBF may have been remobilized from an ophiolitic source at shallow depth, and re-emplaced. The several small, talc-carbonate pods that occur near the south end of the P-F allochton (fig. 6, Du) might have a similar origin. All these ultramafic bodies probably have a mantle origin. Upward expansion of mantle below the SLR is a reasonable inference.

Model for Silurian extension

According to Ludman and others (1993) and Borque and others (1995, p. 349), all of the Ordovician and older rock assemblages that now form the anticlinoriums within T1 and T2 (fig. 1) were firmly accreted to the LC by Late Ordovician time; T3 (or Atlantica of Zen, 1983) was far out to sea, on the opposite side of a remnant of Iapetus. According to Moench (1996b), the T1+T2 belt was far narrower than the present distribution of the anticlinoriums. Beginning in latest Ordovician time, paired subduction zones of opposite polarity—one that dipped northwest below T2 and one that dipped southeast below T3—became active and persisted through Silurian time, much as proposed by Ludman and others (1993); also by Bradley (1983), albeit for a belt now represented by the CMT+FT. T3 became a magmatic island arc, now represented by the Silurian coastal volcanic belt (CVB) (Ludman and others, 1993, p. 76, 77), and by evidence of Silurian tectonism, metamorphism, and plutonism (West and others, 1995). Although the Maine portion of the CVB is strongly bimodal and extensional in character and not typically arc-like (Gates and Moench, 1981; Seaman and others, 1995), the Massachusetts portion (Newbury Volcanics) is more arc-like (Hon and Thirwall, 1985). The Maine portion is therefore reasonably interpreted to represent intra-arc extensional magmatism. Concomitantly, the northwest-dipping subduction zone, perhaps the NBL (fig. 1), produced an accretionary wedge, defined by van Staal (1994) as the Brunswick subduction complex (BSC, fig. 1). Rapid retreat, or rollback, of both subduction zones by processes described by Royden (1993a, b) drew T3 closer to the newly accreted Taconian margin (T2, T1, LC). The Iapetus remnant narrowed rapidly, and became the depocenter of the FT.

Rapid rollback also produced major extension within the T3 arc and the Taconian margin. Grabens, now represented by the CVT, CMT, and AMT, ruptured the margin; the intervening anticlinoriums became horsts that migrated southeastward to positions that probably were much farther than their present locations. Rupturing that initiated the formation of the coextensive CMT and AMT occurred along a zone of crustal thinning and weakness that is now represented by the Grenville margin at depth (Ayuso and Bevier, 1991; Stewart and others, 1993), and by the Silurian tectonic hinges at the surface. Uplift to the northwest occurred in response to the buoyancy of the thick, Grenville-age continental lithosphere, and possibly also in response to extension-induced mantle upwelling below the SLR. Possibly in the middle of Silurian time, the continental lithosphere ruptured along major faults, as the GF and TPF, that bound the CVT. While the CVT widened and deepened, Ordovician and older rocks that now define the BHBMA were sliced from the craton, and migrated southeastward. Concomitantly, the basement below the CVT was necked and ruptured, much as shown in the interpretive cross section of Stewart and others (1993). Incipient seafloor spreading occurred along the SLRA, and rift sediments and volcanics accumulated throughout the enlarging CVT. Deposits of the Piermont sequence accumulated in a saddle over the BHBMA, and, near the end of Silurian time, slid northwestward into the widening and deepening CVT, to form the P-F allochthon. Meanwhile, the CMT to the southeast also widened, deepened, and received an enormous thickness of northwest-derived sediments. Sedimentation in the CMT was accompanied and closely followed by major southeastward slumping, shown by the extensional faults.

In addition to the Standing Pond Volcanics of southern Vermont (Hepburn, 1991), and the mafic and bimodal intrusive and volcanic rocks of the SLR in the Sherbrooke-Lewiston area, magmatic expressions of rifting elsewhere in New England and Canada probably include Silurian plutons that intrude T2 and parts of the CMT, FT, and MT (Bevier and Whalen, 1990; West and others, 1992; Bothner and others, 1993; Zartman and Naylor, 1984).

According to the model presented here, Silurian extension ended in Early Devonian time when oceanic crust was entirely consumed by the paired subduction zones, the Iapetus remnant closed, and T3 came into contact with T2 and became the predominant source for the Lower Devonian cover sequence (**Dc**). If this was the only process of closure that operated, the T3-T2 collision probably would not have had sufficient force to produce the great dynamothermal effects of the Acadian orogeny. A significant push from behind T3 seems to be required, but that's another story.

Early Devonian to Pennsylvanian events

[Rock assemblages numbered 5, 6, and 7 on correlation diagram]

Through Early Devonian time a thick blanket of generally upward- and eastward-coarsening marine turbidites and local volcanic and intrusive rocks was spread over deposits of the Silurian basins and eroded remnants of the island ranges. On map A, this blanket is divided into a parallochthonous sequence (**Dp** and related units) inferred to have accumulated along the southeastern side of the CVT over the P-F allochthon while in transit, and an autochthonous cover sequence (**Dc** and related units) that was spread over all tectonic belts of the map area. As shown by Boucot (1968) and later studies, the principal source of these deposits was probably the encroaching and emerging margin of T3, now exposed along the Atlantic coast (fig. 1). The area of the BHBMA was probably a local source, and it was an axis of subaqueous to subaerial volcanism.

Volcanic and intrusive rocks of Emsian age (**Dcsv**, **Dcsi**) are part of the Piscataquis Volcanic belt of Rankin (1968), long recognized to represent a continental magmatic arc above a subduction zone. Meager petrochemical data from volcanic and intrusive rocks of Gedinnian(?) age (**Dpv**, **Dpid**, **Dcv**) also have arc-like characteristics, in marked constrast to the Fe-Ti basalts that are common in the Silurian metavolcanic sequences. These petrochemical changes accord with geologic evidence that extensional tectonics changed to convergent tectonics at about the Silurian-Devonian time boundary. When correlated with the new time scale of Tucker and McKerrow (1995), available isotopic age data indicate that several orogenic plutons of the New Hampshire Plutonic Suite that yielded isotopic ages in the range of 400–415 Ma, and their correlatives, were emplaced during the deposition of the cover sequence. In reference to figure 2, these probably include the mafic and felsic bodies of indexes 1, 10, 18, 19A–C, 20–24, 32, 33, 68, 84, 85, 90, 94, and 95; the major rock units are the Kinsman Granodiorite, the Bethlehem Gneiss, and the predominantly gabbroic bodies of the belt that includes the Flagstaff Lake, Sugarloaf, and Pierce Pond plutons.

Latest Early Devonian sedimentation was quickly followed by regional folding, cleavage formation, and greenschist-facies metamorphism that accompanied the initial stages of the Acadian orogeny. These events were followed by superposed folding and polymetamorphism described in detail by many authors, most recently by Eusden and Lyons (1993), who have documented an enormous flower structure in central New Hampshire, shown also by Thompson and others (1993, section A–A'). In the Sherbrooke-Lewiston area, major early ductile faulting that preceded the first deformation and metamorphism was accompanied by the emplacement of gabbroic plutons (**Dng**), and was followed through time by ductile to brittle faulting, mainly before emplacement of Devonian plutons, then by purely brittle faulting. Some of the brittle faults contain dikes of Devonian granite, and are therefore no younger than the granite, but others are almost certainly Mesozoic in age; their ages are poorly constrained.

The many Devonian and Carboniferous plutons have characteristics of igneous rocks found in continental magmatic arcs, as shown recently by Ayuso and Arth (1992) for plutons in northeastern Vermont. In accord with mapping, extensive gravity studies of the Devonian and Carboniferous plutons indicate that in areas of high-rank regional metamorphism of central New Hampshire and western Maine, granitic plutons were emplaced mainly as subhorizontal sheets, variably 1–5 km thick, whose metamorphic aureoles are widespread and regional in aspect. In contrast, in areas of lower metamorphic grade to the northeast, the granitic plutons have steep walls and well-defined contact metamorphic aureoles. (See Moench and Zartman, 1976; Nielson and others, 1976; Carnese, 1981;

Carnese and others, 1982; Hodge and others, 1982; Simmons, 1986; Simmons and others, 1988.) Moench and others (1982) proposed that the sheet-like plutons were emplaced at a depth of about 12 km, in the ductile-brittle transition from middle to upper crust. Continental arc plutonism and associated contact metamorphism continued into Pennsylvanian time. However, the small, stock-like Mississippian(?) Androscoggin Lake plutons (index 74), composed of alkalic rocks, are akin to the anorogenic rocks of the White Mountain Plutonic-Volcanic Suite; if correctly dated, these plutons might be considered to herald the beginnings of rifting that preceded the Mesozoic opening of the Atlantic Ocean.

Isotopic age and stratigraphic data from the area of map A (Aleinikoff, *in* Moench and others, 1995) and in the Quebec portion of figure 2 (Simonetti and Doig, 1990) show no evidence of a volcanic and (or) plutonic hiatus from early Middle Ordovician (middle Whiterockian or basal Llanvirnian) to Pennsylvanian time. It can be argued that all of this magmatism, including Silurian extensional magmatism, was generated during closures of various parts of Iapetos. The Devonian and younger igneous rocks are most conspicuously Andean in character, however, and are reasonably interpreted to have been generated during two stages of the final assembly of Pangea. This occurred in at least two stages: first when the northwestern part of composite T3 (fig. 1) approached from the southeast and collided with Laurentia, resulting in the Early to Middle Devonian Acadian orogeny; and second when the outer part of T3 collided with the accreted northwestern part, resulting in the Alleghanian orogeny. The Sennebec Pond thrust fault (fig. 1, SPF) marks the T2-T3 boundary; it is an Acadian structure that cuts contact-metamorphic isogrades associated with the Silurian Sedgwick pluton, dated at 419.5±1 Ma, and is cut by the Lucerne Granite, dated at 380±4 Ma (Stewart and others, 1995, p. A3-6, A3-7). Dubé and others (1996) reported a similar age bracket (between 415 and 386 Ma) for the origin of the Cape Ray fault zone, southwest Newfoundland, which they interpreted as an Acadian suture between Gondwana and Laurentia. Syn- to post-Acadian plutons that are dated in the range of about 400–290 Ma [for example, Lexington and Sebago batholiths (indexes 21A, B, 78)] are considered to represent continental arc magmatism that preceded and accompanied the final Alleghanian collision.

Mesozoic rift-drift

[Rock sequences numbered 8 on correlation diagram]

This part of the region's history mainly involves the mildly alkalic igneous rocks of the Early Cretaceous and Jurassic White Mountain Plutonic-Volcanic Suite. As already mentioned, however, the Mississippian(?) alkalic Androscoggin Lake plutons (index 74) might represent an early precursor of anorogenic magmatism that overlapped the end of Acadian to Alleghenian continental arc magmatism. McHone and Butler (1984) described the history of these rocks from the probable beginnings of major rifting in Triassic time to the opening of the Atlantic Ocean that resulted in the breakup of Pangea. In the Sherbrooke-Lewiston area, the Mesozoic emplacement of the White Mountain igneous rocks was also a time of brittle fracturing, most conspicuously represented by the Ammonoosuc normal fault (AF, fig. 2), displacement on which was on the order of 2–3 km, down to the northwest, near Littleton, and about 5 km near Piermont (Moench, 1993, fig. 6).

COMPLETE BOUGUER GRAVITY AND AEROMAGNETICS (MAPS B AND C)

By

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INTRODUCTION

Numerous gravity and aeromagnetic studies have been conducted in northern New England over the last 35 years covering all of the Lewiston-Sherbrooke area. The results of these studies, supplemented by new data obtained during this project, are combined on maps B and C at 1:250,000 scale, and at 1:500,000 scale on figures 4 and 5. The geology and lithologic types from map A and in more detail from Moench and others (1995) are used as a base for the geophysical maps, because of the common correspondence of particular geophysical signatures to certain lithotypes. For ease of comparison, major tectonic belts, lines, and faults of the Sherbrooke-Lewiston area are identified on the geophysical maps and (or) on figures 1 and 2, which also shows the locations, by number, of named plutons.

GRAVITY SURVEY

All available gravity data from past regional studies (for example, Bean, 1955; Joyner, 1963; Kane and Bromery, 1968) and from more detailed studies (for example, Wetterauer and Bothner, 1977) were compiled and corrected by Bothner and others (1980) to the modern datum. To that compilation some 2,000 new gravity stations within the Lewiston-Sherbrooke area were added during this project, providing more appropriate coverage in previously less accessible areas (Carnese, 1981; Carnese and others, 1982; Jahrling and Bothner, 1983) and resulting in an updated subset of gravity data covering the northeastern United States and adjacent Canada. A total of 5,200 gravity stations lie within the boundaries of the United States portion of the Lewiston and Sherbrooke quadrangles. The new gravity data were reduced following standard USGS reduction methods (G.I. Evenden and R.R. Wahl, USGS, written commun., 1977) using a Bouguer slab density of 2.67 g/cm^3. Anomalies were calculated relative to the 1967 Geodetic Reference System formula for the theoretical gravity

(International Association of Geodesy, 1971), and base values were adjusted to conform to the International Gravity Standardization Net of 1971 (Morelli, 1974). Terrain corrections have been calculated from 0.895 km to 166.7 km using a modification of the terrain correction of Plouff (1977). No terrain corrections have been applied for the zones closer than 0.895 km, but in most cases errors resulting from this omission are substantially less than 1.0 mGal. All data are terrain corrected to a distance of 0.895 km from the station using digital terrain data (Plouff, 1977). The Bouguer gravity map was contoured at an interval of 2 mGal from a 0.75-km grid that was produced by regridding a 2-km grid using USGS gridding (MINC, Webring, 1981) and contouring (CONTOUR, Godson and Webring, 1982) computer programs and plotting facilities.

The most prominent feature of map B and figure 4 is the strong northeast regional gravity trend diagonally crossing the Sherbrooke-Lewiston area. The dominant gravity trough parallels the tectonic grain of the northern Appalachian Mountains, and is flanked by the Appalachian gravity high to the northwest and by the Maine gravity gradient to the southeast (fig. 4). These two positive gravity features are seen spectacularly on smaller scale maps (for example, Simpson and others, 1981; Bothner and Unger, 1989; Bothner and Kucks, 1993).

The regional gravity field was examined by applying several analytical techniques to the gridded data set. Second- and third-degree polynomial surface fitting (SURFIT, M.W. Webring, USGS unpub. program), area averaging using a 30- to 50-km averaging radius (AVER2D, M.W. Webring, USGS unpub. program), and bandpass filtering (100-km ramped high-pass filter, Simpson and others, 1981; FFTFIL, Hildenbrand, 1983) were used. Each technique generated grossly similar surfaces that emphasized (1) a broad, northeast-trending gravity low roughly coincident with the trace of the BHBMA, (2) a moderate positive gradient to the northwest towards the Appalachian gravity high [which coincides with the Baie Verte–Brompton Line of ultramafic rocks (fig. 2, BVBL)], and (3) a gentle positive gradient to the southeast across the CMT—smoother, but little different from the general features of figure 4. The lower frequency, longer wavelength information is important for crustal studies and is not included in this report.

Of greater importance for this study of the Lewiston-Sherbrooke area are the high-frequency, short-wavelength, closed negative and positive anomalies and the few major deflections in linear gradients of the total Bouguer gravity field. Closed negative anomalies and significant negative deflections in the regional gravity field are clearly associated with felsic intrusions of each of the plutonic suites. Conversely, closed positive anomalies occur over denser, more mafic rocks, most notably of the Devonian New Hampshire Plutonic Suite and the Jurassic and Cretaceous White Mountain Plutonic-Volcanic Suite. Each anomaly form can be either exactly or approximately correlated with mapped intrusive bodies or their inferred extension at shallow depth. The host metasedimentary and metavolcanic rocks, unfortunately, have no consistent gravity expression that permits easy correlation with either rock type or structure at this scale.

AEROMAGNETIC SURVEY

The aeromagnetic anomaly map (map C) was compiled from digital data acquired either as new contract digital data or by digitizing older existing maps. The data consist of a diverse group of surveys (see "Sources of aeromagnetic data," map C) with widely varying flight-line spacings and flight elevations. The residual magnetic field was obtained for the new contract data by removing the International Geomagnetic Reference Field (1975 and 1980) after updating to the epoch during which the surveys were flown. A grid of values was created for each individual data set using a minimum curvature method (MINC, Webring, 1981) with the interval dependent upon the original flight-line spacing so as to honor the data as accurately as possible. The grids were then regridded to a consistent 0.5 km for the purpose of merging. An elevation of 1,000 ft (300 m) above ground was chosen as the final flight datum, requiring that most surveys be continued upward or downward to this level. Surveys flown in a barometric mode were continued onto the draped (terrain+1,000 ft) surface. The datum level was adjusted on all grids to be compatible with the most recent USGS survey (designated "USGS, 1982 unpub. data" on "Index to sources of aeromagnetic data," map C). A one-dimensional linear splining technique (Bhattacharyya and others, 1979) was used to merge the sets. This procedure removed two grid values from the western or southern grids and splined across four grid cells using five values on either side of the gap to interpolate and produce new values on the merge boundary. The consistent data set was contoured to produce the final map, which has a contour interval of 50 nT.

A number of the aeromagnetic anomalies can be correlated directly with intrusive rock bodies and with belts of grouped metasedimentary and metavolcanic rocks shown on the geologic base. At larger scales (1:62,500), the aeromagnetic data are useful as a geologic mapping tool because of their sensitivity to near-surface sources. However, even at the small scale of 1:250,000, magnetic trends frequently track metavolcanic belts, and closed anomalies characterize many of the plutonic bodies. Some of the important linear features are shown at 1:500,000 scale on figure 5.

The most prominent magnetic feature of map C is a zone of high-frequency anomalies, usually less than 200 nT, that tracks northeastward following the BHBMA and the southeastern part of the CVT (P-F allochthon) immediately to the west. As discussed later, this linear zone partly corresponds to belts of metavolcanic and associated intrusive rocks, and some less-conspicuous aeromagnetic patterns correspond to pyrrhotite-bearing metasedimentary units. The magnetic patterns along the BHBMA trend are greatly modified by the Ordovician and Silurian(?) intrusive rocks, and those of all three tectonic belts are modified by the Devonian and younger intrusive rocks.

DISCUSSION

The following discussion emphasizes the geophysical characteristics of stratified metamorphic and related intrusive rocks of the BHBMA, the CVT, the CMT, and the Devonian to Cretaceous intrusive rocks that were emplaced across the three tectonic belts. The discussions approximately follow the usual geologic progression from oldest to youngest within each tectonic belt or intrusive assemblage.

Bronson Hill–Boundary Mountains anticlinorium

Diamictite and related rocks of the Chain Lakes massif (€Pc), below the Boil Mountain line (fig. 2, BML), lack a distinctive gravity signature. A gentle, southeast-sloping field gradient is strongly modified by the Devonian Chain of Ponds pluton (index 8; Dnh) and the Ordovician Attean pluton (index 2; Ohu), which depresses the gravity field by –56 mGal (with a residual anomaly of nearly –25 mGal). These felsic bodies superimpose negative anomalies that effectively mask whatever gravity characteristic the massif may have had. As described later, the Chain of Ponds and Seven Ponds plutons (indexes 8, 9; both Dnh), and the Spider Lake pluton (index 7; Dnh) to the northwest in Quebec, share a substantial gravity low and are interpreted to be connected at depth. Between the Chain of Ponds and Attean plutons, isoanomaly contours track northwesterly, and northeast of the Attean pluton, where the pluton is covered by Silurian and Lower Devonian strata (Sns, DSns, Dc), the contours track west-northwest. In both areas the contours reflect the intrusives and not the massif. The granitic Skinner pluton (index 6; Ohu) has no apparent expression in the gravity field, and is probably very thin. A small positive anomaly centering at Holeb (grid 2B) that occurs over Chain Lakes lithologies between the Skinner and the Attean plutons might be a response to massive, medium- to coarse-grained epidiorite and gabbro of the massif (Moench and others, 1995; epidiorite at Holeb). About 20 km to the southeast of this anomaly is a smaller, unexplained positive anomaly that overlaps rocks of the massif, the Attean pluton, and nearshore Silurian deposits (Sns).

The strongest aeromagnetic anomalies within the Chain Lakes massif proper occur in a north-trending belt that overlaps the western border of the Attean pluton. These anomalies might be a response to magnetite-bearing veins reported in this area (Boudette, oral commun., 1990). A second zone of high-frequency anomalies occurs south of the Skinner pluton and extends southwest for a distance of nearly 20 km. Because magnetite-bearing veins are not reported to occur here, these anomalies might be a response to variations in magnetite content within various facies of the Chain Lakes massif. Other possible causes of the two zones of anomalies are mineralization along several mapped faults, and contact metamorphic effects of the intrusive bodies.

Cambrian(?) to Lower Devonian formations of the anticlinorium above the BML and associated plutonic rocks illustrate a variety of geophysical responses. A steep gravity gradient and a zone of high-frequency, short-wavelength magnetic anomalies occur approximately along the southern boundary of the Chain Lakes massif, following the mafic and ultramafic rocks of the Cambrian(?) Boil Mountain Complex (index 17; €op), bimodal metavolcanic rocks of the Cambrian(?) Jim Pond Formation (€ov), and euxinic melange and associated metasedimentary rocks of the Hurricane Mountain Formation (€e). The most prominent magnetic ridge of this belt corresponds to metavolcanic rocks of the Jim Pond Formation. To the northeast, the positive gravity gradient becomes less obvious, but the aeromagnetic anomalies faithfully track this sequence along the Lobster Mountain anticlinorium (fig. 2, LMA), largely because of the occurrence of relatively more magnetic metavolcanic rocks of the Jim Pond. Numerous northwest-trending faults cross the south margin of the Chain Lakes massif and the LMA. Although these faults do not noticeably displace the aeromagnetic contours at the scale of map C, the faults find some expression on larger scale aeromagnetic maps. The LMA has little or no gravity expression.

The Ordovician (Whiterockian) to Cambrian(?) flysch sequence (O€f), which joins the BMA and LMA with the BHA to the southwest, has poor geophysical expression. Some magnetic expression is shown, however, by Ordovician metavolcanic and euxinic metasedimentary sequences (Olv, Ole, Ouv, Oue), partly as a consequence of the presence of magnetite and (or) pyrrhotite in the Ammonoosuc Volcanics (Olv) at the north end of the Jefferson batholith (indexes 63, 64), and along the trend of the plutonic cores of the Owls Head, Moody Ledge, Landaff, and Sugar Hill Oliverian domes (indexes 92, 88, 89, 87, 86). Larger scale aeromagnetic maps depict the Ordovician metavolcanic and euxinic metasedimentary rock units in more detail. Except for broad gravity highs between intrusives that reflect higher density of the surrounding metamorphic rocks, the gravity map does not depict the distribution of these units in a useful way.

The Oliverian plutons and gneiss domes of the BHA do not have a distinctive gravity signature; the Bouguer gravity field is too strongly affected by younger, lower density intrusive bodies. The anticlinorium is marked, however, by an aeromagnetic plateau defined approximately by the 400-nT contour and averaging about 300 nT higher than the surroundings. The plateau is a generally "positive area" that trends southwest to northeast across the study area. The southeastern edge of the plateau was called the Bronson Hill gradient by Bothner and others (1986). The Success lobe (index 64) of the Jefferson batholith (index 63) has a distinctive negative aeromagnetic anomaly (minima <300 nT) that is continuous with the anomaly associated with the Cambridge Black pluton (index 38) and the Chickwolnepy intrusions (index 39). The Jefferson batholith, on the other hand, remains a generally positive aeromagnetic plateau, substantially modified only by the Jurassic Cherry Mountain stock (index 62).

The granitic cores of the remaining four Oliverian domes—Sugar Hill, Landaff, Moody Ledge and its eastern slice, and Owls Head (indexes 86, 87, 88, 89, 92)—and their mantling Ammonoosuc Volcanics (Olv) form a distinctive string of aeromagnetic anomalies, each 100–200 nT higher than their surroundings and each corresponding to respective geologic map patterns. An arcuate magnetic anomaly faithfully tracks the Ammonoosuc Volcanics that mantle the north side of the Owls Head pluton; lower values characterize the core granite of the pluton. The regional aeromagnetic compilation of Zietz and others (1980) shows the full southern extent of the Bronson Hill anomaly through New Hampshire, Massachusetts, and Connecticut as a narrow aeromagnetic ridge punctuated by positive closures over the individual domes. The gravity effect of these domes is minimal.

Unlike the Attean pluton (index 2), no negative gravity anomalies (or only small ones) are associated with the Adamstown, Cambridge Black, Lost Nation, Whitefield, and Highlandcroft plutons (indexes 35, 38, 53, 61, 58) of the Highlandcroft Plutonic Suite. The Adamstown and Highlandcroft plutons have residual anomalies of a few milligals, but the Cambridge Black and Lost Nation plutons have too few nearby gravity stations to assess their effect on the regional field. Similarly, aeromagnetic expression of the Highlandcroft Plutonic Suite also varies—no magnetic expression over the Adamstown pluton, negative and positive magnetic anomalies over the Lost Nation pluton, a small negative magnetic anomaly over the Whitefield pluton, and strongly negative anomalies over the Attean and Cambridge Black plutons.

Connecticut Valley trough

As shown on figure 4 and map B, predominantly metasedimentary rocks of the CVT coincide mainly with a broad low in the gravity field that deepens in northeastern Vermont, in the area underlain by several felsic plutons of the Devonian Northeast Kingdom batholith (Ayuso and Arth, 1992). The mixed calcareous and siliciclastic metaturbidites of this belt have no characteristic gravity or magnetic signatures. They are metamorphosed only to chlorite and biotite grade except adjacent to plutons, where they reach andalusite and sillimanite grade.

In contrast with the significant aeromagnetic anomalies associated with the mafic volcanic and intrusive rocks of the Frontenac Formation and SLR, described later, the small metabasalt and sparse felsic lenses in the Gile Mountain (Dcv) and Waits River Formations (in Srwv) of Vermont, are not mappable geophysically, possibly because excess iron, as magnetite, that occurs in the greenschist-facies metabasalts is taken up by iron-bearing silicate minerals at higher metamorphic grade.

In the southeastern part of the CVT, areas underlain by the Piermont sequence and Frontenac Formation (P-F allochthon and SLR) coincide with a rather vague, complex gravity ridge, interrupted in several places by low-density granitic bodies of Devonian and younger age. High-pass filtered maps (Bothner and Kucks, 1993) covering New Hampshire, Vermont, and adjacent areas enhance that ridge. The part of the gravity ridge that lies southeast of St. Johnsbury, Vt. (grid 8G) is probably produced by a metadiabasic dike swarm that culminates to form the sheeted dikes in Waterford (index 63; DSg). In northern New Hampshire (grids 6D, 6E) a steep, west-dipping, north-trending gravity gradient, according to modelling by Jahrling (1983) and Jahrling and Bothner (1983), is produced by a density contrast between metasedimentary and metabasaltic rocks of the Frontenac Formation across the east-dipping Perry Stream fault (PSF).

The most prominent part of the gravity ridge of the southeastern part of the CVT crosses the international border at Mount Bon Durban (grid 5C) where it coincides with two parallel aeromagnetic anomalies (map C) described later. These anomalies, here collectively called the Mt. Bon Durban geophysical anomaly, coincide with a part of the SLR that was most active magmatically in Silurian time (SLRA). The gravity anomaly is centered over a lithologic belt that includes the thickest sequence of basaltic greenstone in the Frontenac Formation (in Srwv), and the body of sheeted metadiabase, gabbro, and intrusive felsite at Marble Mountain (index 11; DSgf). As shown on the detailed geologic map (Moench and others, 1995), this belt is cut on its east side by the Moose Bog fault (MBF), which is bordered to the east by a belt of proximal and vent-facies felsic and bimodal metavolcanic rocks of the Frontenac Formation, overlain by black, sulfidic slate assigned to the Smalls Falls Formation, and a second, eastern belt of basaltic greenstone of the Frontenac. The eastern greenstone belt is the source of the eastern aeromagnetic ridge of the Mt. Bon Durban geophysical anomaly. The gravity field of the anomaly is not similarly divided, probably because of the lack of gravity stations in the intervening area, which is underlain mainly by felsic metavolcanic rocks. Also within this part of the rift axis are several small bodies of diapiric serpentinite, mainly distributed along the Moose Bog fault, and the high-level, mainly granitic East Inlet pluton (index 12; Sb, Sbm), thought to be comagmatic with felsic metavolcanic rocks of the SLRA. This low-density pluton, flanked by significantly denser basaltic greenstones, might be expected to coincide with a negative gravity anomaly; instead it coincides with a small gravity high. This relationship suggests that the pluton is underlain at shallow depth by mafic rocks.

When reconstructed, the lithologic belts associated with the Mt. Bon Durban anomaly have the form of a spreading ridge with an axial half-graben. As shown on map D and described elsewhere in this pamphlet, Kuroko-type massive-sulfide deposits of the Clinton River district, Quebec (grid 4C), and at Ledge Ridge, Maine (grid 5D), occur within the half-graben and were formed by sea-floor mineralization along the SLRA.

The eastern aeromagnetic ridge of the Mt. Bon Durban anomaly (fig. 5; map C), which, as described above, coincides with the eastern belt of basaltic greenstone, terminates on the south at Rump Mountain (grid 5D), at the south end of the eastern greenstone belt. The more prominent western aeromagnetic ridge of the anomaly coincides with the western greenstone belt. Both are displaced to the southeast by the East Inlet pluton (index 12), which has a negative magnetic signature, but they track together some 45 km farther south, from Beaman Hill (grid 5D) to the Gore Mountain plutons (index 43). Although the eastern aeromagnetic ridge of the Mt. Bon Durban anomaly is temptingly in line with the Beaman Hill to Gore Mountain aeromagnetic ridge, the lithologic control in the Beaman Hill area is adequate to disfavor this correlation. These and other aeromagnetic ridges and parallel negative lineaments shown on map C from the Gore Mountain plutons to the international border, and across southern Quebec to the Canada Lake area (grid 1A), Maine, express the fact that the greenstones are commonly magnetic in outcrops and have exceptionally high iron and titanium contents (for references see p. 10 and Moench, 1990, p. J13).

Additionally, the mafic sills that intrude the Frontenac Formation (**DSg**) exposed northwest of the Chain Lakes massif can be followed in the aeromagnetic data northeastward through Quebec and back into Maine, where they were first recognized by Boucot and others (1964). These rocks (**DSg**, **Srwv**) and associated anomalies terminate in the vicinity of Canada Falls, Maine.

Small aeromagnetic responses in metasedimentary rocks are produced by black, pyrrhotite-bearing metashale of the Smalls Falls Formation northeast and southwest of the Gore Mountain plutons. A prominent aeromagnetic anomaly near the center of grid 7F has its source in a mass of magnetite-bearing metashale and local silicate iron-formation of the Lower Devonian Ironbound Mountain Formation (**Dp**).

Central Maine trough

The CMT, which overlaps the southeast side of the BHBMA, but is mainly southeast of the STH and the Mahoosuc fault (MF), contains a very thick succession of Silurian and Lower Devonian metasedimentary rocks that have been multiply metamorphosed and deformed during the Acadian orogeny. In New Hampshire, the trough is divisible into three regional folds: the Kearsarge–Central Maine synclinorium, the Central New Hampshire anticlinorium, and the Lebanon (Maine) antiformal syncline (Lyons, 1989). In Maine, the trough has the form of a single complex synclinorium. The subsurface configuration as a trough has been supported by recent seismic reflection profiling (Stewart, 1989; Stewart and others, 1993).

The geophysical expression of the metasedimentary rocks of the CMT is limited to those areas along the eastern margin and within the central part of the study area not occupied by Devonian or younger intrusive bodies. The gravity field over the metasedimentary rocks is generally a smooth, slightly northeast trending positive area, paralleling the regional structural grain. This characteristic is also present over large roof pendants of Silurian and Devonian metasedimentary rocks within the Jurassic White Mountains batholith (index 81). No meaningful modelling of structures defined by metasedimentary rocks of the trough is possible at this scale.

Aeromagnetic characteristics of some of the metasedimentary rocks, however, provide important new information and permit detailed mapping to be conducted. Specifically, the rusty weathering, pyrrhotite-bearing Smalls Falls Formation (of **Sbw**) has a small but identifiable magnetic signature at the scale of map C, and becomes clearly traceable, even beneath the granitic Lexington batholith (indexes 21A, B), at larger map scales (Phillips, 1990). Aeromagnetic detail for the central part of the study area is lacking (only NURE data at about 10-km line spacing are available). The north-south linear magnetic anomalies in the southeastern corner of the map area track deflections of sulfidic metasedimentary rocks of the Sangerville Formation (of **Sbe**) near the contact with the Sebago batholith (index 78). Other correlations between aeromagnetic ridges and pyrrhotite-bearing metasedimentary units can be identified, and readers are referred to Moench and others (1995) for distribution of the several pyrrhotite-bearing units of Cambrian(?) to Early Devonian age in all three tectonic belts.

Devonian to Pennsylvanian plutons

The many two-mica granite bodies and other felsic, intermediate, and mafic plutons of the Devonian New Hampshire Plutonic Suite, and two-mica granites of the Mississippian Long Mountain pluton (index 40; **Mt**) and Pennsylvanian Sebago batholith (index 78; **Pt**) commonly have dominating gravity signatures, and local aeromagnetic signatures, that mask the geophysical signatures of the country rocks.

In the area of the Northeast Kingdom batholith of northeastern Vermont (Ayuso and Arth, 1992), biotite granite to granodiorite of the Averill pluton (index 45; **Dnb**) and the northern part of the Echo Pond pluton (index 46A; **Dnb**) share the same gravity low (minimum of –74 mGal) and are probably connected below the surface. Similarly, the two-mica granite of the Willoughby pluton (index 47; **Dnt**) and the northeastern part of the Maidstone pluton (index 50; **Dnb**), and probable biotite granodiorite of the west lobe of the Victory pluton (index 51; **Dnb**), have significant negative gravity anomalies. Because the Maidstone gravity anomaly is similar in form to the anomaly over the nearby Jurassic Gore Mountain plutons (index 43; **Jwc**, **Jwu**), and some similarities also can be seen in the aeromagnetic data (map C), a felsic White Mountain body might exist at shallow depth below the northeast end of the Maidstone. The Nulhegan pluton (index 48; **Dnh**) and the east lobe of the Victory pluton (index 52; Dnh) are composed of hornblende-biotite quartz monzodiorite, and the mafic part of the Echo pond pluton (index 46B; Dnhm) is composed of quartz monzodiorite to gabbro (in Echo Pond). Because the density of these rocks is greater than that of the granites and granodiorites of the same suite, they have little density contrast with the surrounding metasedimentary rocks and consequently have little or no gravity expression.

A small gravity low and a very prominent magnetic high (+400 nT relative to surroundings) coincide with the Newark pluton (index 49; Dnbv), which is composed of variably textured biotite granite and considered a body of the Northeast Kingdom batholith. The combination of negative gravity and strong positive magnetic anomalies is uncharacteristic of granitic rocks of the New Hampshire Plutonic Suite, however, and is a more characteristic geophysical expression of the White Mountain Plutonic-Volcanic Suite, as illustrated within this region by the Monadnock Mountain and Gore Mountain plutons (indexes 44, 43), described later.

To the northeast, on opposite sides of the Quebec-Maine border, are the Spider Lake, Chain of Ponds, and Seven Ponds plutons (indexes 7, 8, 9), composed of hornblende-bearing granodiorite to quartz diorite or tonalite. Although the southeastern contact of the Spider Lake pluton closely parallels the Thrasher Peaks fault (TPF), it apparently intrudes the fault; or, if faulted, has not been significantly displaced by the fault. The Chain of Ponds and Seven Ponds plutons join at the surface. These geologic relationships and the fact that the three bodies share a substantial gravity low (fig. 4, map B) indicate that they are parts of an original single body. As shown on map C, the aeromagnetic pattern is subdued over the Chain of Ponds pluton, but a deep, negative magnetic anomaly is associated with the Seven Ponds pluton.

Several other felsic intrusions of the New Hampshire Plutonic Suite superimpose modest negative gravity and aeromagnetic anomalies along the BHBMA and adjacent areas of the CMT. The areally small Parmachenee (Dnh), Lincoln Pond (Dnb), and Cupsuptic (Dnb) plutons (indexes 13, 15, 16) are noteworthy examples. The Greenough Pond pluton (index 37; Dnt) has little affect on either potential field. Most significant among this suite of intrusives in the northeastern half of the anticlinorium are the northern half of the Mooselookmeguntic batholith (index 34A; Dnt), the Umbagog pluton (index 36; Dnh), and the Flagstaff Lake plutons (index 19A, B; Dng, Dnb). The low-density granitic rocks of the Mooselookmeguntic and Flagstaff Lake bodies have negative gravity anomalies and little or no magnetic expression. In contrast, the Umbagog pluton, composed of hornblende-quartz monzodiorite (Dnh), has no obvious gravity expression and positive and negative magnetic anomalies, and the gabbro bodies (Dng) of the Flagstaff Lake plutons have a very strongly positive gravity anomaly and, interestingly, no significant magnetic anomaly.

Carnese (1981) modelled the two-mica granite body of the Mooselookmeguntic batholith as a thin granitic sheet not exceeding 2.5 km in thickness, and the Umbagog pluton as a sheet only about 1 km thick. He modelled the main gabbro body of the Flagstaff Lake plutons, on the other hand, as a funnel-shaped body extending some 6 km below the present erosional surface.

Farther southwest, the Mississippian Long Mountain pluton (index 40; Mt), composed of two-mica granite, generates a modest gravity low and no magnetic anomaly. In the southwest corner of the map area (grids 7G to 8H), the Alderbrook (Dnbv) and Haverhill (Dnb) plutons (indexes 60, 90) have no gravity expression, but both are centered beneath magnetic lows. Short distances to the east of the Haverhill pluton, the Mount Clough and Lincoln plutons (indexes 85, 84) have no effect on the gravity and magnetic fields. On the basis of gravity modelling, Nielson and others (1976) interpreted the Haverhill and Mount Clough plutons, both composed of the gneissic Bethlehem Granodiorite, and the Lincoln pluton, composed of the Kinsman Granodiorite, as remnants of a subhorizontal sheet complex that once extended over a large part of central New Hampshire. Geologic mapping indicates that the Haverhill pluton is an unrooted, synclinal remnant of the sheet complex.

The Devonian to Cretaceous plutons that intrude metasedimentary rocks of the CMT have the strongest influence on both the gravity and aeromagnetic fields in the map area, varying as functions of plutonic rock type and the metamorphic grade and (or) type of host rock. A major gravity low centered over mildly alkalic rocks of the Jurassic White Mountain batholith (index 81), described later, continues eastward as a gentle rising gravity gradient over two-mica granite of the Pennsylvanian Sebago batholith (index 78), and reaches a circular gravity high over the alkalic Mississippian(?) Androscoggin Lake plutons (index 74). With the exception of the Androscoggin Lake plutons, the Devonian and Carboniferous rocks of the area of the CMT do not significantly influence the magnetic field. Jurassic rocks of the White Mountain batholith strongly influence the magnetic field, but the eastern part of this batholith, and the Sebago batholith to the east, are covered by aeromagnetic data that are too widely spaced to draw meaningful relationships.

The Bretton Woods and Gorham plutons (indexes 65, 66), both two-mica granite bodies exposed just to the northeast of the White Mountain batholith, further deflect the regional gravity low associated with the White Mountain batholith and lie within a broad magnetic low associated with the metasedimentary rocks (Dc, Sbw) of the Presidential Range. The small Mount Hayes pluton (index 67; Dt) has no geophysical expression; nor does the larger Songo pluton (index 69; Dnh).

To the northeast, the southern half of the Mooselookmeguntic batholith (indexes 34A, B, C), the Phillips batholith (indexes 26A, B), and several smaller outlying plutons between these batholiths are related to a complex series of small closed gravity lows that lie west of the −40-mGal contour that passes through the Phillips batholith. The smaller bodies include the Rumford, Whitecap Mountain, Rumford Point, Howard Pond, West Mountain, Bunker Pond, and Plumbago Mountain plutons (indexes 29, 30, 31, 32, 27, 28, 33). In approximate order of deceasing abundance, rocks of these bodies include two-mica granite (**Dnt**), hornblende-bearing granodiorite to diorite (**Dnh**), biotite granodiorite (**Dnb**), pegmatitic granite (**Dp**), gabbro (**Dng**, **Dnhm**), and unique biotite trondhjemite (**Dnb**) in the Howard Pond pluton (index 32), and pentlandite-bearing tonalite (**Dnb**) in the West Mountain pluton (index 32). The gravity field of the area of all these bodies suggests that most are connected in the subsurface as a rather thin, subhorizontal sheet complex (Carnese, 1981; Carnese and others, 1982). The Plumbago Mountain pluton (index 33; **Dng**), composed of poorly layered gabbro and subordinate ultramafic rocks, is expressed as a small closed positive gravity high. This and other gabbroic bodies of this area, and the trondhjemite and pentlandite-bearing tonalite just mentioned, occur along or near the Plumbago Mountain and Blueberry Mountain premetamorphic extensional faults (PMF, BMF); these bodies are probably related to the faults, rather than the sheet complex.

The easternmost two-mica granite bodies (**Dnt**) are the North Jay, Chesterfield, New Sharon, Bromley, Leeds, and Wales plutons (indexes 70, 71, 72, 73, 75, 76). The Sabattus pluton (index 77), in grid 1H, is composed of biotite granite. The northern plutons of this group (indexes 70–73) lie within the same closed gravity low, similar to the gravity field of the Mooselookmeguntic and Phillips batholiths and related bodies, and likewise are probably connected in the subsurface. The southern plutons of the group (index 75–77) may also have a similar subsurface distribution, but their geophysical expression is masked by effect of the Mississippian(?) Androscoggin Lake plutons (index 74).

Farther north are the granodioritic Redington pluton (**Dnb**), the gabbroic or dioritic (**Dng**) Sugarloaf, Huston Brook, and Bog Brook plutons (indexes 25, 24, 23, 22), and the Lexington batholith (indexes 21A, B), which is composed of biotite granite to porphyritic quartz syenite (**Dnb**) and two-mica granite (**Dnt**). The gabbros and diorites are related to those of the Flagstaff Lake plutons (index 19A), astride or northwest of the STH. Gravity contouring indicates a closed low over the felsic Redington pluton, a closed high over the gabbroic plutons, and a closed low over the felsic Lexington batholith. Carnese (1981) modelled the felsic Redington pluton as a northeast-plunging cylindrical mass, and the mafic Sugarloaf pluton as a thin, subhorizontal sheet, which is inferred by Moench and Pankiwskyj (1988a, section A–A') to lie in the plane of the Barnjum premetamorphic extensional fault (BJF). The Lexington batholith has been modelled by Koller (1979) and more recently and thoroughly by Phillips (1990). Modeling by Phillips (1990) of the batholith has demonstrated different thicknesses for the separate lobes (a distribution initially recognized by Boone (1973), on the basis of his observations on the contact metamorphic aureole). By modelling of combined gravity and magnetic profile data, Phillips (1990) has also demonstrated the presence of underlying mafic masses and the presence of two or more bands of the pyrrhotite-bearing Smalls Falls Formation (of **Sbw**) beneath the Lexington batholith.

Moench and Pankiwskyj (1988b) proposed that emplacement of the mafic and unique trondhjemite and pentlandite-bearing tonalite plutons of the western margin of the CVT accompanied premetamorphic extensional faulting in Early Devonian time. However, further studies are needed.

The Lexington batholith and Redington pluton are thicker (3–7 km) than the Mooselookmeguntic batholith (<2.5 km) and similar bodies in New Hampshire. This characteristic has been interpreted to reflect the depth of emplacement of Devonian plutons during the Acadian orogeny—the thinner and more sheetlike the body, the greater the depth of emplacement (Nielson and others, 1976; Hodge and others, 1982; Carnese and others, 1982; Moench and others, 1982).

The largest pluton in New England is the Pennsylvanian Sebago batholith (index 78), about half of which is exposed in the study area. It is composed of two-mica granite and abundant associated pegmatites, some of mineralogical interest. The gravity field over the batholith is characterized as a gradient of increasing gravity values to the east, away from the Jurassic White Mountain batholith (index 81). There is little density contrast between these two bodies (Wetterauer and Bothner, 1977), making regional/residual separation difficult. Hodge and others (1982) and Simmons and others (1988) modelled the batholith as a granitic sheet <1 km thick. Of note, the Sebago batholith was emplaced after the Acadian orogenic maximum, and in rocks of the highest metamorphic grade. The extent of Carboniferous metamorphism and plutonism in coastal/central New England remains a subject of active study.

The Mississippian(?) Androscoggin Lake plutons (index 74; **Msu**) have recently been studied by Creasy (1990). The gabbroic to syenitic rock of these intrusions have the strongest aeromagnetic (>2,000 nT) and gravity (>±4 mGal) signatures in the Lewiston and Sherbrooke quadrangles. Creasy (1990) has collected additional gravity data and has modelled the gravity and aeromagnetic data in a preliminary two-dimensional profile. He depicted the syenite and gabbro of the plutons as a single funnel-shaped body that extends more than 4 km below the present erosion surface. The syenite was emplaced as a ring dike not unlike many of the bodies of the White Mountain Plutonic-Volcanic Suite.

Jurassic and Cretaceous plutonic and volcanic rocks

Post-tectonic Mesozoic plutons of the White Mountain Plutonic-Volcanic Suite occur in a north-northwest-trending belt that extends from coastal (and offshore) New England to Canada, and cuts diagonally across all three tectonic belts of the study area (maps B and C). Although Triassic, as well as Jurassic and Cretaceous, rocks of the suite are recognized in the entire belt, only Jurassic and Cretaceous members are known to occur in the study area. The mildly alkalic volcanic and plutonic rocks of the suite have generated considerable discussion concerning their genesis in relation to the opening of the Atlantic Ocean (see, for example, Foland and Faul, 1977; McHone and Butler, 1984).

Many geophysical features of the White Mountain Plutonic-Volcanic Suite are superimposed on rocks of the BHBMA and adjacent tectonic belts. Closed, but rather subdued, magnetic highs occur locally over Conway Granite and Conway-type granites (Jwc), and, more commonly, prominent magnetic highs occur over quartz syenitic to gabbroic rocks of the suite (Jwu). In a few places, closed magnetic highs that occur over otherwise nonmagnetic, older plutonic and metasedimentary rocks suggest the presence of yet unexposed stocks or feeders of the suite. Even along the southern boundary of the map area, where data coverage is very poor (the NURE data here are widely spaced—10-km flightline spacing), the effect of the Pleasant Mountain pluton (index 80; Kw, Kwv) is obvious.

A broad gravity low occurs over the composite White Mountain batholith (index 81; Jwu, Jwc, Jmw), outlined approximately by the -60-mGal contour on its eastern and western border. Closed gravity minima of –72 mGal occur within the central part of the batholith over stocks of Mount Osceola Granite (in Jwu). Additional closed minima occur marginal to the batholith over mapped stocks, such as the Cannon Mountain lobe (index 83). Closed maxima and relatively positive gravity ridges occur within the batholith only over large roof pendants of Devonian igneous rocks, such as the Lincoln pluton (index 84) and older metamorphic rocks (Dc, Sbw). Gravity modelling by Wetterauer and Bothner (1977) and by Osberg and others (1978) indicates that the steep-walled, discordant stocks of the batholith extend to depths of 3–7 km, and are thickest in the central and western parts of the batholith.

Positive closed aeromagnetic anomalies of the White Mountain composite batholith are concentrated over four mapped blocks of Moat Volcanics (Jwv), the two largest in the eastern part of the batholith. A significant northeast-trending positive anomaly tracks undivided felsic and mafic alkalic rocks (Jwu) along the western marginal ring dike and parallel to the contact with a large roof pendant. A pair of circular anomalies, one centered over the Hart Ledge plutons (index 82; Jwu), and another to the north over Devonian metasedimentary rocks (Dc), reflect exposed or unexposed alkalic intrusions. The stock at Pleasant Mountain (index 80; Kw) shares the same characteristic even where aeromagnetic data are sparse.

Outside the main batholith, bodies of the White Mountain Plutonic-Volcanic Suite perturb the gravity field as a rectilinear, "cross-regional" trend of closed lows (shown by long dashes on fig. 4). Southeast of the Pilot-Pliny plutons (index 55), the –58-mGal and –60-mGal contours outline a northeast-trending gravity trough that contains the Crescent Range ring dike (index 56; Jwu). Near the north end of the ring dike, the trough bends abruptly northwest across the Pilot-Pliny plutons, within which it is a gravity expression of low-density Conway-type granite (Jwc). This northwest trend is normal to the trend of the BHA, and is represented by closed lows (reaching minima of –70 mGal) over the Percy, Gore Mountain, and Monadnock Mountain plutons (indexes 42, 43, 44). The Owlhead Mountain pluton (index 41), slightly to the northeast of this trend, is contained within a northeast-trending extension of the gravity trough, and has no gravity closure. The Cherry Mountain pluton (index 62), composed of syenite, is the only body in this region having both a positive gravity anomaly (which is slightly offset to the west from the mapped pluton) and a very high (>600+ nT) aeromagnetic signature (a characteristic of some Cretaceous complexes south of the study area). Except for the Owlhead Mountain pluton, all of the others have strongly positive magnetic signatures that track magnetite contents in the alkalic granites, syenites, and related rocks of the series (susceptibility values are listed in Bothner and others, 1986).

CONCLUSIONS

At a scale of 1:250,000, the overlay of the Bouguer gravity and aeromagnetic maps onto the tectonic lithofacies map (map A) of the Sherbrooke-Lewiston area serves to characterize the distribution of major intrusive bodies of the four plutonic suites of north-central New England and to trace some major features of the host metamorphic rocks. These maps also provide an up-to-date base for detailed geophysical analyses of the subsurface shape and distribution of both igneous and metamorphic rock masses for both economic and academic evaluation. Broad positive and negative gravity anomalies are commonly directly correlative with mapped intrusive bodies whose effect is a function of density contrast and mass. In areas of multiple intrusions of similar type (for example, the Sebago batholith intruded by the White Mountain batholith), subsurface distinction is difficult because of insufficient density contrast. The various facies of the Mooselookmeguntic batholith or of the Flagstaff Lake plutons, however, may be separated by examination of their gravity effect. Broad gravity highs centered over metasedimentary masses may serve to estimate their gross mass, but otherwise are not particularly helpful. Changes in the regional gravity field, most commonly along northeast-trending increasing gradients (for example, the Maine gravity gradient), may reflect either a step in the crust-mantle interface [noted by Kane and Bromery (1968) and by Kane and others (1972)] or more likely a zone of Mesozoic dike concentration and a few plutons (Stewart and others, 1993, pamphlet p. 7) that might include the Mississippian(?) Androscoggin Lake plutons.

The aeromagnetic character of the Sherbrooke-Lewiston area emphasizes surface and near-surface variations in the magnetic susceptibility of both igneous and metamorphic rock bodies.

Older metavolcanic and sulfidic metasedimentary rocks (black metashales), some of known or suspected economic importance, can be clearly traced by linear magnetic anomalies even at the scale of these maps. Larger scale, more detailed maps prepared from the digital data base used herein may provide an even greater basis for sulfide minerals exploration. Aeromagnetic anomalies also serve to characterize the more mafic bodies of the New Hampshire Plutonic Suite and of the volcanic and generally younger plutonic bodies of the White Mountain Plutonic-Volcanic Suite. Contact relations are often clearly expressed between intrusive and intruded rocks in part as a function of contact metamorphism. Geophysical trends, when recognized in relation to mapped geology, should be used in conjunction with companion geologic and geochemical maps for maximum effectiveness.

METALLIC MINERAL-RESOURCE APPRAISAL (MAP D)

By
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INTRODUCTION

This map presents an assessment of metallic mineral resources of the project area. Although metal mining accounts for only a small percentage of the total historic production of extractable minerals in New England (Bawiec, 1984, 1986), this project was proposed and carried out on the basis that the area has not been extensively explored by industry but is, however, geologically diverse and almost certain to contain important metallic mineral resources. The existence of such resources in the Sherbrooke and Lewiston quadrangles is borne out by bedrock mapping and the geophysical and geochemical surveys carried out during this project, and by recent discoveries made by industry. Pegmatite mines and prospects, long of interest for gems, feldspar, mica, and small amounts of beryllium, are briefly described and shown on the map, but mineral resources that pegmatites might represent are not considered in this report. Because detailed grade and tonnage data are lacking for the various known metallic mineral deposit types, the assessments contained in this report are qualitative, rather than quantitative, and are expressed in terms of the potential for the occurrence of given deposit types within geologic tracts having favorable characteristics.

The United States portion of the Sherbrooke-Lewiston area contains more than 100 nonpegmatitic mines, prospects, and undeveloped mineral occurrences, most of which are in sulfide deposits of several types that are classified according to the symbols shown on map D (see table 1 for a list, and Appendix II for descriptions). The deposits are identified by number within each of the 15-minute quadrangles, which are identified by map grid coordinates. For example, deposit 1B-1 is the Catheart Mountain copper-molybdenum porphyry prospect (deposit number 1), located in the Long Pond 15-minute quadrangle (grid 1B). Pegmatite mines and prospects are identified similarly, but by letter for convenient differentiation from nonpegmatitic deposits on the map (see table 2 for a list, and Appendix III for descriptions). In order to provide additional basis for evaluating mineral resource potential within the United States portion of the map area, more than 30 metal-bearing mines and prospects are shown in Quebec. Figure 6 shows mines, prospects, and occurrences in the southwestern part of the map area (grids 8G, 8H) and farther south and west (grids 8I, 9G, 9H). Not shown on the map are innumerable sand and gravel pits and scattered slate, granite, rip-rap, and crushed gravel quarries, and excavations for other commodities. However, one prospect for contact metamorphic garnet (3E-1) and two undeveloped occurrences of asbestos (3C-3, 3D-2) are shown on the map.

In terms of dimensions, the largest known metal-bearing deposit of the area is the Catheart Mountain copper-molybdenum porphyry (1B-1), which is estimated to contain 20–25 million tons of altered and mineralized granodiorite having an average grade of about 0.25 percent copper and 0.04 percent molybdenum (F.C. Canney, oral commun., 1987), within a weakly to strongly mineralized area of about 5 km^2. Volcanogenic massive-sulfide (VMS) deposits, in contrast, have much smaller dimensions but higher grades. Drilling at the Ledge Ridge prospect (5D-1) indicates a VMS body having a strike length of about 975 m and a maximum width of about 6 m, and containing 3.7 million tons of massive sulfide having a grade of 2.3 percent zinc, 0.95 percent copper, 0.85 percent lead, 0.015 oz gold per ton, and 0.6 oz silver per ton (Cummings, 1988, p. 254). VMS deposits of the Clinton River district (4C-2 to 8), Quebec, have reported reserves (after production of about 2 million tons) of 1.8 million tons containing 1.54 percent zinc and 2.02 percent copper (Chevé, 1978). Other small but productive VMS deposits occur at the Milan mine (6F-1), north of Berlin, N.H., and at the Warren mine (8I-2, fig. 6), south of the map area.

Gauthier and others (1994) have effectively related metallogenesis to tectonic evolution in southern Quebec, and their discussion has a strong bearing on interpretations of the metallogenesis of the Sherbrooke-Lewiston area. In this report the "Summary of plate tectonic history," presented earlier, is intended to provide a guide to metallogenesis, which is treated in terms of the likelihood of occurrence of specific deposit types through time. For example, in the later section entitled "Cambrian to Early Devonian volcanogenic massive-sulfide deposits (VMS)," it is shown that such deposits occur in the subaqueous volcanic sequences of Cambrian, Ordovician, Silurian, and Early Devonian age that are exposed within the area. The subjects of geologic association of mineral deposits and metallogenesis are incorporated in the discussions of resource potential for individual deposit types. Table 3 presents a summary of the metallic mineral-resource assignments. With the exception of resource areas Dsk-2 and Sv2, resource assignments are not extended into Quebec.

METHOD OF METALLIC MINERAL-RESOURCE ASSESSMENT

This report applies the "expert method" of mineral-resource assessment that was developed, under the guidance of Richard B. McCammon, during a meeting held in Reston, Va., May 15–18, 1984, which was attended by seven project scientists and twelve other scientists among whom were experts on the types of mineral deposits known to occur in the project area, and other deposit types that might occur. The complete edited transcript of the four-day meeting is available (McCammon, 1986). By means of give-and-take discussions and questioning, metallogenic models were developed for the deposit types, and tentative assignments of resource potential were made for belts of rock deemed appropriate for each type. The updated ore deposit models that are used in this report are comparable to, though not necessarily identical with, published models (for example, Cox and Singer, 1986; Roberts and Sheahan, 1988). Because the United States portion of the Sherbrooke-Lewiston area remains largely unexplored by the metals industry, with notable exceptions, the area is appropriately treated as a "frontier" for purposes of mineral-resource assessment. As explained in the following paragraphs, this characteristic has an important bearing on the methodology of assessment.

The nomenclature of mineral-resource assessment used in this report, shown in figure 7, is taken largely from that used by Slack (1990, p. R2, R3, fig. 1; 1995) in the Glens Falls 1°x2° quadrangle, but with important exceptions that seem more appropriate for the "frontier" character of the Sherbrooke-Lewiston area, and that take better advantage of the findings that have resulted from the regional geologic mapping done for the project. On figure 7, the nomenclature "Evidence of mineralization" (EM) is substituted for "MINERAL OCCURRENCE" on Slack's (1990) figure 1, and the name "Unknown" is substituted for "No resource potential" on Slack's diagram. In describing his diagram, Slack states (p. R2): "This diagram is the foundation for the mineral-resource assessment of the Glens Falls quadrangle and is based on both diagnostic and permissive recognition criteria. Favorable geology and known mineral occurrences are considered to be diagnostic criteria, because they are required to establish a resource potential and are present for essentially all mineral deposits of a given type. A geochemical anomaly, by contrast, is a permissive criterion, as it suggests the presence of a particular deposit but is not required; also, the absence of a geochemical anomaly does not necessarily preclude the possibility of a given deposit type." Slack further explains (p. R3) that "***a geophysical anomaly, although a permisive criterion, has a lower ranking in the evaluation scheme and, by itself, does not define a resource potential."

The diagnostic criterion "Evidence of mineralization" (fig. 7) includes mines, prospects, and undeveloped metal-bearing occurrences for a given deposit type, as well as other features indicating that appropriate mineralizing processes have occurred, even though an actual deposit has not been found. Examples of evidence of mineralization might include products of premetamorphic subvolcanic alteration or chemical (exhalative) sedimentation for volcanogenic massive-sulfide deposits, or zones of pyritization or greisenization for tin deposits related to the Conway Granite. Broadening "MINERAL OCCURRENCE" to "Evidence of mineralization" takes advantage of mapping that has been done far from the known mineral occurrences, and in places greatly enlarges (or restricts) the areas that can be assigned a high resource potential. By contrast, certain belts of rock that might be good hosts for a specific type of deposit, but have not been adequately investigated, are appropriately assigned an unknown resource potential; further studies might show that assignment of a high resource potential is justified.

In summary, figure 7 provides the basis for metallic mineral-resource assessment in the United States portion of the Sherbrooke-Lewiston area. Figure 7 yields a low resource potential for areas containing only favorable geology (FG) or evidence of mineralization (EM), a moderate resource potential for either area that also contains a geochemical anomaly (GCS or GCR), and a high resource potential for areas containing favorable geology and evidence of mineralization, with or without a geochemical anomaly. An unknown resource potential is assigned to areas whose geologic favorability for a specified deposit type has not been investigated (FGN), with or without a geochemical anomaly, and to areas having a geochemical anomaly of speculative source. A geophysical anomaly (GP) does not define a resource potential, but it may reinforce resource potential that is defined by other diagnostic or recognition criteria.

The geochemical data are from the maps of Nowlan and others (1990a, b, c), and from transparent overlays of additional data furnished by Gary A. Nowlan that are contained in the Open-File Reports cited by Nowlan and others (1990a, b, c). The geophysical maps (maps B, C) are contained in this report. Although the gravity and aeromagnetic data are not used specifically to define mineral-resource potential (GP of fig. 7), they bear strongly on the definition of geologic features of economic importance. For example, the Mt. Bon Durban geophysical (gravity and magnetic) anomaly, on the Quebec–Maine–New Hampshire border, provides an important part of the definition of the SLRA, which hosts the volcanogenic massive-sulfide deposits at Ledge Ridge (5D-1) and in the Clinton River district (4C-2 to 10). Additionally, gravity profiling distinguishes steep-walled plutons that might, where shallow enough, have generated mineralizing hydrothermal systems, from plutons that were emplaced as subhorizontal sheets at depths that were too deep to have produced the same type of hydrothermal system.

In reality, it should be understood that the actual resource potential strongly depends on the size of the area. Other factors being equal, for example, an area of 10 km^2 has one-tenth the resource potential of an area of 100 km^2. The size factor bears strongly on the Sherbrooke-Lewiston area, where belts of metavolcanic rocks, for example, are complexly disrupted by faults and plutons into belts or blocks of territory of greatly differing size. It would be too complex and possibly unrealistic to try to integrate the size factor into an already complex scheme of resource definition.

GEOLOGIC FAVORABILITY FOR INDIVIDUAL NONPEGMATITIC DEPOSIT TYPES

Cambrian to Early Devonian volcanogenic massive-sulfide deposits (VMS)

The most important metallic mineral deposits of the map area are stratabound, conformable accumulations of massive-sulfide minerals that are hosted either by proximal volcanic sequences, or by distal volcanic to predominantly sedimentary volcaniclastic sequences. Such accumulations, called Kuroko-type VMS deposits if they are hosted by volcanics, or Besshi-type if they are largely hosted by sediments, are known to have accumulated on the sea floor, or not far below, in areas of active subaqueous volcanism and high heat flow (see Franklin, 1986; Lydon, 1988). Sea-floor mineralization is an appropriate term for the process. The most important known VMS deposits of the Sherbrooke-Lewiston area are Kuroko-type; they occur in: (1) ophiolitic metavolcanic rocks of the Cambrian(?) Jim Pond Formation (Border and Alder Pond prospects; 4C-13, 1C-2, respectively); (2) back-arc to arc metavolcanic rocks of the Ordovician (Mohawkian and Whiterockian) Ammonoosuc Volcanics (Milan and Warren mines; 6F-1, 8I-2, respectively); (3) rift metavolcanic rocks of the Silurian Frontenac and Rangeley or Perry Mountain Formations (deposits of Clinton River district, Quebec, 4C-2 to 8; Ledge Ridge prospect, 5D-1; Paddock mine, 8G-9); and (4) probable arc metavolcanic rocks of the Lower Devonian Ironbound Mountain Formation (Thrasher Peaks prospect, 5D-3). A possibly important Besshi-type VMS deposit (Hampshire Hills, 5F-1) is hosted by silicate iron-formation enclosed in volcaniclasic metagraywacke of the Ammonoosuc Volcanics. The small deposits at the Essex copper prospects (8G-1) may be transitional between Kuroko- and Besshi-types because they occur along or near the conformable contact of the flysch sequence (O€f) with overlying hydrothermally altered, distal felsic metavolcanic rocks of the Ammonoosuc Volcanics (Olv).

In addition to the known VMS deposits cited above, several features shown on the map indicate that sea-floor mineralization has occurred within specific areas. Examples of such features include (1) small pyritic or pyrrhotitic copper sulfide deposits that may or may not be massive, as the Ammonoosuc River copper occurrence (8H-16), and the Gardner Mountain (Albee) copper mine (8G-6); (2) pyritic iron-formation, as the massive pyrite near York Brook (4F-2); (3) magnetite iron-formation, as the Franconia iron mine (8H-2); (4) silicate iron-formation, as the chlorite iron-formation northeast of Red Ridge (5F-3); (5) and evidence of stratabound hydrothermal alteration, as the Sugar Hill volcanogenic alteration occurrence (8H-1). These features, and others not shown on the map, obviously are not outcrops of VMS deposits. They are, however, evidence of processes involved in sea-floor mineralization and the formation of VMS deposits; in this report they are considered diagnostic criteria of equal rank to actual known VMS deposits for the purpose of defining evidence of mineralization (fig. 7).

Factors that control the size and distribution of VMS deposits can be explained by a set of recognized host-rock characteristics that provide a geologic basis for estimating the likelihood that one or more undiscovered VMS deposits may occur within a given area. They may be grouped into five broad recognition criteria, assembled from many sources by the author, augmented by information from J.F. Slack (*in* McCammon, 1986, p. 1–12, and more recent discussions), and supplemented by review papers that incorporate research on modern sea-floor VMS deposits (Franklin, 1986; Lydon, 1988). The following five criteria, modified from Moench (1990, p. J17–J18), are designed specifically for the variably metamorphosed volcano-sedimentary rocks of the project area.

(1) Occurrence of an originally permeable subaqueous volcanic or volcanic-related rock sequence that was thick enough to have hosted a large, energetic hydrothermal convection cell. A minimum thickness of about 500 m is probably required. A subaqueous environment is indicated by pillow basalts, turbidites, and (or) chemical sediments. Whereas pillow basalts or thickly stratified pyroclastic rocks would be ideal, large amounts of interbedded shaly sediments of relatively low permeability would inhibit circulation across bedding and reduce the likelihood of the formation of large deposits.

A minimum water depth of about 500 m is probably required for ore deposition on the sea floor, because at shallower depths rapid boiling and cooling of ascending hot metalliferous solutions would cause precipitation of the metals in the conduit (see Franklin, 1986, p. 69). Shallower water depths are permitted, however, for ore deposition within the host strata below the sea floor. Although the required depths for both cases are difficult to quantify, the occurrence of known VMS deposits or related iron-formations and alteration features indicates that water was deep enough for sea-floor mineralization.

(2) Evidence that premetamorphic hydrothermal alteration has occurred, either in discordant pipes just below a favorable ore horizon, or in widespread zones at a deeper stratigraphic level (Franklin, 1986, p. 53). Alteration in footwall pipes

is shown particularly by discordant zones of depletion of calcium and sodium and by the introduction of magnesium, and by the occurrence of highly aluminous and locally highly potassic rocks. In areas of greenschist-facies metamorphism, widespread volcanogenic alteration may be expressed as bleached, richly pyritic, metachert-bearing, quartz-sericite phyllite, probably analogous to the "lower semiconformable alteration zones" of Franklin (1986, p. 53), or as more localized zones of chlorite-, chloritoid-, or talc-rich phyllite, perhaps with carbonate. At higher metamorphic grades, the greenschist-facies, pyritic, quartz-sericite phyllite becomes more coarsely textured, pyritic, quartz-muscovite schist (±phlogopite), and the more ferromagnesian rocks become cordierite-rich rocks, commonly with anthophyllite and (or) gedrite, chlorite-garnet-staurolite rock, and chlorite-garnet-anthophyllite rock. Quartz-kyanite gneiss and albitite might also represent volcanogenic alteration. An abrupt change from strongly altered to stratigraphically higher, unaltered rocks may mark the upper contact of a nearby stratabound sulfide zone.

(3) Evidence of a volcanic hiatus that was sufficiently long to permit a large deposit to form on or near the sea floor. Such a hiatus might be expressed by a lithologic break between predominantly mafic and younger predominantly felsic metavolcanic rocks, accompanied by indications of slow, fine-grained clastic or chemical sedimentation, and by evidence of an environment that would prevent oxidation of a newly formed sulfide deposit by sea water. Evidence for a volcanic hiatus might include zones of thinly stratified, fine-grained tuffaceous sediments, and tuffaceous to nontuffaceous exhalative chert, bedded barite, tourmalinite, and iron-formation (pyrite-, magnetite-, hematite-, chlorite-, or carbonate-facies). The iron-formations are indications of sea-floor mineralization, possibly distal to sites of VMS deposition. Modern sea-floor sulfide deposits are protected from oxidizing sea water by precipitation in open spaces below a barite cap (Lydon, 1988, p. 162), or by rapid deposition of covering sediments. The largest deposits form along heavily sedimented crests of sea-floor ridges (Franklin, 1986, p. 60). Barite caps are rarely recognized in association with ancient VMS deposits (Lydon, 1988, p. 162) and have not been found in the Sherbrooke-Lewiston area. In the project area, the sharp contacts between subaqueous metavolcanic sequences and overlying black, sulfidic metasedimentary rocks (for example, the Ammonoosuc-Partridge contact) are possible sites of volcanic hiatus where euxinic sea-floor environments would have protected volcanogenic sulfides from oxidation.

(4) Evidence of a major source of heat for driving a large sub-seafloor convection cell. Large subvolcanic intrusions (see Lydon, 1988, p. 168, for dimensions), many small ones, and (or) abundant proximal pyroclastic rocks would be favorable indicators of a heat source. These features are not critical recognition criteria, however, because adequate circulation may also result from high regional heat flow, transmitted by faults and dikes from a deeper magmatic source. A magmatic source is probably necessary, however, in order to maintain temperatures of about 380°C in a basalt-hosted convection cell (see Franklin, 1986, p. 69).

(5) Evidence of tectonic extension in order to maintain open, permeable conditions for fluid transport. The occurrence of dike swarms, sheeted intrusions, and inferred listric normal faults that strike parallel to regional strike constitute indications of extension normal to strike.

In reference to figure 7, criterion 1 is the most important first step toward the definition of favorable geology, because if there are no subaqueous volcanic rocks, a different ore model is needed to explain known stratabound ore deposits. However, criterion 1, by itself, is insufficient for an area to qualify for a designation of "favorable geology," which also requires at least one of the features listed under criteria 3 or 4. Criterion 2 contributes to the definition of "evidence of mineralization," as do the iron-formations listed under criterion 3, as well as the actual known VMS deposits of the area. Criterion 5 is the least important for resource analysis, because an extensional environment (not to be confused with plate-tectonic divergence) can be reasonably assumed for all of the metavolcanic sequences of the area. The stratigraphic distribution of known VMS deposits of the area may be taken as evidence of tectonic extension at the site of eruption or accumulation of the host sequences, regardless of whether they are ophiolitic, related to subduction, or related to rifting.

The following discussions of VMS resources are listed in order of increasing age: Lower Devonian (Dv1 to Dv6); Lower Devonian and Silurian (DSv1); Silurian (Sv1 to Sv5); Ordovician (Ouv1, and Olv1 to Olv7); and Cambrian(?) (Ɛov1, Ɛov2). Not listed are small tracts of metavolcanic rocks that do not satisfy the requirements of criterion 1. Examples are the subaerial volcanics of the Kineo Volcanic Member of the Lower Devonian (Emsian) Tomhegan Formation (grids 1B, 1C); the small amounts of felsic metavolcanic rocks of the Quimby Formation (Ouv) west of Rangeley, Maine (grid 3E); and rocks tentatively mapped as the Lobster Mountain Volcanics (of Ouv) in grid 1C. The Lobster Mountain Volcanics of this area might be thick enough, but are composed of weakly metamorphosed, probably subaerial or shallow subaqueous graded and crosslaminated volcaniclastic siltstone and sandstone, assorted andesite, volcanic breccia, and sparse conglomerate that are not a likely host for VMS deposits.

Area Dv1 (grids 4C to 5D)

This narrow band of metavolcanic rocks has a long history of exploration and is host to the Thrasher Peaks prospect (5D3), thought to represent a copper-zinc VMS deposit that has been dismembered by shearing related to the Thrasher Peaks fault (TPF). Although some explorationists believe that the sulfide deposits are fault related, others, including the author, consider it to be volcanogenic on the basis of the nature of the host rocks. The area is bounded on the east by the TPF. The metavolcanic rocks are assigned to the Lower Devonian (Gedinnian?) Ironbound Mountain Formation (**Dpv**), on the basis of minor interstratified dark-gray slate characteristic of the Ironbound Mountain. Microgranite at Thrasher Peaks, interpreted by R.A. Cavalero (Boise Cascade Corporation, written commun., February 1988) as a rhyolite dome, has yielded a concordant U-Pb zircon age of about 414 Ma (Eisenberg, 1982, p. 42), equivalent to early Early Devonian (Gedinnian) time (Tucker and McKerrow, 1995). This body is one of many small microgranite intrusions (index 10) within the volcanic sequence and associated dark-gray slate of the Ironbound Mountain Formation. Rocks of the prospect area are weakly metamorphosed, thickly stratified schistose felsic tuff and tuff breccia; gray and black slate; pillowed, hyaloclastic, and agglomeratic basaltic greenstone; and small bodies of predominantly basaltic conglomerate. The mineral deposits are small podlike lenses of massive sulfide discontinusouly distributed for about 5 km in a northeast-trending shear zone about 100 m wide, just west of the TPF. The volcanic sequence is as much as 1 km thick.

Resource potential—Moderate. The area contains thick, proximal, subaqueous metavolanic and related intrusive rocks that would be geologically favorable for the occurrence of VMS deposits, save for the wide zone of intense shearing above the hanging wall of the TPF. Although the Thrasher Peaks prospect represents conclusive evidence of volcanogenic mineralization, the deposits are strongly dismembered. High abundances of copper occur in sediment samples from streams that drain the area; zinc and lead occur in some of the sediment samples. The area has been extensively explored since the 1960's, but to little avail, probably because of the shearing. Accordingly, any major VMS deposit that might occur in the area is likely to have been disrupted into isolated bodies. For this reason, the geology is not favorable and only a moderate potential is justified.

Area Dv2 (grids 5D to 6E)

The southern part of this area is underlain by approximately 500 m of massively bedded, felsic crystal metatuff and subordinate basaltic or andesitic amphibolite and thinly bedded, fine-grained, felsic metatuff of the Lower Devonian Ironbound Mountain Formation (**Dpv**). These rocks are conformably overlain by sulfidic-graphitic phyllite and metatuff of the formation, and are underlain by metasandstone, calc-silicate rock, and local felsite of the Silurian(?) Madrid Formation or, where the Madrid is absent, by sulfidic black schist and quartzite of the Smalls Falls Formation (both of **Srp**). The felsic metatuff intertongues northward into graded-bedded dark-gray slate (mud-silt turbidites) that typify the Ironbound Mountain Formation farther northeast (Marvinney, 1986). Associated with the metatuff of the northern part of area Dv2 is a lens of andesitic amphibolite that is partly pillowed and partly intrusive. Gray, magnetite-bearing, iron-enriched metashale and magnetite iron-formation occur near the lower boundary of the sequence at the south end of the area.

Resource potential—Moderate. The geology is marginally favorable in the southern part of the area, where criteria 1 and 3 are satisfied. Although no evidence of hydrothermal alteration was found, exhalative iron-enriched metasedimentary rocks probably occur in a small area near the base of the sequence at the south end of the area, but are not conclusive evidence of mineralization. Anomalous amounts of copper in three stream-sediment samples (25–36 ppm Cu) and anomalous amounts of copper, lead, and zinc in one heavy-mineral concentrate (70–10,000 ppm Cu, 150–300 ppm Pb, and 1,000–2,000 ppm Zn) were obtained from streams that drain the southern tip of the area, near the location of the iron-enriched rocks. The combination of favorable geology and a geochemical anomaly yields a moderate resource potential on figure 7; the potential decreases from south to north.

Area Dv3 (grid 7F)

This small area is underlain mainly by magnetite-bearing slate and metasiltstone of the Ironbound Mountain Formation, but with abundant garnet-rich laminations, and a small amount of metabasalt and silicate iron-formation. The iron-formation hosts a small, stratabound, Besshi-type copper deposit that is exposed near the north bank of Washburn Brook (7F-4).

Resource potential—Low. This area contains only a small amount of metavolcanic rocks that do not satisfy criterion 1 for favorable geology. The small, Besshi-type copper deposit at Washburn brook is evidence of mineralization.

Area Dv4 (grids 7G and 8G)

This area is underlain by as much as 500 m of thickly stratified, probably intermediate to rhyolitic, ash and lapilli metatuff, and feldspar-clast metawacke (**Dpv**) assigned to the Ironbound Mountain Formation. These rocks are associated with gray slate that is more characteristic of the Ironbound Mountain. A slight hint of stratabound copper mineralization was found in the southern part of the area, near the prospect southwest of Dalton (7G-2).

Resource potential—Low. Criterion 1 for favorable geology for the occurrence of Kuroko-type VMS deposits is satisfied; the bare hint of stratabound copper mineralization seen near the prospect southwest of Dalton (7G-2) is not sufficient to influence the resource assignment.

Areas Dv5 (grids 8G to 9I, fig. 6)

These areas represent metavolcanic rocks that occur in the lower part of the Littleton Formation (**Dcv**), in several belts that extend collectively about 50 km through the southwest corner of the Lewiston quadrangle, as shown on map D and figure 6. The volcanic sequences of the Littleton Formation possibly have an unmeasured maximum thickness of about 500 m. Although not studied in detail, available descriptions and local observations by the author indicate the presence of varied volcanic compositions, and volcanic types include pillowed metabasalt, thinly to thickly stratified metamorphosed felsic tuff, agglomerate, volcanic conglomerate, and volcanic mudflow deposits. In the area of figure 6 (but not shown), a densely trachytic metarhyolite dome (surface dimensions 0.5x1.5 km) associated with felsic metatuff and agglomerate of the Littleton Formation (**Dpv**) centers about 0.5 km north of the northern contact of the Fairlee pluton (index 94).

Resource potential—Low. The geology is marginally favorable; criteria 1 and 4 are at least locally satisfied. The areas contain no known evidence of mineralization, nor do they appear to be the source of geochemical anomalies. A large geochemical anomaly, shown by copper, zinc, and lead in stream sediments (Nowlan and others, 1990b), overlaps the small area of Dv5 in the northwest corner of grid 8H, but its source is likely to be the several Mesozoic(?) vein deposits of that area rather than VMS deposits in the Littleton Formation. The geologic characteristics of the areas justify a low resource potential.

Area Dv6 (grids 7H and 8H)

This area is the belt of metavolcanic rocks of the Littleton Formation that lies between the Mount Clough and Lincoln plutons (indexes 85, 84). The thickness of the metavolcanic sequence is unknown, but since the belt is a truncated remnant between two plutons, its original thickness probably satisfies criterion 1. The metavolcanic rocks are compositionally varied, and they include some proximal volcanic types and hypabyssal intrusives. The metavolcanic rocks of the belt grade laterally southward to distal, fine-grained, volcaniclastic metawacke. A small, Kuroko-type stratabound copper deposit is exposed at the Coppermine brook copper mine (7H-2); the deposit occurs at the sharp transition from massive metabasalt to felsic metatuff.

Resource potential—High. The geology of the area is favorable; criteria 3, 4, and probably 1 are satisified, and the stratabound deposit at the Coppermine Brook mine is good evidence of mineralization. A high resource potential is therefore justified, despite the small size of the area.

Areas DSv1 (grids 8E to 8G)

Some of the most productive metal mines in New England are those of the Orange County copper district in east-central Vermont, southwest of the project area (Slack, 1990, table 1). The largest producer in the past was the Elizabeth mine, which yielded approximately 3.2 million tons of massive sulfide ore containing copper and small amounts of zinc, silver, gold, pyrrhotite, and iron sulfate (Slack and Schruben, 1990, p. H3; Slack and others, 1990, p. Q2–Q3). These deposits are largely sediment hosted (Besshi-type); they occur in association with the predominantly basaltic Standing Pond Volcanic Member of the Waits River Formation, which lies approximately along the boundary between the calcareous Silurian Waits River Formation and the siliciclastic Lower Devonian Gile Mountain Formation. According to Slack and others (1990, p. Q3), the "***wall rocks associated with the (copper) deposits include a variety of unusual lithologies that contain abundant quartz, amphibole, spessartine garnet, tourmaline, carbonate, albite, and (or) mica." Slack and others (1990) interpreted these lithologies to represent metamorphosed hydrothermally altered deposits that formed on the sea floor during mineralization.

The Waits River–Gile Mountain contact is mapped at the west side of the project area (grids 8E, 8F). In areas DSv1, metasedimentary rocks of both formations are interstratified with lenses of basaltic amphibolite and some felsic gneiss (metatuff?) mapped as volcanic-bearing units (**Srwv**, **Dcv**). The unusual lithologies described by Slack and others (1990) have not been recognized, possibly because the rocks on both sides of the contact zone have not been adequately studied.

Resource potential—Unknown. The mixed metasedimentary and metavolcanic rocks of these areas might be favorable for the occurrence of Besshi-type VMS deposits similar to those of the Orange County copper district to the south in Vermont, but have not been adequately investigated. In marked contrast with the prominent geochemical anomalies shown by stream-sediment data from the Orange County copper district (Slack and others, 1990), no anomalies are seen in the geochemical data of Nowlan and others (1990a, b, c) from areas DSv1. For lack of further information, an unknown potential is assigned.

Area Sv1 (grids 1A and 2A)

This area is underlain by at least 1 km of weakly metamorphosed metabasalt originally mapped as the Canada Falls Member (name not used on this map) of the Frontenac Formation (Marvinney, 1986). This basaltic sequence tongues laterally into interbedded meta-arenite and metashale of the Frontenac Formation, and it is conformably overlain by metasedimentary rocks of the Frontenac or (where such rocks are absent above the metabasalt) by gray slate of the Ironbound Mountain Formation (Lower Devonian). The upper part of the basaltic sequence is well pillowed; the lower part is composed of unpillowed flows and basaltic tuff. The anticlinal structure of the body possibly is inherited from an original form as a subsea ridge along the axis of the SLR.

Resource potential—Moderate. The geology of the area is favorable; criterion 1 is amply satisfied on the basis of thickness; although features of criteria 2–4 have not been described, a volcanic hiatus (criterion 3) occurs at the upper contact, where pillowed metabasalt is sharply overlain by fine-grained metasedimentary rocks. A small geochemical anomaly is indicated by 130–860 ppm zinc in three sediment samples from streams that drain the area. The favorable geology and geochemistry therefore justify a moderate resource potential for Kuroko-type deposits.

Area Sv2 (grids 4C to 6E)

This area, which extends about 60 km from near the south end of Lac Mégantic, Quebec, to about 10 km south of Lake Francis, N.H., is the principal magmatic center of the Second Lake rift axis (SLRA). Weakly metamorphosed volcanic rocks of the belt, mapped as part of the Silurian Frontenac Formation (of Srwv), form a major bimodal volcanic center that hosts the polymetallic VMS deposits of the Clinton River district in Quebec (deposits 4C-2 to 10) and the Ledge Ridge and Ledge Ridge extension prospects in Maine (5D-1, 5D-2). Stratigraphically, the volcanic belt contains a lower, well-pillowed basalt member possibly 2 km thick, and an upper member composed of variably felsic-dominated to mafic-dominated bimodal proximal volcanic rocks as much as 1 km thick. Massively bedded, rhyolitic ash- and lapilli-metatuff, and vent-facies fragmental metarhyolite are recognized. In Quebec, the upper member also contains abundant volcaniclastic metagraywacke.

Structurally, the belt is the tight Second Lake anticline (Harwood, 1969), which is creased lengthwise by a faulted syncline. Several small bodies of diapiric serpentinite occur along or near the fault. When the effects of tight folding are removed, this structure has the appearance of a sea-floor ridge having an axial half-graben rift valley. The Ledge Ridge VMS deposit occurs within the half-graben and lies stratigraphically just above the transition from the mafic lower member to the bimodal upper member. Ferruginous metasiltstone and siliceous iron-formation also occur along this boundary. From Chevé's (1978) and Ebinger's (1985) mapping and descriptions, the Clinton River VMS deposits also can be inferred to occur within the half-graben. Although the Clinton River deposits occur within a thick, proximal volcanic sequence, they are directly hosted mainly by fine-grained volcaniclastic metasedimentary rocks. The highest exposed stratigraphic unit within the faulted syncline is graphitic-sulfidic phyllite assigned to the Silurian Smalls Falls Formation (of Srp).

Intrusive rocks of the area include hypabyssal biotite granite of the East Inlet pluton (index 12), the bimodal sheeted dike body at Marble Mountain (index 11), and a bimodal dike swarm that is most abundantly exposed in area Sv3 to the south. Available U-Pb zircon data (*in* Moench and others, 1995) indicate that the East Inlet pluton, the felsic member of the dike swarm, and the bimodal metavolcanic rocks are Silurian. Lead isotope data from the East Inlet pluton and from galena obtained from the VMS deposits (Aleinikoff and Moench, 1987; Slack and others, 1991) indicate little, if any, contribution from underlying continental crust. It is reasonable to infer, therefore, that such crust was greatly attenuated (or absent) beneath the rift axis.

It is further noteworthy that the prominent Mt. Bon Durban geophysical anomaly (described in the "Complete Bouguer gravity and aeromagnetics" section by Bothner and others), which is expressed by strongly positive gravity and aeromagnetic anomalies, coincides with the rift axis across the international border.

Resource potential—High. Rocks of the area have highly favorable geology; criteria 1 and 3 are well satisfied. A stream-sediment copper-zinc anomaly is concentrated mainly in the area of the Ledge Ridge and Ledge Ridge extension deposits, but that area was sampled in greater detail than most of the report area. Undiscovered copper-zinc VMS deposits are most likely to occur in areas underlain by proximal bimodal volcanic rocks, perhaps extending downward a few tens of meters into the basaltic lower member. The most promising horizon is the transition from the basalt member to the bimodal member. Another horizon that should be investigated is where the bimodal member is overlain by strongly euxinic rocks of the Smalls Falls Formation (of Srp).

When this report was written, exploration was ongoing in the vicinity of the Ledge Ridge VMS deposit, considered subeconomic on the basis of published grade and tonnage data (Cummings, 1988, p. 253). Chemical analyses obtained by John F. Slack of samples from drill cores show 0.29–1.1 ppm gold in massive sulfide, and 3 ppm gold in pyritic greenstone (see description of the Ledge Ridge deposit in Appendix II). It is reasonable to surmise that the occurrence of precious metals in altered rocks such as the greenstone, in addition to actual VMS deposits, is the focus of current efforts.

Area Sv3 (grid 6E)

This area, about 25 km long, is a belt underlain by greenschist- to epidote-amphibolite-facies metavolcanic and metasedimentary rocks of the Frontenac Formation (of Srwv), which is divided into a lower metabasaltic member and an upper member of interstratified fine-grained metasedimentary and feslic metavolcanic rocks and metabasalt. The metavolcanic rocks are distal, relative to those of area Sv2, which is on strike to the north. They are intruded, approximately parallel to strike, by many mafic and felsic dikes, one of which has yielded a U-Pb zircon Silurian age of 418±4 Ma (Lyons and others, 1986), considered approximately coeval with felsic volcanic rocks of the belt. The Simms Stream copper occurrence (6E-2) is a small outcrop (not found when looked for in 1995, possibly buried by stream action) of a possible VMS deposit hosted by the Frontenac Formation.

Resource potential—High. The geology of the belt is favorable, although probably less favorable than that of area Sv2. Criterion 1 is satisfied on the basis of thickness, and the upper contact of the basaltic member is reasonably interpreted as a volcanic hiatus, satisfying criterion 3; however, the rather high abundance of interstratified metasedimentary rocks might have inhibited important hydrothermal circulation. There is no well-defined geochemical anomaly. The Simms Stream copper occurrence (6E-2) is evidence of mineralization; it opens the possibility that important VMS deposits occur nearby or elsewhere in the belt. In reference to figure 7, a high resource potential is justified, although not so high as area Sv2.

Areas Sv4 (grids 7F to 9H, fig. 6)

These areas incorporate parts of the Piermont sequence southwest of the Gore Mountain plutons (index 43). The boundaries of the areas are drawn approximately to include the known exposures of metavolcanic rocks in the Rangeley, Perry Mountain, and Smalls Falls Formations (**Srp**, **Srpv**) that show at least minor evidence of volcanogenic mineralization. The metavolcanic rocks are interstratified with metasedimentary rocks that are more characteristic of the listed formations: rusty-weathering, dark-gray to black, pyrrhotitic metashale, feldspathic quartzite, and sparse metaconglomerate of the Rangeley; typically pale-green metashale and variably feldspathic quartzite of the Perry Mountain, which is variably rusty- to nonrusty-weathering; and commonly coaly-black, richly pyrrhotitic metashale and sparse to abundant quartzite of the Smalls Falls. Within areas Sv4, the total maximum thickness of this package of formations is probably slightly greater than 1 km.

The metavolcanic rocks of areas Sv4 are predominantly felsic ash- and lapilli-metatuff, and subordinate basaltic to possibly intermediate greenstone or amphibolite; all may be distal to the volcanics of the SLRA in areas Sv3 and Sv2 to the northeast, although the occurrence of small eruptive centers within areas Sv4 is not ruled out. Immediately south of the Gore Mountain plutons, the Smalls Falls Formation contains the listed volcanic types, local agglomerate, and abundant thinly bedded metachert that is indicative of exhalative processes. Such metachert also is characteristic of the Smalls Falls of areas Sv5. At the southwest end of the small area of Sv4 in grid 8G, black slate and metasandstone of the Smalls Falls contains a small body of well-stratified felsic metatuff, and metatrachyte underlain by a thin sequence of metarhyolite and gossan-pocked, sugary metachert, also indicative of exhalative processes. Thickly bedded felsic ash- and minor lapilli-metatuff is widely distributed in the Perry Mountain and Rangeley Formations of areas Sv4.

The VMS deposit at the Paddock mine (8G9), which produced as much as 50,000 tons of copper ore before the turn of the century (Gair and Slack, 1979), is hosted by felsic metatuff near the upper contact of the Rangeley Formation. The several other VMS deposits of the Gardner Mountain area (southwestern grid 8G to northeastern grid 9H, fig. 6) occur mainly in the Perry Mountain Formation. As described by Margeson (1982), the pyritic copper deposit at the Stevens mine (9H-2, fig. 6) is hosted by weakly metamorphosed, well-stratified tuffaceous shale and sandstone, felsic crystal tuff, lapilli tuff, fine-grained granophyre, vitrophyre, quartz porphyry, and minor amounts of basaltic and andesitic greenstone. The ore horizon at the Stevens mine grades laterally to thinly laminated pyritic iron formation, thence to chloritic silicate iron-formation. Extensive areas in which rocks of the Perry Mountain Formation are rusty weathering and pyritic might express volcanogenic hydrothermal alteration.

The rocks of areas Sv4 are interpreted to represent subaqueous sediments of dual provenance, one from a nonvolcanic continental source to the west, the other probably from several volcanic centers within the basin of deposition. The principal volcanic source was the the SLRA in area Sv2, but there might also have been contributions from several small volcanic centers in areas Sv3 and Sv4.

The Gardner Mountain area (grid 8G and fig. 6) has been extensively explored during the past two decades, presumably mainly for gold associated with the VMS deposits, as somewhat supported by the sampling done for this study. Analyses of samples of pyritic schist and quartzite (or metachert) in alteration zones, deformed chalcopyrite-bearing veins, and fragments of massive sulfide ore from the Paddock mine (8G-9), the Paddock extension prospect (8G-10), and the Gregory Extension prospect (8G-5) consistently yielded 0.15–0.4 ppm gold, as much as 15 ppm silver, and, in samples containing conspicuous chalcopyrite, locally more than 2 percent copper and smaller amounts of zinc and lead.

A conspicuous copper-zinc-lead geochemical anomaly, defined by stream-sediment (Nowlan and others, 1990b) and heavy-mineral-concentrate data, occurs in the area of several mines, prospects, and undeveloped occurrences in grids 8G and 8H between Gardner Mountain and the AF. Because the same and adjacent areas also contain several Mezozoic(?) sulfide-bearing veins as well as evidence of Ordovician volcanogenic mineralization, the specific source of anomaly is difficult to determine. Almost certainly, however, anomalous amounts of copper (26–1,000 ppm) and zinc (110–860 ppm) in stream-sediment samples from streams that directly drain the east side of Gardner Mountain have their source in VMS deposits of that area. The data of Nowlan and others (1990), however, do not reveal geochemical anomalies that can be related to the two northern areas of Sv4 (northern grid 8G and grid 7F).

Resource potential—Moderate and low. The several small VMS deposits of areas Sv4 provide abundant evidence of mineralization, which is supported by the geochemical data for the southern but not the northern areas of Sv4. For reasons given by Moench (1990, p. J20) and in the "Cambrian to Early Devonian volcanogenic massive-sulfide deposits (VMS)" section of this report the geology is probably not favorable for the occurrence of VMS deposits that are significantly larger than the one at the Paddock mine (8G-9). Although the Rangeley, Perry Mountain, and Smalls Falls Formations of the area are thick enough to have hosted large hydrothermal circulation cells, the energy of circulation probably would have been diminished by the large amounts of interbedded shaly deposits of low original across-bed permeability. This relationship is interpreted to explain the small size of known VMS deposits of the belt, and the rarity of iron-formation or other chemical deposits. In reference to figure 7, therefore, a moderate resource potential is justified for the southern areas Sv4, where evidence of mineralization is supported by stream-sediment geochemical data; a low resource potential is justified for the northern areas, where minor evidence of mineralization is not supported by available geochemical data.

Areas Sv5 (grids 5E to 6F)

These areas represent remnants of a synclinal belt, the Rice Mountain syncline of Green (1968), composed of about 500 m of pillowed and massive metabasaltic flows and local metadiabasic intrusive overlain by a few tens of meters of felsic metatuff, all assigned to the Silurian Smalls Falls Formation. Most of the felsic metatuff is very fine grained, but lapilli metatuff occurs locally; intrusive felsite was found at one place. Conspicuous throughout the belt are sharply bedded, fine-grained, commonly manganiferous metachert, and cherty magnetite iron-formation. At the south end of the belt, the lower 100 m of the basaltic sequence contains polymictic conglomerate interbedded with metabasalt and cherty iron-formation. All these rocks are overlain and underlain by rusty-weathering, commonly coaly-black, sulfidic metashale and quartzite characteristic of the Smalls Falls. The Smalls Falls of this belt is conformably underlain by schist and quartzite of the Perry Mountain Formation, succeeded downward by rusty-weathering schist, quartzite, and local quartz metaconglomerate of the Rangeley Formation. Areas Sv5 contain no known metallic mineral deposits and no obvious geochemical anomaly.

Resource potential—Low. The geology of the area is favorable; criterion 1 is marginally satisfied on the basis of thickness, and criteria 3 and 4 are partly satisfied by the abundant metachert felsic intrusion. The contact between the volcanic sequence and the overlying strongly euxinic rocks of the Smalls Falls Formation might be a favorable horizon. A low resource potential is indicated by the favorable geology and the absence of evidence of mineralization, possibly excepting the magnetite-bearing metachert, and the lack of a geochemical anomaly.

Areas Ouv1 (grids 8G to 9I, fig. 6)

These areas, underlain by the volcanic member of the Quimby Formation (Ouv), are mainly in grids 8G, 8H, and 9H, but a small remmnant of the Quimby also is exposed in grid 9I (southwest corner of fig. 6). The main exposures represent two synclinal belts on opposite sides of the west-dipping Ammonoosuc normal fault (AF). According to the author's reconstructions, the western, greenschist-facies belt represents a structural level that is 3–4 km above the higher rank eastern belt. The volcanic member is estimated to be about 1 km thick. In the eastern belt, it is composed mainly of massive very thick to thin graded beds of coarse-grained, felsic metatuff, less common very thick beds of matrix-supported volcanic pebble to boulder metaconglomerate and probable pyroclastic flow deposits, and local metabasaltic flows and graded beds of basaltic metatuff, some containing abundant plagioclase crystals. In the western belt, the member is about equally divided between massively bedded felsic metatuff containing only sparse basaltic greenstone, as in the eastern belt, and calcitic greenstone of basaltic composition containing little felsic metatuff. The greenstone is predominantly pyroclastic, commonly as graded beds containing plagioclase crystals. Flows of massive and pillowed greenstone a meter or two thick occur locally; some of these contain abundant calcite-filled amygdules, suggesting a shallow subaqueous environment. In both belts, the volcanic member is conformably overlain by the euxinic shale and graywacke member (Oue). Along the southeatern side of the eastern belt, the volcanic member is abruptly but conformably underlain by euxinic deposits of the Partridge Formation (Ole), but elsewhere the lower contact of the volcanic member is a sharp disconformity on the Partridge, or an unconformity that channels through the Partridge Formation and Ammonoosuc Volcanics (Olv), and into underlying rocks of the flysch sequence (O€f). Where disconformity is exposed at Bath, N.H., the basal metatuff bed contains abundant rip-ups derived from the underlying Partridge Formation. This bed has yielded a U-Pb zircon age of 444±4 Ma (Moench and others, 1995, site M-10). Where the unconformity is exposed in the western belt, the base of the volcanic member is commonly marked by a thick bed of volcanic-matrix, polymictic debris-flow, boulder conglomerate that contains a wide variety of volcanic, plutonic, and sedimentary clasts.

In both belts, rocks of the volcanic member lack evidence of hydrothermal alteration or chemical sedimentation, and they contain no other evidence of volcanogenic mineralization. The upper contact of the volcanic member might be interpreted as a volcanic hiatus where a VMS deposit would be protected from oxidation by overlying euxinic sediments of the Quimby Formation. Although the area is overlapped by the copper-zinc-lead anomaly described in the discussion of area Sv3, there is no evidence that any part of the anomaly has its source in areas Ouv1.

Resource potential—Low. The geology is favorable on the basis of thickness (criterion 1) and a volcanic hiatus at the top of the volcanic sequence (criterion 3), but the areas lack evidence of volcanogenic mineralization, and there is no evidence that the geochemical anomaly mentioned above has its source in the areas.

Area Olv1 (grids 4D and 4E)

This area, northwest of Rangeley Lake, Maine, is underlain by a lenticular body as much as 1,500 m thick of massive and pillowed flows and local agglomerate of basaltic greenstone of the

Ammonoosuc Volcanics (Olv). There is no reported evidence of chemical sedimentation or premetamorphic alteration. No geochemical anomaly is seen in the stream-sediment data. The greenstone body is underlain by flysch of the Dead River Formation (O€f), and it tongues laterally and is overlain by black slate and interbedded rocks of the Partridge Formation (Ole).

Resource potential—Low. Criterion 1 is satisfied on the basis of thickness, and the upper contact, where the metabasalt is overlain by euxinic rocks of the Partridge Formation, might satisfy criterion 3. The favorable geology, the lack of evidence of mineralization, and the lack of a geochemical anomaly justify a low resource potential.

Areas Olv2 (grids 4F to 6F)

These areas are underlain by varied and complexly interstratified rocks of the Ordovician (Mohawkian and Whiterockian) Ammonoosuc Volcanics (Olv). The rocks are divided into a basaltic lower member, about 500 m thick, and an upper mixed felsic to mafic member, as much as 2 km thick. The lower member is composed of massive and pillowed basaltic amphibolite flows and feldspathic biotite schist interpreted as mafic volcaniclastic graywacke; these rocks locally intertongue with black sulfidic schist of the Partridge Formation (Ole). The basaltic amphibolite, most of which is normal hornblende-plagioclase gneiss (±minor quartz), is locally altered to gedrite-bearing gneiss. The member is conformably underlain by flysch-like rocks of the Dead River Formation (O€f), and both the Dead River and the basal, basaltic member of the Ammonoosuc are intruded by the Chickwolnepy intrusions (index 39). The youngest tonalite body of the intrusion is dated at 467±3 Ma (Moench and others, 1995, site O-7). The Chickwolnepy intrusions and basaltic lower member are interpreted as backarc ophiolite (Fitz and Moench, 1996; Fitz, 1996a, b). The intrusions provide evidence of tectonic extension and a potent heat source for driving an energetic hydrothermal system.

The upper member contains strongly metamorphosed low-potassium felsic tuff, volcanic conglomerate and pyroclastic rocks, basalt, minor andesite, small subvolcanic intrusions, and local massive pyrite and magnetite iron-formation. This unit hosts the zinc-copper-lead VMS deposits at the Milan mine (6F-1), which produced about 500,000 tons of ore prior to 1911. Field observations in the mine area indicate that the ore bodies are Kuroko-type; they occur at the stratigraphic top of a strongly altered felsic tuffaceous metavolcanic sequence that contains (about 72 m southeast of the open stope) a probable dome of altered metarhyolite. This sequence lies just above the mafic lower member. Just above the orebody is normal amphibolite showing little or no evidence of premetamorphic alteration.

Thick sequences of felsic metatuff of the upper member grade laterally to extensive volcaniclastic metagraywacke, which locally contains sulfidic magnetite-garnet-staurolite-chlorite (silicate-facies) iron-formation. The largest body of silicate iron-formation also contains lenses of quartz-kyanite gneiss, interpreted as volcanic rock that has been leached of all components except silica, alumina, and titania. This body of iron-formation hosts the Besshi-type pyrrhotitic copper deposit at the Hampshire Hills prospect (5F-1). Although information on the grade and tonnage of the Hampshire Hills VMS deposit is not available, it has been extensively explored and is assumed to be one of the principal deposits of the Sherbrooke-Lewiston area. The setting of the Hampshire Hills deposit thus differs from those of most of the other volcanic-hosted deposits of the project area, and a somewhat different model of ore deposition is required. Pyke (1985) inferred that the silicate iron-formation is altered tuffaceous exhalite; she proposed that the iron-formation and the copper deposit accumulated in a sea-floor brine pool fed by hydrothermal springs.

In addition to alteration features associated with the silicate iron-formation, metavolcanic rocks of the upper and lower members of the Ammonoosuc Volcanics show abundant evidence of hydrothermal alteration of the types commonly found in VMS districts elsewhere. Metabasalt of the lower member locally contains gedrite, and is chemically depleted in calcium and sodium and enriched in magnesium. Felsic metavolcanic rocks of the upper member are widely pyritic and are variably converted to quartz-muscovite schist and metachert; this type of alteration possibly exemplifies the "lower strataform alteration" of Franklin (1986). The most impressive zone of pyritic quartz-muscovite schist occurs immediately below the upper contact of the Ammonoosuc Volcanics northeast of the Hampshire Hills prospect, where the Ammonoosuc is unconformably overlain by a local thin layer of calc-silicate rock and quartzite at the base of the Quimby Formation. The calc-silicate rock contains a small amount of scheelite (Upton occurrence, 5F2), which either represents a small skarn deposit or a tungsten-bearing hydrothermal spring deposit that developed on the flank of a dormant Ammonoosuc volcano.

Resource potential—High. The geology is highly favorable for the occurrence of Kuroko-type VMS deposits, and locally for the occurrence of Besshi-type deposits. Criteria 1, 3, and 4 are amply satisfied, and evidence of mineralization is abundantly shown by the known VMS occurrences, as well as by the evidence of alteration (criterion 2) and chemical sedimentation (criterion 3). Additionally, stream-sediment data show 26–1,000 ppm copper in scattered samples from the area, and in a cluster of five samples near the chlorite iron-formation northeast of Red Ridge (5F-3). This cluster and the occurrence are in an area underlain by a graywacke facies of the Ammonoosuc Volcanics, and might represent an undiscovered Besshi-type copper deposit similar to the one at Hampshire Hills (5F-1). The lower to upper member transition and slightly higher stratigraphic levels are most favorable for Kuroko-type VMS deposits, as at the Milan mine (6F-1). The sulfide occurrence east of Hodgdon Hill (6F-2) is an example of a possible exploration target seen in outcrop. Areas underlain by metagraywacke and silicate iron-formation have potential for the occurrence of Besshi-type pyrrhotitic copper deposits similar to the Hampshire Hills deposit (5F-1); the chlorite iron-formation northeast of Red Ridge (5F-3) is a possibility, as already noted on the basis of geochemical data.

The assignment of high resource potential primarily applies to the upper member of the Ammonoosuc Volcanics. Although a lower potential might be justified for the basaltic lower member, the two members are combined here for cartographic simplicity. Readers are referred to Moench and others (1995) for the distributions of the lower and upper members.

Areas Olv3 (grids 5F to 8H)

These widely separate outcrop areas of Ammonoosuc Volcanics have not been adequately investigated for features characteristic of regions containing VMS deposits. They contain no conspicuous geochemical anomalies, and no known volcanogenic mineral occurrences.

Resource potential—Unknown. Although the Ammonoosuc Volcanics of these areas probably satisfy criterion 1, they are not known to contain sufficient evidence for assignment of resource potential for VMS deposits. However, the occurrence of anomalous amounts of copper (36–1,000 ppm) and zinc (130–860 ppm) in one stream-sediment sample obtained from the lens at Whitefield (center of grid 7G) suggests the need for further studies in this area. The Crane molybdenite prospect (7G-4) in this area probably is not the source of the anomaly.

Areas Olv4 (grids 7H to 9I, fig. 6)

In these areas, the Ammonoosuc Volcanics (Olv) and the Sugar Hill, Landaff, Moody Ledge, and Owls Head plutons (indexes 86, 87, 88, 89, 92) of the Oliverian domes form the core of the BHA in its type area. Index 89 is a slice of the Moody Ledge pluton and a small body of Ammonoosuc that was displaced by intrusion of the Devonian Mount Clough pluton (index 85). The Oliverian plutons intrude the Ammonoosuc, and available U-Pb zircon age data indicate that they are too young to represent the roots of Ammonoosuc volcanoes, or possible heat sources for alteration associated with sea-floor mineralization in Ammonoosuc time. Whereas the ages obtained from the Oliverian plutons in the report area range from about 441 to 456 Ma, the best available dates for the Ammonoosuc are 461±8 Ma for rhyolitic metatuff intruded by the Moody Ledge pluton, and 469±2 Ma for the tonalitic Joslin Turn pluton (index 57), interpreted to be comagmatic with basal metatuff of the Ammonoosuc (see Moench and others, 1995). The Ammonoosuc of areas Olv4 might be 1 km thick.

Although the Ammonoosuc Volcanics of areas Olv4 has not been mapped adequately for detailed subdivision, a wide variety of volcanic and volcanogenic rock types are recognized, all strongly deformed and metamorphosed. These include thick sequences of basaltic flows and common agglomerate; thinly to thickly interbedded mafic and felsic volcanics; massively bedded felsic pyroclastic flow deposits; and thinly bedded, fine-grained volcaniclastic sedimentary rocks, pyritic chert, and magnetite iron-formation. A large body of iron-formation was mined during the 19th century at the Franconia iron mine (8H-2). Pipelike and widespread alteration features are recognized at Sugar Hill and the Wild Ammonoosuc River (8H-1, 8H-19). Volcaniclastic metagraywacke with sparse basaltic amphibolite is exposed in a small area that centers on Bronson Hill, northwest of the Landaff pluton. South of the area of map D, as much as 100,000 tons of zinc-lead (silver) ore was produced from the VMS deposit at the Warren (Ore Hill) mine (fig. 6, 8I-2).

Resource potential—High. With the exception of a small area underlain by volcaniclastic metagraywcke, the geology is favorable for the occurrence of Kuroko-type VMS deposits. Criterion 1 is satisfied on the basis of thickness, and criterion 4 is satisfied on the basis of the proximal character of the metavolcanic rocks. Evidence of mineralization is shown by the VMS deposit at the Warren mine, by the iron-formation at the Franconia mine, and by alteration features. Although the area underlain by volcaniclastic metagraywacke is less favorable for the occurrence of Kuroko-type VMS deposits, the rocks are not unlike the metagraywacke that encloses the silicate iron-formation that hosts the Besshi-type Hampshire Hills pyrrhotitic copper deposit (5F-1) in area Olv2. Stream-sediment and heavy-mineral-concentrate data indicate high copper and zinc contents in several streams in diverse parts of the area. Gravels of the Wild Ammonoosuc River are known to contain placer gold, possibly derived from the Ammonoosuc Volcanics; gold was detected in two heavy-mineral concentrates obtained from two tributary streams (Nowlan and others, 1990c).

Areas Olv5 (grids 7G to 8H)

In these areas, the Ammonoosuc Volcanics occurs in two belts that are separated by the Ammonoosuc fault (AF), a west-dipping normal fault that has dropped the greenschist-facies terrane on the west as much as 5 km relative to rocks of higher metamorphic grade on the east. The two belts of Ammonoosuc (and overlying formations) are faulted remnants of a single belt, thus providing a view of the same belt at two structural levels. In both belts, the Ammonoosuc is conformably overlain by the Partridge Formation (Ole), which in this area has a maximum thickness of about 200 m. The Partridge Formation is composed mainly of interbedded black sulfidic slate or schist and sparse to abundant metagraywacke; thin lenticular beds of white, sugary metachert are commonly found near the lower contact of the Partridge, also locally characterized by the occurrence of silicate iron-formation and pockets of gossan.

Granophyric tonalite and quartz diorite of the Joslin Turn pluton (index 57), dated at 469±2 Ma

(Aleinikoff, *in* Moench and others, 1995, site O-13), form a lenticular, semiconcordant body that was emplaced slightly diagonal to the contact between the Dead River Formation (of O Ꞓf) and the overlying Ammonoosuc Volcanics. The pluton is interpreted as the upturned edge of a laccolith. Several small offshoots of the pluton occur at approximately the same stratigraphic level. Where they intrude Ammonoosuc felsic metatuff, the offshoots occur as irregular patches and stringers that appear to have injected unconsolidated tuff. The rather consistent stratigraphic position of the main body and its offshoots, their habits in outcrop, and their granophyric textures indicate that the Joslin Turn is coeval with some of the earliest Ammonoosuc eruptions. Additionally, the pluton was an important agent of extensive hydrothermal alteration and local copper mineralization. The thin (about 4 m), northern part of the pluton intrudes poorly stratified, richly pyritic, and sparsely chalcopyrite-bearing quartz-sericite schist of the Ammonoosuc, interpreted as strongly altered metarhyolite. This occurrence is about 60 m west of and stratigraphically above the contact of the Ammonoosuc Volcanics with underlying slate and graded quartzwacke of the Dead River Formation (OꞒf), which is also pyritized and silicified. The pluton is, therefore, reasonably interpreted to have generated a hydrothermal system that altered and locally mineralized the tuff and resulted in at least minor sea-floor mineralization (8G-1 to 3).

The original stratigraphic thickness of the Ammonoosuc Volcanics in areas Olv5 probably varies from less than 500 m to more than 1 km. However, south of Lisbon village, between rocks of the Partridge Formation to the east and Silurian rocks of the P-F allochthon to the west, the Ammonoosuc is exposed in a belt that is 0–200 m wide. As shown on figure 6, all but the uppermost rocks of the Ammonoosuc of this belt have been excised by the Foster Hill fault (FHF). This relationship bears strongly on resources, because the Ammonoosuc of this area was almost certainly thick enough, before faulting, to have hosted a large hydrothermal cell.

The Ammonoosuc Volanics of areas Olv5 is divided on the geologic map (Moench and others, 1995) into mafic, felsic, mixed, and sedimentary submembers or facies. The mafic member, most widely exposed just east of Moore Reservoir, is a thick sequence of metamorphosed massive and pillowed basalt and probable andesite, local basaltic agglomerate, and minor felsite. East of Moore Reservoir, just north of the Highlandcroft pluton (index 58), a more distal, rather slaty, reworked facies of the mafic member is represented. South of Moore Reservoir, the mafic facies tongues into complexly interstratified mafic and felsic volcanics, commonly with proximal fragmental felsite, many small quartz porphyry intrusions, and thickly stratified felsic tuff. Poorly stratified pyritic quartz-sericite schist, some with "quartz eyes" (relict phenocrysts) is widely exposed in the area of the Joslin Turn pluton, and east of the Towns Mountain outlier (TMO) of the P-F allochthon. The pyritic schist is interpreted as strongly altered tuff, perhaps analogous to the stratiform alteration zones described by Franklin (1986, p. 50).

The contact of the Ammonoosuc Volcanics with overlying euxinic rocks of the Partridge Formation marks a major volcanic hiatus and is a horizon of diverse chemical sedimentation. The chemical deposits include white, sugary metachert; laminated anthophyllite-bearing metasedimentary rocks; garnet- and anthophyllite-rich iron-formation; chlorite-rich iron-formation; and magnetite iron-formation. Local evidence of sea-floor sulfide mineralization is exposed at the Salmon Hole volcanogenic alteration occurrence (8H-3), at the Powerline occurrence (8H-18), and possibly at the Lisbon massive pyrrhotite occurrence (8H-14). There is no distinctive geochemical anomaly that appears to be related to the rocks of the area.

Resource potential—High. The geology is highly favorable; criterion 1 is satisfied throughout, and criteria 3 and 4 are variably well satisfied. Although the areas contain no mines or prospects, much evidence of sea-floor mineralization was uncovered during mapping. A large geochemical copper anomaly centers within the western belt of areas Olv5, and lesser zinc and lead anomalies occur in approximately the same area (Nowlan and others, 1990b). It is uncertain, however, whether these anomalies reflect unknown VMS deposits in the Ammonoosuc Volcanics, or the several sulfide-bearing veins of the area, or volcanogenic mineralization in the Gardner Mountain area immediately to the west.

The most favorable horizon is the upper contact of the Ammonoosuc Volcanics, which marks a major volcanic hiatus, and shows the most evidence of chemical sedimentation and mineralization. Additionally, sulfides deposited there would have been protected from oxidation by the euxinic conditions represented by the overlying Partridge Formation.

At large scale, parts of the mafic facies and the massive felsic facies that contain no known volcanogenic occurrences and lack evidence of alteration might be mapped as areas of low potential.

Areas Olv6 (grids 8H to 9I, fig. 6)

These areas are southern extensions of areas Olv5, mainly east of the Ammonoosuc fault (AF) but also west of the fault. As at Lisbon and Bath, N.H., the Ammonoosuc Volcanics of areas Olv6 occurs in very thin but remarkably continuous belts in which the Ammonoosuc is juxtaposed against the Piermont sequence (SOp, Srp) and is stratigraphically overlain by the Partridge Formation (Ole). The Ammonoosuc of these areas is predominantly mafic in composition: amphibolite east of the AF, and calcitic greenstone west of the AF, but felsic rocks are recognized as well. Although the Ammoonoosuc of these belts is now only a few meters to a few tens of meters thick, its original thickness (before emplacement of the P-F allochthon) was probably comparable to that of the Ammonoosuc in areas Olv5 and Olv4. No evidence of mineralization was found during mapping, and the geochemical surveys (Nowlan and others, 1990b; Watts, 1990) revealed no copper, lead, or zinc anomalies having sources that are conclusively in the Ammonoosuc. The small bodies of diapiric ultramafic rocks (Du) that occur in the Ammonoosuc Volcanics and Partridge Formation (fig. 6) are probably genetically unrelated to these units.

Resource potential—Low. On the assumption that the thickness of the Ammonoosuc Volcanics was far greater before emplacement of the P-F allochton, criterion 1 is satisfied. Criterion 3 is satisfied by the sharp contact between the Ammonoosuc and the overlying Partridge Formation.

Areas Olv7 (grids 8G and 9G, fig. 6)

Areas Olv7 contain exposures of the Ammonoosuc Volcanics in the Coppermine Road window (CuRW; fig. 6) and in the lenticular area on-strike to the northeast; these areas might actually be connected at the surface. Within the CuRW are extensive exposures of poorly stratified, richly pyritic quartz-muscovite schist and white metachert, commonly having "quartz eyes," interpreted as a zone of stratiform alteration (Franklin, 1986, p. 50). Also exposed are thickly stratified proximal metavolcanic rocks containing massive thick beds of mafic-clast, felsic-matrix metabreccia (maximum clast size about 15 cm), and rhyolite lapilli metatuff. The northern area is mainly a valley containing no outcrops, except for a west-sloping hillside about 2.5 km south-southwest of Concord, Vt. Exposed here is a sequence of thickly bedded felsic metatuff, matrix-supported felsic lapilli metatuff, and pyritic quartz-sericite schist. The assemblage is similar to, but somewhat finer grained than, the Ammonoosuc of the window. At one locality an outcrop contains banded chlorite-actinolite-cummingtonite(?) gneiss, white metachert, and gossan pockets. All these rocks are abundantly intruded by diabasic greenstone. An anomalous amount of copper (25–26 ppm) occurs in one stream-sediment sample from the CuRW. Depending on its location inside or outside the CuRW, the deposit at Bald Ledge copper mine might be volcanogenic in the Ammonoosuc.

Resource potential—High. The rocks of areas Olv7 are very similar to those of the felsic facies and stratiform alteration zones found in areas Olv5, and are similarly geologically favorable for the occurrence of Kuroko-type VMS deposits. The favorable geologic characteristics, and evidence of mineralization justify assignment of a high resource potential; this is supported by a small geochemical anomaly.

Areas Ꞓov1 (grid 1C)

Metavolcanic rocks of the Jim Pond Formation (Ꞓov) of areas Ꞓov1 are composed of weakly metamorphosed, pillowed and massive basalt flows, basaltic pyroclastic rocks, massive to laminated dacitic tuff, felsic flow rock and probable domes of volcanic breccia, and local iron-formation. The largest mapped body of Jim Pond hosts the possibly major VMS deposit at the Alder Pond prospect (1C-2). Although the lower contact of the formation is not exposed in these areas, a maximum thickness of 1,500 m is a reasonable estimate. The contact with overlying melange of the Hurricane Mountain Formation (Ꞓe) is typically sheared, and in some areas fragments of Jim Pond Formation are incorporated in the melange. Some stream-sediment samples from streams that drain the large, westernmost area show anomalous amounts of copper and zinc (Nowlan and others, 1990b).

Resource potential—High. The geology is favorable; criterion 1 is satisfied and criteria 3 and 4 are at least partly satisfied. Evidence of mineralization is provided by the Alder Pond VMS deposit. A high resource potential is further supported by the geochemical anomaly.

Areas Ꞓov2 (grids 2C to 4D)

These areas are underlain by weakly metamorphosed metavolcanic rocks of the Jim Pond Formation (Ꞓov) that wrap around the south end of the Chain Lakes massif for about 25 km. Here, the ophiolitic Boil Mountain Complex (Ꞓop) is gradationally overlain by the pillow basalt member of the Jim Pond, about 1 km thick, composed of pillowed and massive metabasalt, and minor amounts of basaltic lapilli-metatuff, metabreccia, mafic metagraywacke, and ferruginous phyllite and jasper. Sharply above the basalt member is the dacite member, as much as 500 m thick, composed of massive to laminated metatuff, ash-flow deposits, fragmental metadacite, dacite metabreccia, dacitic flow rock, resedimented metavolcanic rocks, and lenses as thick as 20 m of cherty magnetite-hematite iron-formation. Trondhjemite sheets associated with the Boil Mountain Complex are inferred to be comagmatic with the dacite member and might also have provided heat to drive hydrothermal convection systems. The metavolcanic members of the Jim Pond grade laterally to metaquartzwacke, metagraywacke, and phyllite of the Magalloway Member of the Jim Pond, shown on this map as the volcaniclastic member of the ophiolite (Ꞓow).

VMS and probable VMS deposits of the areas include the Alder Stream sulfide prospect (3D-1), the Boil Mountain sulfide(?) prospect (3D-3), and, in Quebec, the Border prospect (4C-13). Although the data of Nowlan and others (1990b) for copper, lead, and zinc reveal no conspicuous geochemical anomalies, a copper anomaly was uncovered by Cummings (1988, p. 256–261) near the Border prospect.

Resource potential—High. Resource potential is not shown north of the international border. Criterion 1 is satisfied, and criteria 3 and 4 are at least partly satisfied. The favorable geologic setting and the known mineral occurrences justify assignment of a high resource potential.

The most favorable horizon is near the boundary between the metabasalt and metadacite members of the Jim Pond Formation, which are shown separately by Moench and others (1995). Additionally, the metadacite member is considered to be more favorable than the metabasalt member. In the area that hosts the Border deposit (4C-13), Cummings (1988) noted that this deposit is zinc rich and does not account for the copper anomaly shown by his geochemical data; on this basis he suggested that a more important copper-rich deposit might occur nearby.

The predominantly sedimentary Magalloway Member of the Jim Pond Formation (Єow) is an unlikely host for VMS deposits, but it might contain unrecognized favorable metavolcanic rocks in some areas.

Possible Cambrian ophiolitic chromium deposits, locally containing platinum

Areas Єop1 (grids 3C to 4D)

Chromium has been mined from layered or podiform chromite deposits in the ophiolites exposed above the Baie Verte–Brompton line, Quebec (fig. 2, BBL). These deposits are now of considerable interest for platinum-group elements (Gauthier and Trottier, 1987; Gauthier and others, 1994). In the Sherbrooke-Lewiston area, small bodies of layered chromite-magnetite rocks occur at two localities in the ophiolitic Boil Mountain Complex. At the Arnold Pond chromite occurrence (4C-1) disseminated chromite and magnetite occur in amphibolite adjacent to a serpentinite inclusion in probable Hurricane Mountain Formation (Єe). The occurrence is described by Harwood (1973, p. 82) as fine-grained magnetite and chromite in layers a few tenths of an inch thick that separate light-gray feldspar-rich stringers and segregations from the dark-green amphibolite. At the Blanchard Ponds chromite occurrence (3C-2), layered chromite occurs in ultramafic rocks at the base of the Boil Mountain Complex. These deposits and undiscovered ones that might occur elsewhere in the belt of the Boil Mountain Complex might contain platinum-group elements, as in Quebec.

Platinum reported to occur in gravel of Niles Brook (3E-2) occurs within a major stream-sediment chromium anomaly (Nowlan and others, 1990a) that is about 50 km wide and extends southeastward across the map area. Although the anomaly crosses the outcrop belt of the Boil Mountain Complex, it is not enhanced by the Boil Mountain and appears instead to originate at least 100 km farther northwest, in the area of the Thetford Mines ophiolite. John D. Schafer and Carl Koteff (oral commun., May 1984), of the U.S. Geological Survey, suggested that this anomaly is a result of glacial streaming produced by rapid calving into the Gulf of Maine during Late Wisconsin deglaciation. (See McCammon, 1986, p. 42–47.)

Resource potential—High. The area that is underlain by mafic and ultramafic rocks of the Boil Mountain Complex (index 17) is geologically favorable for the occurrence of layered, magmatic chromite deposits; the known chromium-bearing occurrences, albeit very small, are evidence of chromium deposition. These features justify a high resource potential for layered chromite deposits. Although the geochemical data do not indicate a chromium anomaly that can be tied directly to the complex, further stream-sediment and outcrop studies might reveal the presence of undiscovered chromitite bodies, perhaps containing platinum-group elements.

Possible polymetallic resources in diapiric serpentinite along Devonian faults

Areas Du1 (grids 1C and 3C to 3D)

Gold is undocumented but might occur, along with other metallic commodities, in bodies of carbonatized serpentinite that were probably remobilized from ultramafic rocks of the Boil Mountain Complex during Acadian faulting. The small body of probably diapiric, carbonatized ultramafic rock (listwanite) at Gosford, Quebec (4C-14) contains sulfide minerals of nickel, copper, silver, cobalt, and iron. Although gold is not reported to occur here, other similar bodies of altered ultramafic rocks that are shown on the map might contain gold (see Buisson and Leblanc, 1985). The diapiric bodies are labeled Du on map A, because they occur principally along faults of Devonian age, and therefore are considered to have been diapirically emplaced in Devonian time. The bodies were probably hydrated and remobilized from sources in ultramafic rocks of the Boil Mountain Complex. Although the diapiric bodies were not sampled for gold during the Sherbrooke-Lewiston CUSMAP studies, they merit attention.

Resource potential—Unknown. Although the geologic setting is favorable, the individual bodies of diapiric serpentinite have not been investigated.

Possible Jurassic tin-bearing greisen deposits and cassiterite veins related to Conway Granite (modified from Cox, 1990)

The presence of a large tin anomaly centered on the White Mountain batholith (index 81) is documented by analyses of stream-sediment samples (Domenico and others, 1985a) and heavy-mineral concentrates from stream sediments (Domenico and others, 1985b; Nowlan and others, 1990c). Most of the principal anomaly, outline Jt1 (which encompasses outlines Jt2 and areas Jt3), is reasonably attributed to the Jurassic Conway Granite and Conway-type granite (henceforth called Conway Granite), which characteristically has high abundances of tin, uranium, thorium, and several other elements (Butler, 1975; Cox, 1990; Hoisington, 1977; Moench and others, 1984, and references therein). The geochemical data also reveal overlapping anomalies of beryllium, lead, molybdenum, niobium, uranium, and zinc that appear to be associated with the Conway Granite. High abundances of tin (and tungsten) in stream-sediment and heavy-mineral-concentrate samples define less-prominent anomalies that appear to have sources associated with peraluminous Devonian and Carboniferous granitic plutons, discussed later.

Cassiterite was identified in heavy-mineral concentrates and is assumed to be the mineralogic source of the tin. Small amounts of tin were mined more than a century ago from intersecting veins at the Jackson tin mine (5H-1). Magnetite-phenacite replacement deposits in Conway Granite at the Iron Mountain mines (5H-2) contain abundant zinc and silver in addition to iron and beryllium, and anomalous (though far below economic) amounts of tin (Barton and Goldsmith, 1968). Cox (1970) proposed that polymetallic quartz-carbonate veins (mainly lead-silver) that are widely distributed in the project area and farther south in New Hampshire formed from hydrothermal systems that developed during Mesozoic extension that accompanied emplacement of the Conway Granite. The Conway is a tin-specialized granite characteristic of many tin districts worldwide, as in Nigeria (Bowden, 1982) and the Seward Peninsula, Alaska (Reed and others, 1989, and references therein); it also is enriched in uranium, thorium, and other incompatible elements and has been investigated as a source of geothermal energy (Osberg and others, 1978). On the strength of all of these relationships, Moench and others (1984) assigned a moderate resource potential for the occurrence of tin deposits in areas underlain by the Conway Granite, probably mainly in greisenized cupolas of the Conway, in parts of the White Mountain National Forest, N.H. (Users of the map of Moench and others, 1984, should beware that the patterns for the tin and copper anomalies were inadvertently interchanged).

On the basis of further studies, Cox (1990) outlined a broad area having moderate potential for tin resources that encloses (1) an area underlain by the Conway Granite, (2) drainage basins where stream-sediment samples contain 30 ppm or more tin (Domenico and others, 1985a), and (3) an area where heavy-mineral-concentrate samples contain 2,000 ppm or more tin (Domenico and others, 1985b; Nowlan and others, 1990c). Within that broad area, she further delineated several areas in which the Conway Granite and adjacent rocks show: (1) most evidence for tin resources (favorable rock geochemistry, alteration, and geologic setting); (2) less evidence for tin resources (favorable rock geochemistry and geologic setting); (3) two categories of least evidence for tin resources (favorable rock geochemistry or geologic setting); and (4) a broad, northeast-trending area of unfavorable evidence for tin resources (unfavorable geologic setting). Cox's outline of the broad area and her two higher categories of tin resources are used on this map (outline Jt1, outlines Jt2, and areas Jt3, respectively), with modifications.

In reference to figure 7 of this report, the term favorable geology in association with the Conway Granite includes these features listed by Cox (1990): (1) country rock overlying the granite; (2) abundant pegmatite and miarolitic cavities in the granite; (3) fine-grained porphyritic textures in the granite; (4) closely spaced aplite dikes and quartz veins in the country rock; and (5) replacement of granitic texture with greisen mineral assemblage. Favorable geochemistry refers to the geochemical data obtained by Cox (1990) from bedrock samples, rather than the stream-sediment and heavy-mineral-concentrate data of Nowlan and others (1990c) and Domenico and others (1985b). Although the latter data define an anomaly of enormous areal extent, much of the tin (and other elements) probably came from disintegrated unmineralized Conway Granite, rather than from specific mineral deposits. Evidence of mineralization includes evidence of rock alteration and sulfide mineralization, and the known mines.

Outline Jt1 (grids 7E to 5H through 8H)

Tin deposits that might occur here are tin-bearing greisenized cupolas of Conway Granite plutons, and tin-bearing veins in country rock above the Conway plutons. Large skarn or replacement tin deposits (see Reed and others, 1989, fig. 2) are unlikely to occur, because the Conway Granite intrudes country rocks that contain only sparse carbonate rocks. The outline of the area is analogous to the "Boundary of potential tin resources" of Cox (1990; explanation of map symbols), but is defined and mapped differently. On this map the outline encloses plutons of the White Mountain Plutonic-Volcanic Suite, and an area containing 10 ppm or more tin in most stream-sediment samples, and 100 ppm or more in at least 75 percent of the heavy-mineral-concentrate samples collected within the area. For reasons already given, these data are not considered to provide site-specific favorable geochemistry.

It is stressed that the outlined area Jt1 is approximate and, moreover, that some of the tin detected by the geochemical survey within the project area might have come from Carboniferous or Devonian granitic plutons, as discussed later. An effort was made to exclude from outlined area Jt1 tin anomalies that are best interpreted as glacially dispersed tin derived from Paleozoic plutons, such as the Willoughby and Long Mountain plutons (indexes 47, 40).

Resource potential—Moderate. The outlined area is a stream-sediment geochemical anomaly that encloses many sites having favorable geology. Those sites having favorable geochemistry and evidence of mineralization as well as favorable geology are mapped separately within outlined area Jt1 as outlined area Jt2 and areas Jt3.

Outlines Jt2 (grids 6F to 7F, and 5H to 8H)

Tin-bearing greisenized cupolas of the Conway Granite, and tin-bearing veins in country rock above the Conway are considered, as in Jt1. These are the areas of "Less evidence for tin resources" of Cox (1990), which she defines as having favorable (rock) geochemistry of the Conway Granite and a favorable geologic setting, but no known evidence of alteration or mineralization.

Resource potential—Moderate. These outlined areas have favorable geology and rock geochemistry for the occurrence of tin deposits of the types listed for outlined area Jt1.

Areas Jt3 (grids 5H to 7H)

These are two of the areas of "Most evidence for tin resources" of Cox (1990), and two added areas that include the cassiterite veins at the Jackson tin mine (5H-1) and the magnetite-phenacite deposit at the Iron Mountain mines (5H-2). Although these deposits do not represent the tin-greisen model, they constitute evidence of mineralization that might be expected to occur in relation to tin-bearing greisens. The four areas have favorable rock geochemistry, favorable geologic settings, and evidence of alteration, in accord with Cox's (1990) definition, and (or) evidence of mineralization. Included are areas containing the weakly mineralized Moat Volcanics above the Conway Granite at Mount Tom (6H-1), the altered granite occurrences at Bemis Brook and Mount Carrigain (6H-2, 6H-3), the Mount Hitchcock altered granite occurrences (7H-3), the Bartlett Brook polymetallic sulfide occurrence (6H-4), the Iron Mountain magnetite-phenacite mines (5H-2), the cassiterite veins at the Jackson tin mine (5H-1), and the altered granite at South Moat Mountain, just below the Moat Volcanics (5H-3).

Resource potential—High. The favorable geology and rock geochemistry, and the evidence of mineralization yield a high resource potential.

Ordovician or Silurian copper-molybdenum porphyry deposits

The Catheart Mountain copper-molybdenum porphyry deposit (1B-1) is the only known major deposit of its class in northern New England (Hollister and others, 1974; Schmidt, 1978; Ayuso, 1989). The deposit is hosted by altered hypabyssal granodioritic porphyry of the Catheart Mountain pluton (index 3), studied by Ayuso (1989) and previous researchers. The Catheart Mountain pluton intrudes the Attean pluton (index 2), composed of less-altered hornblende-bearing porphyritic granite dated at 443±4 Ma (Lyons and others, 1986; U-Pb zircon method). Isotopic studies and field relationships indicate that the Catheart Mountain pluton and its porphyry deposit can be only slightly younger than the Attean pluton (Lyons and others, 1986; Ayuso, 1989). An apparently small copper-molybdenum porphyry deposit at the Sally Mountain prospect (2B-1) is hosted by more silicified porphyry of the Sally Mountain pluton (index 4), which also intrudes the Attean pluton. On the basis of thorough petrologic studies, Ayuso (1989) concluded that the Catheart, Sally Mountain, and Attean plutons, though approximately coeval, are not comagmatic. Each pluton generated its own hydrothermal system.

Epigenetic veins and related disseminations that are probably related to parts of the Sally Mountain, Catheart Mountain, and Attean plutons include the Sally Mountain sulfide prospect (2B-2), the Pyrite Creek prospect (1B-2), the West Bean Brook Mountain sulfide occurrences (1B-3), and the Grace Pond pyrite prospect (1C-1). These deposits contain pyrite and, variably, sparse copper, lead, and zinc sulfides within the plutons, or in unconformably overlying metasedimentary rocks of Silurian or Early Devonian age. They are tentatively considered to have originated by weak hydrothermal mineralization that accompanied brittle fracturing, perhaps as late as Mesozoic time. Conceivably, the metals of these deposits were derived from nearby unexposed, much older porphyry-type deposits. As such, the vein-type deposits might be considered as "fossil geochemical anomalies."

Albee and Boudette (1972) mapped many dikes and small plutons of quartz porphyry, similar to those associated with the Catheart and Sally Mountain deposits, that intrude rocks of the Chain Lakes massif between the Attean and Skinner plutons (indexes 2, 6). These intrusions are considered of a favorable geologic setting for the occurrence of copper-molybdenum porphyry deposits.

Although the Catheart Mountain copper-molybdenum porphyry deposit is not economic under present or foreseeable conditions, geologic environments are locally favorable for the occurrence of possibly economic deposits of this type. Two areas, labeled SOp1 and Op1, are identified on the map as having potential for the occurrence of Catheart-type copper-molybdenum porphyry deposits. Because major porphyry-type deposits have far larger areal dimensions than massive-sulfide deposits, they are much more likely to be detected by reconnaissance geochemical surveys. For this reason the geochemical data have more direct application to the following resource assignments.

Area SOp1 (grids 2B to 1C)

This area is underlain by the main body of the Attean pluton, but excludes the known mineralized areas and those areas near the western border of the pluton, and farther west, where many small bodies of quartz porphyry are exposed. The area occurs, however, in the central part of a large stream-sediment geochemical anomaly for copper, zinc, lead, and molybdenum (Nowlan and others, 1990a, b, c).

Resource potential—Low. With the exclusion of the known mineralized areas and the quartz porphyry intrusions, the geology is not recognizably favorable. The geochemical anomaly justifies a low resource potential.

Areas SOp2 (grids 1B and 2B)

These two areas encompass the known porphyry-type occurrences associated with the Sally Mountain and Catheart Mountain plutons, and the possibly "fossil geochemical anomalies" described above at the east margin of the Attean pluton. The area also encloses overlapping stream-sediment geochemical anomalies for copper, zinc, lead, and molybdenum (Nowlan and others, 1990a, b, c).

Resource potential—High. The area contains locally favorable geology for the occurrence of copper-molybdenum porphyry deposits, and strong evidence of mineralization. The assignment of a high resource potential is further supported by geochemical anomalies.

Area SOp3 (grids 2B and 3B)

This area includes the western border zone of a wide zone in which many small bodies of quartz porphyry, similar to those of areas SOp2, intrude rocks of the Chain Lake massif and locally occur within the Attean and Skinner plutons (indexes 2, 6). Some of the quartz porphyry bodies might have larger equivalents at depth that generated copper porphyry hydrothermal systems.

Resource potential—Moderate. The geology is favorable and the area is within the overlapping stream-sediment geochemical anomalies for copper, zinc, lead, and molybdenum (Nowlan and others, 1990a, b, c).

Area SOp4 (grid 3C)

The small Jim Pond copper occurrence (3C-1) contains disseminated chalcopyrite and other sulfide minerals in a body of quartz porphyry, too small to show on the map, that intrudes trondhjemite of the Boil Mountain Complex. The quartz porphyry is comparable to those of areas SOp2 and might be a high-level extension above an unexposed larger Highlandcroft body. Alternatively, the quartz porphyry might be a facies of the trondhjemite. Either way, the disseminated sulfide minerals might be the "tip" of a much larger porphyry-type deposit.

Resource potential—Unknown. Although the area contains evidence of porphyry-type mineralization, the geology is insufficiently known to justify more than an unknown resource assignment.

Area Op1 (grid 4E)

This area covers the Late Ordovician Adamstown pluton (index 35), which is petrographically similar to the Attean pluton and might contain unrecognized altered hypabyssal intrusives. However, the Adamstown, although adequately mapped, is not known to contain hypabyssal intrusives that would characterize the geology as favorable for the occurrence of porphyry-type deposits. The area is central to prominent stream-sediment anomalies for molybdenum and zinc (Nowlan and others, 1990a, b).

Resource potential—Low. In the absence of known favorable geology, the stream-sediment geochemical anomaly supports only low potential for the occurrence of porphyry-type deposits.

Possible Devonian or Carboniferous tungsten and (or) tin-bearing skarn, and molybdenum-bearing stockworks

Peraluminous, muscovite-bearing granitic rocks of Devonian and Carboniferous age are widely distributed in the project area (**Dnb**, **Dnp**, **Dnt**, **Mt**, **Pt**), but few of the known metallic mineral deposits south of the international border can be demonstrated to be directly related to them. Very minor exceptions are the small scheelite-bearing deposits in Maine (1F-2, 3E-5, 3F-2). North of the border, however, important porphyry-like molybdenum-bearing stockworks and disseminations occur at the Copperstream-Frontenac mine (4A-1) and Sainte Cécile prospects (4B-1), at opposite ends of the Devonian Mont Ste.-Cécile pluton (index 104). Exploration at the Copperstream-Frontenac mine has delineated mineralized zones having reserves of more than 400,000 tons at a grade of 0.39 percent molybdenum (Gauthier and others, 1994, p. 1359). Just north of Vermont, scheelite-bearing skarn deposits occur at the Lyster Lake prospects (8D-1), in hornfels at the northern contact of the Averill pluton (index 45).

The major difference between the Quebec plutons and those that occur south of the international border, particularly with regard to molybdenum deposits, probably is a function of depth of emplacement. Whereas most peraluminous plutons exposed in the amphibolite-facies terrane were emplaced as subhorizontal sheets at depths of 10 or 12 km, as shown by gravity and metamorphic studies, those of Quebec have associated hypabyssal porphyry dikes and were probably emplaced as steep-walled bodies no deeper than about 2 km. The shallower depths are more favorable for the development of large hydrothermal systems during cooling of a granitic body.

The interpretation that most of the peraluminous Devonian and Carboniferous plutons south of the international border were emplaced too deep for the formation of porphyry-like molybdenum deposits comparable to those of Quebec is supported by molybdenum stream-sediment and heavy-mineral-concentrate data (Nowlan and others, 1990a, b), which show strong correlations with plutons of the Ordovician Highlandcroft Plutonic Suite and the Jurassic White Mountain Plutonic-Volcanic Suite, but only weak correlations with the Devonian and Carboniferous peraluminous plutons.

This relationship, however, may not apply as closely to the occurrence of skarn- or greisen-type tungsten and (or) tin deposits. As described by Ayuso and Arth (1992), the Willoughby pluton (index 47) of the Northeast Kingdom batholith, for example, contains miarolitic cavities as well as pegmatitic granite, suggestive of shallower emplacement than the plutons of the amphibolite-facies terrane, which have abundant pegmatite but no miarolitic cavities. Additionally, Ayuso and Arth (1992) have shown that the Willoughby and possibly other plutons of the Northeast Kingdom batholith are favorable for the occurrence of granitophile ore deposits that might contain tin, tungsten, molybdenum, and other metals. The Willoughby pluton, composed of leucocratic two-mica granite, is the most evolved of all the batholith's plutons. At the Westmore altered granite occurrence (8E-1), the pluton hosts a small (1.5x3 km) zone of hydrothermally altered, leached, and silicified pegmatitic granite containing pyrite clusters, and trace amounts of fine-grained sulfide minerals concentrated along fractures. Granite of this zone is characterized by high abundances of tin (to 26 ppm), beryllium (to 11 ppm), tantalum (to 13 ppm), uranium (to nearly 11 ppm), and other granitophile elements relative to granite of the Willoughby pluton outside the alteration zone, and particularly relative to other plutons of the batholith. Ayuso and Arth (1992) suggested that the high concentrations of some commercially used elements in the Willoughby, particularly in its alteration zone, are probably due to concentration of the elements in late magmatic liquid and vapor phases. The Willoughby has some of the characteristics of the Jurassic Conway Granite (miarolitic cavities; high abundances of the above-listed elements) considered to have potential for the occurrence of tin-bearing greisen deposits. Moreover, the Willoughby pluton intrudes calcareous rocks of the Waits River Formation that might host skarn or replacement tin deposits (see Reed and others, 1989, fig. 2).

Stream-sediment and heavy-mineral-concentrate data delineate extensive tungsten and tin anomalies that overlap the plutons of the Northeast Kingdom batholith and many other peraluminous Devonian and Carboniferous plutons exposed farther east in New Hampshire and western Maine. As spectacularly shown by Maurice (1986), the northern boundary of the largest tungsten anomaly closely conforms to the northern side of the Averill pluton (index 45), which is the site of the Lyster Lake scheelite-bearing skarn deposits (8D-1). This anomaly extends far south of the international border, through areas labeled CDsk1, Dsk1, and Dsk2. Although Nowlan and others (1990c) used a minimum value of 700 ppm tungsten in heavy-mineral concentrates to define an anomalous quantity, on the basis of statistics, the minimum detection limit (100 ppm W) can also be considered anomalous. Extensive anomalies can be delineated in which approximately 75 percent, or more, of the samples contain detectable tungsten. The southeastern boundaries of the anomalies are extremely sinuous along southeast trends that cross several geologic belts. It is uncertain whether the tungsten of the anomalies is glacially dispersed from one main source in southern Quebec, or from many local sources around peraluminous plutons southeast of the international border.

A local source for a major tungsten anomaly in the western New Hampshire portion of the Glens Falls 1°x2° quadrangle has been suggested by Slack (1990) and Watts (1990), who noted a close spatial association between tin and tungsten anomalies and areas underlain by the Bethlehem Granodiorite. The Bethlehem is characteristically composed of gneissic, muscovite-bearing biotite granodiorite and local granite. Bodies of Bethlehem Granodiorite (in Dnb) also occur in the area of this report, where they form the Haverhill, Mount Clough, Indian Pond, and Fairlee plutons (indexes 90, 85, 95, 94), in an area that is overlapped by the northern extension of the tungsten anomaly described by Watts (1990). The Bethlehem, dated in the range of 407–410 Ma (Moench and others, 1995, site D-9), was probably emplaced at a shallow depth below the Early Devonian sea floor, in an environment that might have been quite favorable for the generation of tungsten- and tin-bearing skarn or greisen deposits.

Outline CDsk1 (grids 5D to 6F)

This outlined area includes two-mica granites of the Mississippian Long Mountain pluton (index 40), the Devonian(?) Greenough Pond pluton (index 37), and smaller bodies. Although no zone of alteration that is comparable to the Westmore altered granite occurrence (8E-1) of the Willoughby pluton has been recognized, the Dummer Ponds altered granite occurrence (6F-6), containing disseminated pyrite and arsenopyrite(?), at the southeast corner of the Long Mountain pluton, is at least meager evidence of mineralization.

Resource potential—Moderate. The tungsten geochemical anomaly and the Dummer Ponds altered granite occurrence justify a moderate resource potential for tungsten-bearing skarn deposits near the borders of peraluminous plutons in outlined area CDsk1.

Area Dsk1 (grids 8E and 8F)

As already described, the Willoughby pluton (47) is the most evolved pluton of the Northeast Kingdom batholith, and has the most convincing evidence of mineralization in the batholith south of Quebec.

Resource potential—High. The combination of favorable geology and convincing evidence of mineralization yields a high potential for the occurrence of tin-bearing greisens, and possibly for sulfide disseminations. This area, recommended by Robert A. Ayuso, overlaps the part of the Willoughby pluton exposed in the project area. The entire pluton is included because the highly irregular-shaped map pattern suggests that all of the exposed pluton is close to its original roof. The area includes the Westmore altered granite occurrence (8E-1), which is a possible target. Additionally, the contacts of the pluton against calc-silicate rocks of the Silurian Waits River Formation (Srwc) might host tin and (or) tungsten-bearing skarn deposits. The assignment is supported by a low-level, probably glacially dispersed stream-sediment and heavy-mineral-concentrate tin anomaly that overlaps the southeast side of the Willoughby pluton (Nowlan and others, 1990c).

Outlines Dsk2 (many grids), and area Dsk2 (grids 7D and 8D)

Dsk2 is intended to include most of the peraluminous, muscovite-bearing granitic rocks of Devonian age that are overlapped by extensive tungsten anomalies, locally accompanied by tin, as defined by analyses of heavy-mineral concentrates (Nowlan and others, 1990c). The specific plutons of the Northeast Kingdom batholith, mainly two-mica granite and muscovite-bearing biotite granite and granodiorite, are the Averill, Echo Pond (northern part), Willoughby, Newark, and Victory (west lobe) (indexes 45, 46A, 47, 49, 51). Plutons of similar composition that are within Dsk2 include parts of the Mooselookmeguntic and Phillips batholiths and the North Jay pluton (indexes 34A, 26A, 70) in western

Maine. Excluded from Dsk2 are plutons composed of the Bethlehem Granodiorite (indexes 85, 90, 94, 95) in grids 7H to 9I (fig. 6), which are discussed under areas Dsk3.

The Newark pluton (index 49), in contrast with other plutons of the Northeast Kingdom batholith, is the source of a conspicuous positive aeromagnetic anomaly (see map C), undoubtedly produced by abundant accessory magnetite. The possibility that the magnetite would have prevented the formation of sulfide-bearing mineral deposits needs evaluation.

Resource potential—High in Quebec (area Dsk2), unknown to the south (outlines Dsk2). The geochemical data and the peraluminous composition of granitic rocks of Devonian and Carboniferous age suggest that tungsten and tin-bearing skarn might occur near their borders. Because the plutons and their borders have not been investigated with that in mind south of the international border, an assignment of unknown resource potential is appropriate there. In Quebec, however, a high resource potential is justified on the basis of favorable geology, a major stream-sediment anomaly, and known skarn deposits.

Areas Dsk3 (grids 7H to 9I, fig. 6)

Slack (1990, p. R15) has noted that heavy-mineral-concentrate data (Watts, 1990) indicate high tin and tungsten anomalies in areas underlain by the Bethlehem Granodiorite (his Bethlehem Gneiss), and he assigned (Slack,1995) a moderate resource potential for tin±tungsten±molybdenum to approximately the southern one-third of the Indian Pond pluton (index 95). He suggested (Slack, 1990, p. R15) that tin and tungsten might occur in porphyry-related veins and (or) greisens along the borders of Bethlehem plutons. Along the same trend to the northeast, the heavy-mineral-concentrate data of Nowlan and others (1990c, map B) reveal a major tungsten anomaly (but without tin) that overlaps the outcrop belts of the Mount Clough and Haverhill plutons (indexes 85, 90). Although this anomaly overlaps other rock assemblages as well, we propose that the Bethlehem plutons, including the Fairlee (index 94) in addition to the Mount Clough, Haverhill, and Indian Pond, are the principal source of the tungsten. According to Moench (1990, fig. 3), the Fairlee and Indian Pond plutons are displaced remnants of the same body; they are dated at 410±5 and 407±5, respectively (Moench and others, 1995, site D-9). The Bethlehem plutons semiconcordantly intrude the basal portion of the Lower Devonian cover sequence (Dc) and, as shown by a comparison of isotopic dating and fossil data (Tucker and McKerrow, 1995; Rankin and Tucker, 1995), were emplaced during Siegennian to Emsian sedimentation of the cover sequence. Accordingly, emplacement was probably at a shallow depth below the Early Devonian sea floor. Inferred shallow emplacement is supported by evidence of marked chilling observed at the northern contact of the Fairlee pluton (Moench, 1996, stop 11). Such an environment might have been highly favorable for the generation of tungsten-bearing skarn deposits, as well as porphyry-related veins and greisens.

Resource potential—Unknown. Although Slack (1995) assigned a moderate resource potential for tin±tungsten±molybdenum in porphyry-related veins or greisens to the southern part of the Indian Pond pluton, we prefer to assign an unknown potential, primarily for tungsten deposits (as suggested by the geochemical data of Nowlan and others, 1990c), to all of the Bethlehem Granodiorite plutons exposed in the area of map D and figure 6. An unknown potential is preferred herein, because these plutons have not been investigated with this resource possibility in mind.

Possible contact metamorphic replacement deposits associated with Devonian gabbro

Area Dcm1 (grid 3D)

At the Black Mountain copper prospect (3D-4), small concentrations of pyrrhotite, pyrite, and chalcopyrite occur in graphitic-sulfidic hornfels of the Hurricane Mountain Formation (Ꞓe) within the contact metamorphic aureole of the Elephants Head pluton (index 18), composed of gabbro and minor granodiorite. Stream-sediment geochemical data suggest that the deposit, or unexposed similar ones nearby, is more extensive than one would expect from the exposures seen only at the prospect, and is polymetallic. Samples collected from streams that drain the south side of Black Mountain, at the west end of the pluton, show strongly anomalous abundances of copper, lead, zinc, molybdenum (Nowlan and others, 1990a, b), and cobalt (McDanal and others, 1985). These data define a distinctive geochemical anomaly, possibly skewed somewhat downglacier. Whereas the gabbro is the likely source of the copper and cobalt, the granodiorite is the likeliest source of at least the molybdenum. Additionally, the Elephants Head pluton is the site of a positive aeromagnetic anomaly (see map C) that is probably partly produced by magnetic pyrrhotite in the country rocks.

Although alternative models need to be considered, the Black Mountain copper deposit is here interpreted to have been produced by redistribution of metal-bearing sulfides from the surrounding sulfide-bearing metasedimentary rocks during contact metamorphism.

Resource potential—High. The favorable geology, evidence of mineralization, and the multi-element geochemical anomaly justify a high potential for the occurrence of gabbro-related contact metamorphic sulfide deposits in the area surrounding the gabbroic Elephants Head pluton. This is the area considered most likely to contain undiscovered pyrrhotite-chalcopyrite deposits. Stream-sediment geochemical data suggest a polymetallic composition that includes cobalt.

Also worthy of consideration for deposits of this type are contact zones between gabbro and the various graphitic-sulfidic formations of the map area, such as the euxinic Hurricane Mountain (€e), Partridge (Ole), and Quimby (Oue) Formations, and the Rangeley and Smalls Falls Formations (of Sbw), which are shown separately on the map of Moench and others (1995).

Possible magmatic nickel deposit in Devonian hybrid tonalite

Area Dm1 (grid 3F)

The West Mountain pluton (index 27) is a small, discordant body of unfoliated, medium-grained, garnetiferous tonalite, having an unusual, magnesium-rich composition. Where exposed near the northeast side of the body, the tonalite contains scattered, rusty-weathering nodules about 1 cm across and forming perhaps 1 percent of the rock. Study of polished surfaces indicates that the nodules are composed mainly of graphically intergrown pyrrhotite and pentlandite. Spectrographic analyses of a sample composed of several, variably weathered nodules that were concentrated from a bulk sample of the tonalite yielded 1,000 ppm each of copper and nickel, and 150 ppm each of cobalt and chromium; spectrographic analyses of the bulk sample yielded smaller but anomalous amounts of the same elements (N.M. Conklin, analyst).

This body of magnesium-rich tonalite is unique in the map area. Preliminary microprobe study indicates that the garnet is almandine and that the magnesium resides in mica, which is phlogopite. On the basis of its magnesian composition and the occurrence of the pentlandite-bearing nodules, the tonalite is thought to be a hybrid formed by interaction between gabbroic and felsic magma.

Resource potential—Unknown. The pyrrhotite-pentlandite nodules are too sparsely distributed to indicate a nickel resource. The geochemical data do not show a nickel anomaly. The locality is included on this map in order to highlight an intriguing unsolved problem.

Possible Silurian or Early Devonian sedimentary (SEDEX) copper and cobalt resources in the Central Maine trough (CMT)

This section presents geologic and geochemical evidence favoring the possible occurrence of metalliferous sulfide deposits in metasedimentary rocks of turbidite association along the western side of the CMT.

A type of very local sedimentary deposit not considered is represented by magnetite and specular hematite concentrations found at the Cross Iron mine (8I-1, fig. 6) and No. 4 prospect (8H-20). Here, massive and disseminated specular hematite, magnetite, and probably minor amounts of barite occur in the Clough Quartzite (of Sns). Tentatively, the deposit is interpreted as a stratabound accumulation of iron oxide that originated by subaerial weathering of the underlying Ammonoosuc Volcanics (Olv) and reconcentration of iron oxide before and during subaerial deposition of the Clough Quartzite. This model, however, does not explain the occurrence of barite (see description in Appendix II).

Outline DSsx1 (many grids)

The outlined area includes broad tracts underlain by Silurian and Lower Devonian turbidite-rich formations of the CMT, southeast of the STH. The many plutons that are shown within the area are excluded from the resource analysis.

The geochemical data show an extensive stream-sediment copper anomaly in parts of several 15' quadrangles (grids 3E, 2E, 1E, 2D, 1D) in Maine (Nowlan and others, 1990b). The area from which most of the samples were obtained is underlain by moderately to strongly metamorphosed sedimentary rocks of the CMT and is restricted to the units that lie above the Rangeley Formation (of Sbw). Readers are referred to the map of Moench and others (1995) for the distribution of the named formations. The western boundary of the anomaly coincides remarkably well with a stratigraphic level that lies slightly below the contact between the Silurian Perry Mountain and Smalls Falls Formations, and the main area of the anomaly is underlain by strongly euxinic turbidites of the Smalls Falls Formation and less euxinic shale-rich turbidite sequences of the Lower Devonian Carrabassett Formation and higher formations of the Seboomook Group. The Madrid Formation (above the Smalls Falls Formation and below the Carrabassett Formation) is composed mainly of noneuxinic calcareous metasandstone and is largely excluded from the anomaly. A similar stream-sediment copper anomaly, mainly in grid 3F, occurs in an area underlain by stratigraphically equivalent but more strongly metamorphosed rocks (Canney and others, 1987; Moench and others, 1984). (Note that tin and copper anomalies have been inadvertently exchanged on the map of Moench and others, 1984.) These relationships, particularly the sharply defined stratigraphic control of the west side of the copper anomaly in grid 3E, suggest that the source of the copper is mainly in the Smalls Falls and Carrabassett Formations. The only known suggestion of sedimentary sulfide mineralization is a 5-cm-thick lens of copper-bearing ironstone about 1.5 km south of Madrid, Maine (2E-1).

Also noteworthy is the distribution of cobalt in stream sediments (McDanal and others, 1985). Samples collected from areas underlain by the Rangeley to Carrabassett sequence commonly show high cobalt abundances (30–700 ppm), particularly in grids 2E, 3E, and 5G. Although it is tempting to suggest that the cobalt, as well as copper, in the stream sediments was derived from local sources in the Silurian and Lower Devonian metasedimentary rocks, two observations suggest that the cobalt and copper do not have a common source. First, the most strongly anomalous cobalt and copper data do not occur in the same samples. Second, the cobalt anomaly in grid 3E occurs in an area underlain by the Rangeley Formation, as well as younger units, and is not bounded by the stratigraphic horizon that marks the western boundary of the copper anomaly. On the assumption that cobalt and copper in the stream-sediment samples have local bedrock sources, these relations reasonably suggest the presence of cobalt-dominant SEDEX-type deposits in the Rangeley Formation and copper-dominant SEDEX-type deposits in the Smalls Falls and Carrabassett Formations.

The overall setting of the cobalt and copper anomalies described above is similar in important respects to the Sheep Creek copper-cobalt sulfide deposits of the Upper Proterozoic Belt Supergroup in west-central Montana (Himes and Peterson, 1990). These deposits are hosted by shales and associated debris-flow conglomerates exposed near the margin of an inferred penecontemporaneous graben. Himes and Peterson (1990, p. 544) proposed that the sulfide deposits formed on the sea floor during the transition from quiet deposition of fine-grained clastic sediments to rapid deposition of fine clastics, conglomerate, and breccia associated with extensional growth faulting and high heat flow. Conglomerate, conglomeratic mudstone, and proximal turbidites are characteristic of the Rangeley Formation in grid 3E in the area of the cobalt anomaly, and the cobalt and copper anomalies occur within areas of several mapped premetamorphic extensional faults that might have served as conduits for the transport of hot fluids to the sea floor, much like the role that Himes and Peterson (1990) inferrred for the penecontemporaneous faults of the Belt Supergroup.

If the interpretations given above are correct, SEDEX-type copper deposits that might occur in Silurian rocks of the anomaly would be approximately coeval with the Ledge Ridge and Clinton River VMS deposits of area Sv2. Additionally, those that might occur in the Devonian rocks would be approximately coeval with the probable Lower Devonian Thrasher Peaks VMS deposit of area Dv1. The most likely host for a copper SEDEX-type deposit is the strongly euxinic Smalls Falls Formation. This unit contains 5–10 percent disseminated pyrrhotite, which in polished surfaces is seen to contain blebs of sphalerite and chalcopyrite. On the assumption that economic sedimentary sulfide deposits might be present, the author sampled much of the Rangeley to Seboomook sequence during the 1960's for their metal contents, concentrating on various lithologic types in the Smalls Falls Formation. The analyses yielded only normal amounts of metals.

Resource potential—Unknown. Stratiform copper and (or) cobalt deposits might occur in turbidites of the Silurian Rangeley, Perry Mountain, and Smalls Falls Formations, and the Lower Devonian Carrabassett Formation. This suggestion is based on geochemical data and similarities of sedimentary and tectonic setting of the resource area to the setting of the Sheep Creek deposits in Montana (Himes and Peterson, 1990). The area is drawn along the northwest side of the CMT, southeast of the STH, which is an area of rapid Silurian clastic sedimentation and major extensional faulting (Moench, 1970, 1973; Moench and Pankiwskyj, 1988a, b). The stream-sediment data suggest that the deposits, if present, are cobalt-dominant in the Rangeley and Perry Mountain Formations, and copper-dominant in the Smalls Falls and Carrabassett Formations.

Because the rocks have not been studied for their favorability for the occurrence of stratiform SEDEX deposits, only an unknown potential is justified. The very minor copper-bearing ironstone (2E-1) occurrence is not sufficient to raise the assignment to a low or higher resource potential.

Possible gold and uranium resources in Mesozoic veins—A proposed genetic model

Metal-bearing quartz veins, quartz-carbonate veins, and unspecified shear zones are widely distributed throughout the project area and southeastern Quebec. With local exceptions, as at the Jackson tin mine (5H-1) and perhaps at the Saint-Robert mine (3A-1) and Saint Hermenegilde prospect (7D-3), the veins cannot be shown to be genetically related to specific plutons. Cox (1970) proposed that lead-silver veins in New Hampshire are genetically related to the White Mountain Plutonic-Volcanic Suite. The veins are probably not related to individual White Mountain plutons, however, because some veins, such as the cluster of lead-bearing veins at the Mount Glines, Champion Consolidated, Lone Star, and Woodstock prospects (3G-1 to 4), are 40 km or farther from the nearest mapped White Mountain pluton. In the southwestern corner of the map area (grid 8H, fig. 6), a cluster of quartz-carbonate veins that contain galena and native gold occurs on opposite sides of the Ammonoosuc fault (AF), here interpreted as a Triassic normal fault that is coextensive with the normal faults associated with the Triassic basin of Massachussetts and Connecticut.

Several other metalliferous veins occur along or near the trends of the Monroe fault (MNF) in Vermont, and the Perry Stream and Victoria River faults (PSF, VRF) in Quebec. These are primarily Devonian faults, but evidence of brittle reactivation of at least the Monroe fault is recognized (Hatch, 1988). Hatch (1988) suggested a Mesozoic age for the reactivation, but it might have occurred at any time after the Devonian metamorphism. From south to north, the veins are: (1) discordant veins and concordant pods of quartz containing chalcopyrite, molybdenite, and a trace of gold at Granby Stream (7F-1); (2) veins in carbonatized slate carrying trace amounts of base and precious metals at an unnamed occurrence west of Notre Dame de Bois, Quebec (5C-2); (3) a carbonatized shear zone containing precious metals about 11 km farther northeast (5C-1); (4) a sheared, carbonatized porphyry dike containing pyrite, precious metals, copper, and lead at the Marston gold prospect (4B-2); and (5) copper-bearing veins at an unnamed prospect some 40 km farther northeast (3A-2). Also noteworthy is the northeast-trending alignment of the Saint-Robert mine (3A-1) and tungsten-bearing veins at two prospects farther southwest (3B-2, 3B-3), possibly controlled by an unmapped brittle fault. The deposit at the Saint-Robert mine is a zoned stockwork of scheelite-bearing porphyry and polymetallic quartz veins, with reported gold, associated with a 1x2-km phyllic alteration zone above an undated Devonian(?) pluton. Additionally, at the Nebnellis prospect (4B-3), sheared, altered, and quartz-veined rocks that carry base and precious metals occur on or near the Deer Pond fault (DPF), outcrops of which display brittle features.

Although brittle fracturing might have occurred at any time after Devonian (Acadian) orogenic deformation and metamorphism, it is likely that the majority occurred during extension that closely preceded and accompanied opening of the present Atlantic Ocean. None of the metalliferous veins have been dated, but their known geologic relationships permit the interpretation that most are Mesozoic in age. Some support for this interpretation is provided by a recently determined preliminary Mesozoic age for vein and stockwork mineralization at Ellenville, N.Y. (Jules D. Friedman, USGS, oral and written communs., May 1991), determined by $^{40}Ar/^{39}Ar$ analyses of potassium-bearing fluid inclusions in quartz (reported to Friedman by E.H. Mckee and J.E. Conrad, USGS). Friedman also reported that lead isotope compositions of galena from the Shelburne mine (5G-1) and other vein deposits in New England are similar to those of sulfide veins and stockworks that occur in the Silurian Shawangunk Formation, New York and Pennsylvania, and particularly to those at Ellenville. On this basis, he suggested that the New Hampshire and Ellenville veins have the same age and origin.

It seems appropriate, therefore, to explain the veins in terms of a single general model. According to the model proposed here, the veins are assumed to have formed in Mesozoic time, during regional uplift, normal faulting, and widespread extensional fracturing that produced high fracture-permeability in the upper kilometer or two of the Earth's crust. The minerals that now occur in the veins were precipitated from hydrothermal fluids, perhaps mainly meteoric, that circulated in large convection cells driven by heat derived from at least two sources. One heat source was magmas that now form the high-level plutons, dikes, and volcanic rocks of the White Mountain Plutonic-Volcanic Suite. A second possible source was radiogenic heat produced by radioactive decay of uranium, thorium, potassium, and their daughter products, which are widely dispersed through various rock units of the area, particularly in Jurassic Conway and Conway-type granites and in the Carboniferous and Devonian two-mica granites.

Noting that vein-type uranium deposits are commonly associated with granites having abnormally high uranium contents, Fehn and others (1978) calculated that the heat produced by radioactive decay of uranium, thorium, potassium, and their daughter products within a Conway-type granite pluton is capable of generating energetic hydrothermal convection, given sufficient fracture-permeability within the pluton and its country rocks. The potassic Conway Granite has long been recognized to be particularly rich in uranium and thorium (Butler, 1975; Hoisington, 1977) and has been considered as a geothermal energy resource (Osberg and others, 1978). Fehn and others (1978) showed that a significant vein-type uranium deposit can result from this process. The obvious source of the uranium would be the immediate pluton.

Meager available data suggest that the Devonian and Carboniferous two-mica granites of the project area also have high contents of radioactive elements (Boudette, 1977), and might provide a heat source of much greater areal extent than the Jurassic intrusions. A remarkable correlation is seen between two-mica granite plutons (Dnt, Mt, ℙt) and uranium in stream sediments (Nowlan and others, 1990a). Analyses as high as 10 ppm uranium have been obtained from leucocratic two-mica granite of the Willoughby pluton (Ayuso and Arth, 1992) (index 47), and analyses of five samples (one from an outcrop, four from a drill core) of two-mica granite and related pegmatite from the Mooselookmeguntic batholith and Whitecap Mountain plutons (indexes 34A, 30) indicate 14–23 ppm uranium (delayed neutron analyses by H.T. Millard and others, USGS, 1973). The informally named Sunapee granite, a two-mica granite body exposed in west-central New Hampshire, south of the project area, is host to secondary uranium deposits; fresh samples of the granite contain as much as 32 ppm uranium. The Sunapee granite is the source of abundant uranium in overlying moss and peat in Messner Pond (Cameron and others, 1990).

In contrast, analyses of uranium contents of metasedimentary rocks of the CMT in the project area indicate maximum uranium contents in the range of 5–7 ppm, in black pyrrhotitic schists of the Smalls Falls and Temple Stream Formations (of Sbw and Dc), and typically 1–4 ppm in samples obtained from other formations of the CMT (delayed neutron and instrumental activation analyses by H.T. Millard, Jr., and others, 1973, 1978). Although uranium, thorium, and potassium in sediments deposited under euxinic conditions might provide a partial heat source for metamorphism, as proposed by Chamberlain and Sonder (1990) for the CMT, two-mica granite plutons are a more promising source of radiogenic heat both for some metamorphism and for the origin of the widely distributed veins.

Geologic mapping and gravity studies (map B, discussed earlier by Bothner and others) show that the Devonian and Carboniferous two-mica granite plutons exposed in areas of sillimanite zone metamorphism form a complex of rather thin, probably overlapping, subhorizontal sheets, typically 1–3 km thick. The two largest two-mica granite bodies are most of the Mooselookmeguntic batholith (index 34A), dikes of which are common in the Ordovician Adamstown pluton (index 35) to the north, and the Sebago batholith (index 78). Other major bodies are the North Jay, Chesterfield, New Sharon, Bromley, Leeds, Bretton Woods, and Gorham plutons (indexes 70–73, 75, 65, 66), and abundant dikes in the north lobe of the Phillips batholith (index 26A). These sheetlike bodies are inferred to have been emplaced at depths of 10–12 km, within or below the prevailing brittle-ductile crustal transition (Carnese and others, 1982; Moench and others, 1982).

Two-mica granite is less abundant north of the sillimanite isograd, but is exposed in part of the Lexington batholith, and in the Long Mountain and Greenough Pond plutons (indexes 21B, 40, 37). Whereas the Long Mountain and Greenough Pond plutons are probably part of the subhorizontal sheet complex, although emplaced slightly above the brittle-ductile transition, the Lexington batholith is a steep-walled body that was emplaced well within the brittle upper crust (Koller, 1979; Phillips, 1990; Bothner and others, this report). The subhorizontal sheets are more pertinent to the proposed model than the steep-walled plutons.

The proposed model assumes that granitic sheets emplaced at depths of 10–12 km in already hot country rocks would not lose heat rapidly after crystallization. Instead, granite containing abnormally high amounts of radioactive elements would generate heat continuously after emplacement. During uplift and erosional uncovering, radiogenic heat would continue to accumulate until the relatively insulating environment was disrupted. Then, during extensional fracturing in the upper 1–2 km of the Earth's crust, radiogenic heat would drive hydrothermal convection that produced most of the vein deposits of the project area, much as proposed by Fehn and others (1978) for possible uranium-bearing veins associated with the Conway Granite, and by Cuney (1978) for known uranium-bearing veins associated with the Bois Noirs uranium-enriched granite in France. We propose that this process resulted in the observed wide distribution of veins, many of which are not spatially associated with individual plutons. Resource implications of this model follow.

Unmapped gold resources along or near brittle faults

According to the proposed model, the gold-bearing veins of the area formed at shallow depth, in a large hydrothermal system that prevailed during Mesozoic extensional faulting and fracturing. The hydrothermal fluids may have leached the gold and other metals from older VMS deposits of the area (see discussions of areas Sv4, Olv5), in a manner proposed by Fulp and Woodward (1990) for the origin of Late Cenozoic gold-bearing quartz veins in New Mexico, which commonly occur in areas that also contain Proterozoic VMS deposits.

By analogy with Fulp and Woodward's (1990) proposal, gold-bearing veins might be sought in those parts of the metavolcanic belts of the map area known to contain VMS deposits, or that are most likely to contain undiscovered VMS deposits. Other sources of gold that now occurs in veins might also include fossil gold placers in the Silurian Clough Quartzite, possibly at the Atwood mine (8H-13) and Allen prospect (8H-15), which might ultimately have also come from VMS deposits in the Ammonoosuc Volcanics. Because economic viability of gold-bearing veins depends on vein spacing as well as grade, the most promising area is probably near the unmapped convergence of the Ammonoosuc and Bill Little faults (AF, BLF), mapped separately (outlined area MzAu1).

Resource potential—Low. This assignment is based on the favorable geologic settings. The actual traces of the AF and other possibly Mesozoic brittle faults shown on the map are also recommended for exploration, particularly where such faults are closely spaced and occur in areas of known older mineralization, as in outlined area MzAu1, which is mapped separately. Based on heavy-mineral-concentrate data (Watts, 1990), Slack (1990, fig. 6, locality 6-1) has assigned a moderate resource potential for gold along the AF at four localities in the eastern part of the Glens Falls 1°x2° quadrangle. All these data and relationships (described in outlined area MzAu2) suggest that the known length of the AF is a potential source for gold.

Outline cAu1 (grids 8G and 8H)

Quartz-carbonate-sulfide veins known to contain visible native gold are most abundant in the "Ammonoosuc gold field" (Hitchcock, 1878; Heylmun, 1986), approximately in the area of convergence of the Triassic Ammonoosuc (AF) and Bill Little (BLF) normal faults. Rocks of this area host many crosscutting quartz-carbonate veins that contain sulfide minerals and native gold; such veins have been developed at several mines and prospects (8G-12 and 13, 8H-4 to 9, 8H-12). The area is one of intensive brittle fracturing in the hanging-wall block above the AF.

Resource potential—High. This assignment is based on favorable geology and the evidence of vein-type gold mineralization shown at several mines and prospects. Rocks of this area are particularly favorable for the occurrence of vein-type gold, because of the southwestward convergence of the AF and BLF, and because of the nearby evidence of older, volcanogenic mineralization (areas Olv5, Sv4).

Unmapped uranium resources related to uranium-rich granite

Uranium-bearing veins are unknown in the area but might occur in areas underlain by plutons of the Jurassic Conway Granite and subhorizontal sheet-like bodies of Devonian and Carboniferous two-mica granite. Available data indicate that all these rocks are rich in radioactive elements, and the model of radiogenic heat-driven hydrothermal circulation (Fehn and others, 1978) for the origin of possible uranium-bearing veins in the Conway Granite might be extended to wide areas underlain by Paleozoic two-mica granite.

Resource potential—Low. This assignment is justified by the stream-sediment geochemical data. The most favorable areas are where these granites are cut by closely spaced brittle faults, as in outlined area MzU1, which is mapped separately.

Outline MzU1 (grid 6G)

A line of several stream-sediment samples having high uranium abundances coincides with the Pine Peak fault (PPF). Although this concentration of samples is in an area underlain by Ordovician granite and the Ammonoosuc Volcanics, the PPF is a brittle feature that also cuts Silurian metamorphic rocks and Devonian two-mica granite; the PPF is cut by the Jurassic Conway Granite. Before and possibly after emplacement of the granite, the PPF was probably an open fissure that provided a channelway for hydrothermal fluids that had easy access to a variety of rock units, including two-mica granite.

Resource potential—Moderate. This assignment is justified by the favorable geologic setting and the stream-sediment geochemical data.

Possible gold resources associated with Mesozoic alkalic intrusive rocks

Based on studies of gold mineralization at the Cretaceous Cuttingsville syenite stock, Cuttingsville, Vt., Robinson (1990) suggested that gold deposits might also be associated with other syenitic intrusions in New England. Arsenic, bismuth, copper, gold, and silver at Cuttingsville occur in a massive pyrrhotite body that has replaced stratified Proterozoic marble cut by the stock (Robinson, 1990, fig. 1), which is locally hydrothermally altered and contains gold- and tungsten-bearing quartz-pyrite-carbonate veins. Robinson (1990, p. O15) listed several other sites that are favorable for the occurrence of syenite-related gold deposits, including: (1) the Norton gold(?) prospect (7E-2), at the border of the Mount Monadnock syenite pluton (index 44); (2) a zone of hydrothermal alteration in the Mount Megantic pluton, Quebec (index 102) that might be the source of nearby angular placer gold (Gauthier, 1986); (3) the Saint Hermenegilde prospect, Quebec (7D-3), where a polymetallic stockwork, with minor gold (as much as 0.18 ppm) and bismuth and tellurium minerals, is associated with greisenized pegmatite dikes probably related to the Hereford Mountain pluton (index 101) (Gauthier and others, 1988, p. 415–525, fig. 2.515; Gauthier and others, 1994, p. 1345); and (4) alkalic dikes and stocks of the White Mountain batholith. On the basis of its proximity to the Hermenegilde prospect, Gauthier and others (1994, p. 1345) suggested that the Hereford Mountain pluton is Mesozoic in age; on the map it is shown as possible Conway-type granite (**Jwc**).

Readers are referred to the exploration criteria listed by Robinson (1990, p. O15–O17). Specific targets follow.

Unmapped gold resources

Although the mildly alkalic rocks of the White Mountain Plutonic-Volcanic Suite in the project area have not been investigated with specific reference to the criteria of Robinson (1990), attention is directed to the contacts of the syenite, quartz syenite, and alkali granite bodies that are distinguished on the map of Moench and others (1995).

Resource potential—Unknown. This assignment is justified by possibly favorable geologic settings, which have not been investigated.

Outline MzAu2 (grid 6G)

High abundances of gold and silver occur in one heavy-mineral concentrate obtained from stream sediment (Nowlan and others, 1990c) at the point of truncation of the Triassic Ammonoosuc fault (AF) by Jurassic riebeckite granite at the west side of the Pilot-Pliny plutons (index 55). It would be an extraordinary coincidence if the gold did not come from bedrock at or near the contact of the pluton. This occurrence might be an example of gold mineralization associated with alkalic plutons in New England and Quebec (Robinson, 1990, p. O15).

Resource potential—Moderate. This assignment is supported by a favorable geologic setting and by heavy-mineral-concentrate data.

Outline MzAu3 (grid 7E)

Robinson (1990, p. O15) listed the Norton mine [7E-2; Norton gold(?) prospect] as a possible example of gold associated with the borders of alkalic plutons. This locality is at the border of the syenitic Monadnock Mountain pluton (index 44), which, well within the pluton, also contains sulfide-bearing veins (7E-1) that contain galena, chalcopyrite, sphalerite, and pyrite. Sampling by Laurel Woodruff (written commun., December 1986, USGS) did not reveal the presence of gold at the prospect. The veins have not been analyzed for gold contents, but the presence of at least detectable gold can be assumed.

Resource potential—High. This assignment is based on the favorable geologic setting and the evidence of mineralization.

Outline MzAu4 (grids 4F and 5F)

The probable breccia pipe northeast of Red Ridge (occurrence 4F-3) contains highly gossanized breccia in association with intrusive alkali-olivine basalt. Here, limonitic breccia is exposed over a width of 46 m along a brook bed. The breccia is in sharp contact with rusty-weathering felsic gneiss at the northeast end of the Success lobe of the Jefferson batholith (indexes 64, 63). Bodies of dense, black, feldspar-porphyritic alkali olivine basalt intrude the felsic gneiss just upstream and downstream from the breccia, possibly as separate plugs or a ring dike. Although spectrographic and chemical analyses of the breccia revealed no unusual metal contents, the gossanized breccia is evidence of mineralization and merits further investigation for gold.

Resource potential—High. This assignment is justified by the favorable geologic setting and the evidence of mineralization shown by the gossanized breccia.

Gold placers

Gauthier and others (1994, p. 1346) briefly discussed the gold placers of southern Quebec, where the distribution of placers is widespread and well documented. The best known placers south of the international border are in the East Branch of the Swift River, north of Rumford, Maine (grids 3E, 3F), in Indian Stream, northernmost New Hampshire (grid 6D), and in the Wild Ammonoosuc River, near Swiftwater, N.H. (grid 8H). Gold can be panned from many other streams in the Sherbrooke-Lewiston area, however, and it has not been possible to compile a comprehensive map of the distribution of the gold placers south of the international border. Because the purpose of showing placer deposits would be to indicate potential bedrock sources, a more efficient way to find such sources would be to conduct thorough bedrock and stream-sediment studies at the potential sources already mentioned.

PEGMATITES (NOT EVALUATED)

The pegmatites, principally in the high-grade metamorphic terrane of southwestern Maine, are gently to steeply dipping discordant dikes or conformable lenses of coarsely crystalline to aplitic sodic plagioclase, alkali feldspar, quartz, mica, and, locally, one to many rare minerals. All the pegmatites are in the Oxford pegmatite field of Francis and others (1993). Only a few of the largest bodies (**Dnp**) are shown on the map; the majority are too small to map even at a scale of 1:62,500. The largest pegmatites appear to be subhorizontal sheets that cap hills and mountains, as at Whitecap Mountain (index 30; Moench and Hildreth, 1976, section D–D'). Pegmatites of all sizes are far more numerous than those that have been explored at the mines and prospects shown on the map. Almost all of the large, mesozonal, granitic to intermediate Paleozoic plutons of the map area contain pegmatite dikes. The high-level Jurassic granites have coarsely crystalline granitic phases and miarolitic cavities, but they generally lack discrete pegmatite dikes. The Devonian Willoughby pluton (index 47) in Vermont (Ayuso and Arth, 1992) may be considered transitional between mesozonal and epizonal because it has abundant miarolitic cavities as well as pegmatitic granite and pegmatite.

The vast majority of pegmatites in the map area are mineralogically simple, having only garnet, black tourmaline, apatite, and zircon as common accessory minerals, and they may or may not be zoned (Cameron and others, 1949). Most of the economically developed pegmatites are zoned. Some of these are mineralogically simple but have a core characterized by giant feldspar crystals or well-formed book muscovite; such bodies have been quarried for feldspar mainly for use as a mild abrasive or for mica for electronic purposes. Mineralogically complex pegmatites may have beryl and varicolored tourmaline and a wide variety of minerals bearing beryllium, fluorine, lithium, cesium, phosphorous, uranium, niobium, tantalum, and other elements. Such pegmatites have been developed principally for beryllium, lithium, or tantalum, and some are famous mineral collecting localities, as at the Newry (3F-M), Black Mountain (3F-E), Mount Mica (2G-H), and Mount Apatite (2H-Q) mines.

Most of the pegmatite mines and prospects are concentrated into well-defined groups, shown on the map as the Rumford and Paris pegmatite districts. Pegmatites of the Rumford district form a northeast-trending belt that centers on the very large Whitecap Mountain pegmatite (3F-I), a thick but mineralogically simple, unzoned, subhorizontal sheet. The more complex peripheral bodies of the district may be genetically related to the Whitecap Mountain pegmatite. On the basis of mapping and Rb-Sr isotopic whole-rock data, Moench and Zartman (1976, p. 230) inferred that the Whitecap Mountain pegmatite is genetically related to two-mica granite of the main body of the Mooselookmeguntic batholith (index 34A), dated at 371±6 Ma (Moench and Zartman, 1976; recalculated using new constants) and also shown to have been emplaced as a subhorizontal sheet (Moench and Zartman, 1976; Carnese, 1981). Other pegmatites of the district are assumed to be Devonian in age.

Pegmatites of the Paris district form an arcuate belt that approximately conforms to the northern margin of the Sebago batholith (index 78), which has been dated at about 290–300 Ma (Aleinikoff, *in* Moench and others, 1995; U-Pb zircon method). Accordingly, these pegmatites are reasonably inferred to be Carboniferous in age, which is also the age of the youngest deformation and high-grade metamorphism near the batholith (Lux and Guidotti, 1985; Aleinikoff and others, 1985). Like the Devonian Mooselookmeguntic batholith, the Carboniferous Sebago batholith is composed of strongly peraluminous two-mica granite emplaced as a subhorizontal sheet (Hodge and others, 1982).

The pegmatites of both districts have been mined largely for feldspar (used as a mild abrasive) and mica (used during the early stages of the electronics industry, particularly during World War II). Other commodities that have been produced or explored are beryllium, lithium, niobium, tantalum, uranium, and other rare elements; some of the pegmatites are famous mineral collecting localities and some have recently produced gem-quality tourmaline. Because of the generally small size of the pegmatites and the labor-intensive methods that must be used to extract all but feldspar, under foreseeable economic conditions pegmatites are unlikely to be a major metallic-mineral or rare-mineral resource in the study area. Accordingly, the pegmatite districts were not studied by this project. See Appendix III for further information.

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APPENDIX I. DESCRIPTION OF MAP UNITS

PLUTONIC ROCKS

White Mountain Plutonic-Volcanic Suite (Early Cretaceous and Jurassic)—Unmetamorphosed, mildly alkalic intrusive and local volcanic rocks of high-level stocks, ring dikes, and cauldrons extending from southeastern New Hampshire to southern Quebec (Billings, 1956; Foland and others, 1986). Now exposed 1–2 km below the Mesozoic surface of erosion. Interpreted to have originated during opening of present Atlantic Ocean. Have identical counterparts in Nigerian tin districts (Read, 1948, p. 8; Greenwood, 1951; Moench and Gazdik, 1984; Moench and others, 1984; Cox, 1990)

Early Cretaceous rocks—Equivalent to New England–Quebec igneous province of McHone and Butler (1984)

Kw **Granite, syenite, and gabbro-diorite**—Megantic Mountain plutons (index 102) and Pleasant Mountain pluton (index 80). Megantic Mountain plutons contain a central core of pink biotite granite, and peripheral ring dikes of hornblende syenite and diorite to gabbro; diorite dated at 124±2 Ma (Foland and others, 1986). Pleasant Mountain pluton composed of porphyritic hornblende-biotite syenite; dated at 112±3 Ma (Foland and Faul, 1977)

Kwv **Trachyte**—Trachytic tuff and pyritic volcanic breccia overlying syenite of Pleasant Mountain pluton (index 80)

Early Cretaceous or Jurassic rocks

KJwb **Basalt plug and volcanic breccia**—Alkali-olivine basalt intruding pyritic breccia; exposed near Red Ridge (straddles grids 4F and 5F)

KJwg **Gabbro or diorite**—Massive, medium-grained gabbro or diorite exposed at two localities near Bridgton (grid 3H), either as two plugs or one northeast-trending dike

Jurassic rocks—Equivalent to White Mountain Magma Series province of McHone and Butler (1984)

Jwc **Conway Granite and Conway-type granite**—Pink biotite granite at type locality near Redstone in White Mountain batholith (index 81), and similar granite in same batholith and other plutons. Also includes intrusive rhyolite of Gay Brook ring dike(?) (index 43A) and, tentatively, biotite granite of Hereford Mountain pluton (index 101; see Gauthier and others, 1994). Commonly has miarolitic cavities; discrete pegmatite bodies uncommon. Has chemical characteristics of "specialized" granite (Tischendorff, 1977), enriched in uranium, thorium, tin, and other incompatible elements, and is the source of possibly important tin resources (Cox, 1990). Uranium contents range from 10 to 13 ppm, and thorium contents range from 45 to 80 ppm from one pluton to another in White Mountain batholith (Hoisington, 1977). Ages determined within map area range from 155±4 to 194±4 Ma (Foland and Faul, 1977; Randall and Foland, 1986; Eby and others, 1992)

Jwu **Undivided felsic to mafic alkalic rocks**—Amphibole- and pyroxene-bearing granite, quartz syenite, syenite, and smaller amounts of quartz monzodiorite to gabbro. Mount Osceola Granite of White Mountain batholith is most widely exposed, but unit contains several other named and unnamed units of various compositions. Approximately coeval with Conway Granite and Conway-type granite (Jwc), as shown by several age determinations (Foland and Faul, 1977; Eby and others, 1992). Ferrorichterite syenite and quartz syenite of Hart Ledge plutons (index 82), which intrude White Mountain batholith, long considered Cretaceous in age, but recently dated at 168±1 Ma (Eby and others, 1992)

Jwv **Moat Volcanics**—Exposed in White Mountain batholith. Mainly rhyolite tuff, tuff-breccia, and trachyte; local basalt and andesite. Rhyolite tuff and trachyte dated at 162±4, 169±4, 168.2±1.2, and 173.1±1.5 Ma (Eby and others, 1992)

IPt **Two-mica granite (Pennsylvanian)**—Sebago batholith (index 78) and related bodies. Metamorphosed, gray to pink, fine- to coarse-grained two-mica granite; commonly seriate-porphyritic and pegmatitic. Muscovite commonly occurs as poikiloblastic crystals of metamorphic origin. Emplaced as subhorizontal sheet, possibly as thin as 1 km, in regional sillimanite zone (Simmons, 1986; Simmons and others, 1988). A U-Pb zircon age of 325±3 Ma has been reported (Aleinikoff and others, 1985), but further studies of zircons by J.N. Aleinikoff (oral commun., October 1993) indicate a Pennsylvanian age of about 290–300 Ma

Msu **Syenite, quartz syenite, alkali gabbro, and ultramafic rocks (Mississippian?)**—Androscoggin Lake plutons (index 74). Unmetamorphosed alkalic rocks similar to bodies of White Mountain Plutonic-Volcanic Suite. Long considered Permian in age, on the basis of K-Ar hornblende ages of 287 and 289 Ma (Northeast Utilities Corporation, 1975), but here tentatively thought to be Mississippian in age on the basis of $^{40}Ar/^{39}Ar$ hornblende plateau ages of about 330 Ma by D.R. Lux (*in* Lathrop, 1990). The younger ages might represent a Permian thermal event

Mt **Two-mica granite (Mississippian)**—Long Mountain pluton (index 40). Light gray, medium grained, typically equigranular, but locally subporphyritic; locally hydrothermally altered near contact. Probably emplaced as a subhorizontal sheet similar to the Sebago batholith and granitic bodies of the New Hampshire Plutonic Suite southwest of the regional sillimanite isograd. Dated at about 350 Ma (Harrison and others, 1987)

Du **Diapiric ultramafic talc-carbonate rock and serpentinite (Devonian?)**—Hydrated and probably remobilized from mantle, or from ophiolitic Boil Mountain Complex, during the Acadian orogeny, and emplaced along and near Acadian faults. Small bodies exposed in grids 3C, 3D, 4C, 5C, and 9I (fig. 6)

New Hampshire Plutonic Suite (Devonian)—Strongly metamorphosed to unmetamorphosed, Acadian to post-Acadian peraluminous granite and calc-alkalic granite to gabbro. Gabbro and related mafic to ultramafic rocks in Maine emplaced along or near major extensional faults (BF, BMF, MF, PMF, WBF, and 2808F on map). In areas of middle and upper amphibolite facies metamorphism (AB and AC on map, respectively), granitic rocks emplaced mainly as thin (1–3 km), subhorizontal sheets (Carnese, 1981; Carnese and others, 1982; Moench and others, 1982); sheets lack well-defined contact metamorphic aureoles, except at northeast margin of main body of Mooselookmeguntic batholith (index 34A). Northeast to northwest of area of middle amphibolite facies metamorphism, emplaced mainly as steep-walled plutons that have well-defined aureoles

Dnbv **Variably textured biotite granite (Late Devonian)**—French Pond (index 91) pluton, and, tentatively, Alderbrook (index 60) and Newark (index 49) plutons. Gray to pink, medium- to coarse-grained, seriate and locally porphyritic, muscovite-bearing granite. Granite of Newark pluton contains magnetite; source of major aeromagnetic anomaly (map C). French Pond pluton dated at 365±3 Ma (Aleinikoff and Moench, 1987)

Dnt **Two-mica granite (Late to Early Devonian)**—Many bodies in Maine and New Hampshire. Typically gray, massive, fine to medium grained, and equigranular; euhedral primary muscovite recognized in some bodies. Includes Willoughby pluton (index 47), which is seriate, leucocratic, and locally pegmatitic, and contains garnet, miarolitic cavities, and local evidence of weak hydrothermal alteration (mineral occurrence 8E-1); where altered, contains as much as 10 ppm uranium and 26 ppm tin (Ayuso and Arth, 1992, table 3). Distribution of uranium in stream sediments in study area (Nowlan and others, 1990a) suggests typical two-mica granite also has high uranium contents. This observation supported by delayed neutron analyses that yielded 22 ppm uranium in a sample of two-mica granite from the Mooselookmeguntic batholith (index 34A), 14–23 ppm uranium in three samples from pegmatitic granite (Dnp) obtained from drill core that penetrated the Whitecap Mountain pluton (index 30), and 16 ppm uranium in a sample of two-mica granite obtained from near the bottom of the core (analyses by H.T. Millard, Jr., and others, USGS, 1973). Two-mica granite of Mooselookmeguntic batholith dated at 371±6 Ma (Moench and Zartman, 1976; Rb-Sr whole-rock, revised constants). Smith and Barreiro (1990) obtained a U-Pb monazite age of 363±2 Ma from the same body, but were uncertain whether that age represents primary crystallization or cooling through about 525°C. Two-mica granite of the Lexington batholith (indexes 21A, B) dated at 399±3 Ma (Gaudette and Boone, 1985; Rb-Sr whole-rock and mineral isochron)

Dnp **Pegmatitic granite and pegmatite (Late and Middle Devonian)**—Whitecap Mountain pluton (index 30), parts of Rumford pluton (index 29), and smaller unmapped pegmatite bodies related to two-mica granite. White, coarsely crystalline quartz, alkali feldspar, and mica; many bodies also contain beryl, spodumene, tourmaline, and other rare minerals. Occurs as subhorizontal sheets and steeply dipping lenses. Many small bodies have been quarried in the past for quartz, feldspar, mica, gems, and other commodities. See description of two-mica granite (Dnt) of Mooselookmeguntic batholith for uranium data for Whitecap Mountain pluton, which is interpreted to be comagmatic with unit Dnt

Dnh **Hornblende-biotite granodiorite to diorite (Late to Early Devonian)**—Variably medium to dark gray, fine to medium grained granodiorite, quartz monzodiorite, tonalite, and sparse granite and quartz diorite to diorite; muscovite generally absent. May have primary foliation, but generally not metamorphically foliated. Age determinations range from about 368 to 390 Ma (see Moench and others, 1995)

Dnhm **Hornblende-quartz monzodiorite to gabbro (Late? to Early? Devonian)**—Facies of unit Dnh in Mooselookmeguntic batholith (index 34C), and facies of unit Dnb in Echo Pond plutons (index 46B)

Dnb **Biotite granite, granodiorite, tonalite, and sparse trondhjemite (Middle to Early Devonian)**—Variably light to medium gray, and fine to coarse grained; typically muscovite bearing and commonly feldspar porphyritic. Includes the feldspar-porphyritic Kinsman Granodiorite, the gneissic Bethlehem Granodiorite, and unnamed rocks of many plutons. Trondhjemite known only in Howard Pond pluton (index 32). Ages range from 374±2 Ma (Simonetti and Doig,

1990) for Mont Ste.-Cécile pluton (index 104) to 407±5 or 410±5 Ma (Kohn and others, 1992; Aleinikoff *in* Moench and others, 1995, site D-9) for Bethlehem Granodiorite of the Indian Pond and Fairlee plutons (indexes 95 and 94). Indian Pond and Fairlee plutons are faulted remnants of one pluton that intrudes rocks of the BHA and the P-F allochthon and (Moench, 1990, 1996a)

Dng **Gabbroic and hybrid rocks (Early Devonian)**—Includes: (1) Gabbro, local diorite, and sparse ultramafic rocks of several plutons in Maine (indexes 19A, 20, 24, 33, and others), some emplaced along or near major premetamorphic extensional faults; foliated granitic dike in gabbroic Sugarloaf pluton (index 24) dated at 406±12 Ma (Zartman and others, 1970, table 1, Maine sample No. 8; recalculated using revised constants). (2) Hybrid tonalite of West Mountain plutons (index 27), emplaced as small semiconcordant plutons that locally contain nodules of intergrown pyrrhotite and pentlandite

Mafic and bimodal dikes (Early Devonian? and Silurian)—High-level intrusive rocks mainly within the P-F allochthon; in part coeval with volcanic rocks of the SLR (Srwv, Srpv)

DSg **Diabase and gabbro dikes, sills, and small plutons**—Includes: (1) Small body of partly altered metadiabase in Smalls Falls Formation of Piermont sequence (Srp) near Magalloway Mountain (grid 5D). (2) Several north- to northeast-trending greenstone dikes in Frontenac Formation of western rift sequence (Srw); chemically similar to iron-titanium-rich metabasalts of Frontenac Formation. (3) Sheeted dikes in Waterford, at Leighton Hill, and at Peaked Mountain (figs. 2 and 6, indexes 93, 99, 100), which are parts of dike swarms that intrude Silurian rocks of Piermont sequence (Srp) and Frontenac Formation of western rift sequence (Srw). Sheeted dikes in Waterford and at Leighton Hill, and a few isolated metadiabase dikes, also locally intrude Lower Devonian rocks northwest of the Monroe fault (MNF; White and Billings, 1951; R.H. Moench, 1992 field observation). Dikes and dike bodies composed of greenstone and hornblende-plagioclase amphibolite, with local gabbroic or dioritic pegmatite; locally contain fine-grained two-mica granite and aplite. Pegmatitic diorite from sheeted dikes at Waterford recently dated at 419.8±2.6 Ma (Tucker, *in* Rankin, 1996; R.D. Tucker, written commun., September 1996)

DSgf **Sheeted diabase, gabbro, and intrusive felsite**—Sheeted dikes at Marble Mountain (index 11). Interpreted as culmination of bimodal dike swarm of the SLRA northeast of Gore Mountain plutons (index 43). One felsic dike of swarm, dated at 418±4 Ma, considered comagmatic with felsic tuff of the same age in Frontenac Formation (Lyons and others, 1986; Moench and others, 1995, sites S-2 and M-3)

Sb **Epizonal biotite granite (Silurian)**—East Inlet pluton (index 12); tentatively includes Morse Mountain sheet (index 53A). East Inlet pluton composed mainly of weakly foliated to massive, light-gray, fine-grained granite; dated at 430±4 Ma (Eisenberg, 1982; Lyons and others, 1986). Small offshoots commonly granophyric (Green, 1968). Intrudes metabasalt of Frontenac Formation of western rift sequence (Srwv), and cut by mafic greenstone dikes having chilled contacts. Granite approximately coeval with, and considered a feeder to, metarhyolite of western rift sequence (Srwv) within the SLRA. Morse Mountain sheet composed of fine- to coarse-grained biotite granite, locally altered and intruded by metadiabase of dike swarm; intrudes country rocks of uncertain identity

Sbm **Mafic to intermediate border facies of East Inlet pluton**—Foliated quartz diorite to possible gabbro where pluton intrudes metabasalt of western rift sequence (Srwv); intruded by, and possibly intrusive into, granite of pluton. Some features suggest felsic and mafic magmas are coeval and comingled, but further studies needed

Oliverian Plutonic Suite (Silurian? and Ordovician)—Weakly to strongly foliated, semiconcordant granitic rocks that form intrusive cores of Oliverian domes along the BHA (Leo, 1985; Zartman and Leo, 1985; Lyons and others, 1996). Plutons dated in the range of 441–447 Ma (indexes 86, 87, 92, and part of 63) probably coeval with felsic volcanic rocks of Quimby Formation (of Ouv); bodies dated at about 450, 454 and 456 Ma (index 88, and parts of 63) may not have volcanic equivalents. Tentatively divided into Silurian or Ordovician (Cincinnatian) rocks, and Ordovician (Cincinnatian and Mohawkian) rocks, based on available isotopic ages relative to Ordovician-Silurian boundary as dated by Harland and others (1989) at about 441 Ma; although recently placed at about 443 Ma by Tucker and McKerrow (1995)

SOoh **Hornblende-biotite syenite, quartz syenite, quartz monzonite, and granite (Silurian or Ordovician—Cincinnatian)**—Lobate body in core of Jefferson batholith (index 63), intruded by Jurassic alkalic rocks of Cherry Mountain and Pilot-Pliny plutons (indexes 62, 55). Syenite to quartz syenite dated at 441±5 Ma (Foland and Loiselle, 1981; Rb-Sr whole-rock method); other listed rock types considered to be approximately coeval

Oou **Undivided biotite granite, biotite granodiorite to quartz diorite and trondhjemite, and hastingsite granodiorite (Ordovician—Cincinnatian and Mohawkian)**—Most abundant rock is variably foliated, pink to light-gray, fine- to coarse-grained, muscovite-bearing biotite granite; pooled U-Pb zircon data from several plutons yield age of 444±8 Ma (Zartman and Leo, 1985); maximum U-Pb zircon age of 456±3 Ma (Aleinikoff and Moench, 1987) obtained from granite at southwest end of Jefferson batholith (index 63). Biotite granite of Moody Ledge pluton (index 88) dated at 450±2 Ma (Aleinikoff, *in* Moench and others, 1995, U-Pb zircon); similar granite in eastern slice of Moody Ledge pluton (index 89) is deformed near margins of the pluton by high-temperature mylonite that yielded a U-Pb zircon age of 435±3 Ma (Aleinikoff, *in* Moench and others, 1995), which might date mylonitization or igneous crystallization. Biotite granodiorite to quartz diorite and trondhjemite exposed on north side of Jefferson batholith (index 63) dated at 454±5 Ma (Aleinikoff and Moench, 1987). Hastingsite granodiorite exposed in Landaff pluton (index 87); pink to light gray, massive to weakly foliated, fine grained; dated at 447±4 Ma (Aleinikoff, *in* Moench and others, 1995)

Highlandcroft Plutonic Suite (Silurian? and Ordovician—Cincinnatian, Mohawkian, and Whiterockian?)—Weakly to strongly foliated, discordant plutons exposed northwest of axial trace of the BHA and along the BMA. Plutons dated at about 442 and 443 Ma (indexes 2, 53) probably coeval with felsic volcanic parts of Quimby Formation (Ouv); plutons dated at about 450, 452, and tentatively at 458 Ma (indexes 35, 58, 61) may have no volcanic equivalents; pluton dated at 468 Ma (index 38) coeval with Chickwolnepy intrusions and lower part of Ammonoosuc Volcanics (Olv). Tentatively divided into Silurian or Ordovician (Cincinnatian) rocks, and Ordovician (Cincinnatian to Whiterockian) rocks, based on available isotopic ages relative to Ordovician-Silurian boundary as dated by Harland and others (1989) at about 441 Ma; although recently placed at about 443 Ma by Tucker and McKerrow (1995)

SOha **Altered aplitic granite, granodiorite, and quartz porphyry (Silurian or Ordovician—Cincinnatian)**—Catheart Mountain pluton (index 3) and Sally Mountain pluton (index 4). Catheart Mountain pluton consists of typically sheared, hydrothermally altered, light-rusty-weathering, aplitic biotite granodiorite, granite, and quartz porphyry. Host to copper-molybdenum prospect, which contains greisen dated at 441±8 Ma (K-Ar) and 447±10 Ma (Rb-Sr) by Lyons and others (1986). Sally Mountain pluton composed of similar, but more silicified, aplitic granite and quartz porphyry. Host to copper-molybdenum prospect

Ohu **Undivided biotite or hornblende granite to quartz diorite and local gabbro (Ordovician—Cincinnatian to Whiterockian?)**—Typically foliated, pink or gray, medium to coarse grained. Granite to granodiorite predominant; more mafic varieties mainly in Lost Nation pluton (index 53). Ages determined for most plutons range from 442±4 Ma (Aleinikoff, *in* Moench and others, 1995) for Lost Nation pluton to 452±4 Ma (Lyons and others, 1986) for Adamstown pluton (index 35). Cambridge Black pluton (index 38) composed of foliated, pink, medium-grained, equigranular, muscovite-bearing biotite granite; intrudes Chickwolnepy intrusions (Ocg, Oct; index 39) and Ammonoosuc Volcanics (Olv). Studies of zircons recovered from the granite yield a U-Pb concordia upper intercept age of 468±3 Ma (J.N. Aleinikoff, written commun., 1997)

Chickwolnepy intrusions (Ordovician—Whiterockian)—Metamorphosed gabbro, sheeted diabase, and tonalite (index 39). Considered coeval with lowermost metavolcanic rocks of Ammonoosuc Volcanics (Olv)

Ocg **Massive to foliated gabbro and sheeted diabase dikes**—Gabbro is variably massive to gneissic hornblende-plagioclase amphibolite, commonly with dikelets and blebs of aplitic trondhjemite; forms central part of intrusions. Diabase is fine-grained to dense amphibolite; forms typically north-northwest-trending dikes, commonly chilled against one another, and locally having subparallel dikelets of aplitic trondhjemite

Oct **Hornblende-biotite tonalite**—Gray, foliated, medium grained; variably equigranular to quartz porphyritic; youngest body (Fitz, 1996a, b) dated at 467±3 Ma (Aleinikoff, *in* Moench and others, 1995, site O-7). Tonalite of northwestern lobe (Oct? on map) contains exceptionally large quartz phenocrysts (1 cm); might be unrelated to Chickwolnepy intrusions

Ojt **Tonalite of Joslin Turn pluton (Ordovician—Whiterockian)**—Main body is lenticular pluton at Moore Reservoir (index 57), composed of granophyric tonalite and quartz diorite, locally altered; many offshoots occur northeast and southwest of the main body. Mapping indicates that all were emplaced as subhorizontal lenses at or near the lower contact of the Ammonoosuc Volcanics (Olv), which was subsequently folded. The main pluton is interpreted as the eroded edge of a west-topping laccolith. The north end of the pluton is enveloped by distal, felsic metatuff that is strongly pyritized, silicified, and locally copper-mineralized (mineral occurrences 8G-1, 1A, 1B, 2, and 3); evidence of this alteration extends downward, stratigraphically, into the underlying Dead River Formation (of O€d). Dated at 469±2 Ma (Aleinikoff, *in* Moench and others, 1995); considered coeval with lowermost part of Ammonoosuc Volcanics

STRATIFIED METAMORPHIC ROCKS

[Selected metamorphic boundaries are shown on map. Because primary sedimentary and volcanic features are typically well preserved, primary terms are emphasized in the following descriptions. The terms *basaltic greenstone* or *basaltic amphibolite* are used respectively for weakly and strongly metamorphosed volcanic and hypabyssal intrusive rocks of basaltic composition. *Metasandstone* is used as a general term for quartz- and (or) feldspar-rich, mica-poor granofels displaying sedimentary features characteristic of sandstone; *quartzite* is used for metasandstone having at least 80 percent quartz; *feldspathic quartzite* for quartz-rich metasandstone having appreciable, although subordinate, feldspar; *meta-arkose* for metasandstone having quartz-feldspar ratios of 1:1 to 2:1; *metawacke* for mica-rich metasandstone interpreted to have been originally matrix rich; and *metagraywacke* for relatively dark gray metawacke of more mafic composition. *Metashale* is used as a general term for metamorphosed shale, which varies according to metamorphic grade and structural style from *slate* and *phyllite* to *schist* and *hornfels*. Synonyms for *metashale* include *pelitic slate*, *pelitic schist*, and so forth. *Metalimestone* is used for weakly metamorphosed limestone, and *calc-silicate rock* and *marble* are used respectively for impure to pure, strongly recrystallized metamorphosed limestone]

Connecticut Valley trough (CVT)

Tectonic belt lying northwest of Foster Hill and Thrasher Peaks faults (FHF, TPF), and southeast of Guadeloupe fault (GF) (fig. 2)

Dc **Autochthonous metashale and metasandstone of cover sequence (Lower Devonian—Emsian to Gedinnian?)**—Includes unnamed metashale and metasandstone of Seboomook Group, Compton Formation, and Gile Mountain Formation (possibly except Meetinghouse Slate Member of Gile Mountain Formation, tentatively assigned to Dp). Composed mainly of gray pelitic slate or schist, variably interbedded with metasiltstone and metasandstone; commonly well graded. Early Devonian (Emsian) land plant remains recovered from Compton Formation in Quebec (Hueber and others, 1990), but lower beds of sequence are unfossiliferous. Contact with underlying parallochthonous rocks of Ironbound Mountain Formation (Dp) is gradational. Correlated, along with underlying Lower Devonian parallochthonous rocks (Dp), with Lower Devonian cover sequence of the BHBMA and the CMT. As much as 2 km thick

Dcv **Metavolcanic-bearing facies**—Mixed metasedimentary and bimodal metavolcanic rocks of Gile Mountain Formation (grids 8F, 8G). Characteristic metasedimentary rocks of formation interstratified with basaltic amphibolite and minor amounts of felsic gneiss; interpreted as felsic metavolcanic rock

Dp **Parallochthonous metashale and local volcaniclastic metawacke (Lower Devonian—Gedinnian?)**—Includes Ironbound Mountain Formation of Seboomook Group and, where queried, tentatively includes Meetinghouse Slate Member of Gile Mountain Formation. Delineation in Quebec uncertain, based in part on mapping cited by Tremblay and Pinet (1994). Typically massive to faintly bedded, dark-gray pelitic slate or schist, in places cyclically interbedded with lighter gray, graded metasiltstone; locally contains lenses of coarse-grained volcaniclastic metawacke (particularly abundant in northwestern Maine), and locally contains metavolcanic rocks (Dpv) and microgranite intrusions and domes (Dpid). Conformably underlain by rocks of western rift sequence (Srw), and conformably to probably unconformably underlain by Piermont sequence (Srp). Correlated with Carrabassett Formation, the basal unit of the Lower Devonian cover sequence of the CMT (Dc). Interpreted to have accumulated over rocks of the P-F allochthon while in transit. Maximum thickness about 900 m

Dpv **Metavolcanic facies**—Narrow belts between Deer Pond and Thrasher Peaks faults (DPF, TPF) in grids 4D to 6E, and in the TMO of the P-F allochthon, straddling grids 7G and 8G; also small queried body in grid 8G (in Meetinghouse Slate Member of Gile Mountain Formation), northwest of Monroe fault (MNF). Layer straddling grids 4D and 5D composed of weakly metamorphosed felsic tuff breccia, pillow basalt and basaltic conglomerate, and interbedded felsic tuff, iron-formation, and sedimentary rocks. Host to probable volcanogenic sulfide deposits at Thrasher Peaks (mineral occurrence 5D-3), probably dismembered by deformation adjacent to the TPF. Lens extending from grid 5D to grid 6E composed of weakly to strongly metamorphosed, massively bedded, coarse-grained rhyolitic crystal tuff and volcaniclastic wacke, variably interbedded fine-grained felsic tuff and gray pelitic phyllite, pillowed andesitic flows and intrusions, and interbedded felsic tuff and black sulfidic phyllite. Lens straddling grids 7G and 8G composed of complexly interstratified gray pelitic slate, feldspar-spotted metawacke, felsic crystal metatuff, dacitic(?) lapilli metatuff, and quartz-phenocrystic rhyolite metatuff. Evidence of weak copper mineralization near prospect southwest of Dalton (mineral occurrence 7G-2). Body northwest of the MNF in grid 8G composed of metamorphosed interlayered gray pelitic slate and coarse-grained felsic volcanics or dikes, and a west-younging sequence, exposed in an abandoned quarry, of probably three, strongly vesicular andesitic(?) flows

Dpid **Metamorphosed microgranite intrusions and domes**—Thrasher Peaks plutons (index 10). Light gray, massive, fine grained to aphanitic, equigranular; commonly has blotches and spherules of tourmaline, and ragged to euhedral muscovite. Forms many small lenticular bodies. Interpreted by Richard A. Cavalero (Boise Cascade Corp., unpub. data, 1987) as rhyolite domes related to felsic volcanic rocks assigned by Moench and others (1995) to Ironbound Mountain Formation (Dpv); dated at about 414 Ma (Eisenberg, 1982, p. 42, table 3; one zircon size fraction analyzed)

Metasedimentary and metavolcanic rocks within and tentatively within the Second Lake rift (Silurian, Silurian?, and Ordovician—Cincinnatian)—Sequences of the P-F allochthon, and related parautochthonous to autochthonous rocks of the CVT. Divided into western rift sequence (Srw, Srwc, Srwv) and lower (SOp) and upper (Srp, Srpv) formations of the Piermont sequence. Only the Piermont sequence may be truly allochthonous, as discussed in the section entitled "Late Ordovician and Silurian sedimentation and magmatism related to synconvergent extension—Connecticut Valley trough." Whether or not the allochthon exists as it is shown and interpreted in this report is controversial; for discussions see Billings (1992), Moench (1992), Rankin (1995, 1996), and Moench (1995, 1996a)

Western rift sequence (Silurian and Silurian?)—Frontenac Formation (Silurian) and, tentatively, Waits River Formation (Silurian) and Ayers Cliff Formation [shown as Silurian and Lower Devonian(?) by St. Julien and Slivitsky (1987), but for convenience shown as Silurian? on this map]. Interpreted to have accumulated in a basin of extensional origin (Marvinney and others, 1994; Moench and others, 1992; Moench, 1990, and references therein) on the basis of associated dike swarms and sheeted dike bodies (DSg, DSgf), chemistry of metabasalt and metadiabase, and restored ancestral structure of the SLRA (see Srwv description). Maximum thickness unknown; probably greater than 1 km

Srw **Predominantly siliciclastic turbidites (Silurian)**—Metasedimentary facies of Frontenac Formation. Mainly weakly metamorphosed, gray to greenish-gray pelitic slate or schist interbedded in various proportions with poorly graded to well-graded lithic metawacke; locally mildly calcareous; tends to be green where sheared, particularly near mapped faults. Metawacke beds typically pervasively cleaved, owing to originally abundant intergrain matrix and labile rock fragments. Locally interstratified with pillowed basaltic greenstone (Srwv). In grids 4C and 5C, conformably underlain by, and laterally gradational eastward into, main bimodal volcanic belt of Frontenac Formation (Srwv). In grids 7F and 8G, gradationally underlain by basal strata of Perry Mountain Formation of Piermont sequence (Srp), and laterally gradational eastward into Perry Mountain, Smalls Falls, and Madrid(?) Formations of Piermont sequence; here, locally contains thin lenses of black sulfidic schist interpreted as western feather edge of Smalls Falls Formation. Maximum thickness unknown, possibly more than 1 km

Srwc **Predominantly calcareous metasedimentary rocks (Silurian and Silurian?)**—Includes calcareous member of Frontenac Formation and, tentatively, Waits River Formation (in grid 8F) and Ayers Cliff Formation (in grid 8D); tentatively included within the SLR. Calcareous member of Frontenac Formation and Waits River Formation composed of variably metamorphosed, gray, fine-grained quartzose marble and calc-silicate rock interbedded with impure quartzite and gray to black, commonly graphitic phyllite. Ayers Cliff Formation composed of calcareous slate, metasiltstone, and argillaceous to silty metalimestone. Thicknesses unknown; lower contacts not exposed

Srwv **Metavolcanic and mixed metasedimentary and metavolcanic facies (Silurian)**—Includes volcanic-bearing part of Frontenac Formation of SLR and SLRA, as defined herein, and volcanic-bearing part of Waits River Formation, tentatively of SLR. In Quebec, mainly exposed southeast of the Victoria River fault (VRF), but locally mapped northwest of the VRF (Tremblay and Pinet, 1994).

Waits River Formation component includes basaltic amphibolite and sparse felsic gneiss interbedded with calcareous metasedimentary rocks (Srwc). Tentatively correlated with the Silurian Standing Pond Volcanics of southeastern Vermont (Aleinikoff and Karabinos, 1990), having chemical characteristics of basalt erupted in regions undergoing tectonic extension (Hepburn, 1991).

Frontenac Formation component includes:

(1) Proximal bimodal metavolcanic rocks from Spider Lake pluton (index 7) to Second Connecticut Lake (grid 5D), along the former Second Lake anticline (Harwood, 1969), which is here interpreted as the SLRA. [See description of SLRA in "Late Ordovician and Silurian sedimentation and magmatism related to synconvergent extension—Connecticut Valley trough (CVT)"]. Composed of thick sequences of pillowed and pyroclastic

greenstone overlain by thickly stratified rhyolitic ash- to lapilli-metatuff, fragmental metarhyolite; complexly interlayered metabasalt and metarhyolite, and local iron-formation and related chemical deposits. From Moose Bog northeast to the international border (grid 5C), conformably overlain by black sulfidic phyllite assigned to Smalls Falls Formation (of Srp). Total thickness at least 1,750 m.

(2) Relatively distal metavolcanic and associated metasedimentary rocks exposed along the SLRA from Second Connecticut Lake southwest to Gore Mountain plutons (index 43). Composed of basaltic amphibolite flows and pyroclastic rocks, fine-grained felsic schist interpreted as distal tuff, and metasedimentary rocks. Assemblage is overlain by an inferred synclinal lens of black sulfidic schist assigned to Smalls Falls Formation (of Srp), and underlain by schist and quartzite mapped as Perry Mountain and Rangeley Formations of Piermont sequence (of Srp).

(3) Layers of pillowed flows and pyroclastic basaltic greenstone in grids 1A to 3B, and west of the SLRA in grids 4B to 6E, within siliciclastic turbidites (Srw) of Frontenac Formation

Piermont sequence (Silurian, Silurian?, and Ordovician—Cincinnatian)—Six formations (two mapped in SOp, and four overlying units mapped in Srp) whose type localities are near Rangeley, Maine (grid 3E; Moench and Boudette, 1987, and references therein), on the opposite side of the BHBMA. Units SOp and Srp have a total thickness of 1–2 km

Srp **Upper formations (Silurian and Silurian?)**—Rangeley Formation (Llandoverian), Perry Mountain Formation (Ludlovian? and Wenlockian?), Smalls Falls Formation (Ludlovian), and Madrid Formation (Pridolian? and Ludlovian?).

Rangeley Formation composed mainly of rusty-weathering, gray to black phyllite, sharply interbedded with variably rusty weathering, somewhat feldspathic quartzite. Polymictic pebble to cobble metaconglomerate is exposed as thin lenses just above lower contact near Piermont, N.H., south of map area (Moench, 1990, fig. 2; 1996); correlated with metaconglomerate of members A or B of Rangeley Formation near Rangeley, Maine (Moench and Boudette, 1987). Near upper contact, interbedded quartz-rich granule or pebble metaconglomerate, quartzite, and pelitic schist (correlated with lower part of member C of Rangeley Formation near Rangeley, Maine) is exposed on east side of Deer Mountain (grid 5F), on Badger Mountain (in west-central grid 8G), and near Piermont, N.H., and Bradford, Vt. (in grid 9I). Near Bradford, the quartz metaconglomerate becomes increasingly rich in metarhyolite clasts toward the overlying Perry Mountain Formation. No more than about 500 m thick in the allochthon, in contrast with a maximum thickness of 3 km in the CMT.

Perry Mountain Formation of the CVT is more diverse than its counterpart in the CMT. In both areas the formation is composed mainly of interbedded variably feldspathic quartzite and nongraphitic slate or schist, locally rusty weathering. Whereas Perry Mountain of the CMT contains mainly planar-bedded turbidites and only sparse metavolcanic rocks (known only in grid 3D), in the CVT divisible into two, more proximal facies: (1) interbedded metashale and planar- and lenticular-bedded feldspathic quartzite; (2) metavolcanic and mixed metasedimentary and metavolcanic rocks (in Srpv). Whereas planar-bedded quartzites are turbidites, commonly having Bouma features, lenticular-bedded quartzites commonly channel into underlying rocks, and locally contain rip-ups derived from underlying metashale. In grid 7F, all but lower part of formation grades westward into Frontenac Formation (Srw). Lower contact typically abruptly gradational. Thickness varies from 300 m to possibly as much as 1,000 m.

Smalls Falls Formation typically composed of rust-encrusted, black to coaly-black, graphitic, pyrrhotitic phyllite sharply interbedded with sparse to abundant sulfidic quartzite; however, locally no more euxinic than Rangeley Formation, from which it is distinguished by position above, rather than below, Perry Mountain Formation. Volcanic-bearing facies included in unit Srpv. Contact with underlying Perry Mountain Formation, or Frontenac Formation (Srwv) in grids 4C and 6E, sharp and conformable. As thick as 800 m where volcanic rocks abundant, but thins westward to feather edge. Northernmost known Smalls Falls (of Srp) occurs in faulted syncline along crest of SLRA in Quebec (Cousineau, 1995).

Madrid Formation composed of brownish-weathering, typically weakly calcareous, laminated to thinly bedded feldspathic metasandstone, phyllitic metasiltstone, local impure marble, and local thin to thick beds of fine-grained, well-sorted quartz metasandstone. Locally contains strongly calcareous metasandstone; thin beds of impure metalimestone or calc-silicate rock; and metavolcanic rocks (in Srpv). Contact with underlying Smalls Falls Formation sharp and conformable; contact with overlying Ironbound Mountain Formation (Dp) variably conformable to possibly unconformable. Forms discontinuous lenses having maximum thicknesses of 60 m, but more commonly about 3 or 4 m

Srpv **Metavolcanic and mixed metasedimentary and metavolcanic facies**—Metavolcanic rocks of Rangeley, Perry Mountain, Smalls Falls, and Madrid Formations. Interpreted as products of small volcanic centers distributed along the subdued southern continuation of the SLRA, from the Gore Mountain plutons (index 43) to Gardner Mountain (grid 8G), and in a belt extending east of the SLRA from Magalloway Mountain (grid 5D) to near Pontook Reservoir, N.H. (grids 5F, 6F).

Metavolcanic rocks of Rangeley Formation occur within otherwise characteristic dark-gray slate or schist and feldspathic quartzite of formation. Composed of thin to very thick (several meters) beds of felsic ash or feldspar-crystal metatuff, and smaller amounts of basaltic or andesitic metatuff. Hosts massive-sulfide deposit at Paddock mine (8G-9). Metarhyolite-rich debris-flow beds as much as 3 m thick occur near the upper contact of the formation near Bradford, Vt. (in grid 9I).

Metavolcanic rocks of Perry Mountain Formation interstratified with characteristic metasedimentary rocks of formation. Occur mainly near the upper contact, as thin to thick graded beds of white-weathering, feldspathic ash and crystal metatuff, sparse felsic lapilli metatuff (maximum clast size about 7 mm), and sparse stratified basaltic metatuff.

Metavolcanic member of Smalls Falls Formation most abundantly exposed in a north-trending belt about 10 km west of Errol, N.H. (grids 5E, 6E); composed of basaltic amphibolite, some pillowed, associated with abundant metachert and siliceous iron-formation, minor felsic metatuff, local felsic lapilli metatuff, and sparse intrusive felsite. About 3.7 km east-northeast of West Milan (grid 6F), polymictic plutonic-volcanic metaconglomerate is interstratified with cherty magnetite iron-formation and basaltic amphibolite is exposed in the basal 100 m of volcanic member. Near Magalloway Mountain (grid 5D), contains lenses of pillowed basaltic greenstone and felsic metatuff. At best exposures of metavolcanic rocks south of Gore Mountain plutons (index 43), coaly black sulfidic metasedimentary rocks of formation are interbedded with felsic metatuff, felsite, agglomerate, and thinly bedded metachert (on ridge between Stratford Bog Pond and Connary Brook, grid 7F), and well-stratified felsic metatuff, metatrachyte, metarhyolite, and sugary, gossan-pocked metachert (on west side of Badger Mountain, west-central part of grid 8G).

Metavolcanic rocks of Madrid Formation are basaltic greenstone, felsite, and calcareous felsic crystal metatuff

SOp **Lower formations (Silurian? (Llandoverian?) and Ordovician (Cincinnatian))**—Quimby (Cincinnatian) and Greenvale Cove (Llandoverian?) Formations; exposed southwest of map area (see fig. 6). Quimby Formation composed of black sulfidic schist and metagraywacke; mapped body (Moench, 1990, fig. 2; 1996, fig. 3) is a remnant that represents uppermost few tens of meters of formation. Conformably overlain by Greenvale Cove Formation, which is composed of nonsulfidic, laminated, mildly calcareous metasiltstone and metasandstone, metamorphosed to garnet-bearing feldspathic two-mica schist, granofels, and calc-silicate rock; about 200 m thick. Greenvale Cove Formation sharply overlain by basal polymicitic metaconglomerate of Rangeley Formation, or, where metaconglomerate absent, by rusty-weathering schist and feldspathic quartzite of Rangeley

Bronson Hill–Boundary Mountains anticlinorium (BHBMA)

Tectonic belt lying mainly southeast of the Foster Hill and Thrasher Peaks faults (FHF, TPF), and mainly northwest of the STH (figs. 2, 6). Exceptions are where Ordovician or older rocks of the BHBMA are exposed in the Coppermine Road window through the P-F allochthon (grids 8G and 9G), and where Silurian deposits of the CMT overlap southeast side of the BHBMA (grids 3d and 3E)

Dcs **Shoal-facies metasandstone, metaconglomerate, and subaerial metavolcanic rocks of cover sequence (Lower Devonian—Emsian)**—Tomhegan Formation (grids 1B, 1C), and metasandstone and metaconglomerate at Dalton Mountain (grid 7G). Represents shoaling that immediately preceded onset of Acadian compression; age and shoaling environment indicated by faunal data of Boucot and Heath (1969) and Boucot and Arndt (1960).

Tomhegan Formation composed of weakly metamorphosed, shallow-water tuffaceous sandstone, siltstone, and shale, and associated subaerial volcanic rocks mapped separately as unit Dcsv. Lower contact a disconformity. Maximum thickness about 1,800 m east of map area.

Rocks at Dalton Mountain include two lenses of weakly metamorphosed, poorly sorted, quartz-rich polymictic pebble to cobble conglomerate and slaty sandstone. Contains rounded to subangular clasts of quartzite, vein quartz, black chert, amphibolite, felsite, gray slate, and coarse-grained feldspar. Lower contact an unconformity; conformably overlain by gray slate of Littleton Formation (Dc). Maximum thickness about 50 m

Dcsv **Subaerial metavolcanic member**—Kineo Volcanic Member of Tomhegan Formation. Weakly metamorphosed rhyolitic ash-flow tuff, flows, domes, volcanic breccia, grit, and conglomerate, and associated garnet-bearing intrusive rhyolite, the largest bodies of which are mapped separately as unit Dcsi. Represents Grannys Cap and Cold Stream volcanic centers of Piscataquis volcanic belt of Rankin (1968, fig. 27-1). Maximum thickness about 1,200 m

Dcsi **Intrusive garnet metarhyolite**—Several small bodies of weakly metamorphosed, massive, greenish-white-weathering rhyolite containing scattered phenocrysts of garnet and feldspar in matrix of fine-grained, locally spherulitic or flow-banded rhyolite. Forms discordant intrusions and possible domes

Dc **Metashale and metasandstone of cover sequence (Lower Devonian)**—Unnamed metashale and metasandstone of Seboomook Group (Emsian to upper Gedinnian?), Littleton Formation (Emsian to Gedinnian?), and Tarratine Formation (upper Siegenian). Predominantly a variably metamorphosed, upward-coarsening siliciclastic sequence of mud-silt and mud-silt-sand turbidites, and rocks of local volcanic centers that are mapped separately (Dcv). Siliciclastic deposits probably derived mainly from T3 (fig. 1), which emerged in earliest Devonian time (Gates and Moench, 1981), but with local contributions from islands in the BHBMA. Lower contact variably conformable to unconformable. Total thickness possibly as much as 3,000 m

Dcv **Metavolcanic members**—Includes parts of Littleton Formation in grids 8G and 8H, and greenstone of Seboomook Group at Camera Hill in grid 2C. Littleton Formation component present at a low stratigraphic level and composed of interbedded gray pelitic schist, felsic crystal- and lithic-metatuff, metatuff breccia, basaltic greenstone or amphibolite (locally pillowed), and volcaniclastic metagraywacke; maximum thickness about 250 m. Seboomook Group component consists of lenticular bodies of porphyritic flows of probable intermediate composition containing feldspar phenocrysts; maximum thickness about 120 m

Near-shore deposits (Lower Devonian and Silurian)—Thin, commonly fossiliferous, shelf to shoreline sedimentary and local volcanic rocks. Silurian deposits considered to represent eastern side of a landmass that was source of most of the Silurian sediments of the CMT; main body of landmass tentatively interpreted to have been faulted away by pre-Devonian movements along Foster Hill and Thrasher Peaks faults (FHF, TPF). Lower Devonian deposits accumulated around islands that remained during the submergence that preceded late Early Devonian shoaling (deposits of Dcs) and emergence

Dns **Lower Devonian (upper Siegenian and upper Gedinnian) deposits**—Includes Parker Bog Formation and Beck Pond Limestone (both upper Gedinnian) and Hobbstown Formation and McKenney Ponds Limestone Member of Tarratine Formation (both upper Siegenian) in grids 1C and 2C. Composed variably of weakly metamorphosed limestone, conglomerate, arkose, quartzose sandstone, finer grained sedimentary rocks, and sparse volcanic rocks; typically fossiliferous. Lower contacts unconformable. Typically less than 200 m thick

DSns **Lower Devonian (Gedinnian?) or Silurian (Pridolian?) deposits**—Red slate and felsic metatuff near Arnold River (grids 4C, 4D), about 10–30 m thick, and conglomeratic metasandstone near Crocker Pond (grid 2B), about 100 m thick. Both conformably underlain by Silurian calcareous near-shore deposits (Sns)

Sns **Silurian (Pridolian to upper Llandoverian) deposits**—Includes Clough Quartzite (mainly grids 8G, 8H; upper Llandoverian), impure metalimestone at Flagstaff Mountain (grids 2C, 2D; lower Wenlockian? and upper Llandoverian), Hardwood Mountain Formation (grid 2C; Ludlovian? and Wenlockian), metaconglomerate at Wood Pond (grid 2B; Pridolian or Ludlovian), metalimestone and slate at Little Big Wood Pond (grid 2B; Pridolian and Ludlovian?), Fitch Formation (mainly grids 8G, 8H; Pridolian and upper Ludlovian), and The Forks Formation (grids 1C, 1D; Pridolian? and Ludlovian?); also includes undated, unnamed argillite, quartzite, and tuff near Parmachenee Lake (grids 4D, 5D) that lies below probable Clough Quartzite. Most prominent units in the BHA are (1) quartz conglomeratic Clough Quartzite, considered the on-shore equivalent of quartz metaconglomerate in upper part of Rangeley Formation of the CMT and CVT and (2) the calcareous Fitch Formation, interpreted to be shelf facies of Madrid Formation of the CMT and CVT. Lower contacts are disconformities or unconformities. Units typically less than 100 m thick

Euxinic metasedimentary and metavolcanic rocks of Bronson Hill arc (Ordovician—Cincinnatian to Whiterockian)—Divided into a lower sequence (Olv, Ole, Olve) composed of Ammonoosuc Volcanics and black slate or schist and metagraywacke of Partridge Formation (both Mohawkian and late Whiterockian), and an upper sequence (Ouv, Oue) composed of metavolcanic rocks and black slate or schist and metagraywacke of Quimby Formation (Cincinnatian), and rocks tentatively correlated with the Lobster Mountain Volcanics (late Cincinnatian). Felsic metatuff beds within Ammonoosuc Volcanics dated at 461±8 (Aleinikoff, *in* Moench and others, 1995), but lowermost beds of Ammonoosuc probably coeval with the high-level Joslin Turn pluton and Chickwolnepy intrusions, dated at

469±2 and 467±3 Ma respectively (Aleinikoff, *in* Moench and others, 1995). Partridge Formation dated by *Climacograptus bicornis* zone graptolites found northeast of Oquossoc (Harwood and Berry, 1967), equivalent to a middle Mohawkian (or early Caradocian) age of about 458 Ma (Ross and others, 1982; Tucker and Mckerrow, 1995). The graptolites occur in black slate exposed about 360 m southeast of the upper contact of the Ammonoosuc; because bedding dips about 70° SE. near the locality (Harwood, 1973, section D–D'), the fossils probably occur about 340 m stratigraphically above the upper contact of the Ammonoosuc.

Feslic metavolcanic rocks at the base of the Quimby Formation have yielded a late Cincinnatian (Ashgillian) U-Pb zircon age of 444±4 Ma (Aleinikoff, *in* Moench and others, 1995), which is consistent with the Late Ordovician age of fauna obtained from the Lobster Mountain Volcanics (Neuman, 1973). Mapping, faunal data, and isotopic age data therefore consistently support a Middle Ordovician age of 460–470 Ma for Ammonoosuc volcanism, and a Late Ordovician age of 440–450 Ma for Quimby and Lobster Mountain volcanism

Upper sequence (Ordovician—Cincinnatian)—Quimby Formation and Lobster Mountain Volcanics(?)

Oue **Euxinic metashale and metagraywacke**—Metasedimentary members of Quimby Formation exposed near Rangeley, Maine (grid 3E), south of Umbagog pluton (index 36), and southwest of Littleton, N.H. (grids 8G, 8H). Near Rangeley, divided into a lower metagraywacke member, about 300 m thick, and an upper interbedded euxinic metashale and metagraywacke member, about 700 m thick; lower member grades downward to Partridge Formation (Ole).

South of Umbagog pluton, composed of black schist and metagraywacke, as much as 800 m thick, but locally thinned, possibly tectonically, to about 100 m; conformably underlain by an 8-m-thick layer of interlaminated marble, calc-silicate rock, and quartzite (not shown on map) that is unconformably underlain by Ammonoosuc Volcanics (Olv); calc-silicate rocks locally contain sparse scheelite.

Southwest of Littleton, interbedded black schist and metagraywacke of member occur in narrow lenses along the trough lines of two late Taconian synclines exposed on opposite sides of the Triassic Ammonoosuc fault (AF) (see fig. 6); inferred to be faulted remnants of the same syncline. In both areas, rocks of unit are conformably underlain by felsic and mafic metavoclanic rocks of the Quimby Formation (Ouv)

Ouv **Felsic and mafic metavolcanic rocks**—Small bodies in Quimby Formation west of Rangeley, Maine (grids 3E, 4D), and extensive layers in lower part of Quimby Formation southwest of Littleton, N.H. (grids 8G, 8H); includes rocks exposed at Johns Pond and Grace Pond (grid 1C) and north of Baker Pond (grid 2C), tentatively correlated with the Lobster Mountain Volcanics(?), the type locality of which is east of map area (Boucot and Heath, 1969, p. 56).

Near Rangeley, composed of weakly metamorphosed, chalky weathering, thickly bedded felsic tuff, massive to flow-laminated sodarhyolite flows, and intrusive felsite. Grades laterally to metagraywacke member of Quimby Formation. Probable thickness about 200 m.

Southwest of Littleton unit forms lower part of Quimby Formation in two synclines exposed on opposite sides of Ammonoosuc Fault (AF); as much as 1 km thick. East of the AF, composed of variably metamorphosed (1) massively bedded felsic ash- and lapilli-tuff, and graded, thickly to thinly bedded felsic metatuff, (2) graded, matrix-supported, felsic, conglomeratic or agglomeratic pyroclastic flow deposits, (3) basalt, some as graded tuff beds, and (4) thinly bedded felsic tuff and slaty, tuffaceous siltstone. On southeast limb of syncline, gradationally underlain by Partridge Formation. On northwest limb, probably disconformably to unconformably underlain by the Partridge; at Bath, N.H., the very thick basal metatuff bed, dated at 444±4 Ma (cited above), contains rip-up slivers of black slate and metasiltstone derived from the underlying Partridge Formation.

West of the AF, composed of greenschist-facies rocks similar to more strongly metamorphosed rocks exposed in syncline east of AF, but with more abundant metabasalt. The metabasalt, now very dark greenish gray calcitic greenstone, is mainly stratified pyroclastic tuff that commonly contains graded beds composed of plagioclase crystals supported by chloritic matrix; meter-thick layers of massive and pillowed flows occur locally. Lower contact an unconformity that truncates across the Partridge Formation and Ammonoosuc Volcanics (of Olve) and into the Dead River Formation (of O€f). Unconformity commonly marked by volcanic-plutonic metaconglomerate that contains rip-ups derived from the underlying Partridge Formation.

On both sides of the AF, rocks of unit show little or no evidence of premetamorphic hydrothermal alteration or mineralization.

Metavolcanic and metasedimentary rocks of Lobster Mountain Volcanics(?) are exposed in three small areas in grids 1B and 2B. At Johns Pond, composed of weakly metamorphosed, tan- to brown-weathering, graded and cross-laminated beds of volcaniclastic siltstone and sandstone, and andesite(?) tuff, breccia, and sparse conglomerate. At Grace Pond, composed mainly of massive porphyry. North of Baker Pond, composed of poorly bedded feldspathic metatuff. Lower contacts not exposed. Possibly an eruptive facies of Attean pluton (index 2), dated at 443±4 Ma (Lyons and others, 1986). Thicknesses of Lobster Mountain(?) bodies unknown

Lower sequence (Ordovician—Mohawkian and Whiterockian)

Ole **Euxinic metasedimentary rocks**—Partridge Formation, exposed (1) near Oquossoc, Maine (grids 3D, 4D, 3E, 4E), (2) in small area west of Baldpate Mountain, Maine (grid 4F), (3) and extensively southwest of Littleton, N.H. (grids 8G, GH), where combined with Ammonoosuc Volcanics (Olve). Composed mainly of rusty-weathering, black, sulfidic slate or schist, interbedded with sparse to abundant metagraywacke. Near Oquossoc, also contains sparse, weakly metamorphosed polymictic conglomerate and basaltic greenstone; maximum thickness 1,800 m, but lower part intertongues with basaltic greenstone of Ammonoosuc Volcanics (Olv). West of Baldpate Mountain, probably <200 m thick; intertongues with basaltic flows and metasedimentary rocks of lower part of Ammonoosuc Volcanics

Olv **Bimodal metavolcanic and related metasedimentary rocks**—Ammonoosuc Volcanics, exposed: (1) near Oquossoc, Maine (grids 3D, 4D, 3E, 4E); (2) between Umbagog pluton (index 36) and Jefferson batholith (index 63); (3) in an arcuate belt, crossing Franconia, N.H. (grid 8H), intruded by four plutons of Oliverian Plutonic Suite (indexes 92, 88, 87, 86); (4) in unstudied lenses along margins of Jefferson batholith; (5) in the CuRW, on opposite sides of the Connecticut River, Vt. and N.H. (grids 8G, 9G); (6) north and south of Moore Reservoir (grid 8G), where intruded by the Joslin Turn pluton (index 57) and related bodies; and (7) south of Moore Reservoir (grids 8G, 8H), where combined with Partridge Formation (Olve). Exposed contacts with underlying flysch sequence (O€f) and overlying Partridge Formation (Ole) conformable, and with overlying Quimby Formation (of Oue, Ouv) unconformable.

Near Oquossoc, composed of massive and pillowed basaltic greenstone flows and local meta-agglomerate that intertongues with lower part of Partridge Formation. Maximum thickness about 1,500 m.

Between Umbagog pluton and Jefferson batholith divided into a lower basaltic and metasedimentary member, and an upper member containing a proximal bimodal metavolcanic facies and a volcaniclastic metagraywacke facies. Local magnetite, pyrite, and silicate iron-formation, and common evidence of intense premetamorphic alteration in both members. Small (0.5 million tons) Kuroko-type volcanogenic massive-sulfide deposit mined at Milan mine (mineral occurrence 6F-1), just above the basaltic to bimodal transition, and Besshi-type copper deposit prospected at Hampshire Hills (mineral occurrence 5F-1). Maximum thickness possibly 1–2 km.

Belt crossing Franconia, N.H., underlain by mixed assemblage of strongly metamorphosed basaltic flows and local agglomerate, thickly stratified felsic metatuff and agglomeratic pyroclastic flow deposits, interbedded mafic and felsic volcanic rocks, volcaniclastic metagraywacke, and local black schist similar to parts of Partridge Formation. Evidence of premetamorphic alteration common; magnetite iron-formation mined for iron in the past at the Franconia iron mine (mineral occurrence 8H-2); small (0.1 million tons) volcanogenic massive-sulfide deposit mined south of map area (fig. 6) at Warren mine (mineral occurrence 8I-2). Thickness unknown; probably at least 1 km.

In the CuRW, composed of weakly metamorphosed, massively bedded, felsic to intermediate(?) ash- and lapilli-metatuff, poorly stratified, fine-grained ash metatuff (commonly containing scattered quartz phenocrysts), and richly pyritic quartz-sericite schist, interpreted as hydrothermally altered felsic metatuff. Thickness unknown.

North of Moore Reservoir, composed of poorly stratified, fine-grained felsic ash tuff [commonly containing scattered tiny (1 mm) quartz phenocrysts], pyritic quartz-sericite schist like that of the CuRW, and subordinate slaty volcanic metasiltstone. Evidence of sea-floor mineralization and premetamorphic hydrothermal alteration shown by mineral occurrences (map D) represented by the Essex copper prospects (8G-1), by locally chalcopyrite-bearing, pyritic quartz-sericite schist (8G-2A, 2B), and by pyritic iron-formation (8G-3). Interpreted as variably altered, and locally mineralized, distal volcanic facies, relative to Ammonoosuc Volcanics exposed farther south (in Olve). Joslin Turn pluton (index 57) and related offshoots considered coeval with associated metatuff, and interpreted as heat sources for hydrothermal systems and sea-floor mineralization

Olve **Bimodal metavolcanic and euxinic metasedimentary rocks, undivided**—Ammonoosuc Volcanics and conformably overlying Partridge Formation south of Moore Reservoir (grids 8G, 8H). Exposed in two structural belts separated by Ammonoosuc fault (AF); metamorphosed to greenschist facies west of fault, amphibolite facies east of fault.

Ammonoosuc Volcanics portion divided into a metabasaltic to locally meta-andesitic facies (with some pillowed basaltic greenstone or amphibolite), a thinly bedded metasedimentary and metabasaltic facies (with common felsite and local iron-formation), a proximal bimodal metavolcanic facies (with common meta-agglomerate and fragmental metarhyolite), and a massively bedded felsic volcanic facies. Contains metadiabase not easily distinguished from metabasalt, and locally abundant small intrusions of trondhjemitic quartz porphyry near upper contact. Evidence of sea-floor mineralization locally seen just below or at contact with overlying Partridge Formation (mineral occurrences 8H-3, 8H-14(?), 8H-18). Total thickness possibly more than 1 km, but near Lisbon and Bath, N.H., almost entirely removed by displacements along premetamorphic Foster Hill fault (FHF).

Partridge Formation component composed mainly of black, sulfidic, pelitic schist or slate, locally interbedded with graded metagraywacke. Commonly has thin beds of white metachert and laminated, anthophyllite-bearing metasedimentary rocks near lower contact. Forms an extensive layer <200 m thick, conformably to unconformably overlain by metavolcanic rocks of Quimby Formation (Ouv); completely eroded below the Quimby west of Partridge Lake (grid 8G)

O€f **Flysch sequence (Ordovician (lower Whiterockian) to Upper Cambrian?)**—Aziscohos and Dead River Formations. Aziscohos Formation exposed in area of Aziscohos Lake, Maine (grid 5D), and along the Maine–New Hampshire border southwest to near Errol, N.H. (grids 5D, 5E); divided into a lower dark-gray to black sulfidic shale member, commonly containing laminations of manganiferous metachert, and an upper greenish-gray shale member; intertongues with lower part of Dead River Formation, and may be considered a pelitic facies of the Dead River. Dead River Formation, discontinuously exposed from Pierce Pond (grid 1C) southwest across Moore Reservoir (grid 8G); composed mainly of thinly interbedded, greenish-gray slate or schist and graded metasandstone or metasiltstone, but with gray, red, and black sulfidic facies, and metasandstone-rich or metashale-rich facies. Conformably underlain by melange of Hurricane Mountain Formation (€e), and conformably overlain by Ammonoosuc Volcanics (Olv). Interpreted as turbidite flysch deposited when the melange became inactive in early Paleozoic time. About 700 m thick at type locality in grid 1D (Boone, 1973), but upper part eroded; as much as 2 km thick farther southwest, where conformably overlain by Ammonoosuc Volcanics or Partridge Formation

€e **Euxinic melange (Cambrian?)**—Hurricane Mountain Formation, exposed in vicinity of West Forks, Maine (grid 1C), extending westward to north side of Diamond Ridge, N.H. (grid 5D), where truncated by the Thrasher Peaks fault (TPF). Dated using primitive sponges (Harwood, 1973, p. 23, locality O-3) for which R.M. Finks (oral commun., 1982) prefers a Cambrian age, although he does not rule out an Ordovician age. Typically weakly metamorphosed, rusty weathering, sparsely sulfidic siltstone characterized by scaly cleavage and abundant phacoidal lenses of fine-grained feldspathic quartzite and possible felsic metatuff. Poorly bedded except in upper part, which also has pebbly to bouldery pelitic phyllite (metamudstone) with clasts of metamorphosed quartzite and other sedimentary rocks, volcanic rocks, granite, and mafic and ultramafic plutonic rocks. Locally contains raftlike bodies of quartzite, metavolcanic rocks, and ultramafic rocks that are mappable at scale of 1:62,500. Contact with underlying Jim Pond Formation typically sheared, and parts of Jim Pond (€ov) commonly incorporated within melange. See Boone and others (1989) for more detailed description. Interpreted to have formed in an oceanic trench during early Paleozoic subduction. About 900–1,200 m thick

Ophiolite (Cambrian?)—Rock sequence, extending from West Forks, Maine (grid 1C) to Rump Pond (grid 5D), divided into the stratiform plutonic Boil Mountain Complex (€op) (index 17) and the overlying bimodal volcanic and volcaniclastic rocks of the Jim Pond Formation (€ov, €ow). Tonalite of Boil Mountain Complex and dacite of Jim Pond Formation tentatively dated at about 520 Ma (Eisenberg, 1981, 1982; Aleinikoff, *in* Moench and others, 1995). As described by Boudette (1982) and Coish and Rogers (1987), sequence is much thinner than, contains more abundant felsic volcanic rocks than, and lacks sheeted dikes characteristic of typical mid-ocean ridge ophiolite. Chemical characteristics suggest origin in a marginal basin, above a subduction zone (Coish and Rogers, 1987). Tentatively interpreted to have been ramped onto Chain Lakes massif (€Pc) during early Paleozoic (Penobscottian) collision between terrane 2 to southeast and terrane 1 (fig. 2). Total thickness about 3 km

€ov **Bimodal metavolcanic rocks**—Jim Pond Formation. Weakly metamorphosed volcanic and sedimentary rocks of ophiolitic association containing an upper metadacitic member, a lower metabasaltic member, and the separately mapped volcaniclastic metawacke Magalloway Member (€ow). Metabasaltic member composed of weakly metamorphosed, pillowed and massive basaltic flows variably interstratified with lapillite, breccia, mafic graywacke, dacite, ferruginous phyllite, and purple jasper. Metadacitic member composed of weakly metamorphosed, thickly layered, massive to laminated dacitic tuff and ash-flow deposits, and massive and fragmental sodic quartz latite or sodarhyolite flow rocks, felsic breccia, and resedimented felsic volcanic rocks, and local cherty hematite-magnetite iron-formation. Hosts possibly major volcanogenic massive-sulfide deposits, as at Alder Pond (grid 1C). Contact with underlying Boil Mountain Complex (Ꞓop) conformable. Maximum total thickness about 1,500 m

Ꞓow **Volcaniclastic metawacke member**—Magalloway Member of Jim Pond Formation. Typically weakly metamorphosed, massively bedded, greenish-brown to greenish-gray, fine-grained to very coarse grained, poorly sorted metawacke interbedded with minor amounts of slate and polymictic conglomerate, and a few large bodies, probably slide blocks, of pillowed basaltic greenstone. Grains in metawacke are quartz, plagioclase, potassium feldspar, muscovite, rock fragments, and heavy minerals; matrix is fine-grained chlorite, sericite, calcite, and epidote. Mapped as a lateral volcaniclastic facies of dacitic and basaltic members of Jim Pond Formation

Ꞓop **Stratiform plutonic ophiolite**—Gabbro, epidiorite, ultramafic rocks, and trondhjemite of Boil Mountain Complex (index 17). Divided (Boudette, 1991) into (1) lower serpentinite facies, composed of altered harzburgite and lherzolite; (2) medial and upper facies composed of gabbro, epidiorite (with epidiorite autobreccia), and pyroxenite; and (3) semiconcordant intrusive sheets of tonalite. Distributed in a main body frozen to south side of Chain Lakes massif, and several small bodies incorporated in melange (Ꞓe). Contact with underlying Chain Lakes massif is knife sharp; interpreted as a thrust fault that originated when hot rocks of ophiolite were ramped over cold rocks of massif. Maximum total thickness, including tonalite, about 1.5 km

ꞒPc **Clastic and plutonic rocks of Chain Lakes massif (Cambrian or Proterozoic)**—Centered in grid 3C. Reconnaissance mapping indicates a sequence that includes, in probable ascending order: (1) stratified feldspathic metasiltstone intruded by gabbro and epidiorite; (2) massive, matrix-supported, polymictic diamictite and polycyclic breccia; and (3) variably stratified meta-arkose and matrix-supported metaconglomerate. Undated; long considered Proterozoic on the basis of discordant U-Pb zircon data that suggested an age of about 1,500 Ma, but U-Pb ages as young as 1,013 Ma recently obtained from detrital zircons from the massif, and as young as 571 Ma from detrital zircons from rocks correlated with the massif (Dunning and Cousineau, 1990). See "Early Paleozoic Penobscottian and Taconian accretions" section for discussion of alternatives

Central Maine trough (CMT)

Tectonic belt of Lower Devonian and Silurian or Silurian(?) rocks lying mainly southeast of the STH (fig. 2), but overlapping the southeast side of the BHBMA. In ascending order, includes (1) Silurian and Silurian(?) deposits of transition to underlying arc sequences, divided into western (Stw) and eastern (Ste) sequences; (2) similarly divided Silurian and Silurian(?) sequences of extensional basin (Sbw, Sbe); and (3) Lower Devonian formations (Dc) that covered all tectonic belts of map area. Maximum total thickness of Silurian and Silurian(?) deposits nearly 5 km, and of Lower Devonian deposits about 3 km

Dc **Metashale, metasandstone, and associated deposits of cover sequence (Lower Devonian)**—Carrabassett, Hildreths, Mount Blue, Temple Stream, and Day Mountain Formations of Seboomook Group, widely exposed northeast of Songo pluton (index 69); metashale and metasandstone of Seboomook Group, exposed northeast of Sugarloaf pluton (index 24); and Littleton Formation, exposed northwest of Songo pluton and west of Sebago batholith (index 78). Metashale and metasandstone of Seboomook Group appoximately equivalent to Mount Blue Formation; Littleton Formation equivalent to Carrabassett, Hildreths, and Mount Blue Formations. These formations, except the Hildreths, form a conformable, upward-coarsening sequence of metamorphosed mud-silt-sand turbidites, typically in rhythmically graded beds. Lower contacts of all formations conformable.

Carrabassett Formation composed mainly of massive to faintly graded bedded, dark-gray pelitic schist, but locally having thinly to thickly bedded metasandstone-rich sequences; locally contains thin beds of manganiferous meta-ironstone, some containing copper. Similar to, and probably coeval with, Ironbound Mountain Formation (Dp) of the CVT. Maximum thickness about 1,200 m. Hildreths Formation composed of rusty-weathering, dark-gray, biotite-rich metagraywacke, bedded calc-silicate rock, and local white marble; 100–300 m thick. Mount Blue Formation composed of subequal amounts of dark-gray pelitic schist and light-gray to white, graded metasandstone beds; about 500–750 m thick. Temple Stream Formation composed of rusty-weathering, sulfidic, graphitic schist, metasandstone, and subordinate calcareous beds; about 250 m thick. Day Mountain Formation similar to Mount Blue but contains more abundant metasandstone, and thick lenses of granule metaconglomerate and of impure metalimestone; at least 1,000 m thick. Unit Dc derived mainly from rising, and possibly encroaching, landmass southeast of the CMT. Total thickness probably more than 3 km

Sequences of extensional basin (Silurian and Silurian?)—Divided into a western siliciclastic sequence (**Sbw**) having a maximum thickness of nearly 5 km, and a relatively distal eastern siliciclastic and carbonate sequence (**Sbe**) no thicker than about 3.2 km. Boundary between sequences is an unmapped line that extends arcuately through the Rumford allochthon, from near the north end of Songo pluton (index 69) to the east end of New Portland Hill (grid 1E). For interpretations see "Late Ordovician and Silurian sedimentation and magmatism related to synconvergent extension—Connecticut Valley trough" section

Sbw **Western siliciclastic sequence**—Rangeley Formation (Llandoverian), Perry Mountain Formation (Ludlovian? and Wenlockian?), Smalls Falls Formation (Ludlovian), and Madrid Formation (Pridolian? and Ludlovian?); all lower contacts conformable. Mainly northwest-derived turbidites; only known metavolcanic rocks are in Perry Mountain Formation (**Sbwv**), on East Kennebago Mountain (grid 3D). Type localities are between Rangeley and Madrid, Maine (grids 2E, 3E). Total maximum thickness about 4,750 m.

Rangeley Formation divided into members A, B, and C (ascending order). Member A is an upward-coarsening, southeastward-fining body of massively bedded arkosic metasandstone and polymictic boulder to pebble metaconglomerate that thins and wedges out abruptly northwestward, and tongues gradually southeastward into rusty-weathering, gray pelitic schist of the formation. Interpreted as a subaqueous fanglomerate body derived from the northwest; maximum thickness 1,200 m. Member B composed of rusty-weathering, dark-gray schist interbedded with feldspathic quartzite and southeastward-fining, quartz-rich polymictic boulder to pebble metaconglomerate and conglomeratic mudflow deposits; slump folds and features of proximal turbidites common. Member thins and wedges out northwestward; near-shore channel fill boulder metaconglomerate of member exposed 6 km southwest of Kennebago Lake, Maine; maximum thickness 1,200 m. Member C divided into a lower part composed of southeastward-fining, quartz cobble to granule metaconglomerate interstratified with feldspathic, variably calcareous quartzite, and gray pelitic schist, and an upper part composed of interbedded rusty-weathering, dark-gray schist and quartzite similar to nonconglomeratic parts of member B; about 600 m thick. In Kennebago Lake area (grid 3D), member C overlaps members B and A; here, the quartz conglomeratic lower part contains an upper Llandoverian shell fauna, found near the south end of Kennebago Lake, and is represented farther northwest by a more landward facies of quartz metaconglomerate, exposed near the north end of Kennebago Lake. Source terrane of formation considered a rapidly uplifted mountain range, eroded at first mainly by mechanical processes. Rangeley Formation is about 3,000 m thick southeast of the STH; northwest of the STH the formation thins to <600 m.

Perry Mountain Formation composed of sharply interbedded, nearly white weathering, planar-bedded quartzite and light-gray to pale-green slate at low metamorphic grade (garnet to chlorite), or muscovite-rich pelitic schist at higher grade (staurolite to first sillimanite); also contains local thin planar beds of calc-silicate rock. Felsic metavolcanic rocks mapped separately (**Sbwv**). Features of Bouma cycle turbidites common, but many beds cross-laminated from bottom to top, probably a result of reworking by bottom currents. Source terrane of formation considered an area reduced to chemically weathered low hills that mainly shed quartz and clay. About 600 m thick.

Smalls Falls Formation composed of strongly euxinic, typically rust-encrusted siliciclastic rocks. Divided into a lower main body (600 m thick) composed of sharply interbedded pyrrhotite-rich black schist and quartzite, and an upper calcareous member (150 m thick) composed of sulfidic calcareous quartzite, metasiltstone, and platy-bedded meta-ironstone. Northernmost exposures have very thick beds of quartz metawacke. Source terrane to northwest similar to that of Perry Mountain Formation, but subsidence of sedimentary basin resulted in euxinic conditions. Maximum thickness about 750 m.

Madrid Formation divided into a lower member (100 m thick) composed mainly of thinly bedded calcareous metasandstone, metasiltstone, and calc-silicate rock, and an upper member (200 m thick) composed of thickly bedded, fine-grained, mildly calcareous, feldspathic metasandstone with subordinate interbeds of gray pelitic schist like that of the conformably overlying Lower Devonian Carrabassett Formation (of **Dc**). Lower member wedges out and upper member thickens southeastward. Source terrane uncertain; possible volcanic area to northwest, north, or east. About 300 m thick

Sbwv **Felsic metavolcanic facies**—Exposed in Perry Mountain Formation near top of East Kennebago Mountain (grid 3D). Composed of layers, individually as much as 7 m thick, of weakly metamorphosed porphyritic quartz latite and flow-banded aphanitic rock (Boudette, 1991), interstratified with characteristic siliciclastic rocks of formation. Volcaniclastic metawacke recognized in Perry Mountain Formation east of map area, east of New Portland

Hill (grid 1E). Correlated with metavolcanic rocks of Perry Mountain Formation in the P-F allochthon (Srpv). Thickness of sequences containing volcanic or volcaniclastic beds probably <100 m

Sbe **Eastern siliciclastic and carbonate sequence**—Sangerville Formation (Wenlockian and Llandoverian?), Perry Mountain Formation (Ludlovian? and Wenlockian?), eastern facies of Smalls Falls Formation (Ludlovian), and eastern facies of Madrid Formation (Pridolian? and Ludlovian?). Mainly distal turbidites. Total maximum thickness 3,150 m. Lower contacts of all formations conformable.

Sangerville Formation interpreted to grade westward to lower part of Perry Mountain Formation and upper part of Rangeley Formation of western siliciclastic sequence (Sbw). Dated using graptolites found east of map area (see Pankiwskyj and others, 1976; Moench and Pankiwskyj, 1988a). Principal metasandstone and metashale facies composed of lithic metasandstone showing features of Bouma turbidites, interbedded with laminated or massive, gray to greenish-gray slate or schist. Sedimentary breccia and slump folds locally observed. Granule metaconglomerate member exposed near lat 45° N. at east border of map area; lenses as thick as 250 m containing polymictic granule metaconglomerate thickly interbedded with rocks characteristic of principal facies. Patch Mountain Limestone Member widely distributed in area of eastern sequence. In areas of low metamorphic grade, composed of thinly interbedded, gray micritic limestone, calcareous metasandstone, metasiltstone, and slate; display features common to turbidites. In areas of high metamorphic grade, composed of thinly layered, typically coarsely crystalline calc-silicate rocks. Maximum thickness of member about 600 m. Formation also contains (1) euxinic metashale lenses; (2) an extensive thin metalimestone member similar to Patch Mountain Limestone Member; (3) Thorncrag Hill Member of Hussey (1983), composed of pelitic gneiss and calc-silicate rock; and (4) Taylor Pond Member of Hussey (1983), composed of feldspathic hornblende-biotite granofels, calc-silicate rocks, and sparse garnet-rich laminations (see Moench and others, 1995). Sangerville possibly as thick as 2,000 m.

Perry Mountain Formation exposed east of Bromley pluton (index 73). Composed of sharply interbedded feldspathic metasandstone and greenish-gray slate having sedimentary features identical to those of same formation in western sequence. Thickness 100 m, or thinner.

Eastern facies of Smalls Falls Formation exposed east of Bromley pluton (index 73). Dated using graptolites found east of map area (Pankiwskyj and others, 1976, Parkman Hill Formation, later assigned to Smalls Falls Formation; Moench and Pankiwskyj, 1988a). Composed of sulfidic-graphitic slate interbedded with quartzose metasandstone, quartz-rich granule metaconglomerate, and thinly laminated metasiltstone; lacks calcareous upper member of same formation in western sequence. Maximum thickness about 300 m, but wedges out to southeast.

Eastern facies of Madrid Formation exposed in wide belt at Pratt Mountain (grid 1E), and in windows through southeastern part of Rumford allochthon. Composed of light-purplish-gray, well-sorted, medium- to thick-bedded, variably calcareous, feldspathic metasandstone with thin partings of slate or schist; locally interstratified with thinly bedded, cross-laminated metasandstone. Lacks thinly bedded, calcareous lower member of same formation in western sequence. Possibly more than 750 m thick

Deposits of transition to underlying arc sequences (Silurian and Silurian?)—Fine-grained detrital and local carbonate deposits interpreted to represent the first deposits shed from an emerging western Silurian source area. Divided into the western transition (Stw), containing the Greenvale Cove Formation (Silurian?–Llandoverian?), and the eastern transition (Ste), containing the Waterville Formation. Whereas the Greenvale Cove Formation is conformably underlain by metasedimentary rocks of the Ordovician (Cincinnatian) Quimby Formation (of Oue), the Waterville Formation is conformably underlain by the Ordovician or Silurian Hutchins Corner Formation of Osberg (1988), southeast of area of map A. Quimby and Hutchins Corner probably coeval

Stw **Western transition**—Greenvale Cove Formation; composed of interlaminated light-purplish-gray, weakly calcareous, feldspathic metasiltstone and metasandstone, gray slate, and minor calc-silicate rock. Unfossiliferous; assigned an early Llandoverian(?) age on basis of long-distance correlation with dated rocks of similar character and sequence (Moench and Pankiwskyj, 1988a). About 200 m thick

Ste **Eastern transition**—Waterville Formation; composed of thinly interbedded fine-grained, feldspathic metasandstone and greenish-gray slate or schist, subordinate layers of thinly bedded calc-silicate rock, and sparse rusty-weathering, black sulfidic slate or schist. Dated using graptolites found east of map area (Osberg, 1988, p. 55, and references therein). Where queried, tentatively includes rocks previously mapped as Anasagunticook Member of Sangerville Formation (Moench and Pankiwskyj, 1988a), correlated with Waterville

Formation by Osberg (1988, table 1, fig. 3). Interpreted to grade westward to Greenvale Cove Formation and possibly to lower part of Rangeley Formation. Estimated thickness of Waterville east of map area about 500–600 m (Osberg, 1988, p. 57)

APPENDIX II. DESCRIPTIONS OF NONPEGMATITIC MINES, PROSPECTS, AND UNDEVELOPED MINERAL OCCURRENCES

Individual descriptions are organized in the following order: (1) map index and name of occurrence, latitude and longitude, nature of workings, if any, and brief history of discovery, development, and resource information, where available; (2) description of deposit; (3) classification and interpretation of deposit; and (4) sources of information. Localities are identified on the map by number within each of the 15-minute quadrangles, which are identified by map grid coordinates; for example, 5D-1 is the Ledge Ridge massive-sulfide prospect. VMS, volcanogenic massive sulfide

SHERBROOKE QUADRANGLE (UNITED STATES PORTION) AND LEWISTON QUADRANGLE

1B-1 Catheart Mountain copper-molybdenum prospect—Lat 45°32'07" N., long 70°13'05" W.; plotted at approximate center of prospect area, west end of Catheart Mountain (grid 1B). Discovered in 1963 and extensively drilled by Noranda Exploration Co., Ltd. Estimated to contain 20–25 million tons of mineralized rock having an average grade of 0.25 percent copper and 0.04 percent molybdenum.

Disseminations and veinlets of pyrite, chalcopyrite, molybdenite, and smaller amounts of galena, sphalerite, and stannite in altered equigranular granodioritic and quartz porphyry dikes of the Catheart Mountain pluton (index 3). Molybdenite-bearing greisen vein from prospect dated at 444±10 Ma (Lyons and others, 1986; Rb-Sr muscovite). Ayuso (1989, fig. 1), following Schmidt (1974), distinguished propylitic, quartz-sericitic (phyllic), and potassic alteration zones in the prospect area. Ore minerals, sparsely disseminated in most of the altered rock, are most abundant near the interface between the quartz-sericitic and potassic alteration zones (Schmidt, 1974), which occur within an area of about 5 km^2 (Ayuso, 1989, fig. 1). Schmidt (1978, p. E7–E8) has described areas containing potentially extractable amounts of ore minerals.

Interpreted as a porphyry-type copper-molybdenum deposit having characteristics that accord with the model of Lowell and Guilbert (1970). According to Ayuso (1989, p. 160), the Catheart Mountain pluton was derived from a mixed sialic and mantle-derived source in continental lithosphere.

Atkinson (1977); Schmidt (1974, 1978); Hollister and others (1974); Young (1968, p. 133–134); Nowlan (1988); Ayuso (1989).

1B-2 Pyrite Creek sulfide prospect—Lat 45°33'35" N., long 70°08'52" W.; in brooks 0.4–0.6 km west-southwest of Jackman Field; occurs 152 m upstream and the same distance downstream from a 40-acre forested bog. Surface prospect and three drill holes to depths of 30 m or less.

Sparse galena, pyrite, chalcopyrite, sphalerite, and local specular hematite in quartz veins and silicified granitic rocks near the veins hosted by Catheart Mountain pluton (index 3). Occurrence is within several hundred feet of unconformably overlying metasedimentary rocks (of **Dc**).

Interpreted as hydrothermal veins in the Catheart Mountain pluton (index 3).

Nowlan (1976, p. 45; 1988).

1B-3 West Bean Brook Mountain sulfide occurrences—Lat 45°31'50" N., long 70°09'20" W.; in saddle at west end of Bean Brook Mountain (grid 1B); location approximate. Sulfide minerals noted at two separate locations, approximately 244 m apart.

Quartz veins containing minor amounts of sphalerite and galena and traces of chalcopyrite, and disseminations of sulfide minerals in weakly metamorphosed arkose and conglomerate of Hobbstown Formation (of **Dns**), and in felsite dikes that intrude the Hobbstown. The occurrences are just above the unconformity with granite of Attean pluton (index 2).

Quartz veins possibly representing Devonian hydrothermal redistribution from an unexposed larger sulfide-bearing deposit associated with underlying Attean pluton.

Delaney (1968, p. 84–89); Nowlan (1988); F.C. Canney (oral commun., 1987).

1C-1 Grace Pond pyrite prospect—Lat 45°29'07" N., long 70°10'15" W.; about 0.5 km northeast of Grace Pond, between Grace Pond and Fourmile Brook; location approximate. Drilling on geochemical anomaly; not otherwise developed.

According to core log (Boucot and Heath, 1969, p. 41), pyrite and purple fluorite occur at a depth of 98.2–98.6 m in coarse-grained meta-arkose of Hobbstown Formation (of **Dns**).

Disseminations probably associated with veins; possibly similar in habit and origin to West Bean Brook Mountain sulfide occurrences (1B-3).

Boucot and Heath (1969, p. 41); F.C. Canney (oral commun., 1987).

1C-2 Alder Pond polymetallic massive-sulfide prospect—Lat 45°05'23" N., long 70°12'10" W.; on a low ridge about 1,220 m northeast of the northeast shore of Alder Pond. Intensive geochemical and geophysical studies and drilling by BHP–Utah International resulted in the delineation of a small but high-grade VMS deposit. Development plans (BHP–Utah International, 1990) call for sinking a decline into the highest grade body; in 1993, economics of the project underwent internal review by the company (Mattson, 1993).

Drilling and assay data indicate the presence of two small but high-grade zinc-copper (lead) VMS deposits, said to contain possible reserves of as much as 5 million tons. Analyses of high-grade ore

(BHP–Utah International, 1990, table 13.2, p. 66) show 14.3 percent zinc, 2.33 percent copper, 1.37 pecent lead, and 181 ppm silver. The ore occurs conformably within a sequence of weakly metamorphosed basalt, iron-formation, rhyolite porphyry, and crystal tuff of the Jim Pond Formation (Ꞓov).

Considered the most important known VMS deposit in the Jim Pond Formation (Ꞓov).

BHP–Utah International (1990); Mattson (1993).

1F-1 Scheelite occurrence north of Farmington Falls—Lat 44°37'55" N., long 70°05'12" W.; location approximate. Outcrop on U.S. Highway 2 about 1.3–1.6 km north of Farmington Falls.

Scheelite-bearing veins about 2 cm thick composed mainly of coarse-grained quartz and calcite.

Interpreted as epigenetic veins of Late Paleozoic or Mesozoic age.

Trefethen and others (1955, p. 69). Interpretation by R.H. Moench.

1F-2 Scheelite occurrence south of West Farmington—Lat 44°37'55" N., long 70°06'45" W.; location approximate. Outcrop on road from West Farmington to Farmington Falls, about 5 km south of West Farmington.

Sparse minute grains of scheelite in calc-silicate rock near granite.

Tentatively interpreted as a low-grade skarn deposit related to the granite.

Trefethen and others (1955, p. 69). Interpretation by R.H. Moench.

2B-1 Sally Mountain copper-molybdenum prospect—Lat 45°34'52" N., long 70°19'30" W.; at southwest end of Sally Mountain. Evidence of only minor prospecting.

Disseminated chalcopyrite and molybdenite in quartz veins, and in sheared and silicified quartz porphyry and aphanite of Sally Mountain pluton (index 4). Although the Sally Mountain and Catheart Mountain plutons are somewhat similar, the abundance of metals is significantly lower in the Sally Mountain and geochemical data suggest that the two plutons are not comagmatic (Ayuso, 1989).

Possibly a small remnant of a Silurian or Ordovician porphyry-type deposit.

Young (1968, p. 133–134); Ayuso (1989).

2B-2 Sally Mountain sulfide prospect—Lat 45°20'10" N., long 70°18'30" W.; location approximate; on Sally Mountain about 1.2 km northeast of Sally Mountain copper-molybdenum prospect (2B-1).

Sparse chalcopyrite and pyrite occur at the unconformity between granite of Sally Mountain pluton (index 4) and overlying Silurian conglomerate (of Sns); sparse galena occurs in a quartz vein that cuts the conglomerate at least 30 m above the unconformity.

Veins and disseminations, probably similar in habit and origin to West Bean Brook Mountain sulfide occurrences (1B-3). Primary source might be a sulfide deposit in Sally Mountain pluton.

Young (1968, p. 133–134); Nowlan (1988).

2E-1 Copper-bearing ironstone lens—Lat 44°51'17" N., long 70°26'48" W.; outcrop in Sandy River below Route 4 bridge, 1.6 km south of Madrid, Maine.

Rusty-weathering, metalliferous ironstone lens, about 5 cm thick and 1 m long, in pelitic schist of Carrabassett Formation (of Dc). Composed of biotite, iron-chlorite, almandine-spessartite, and disseminated pyrrhotite and chalcopyrite. Spectrographic analysis indicates the presence of 1,500 ppm copper (J.C. Hamilton, analyst) and rapid rock analysis indicates 12.5 percent Fe_2O_3, 7.6 percent FeO, and 1.6 percent P_2O_5 (Herbert Kischenbaum, analyst).

Sole known occurrence of sedimentary copper in the turbidite sequences of the report area.

R.H. Moench (1967 field observations).

2E-2 Phillips metalliferous(?) marble trench—Lat 44°40'25" N., long 70°20'50" W.; several trenches uphill from old lime kiln on east side of Route 142 northeast of Phillips, Maine.

White marble of Hildreths Formation (of Dc) near contact at north end of Phillips batholith (index 26A); marble excavated for agricultural use. Reported to contain sparse galena, chalcopyrite, and pyrite.

If metalliferous, probably a small Mesozoic vein discovered during trenching for agricultural lime.

Morrill and others (1958, p. 40). Interpretation by R.H. Moench.

2F-1 Beal zinc propsect—Lat 44°38'05" N., long 70°28'10" W.; location approximate.

Probably a small lead-zinc-silver vein.

Interpreted as an epigenetic vein of Mesozoic age.

Morrill and others (1958, p. 18). Interpretation by R.H. Moench.

2F-2 Stone Rock–Briggs sulfide prospect—Lat 44°38'30" N., long 70°28'40" W.; location approximate.

Probable small vein that carries sphalerite, pyrite, galena, and arsenopyrite.

Interpreted as an epigenetic vein of Mesozoic age.

Morrill and others (1958, p. 14). Interpretation by R.H. Moench.

3C-1 Jim Pond copper occurrence—Lat 45°17'05" N., long 70°30'35" W.; on a knoll about 1.6 km north of Jim Pond. Not developed.

Chalcopyrite and possibly other sulfide minerals disseminated in small, unmapped body of quartz porphyry.

Possibly the outcrop of a porphyry-type copper deposit. Although small, possibly the "tip" of a much larger pluton and associated copper deposit.

E.L. Boudette (field observations).

3C-2 Blanchard Pond chromite occurrence—Lat 45°16'10" N., long 70°36'14" W.; about 0.5 km southwest of Blanchard Pond. Not developed.
Layered chromite in ultramafic rocks at the base of the Boil Mountain Complex (index 17, **Ꞓop**).
Interpreted to be comagmatic with the Boil Mountain Complex.
E.L. Boudette (field observations).

3C-3 Onion Hill asbestos occurrence—Lat 45°15'39" N., long 70°42'58" W.; at approximate elevation of 750 m on northeast slope of Onion Hill; location approximate. Not developed.
Abundant intersecting veinlets of cross-fiber asbestos in serpentinite of Boil Mountain Complex (index 17, **Ꞓop**); fibers as long as 12 mm.
Interpreted as fractured and altered dunite of ophiolite.
E.L. Boudette and G.M. Boone (field observations).

3D-1 Alder Stream sulfide prospect—Lat 45°14'08" N., long 71°36'10" W.; approximately 0.8 km southeast of Alder Stream Farm. Extensive geochemical survey starting in 1969, and subsequent trenching, geophysical surveying, and drilling in 1971, by J.S. Cummings, Inc., (Cummings, 1988, p. 271–277).
Core drilling adjacent to an east-trending, 762-m-long trench zone revealed a zone, 91–152 m thick, of weakly metamorphosed tuff, tuffaceous sedimentary rocks, and flows containing 2–10 percent pyrite and small, erratic amounts of copper sulfides. The best core intercepts showed 8.93 m containing 0.33 percent copper, 1.16 m containing 1.0 percent copper, and 0.46 m containing 2.6 percent copper. The prospect occurs within the mafic volcanic member of the Jim Pond Formation (Boudette, 1991).
Interpreted as volcanogenic, locally copper-bearing, pyritic iron-formation.
Cummings (1988, p. 271–277).

3D-2 Alder Stream asbestos occurrence—Lat 45°01'10" N., long 70°40'00" W.; surface outcrops on knoll southwest of North Branch of Alder Stream. Not developed.
Veinlets containing cross-fiber asbestos in diapiric serpentinite(s).
Interpreted as fractured and altered serpentinite derived from ophiolite.
E.L. Boudette (field observations).

3D-3 Boil Mountain sulfide(?) prospect—Lat 45°14'18" N., long 70°43'05" W.; location approximate. Drilling at approximate elevation of 854 m on north side of east shoulder of Boil Mountain.
Nature and composition of deposit unknown.
Tentatively interpreted as a possibly dismembered VMS deposit, on the basis of association with sheared, siliceous iron-formation in bimodal volcanic rocks of Jim Pond Formation (**Ꞓov**).
E.L. Boudette (field observations and tentative interpretation). Shown in order to highlight the importance of the setting for VMS deposits.

3D-4 Black Mountain copper prospect—Lat 45°10'55" N., long 70°38'50" W.; location approximate. Trenching and drilling near stream that drains southeast side of Black Mountain and Elephants Head (grid 3D).
Small concentrations of pyrrhotite and pyrite and sparse chalcopyrite in graphitic-sulfidic hornfels of Hurricane Mountain Formation (**Ꞓe**) within the contact metamorphic aureole of the gabbroic Elephants Head pluton (index 18).
Tentatively interpreted as a gabbro-related contact metamorphic replacement deposit.
R.H. Moench (discussions with Boise Cascade Corporation geologist, February 1988); E.L. Boudette (field observations).

3E-1 Wing Hill garnet prospect—Lat 44°59'59" N., long 70°38'35" W.; location approximate. On hillside approximately 3.6 km north of Rangeley village. Extensively prospected and drilled.
Garnet granofels composed of 50–60 percent garnet, subordinate andesine, and minor amounts of pyroxene, quartz, biotite, and pyrrhotite. Dimensions of potential garnet ore zone about 1 km east-west, as much as 200 m north-south, and at least 60 m in depth.
Interpreted as product of reaction and assimilation between gabbro of Flagstaff Lake plutons (index 19A) and metasedimentary rocks of Quimby Formation (of **Oue**).
O'Connor (1981).

3E-2 Nile Brook platinum-bearing placer—Lat 44°56'37" N., long 71°07'40" W.; along Nile Brook (grid 3E).
Platinum, iridium, and gold reported from gravel.
Transported by glacier, most likely from platinum-bearing chromitite in the Thetford Mines ophiolite in Quebec (Gauthier and Trottier, 1987).
Morrill and others (1958, p. 43); Gauthier and Trottier (1987).

3E-3 Scheelite prospect and occurrences along Swift River—Lat 44°47'03" N., long 70°38'10" W.; short adit driven about N. 55° W. into west bank of Swift River, approximately 550 m upstream from Highway 17 bridge. Portal partly filled with gravel when visited in 1964.
The adit is approximately centrally located between scheelite occurrences downstream and upstream in the bed of the Swift River. It is driven into a vein of white, iron-stained quartz (no scheelite observed) that strikes N. 25° E., dips 40° SE., and cuts schist of the Rangeley Formation (of **Sbw**), which is altered adjacent to the vein. Trefethen and others (1955) reported the occurrence of scheelite near the Highway 17 bridge, in the core of a pod of calc-silicate rock in the Rangeley

Formation, and about 550 m upstream from the bridge (300 m upstream from the adit), where scheelite pinpoints and grains as large as 1 cm occur in calc-silicate pods in the Rangeley Formation, and in a vein of quartz and calcite. The vein, about 1 cm thick, crosses a scheelite-bearing pod at a high angle. An assay of unspecified material from this locality yielded 0.26 percent tungsten (Trefethen and others, 1955, p. 64). For a distance of about 600 m upstream from the adit (nearly to the Oxford County–Franklin County line), the Swift River follows a set of fracture zones containing narrow quartz-carbonate veins; wall rocks adjacent to the veins are chloritized and pyritized.

The scheelite is tentatively interpreted to be related to Mesozoic(?) fractures.

Trefethen and others (1955, p. 64; scheelite occurrences); R.H. Moench (1964 field observations).

3E-4 Scheelite occurrence in Berdeen Stream—Lat 44°46'10" N., long 70°39'20" W.; location approximate. Occurrence described as approximately 0.8 km upstream along the second south-flowing tributary (probably Berdeen Stream) from the mouth of the East Branch of the Swift River.

Many rusty, massive quartz veins that average about 30 cm thick and strike northeast, parallel to schistosity that deforms the Rangeley Formation (of **Sbw**). Scheelite was found by prospectors, who traced float blocks of scheelite-bearing vein quartz to this locality.

Epigenetic Mesozoic(?) veins.

Trefethen and others (1955, p. 64–65). Interpretation by R.H. Moench.

3E-5 Scheelite occurrence in Mountain Brook—Lat 44°47'03" N., long 70°42'25" W.; along stream pavement in Mountain Brook, approximately 150–460 m upstream from confluence with Berdeen Stream.

Scattered pinpoints in laminated calc-silicate rock of the Greenvale Cove Formation (of **Stw**) near contact with two-mica granite of Mooselookmeguntic batholith (index 34A).

Possibly a low-grade skarn deposit related to the granite.

Trefethen and others (1955, p. 64–65). Interpretation by R.H. Moench.

3F-1 West Brook pentlandite-bearing tonalite occurrence—Lat 44°43'35" N., long 70°33'10" W.; outcrops along and near West Brook and on east side of West Mountain.

Small, discordant body of unfoliated, medium-grained, equigranular almandine-phlogopite tonalite of West Mountain plutons (index 27); garnet and mica compositions determined by microprobe analysis. Where exposed near the northeast side of the body, the tonalite contains scattered 1-cm nodules seen in polished sections to be composed of graphically intergrown pyrrhotite and pentlandite. Spectrographic analyses of a sample composed of several variably weathered nodules that were concentrated from a bulk sample of the tonalite yielded 1,000 ppm each of copper and nickel, and 150 ppm each of cobalt and chromium; spectrographic analyses of the bulk sample yielded smaller but anomalous amounts of the same elements (N.M. Conklin, analyst).

The almandine-phlogopite tonalite is unique in the map area; tentatively interpreted as a hybrid of felsic and ultramafic magmas. Although the pyrrhotite-pentlandite nodules are of unknown origin and are too sparse to indicate a resource, their occurrence is highlighted as an unsolved problem.

R.H. Moench (1972 field obervations); see Moench and Hildreth (1976).

3F-2 Scheelite occurrence on Partridge Peak—Lat 44°38'00" N., long 70°37'43" W.; location approximate, on west side of Partridge Peak (grid 3F).

Scattered pinpoints of scheelite in calc-silicate rock of the upper member of the Smalls Falls Formation (of **Sbw**).

Possible low-grade skarn deposit related to a nearby granitic pluton.

Trefethen and others (1955, p. 65). Interpretation by R.H. Moench.

3G-1 Mount Glines lead prospect—Lat 44°28'20" N., long 70°34'50" W.; location approximate, on south(?) side of Mount Glines. At least one shallow shaft and an adit. No reported production.

Two principal fissure veins and several smaller ones. Main veins as wide as 2 m; composed of quartz and irregularly scattered "bunches" and cross veinlets of galena and pyrite; strikes are N. 25° E. (dip 65°–70° SE.) and N. 20° E. (dip steep to NW.). Country rock is gneissic granite, altered to clay adjacent to the veins.

Interpreted as Mesozoic epigenetic veins.

Smith (1904); Emmons (1910, p. 49–50); Rand (1959). Interpretation by R.H. Moench.

3G-2 Champion Consolidated lead prospects—Lat 44°28'25" N., long 70°33'30" W.; location approximate. Probably several adits on Mount Zircon (grid 3G). In listed references also named Oxford Silver, Mount Zircon, and Champion mines.

Probably quartz veins that contain silver-bearing galena.

Interpreted as Mesozoic epigenetic veins.

Pratt and Condon (1947); Rand (1959); Morrill and others (1958). Interpretation by R.H. Moench.

3G-3 Lone Star lead prospect—Lat 44°24'05" N., long 70°34'40" W.; location approximate. On south slope of Spruce Mountain (grid 3G).

Probably a galena-bearing quartz vein.

Interpreted as Mesozoic epigenetic veins.

Rand (1959); Morrill and others (1958); Pratt and Condon (1947). Interpretation by R.H. Moench.

3G-4 Woodstock lead prospect—Lat 44°23'40" N., long 70°35'25" W.; location approximate. On southwest slope of Spruce Mountain (grid 3G).

Probably a quartz vein that contains silver-bearing galena. Copper, lead, silver, and gold listed by Rand (1959).

Interpreted as Mesozoic epigenetic veins.

Rand (1959); Morrill and others (1958). Interpretation by R.H. Moench.

4C-1 Arnold Pond chromite-magnetite occurrence—Lat 45°23'29" N., long 70°47'40" W.; on steep southwest-facing slope about 1.6 km northeast of international border at Coburn Gore; about 100 m north of Maine Highway 27.

Disseminated chromite and magnetite in amphibolite adjacent to serpentinite inclusion in probable Hurricane Mountain Formation (Ꞓe). Described by Harwood (1973, p. 82) as fine-grained magnetite and chromite in layers about one-half centimeter thick that separate light-gray feldspar-rich stringers and segregations from the dark-green amphibolite.

Tentatively interpreted as chromitite comagmatic with Boil Mountain Complex (index 17), later incorporated into melange of Hurricane Mountain Formation (Ꞓe), and subsequently incorporated as a screen in Chain of Ponds pluton (index 8).

Harwood (1973, p. 82). Interpretation by E.L. Boudette.

4D-1 Arsenopyrite occurrence near Johns Pond—Lat 45°10'10" N., long 70°45'55" W.; northeast of Johns Pond in the Cupsuptic 15-minute quadrangle (grid 4D). Not developed.

Arsenopyrite in interstices between quartz pebbles of Clough Quartzite (of Sns). The arsenopyrite makes up as much as 1.5 percent of the rock. Analyses of arsenopyrite-bearing conglomerate (Harwood, 1973, table 6) yielded 0.1 ppm gold (one sample) and 0.5 ppm gold (two samples).

Disseminations probably related to epigenetic veins. The anomalous amounts of gold might have been concentrated from lower-grade fossil placer gold in the quartzite.

Harwood (1973, p. 82). Interpretation by R.H. Moench.

4F-1 Disseminated sulfides in Mountain Brook—Lat 44°42'05" N., long 70°53'30" W.; approximately located between elevations 476 and 497 m along Mountain Brook. Not developed.

Extensively bleached and pyritized, stratified felsic gneiss. Spectrographic analysis of one of two samples indicated 1,500 ppm zinc (J.A. Domenico, analyst).

Interpreted as metamorphosed, weakly mineralized, hydrothermally altered felsic tuff of Ammonoosuc Volcanics (Olv).

R.H. Moench (1979 field observations).

4F-2 Massive pyrite near York Brook—Lat 44°37'26" N., long 70°57'58" W.; on side of logging road 0.3 km west of Highway 26, on Boise Cascade Corporation land. Not developed.

Bed of massive pyrite about 10 cm thick associated with well-stratified amphibole-bearing feldspathic schist, felsic gneiss, and magnetite-chlorite iron-formation of Ammonoosuc Volcanics (Olv). Spectrographic analysis of the massive pyrite indicated 0.7 ppm silver, 10 ppm bismuth, 150 ppm cobalt, 200 ppm copper, and 500 ppm zinc (J.A. Domenico, analyst). No gold was detected by atomic absorption analysis (J. Sharkey, analyst).

Interpreted as sparsely metalliferous pyritic iron-formation.

R.H. Moench (1979 field observations).

4F-3 Breccia pipe(?) northeast of Red Ridge—Lat 44°36'49" N., long 70°59'40" W.; in bed of unnamed brook that drains northeast side of Red Ridge; 300 m upstream from logging road culvert.

Limonitic breccia exposed over width of 46 m along brook bed, in sharp contact with rusty-weathering felsic gneiss at northeast end of Success lobe (index 64) of Jefferson batholith. Dense, black, feldspar-porphyritic alkali olivine basalt intrudes the felsic gneiss just upstream and downstream from the breccia, possibly as separate plugs or a ring dike. Although spectrographic and chemical analyses of the breccia revealed no unusual metal contents, it might be of interest for gold.

Interpreted as a breccia pipe produced by basalt intrusion(s).

R.H. Moench (1979 field observations).

5D-1 Ledge Ridge massive-sulfide prospect—Lat 45°14'35" N., long 70°03'05" W.; high on northwest slope of Ledge Ridge (grid 5D); plotted at approximate center of northeast-trending layer (information furnished in 1987 by Boise Cascade Corporation). The deposit, entirely concealed by glacial drift, was discovered in 1973 by J.S. Cummings, Inc., by intensive geochemical survey and drilling. Drilling delineated a VMS deposit having a strike length of 976 m, and varying from 0.4 to 6.2 m in thickness. According to Cummings (1988, p. 253), the deposit has a probable tonnage grade of 3.7 million tons containing 2.3 percent zinc, 0.95 percent copper, 0.85 percent lead, 0.015 oz gold per ton, and 0.60 oz silver per ton. Cummings (1988, p. 254) reported an indicated 5.0 million tons of VMS with similar metal contents, and he estimated that the deposit contains at least 10 million tons of VMS.

Quantitative atomic absorption analyses obtained by J.F. Slack on four core specimens of VMS yielded (range in parentheses): 2.15 (1.9–3.0) percent copper, 3.27 (2.2–5.2) percent zinc, 0.51 (0.26–0.75) percent lead, and 0.59 (0.29–1.1) ppm gold. Emission spectrographic analyses of the same samples yielded 60 (18–86) ppm silver. Analyses by the same methods of one sample of pyritic greenstone, presumably but not necessarily within the footwall of the VMS deposit, yielded 2.1 percent copper, 0.6 percent zinc, 0.05 percent lead, 3 ppm gold, and 9 ppm silver. [Analyses by C.J.

Skeen and B.S. Spillare (emission spectrography), and J.R. Gillison, R. Moore, and Philip Aruscavage (atomic absorption).] The presence of 3 ppm gold in the pyritic greenstone is uncommon and may represent an important resource.

The Ledge Ridge deposit is hosted by strongly bimodal metavolcanic rocks of the Frontenac Formation (of Srwv). The deposit is mostly enclosed within a layer of pyritic, tuffaceous metasiltstone, several meters thick, that lies above pillowed metabasalt, as much as 1,500 m thick, and below a similar thickness of rhyolite ash and lapilli metatuff, fragmental metarhyolite, metabasalt, and minor amounts of iron-formation and ferruginous chert. U-Pb zircon data obtained from amygdalloidal fragmental metarhyolite exposed on the unnamed ridge just north of Moose Bog (grid 5D) indicates that the felsic metavolcanic rocks associated with the Ledge Ridge VMS deposit are no older than 430 Ma (Aleinikoff, *in* Moench and others, 1995, site M-8).

Interpreted as a Kuroko-type VMS deposit that originated on the sea floor within the axial half-graben of the Second Lake rift axis (SLRA).

Eisenberg (1981, 1982, 1983); Stephens and others (1984, p. 1466–1468); Cummings (1988, p. 234–256); R.H. Moench (1981–85 field observations). J.F. Slack (written commun., 1987) provided the analytical data that he obtained from drill core in cooperation with the Boise Cascade Corporation.

5D-2 Ledge Ridge extension prospect—Lat 45°14'07" N., long 71°02'50" W.; on Ledge Ridge approximately 1 km southeast of Ledge Ridge VMS prospect (5D-1). Extensive geochemical and geophysical surveys followed by drilling, by J.S. Cummings, Inc.

Drilling delineated a conformable zone containing about 3–10 percent pyrite distributed through a thickness of 3–61 m, and a length of at least 1,372 m (Cummings, 1988, p. 280). Although most of this zone proved to be almost barren of base-metal sulfides, two holes near the northeast end of the zone intersected a narrow layer (33- and 43-cm intercepts) containing slightly more than 80 percent sulfide minerals. The best of the two intercepts contained 7.2 percent zinc, 0.55 percent copper, and 0.7 oz silver per ton. The sulfidic zone is hosted by weakly metamorphosed, stratified, intermediate to felsic tuffaceous sedimentary rocks within a thick sequence of predominantly basaltic pyroclastic rocks and pillowed flows of the Frontenac Formation.

Interpreted as a small copper-zinc VMS deposit associated with pyritic iron-formation.

Cummings (1988, p. 280).

5D-3 Thrasher Peaks sulfide prospect—Lat 45°12'55" N., long 71°00'38" W.; plotted near the discovery outcrop (called the Rump Pond deposit by Cummings, 1988, p. 238–239) at approximate southwest end of prospect area. Prospected more than 5 km to the northeast along southeast side of Thrasher Peaks (grids 4D, 5D). Extensive drilling and surface prospects.

As described by Eisenberg (1982, p. 3) and other sources, the sulfide mineral deposits occur discontinuously within a northeast-trending zone more than 5 km long and as much as 91 m wide. The deposits are grossly stratabound and include small pods and lenses of VMS and sulfide-bearing stringers and disseminations; ore minerals are mainly pyrite, chalcopyrite, and sphalerite. Massive accumulations of pyrite, chalcopyrite, and sphalerite occur in transposed fold hinges. Galena is found in discrete thin lenses near the massive bodies, but is uncommon within the bodies. Spectrographic analyses of a 20-cm layer of pyrite-chalcopyrite-sphalerite rock indicated 0.007 percent silver, 7 percent copper, 0.015 percent lead, and >10 percent zinc; analysis of adjacent pyritic graywacke indicated 2 percent copper, 0.001 percent lead, and 5 percent zinc (Harwood, 1973, table 6). Combined fire assay and atomic absorption analysis of the 20-cm sulfide-rich layer yielded 0.08 ppm gold (Harwood, 1973, table 7).

The sulfide mineral deposits are hosted by schistose felsic metatuff and felsic tuff breccia interstratified with gray slate, black sulfidic slate, two lenticular bodies of pillowed, hyaloclastic, and agglomeratic basaltic greenstone, and local basaltic metaconglomerate. Small bodies of microgranite shown as the Thrasher Peaks plutons (index 10) are interpreted, by R.A. Cavalero (Boise Cascade Corporation, written commun., February 1988), as rhyolite domes related to the volcanic sequence, herein assigned to the Lower Devonian (Gedinnian?) Ironbound Mountain Formation (Dpv). One of the microgranite bodies has yielded a concordant U-Pb zircon age of about 414 Ma (Eisenberg, 1982, p. 42, table 3), based on a single analysis; according to the time scale of Tucker and McKerrow (1995), this age is consistent with the Gedinnian(?) age assigned to the Ironbound Mountain Formation.

The host sequence is cut on the southeast by the Thrasher Peaks fault, previously mapped on the northwest slope of Thrasher Peaks, but now placed on the southeast slope, at a zone of intense shearing mapped and described by Eisenberg (1982, p. 34, fig. 4).

Interpreted as a VMS deposit hosted by weakly metamorphosed volcanic rocks of the Ironbound Mountain Formation. The deposit was probably sheared and disrupted by deformation in the hanging wall of the Thrasher Peaks fault.

Fournier (1970); Eisenberg (1982, p. 30–34); Young (1968); Harwood (1973); R.A. Cavalero (Boise Cascade Corporation, written commun., February 1988).

5D-4 Parmachenee sulfide prospect—Lat 45°11'40" N., long 70°00'30" W.; located about 3.2 km northwest of north end of Parmachenee Lake (grid 5D). Surface prospects but not otherwise developed.

Subparallel veins and lenses of quartz, galena, and arsenopyrite in mineralized zones as much as 4.6 m wide. Assays of two samples yielded (1) 0.55 oz gold and 1.9 oz silver per ton, 1.9 percent lead, and 0.2 percent zinc, and (2) 0.07 oz gold and 1.7 oz silver per ton, 5.5 percent lead, 0.2 percent copper, and 1.6 percent zinc (Young, 1968, p. 133). The veins and lenses are subparallel to local schistosity of the country rocks, which are metamorphosed arkose or quartzwacke within the Magalloway Member of the Jim Pond Formation (Ꞓow). The veins and enclosing rocks appear to have been sheared and dismembered.

Interpreted as Ordovician(?) deformed epigenetic veins.

Young (1968, p. 133). Interpretation by R.H. Moench.

5D-5 Unnamed arsenopyrite-galena prospects—Lat 45°10'54" N., long 71°01'20" W. (northeastern prospect); lat 45°10'35" N., long 71°01'38" W. (southwestern prospect); hilltop northwest of Parmachenee Lake. Surface trenching but not otherwise developed. Boise Cascade Corporation land.

Quartz veins containing arsenopyrite and galena.

Interpreted as Ordovician(?) deformed epigenetic veins.

Information furnished by Boise Cascade Corporation (written commun., February 1988).

5F-1 Hampshire Hills copper prospect—Lat 44°41'06" N., long 71°02'50" W.; plotted on the northernmost of two hills known as Hampshire Hills. Prospect is about 2.5 km south of Sargent Cove, Umbagog Lake (grid 5F). Extensive drilling and geochemical and geophysical surveys by Al Aquataine, Kidd Creek Mines, Ltd., and Newmont Exploration. Grade and tonnage data not available.

Conformable lens of massive and disseminated pyrrhotite and chalcopyrite associated with silicate iron-formation and local quartz-kyanite gneiss enclosed within volcaniclastic metagraywacke of the Ammonoosuc Volcanics (Olv). The metagraywacke (and the enclosed iron-formation, quartz-kyanite gneiss, and copper deposit) is about 350 m thick; it lies stratigraphically above basaltic amphibolite and metasedimentary biotite schist, and below schistose felsic metatuff, which is extensively altered to pyritic quartz-muscovite schist and metachert.

The chalcopyrite-pyrrhotite deposit occurs above a lens of white, faintly layered, medium-grained quartz-kyanite gneiss, as much as 30 m thick, composed of quartz, kyanite, and sparse muscovite; locally it contains "floating" rounded pebbles of the same material. Chemical analyses (Pyke, 1985, table 3) indicate that the gneiss contains 81.0 percent SiO_2, 16.8 percent Al_2O_3, 1.25 percent TiO_2, and 0.19 percent volatile components. The gneiss is interpreted as altered felsic tuff from which calcium, sodium, and potassium have been removed.

The silicate iron-formation, above the quartz-kyanite gneiss, is dark-greenish-gray, pyritic quartz-magnetite-garnet-chlorite gneiss, commonly interlaminated with white quartz-feldspar gneiss. Chemical analyses (Pyke, 1985, table 3) indicate that the pyritic quartz-magnetite-garnet-chlorite gneiss is composed of 60.8 percent SiO_2, 12.5 percent Al_2O_3, 1.01 percent TiO_2, 17.7 percent Fe_2O_3, 4.99 percent MgO, and 2.11 percent volatile components. This rock also probably originated as tuff, but, to judge from its laminated structure, was strongly reworked by currents; the rock is extremely enriched in iron and depleted in calcium, sodium, and potassium. Pyke (1985) interpreted the iron-formation as metamorphosed tuffaceous exhalite.

The pyrrhotite-chalcopyrite deposit is a Besshi-type VMS deposit, hosted by altered volcaniclastic sediments. According to Pyke (1985), the copper deposit and associated altered tuff and iron-rich tuffaceous exhalite accumulated in a pool of hot brine, probably derived from hot springs within a volcano-sedimentary basin.

Pyke (1985); R.H. Moench (1979–84 field observations).

5F-2 Scheelite occurrence south of Upton—Lat 44°40'57" N., long 71°00'23" W.; at elevation of 628 m on a northeast-sloping hillside about 1.3 km S. 15° E. from Upton. Not developed.

Sparse scheelite associated with a conformable layer of laminated calc-silicate rock and quartzite, about 9 m thick, at the base of the Quimby Formation (Oue), and interpreted to be disconformably or unconformably underlain by pyritic quartz-muscovite schist of the Ammonoosuc Volcanics (Olv). The calc-silicate and quartzite layer extends at least 11 km along the Ammonoosuc-Quimby contact. Scheelite was found in a crushed sample of calc-silicate rock that yielded 7,000 ppm tungsten by semiquantitative spectrographic analysis (J.A. Domenico, analyst). Tungsten was also detected by W.J. Ficklin in surface water in a nearby brooklet that drains the calc-silicate unit. Further sampling failed to detect more tungsten.

Probably a low-grade skarn deposit, but might be a tungsten-bearing tufa that formed along a line of possibly subaqueous hydrothermal springs.

R.H. Moench (1979–80 field observations).

5F-3 Chlorite iron-formation northeast of Red Ridge—Lat 44°38'07" N., long 71°00'32" W.; 3,200 m N. 23° E. from top knoll on Red Ridge (grid 5F), in brook bed just downstream from logging road culvert. Boise Cascade Corporation land. Not developed.

Large outcrop of quartz-magnetite-garnet-chlorite rock, similar to silicate iron-formation at Hampshire Hills prospect (5F-1), in Ammonoosuc Volcanics (Olv). Contains clots of coarsely crystallized pyrite. Spectrographic analysis of pyrite-rich sample showed 100 ppm copper, 70 ppm lead, and 1,000 ppm zinc (J.A. Domenico, analyst).

Interpreted as weakly mineralized silicate iron-formation.
R.H. Moench (1979 field observations).

5F-4 Old Howard copper prospect—Lat 44°31'25" N., long 71°10'25" W.; location approximate, probably about 2 km north-northeast of top of Cates Hill (grid 5F).
No description found.
Probably a small chalcopyrite-bearing VMS deposit in the Ammonoosuc Volcanics (Olv).
Meyers and Stewart (1956).

5F-5 Joseph Gagne copper prospect—Lat 44°30'53" N., long 70°10'59" W.; location approximate, probably on knoll 1 km north of top of Cates Hill (grid 5F).
Probably the deposit described by Hitchcock (1878, p. 48) as "***a vein showing the minerals pyrite, chalcopyrite, bornite, magnetite, hornblende, and tremolite. The ores are sparsely disseminated."
Probably a small chalcopyrite-bearing VMS deposit.
Meyers and Stewart (1956); Hitchock (1878, p. 48).

5G-1 Shelburne lead mine—Lat 44°25'10" N., long 71°07'54" W.; about 5 km northeast of Gorham, N.H., on west fork of Leadmine Brook. Adit driven 9 m west into mountainside and three shafts sunk along brook. Mined intermittently from late 1830's into 1850's, followed by an unsuccessful attempt in 1880. Small production.
Vein strikes N. 75° E. and is exposed for 91 m along the bed of the brook (Cox, 1970, p. D12); 3–4.5 m wide; similar to the Mascot vein. Breccia of granite and schist are enclosed in cockscomb-structured quartz and carbonate minerals. The principal ore minerals, which occur in veinlets and patches, are galena, sphalerite, and minor chalcopyrite. Assays indicated as much as 10 percent lead, 3 percent zinc, and 9 oz silver per ton (Cox, 1970, p. D13).
Interpreted as a Mesozoic fissure vein.
Cox (1970); Billings and Fowler-Billings (1975, p. 95); Hitchcock (1878, p. 64–65).

5G-2 Stevens lead prospect—Lat 44°24'04" N., long 71°08'47" W.; about 3.2 km northeast of Gorham, N.H. Small prospect pit on Stevens Brook. No production.
Vein, probably containing galena, about 0.6 m wide; strikes N. 35° E. and dips 70° NW.
Interpreted as a Mesozoic fissure vein.
Billings and Fowler-Billings (1975).

5G-3 Mascot lead mine—Lat 44°24'06" N., long 71°10'40" W.; about 1.3 km northeast of Gorham, N.H., on Leadmine Ridge just northeast of Mascot Pond. Three drift-adits driven northeast into Leadmine Ridge, connected by stopes. Mined from 1881 to 1885 (about 50,000 tons of vein material produced) and again in 1906 (70 tons of lead and 174 oz of silver produced).
Breccia vein composed of angular fragments of altered granite in a matrix of quartz and manganiferous siderite. Ore minerals, mainly restricted to veinlets within the breccia, are silver-bearing galena, sphalerite(?), and sparse chalcopyrite. Assays indicated that the ore is rich in zinc (Cox, 1970, p. D12). Vein strikes N. 35° E., dips 70° NW., is 3–6 m wide, and has a vertical range of at least 61 m; cuts two-mica granite and aphanitic dike rocks. Granitic wall rocks in and near the vein are sericitized and carry disseminated pyrite; aphanitic dike rocks are altered to sericite, chlorite, and carbonate minerals.
Interpreted as a Mesozoic fissure vein.
Cox (1970); Billings and Fowler-Billings (1975, p. 95).

5H-1 Jackson tin mine—Lat 44°09'00" N., long 71°09'25" W.; location approximate; on southwest side of Tin Mountain, about 2 km east-northeast of Jackson, N.H. Discovered by C.T. Jackson in 1840 and worked, probably intermittently, until about 1865. Small production, amount unknown.
Thin, sharply defined veins that cut metasedimentary schist or gneiss. Jackson (1844, p. 66–68) recognized four intersecting veins that strike N. 56° E., N. 60° E., N. 80° E., and N. 7° W. The ore is composed of massive cassiterite and small amounts of arsenopyrite, chalcopyrite, wolframite, fluorite, and molybdenite. Selected high-grade ore in veins as thick as 20 cm yielded as much as 30 percent tin.
Interpreted as fissure veins related to Jurassic Conway Granite.
Jackson (1844, p. 138–145); Hitchcock (1878, p. 66).

5H-2 Iron Mountain magnetite-phenacite mines—Lat 44°07'30" N., long 71°14'26" W. (upper workings); on south slope of Iron Mountain about 5.6 km southwest of Jackson, N.H. (grid 5H). Five small adits worked for iron prior to the Civil War.
Replacement lenses of magnetite and phenacite in the Conway Granite (Jwc). Composed of magnetite (about 80 percent) with irregular veinlets and aggregates of phenacite ($BeSiO_4$), danalite-helvite ($(FeMn)_4\ (Be_3Si_3)_{12}S$), drusy quartz, fluorite, and pyroxene, and small veinlets of galena, pyrite, and sphalerite. The weighted average beryllium content of ore samples is 0.9 percent BeO (Barton and Goldsmith, 1968, p. 65). Semiquantitative spectrographic analyses listed by Barton and Goldsmith (1968, table 19) indicated high iron and zinc and somewhat smaller lead contents, possibly as much as 3,000 ppm tin, and possibly as much as 1,000 ppm silver. The attitude of the ore lenses is strongly controlled by intersecting, steeply dipping joints whose average strikes are N. 43° E. and east-west.

Interpreted as a replacement body related to a possibly large hydrothermal system that developed soon after emplacement of the Conway Granite (Jwc).

Barton and Goldsmith (1968, p. 51–67); Hitchcock (1878, p. 57–60).

5H-3 Altered granite at South Moat Mountain—Lat 44°02'10" N., long 71°11'10" W.; location approximate; in stream that drains northeast slope of South Moat Mountain.

Evidence of the apical part of a Conway Granite pluton (Jwc) below the Moat Volcanics (Jwv); contact zone considered favorable for the occurrence of tin deposits. Spectrographic analyses indicated 150 ppm niobium and 500 ppm zinc in a sample of miarolitic-cavity-rich quartz porphyry exposed at the contact between the Conway Granite and the overlying Moat Volcanics. Spectrographic analyses indicated 150 ppm tin and anomalous amounts of bismuth and silver in a sample of thin quartz veins with greisen selvages obtained from the underlying Conway.

Interpreted as weak alteration and mineralization that occurred near the upper contact of the Conway Granite shortly after emplacement.

Cox (1990, occurrence G).

6E-1 Galena vein in West Branch of Clear Stream—Lat 44°49'05" N., long 71°17'08" W.; crops out at approximate elevation of 610 m in stream.

Vein, about 30 cm wide, that strikes north and dips steeply; contains galena and probably sphalerite.

Interpreted as a Mesozoic fissure vein.

N.L. Hatch, Jr. (1958–60 field observations).

6E-2 Simms Stream copper occurrence—Lat 45°49'13" N., long 71°26'27" W.; small outcrops in bed of Simms Stream about 122 m downstream from confluence with Uran Brook. Not developed. Outcrops not recovered when looked for by R.H. Moench in 1995; possibly buried by stream action. The occurrence, though small, suggests that the belt of metavolcanic rocks of the Frontenac Formation (Srwv) extending from the Gore Mountain plutons (index 43) to the Ledge Ridge prospect (5D-1) has potential for the occurrence of VMS deposits.

Strongly banded, slip-cleaved, probably silicified chlorite-amphibole schist containing pockets of chalcopyrite, pyrrhotite, and probable sphalerite intergrown with amphibole.

Interpreted as a possible Besshi-type VMS deposit hosted by distal metavolcanic rocks of the Frontenac Formation (Srwv).

L.J. Cox and M.J. Carnese (field observations, July 12, 1982).

6F-1 Milan massive-sulfide mine—Lat 44°33'55" N., long 71°15'38" W.; on west side of an eastern tributary to the North Branch of the Upper Ammonoosuc River; about 5 km southeast of West Milan, N.H. (grid 6F). Water-filled open stope about 52 m long, four shafts, a large dump, and extensive underground workings. Operated through a 81-m shaft (main shaft, at bottom of open stope) with levels at 21, 27, 38, and 81 m; aggregate length of levels about 457 m. The deposits were discovered in the 1870's and worked steadily until 1886, with a monthly production of 2,600 tons; opened again in 1895, when 1,500 tons were mined. Regular shipments were made from 1907 to 1910, and the mine was closed in 1911. From 1895 on, the deposits were mined primarily for pyrite used in the manufacture of sulfuric acid, but copper-rich ore was hand picked and smelted for copper. Total production was probably about 500,000 tons.

Two deformed, metamorphosed, semiconcordant, overlapping lenses of ore separated by 3–4.5 m of schist; ore bodies strike north-northeast and dip steeply west (Emmons, 1910, p. 54–59). The southern ore body, as wide as 8 m, is developed near the surface for a distance of 84 m; northern ore body, as wide as 4.6 m, is developed for a distance of 168 m. In decreasing order of abundance, ore minerals are pyrite, sphalerite, chalcopyrite, sparse galena, and secondary bornite and chalcocite. Solid massive pyrite is common; some ore is massive sphalerite, pyrite, chalcopyrite, and sparse galena. Locally, massive white quartz containing specks of pyrite and galena occurs structurally above the ore; ore that lies below the white quartz is pyrite and chalcopyrite cut by paper-thin films of secondary chalcocite. The ore contains as much as 1/4 oz gold per ton, which appears to be richer in copper-rich ore. An analysis of cobbed shipping ore showed 2.25 percent copper, 1.57 percent lead, and 7.26 percent zinc (Emmons, 1910, p. 52). A specimen of slip-cleaved pyrite-rich schist collected from the dump contained a veinlet of coarse pyrite, less chalcopyrite, and a little galena. Combined fire assay and atomic absorption analyses of the veinlet showed 20.6 ppm gold and 60 ppm silver (Breedon and Thomas, analysts); spectrographic analyses of this material indicated 3,000 ppm barium, 70,000 ppm copper, 1,500 ppm lead, and 7,000 ppm zinc (B.W. Lantham, analyst). These data accord with Emmons' suggestion that gold is richer in copper-rich ore, and also suggest that ore is richest where it is redistributed along cross fractures.

Field observations in the mine area indicate that the ore bodies, in Ammonoosuc Volcanics (Olv), occur conformably within stratified felsic and mafic metavolcanic rocks, stratigraphically below unaltered amphibolite exposed northwest of the main open stope, and within and above a strongly altered, predominantly felsic metavolcanic sequence exposed southeast of the stope. Altered, massive, fine-grained metafelsite exposed in the tributary (just east of a slag pile) about 75 m southeast of the stope is interpreted as part of a rhyolite dome; it contains about 35 percent quartz, 55 percent potassium feldspar, and 10 percent biotite and magnetite. Exposed between the metafelsite and the stope is thinly stratified hornblende-sericite-quartz-chlorite schist, chlorite-biotite-sericite schist, felsic metatuff, and probable metachert, and pyritic quartz-muscovite schist and metachert. On the footwall of the stope is pyritic cordierite-magnesium-chlorite schist, possibly part of an alteration pipe. At the hanging wall of the stope is 15 cm of pyritic chlorite-quartz schist containing sphalerite and sparse chalcopyrite; this material represents the ore horizon. Combined fire assay and atomic absorption analysis of this material showed 0.3 ppm gold (Breedon and Thomas, analysts); spectrographic analyses indicated 10 ppm silver, 3,000 ppm barium, 10,000 ppm copper, 3,000 ppm lead, and 30,000 ppm zinc (B.W. Lantham, analyst). The ore horizon is succeeded 0.6 m to the northwest by hornblende-epidote amphibolite, and then by normal, thinly bedded hornblende-plagioclase amphibolite, which is exposed in the stream bed about 23 m north of the stope.

Interpreted as a Kuroko-type VMS deposit, locally redistributed and enriched in precious metals along cross fractures.

Emmons (1910); Eric (1943); R.H. Moench (1969 and 1979 field observations); Gair and Slack (1979); Earl (1950). Interpretation by R.H. Moench.

6F-2 Sulfide occurrence east of Hodgdon Hill—Lat 44°33'10" N., long 71°15'40" W.; along logging trail near beaver ponds at azimuth N. 83° E., 1,555 m from top of Hodgdon Hill, approximate elevation of 311 m. Not developed.

Deeply rusty and bleached, pyrite-rich felsic gneiss and gossan, hosted by Ammonoosuc Volcanics (Olv). Spectrographic analysis of a gossan sample yielded 5 ppm silver, 1,500 ppm copper, 150 ppm lead, and 700 ppm zinc (J.A. Domenico, analyst); a trace of gold (0.05 ppm) was detected by atomic absorption analysis (J. Sharkey, analyst). Unaltered agglomeratic basaltic amphibolite is exposed about 41 m to the northwest, presumably at a higher stratigraphic level.

Interpreted as the outcrop of a possible Kuroko-type VMS deposit.

R.H. Moench (1979 field observations).

6F-3 Twitchell and Mason(?) copper prospect—Lat 44°33'52" N., long 71°17'45" W.; on hillside at approximate elevation of 384 m, about 3.5 km south of West Milan. Prospect pit, bulldozer scrapings, and evidence of geochemical sampling and drilling in the area. Tentatively considered to be the Twitchell and Mason deposit mentioned by Hitchcock (1878, p. 47–48), and not the Nay Pond prospect of Gazdik and others (1988) and Barton and Stewart (1976). According to Barton and Stewart (1976), Standard Metals Corporation of Portland, Maine, considered plans to mine zinc-copper ore from the deposit.

Lenses of pyrrhotite-rich schist as much as 15 cm thick with massive chalcopyrite in deformed discordant layers; layering strikes N. 55° W. and dips at a shallow angle to the northeast. Hanging wall is dark, sulfide-rich chlorite-sericite schist. Footwall is pyritic quartz-muscovite schist and metachert(?).

Interpreted as a transposed VMS deposit in Ammonoosuc Volcanics (Olv).

R.H. Moench (1979 field observations); Hitchcock (1878); Barton and Stewart (1976); Gazdik and others (1988).

6F-4 Nay lead prospect—Lat 44°33'35" N., long 71°17'20" W.; location approximate.

Described by Hitchcock (1878, p. 47) as "***a seam running northwest, though tending to take the northeast course of the strata, which contains argentiferous galena." Hosted by Ammonoosuc Volcanics (Olv).

Probably an argentiferous galena-bearing crosscutting vein, possibly akin to the veinlets containing abundant precious metals seen in an ore specimen from the Milan mine dump (6F-1).

Hitchcock (1878, p. 47). Interpretation by R.H. Moench.

6F-5 Route 110 iron-formation occurrence—Lat 44°33'17" N., long 71°17'00" W.; a prominent outcrop on the east side of Route 110, about 5 km south of the intersection of Routes 110 and 110A at West Milan. Not developed.

A layer of magnetite iron-formation as thick as 20 cm, underlain to the northwest by rusty-weathering, mesh-veined, probably altered metarhyolite (possibly the top of a rhyolite dome), and overlain to the southeast by amygdalloidal basaltic amphibolite that shows no evidence of premetamorphic alteration.

Interpreted as volcanogenic iron-formation in a setting that might be peripheral to a VMS deposit.

J.L. Schneider and R.H. Moench (September 9, 1979 field observations).

6F-6 Dummer Ponds altered granite occurrence—Lat 44°41'13" N., long 71°15'51" W.; small bulldozed pit on side of logging road.

Rubble and outcrop of altered two-mica granite of Long Mountain pluton (index 40). Has orange rust spots in matrix and on joint surfaces, and locally contains disseminated pyrite and arsenopyrite(?). Similar altered granite exposed about 300 m farther northwest along road suggests that the alteration zone is extensive.

Interpreted as hydrothermal alteration and weak mineralization evolved during cooling of the pluton.

R.H. Moench (September 6, 1991 field observations).

6H-1 Weakly mineralized Moat Volcanics at Mount Tom—Lat 44°12'50" N., long 71°27'25" W.; location approximate; on southwest side of northwest spur of Mount Tom.

Evidence of weak mineralization near the contact of Conway Granite (Jwc) and overlying Moat Volcanics (Jwc). Spectrographic analyses of one of many aplite dikes that intrude basalt of the Moat indicated 200 ppm tin and 200 ppm beryllium, and analyses of unaltered felsic volcanics of the Moat indicated anomalous amounts of tin, beryllium, lead, and bismuth. The underlying Conway Granite (contact not exposed) has features of a cupola zone favorable for the occurrence of tin deposits.

Occurrence is interpreted as an expression of tin mineralization near cupola of a Conway Granite pluton.

Cox (1990, occurrence J).

6H-2 Bemis Brook altered granite occurrence—Lat 44°08'50" N., long 71°22'45" W.; in Bemis Brook approximately 1,311 m upstream from U.S. Highway 302.

The occurrence is at the western contact of an oval body of a fine-grained facies of the Conway Granite (**Jwc**) against a larger body of Mount Osceola Granite (of **Jwu**). The exposed contact is a weakly mineralized, subvertical alteration zone about 3 m wide. The altered granite contains disseminated pyrite and fluorite and is cut by quartz veins as much as 2.5 cm thick. Spectrographic analyses indicated that the altered and nearby unaltered granites and the quartz veins contain anomalous amounts of tin and bismuth. The altered rocks also carry anomalous amounts of molybdenum and lead, and the veins carry anomalous amounts of beryllium, zinc, manganese, and silver. The entire contact zone is thought to be favorable for the occurrence of tin deposits.

Probably similar in origin to Bartlett Brook polymetallic sulfide occurrence (6H-4).

Cox (1990, occurrence L).

6H-3 Mount Carrigain altered granite occurrence—Lat 44°06'10" N., long 71°25'50" W.; location approximate; on southeast slope of Vose Spur of Mount Carrigain.

Weakly altered, high-level facies of Conway Granite (**Jwc**) chilled against quartz syenite. Granite is gray and contains scattered miarolitic cavities and sparsely disseminated pyrite and molybdenite. Adjacent quartz syenite is cut by quartz veins with dark-gray alteration selvages. Spectrographic analysis of vein and selvage material indicated anomalous amounts of tin, beryllium, and molybdenum.

Occurrence is interpreted as an expression of tin mineralization near the cupola of a Conway Granite pluton.

Cox (1990, occurrence N).

6H-4 Bartlett Brook polymetallic sulfide occurrence—Lat 44°02'53" N., long 71°16'07" W.; along Bartlett Brook between elevations 390 and 409 m, about 3.2 km south of Bartlett, N.H.

Near upstream end of outcrops, pervasively altered and fractured, yellowish-red and black-stained rocks are exposed intermittently along the contact between Conway Granite (**Jwc**) and Mount Osceola Granite (of **Jwu**). The most strongly altered and mineralized rocks occur in a subvertical, east-west-trending shear zone, about 0.9 m wide, distinguished by yellow, kaolinized feldspar and containing disseminated fluorite, brown to black sphalerite, and galena. Spectrographic analyses of this material indicated more than 10,000 ppm zinc, 500–5,000 ppm lead, and as much as 200 ppm tin and 30 ppm silver (Cox, 1990, table 7). Less altered or unaltered granite exposed 488 m downstream to the north carries a smaller but still anomalous amount of zinc.

Cox (1990) inferred that the Bartlett Brook occurrence formed near the roof of the host stock of Conway Granite (**Jwc**); by analogy with similar zinc-rich occurrences in Nigeria, this deposit may be underlain by mineralized rock that is richer in tin. She suggested that the contact zone of the Conway Granite south of the Saco River valley should be explored for tin, particularly at elevations above 396 m.

Cox (1990, occurrence H).

7E-1 Monadnock Mountain sulfide occurrence—Lat 44°53'50" N., long 71°32'40" W.; location approximate. Possibly several occurrences at unspecified locations on mountain.

Shear zones containing galena, chalcopyrite, sphalerite, and pyrite in Jurassic syenite of Monadnock Mountain plutons (index 44).

Epigenetic veins of Jurassic age.

Myers (1964, p. 65).

7E-2 Norton gold(?) prospect—Lat 44°53'55" N., long 71°31'11" W.; at approximate elevation of 488 m on east side of Monadnock Mountain. Site consists of abundant rock quarried from the mountainside.

As described by Laurel Woodruff (written commun., December 1986), the deposit is composed of about 18 cm of crumbly, micaceous, altered rock with abundant pyrite along the contact between syenite (of **Jwu**) of the Monadnock Mountain plutons (index 44) and a dike of quartz bostonite. Although called an old gold mine by local residents, no gold was detected by analyses of several samples.

Interpreted as Jurassic or Cretaceous epigenetic vein and alteration.

Laurel Woodruff (written commun., December 1986); Wolff (1929, 1930).

7F-1 Granby Stream copper-molybdenum-quartz occurrences—Lat 44°38'40" N., long 71°41'20" W.; on west bank of Granby Stream about 300 m northeast of the Granby-Ferdinand town line. Also lat 44°38'55" N., long 71°41'10" W., about 518 m farther downstream, within sight of a logging road bridge.

Upstream occurrence is a sharp-walled tabular quartz vein about 1.2 m thick that cuts interbedded chlorite-actinolite greenstone, biotite-rich schist, and feldspathic biotite schist that is tentatively assigned to the Gile Mountain Formation (of **Dc**). The host rocks contain conspicuous pyrrhotite and sparse chalcopyrite. Vein strikes N. 85° W., dips 87° N., and is composed of coarsely crystallized quartz, sparsely disseminated molybdenite, and scattered clots of coarsely crystallized chalcopyrite. Spectrographic analyses of a chalcopyrite-rich clot yielded 5 ppm silver, 2,000 ppm copper, and 200 ppm molybdenum (B. Adrian and A. Erlich, analysts); spectrographic analyses of a chip sample representing the full width of the vein yielded 0.5 ppm silver, 200 ppm copper, and 300 ppm molybdenum (same analysts). Gold was detected in the clot by atomic absorption analysis, but below detection limit (0.05 ppm) (P. Hageman, analyst). A short distance downstream are smaller, lenticular quartz veins that conform to the northeast-trending schistosity. At the downstream occurrence, conformable lenticular quartz veins as much as 0.5 m thick contain sparse chalcopyrite, which is particularly associated with dark-colored, chloritic slivers. Spectrographic analyses of this material yielded no detected silver, 700 ppm copper, and 5 ppm or less of molybdenum (same analysts); no gold was detected by atomic absorption analysis (same analyst).

Crosscutting Mesozoic veins.

Johansson (1963, p. 83); R.H. Moench (1986 field observations).

7F-2 Bear Mountain lead occurrence—Lat 44°38'00" N., long 71°34'55" W.; at approximate elevation of 503 m on west slope of Bear Mountain. Not developed.

Small quantities of galena and pyrite in shear zones that strike about N. 15° E. in massive, gray, chert-like quartzite.

Probable Mesozoic epigenetic vein along a minor brittle fault.

Johansson (1963, p. 83).

7F-3 Morse Mountain lead-copper occurrence—Lat 44°37'10" N., long 71°32'29" W.; in large roadcut on U.S. Highway 3, about 3.2 km north of Groveton, N.H. Not developed.

Fissure veins along and adjacent to a small normal fault in sulfidic quartzite and hornfelsic black phyllite Smalls Falls Formation (of Srp). The principal vein ranges in thickness from zero to as much as 30 cm, in a breccia zone; strikes N. 25°–60° E., dips 40°–70° NW. The vein is thickest on the steepest part, which indicates a normal sense of movement; contains drusy quartz, calcite, conspicuous sphalerite and galena, and minor chalcopyrite. Spectrographic analyses showed 50 ppm silver, 300 ppm copper, 300 ppm molybdenum, more than 2 percent lead, and more than 1 percent zinc (B. Adrian and A. Erlich, analysts). Atomic absorption analysis of this material indicated 0.05 ppm gold (P. Hageman, analyst). Several thin veinlets of massive pyrite and chalcopyrite that strike N. 10°–25° E. and dip 60°–85° E. splay off the footwall; they are 1 mm to 1 cm thick and are sparsely distributed through about 2.1 m of rock immediately below the footwall. Spectrographic analyses of massive pyrite yielded 1 ppm silver, 2,000 ppm copper, 5 ppm molybdenum, 100 ppm lead, and no detected zinc (same analysts). Atomic absorption analysis of the same material detected gold, but below detection limit (0.05 ppm) (P. Hageman, analyst).

Interpreted as Mesozoic epigenetic veins.

R.H. Moench (1985 field observations).

7F-4 Washburn Brook copper occurrence—Lat 44°35'43" N., long 71°38'28" W.; on north bank of Washburn Brook, azimuth N. 19° E. from summit of Burnside Mountain. Not developed.

Layer of chalcopyrite-bearing, silicate-facies iron-formation about 0.5 m wide associated with dark-gray to greenish-gray, magnetite-bearing schist and granofels, magnetite-chlorite-quartz iron-formation, and basaltic greenstone of Ironbound Mountain Formation (Dp). This sequence of rocks crops out over a width of about 90 m, and occurs within a large body of gray, commonly magnetite-bearing pelitic schist of the formation. The chalcopyrite-bearing zone is chlorite-garnet-quartz schist containing several percent magnetite and subordinate chalcopyrite. Spectrographic analyses of this material yielded approximately 20 percent iron, more than 5,000 ppm manganese, 5 ppm silver, 5,000 ppm copper, and 200 ppm zinc (D.E. Detro, analyst). Spectrographic analyses of the magnetite-chlorite-quartz iron-formation (without chalcopyrite) collected nearby yielded about 20 percent iron, more than 5,000 ppm manganese, 7 ppm silver, and negligible copper (D.E. Detro, analyst). Trace amounts of gold (0.05 and 0.2 ppm) were detected in both samples by atomic absorption analyses (P. Hageman, analyst).

Interpreted as a small Besshi-type, volcanogenic copper deposit hosted by silicate iron-formation of Early Devonian age.

R.H. Moench (1984 field observations).

7F-5 Flynn Hill lead occurrence—Lat 44°32'44" N., long 71°36'10" W.; just west of top of Flynn Hill. Not developed.

Traces of galena and pyrite in quartz associated with fault that strikes N. 15° E. Host is granite of Lost Nation pluton (index 53).

Probable Mesozoic epigenetic vein along a minor brittle fault.

Johansson (1963, p. 83).

7F-6 Bolles Hill pyritic copper prospects—Lat 44°32'33" N., long 71°37'25" W.; on west slope of a hill known locally as Bolles Hill. Small workings. Several small pits also occur at and near the prospect and are shown about 0.8 km south-southwest.

Minor amounts of pyrite and chalcopyrite in quartz veins(?). Hosted by interbedded green phyllite, feldspathic quartzite, and fine-grained felsic metatuff, locally intruded by quartz porphyry, of the Perry Mountain Formation (of **Srpv**).

Tentatively interpreted as small stratabound pyritic copper deposits, possibly redistributed along crosscutting veins.

Johansson (1963, p. 82).

7G-1 Prospect near Dalton—Lat 44°24'53" N., long 71°41'30" W.; water-filled pit and small dump on a small knoll in woods about 300 m southeast of center of Dalton village. Probably not the Dalton mine described by Hitchcock (1878, p. 47).

When visited in 1986, several fragments of vein quartz showing evidence of the former presence of a carbonate mineral but no sulfide minerals were found on the dump. The host is strongly foliated pyritic quartz-sericite schist and metamorphosed quartz porphyry, which has euhedral crystals of blue quartz in a matrix of fine-grained schist.

Probably sulfide-bearing quartz-carbonate veins that cut pyritically altered felsic metatuff of the Ammonoosuc Volcanics (**Olv**).

R.H. Moench (1986 field observations).

7G-2 Prospect southwest of Dalton—Lat 44°22'57" N., long 71°44'27" W.; on hilltop 5 km southwest of Dalton and 2 km south of Connecticut River. Open pit about 3x4.5 m across, with rubble and water at a depth of 4.5 m; possibly prospected for quartz specimens.

Greenstone sill that strikes N. 50° E., dips 58° NW., and emplaced approximately along the contact between metavolcanic facies (**Dpv**) and overlying gray pelitic slate (**Dp**) of Ironbound Mountain Formation (**Dp**), within the Towns Mountain outlier (TMO). The greenstone is crossed by many irregular, commonly vuggy quartz veins, some with orange gossan. Although spectrographic and atomic absorption analyses of the veins revealed no unusual metal contents [analysts: B. Adrian and A. Erlich (spectrographic), and P. Hageman (atomic absorption)], the adjacent country rock at the pit and about 100 m along strike to the southwest contains sparse malachite.

Evidence of minor volcanogenic copper mineralization.

R.H. Moench (1985 and 1994 field observations).

7G-3 Dalton(?) prospect—Lat 44°27'30" N., long 71°42'45" W.; location approximate; plotted from Gazdik and others (1988), who obtained the location from Meyers and Stewart (1955).

If this is the Dalton prospect described by Hitchcock (1878, p. 47), the deposit has a gangue of talc-bearing schist about 5 m wide crossed by numerous quartz veins, "***often carrying fine specimens of the purple ore, or bornite." As mapped, appears to be hosted by poorly stratified pyritic quartz-muscovite schist in lower part of Ammonoosuc Volcanics (**Olv**), near contact with unconformably overlying conglomerate (**Dns**) of Littleton Formation.

Interpreted as crosscutting quartz veins containing copper.

Hitchcock (1878, p. 47). Tentative location from Gazdik and others (1988). Interpretation by R.H. Moench.

7G-4 Crane molybdenite prospect—Lat 44°21'30" N., long 71°37'20" W.; location approximate; on north ridge of Kimball Hill, about 1.6–2.4 km south of Whitefield. Two prospect shafts, 7.6 and 12 m deep; no production.

Quartz vein, about 8 cm wide, containing molybdenite crystals; exposed length about 45 m. Cuts granitic rock of Jefferson batholith (index 63), but shown near contact with Ammonoosuc Volcanics.

Quartz vein of unknown age; possible hint of molybdenum mineralization associated with Ordovician granitic rocks.

Gazdik and others (1988, table 2).

7H-1 Brook and Company lead prospect—Lat 44°10'05" N., long 71°42'40" W.; location uncertain; small open pit at low elevation on west slope of Cannon Mountain, north of Coppermine Brook.

Probably a small galena-bearing quartz vein.

Probably a Mesozoic vein.

Moench and others (1984); Hammack and Girol (1982).

7H-2 Coppermine Brook copper mine—Lat 44°10'38" N., long 71°44'53" W.; on banks of Coppermine Brook. Small overgrown trenches and pits, and possible underground workings extending to a depth of about 60 m. According to information acquired by Hammack and Girol (1982), ore from the mine was smelted at Franconia; the quantity must have been small.

Stratabound copper deposit along the contact between mafic and felsic metavolcanic rocks of the Littleton Formation (of **Dcv**). Where exposed at the entrance to a trench on the north bank of the brook, the ore-bearing zone is about 28 cm thick and is divisible into two parts. The structural upper part is about 15 cm thick and is composed of fine-grained siliceous mica schist that contains a few percent of disseminated chalcopyrite. Atomic absorption analyses of this rock showed 0.4 ppm gold (T. Huyck, analyst). Spectrographic analyses of the same material indicated more than 1 percent arsenic, 70 ppm bismuth, 200 ppm cobalt, and 5,000 ppm copper (D.E. Detro, analyst). The lower part is 13 cm thick and is composed of mottled amphibolite, probably altered from basalt prior to metamorphism. Atomic absorption analyses of this rock showed 0.2 ppm gold, and spectrographic analyses revealed 50 ppm bismuth, 70 ppm cobalt, and 5,000 ppm copper (same analysts). The ore-bearing zone is underlain by massive, unaltered basaltic amphibolite, and it is overlain by thickly layered, light-gray biotite-quartz-feldspar gneiss interpreted as felsic metatuff.

Interpreted as a small VMS deposit of Early Devonian age; probably accumulated in a small depression at the top of a basalt flow.

Moench and others (1984); Hammack and Girol (1982); R.H. Moench (1983 field observations).

7H-3 Mount Hitchcock altered granite occurrences—Lat 44°04'35" N., long 71°33'10" W.; location approximate; in brook bed at an elevation of about 854 m west of summit of Mount Hitchcock, and to the northwest in same brook bed at an elevation of about 427 m.

At the topographically higher locality, altered Conway Granite (**Jwc**) contains anomalous amounts of tin, copper, bismuth, and disseminated pyrite, sphalerite, ilmenite, niobium-bearing rutile, and magnetite. At the lower locality, fresh Conway Granite is intruded by many felsic and aplitic dikes, and contains anomalous amounts of tin and niobium.

Cox (1990) suggested that the roots of a greisen system are exposed at shallow depth below the present surface on the west side of Mount Hitchcock.

Cox (1990, occurrence O).

8E-1 Westmore altered granite occurrence—Lat 44°45'30" N., long 72°02'00" W.; a small area (about 1.5x3 km) of weakly altered granite in Willoughby pluton (index 47) centering about 2.7 km southeast of Westmore village, just west of long 72° W.

A small zone of hydrothermally altered, leached, and silicified pegmatitic leucogranite described by Ayuso and Arth (1992). Within the zone are pyrite clusters and trace amounts of very fine grained sulfide minerals, concentrated along fractures. The altered granite contains as much as 26 ppm tin, 11 ppm beryllium, 670 ppm rubidium, 310 ppm lithium, 13.1 ppm tantalum, and 10.7 ppm uranium. Abundances of these elements are significantly lower in less altered granite of the Willoughby pluton outside the altered zone, and lower still in granitic rocks of the other plutons of the Northeast Kingdom batholith that were studied by Ayuso and Arth [1992; Echo Pond and Nulhegan (indexes 46A, 46B, 48), and, west of the map area, West Charleston and Derby plutons]. The Willoughby is the only pluton of the batholith containing abundant miarolitic cavities, aplites, and pegmatitic segregations.

Ayuso and Arth (1992) interpreted the Northeast Kingdom batholith as a comagmatic suite of quartz gabbro, quartz diorite, quartz monzodiorite, granodiorite, and granite. The Willoughby leucogranite is the most evolved pluton; its high concentrations, particularly in the alteration zone, of some commercially used minor and trace elements are probably due to late-magmatic fluid and vapor phases.

Ayuso and Arth (1992).

8G-1 Essex copper prospects—Northern location, lat 44°23'40" N., long 71°50'19" W; one or more small pits and waste dumps obscured by vegetation. Southern location, lat 44°23'31" N., long 71°50'24" W., about 300 m S. 25° W. of northern location, on a small knoll [elevation 503 m (1,650 ft)] on ridge that leads southwest from the main hilltop [elevation 512 m (1,680 ft)]; small water-filled shaft and waste dumps.

Deposit at southern location consists of thin conformable layers composed chiefly of quartz, feldspar, pyrite, chalcopyrite, and bornite (Eric and Dennis, 1958, p. 62). According to R.H. Moench (1996 mapping), deposit occurs just east of the inferred trace of the Foster Hill fault, along or near contact of quartzite and slate of Dead River Formation (of **O€f**) with overlying felsic metavolcanic rock and pyritic quartz-muscovite schist of Ammonoosuc Volcanics. Near northern location, R.H. Moench (1994 field observations) found a conformable, 5- to 10-cm layer of coarsely intergrown quartz, pyrite, and sparse chalcopyrite hosted by pyritic quartz-muscovite schist.

Interpreted as small pyritic copper VMS deposits near lower contact of weakly to strongly hydrothermally altered felsic tuff of the Ammonoosuc Volcanics (**Olv**). Probable heat source was Joslin Turn pluton (index 57) and related intrusives, emplaced at approximately the same stratigraphic horizon.

Eric and Dennis (1958, p. 62); R.H. Moench (1985–96 field observations).

8G-2A Altered metatuff northeast of Concord Corner—Lat 44°24'22" N., long 71°50'06" W.; several small pavement outcrops distributed about 425 m along graded dirt road, centering about 2 km N. 75° E. of road intersection at Concord Corner, Vt. Amount of exposure varies with road grading.

Mainly pyritic quartz-sericite schist, locally containing sparsely disseminated chalcopyrite and secondary copper carbonate minerals.

Interpreted as metamorphosed, hydrothermally altered and locally mineralized felsic tuff of Ammonoosuc Volcanics (**Olv**).

R.H. Moench (1986 field observations).

8G-2B Pyritic iron-formation east of Concord Corner—Lat 44°23'52" N., long 71°49'13" W.; pavement outcrops along graded dirt road about 3.4 km S. 83° E. of road intersection at Concord Corner, Vt.

Layers as thick as 10 cm of pyritic iron-formation, hosted by poorly stratified, variably pyritized, fine-grained felsic metatuff and volcanic siltstone(?) of Ammonoosuc Volcanics (**Olv**). Iron-formation composed of subequal amounts of quartz, pyrite, and magnesium-chlorite, and sparse sericite.

Interpreted as volcanogenic pyritic iron-formation.

R.H. Moench (1986, 1994 field observations).

8G-3 Joslin Turn disseminated chalcopyrite occurrence—Lat 44°22'15" N., long 71°50'17" W.; at high point on power line about 1.3 km northeast of Joslin Turn, northwest of Moore Reservoir. Occurrences were found 3 m northeast of eastern foundation of brown steel pole of power line, and along logging road cut recently west of power line.

Chalcopyrite and secondary copper minerals are sparsely disseminated in unstratified, pyritic quartz-sericite schist, commonly having small quartz phenocrysts. These rocks, interpreted as altered and weakly mineralized felsic metatuff of Ammonoosuc Volcanics (Olv), are exposed on opposite sides of a 4-m-wide body of granophyric quartz diorite considered the north end of the Joslin Turn pluton. The pyritic-sericitic alteration zone extends eastward about 50–75 m, stratigraphically downward into rocks of the Dead River Formation (O€f), below the Ammonoosuc.

Interpreted as metamorphosed, hydrothermally altered, weakly copper-mineralized felsic tuff near the lower contact of the Ammonoosuc Volcanics. Alteration system probably driven by heat from the Joslin Turn pluton.

R.H. Moench (1985, 1994, 1995 field observations).

8G-4 Quint (White Mountain) copper-quartz-carbonate prospect—Lat 44°19'02" N., long 71°54'08" W.; on south side of a beaver swamp about midway between Caswell and Reynolds Ponds (grid 8G). Short adit driven south into hillside, and numerous dumps on south side of swamp. When visited by Hitchcock in 1869, this was the most thoroughly explored property in the region. He noted several mine buildings and a shaft sunk to a depth of 30 m. No reported production.

Several lenticular, semiconcordant quartz-ankerite veins as thick as 30 cm, and thinner discordant veins, in a zone at least 12 m wide; hosted by schistose felsic metatuff of Ammonoosuc Volcanics (of Olv). One fragment of vein material found on the dump contains a clot of fine-grained ultramafic rock and green, probably chromium-bearing mica. According to Hitchcock (1878, p. 46), the veins, which contain quartz, ankerite, pyrite, chalcopyrite, and chlorite, yielded beautiful ore specimens.

Mesozoic epigenetic fissure veins.

Hitchcock (1878, p. 46); R.H. Moench (1985 field observations).

8G-5 Gregory extension copper prospect—Lat 44°19'02" N., long 71°55'00" W.; on north slope of Mining Hill. Small open pit.

Pyritic quartz vein several inches thick within a breccia of somewhat altered pyritic phyllite and quartzite. Atomic absorption analysis of the vein yielded 0.25 ppm gold (T. Huyck, analyst); spectrographic analysis indicated 1,500 ppm copper (D.E. Detro, analyst).

Premetamorphic vein and dissemination containing metals possibly redistributed from nearby pyritic copper VMS deposits in Perry Mountain Formation (of Srp).

R.H. Moench (1985 field observations).

8G-6 Gardner Mountain (Albee) copper mine—Lat 44°19'38" N., long 71°56'36" W.; on east side of Albee Hill. Water-filled shaft to depth of 21 m(?); mine dump about 8 m across and 3 m high. No reported production, but pile of dressed ore noted by Hitchcock (1878, p. 39) suggests that small shipments might have been made.

Ore not exposed. The most abundant material in the dump is pyritic siliceous phyllite, a few fragments of which have massive pyrite and cross veinlets of quartz and ankerite. A small stockpile of dressed ore seen by Hitchcock (1878, p. 39) contained fragments of massive pyrite intergrown with quartz, pyrrhotite, and sparse chalcopyrite. The host rock is rusty-weathering, pyritic, tuffaceous metasandstone interbedded with greenish-gray phyllite of the Perry Mountain Formation (of Srp). Hitchcock (1878) greatly overestimated the width of the deposit, possibly because he estimated width subparallel to bedding, which here is at a wide angle to schistosity.

Tentatively interpreted as a small pyrtic copper VMS deposit.

Hitchcock (1878, p. 38–39); R.H. Moench (1986 field observations).

8G-7 Gregory copper mine—Lat 44°19'10" N., long 71°56'07" W.; on south side of Mining Hill. Shafts to depths of 18 or 21 m (at least one with short drifts) and shallow pits; not visited during this study. Probable small production. Hitchcock (1878, p. 40) reported "***one lot of twelve tons of seven percent (copper) ore has been sold from the barn shaft, and much remains there dressed to about the same proportion."

Wide belt of pyritic schist carrying chalcopyrite-rich bands, several centimeters to a meter or so thick, and massive chalcopyrite associated with quartz "bunches."

Tentatively interpreted as a small pyritic copper VMS deposit.

Hitchcock (1878, p. 39–40).

8G-8 Carter(?) copper prospect—Lat 44°18'50" N., long 71°56'03" W.; at elevation of 396 m approximately 1 km south of Mining Hill. Two short trenches (one water filled) driven into hillside; dump about 4.5 m across.

Small stockpile contains blocks of bleached, silicified, pyritic schist with pockets of pyrrhotite and a trace of chalcopyrite. Host is pyritic schist and feldspathic quartzite of the Perry Mountain Formation (of Srp).

Interpreted as a small pyritic copper VMS deposit.

R.H. Moench (1986 field observations).

8G-9 Paddock massive-sulfide mine—Lat 44°16'47" N., long 71°58'20" W.; shaft at elevation of 534 m southeast of Signal Mountain, which is the highest point on Gardner Mountain. This shaft is probably the Osgood mine, or No. 1 shaft. An adit and the main dump are downhill to the southeast, at an elevation of 494 m. In April 1878, No. 1 shaft was 52 m deep, with drifts at 18 and 37 m. Gair and Slack (1979) estimated that the mine produced less than 50,000 tons of ore. In 1880, about 34,000 lbs of copper was smelted from ore produced by the mine (Weed, 1911). The Paddock mine was the only important producer in the Gardner Mountain belt.

Hitchcock (1878) reported that good copper (chalcopyrite) ore 1.2–1.8 m wide was taken from levels off the No. 1 shaft; a 25-cm layer of massive, silver-bearing galena and sphalerite occurred along the footwall. At the No. 2 shaft (not found during this study), Hitchcock noted that veins as much as 60 cm wide cut across the strata; these veins were said to contain more copper than the "regular veins." The host rocks at the No. 1 shaft and adit are thickly interbedded, feldspathic quartzite, sparsely pyritic phyllite, and felsic crystal metatuff in the upper part of the Rangeley Formation (of Srp). Ore found by Moench at the adit consists of massive quartz, pyrite, and chalcopyrite. Atomic absorption analysis of this material yielded 0.3 ppm gold (T. Huyck, analyst); spectrographic analyses of the same material yielded 15 ppm silver, >20,000 ppm copper, and 1,000 ppm zinc (D.E. Detro, analyst).

On the basis of the rich cross veins, Hitchcock (1878, p. 43) inferred that the deposit is a "fissure lode." Here interpreted as a pyritic copper VMS deposit of Silurian age; the metals in the high-grade veins might have been redistributed from the primary sulfide deposit.

Hitchcock (1878, p. 42–43); Weed (1911, p. 16); Gair and Slack (1979); R.H. Moench (1983, 1995 field observations).

8G-10 Paddock copper-zinc prospect—Lat 44°16'24" N., long 71°58'18" W.; about 670 m southwest of the Paddock No. 1 shaft (8G-9); an open trench about 15 m long that trends N. 25°–30° W. across the strike of stratification.

The following rock sequence is exposed from northwest to southeast along the trench:

Zone A—2.1 m of sparsely pyritic quartz-sericite phyllite. Atomic absorption analyses yielded 0.15 ppm gold (T. Huyck, analyst), and spectrographic analyses yielded no silver or zinc, detectable arsenic, 50 ppm copper, and 10 ppm lead (D.E. Detro, analyst).

Zone B—6 m of quartz-sericite phyllite containing more pyrite than zone A and conspicuous disseminated chalcopyrite. Atomic absorption analyses yielded 0.3 ppm gold, and spectrographic analyses of the same material yielded 5 ppm silver, 200 ppm arsenic, 2,000 ppm copper, 500 ppm lead, and 2,000 ppm zinc.

Zone C—9 m of fragmented, white, massive quartzite in a matrix of quartz-sericite schist that contains veinlets of massive pyrite, chalcopyrite, and quartz. The veinlets, about 5 cm thick, are deformed fissure veins crossed by schistosity; a polished surface shows about 50 percent of corroded, anhedral pyrite in a matrix of quartz and sericite, and a few percent of patchy chalcopyrite elongate parallel to schistosity. Atomic absorption analyses of the vein material yielded 0.4 ppm gold, and spectrographic analyses of the same material yielded 15 ppm silver, 500 ppm arsenic, 10,000 ppm copper, 7,000 ppm lead, and 7,000 ppm zinc. Atomic absorption analyses of an ore fragment found in float downhill from the trench and presumed to have come from a crosscutting, pre-cleavage vein yielded 0.4 ppm gold, and spectrographic analyses of the same material yielded 10 ppm silver, 200 ppm arsenic, 20,000 ppm copper, 150 ppm lead, and 1,500 ppm zinc.

Zone D—At least 9 m of massive quartzite variably cut by irregular-shaped quartz veinlets. Atomic absorption analyses of the quartzite yielded 0.3 ppm gold, and spectrographic analyses of the same material yielded no silver, arsenic, or zinc, 100 ppm copper, and 20 ppm lead.

Interpreted as a pyritic copper VMS deposit, partly redistributed along fissures prior to metamophism; hosted by Rangeley Formation (of Srp).

R.H. Moench (1983 field observations); Hitchcock (1878, p. 20).

8G-11 Titus quartz-carbonate prospect—Lat 44°15'08" N., long 71°59'02" W.; about 152 m northwest of Moulton Hill Road. Probably a small adit.

Probably quartz-carbonate vein. Listed by Hitchcock (1878, p. 20) under "other quartz openings."

Mesozoic epigenetic fissure-vein.

Hitchcock (1878, p. 20). Interpretation by R.H. Moench.

8G-12 New England Mining gold mine (Cook and Brown)—Lat 44°15'13" N., long 71°55'40" W.; location approximate, just northwest of Stickney Road, about 1.9 km southwest of Ogontz Lake (Youngs Pond). Probably a shallow shaft. Ore reported to have been treated in Boston, yielding nearly $24 per ton (period price).

Described as a quartz vein about 25 cm wide containing crystals and bands of arsenopyrite, and said to contain visible free gold "in respectable quantity." Assay reported to yield as much as 20 oz silver and 2.0–5.0 oz gold per ton. Additionally, the schistose wall rocks carried arsenopyrite and gold. Occurs in a line of outcrops of Clough Quartzite (of Sns).

Mesozoic epigenetic fissure-vein; gold possibly redistributed from a fossil placer source in Clough Quartzite.

Hitchcock (1878, p. 25–26); Heylmun (1986). Interpretation by R.H. Moench.

8G-13 Dodge Pond sulfide occurrence—Lat 44°16'57"N., long 71°55'34"W.; near east side of south-flowing brook tributary to south end of Dodge Pond. Occurrence is on hillside about 6 m above brook, and about 244 m upstream from Dodge Pond Road.

Outcrop of 3-mm-thick vein of sphalerite, galena, chalcopyrite, and pyrite in a zone of sheared, bleached, carbonatized greenstone 30–35 m wide; mineralized zone strikes N. 35° E., parallel to the greenstone foliation, and dips 65° SE. Mineralized zone inferred to extend northeastward a distance of at least 800 m to outcrops of similarly altered greenstone on ridgetop [elevation about 370 m (1,220 ft)].

Mesozoic(?) shear zone of propylitic alteration and sulfide mineralization.

R.H. Moench (1995 field observations).

8H-1 Sugar Hill volcanogenic alteration occurrence—Lat 44°12'40" N., long 71°46'16" W.; low pavement outcrop about 9 m across in open field a short distance northeast of a large house on the southeast side of The Birches Road, about 91 m east of its intersection with Carpenter Road.

Stratified altered rocks of Ammonoosuc Volcanics that strike N. 70° W., and dip 60° SW. From northeast to southwest across strike, the observed sequence is: (1) 2 m of layered chloritic biotite-quartz-feldspar gneiss containing about 10 percent partly chloritized biotite; interpreted as weakly altered felsic metatuff. (2) 1 m of coarsely crystallized pyritic garnet-biotite gneiss with quartzofeldspathic lenses; interpreted as more strongly altered metatuff. (3) 3 m of chloritic quartz-feldspar gneiss with several irregular-shaped pipelike masses containing silicate iron-formation composed of richly pyritic garnet-chlorite-quartz-magnetite schist; pipes interpreted as channelways for hydrothermal solutions that leached calcium, potassium, and sodium from the original tuff bed. (4) About 7 m of white-weathering, porphyritic, fine-grained biotite-quartz-feldspar gneiss. Layer 4, which sharply overlies layer 3, is interpreted as felsic tuff that was deposited over the pipes subsequent to alteration.

Interpreted to represent part of a volcanogenic hydrothermal alteration system that vented onto the sea floor.

R.H. Moench (1983 field observations).

8H-2 Franconia iron mine—Lat 44°11'33" N., long 71°47'27" W.; at elevation of 479 m on south ridge of Ore Hill, about 5 km south-southwest of Franconia, N.H. Workings consist of several open cuts and pits, a shaft, and two short adits. Iron ore was mined principally between 1810 and 1870. The annual yield of the blast furnaces at Franconia village, furnished mainly by this mine, is said to have been about 250–500 tons of pig iron.

Conformable layers of banded quartz-magnetite iron-formation along the contact between basaltic amphibolite and pyritic quartz-muscovite schist, interpreted as altered rhyolitic tuff in Ammonoosuc Volcanics (Olv). The ore zone has a maximum thickness of about 15 m; most common rock is biotite-quartz schist, locally containing hornblende, interlaminated with nearly pure magnetite. The best ore is composed of alternating laminations, less than a few centimeters thick, of magnetite and quartz. Epidote and garnet are common along lamination boundaries. Epidote also occurs along cross fractures and in massive epidosite bodies along the contact between the ore zone and the pyritic quartz-muscovite schist.

Interpreted as stratabound, volcanogenic iron-formation.

Annis (1982; written commun., 1981); Hitchcock (1878, p. 56–57).

8H-3 Salmon Hole volcanogenic alteration occurrence—Lat 44°14'15" N., long 71°52'35" W.; on southeast bank of Ammonoosuc River, approximately 457 m east of intersection of Routes 302 and 117; outcrop is westernmost of two outcrops about 15 m apart that protrude into the river near the confluence of Salmon Hole Brook. Not developed.

An inferred west-topping sequence that includes: (1) At least 1.5 m of siliceous, pyritic felsic gneiss variably stained with manganiferous iron oxides; interpreted as hydrothermally altered probable rhyolite. (2) 10–30 cm of garnet-chlorite-anthophyllite gneiss with pockets of gossan; interpreted as silicate iron-formation and possible VMS. (3) At least 1.5 m of nonsulfidic felsic gneiss with sparse garnet; interpreted as unaltered postmineralization volcanic cover. Rock of the riverbank outcrop 15 m to the east is composed of thinly laminated fine-grained metasedimentary gneisses, with many laminations containing sunbursts of anthophyllite. These rocks are interpreted as altered tuffaceous and chemically deposited sediments. The locality is in the uppermost part of the Ammonoosuc Volcanics, near the contact with the overlying Partridge Formation.

Interpreted as a possible VMS "ore horizon" near the Ammonoosuc Volcanics–Partridge Formation contact.

R.H. Moench (1990 field observations); Moench (1993, p. DD26).

8H-4 Tunnel gold-quartz mine—Lat 44°14'16" N., long 70°55'23" W.; a short distance east of Dodge mine (8H-5). Adit driven with the purpose of intersecting the Dodge vein at depth. The Dodge vein was not reached, but small veins were encountered.

Specimens typical of the class consist of glassy quartz with fluid inclusions, ankerite, and a few striated cubes of pyrite; gold reported to occur with the pyrite. A little ore was mined, said to have assayed as high as $35 gold per ton (period price).

See Dodge mine (8H-5) for interpretation.

Ross (1923, p. 291–292); Heylmun (1986).

8H-5 Dodge gold-quartz mine—Lat 44°14'08" N., long 71°55'53" W.; about 3.2 km northwest of Lisbon village. At least three shafts (maximum reported depth 30 m) with drifts; abandoned before 1915. Hitchcock (1878, p. 11) estimated a total production of $50,000 (period price) from the town of Lisbon, mainly from this mine. Most productive deposit of "Ammonoosuc gold field." According to Heylmun (1986, p. 4), for a period of two years in the late 1860's the average tenor of ore was about 0.75 oz gold per ton.

Described as a quartz vein as much as 5 m wide that strikes northeast and dips northwest; contains masses of slate and crystals of pyrite, ankerite, and galena; spangles of free gold reported to occur, especially along quartz-slate contacts. Samples said to have an average assay of $18.90 gold per ton (period price).

One of several crosscutting epigenetic veins interpreted to have formed during brittle fracturing that was concentrated in the downdropped wedge between the Triassic Ammonoosuc and Bill Little normal faults (AF, BLF). Other veins of this setting are at 8G-12 and 8H-4, 6, 7, 8, 12, and 17.

Hitchcock (1878, p. 9–19); Heylmun (1986). Interpretation by R.H. Moench.

8H-6 Maine gold(?)-quartz prospect—Lat 44°14'19" N., long 71°56'43" W.; about 1.6 km west of Dodge mine (8H-5).

No description available.

See Dodge mine (8H-5) for interpretation.

Name and location obtained by R.H. Moench from local source.

8H-7 Little May gold(?)-quartz prospect—Lat 44°13'39" N., long 71°56'43" W.; location approximate; about 1.4 km west of Dodge mine (8H-5).

No description available.

See Dodge mine (8H-5) for interpretation.

Name and location obtained by R.H. Moench from local source.

8H-8 Bedell gold-quartz prospect—Lat 44°13'09" N., long 71°56'42" W.; location approximate; about 1.4 km southwest of Dodge mine (8H-5). Shallow shaft. No known production.

Vein about 0.6 m wide, probably similar in structure and mineralogy to vein at the Dodge mine (8H-5), but containing more galena. Hitchcock (1878, p. 19) claimed to have panned free gold from surface scrapings of the vein and reported reliable assays of $12 gold and $33 silver per ton (period price).

See Dodge mine (8H-5) for interpretation.

Hitchcock (1878, p. 19).

8H-9 Grafton quartz-carbonate prospect—Lat 44°14'22" N., long 71°59'27" W.; on north bank of Moulton Hill Brook about 150 m upstream from Moulton Hill Road. Trench, 1.5–3 m deep and about 38 m long, extends N. 40° E. from the brook; Hitchcock (1878) reported a shaft to depth of 23 m. No reported metal production. The ore was sold locally for fertilizer, but Hitchcock was skeptical of the testimonials about the powers of the "Grafton fertilizer."

Three veins, each about 30 cm thick, composed of massive ankerite or dolomite complexly laced by white quartz veinlets; contain narrow slaty partings. Hitchcock reported pyrite, galena, chalcopyrite, and free gold. The veins dip steeply and strike about N. 40° E. subparallel to schistosity; they occur in a zone about 45 cm wide in which the country rock is reddened by weathered ankerite. The country rock is poorly stratified, foliated greenstone of the Ammonoosuc Volcanics. Company assays showed $7 and $60 worth of gold per ton (period price) and a little silver. One 50-lb mass of quartz assayed 3.45 oz gold per ton.

See Dodge mine (8G-5) for interpretation.

Hitchcock (1878, p. 22–23); Heylmun (1986); R.H. Moench (1986 field observations).

8H-10 Haviland copper mine—Lat 44°14'13" N., long 71°59'48" W.; one of possibly several openings on the Haviland property. Adit, with water-filled pit at the entrance, driven N. 55° W. into hillside; small dump. Hitchcock (1878) reported a shaft sunk to depth of 52 m, a drift at depth of 21 m, and crosscuts at the bottom; probably not at this location. No reported production, but description of workings suggests that some mining occurred.

Fragments found at the dump are of pyritic quartzite or metachert, and massive pyrite. According to Hitchcock, four copper-bearing veins cross the property.

Probably a pyritic copper VMS deposit; stratigraphic correlation of host uncertain.

Hitchcock (1878, p. 40–41); R.H. Moench (1986 field observations).

8H-11 Pyritic prospect west of Smith Road—Lat 44°13'46" N., long 71°59'33" W.; prospect pit about 122 m west-northwest of Smith Road.

Stratified, bleached, pyritic quartz-sericite schist, fine-grained pyritic phyllite, and dense pyritic metachert. Atomic absorption analyses of pyritic schist and pyritic metachert obtained from a small prospect pit yielded 0.25 and 0.35 ppm gold (T. Huyck, analyst); spectrographic analyses did not show unusual amounts of other metals (D.E. Detro, analyst).

Probably a pyritic copper VMS deposit; stratigraphic correlation of host uncertain.

R.H. Moench (1983 field observations).

8H-12 Hartford (Grote property) gold-quartz prospect—Lat 44°13'36" N., long 71°59'48" W.; about 300 m northwest of Smith Road, and 180–400 m south of the Bath-Lyman town line. Shaft sunk to depth of 30 m. Prospect trenching and drilling in late 1980's (BP Minerals America, 1988). Said to have assayed $30 gold and $10 silver per ton (period price) at a depth of 7 m in the shaft. No reported production.

Thin quartz-ankerite veins containing sparse galena, other sulfide minerals, and native gold, which is commonly visible in hand specimens. The veins cut black phyllite of the Partridge Formation (Ole) and felsic metavolcanic rocks of the Quimby Formation (Ouv).

Mesozoic epigenetic fissure-veins.

Hitchcock (1878, p. 19–20); BP Minerals America (1988).

8H-13 Atwood gold-quartz mine—Lat 44°12'48" N., long 71°53'49" W.; near Gulf Road about 1.6 km east of Lisbon village. Shaft sunk to depth of 29 m and two shallower openings nearby. Said to have yielded about $300 worth of gold (period price).

Quartz vein in Clough Quartzite (of Sns). Described as a vein 1.2 m thick, or thicker, bounded by hard quartzite; composed of quartz, about 5 percent pyrrhotite, and sparse chalcopyrite. Best specimens reported to show free gold associated with pyrrhotite. Assays for gold said to show at least $60 per ton (period price).

Crosscutting quartz vein, particularly prominent in Clough Quartzite because of the competent but brittle character of the Clough compared with overlying and underlying schist. Gold, if present, might have been concentrated in the vein from a low-grade placer source in the quartzite.

Hitchcock (1878, p. 8–9); Heylmun (1986). Interpretation by R.H. Moench.

8H-14 Lisbon massive pyrrhotite occurrence—Lat 44°12'48" N., long 71°54'40" W.; under the main streets of Lisbon village. Not developed. Large, equidimensional blocks about 2 m across placed along the west bank of the Ammonoosuc River about 0.5 km south of Ash Hill Road, Lisbon, for protection against ice damage; removed from streets when a new sewer line was constructed during the early 1970's.

The blocks are composed of interlayered, silicified and chloritized felsic gneiss and massive pyrrhotite, some forming layers 5–10 cm thick; textures locally suggest that the massive pyrrhotite filled interstices in fragmental rhyolite. In addition to predominant pyrrhotite, the massive sulfide contains pyrite and sparse sphalerite and chalcopyrite. Spectrographic analyses yielded about 20 percent iron, more than 5,000 ppm manganese, 100 ppm copper, and no detected lead or zinc (B. Adrian and A. Erlich, analysts); gold was detected (but <0.05 ppm) by atomic absorption analysis (P. Hageman, analyst). The blocks probably were obtained from near the contact of the Ammonoosuc Volcanics with the overlying Partridge Formation.

Interpreted as sulfide-facies iron-formation, hosted by the Ammonoosuc Volcanics (Olv).

Shumway (1984, p. 34–35); R.H. Moench (1983 field observations).

8H-15 Allen gold(?)-quartz prospect—Lat 44°12'02" N., long 71°54'00" W.; location approximate; on hillside about 1.6 km southeast of Lisbon village. Small excavations. No known production.

Quartz vein 0.5–1 m thick in Clough Quartzite (of Sns). Said to contain small grains of free gold and galena in decomposed rock. Assays for gold reported.

See Atwood gold-quartz mine (8H-13) for interpretation.

Hitchcock (1878, p. 21).

8H-16 Ammonoosuc River copper occurrence—Lat 44°11'23" N., long 71°57'13" W.; at a stream-washed outcrop in the Ammonoosuc River, about 45 m downstream from the head of a rapid; exposed only during periods of low water. Not developed.

Deposit is a bed, about 1 m thick, of irregularly layered and mottled gneiss composed of white sugary quartz, phlogopite(?), and several percent of pyrrhotite, chalcopyrite, and sparse probable sphalerite. Spectrographic analyses of a chalcopyrite-rich sample indicated 1.5 ppm silver, 5,000 ppm copper, and 200 ppm or less zinc (B.M. Adrian and A. Erlich, analysts); no gold was detected by atomic absorption analysis (P.L. Hageman, analyst). Occurs in a volcanic facies of the Perry Mountain Formation, along the contact between mafic or intermediate volcanic greenstone and rusty-weathering, lenticularly bedded, probable tuffaceous metasandstone. Volcanics are intruded by lenses of metarhyolite.

Interpreted as a distal volcanic-hosted, volcanogenic pyrrhotitic copper deposit, hosted by the Silurian Perry Mountain Formation (of Srpv).

R.H. Moench (1985, 1997 field observations).

8H-17 Pettyboro Road prospect—Lat 44°11'42" N., long 71°57'54" W.; location approximate; near Pettyboro Brook about 300 m N. 70° E. of intersection of Pettyboro and Cross Roads.

No description found. Shown as a gold mine or prospect on map of Heylmun (1986, p. 5).

Tentatively interpreted as a gold-bearing quartz-carbonate vein on a subsidiary fracture of Triassic Ammonoosuc fault (AF).
Heylmun (1986, p. 5).

8H-18 Powerline occurrence—Lat 44°07'28" N., long 71°58'38" W.; near center of north-northwest-trending power line, about 2.2 km S. 60° W. of covered bridge at Swiftwater. Not developed.
Contact between (1) laminated biotite schist and basaltic amphibolite of Ammonoosuc Volcanics, intruded by metagabbro, on the southwest, and (2) black sulfidic schist of the Partridge Formation, on the northeast. The contact displays pockets of gossan and weak copper staining, and is also marked by abundant lenticular beds of white sugary metachert, and small intrusive bodies of quartz porphyry. Atomic absorption analysis of one sample of the metachert yielded 0.55 ppm gold (T. Huyck, analyst), and spectrographic analysis of one sample of copper-stained black phyllite yielded 150 ppm copper (D.E. Detro, analyst).
Interpreted as evidence of volcanogenic mineralization along Ammonoosuc-Partridge contact.
R.H. Moench (1983 field observations).

8H-19 Wild Ammonoosuc River pyrrhotite occurrence—Lat 44°04'06" N., long 71°51'23" W.; at stream-washed outcrops along Wild Ammonoosuc River, 1.8–2.2 km west of eastern intersection of New Hampshire Highways 112 and 116; exposed only at times of low water. Not developed.
Long outcrops of pyrrhotite-bearing felsic gneiss (metatuff) and agglomeratic amphibolite succeeded downstream by felsic gneiss containing clots, a few centimeters across, of massive pyrite, pyrrhotite, sparse sphalerite, and traces of chalcopyrite. Farther downstream, the rock assemblage includes stratified pyritic phlogopite(?) schist, alternating layers of felsic gneiss and basaltic amphibolite intruded by metagabbro, sulfidic basaltic meta-agglomerate, and, at the downstream end, apparently pillowed basaltic amphibolite. Spectrographic analyses of 11 samples of assorted mineralized rocks containing disseminations and small pods of massive pyrite and pyrrhotite do not show unusual amounts of metals, except for 7,000 ppm zinc and 0.5 ppm silver in one small sulfide-rich clot in metachert (B.M. Adrian, A. Erlich, and D.E. Detro, analysts). Trace amounts of gold (<0.05 ppm) were detected by atomic absorption analysis in some samples (T. Huyck and P.L. Hageman, analysts).
Interpreted as part of a center of volcanogenic alteration and mineralization in Ammonoosuc Volcanics (Olv).
R.H. Moench (1983 and 1986 field observations).

8H-20 Cross iron mine, No. 4 prospect—Lat 44°00'17" N., long 71°59'20" W.; near north end of Lake Constance; location approximate, from Hitchcock (1878, p. 60).
Massive and disseminated specular hematite, magnetite, and minor barite in Clough Quartzite (of Sns).
Tentatively interpreted to have been produced by subaerial weathering and reconcentration of iron before and during deposition of the Clough Quartzite. However, this model does not account for the barite.
Hitchcock (1878, p. 60–61); Jackson (1844, p. 149–150, 181). Interpretation by R.H. Moench.

SOUTH AND WEST OF LEWISTON QUADRANGLE

[Occurrences are shown on fig. 6]

8I-1 Cross iron mine—Lat 43°59'36" N., long 71°59'20" W.; southwest of knoll at elevation of 489 m and about 76 m vertically downhill from hilltop; location from Hitchcock (1878, p. 60). Jackson (1844, p. 149–150) noted 100 tons of high-grade ore ready for transport.
Massive and disseminated specular hematite, magnetite, and probably minor amounts of barite in the Clough Quartzite (of Sns). Jackson (1844, p. 149–150) observed a 3- to 4.5-m width of solid hematite and magnetite, and (p. 181) bunches and nests of barite. The specular hematite crystals are aligned parallel to schistosity.
Tentatively interpreted to have been produced by subaerial weathering and reconcentration of iron before and during deposition of the Clough Quartzite. However, this model does not account for the barite.
Hitchcock (1878, p. 60–61); Jackson (1844, p. 149–150, 181); Laurel Woodruff (written commun., 1987). Interpretation by R.H. Moench.

8I-2 Warren (Ore Hill) massive-sulfide mine—Lat 43°56'00" N., long 71°57'00" W.; about 5 km northwest of Warren, N.H., on south shoulder of Ore Hill. Large open cut and extensive underground workings, flooded long ago. Mined intermittently from 1841 to 1944. Estimated production 50,000–100,000 tons.
Main orebody is a conformable lens of massive sulfide as much as 6 m thick within the Ammonoosuc Volcanics (Olv). The ore, which has a cap rock of phlogopite-tremolite schist, lies stratigraphically below pyritic phlogopite-muscovite schist and felsic biotite-muscovite schist interpreted respectively as altered and unaltered felsic tuff; ore lies above a footwall lens of pyritic kyanite-cordierite schist, 0–5 m thick, interpreted as tuff or volcanic sediment that was metasomatically altered during ore formation. Successively, the kyanite-cordierite schist comprise: (1) a bed, 8–15 m thick, of pyritic

phlogopite-muscovite schist, interpreted as hydrothermally altered felsic tuff; (2) about 25 m of epidote-rich, pillowed basaltic amphibolite; and (3) felsic biotite-muscovite gneiss of unknown thickness, interpreted as unaltered felsic tuff. In decreasing abundance, the ore minerals are black sphalerite, pyrite, galena, and small amounts of chalcopyrite and pyrrhotite. Analysis of underground channel samples yielded 21 percent zinc, 11.4 percent lead, 0.5 percent copper, 2.7 ppm gold, and 274 ppm silver (Gair and Slack, 1979, sheet 3).

Interpreted as a polymetallic VMS deposit in Ammonoosuc Volcanics (Olv).

Secord and Brown (1986, and references therein); Gair and Slack (1979).

9G-1 Copper prospect northeast of Monroe—Lat 44°16'13" N., long 72°02'15" W.; small prospect pit just east of Coppermine Road, about 1.6 km northeast of Monroe village. Presumably the site of the vein mentioned by Hitchcock (1878, p. 46) located downhill from the Bald Ledge mine (9G-2).

Little information available from present exposures in pit. See Bald Ledge copper mine (9G-2) for possible alternative deposit types and interpretations.

Tentatively interpreted as deformed veins.

Hitchcock (1878, p. 46).

9G-2 Bald ledge copper mine—Lat 44°16'25" N., long 72°01'33" W.; location approximate; plotted near top of sharp hill about 3.2 km northeast of Monroe village. Shaft sunk to depth of 24.4 m. Produced 10 tons of ore that contained 10 percent copper.

Described by Hitchcock (1878, p. 46) as a copper-rich schist layer 2 m wide containing, in addition to the usual minerals (presumably pyrite and chalcopyrite), sphalerite and obliquely crossing veins of quartz. Because the mine was not found during this study, the nature of the host rocks is uncertain. The mine is located very near the Foster Hill fault (FHF) at the south end of the Coppermine Road window. Tentatively plotted outside the window; if correctly located, the host is dark-gray phyllite and quartzite of the Rangeley Formation. Alternatively, if located inside the window, the host is pyritic quartz-muscovite schist and metachert of the Ammonoosuc Volcanics; such schist, widely exposed within the window, is interpreted as metamorphosed hydrothermally altered felsic tuff.

Tentatively interpreted as copper-bearing deformed quartz veins hosted by the Silurian Rangeley Formation. Alternatively, might be a small, copper-dominant VMS deposit hosted by the Ammonoosuc Volcanics.

Hitchcock (1878, p. 46). Alternative interpretations by R.H. Moench.

9H-1 Paddock lead prospect—Lat 44°14'55" N., long 72°00'35" W.; south of Hunt Mountain Road near crest of Gardner Mountain. Small surface excavations.

Described by Hitchcock (1878, p. 32) as "***a vein of clear pyrites and galena over 4 inches thick." Strikes N. 70° E., dips 40° SE., and cuts bedding of country rock at an angle of 70°. Hitchcock reported assays of $15–$36 per ton (period price).

Probably a lead-rich crosscutting vein, but uncertain whether premetamorphic or postmetamorphic. Descriptions in Hitchcock (1878, p. 32–33) of so-called West lodes and Orchard vein, characterized by "heavy quartz" and "honeycombed cavities," probably pertain to unrelated properties on late crosscutting veins.

Hitchcock (1878, p. 32–33).

9H-2 Stevens copper mine—Lat 44°13'27" N., long 72°00'25" W.; about 7 km north-northwest of Bath, N.H., on southeast side of Gardner Mountain. Shaft about 30 m deep with 45-m crosscut; four small prospect pits occur as much as 520 m north and 183 m southwest of the shaft. Probably small production; developed about 1877.

Conformable sulfide-bearing laminations and lenses associated with variably tuffaceous metasedimentary and felsic metavolcanic rocks mapped within the Perry Mountain Formation (of Srpv). Concentrations of pyrite, arsenopyrite, chalcopyrite, sphalerite, and galena occur where thin laminations of quartz and pyrite coalesce into layers as much as 2 m thick. Ore changes gradationally along strike to iron-rich laminations composed of quartz and pyrite, and then to iron-rich laminations composed of quartz, chlorite, and sericite. Ore typically copper rich, locally zinc rich, and locally contains abundant galena; in places ore minerals are redistributed along cross fractures. Host is metamorphosed interbedded tuffaceous shale, sandstone, felsic crystal tuff, lapilli tuff, fine-grained granophyre, vitrophyre, quartz porphyry, and minor basaltic and andesitic greenstone of Perry Mountain Formation (of Srpv).

Ore interpreted by Margeson (1982) to have precipitated on the sea floor from metal-bearing brine derived from subaqueous fumaroles. Can be considered a Besshi-type, distal VMS deposit.

Margeson (1982); Hitchcock (1878, p. 41–42).

9H-3 Forsaith copper prospect—Lat 44°12'15" N., long 72°01'38" W.; about 6.5 km northwest of Bath, N.H., on southern part of Gardner Mountain. Large open cut and adit. No reported production.

Probably similar in structure, mineralogy, and host to deposit at Stevens copper mine (9H-2).

Probably a small, copper-dominant, Besshi-type VMS deposit.

Hitchcock (1878, p. 46; brief mention).

SHERBROOKE QUADRANGLE (QUEBEC PORTION)

[Except where cited separately, deposits are located and classified from an unpublished 1:250,000-scale map furnished by Michel Gauthier (Department of Earth Sciences, University of Montreal, written commun., 1984)]

2A-1 Unnamed gold prospect.
Gold-bearing vein; strike unknown.

3A-1 Saint-Robert mine—Adit driven in 1955. Production from central zone of deposits of 1,000 tons in 1958, which yielded 6.28 percent lead, 0.91 percent zinc, 0.64 percent bismuth, 0.06 percent copper, and 381 ppm silver. Reserves in central zone of 129,000 tons containing 0.6 percent tungsten oxide, and 6,000 tons containing 1.36 percent lead, 0.5 percent bismuth, and 105 ppm silver (Gauthier and others, 1994, p. 1359). Gauthier and others (1989, fig. 2.496) also reported reserves of 250,000 tons containing 0.4 oz gold per ton. Reserves in south zone reported as 8,000 tons per vertical 30 m containing 1.5 percent lead, 0.2 percent bismuth, 0.4 percent tungsten oxide, and 120 ppm silver.
Two recognized types of mineral deposits: (1) fine-grained scheelite disseminated in felsic porphyritic dikes; and (2) stockworks of quartz veins containing pyrite, sphalerite, silver-rich galena, scheelite, cosalite, chalcopyrite, and pyrrhotite. Host rock is hornfels of Frontenac Formation (of **Srw**). Exploration has delineated three stockwork zones: (1) a southern zone that contains lead, silver, bismuth, tungsten, molybdenum, and zinc; (2) a central, gold-bearing zone with lead bismuth, tungsten, silver, and a little copper; and (3) a northern zone that contains lead, bismuth, and tungsten.
The complex distribution of mineral compositions suggests that the deposits are a result of telescopically zoned hydrothermal mineralization above one or more Mesozoic(?) hypabyssal intrusions.
Gauthier and others (1988, p. 490–505, fig. 2.496; 1989); Gauthier and others (1994, p. 1342, 1359).

3A-2 Unnamed copper prospect.
Copper-bearing vein; strike unknown.

3B-1 Unnamed gold-silver prospect.
Vein containing gold, silver, pyrite, and pyrrhotite; strike unknown.

3B-2 Unnamed tungsten prospect.
Tungsten-bearing vein; strike unknown.

3B-3 Unnamed tungsten prospect.
Tungsten-bearing vein that strikes N. 10° E.

4A-1 Copperstream-Frontenac molybdenum mine—Exploration (by 1984) delineated two mineralized zones separated by about 1 km; reserves reported by Gauthier and others (1994, p. 1359) of 414,362 tons having a grade of 0.39 percent molybdenum. Production of 40 tons in 1941 containing >0.21 percent molybdenum.
Stockworks of quartz veins that carry <5 percent molybdenite, 10 percent pyrrhotite, 3 percent pyrite, 3 percent chalcopyrite, and sparse sphalerite; they occur along a strike length of at least 1 km. Host is hornfels of Compton Formation (of **Dc**) at the north end of the Mont Ste.-Cécile pluton (index 104).
Interpreted as hypabyssal molybdenum-copper mineralization related to biotite granite of the Devonian Mont Ste.-Cécile pluton (index 104).
Gauthier and others (1988, p. 488–505, fig. 2.486; 1989); Gauthier and others (1994, p. 1341–1342, 1359).

4B-1 Sainte Cécile molybdenum prospects.
Weakly mineralized but widespread stockwork of quartz-molybdenite veins (also containing chalcopyrite and pyrrhotite) associated with aplitic dikes that cut hornfels of Compton Formation (of **Dc**), in contact zone at south end of Mont Ste.-Cécile pluton (index 104); contain molybdenum, bismuth, silver, lead, and zinc.
Interpreted as hypabyssal molybdenum-copper related to biotite granite of the Mont Ste.-Cécile pluton.
Gauthier and others (1994, p. 1342).

4B-2 Marston gold prospect.
Sheared, carbonatized porphyritic dike traced for 600 m; strikes N. 45° E., subparallel to nearby Victoria River fault (VRF). Contains gold, copper, silver, lead, and pyrite. Probably similar to gold-bearing, carbonatized shear zone of unnamed gold-silver prospect at map No. 5C-1.

4B-3 Nebnellis base metals prospect.
Mineralized shear zone about 5 m wide on or near the Deer Pond fault (DPF), hosted by basaltic greenstone of Frontenac Formation. Sheared rock is silicified, sericitized, chloritized, and quartz veined; carries pyrite, chalcopyrite, sphalerite, and galena, distributed in the plane of schistosity and in the quartz veins. Assays, at different sample sites, show as much as 1.58 percent copper, 2.71 percent lead, 1.51 percent zinc, 0.15 ppm gold, and 20 ppm silver.
Interpreted as a hydrothermal vein deposit along a reactivated portion of the Deer Pond fault.
Gauthier and others (1988, p. 468, fig. 2.456; 1989).

4C-1 Arnold Pond chromite-magnetite occurrence.

Described in "Sherbrooke quadrangle (United States portion) and Lewiston quadrangle" section.

4C-2 Clinton "O" mine—Principal deposit of Clinton River district; mined for 18 months from 1973 to 1975. Production of 114,479 tons in 1973–1975 that yielded 2.65 percent copper, 2.43 percent zinc, 0.46 percent lead, 29.3 ppm silver, and 0.44 ppm gold. Reserves contained in "O," "A," "C," "D," "E," and "F" deposits estimated at 1,524,000 tons containing 2.022 percent copper and 1.54 percent zinc, as well as some lead, silver, and gold.

The "O" deposit is 115 m long in plan view, has an average thickness of 4 m, and plunges northwest to a depth of 150 m, parallel to plunge. It is composed of massive pyrite, chalcopyrite, tetrahedrite, sphalerite, and accessory galena; gangue minerals are recrystallized quartz, and less common barite grains and quartz-feldspar-sericite banded rocks. The deposit occurs in a weakly metamorphosed sequence of mixed volcanic, volcaniclastic, and exhalative rocks, in ascending stratigraphic order: quartz-chlorite schist; massive siliceous rocks (altered rhyolite?) with disseminated pyrite and sparse chalcopyrite; layered massive sulfides; interlayered ferruginous argillite and chert; and chlorite schist and basalt.

Interpreted as a VMS deposit hosted by volcanic, volcaniclastic, and exhalative sequences within the Silurian Frontenac Formation (Srwv). Although difficult to prove, the seven Clinton deposits are thought to occur along a single stratigraphic horizon; sea-floor mineralization is inferred to have occurred in a linear topographic depression, probably within the axial half-graben of the Second Lake rift (SLRA). Although considered by some to be a mainly sediment-hosted, Besshi-type deposit, the occurrence of at least small amounts of coarse fragmental metavolcanic rocks in the mine area, seen by the authors during a field trip, suggests that a Kuroko-type classification might be more appropriate. This interpretation applies to the other deposits of the district.

Chevé (1978); Gauthier and others (1988, p. 279–329); Gauthier and others (1994, p. 1337, 1359), who cite Chevé (1990). Also see Ebinger (1985, p. 61–67).

4C-3 Clinton "A" prospect.

VMS deposit having an outcrop length of 180 m, northwest plunge length of about 300 m, and an average thickness of 1.5 m. Composed of massive pyrite and less than 1.5 percent total chalcopyrite, sphalerite, and sparse accessory galena, arsenopyrite, and magnetite. Hosted by interlayered quartz-chlorite-stilpnomelane schist and magnetic metabasalt. Somewhat deformed and metamorphosed by the contact aureole of the Spider Lake pluton (index 7).

Northernmost of seven VMS deposits of the Clinton River district.

See Clinton "O" mine for interpretation (4C-2).

Chevé (1978, p. 72); Gauthier and others (1994, p. 1337).

4C-4 Clinton "B" prospect.

A thin VMS deposit interpreted by Chevé (1978, p. 68) to demonstrate the continuity between deposits at the "A" and "C" prospects.

See Clinton "O" mine for interpretation (4C-2)

Chevé (1978, p. 68); Gauthier and others (1994, p. 1337).

4C-5 Clinton "C" prospect.

Deposit is 100 m long in plan, and has a plunge length of 140 m and an average thickness of 4 m. The massive sulfide is composed of pyrite (65–80 percent), chalcopyrite, sphalerite, and accessory galena, pyrrhotite, and magnetite. The deposit is underlain by quartz-chlorite-sericite schist, and is overlain by mafic tuff, chlorite schist, and ferruginous and manganiferous argillite, and by characteristic metasedimentary rocks of the Frontenac Formation.

See Clinton "O" mine for interpretation (4C-2).

Chevé (1978, p. 71); Gauthier and others (1994, p. 1337); Ebinger (1985, p. 65).

4C-6 Clinton "D" prospect.

Thin VMS deposit interpreted by Chevé (1978, p. 68) to demonstrate the continuity between deposits of the Clinton "C" and "E" prospects.

See Clinton "O" mine for interpretation (4C-2).

Chevé (1978, p. 68); Gauthier and others (1994, p. 1337).

4C-7 Clinton "E" prospect.

This deposit has a strike length of 120 m, a northwest plunge length of 90 m, and an average thickness of 1.8 m. The recognized ascending stratigraphic sequence in the prospect area includes (1) 65 m of mafic metavolcanic rocks, (2) 1.5–5 m of felsic metavolcanic rock, (3) 1.8 m of massive sulfide, (4) 10 m of laminated quartz-chlorite-magnetite-stilpnomelane rocks, and (5) 2–3 m of ferruginous-manganiferous argillite. The VMS deposit is composed of pyrite, chalcopyrite, sphalerite, and accessory galena and pyrrhotite. Secondary covellite occurs along fractures in chalcopyrite and pyrite. The principal gangue minerals are sericite, quartz, and barite; biotite and epidote occur locally.

See Clinton "O" mine for interpretation (4C-2).

Chevé (1978, p. 70); Gauthier and others (1994, p. 1337); Ebinger (1985, p. 62).

4C-8 Clinton "F" prospect.

This is a conformable tabular body, 0.3–1.5 m thick; horizontal and plunge-length dimensions are not reported. The massive sulfide is composed of pyrite, chalcopyrite, sphalerite, accessory galena and tetrahedrite, and secondary covellite. The deposit is hosted by 15 m of chlorite schist, the uppermost 5 m of which contains the VMS deposit; this sequence is overlain by approximately 100 m of bedded epiclastic schist, then by about 30 m of massive to schistose porphyritic metabasalt.

See Clinton "O" mine for interpretation (4C-2).

Chevé (1978, p. 73); Gauthier and others (1994, p. 1337); Ebinger (1985, p. 66).

4C-9 Unnamed copper-silver prospect in Clinton River district.

Stockwork of intersecting veins in metavolcanic rocks of Frontenac Formation (of Srwv) containing copper, silver, and pyrite.

Mesozoic(?) veins containing metals possibly redistributed from VMS deposits of district.

4C-10 Unnamed copper prospect in Clinton River district.

Copper-bearing stratabound sulfide lens in metavolcanic rocks of Frontenac Formation (of Srwv).

Interpreted as a small VMS deposit.

4C-11 Unnamed molybdenum prospect—Approximate location plotted from Gauthier (1985, fig. 10; 1986, fig. 6).

No description found; probably a quartz vein containing molybdenum, and possibly copper, approximately at the point of truncation of the Thrasher Peaks fault (TPF) by the Spider Lake pluton (index 7).

Tentatively interpreted as molybdenum mineralization related to the pluton, and "leaked" along the preexisting fault.

Gauthier (1985, fig. 10; 1986, fig. 6).

4C-12 Unnamed copper prospect.

Stratabound lens of chalcopyrite, pyrrhotite, and pyrite; strikes about N. 45° E. If correctly plotted, the deposit is just southeast of the Thrasher Peaks fault (TPF) and is hosted by volcaniclastic wacke of the Magalloway Member of the Jim Pond Formation (€ow). If instead the deposit occurs northwest of the fault, it is hosted by metavolcanic rocks of the Ironbound Mountain Formation (of Dpv) and represents an extension of the mineralized zone at the Thrasher Peaks sulfide prospect (5D-3).

Interpreted as a small VMS deposit of Cambrian(?) or Early Devonian age.

Interpretation by R.H. Moench.

4C-13 Border massive-sulfide prospect—In the southern part of Woburn Township, Quebec. Discovered in 1972 by J.S. Cummings, Inc. (Cummings, 1988, p. 256–261).

Drilling following upon an intensive geochemical survey resulted in the discovery of a zinc-bearing zone having a strike length of at least 90 m and variable widths of 3–17 m. A body containing at least 50,000 tons of 8 percent zinc occurs within 45 m of the surface. The best drill intercept showed 5.8 m of massive sulfide having an average content of 26.9 percent zinc, 1.3 percent lead, 0.5 percent copper, 12 oz silver per ton, and 0.035 oz gold per ton. On the basis of the very low copper to zinc ratio, Cummings (1988, p. 261) suggested that the copper response in the geochemical data did not originate from the delineated Border deposit, but rather from undiscovered sulfides in the unexplored part of his "A" zone (Cummings, 1988, fig. 7-11).

Interpreted as a zinc-rich VMS deposit hosted by weakly metamorphosed volcanic rocks of the Jim Pond Formation (€ov). A more characteristic, copper-dominant deposit might occur nearby.

Cummings (1988, p. 256–261).

4C-14 Gosford sulfide-bearing listwanite prospect.

Pyrite, pyrrhotite, chromite, and chalcopyrite, and nickel, silver, and cobalt minerals in ultramafic talc-carbonate schist and talc-quartz-chlorite-carbonate schist (listwanite) in serpentinite.

Probable hydrothermal replacement deposits in diapiric(?) serpentinite, probably remobilized from the Boil Mountain Complex (€op).

Gauthier and others (1988, p. 357, table XXIV; 1989).

5B-1 Unnamed molybdenite prospect.

Molybdenite-bearing veins(?) and disseminations in unmapped hypabyssal granite that is probably related to the Mont Ste.-Cécile pluton (index 104).

Interpreted as hypabyssal molybdenum mineralization, probably above a shallow Devonian granite pluton.

5C-1 Unnamed gold-silver prospect.

Probable Mesozoic carbonatized shear zone containing gold and silver.

5C-2 Unnamed base metals occurrence—Located in roadcut on north side of Route 212, about 8 km west of Notre Dame de Bois.

North-northeast-striking veins that carry traces of copper, zinc, lead, and precious metals. Assays of materials from two sites indicate 70 and 38 ppm copper, 84 and 18 ppm zinc, 14 and 8 ppm lead, and 0.7 and 1.2 ppm silver; gold was barely detected. The veins are hosted by fractured and carbonatized slate or phyllite of the Ironbound Mountain Formation.

Interpreted as weak hydrothermal mineralization in a fracture zone.

Gauthier and others (1988, p. 465–466, figs. 2.453, 2.454; 1989).

5C-3 Unnamed gold-silver prospect.

Probable Mesozoic vein containing gold and silver.

6C-1 Collaianni sulfide prospect.
Intersecting veins containing gold, silver, molybdenum, lead, and arsenic.
Interpreted as Mesozoic hydrothermal veins.
Gauthier (1986, fig. 9, table 1).

7C-1 Unnamed sulfide prospect.
Vein containing gold, silver, and lead; strikes N. 50° E., dips southeast.
Interpreted as a Mesozoic hydrothermal vein.

7D-1 Goose Neck lead-zinc-silver-copper prospect—Name from Gauthier and others (1988, fig. 2.470).
Quartz veins containing lead, zinc, silver, and copper; strike N. 5° E., dip east; occur in metasedimentary rocks of Compton Formation (of Dc) near Hereford Mountain pluton (index 101).
Interpreted as Mesozoic hydrothermal vein.
Gauthier and others (1988, fig. 2.470; 1989), and other sources.

7D-2 Leach lead-zinc-silver-copper prospect—Name from Gauthier and others (1988, fig. 2.470).
Quartz vein in metasedimentary rocks of Compton Formation near Hereford Mountain pluton (index 101), containing lead, zinc, silver, and copper.
Interpreted as Mesozoic hydrothermal vein.
Gauthier and others (1988, fig. 2.470; 1989).

7D-3 Saint Hermenegilde polymetallic stockwork prospect—Location approximate; on hill about 5 km west of Hereford Mountain (grid 7D). Several prospect trenches and open pits.
Polymetallic stockwork associated with greisenized syenitic(?) pegmatite dikes that intrude hornfels of Compton Formation. The veins and greisens are marked by sericitic, silicic, and chloritic alteration zones, and contain pyrrhotite, pyrite, marcasite, chalcopyrite, sphalerite, galena, and molybdenite; also native copper, bismuth, and bismuth telluride minerals. Assays indicate as much as 0.2 percent copper, 0.17 percent bismuth, 0.1 percent zinc, 0.1 percent lead, 600 ppm molybdenum, 3.5 ppm silver, and 0.18 ppm gold. Small but anomalous amounts of fluorine (610 ppm), mercury (390 ppm), and tellurium (32 ppm) also reported.
Included by Gauthier and others (1988) in a group of occurrences related to alkalic intrusive rocks of the White Mountain Plutonic-Volcanic Suite. Gauthier and others (1994, p. 1345) suggested that the Hereford Mountain pluton (index 101), 5 km to the east, is Jurassic (as tentatively shown on map A), rather than Devonian (as previously mapped).
Gauthier and others (1988, p. 514–525, fig. 2.515; 1989); Gauthier and others (1994, p. 1345).

7D-4 Comins Mills lead-zinc-silver prospect—On south shoulder of knoll about 1.4 km northwest of the international border at the New Hampshire–Vermont border.
Quartz vein containing lead, zinc, and silver; strikes N. 10° E., dips east. Assay indicates 0.55 percent zinc, 0.24 percent lead, and 0.7 ppm silver.
Interpreted as a Mesozoic hydrothermal vein.
Gauthier (1985, annexe no. 1, p. 177–178).

8D-1 Lyster Lake tungsten prospects—Tungsten prospects and undeveloped occurrences over a length of 5 km in the contact metamorphic aureole of the Averill pluton (index 45; called Stanhope granite in Quebec), and within 400 m of the contact of the pluton. Maximum grades of 3 percent WO_3 obtained locally, but grades typically range from 0.1 to 0.4 percent WO_3. Other scheelite occurrences as far as 2 km to east and 1 km to west are shown on figure 2.473 of Gauthier and others (1988).
At the main prospect, disseminated scheelite is confined to three layers of garnet-diopside-quartz-calcite skarn interstratified with other calc-silicate rocks and quartz-garnet-diopside-biotite-quartz or biotite-staurolite hornfels. The scheelite, locally associated with molybdenite, chalcopyrite, and sphalerite, occurs in grains as large as 1 cm in diameter that are unevenly disseminated in the skarn. Hosted mainly by metamorphosed calcareous rocks of the Silurian(?) Ayers Cliff Formation (of Srwc).
Interpreted as a skarn-type deposit related to the Averill pluton.
Gauthier and others (1988, p. 475–488; 1989); Gauthier (1985, annexe no. 1, p. 176); Gauthier and others (1994, p. 1342).

APPENDIX III. DESCRIPTIONS OF PEGMATITE MINES AND PROSPECTS

Most of the important pegmatites have been described in considerable detail, and only essential information in skeleton form is furnished here, in the following order: (1) map index and name of mine or prospect; (2) pertinent description and resource information (if available); (3) mineral(s) of economic or collecting interest; (4) reference(s). In addition to the cited reports provided with each listing, the report of Morrill and others (1958) provided valuable information on the location and minerals of interest for many pegmatites. Readers are also referred to articles by Wise and Francis (1992) and Francis and others (1993) for information on the geologic setting, mineralogy, and petrology of pegmatites of the map area. On map D, pegmatite mines and prospects are identified by letter within each of the 15-minute quadrangles, which are identified by map grid coordinates; for example, 3F-M is the Newry gem mine (Dunton) and quarries

1F-A Vienna Mountain prospect.
Feldspar, muscovite.
Rand (1957).

1G-A Nurse Farm prospect.
Feldspar, muscovite.
Rand (1957).

2F-A Perry prospect.
Autunite, petalite, spodumene, triphylite.
Rand (1957).

2G-A Lobokis mica mine.
About 1 percent crude mica.
Beryl, pyrrhotite, triphylite, vivianite.
Cameron and others (1954); Rand (1957).

2G-B Hedgehog Hill mine.
Gem beryl, chrysoberyl, garnet, muscovite.
Rand (1957).

2G-C Ragged Jack Mountain prospect area.
Chrysoberyl.
Rand (1957).

2G-D Bessey mine.
Feldspar, muscovite, arsenopyrite, beryl, smoky quartz, sphalerite.
Rand (1957).

2G-E Ryerson Hill mine.
Feldspar, gem beryl, columbite.
Rand (1957).

2G-F Bennett feldspar quarry.
This pegmatite is strongly zoned and has an outcrop length of about 380 m and a maximum width of 200 m; it strikes east-west and dips steeply south (Francis and others, 1993, and references therein). Cameron and others (1954, p. 60) reported that the quarry produced several thousand tons of feldspar; also contains beryl, lepidolite, and columbite-tantalite. Barton and Goldsmith (1968, p. 89–91) reported less than 0.02 percent BeO in random grab samples, and suggested that only the megascopic beryl is of interest for BeO.
Feldspar, quartz, muscovite, amblygonite, apatite, arsenopyrite, cassiterite, columbite-tantalite, garnet, lepidolite, pollucite, rhodochrosite, spodumene, topaz, tourmaline.
Cameron and others (1954, p. 58–60); Barton and Goldsmith (1968, p. 89–91); Bastin (1911, p. 70); Rand (1957); Francis and others (1993).

2G-G Cummings mine.
Quartz.
Rand (1957).

2G-H Mount Mica mines.
Early history and general character described by Bastin (1911, p. 81–93); a gently dipping pegmatite sheet that covers a wide area; contains many vugs.
Feldspar, rose and smoky quartz, mica, beryl, cassiterite, lepidolite, pollucite, gem tourmaline.
Bastin (1911, p. 81–93); Hess and others (1943, p. 32–33); Rand (1957).

2G-I Scott Colby mine.
Feldspar, rose quartz.
Rand (1957).

2G-J Stoney Brook mine.
Feldspar, muscovite, lepidolite, tourmaline (damourite).
Rand (1957).

2G-K Slattery mine.
Feldspar, rose quartz, gem beryl, bertrandite.
Rand (1957).

2G-L Hooper's Ledge.
Feldspar, rose quartz, beryl, chrysoberyl.
Rand (1957).

2G-M Irish mine.
Beryl, pollucite, tourmaline.
Rand (1957).

2G-N Fletcher mine.
Beryl.
Rand (1957).

2G-O General Electric Company mine.
Pollucite.
Rand (1957).

2G-P Dudley prospect.
Reported to have produced 800 lbs of pollucite (Hess and others, 1943, p. 24). Very low BeO content (Barton and Goldsmith, 1968, p. 93–95).
Amblygonite, beryl, pollucite.
Barton and Goldsmith (1968, p. 93–95); Hess and others (1943, p. 24); Rand (1957).

2H-A Streaked Mountain prospect.
Pegmatite caps mountain.
Feldspar.
Rand (1957); Bastin (1911, p. 74–75).

2H-B Barrett beryl prospect.
Cameron and others (1954, p. 58) suggested pegmatite may contain mineable feldspar at depth.
Feldspar, muscovite, garnet, black tourmaline.
Cameron and others (1954, p. 58); Rand (1957).

2H-C Hill No. 4 quarry.
Feldspar, gem tourmaline, cassiterite.
Rand (1957).

2H-D Little Singepole feldspar quarries.
Cameron and others (1954, p. 78) reported large reserve for graphic granite.
Feldspar, quartz, muscovite, beryl (gem), columbite, garnet, pollucite, gem tourmaline.
Cameron and others (1954, p. 78); Rand (1957).

2H-E Hibbs feldspar quarry.
According to Cameron and others (1954, p. 75–76), this pegmatite is one of the few promising mica prospects in Maine, and may have high-grade feldspar.
Feldspar, muscovite, garnet, beryl, cassiterite, columbite, gem tourmaline.
Cameron and others (1954, p. 72–74); Rand (1957).

2H-F Rubellite mine.
Beryl, gem tourmaline, pollucite.
Rand (1957); Bastin (1911, p. 74); Hess and others (1943, p. 28–29).

2H-G Conant mine.
Feldspar.
Rand (1957).

2H-H Sturtevant (Sanitarium) mine.
Beryl.
Rand (1957).

2H-I Jordan prospect.
Feldspar, muscovite, quartz.
Rand (1957).

2H-J Sturtevant mine.
Feldspar, black tourmaline.
Rand (1957).

2H-K La Flamme mine.
Feldspar, tourmaline, pollucite.
Rand (1957).

2H-L Phillips mine.
Feldspar, quartz (amethyst), autunite, black tourmaline.
Rand (1957).

2H-M Bell prospect.
Feldspar, muscovite, black tourmaline.
Rand (1957).

2H-N Pitts-Tenney mine.
Feldspar, beryl, diopside, grossular.
Rand (1957).

2H-O Pitts mine.
Feldspar, quartz, muscovite.
Rand (1957); Bastin (1911, p. 59).

2H-P Kennedy mine.
Beryl.
Rand (1957).

2H-Q Mount Apatite mines.
This pegmatite has an exposed length of about 750 m; its contacts strike about N. 75° E. and dip gently north (Francis and others, 1993, p. E13). Best known for its green tourmaline and fluorapatite, and is mineralogically complex (Francis and others, 1993, table 7). Barton and Goldsmith (1968, p. 85) reported an average of 0.03 percent BeO in grab samples from the Pulsiver mine, one of seven mines of this group listed by Rand (1957).
Barton and Goldsmith (1968, p. 85, Pulsiver mine); Bastin (1911, p. 49); Hess and others (1943); Francis and others (1993); Rand (1957).

2H-R Berry feldspar quarry.
Cameron and others (1954, p. 56) reported it as potential source for feldspar.
Feldspar, muscovite, apatite, beryl, cassiterite, lepidolite, tourmaline.
Cameron and others (1954, p. 56); Rand (1957).

3E-A Hardin-Keith-Small prospect.
Feldspar, muscovite, columbite, spodumene, tourmaline.
Rand (1957).

3F-A Binford prospect.
Muscovite.
Rand (1957).

3F-B Gogan mine.
Feldspar, muscovite.
Cameron and others (1954, p. 71); Rand (1957).

3F-C Belliveau prospect.
Feldspar, muscovite.
Rand (1957).

3F-D Brown-Thurston beryl prospect.
Exposed areas, totalling 5.5 m^2, of beryl-bearing quartz-perthite lenses within the pegmatites contain about 0.2 percent beryl; the average beryl content for all exposed pegmatite in the prospect area is about 0.004 percent (Cameron and others, 1954, p. 67).
Beryl, cassiterite, columbite, muscovite, tourmaline.
Cameron and others (1954, p. 65–67); Rand (1957).

3F-E Black Mountain quarries.
Well-known mineral collecting locality in several pegmatite pods that strike northwest and dip gently northeast. Opened for scrap mica in 1901. Hess and others (1943, p. 20–23) described occurrence of lithium-bearing minerals, and the pegmatites are best known for radial aggregates of pink tourmaline in fine-grained lepidolite (Francis and others, 1993, p. E-17). Cameron and others (1954, p. 61–65) estimated 220 tons of beryl in the easternmost pegmatite.
Apatite, beryl, cassiterite, columbite, garnet, lepidolite, muscovite, spodumene, tantalite, tourmaline, triphylite, uraninite, and others.
Cameron and others (1954, p. 60–65); Francis and others (1993); Hess and others (1943); Rand (1957).

3F-F Leach beryl prospect.
Small beryl crystals.
Rand (1957).

3F-G Carver prospect.
Beryl, purpurite.
Rand (1957).

3F-H Whitehall prospect.
Beryl.
Rand (1957).

3F-I Whitecap Mountain pegmatite.
Caps Whitecap Mountain and covers an area of about 3 km^2; shown by mapping and drilling to be an unzoned, mineralogically simple, subhorizontal sheet (Moench and Hildreth, 1976, section D-D'; Louis Moyd and Whitecap Mountain Syndicate, written commun., 1961).
Sparse beryl; accessory apatite, garnet, black tourmaline.
Moench and Hildreth (1976); Rand (1957).

3F-J Red Hill mine.
Feldspar, beryl, triphylite.
Rand (1957).

3F-K Roy prospects.
Beryl, corundum(?), pyrrhotite, sphalerite.
Rand (1957).

3F-L George Elliot (Elliot) mica mine.
Opened for mica in 1878; small reserve for book mica (Cameron and others, 1954, p. 68–71).
Apatite, beryl, garnet, muscovite, black tourmaline.
Cameron and others (1954, p. 68–71); Rand (1957).

3F-M Newry gem mine (Dunton) and quarries.
Famous mineral collecting locality and site of a major watermelon tourmaline discovery in 1972. Thin, zoned, gently dipping pegmatite sheets that may have coalesced northward and joined the Whitecap Mountain pegmatite prior to erosion. Barton and Goldsmith (1968, figs. 12–17) illustrated relationships between Newry and Plumbago Mountain (3F-N) pegmatites, based on mapping and drilling. Main quarry produced feldspar and spodumene; scrap mica, beryl, and amblygonite recovered as byproducts. Barton and Goldsmith (1968, p. 43–50) estimated a content of 0.02 percent BeO, and described beneficiation tests for BeO as a byproduct of feldspar mining. Hess and others (1943, p. 12–20) described occurrence of lithium-bearing minerals.
Amblygonite, autunite, beryl, beryllonite, cassiterite, columbite, pollucite, spodumene, tantalite, torbernite, gem and black tourmaline, triphylite, uraninite, and many others.
Cameron and others (1954, p. 80–83); Barton and Goldsmith (1968, p. 14–51); Shainin and Dellwig (1955); Hess and others (1943); Rand (1957).

3F-N Plumbago Mountain beryl prospect.
Barton and Goldsmith (1968, p. 50) suggested that this body is a potential source for beryl, feldspar, and spodumene; they estimated a grade of 0.03 percent BeO.
Beryl, spodumene.
Cameron and others (1954, p. 87–89); Barton and Goldsmith (1968, p. 14–51, figs. 12–17); Rand (1957).

3G-A Immonen Ledge No. 1.
Feldspar, muscovite, rose quartz, beryl, garnet.
Rand (1957).

3G-B Perham feldspar quarry.
Large production of feldspar and potential for more, with minor scrap mica byproduct (Cameron and others, 1954, p. 87).
Feldspar, muscovite, apatite, beryl, garnet, tourmaline.
Cameron and others (1954, p. 87); Rand (1957).

3G-C Cobble Hill prospect.
Pegmatite has yielded small but perfect crystals of chrysoberyl, zinc spinel, and zircon (Bastin, 1911, p. 78).
Chrysoberyl, lepidolite, pollucite, zinc spinel, zircon.
Hess and others (1943, p. 27); Bastin (1911, p. 78).

3G-D Whispering Pines mine.
Feldspar, rose quartz.
Rand (1957).

3G-E Ohtonen's quarry.
Feldspar, apatite, beryllium minerals, pyrite.
Rand (1957).

3G-F Heikkinen and Tamminen (old) mines.
Feldspar, muscovite, quartz, beryl, idocrase, pyrite.
Rand (1957).

3G-G Hayes Ledge prospect.
Muscovite, beryl.
Rand (1957).

3G-H Harvard quarry.
Opened for quartz crystals in the late 1800's and quarried later for mica (Cameron and others, 1954, p. 73–74); some good quality sheet mica recovered. Sampling indicates 0.02 percent or less BeO (Barton and Goldsmith, 1968, p. 95–96).
Feldspar, muscovite, quartz (crystal), apatite, beryl, cassiterite, garnet, lepidolite, spodumene, black and green tourmaline.
Cameron and others (1954, p. 73–74); Barton and Goldsmith (1968, p. 95–96); Rand (1957).

3G-I Tamminen, Heath, and Tamminen-Waisanen mines.
Feldspar, quartz (crystals), apatite, beryl, bertrandite, herderite, pollucite, spodumene, topaz, uraninite.
Rand (1957); Hess and others (1943, p. 25).

3G-J Waisanen mica mine.
According to Cameron and others (1954, p. 93–94), pegmatite may have large potential for sheet-bearing muscovite; sheet-bearing books of muscovite and beryl crystals as much as 0.5 m long are scattered through the quartz-perthite-muscovite zone.
Feldspar, muscovite, beryl.
Cameron and others (1954, p. 93–94); Rand (1957).

3G-K BB No. 1 quarry.
Feldspar, muscovite, smoky quartz, arsenopyrite, beryl, sphalerite.
Rand (1957).

3G-L Dunn mine.
Feldspar, muscovite, beryl.
Rand (1957).

3G-M Tiger Bill mine.
Feldspar, autunite, bertrandite, herderite, spodumene.
Rand (1957).

3G-N Uncle Tom mine.
Hess and others (1943, p. 25) reported that more than 4,600 lbs of pollucite were mined containing 29 percent Cs_2O.
Amblygonite, beryl, lepidolite, pollucite, gem tourmaline, spodumene.
Hess and others (1943, p. 25); Rand (1957).

3G-O General Electric glass quartz prospect.
Probably the Hodgeon Hill mine reported by Hess and others (1943, p. 23–24) to have been worked for pollucite.
Feldspar, quartz, beryl, columbite, garnet, pollucite(?).
Hess and others (1943, p. 23–24); Rand (1957).

3G-P Johnson mine.
Feldspar, muscovite, quartz, beryl, black tourmaline.
Rand (1957).

3G-Q Stearns beryl prospect.
Approximately 400 tons were mined and yielded 0.07 percent beryl (Cameron and others, 1954, p. 92).
Feldspar, quartz, muscovite, beryl.
Cameron and others (1954, p. 92); Rand (1957).

3G-R Scribner mica mine.
Produced a small amount of sheet mica (Cameron and others, 1954, p. 91–92).
Feldspar, rose quartz, muscovite, garnet, apatite, beryl, black tourmaline.
Cameron and others (1954, p. 91–92); Rand (1957).

3G-S Wentworth mine.
Feldspar, quartz, muscovite, apatite, beryl, pyrite.
Rand (1957).

3G-T Wardwell No. 1 mica mine.
Cameron and others (1954, p. 96) reported that the pegmatite contains no large reserve; described beryl crystals as long as 25 cm in the quartz-perthite zone. Pegmatite has a very low BeO content (Barton and Goldsmith, 1968, p. 100–103).
Feldspar, rose quartz, muscovite, beryl.
Cameron and others (1954, p. 96–97); Barton and Goldsmith (1968, p. 100–103); Rand (1957).

3G-U Holt prospect.
Muscovite.
Rand (1957).

3H-A Tubbs Ledge prospect.
Rose quartz, cassiterite, lepidolite, green tourmaline, triphylite.
Rand (1957); Bastin (1911, p. 78).

3H-B South Waterford prospect.
Muscovite.
Rand (1957).

4F-A Spruce Mountain pegmatite area.
Beryl.
Rand (1957).

4F-B Frye Brook–West Branch prospect.
Beryl.
Rand (1957).

4F-C Baldpate Mountain pegmatite area.
Beryl.
Rand (1957).

4F-D Puzzle Mountain pegmatite area.
Beryl.
Rand (1957).

4G-A Peaked Hill mica mine.
Mica, poor quality.
Cameron and others (1954, p. 84–87); Rand (1957).

4G-B Wheeler mines.
Feldspar, muscovite, beryl.
Rand (1957).

4G-C Anderson mine.
Muscovite.
Rand (1957).

4G-D Peabody Mountain feldspar quarry.
Opened for feldspar in 1938; possible potential for feldspar and scrap mica.
Apatite, tourmaline.
Cameron and others (1954, p. 83–84); Rand (1957).

4G-E Donahue prospect.
Opened for feldspar and mica in 1942; no production (Cameron and others, 1954, p. 68).
Feldspar, muscovite, beryl.
Cameron and others (1954, p. 68); Rand (1957).

4G-F Pingree prospect.
Feldspar, beryl, columbite.
Bastin (1911, p. 70); Rand (1957).

4G-G Bumpus feldspar quarry.
Produced high-quality feldspar and some scrap mica; potential for feldspar and large beryl crystals (one reported 5.5 m long, 1.2 m in diameter) (Cameron and others, 1954, p. 67–68).
Feldspar, muscovite, rose quartz, beryl.
Cameron and others (1954, p. 67–68); Rand (1957).

4G-H Rattlesnake Mountain pegmatite area.
Beryl.
Rand (1957).

4G-I Butters Mountain pegmatite area.
Beryl, garnet.
Rand (1957).

4G-J Durgin Mountain pegmatite area.
Beryl.
Rand (1957).

4G-K Aldrich prospect.
Feldspar, muscovite, beryl, pyrite, serpentine(?), black tourmaline.
Barton and Goldsmith (1968, p. 87–88); Rand (1957).

4G-L Melrose prospect.
Described by Bastin (1911, p. 99) as a coarse pegmatite on the south flank of Sugar Hill (Sugarloaf Mountain) that has yielded a number of fine transparent beryl crystals.
Beryl, bertrandite, beryllonite, apatite, cassiterite, columbite.
Bastin (1911, p. 99); Rand (1957).

4G-M Willis Warren feldspar quarry.
Cameron and others (1954, p. 97) reported small quantity of excellent quality mica along the hanging-wall contact of the pegmatite; possible source for block feldspar and beryl byproduct.
Feldspar, muscovite, garnet, apatite, beryl, tourmaline.
Cameron and others (1954, p. 97); Rand (1957).

4H-A Foster Hill prospect.
Feldspar, muscovite.
Rand (1957).

4H-B Forks Farm prospect.
Feldspar, muscovite, beryl.
Rand (1957).

4H-C Knight mines.
Knight No. 1 mine (six small pits) was worked for mica, beryl, and columbite; production as of 1962 was 2 tons mica and 3 tons beryl. Knight No. 2 mine (a small crosscut pit) was worked for mica and beryl; produced 2 tons mica and 25 lbs beryl. Samples from both pegmatites proved to be barren of BeO (Barton and Goldsmith, 1968, p. 96–99).
Muscovite, beryl, columbite.
Barton and Goldsmith (1968, p. 96–99); Rand (1957).

4H-D Saunders feldspar mine.
Small production of feldspar and mica; possible source for blocky feldspar (Cameron and others, 1954, p. 89–90).
Feldspar, quartz, muscovite, garnet, chalcopyrite, magnetite, pyrrhotite, black tourmaline.
Cameron and others (1954, p. 89–90); Rand (1957).

4H-E Maxim prospect.
Feldspar, quartz, muscovite.
Rand (1957).

4H-F Beech Hill mica mine.
Feldspar, quartz, muscovite, garnet.
Bastin (1911, p. 104); Rand (1957).

4H-G Stearns Hill feldspar mine.
Feldspar.
Rand (1957).

4H-H Styles Mountain prospect.
Beryl.
Rand (1957).

4H-I Andrew's Ledge.
Beryl, muscovite.
Rand (1957).

4H-J Lord Hill (Harndon Hill) mine.
Probably the gem topaz locality described by Bastin (1911, p. 100–101) on Harndon Hill.
Beryllium minerals, columbite, gem topaz, fluorite, herderite, triplite.
Bastin (1911, p. 100–101); Rand (1957).

4H-K Deer Hill pegmatite area.
Feldspar, muscovite, garnet, amethyst, pyrite.
Rand (1957).

4H-L Colton Hill prospect.
Feldspar, quartz.
Rand (1957).

5G-A Fischer prospect.
Probably little or no production.
Muscovite.
Cameron and others (1954, p. 139).

5G-B Chandler mine.
Coarse perthite (1.5-m-long crystals), and 3-m masses of quartz, beryl, and low-quality mica. Produced 800 tons of feldspar and 200 lbs of beryl in 1942.
Billings and Fowler-Billings (1975, p. 96); Welsh and others (1982).

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