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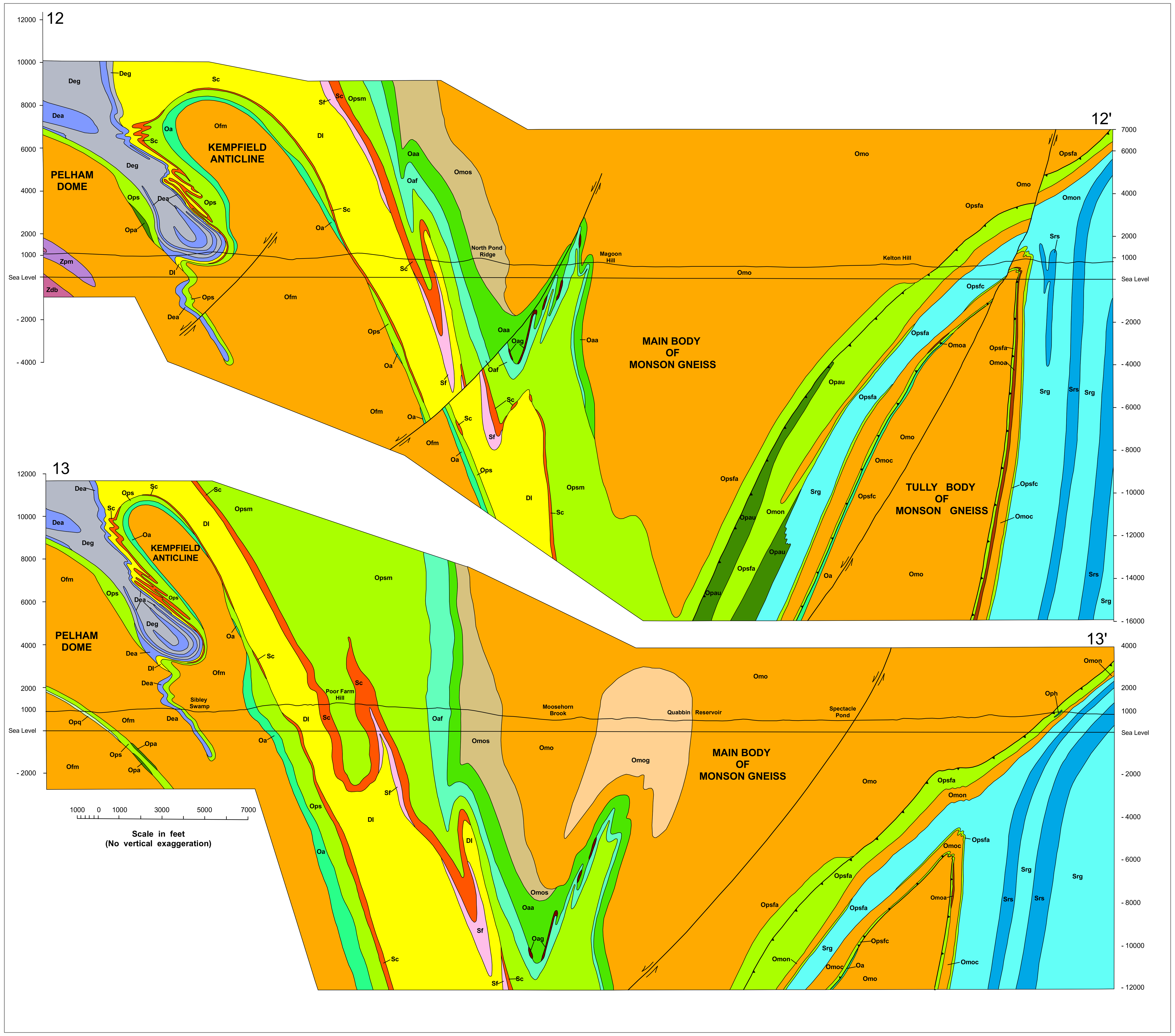


The overlying **Partridge Formation (Op)** is dominated by metamorphosed sulfidic black shales, now garnet-mica-kyanite or sillimanite-ilmenite-graphite-pyrrhotite schists (Fig. 14). Locally there are metamorphosed former dolomitic beds consisting of calc-silicate rocks with various proportions of diopside, zoisite, actinolite, grossular garnet, and locally calcite (Fig. 15). The lower part contains abundant volcanic interbeds now amphibolite and felsic gneiss (Hollocher 1985) like those of Lower and Upper Members of the Ammonoosuc. Mapped lenses of hornblendite **(Oph)** within sub-unit Opsfa with or without olivine, orthopyroxene, spinel, Mg-chlorite, anthophyllite, talc, and ankerite are interpreted as metamorphosed komatiite lavas, a rock type very rare outside the Precambrian (Wolff, 1978). That mafic volcanism characteristic of the Lower Ammonoosuc continues into the Partridge, suggests that the Felsic Upper Ammonoosuc may not represent a termination of mafic magmatism so much as a prodigious and possibly very brief explosive punctuation by felsic magmatism. A l m-thick pyroclastic rhyolite bed about 10 m above the base of the Partridge near Bernardston, Massachusetts, has yielded a U-Pb zircon age of 449+3/-2 Ma.

The basal contact of the Ammonoosuc is a major regional problem. It has been described as an intrusive contact (Billings, 1937; Leo 1991), but none of the well mapped contacts within the Ammonoosuc or between the Ammonoosuc and Partridge are ever seen truncated by the contact, nor do any of the mafic xenoliths in the gneisses correspond to any of the distinctive and unusual amphibolites of the Ammonoosuc. On the basis of three occurrences of quartzite and quartz-pebble conglomerate at the base of the Ammonoosuc, including the **Moosehorn Conglomerate Member (Oamc)** in the Orange area, and the petrographic and geochemical dissimilarity of the two sequences (Robinson et al. 1989), this contact has also been described as an unconformity (Robinson, 1981). Present geochronology indicating the two sequences overlap in age, seems to preclude both these possibilities, and to suggest instead a fault, possibly a detachment fault in an arc setting, that juxtaposed a tholeiitic back-arc cover sequence on top of the roots of an adjacent calc-alkaline arc. Further work will aim to resolve the question, including detrital zircon work on Moosehorn Conglomerate Member from its one excellent exposure.

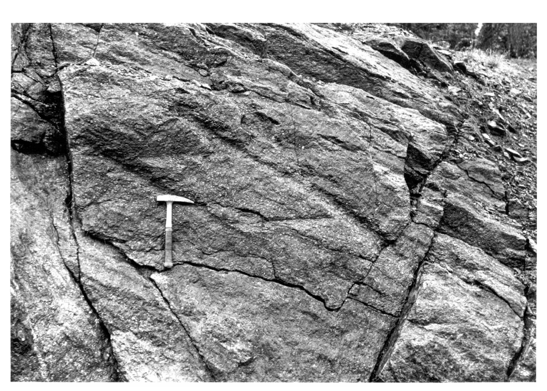


Fig. 14 Sulfidic mica schist of sulfidic schist member of the Partridge Formation (Opms). Medium-grained mica-plagioclase-garnet-sillimanite schist with coarse muscovite plates (visible in photograph). Late Quaboagian lineation and minor fold axes plunge about 25° to the south (right). At cut on Route 2 northwest of Walnut Hill.

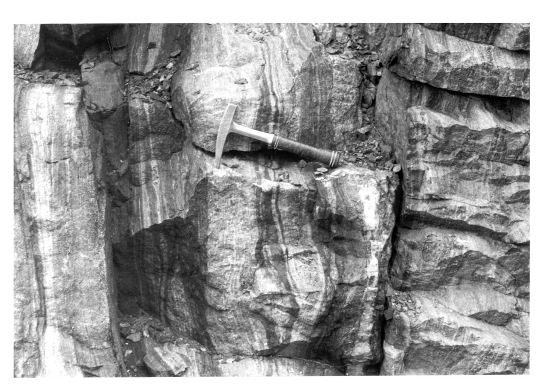
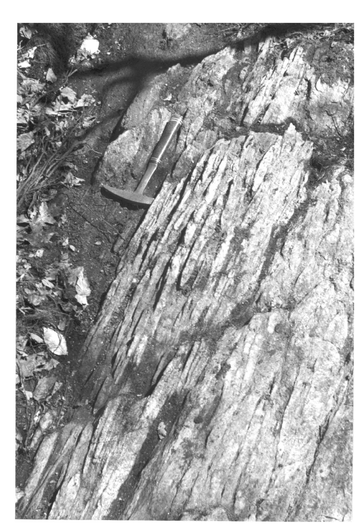


Fig. 15 Coarse-grained diopside calc-silicate and medium- to fine-grained actinolite biotite calc-silicate beds in sulfidic mica schist of the Partridge Formation. Road cut on West River Street, Orange Village.



Silurian and earliest Devonian Stratified Cover: Clough Quartzite (Sc), Fitch Formation (Sf)

The Silurian-Devonian cover rests unconformably on the older rocks, locally in contact with the Partridge Formation, the Ammonoosuc Volcanics, or the tonalitic gneisses and amphibolites of the Ordovician intrusive basement. The Silurian and earliest Devonian section is divided into two facies, originally separated by a tectonic hinge situated close to the present eastern edge of the Bronson Hill anticlinorium. A western sediment source is inferred from studies of less metamorphosed strata in Maine. The western sequence or Connecticut Valley belt is a relatively thin and discontinuous section deposited across the ruins of the Taconian orogeny near the Connecticut Valley and to the west. The eastern sequence or Merrimack belt is a much thicker, continuous sequence of coarse and more impure clastic sedimentary rocks deposited east of the tectonic hinge, either in an extensional trough or as part of the continental slope-rise deposits of post-Taconian North America. This latter interpretation could be consistent with the separation of South America following the Taconian collision according to the interpretation of Dalla Salda et al. (1992), although this has found few adherents subsequently, and the paleogeography of the Taconian collision remains uncertain.

Fig. 16 Stretched and flattened basal quartz-cobble conglomerate of Clough Quartzite in contact with sulfidic schist of Partridge Formation. Hammer handle lies along the actual contact. Long axes of cobbles plunge steeply south almost directly away from observer and parallel to late Quaboagian fold axes. South of powerline on east side of a narrow syncline ending on Mayo Hill in the adjacent Mount Grace Quadrangle.

The thin western Silurian consists of two units, the Late Llandovery Clough Quartzite, and the Pridoli to Lochkovian Fitch Formation. The basal **Clough Quartzite (Sc)** is typically conglomerate with over 95% vein quartz pebbles with garnet and muscovite ± sillimanite in the matrix (Fig. 16). The conglomerate is succeeded upward or in facies relation with finer-grained well bedded quartzite (Figs. 17, 18), The uppermost part of the Clough, where exposed, is a metamorphosed calcareous sandstone, commonly diopside-grossular calc-silicate, and in western New Hampshire and Bernardston, Massachusetts with rare fossil fragments including crinoid columnals and brachiopods preserved in coarsely crystalline calcite (Boucot et al. 1958). The **Fitch Formation (Sf)** is predominantly metamorphosed calcareous shale, now commonly well layered to massive zoisite-diopside-biotite-plagioclase calc-silicate granulite (Fig. 19), with interbeds of sulfidic shale, now mica schist, and rare interbeds of marble, for example, near Moosehorn Road in the Orange area. At Littleton, New Hampshire, where corals and brachiopods had long been known (Hitchcock, 1871; Billings and Cleaves, 1934), a study of conodonts (Harris et al., 1983) indicates a Pridoli (uppermost Silurian) age. At Bernardston, Massachusetts, a crinoid-bearing marble has yielded Lochkovian (lowermost Devonian) conodonts (Elbert et al., 1988). The conodont used to make the Lochkovian assignment at Bernardston has since been found to be more abundant in the Pridoli of the Silurian- Devonian type section in Bohemia (Leonart Jepsen, personal communication, Lund, Sweden, 1993), but no formal resolution of this matter has yet been reached.

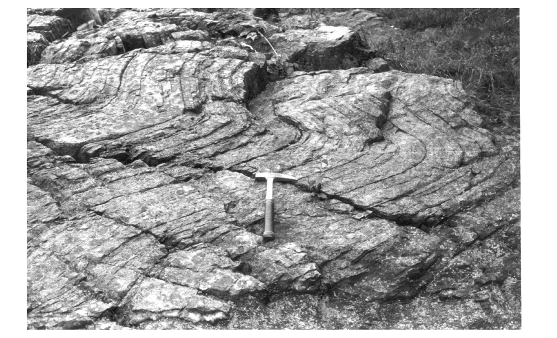


Fig. 17 Fine-grained well bedded Clough Quartzite on east limb of Wendell syncline. Northfieldian folds plunge about 30° north (outcrop surface dips about 45° south, toward viewer). South face of hill above Route 2 east of Stoneville, Millers Falls Quadrangle.

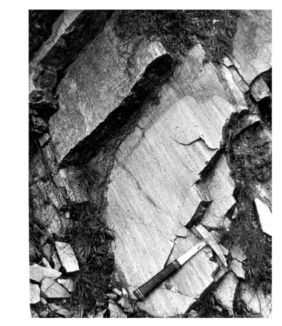


Fig. 18 Fine-grained, well bedded, flaggy muscovite-garnet quartzite of Clough Quartzite on east limb of Kempfield anticline. Strong Northfieldian mica-quartz lineation plunges 45° north (right). Garnets are visible on bedding surfaces. Cut on Route 2 southwest of West Orange.

Fig. 19 Fine-grained, poorly bedded, gray weathering, feldspar-calc-silicate granulite of Fitch Formation. Hammer handle is perpendicular to bedding. Northeast of junction of Routes 2A and 78 in West Orange.

The thick eastern Silurian sequence is dated by lithic correlation with fossiliferous strata in central and eastern Maine (Robinson et al., 1991). It begins with the thick Lower Silurian **Rangeley Formation** of mixed graphitic **(Srg)** and sulfidic feldspathic turbidites **(Srs)** with small lenses of calc-silicate rock and rare lenses of polymict conglomerate. Of this eastern Silurian sequence, only the Rangeley Formation is exposed in the Orange area, whereas higher formations are important to the north and east in the Mount Grace, Royalston, Templeton and several other quadrangles in central Massachusetts, as well as the Monadnock Quadrangle, New Hampshire (P. J. Thompson, 1985). The Rangeley grades upward into the relatively thin Perry Mountain Formation, a more quartzose, better bedded, thinner bedded turbidite, locally characterized at its top by apatite-bearing garnet quartzite or garnet-magnetite iron formation (Robinson and Elbert, 1992). The Rangeley-Perry Mountain is overlain by a distinctive sulfidic zone, possibly related to a widespread anoxic event. In the west this is a calcareous, now calc-silicate section, the Francestown Formation. In the east this is interbedded sulfidic pelite and quartzite, the Smalls Falls Formation. These sulfidic rocks should be assigned to the Upper Silurian on the basis that the graptolites of the correlative Parkman Hill Formation in central Maine are now assigned to the early Ludlow (Tucker, Osberg and Berry, 2001). Above the sulfidic zone are thick calcareous feldspathic turbidites and interbedded shales, now interbedded biotite granulites, calc-silicates, and schists, of Ludlow to Lowest Devonian age, named Warner Formation in New Hampshire or Madrid Formation in Maine. Some of these rocks resemble the Fitch Formation of the Orange area. Within this upper package in Maine evidence has been found for the earliest reversal of source direction from North America in the west to tectonic lands to the east, presumably the approaching Acadian tectonic front. In Maine, and presumably also in Massachusetts, the better-defined Merrimack-belt sequence appears to grade eastward into a section from lowest to highest Silurian dominated by calcareous turbidites like the Warner-Madrid. Such rocks are assigned to the Paxton Formation in east-central Massachusetts. The pattern of Late Silurian - Earliest Devonian sediment sources is discussed in more detail in Robinson et al., 1998.

Lower Devonian Stratified Cover: Littleton Formation (Dl), Erving Formation (De).

The major Lower Devonian stratigraphic unit is the **Littleton Formation (Dl)** of metamorphosed carbonaceous non-sulfidic shale and quartzose sandstone, now mica-garnet-staurolite schist in the kyanite zone, mica-garnet-sillimanite schist with or without staurolite in the sillimanite zone, and mica-chlorite-garnet phyllite with staurolite pseudomorphs in the New Salem retrograde zone (Fig. 20). A simple hornblende amphibolite **(Dla)** was found at one outcrop north of West Orange. The Littleton in western New Hampshire is dated by brachiopods as Emsian (Boucot and Arndt, 1960). It is interpreted as a westward spreading deltaic complex or Acadian flysch with a source in early Acadian tectonic lands to the east (Hall et al., 1976; Robinson et al., 1998).

In the western part of the Orange area, the Littleton is overlain with apparent unconformity by the **Erving Formation**, a controversial unit consisting of alternating metamorphosed basaltic tuff and probable lavas including pillow basalt, and calcareous siltstone and shale (Robinson et al., 1988). The basaltic rocks are now rather monotonous delicately laminated fine-grained to massive coarse-grained epidote amphibolite **(Dea)**. Some of the laminated zones are only 1-5 m thick, and in the adjacent Northfield Quadrangle, have been traced for 1 km or more. The coarse-grained massive amphibolites are most common near the base of the Erving in the Orange area. The siltstones and shales are now gray fine-grained biotite-feldspar granulite **(Deg)** with green, calc-silicate layers, and interbedded graphite-free mica-garnet-staurolite-kyanite schists, quite distinct from the Littleton Formation (Fig. 21). Within the granulites, but always close to amphibolite contacts, are distinctive thin biotite granulites with 2-3 mm magnetite octahedrons and thin layers of pink, ultra-fine-grained garnet (coticule). These manganese-rich beds are considered to be volcanic-exhalative deposits related to the adjacent mafic tuffs and lavas.

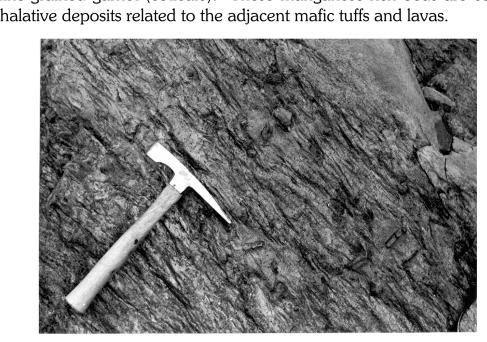


Fig. 20 Gray mica-chlorite-garnet phyllite with pseudomorphs after staurolite in the Littleton Formation in the New Salem Retrograde Zone. The foliation surface is parallel to bedding. A late Quaboagian metamorphic lineation plunges south (left) parallel to the hammer handle. Crenulations associated with the zone of retrograde metamorphism plunge north parallel to the hammer head. Small road cut on Nielson Road south of junction with East Road.

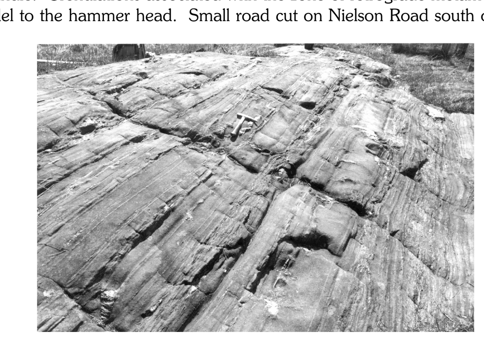


Fig. 21 Typical well bedded, fine-grained plagioclase-quartz-biotite granulite of the Erving Formation. There are a few thin layers of mica-kyanite schist to right. In back yard of "Old Piper Place" just south of junction of Gulf and Orange Roads east of Brush Mountain in the Northfield Quadrangle.

The type locality of the Erving Formation is at Erving in the Orange area and was defined to include the Erving Hornblende Schist of B. K. Emerson (1898) and interbedded feldspathic granulites (Robinson and Luttrell 1985). Robinson et al. (1998) have correlated Erving with a section in the Connecticut Valley synclinorium consisting of Goshen Formation, Waits River Formation, Standing Pond Volcanics, and Gile Mountain Formation, thus implying that these units are also Devonian. These correlations are strengthened by the major and trace element similarities (J. C. Hepburn, personal communication, 1990) of Erving and Standing Pond Volcanics, and Emsian plant fossils have recently been described from correlatives of the Gile Mountain in southern Quebec (Hueber et al., 1990). Trzcienski et al. (1992), on the basis of interpretations in Vermont, suggested that the Erving is Ordovician. They no longer adhere to this Ordovician age assignment, but they can demonstrate that the Whately thrust, a key element in an earlier stratigraphic interpretation (Robinson et al. 1988), is not present at its type locality in Whately, though not ruled out elsewhere (Trzcienski et al., 1993).

Acadian, Quaboagian and Northfieldian Intrusions

Devonian and Mississippian intrusions are abundant in the region, but in the Orange area are limited to a few lenses of foliated two-mica granite gneiss **(Mgn)** plus nearly ubiquitous granitic pegmatites that could not be mapped separately, and which in fact contribute considerable difficulty to stratigraphic mapping. The regional intrusions range from early tectonic to post-tectonic and from gabbro to granite, and several have been studied in detail. Geochronologic work mainly by R. D. Tucker, cited by Robinson et al. 1998, now allow many intrusions to be placed in three major groups, an early group of Acadian intrusions (412-396 Ma), a middle Belchertown group (380 Ma), and a Quaboagian (late Neo-Acadian) group (366-354 Ma), which is the largest. The intrusions closest to the Orange area include the Prescott Complex gabbro (Makower, 1964) at 412 Ma just southwest of New Salem in the Quabbin Reservoir Quadrangle, the enormous Hardwick Tonalite (Shearer, 1983; Shearer and Robinson, 1988) dated at 360±1 and 361±2 Ma (Robinson and Tucker, 1992) shortly to the east in the Athol Quadrangle, and the Coys Hill Granite dated at 396±2 Ma in the Winchendon Quadrangle. The Hardwick Tonalite and related intrusions, and the Fitchburg Complex dated at 359.4±1.1 Ma show locally preserved contact-metamorphic effects strongly overprinted by regional metamorphism and deformation that must have ended after 359 Ma and which has been named Quaboagian.

Late Pennsylvanian intrusions, here called Northfieldian, consist entirely of granitic pegmatites confined to the vicinity of the Pelham dome, Warwick dome and Kempfield anticline. A distinctive swarm of late pegmatites in little deformed sills and dikes intrudes all the rocks and fold structures of the west limb of the Kempfield anticline and east limb Wendell syncline (Figs. 22, 23). The U-Pb ages of igneous monazites of 295 Ma in two of these intrusions provide strong constraints on ages of the youngest regional metamorphism.

Fig. 22 Discordant Northfieldian pegmatite cutting interbedded amphibolite and feldspar-quartz gneiss of the undifferentiated Ammonoosuc Volcanics (Oa) on the northwest corner of the Kempfield anticline. Cut on Route 2 at junction with Route 2A east of Stoneville.

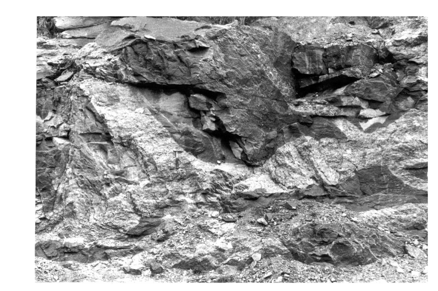


Fig. 23 Discordant Northfieldian pegmatite cutting well lineated, poorly foliated Fourmile Gneiss in the core of the Kempfield anticline. Cut on Route 2 east of junction with Route 2A east of Stoneville.

Jurassic Diabase Dikes

The Connecticut Valley of Massachusetts and Connecticut is underlain extensively by Late Triassic and Early Jurassic continental sedimentary rocks and Jurassic basaltic lavas in the Northfield, Deerfield, and Hartford basins, best dated by fossil pollen (Cornet, 1977). These strata lie in a complex half graben structure with a major listric normal fault along the east side, having a vertical displacement of about 5 km, 10 km west of the edge of the Orange area map. Although the Orange area contains none of these stratified rocks, subsidiary listric normal faults are important in the geology. The highlands east and west of the half graben are cut by four sets of Jurassic tholeiite dikes, two correlative with the first and third lava extrusions in the valley (McEnroe and Brown, 1992, 2000), two younger Jurassic sets not related to any lavas, and two sets of Cretaceous tholeiite dikes, unlike the alkali diabases and lamprophyres typical of the Cretaceous intrusions elsewhere in New England (McEnroe et al., 1987; McEnroe, 1989). There are four small dike exposures **(Jd)** in the Orange area, all on Rattlenake Hill east of New Salem, and all apparently belong to the Pelham-Loudville dike system correlated chemically with the third Jurassic lava extrusion in the Connecticut Valley.

STRUCTURAL DEVELOPMENT

Introduction

Before results of precise geochronology on igneous and metamorphic minerals were available around 1991, the structural and metamorphic development of west-central Massachusetts was considered to have occurred mainly in the Devonian Acadian orogeny lasting roughly 410-360 Ma. The history was grouped into an early nappe stage, an intermediate and poorly understood backfold stage, and a late gneiss-dome stage. This view was demolished by new geochronology, production of a more precise Devonian time scale (Tucker et al. 1998) indicating a Devonian period beginning at 418 Ma and ending at 362 Ma, and new stratigraphy and geochronology in Maine (Robinson et al., 1998; Tucker et al., 2001). Present evidence suggests that what was previously considered "Acadian" ductile deformation and regional metamorphism, should be divided into three distinct episodes spread over more than 100 m.y.: Acadian 410-385 Ma; Quaboagian ("Neo- Acadian") 370-350 Ma, and Northfieldian 305-285 Ma. The last is not to be confused with Alleghanian sensu strictu at 270- 260 Ma. Determination of which structural and metamorphic features belong with each of these episodes has begun, but is far from finished, and much of the key information comes from the Orange area. In addition, in the southwestern part of the Orange area and extending into the Quabbin Reservoir quadrangle, there is the New Salem zone of retrograde metamorphism, with development of its own two generations of ductile folds (Robinson, 1963; Hollocher 1981). Although never precisely dated, the zone is overprinted across the complex boundary between the Quaboagian and Northfieldian zones of deformation and metamorphism, and hence is younger than Late Pennsylvanian, but older than the Mesozoic brittle faulting.

Taconian Deformation

The Bronson Hill anticlinorium, and the eastern flank of the Berkshire anticlinorium to the west, lacks evidence for major pre-Silurian deformation just beneath the Silurian-Devonian rocks. The base of the Clough Quartzite in the Orange and adjacent areas, does cut down from the Partridge through the Ammonoosuc and locally into the underlying Ordovician intrusives, but the author has found only one place where there is evidence for a pre-Silurian fold, and evidence for pre-Silurian faults (detachments, etc.) is circumstantial. In view of the closeness of known major Taconian folds and thrusts in western Massachusetts, this is surprising. It appears that the Silurian-Devonian strata were deposited mainly on rocks of the Bronson Hill arc tectonically higher than the Taconian subduction/deformation zone.

Acadian Nappe Stage

Most structural features previously described as belonging to the nappe stage were probably produced during the Acadian period, partly argued on the basis of structural continuity with central and northern New Hampshire and Vermont where currently geochronology does not indicate importance of the two later episodes, although that could change. The early nappe stage produced west-directed fold nappes with tens of kilometers of transport (Thompson, 1954; Thompson et al., 1968; Robinson et al., 1991) during regional metamorphism, soon after the end of Early Devonian sedimentation, and very soon after the intrusion of the Kinsman Granite. This granite was dated in Cardigan pluton by Sm-Nd and U-Pb garnet at 413±5 Ma (Barreiro and Aleinikoff, 1985), in the Ashuelot pluton at 403±3 Ma. (Robinson et al. 1998) and in the Coys Hill pluton in Massachusetts at 396±2 Ma (Robinson et al., 1998). The best characterized of these fold nappes are the Bernardston nappe and the overlying Skitchewaug nappe near Springfield, Vermont, first described by J. B. Thompson. The type area of the Bernardston nappe is at Bernardston, Massachusetts and its root zone is identified in the Mount Grace Quadrangle directly north of the Orange area (Robinson et al. 1991; Robinson and Elbert 1992). Another fold nappe at a higher tectonic level, based on detailed mapping in the Mount Grace, Orange and Royalston areas is the North Orange nappe. This fold nappe, though not its hinges, is extensively exposed in Orange area (Fig. 2), where the nappe has a core delineated by the narrow North Orange and Creamery Hill bands of Monson Gneiss. The configuration of the North Orange Nappe is illustrated in the inset of Figure 3.

Bedrock Geologic Map and Cross Sections of the Orange Area, Massachusetts

Consisting of the Orange 7.5-Minute Quadrangle, the Western Part of the Athol 7.5-Minute Quadrangle and the Eastern Part of the Millers Falls 7.5-Minute Quadrangle

by Peter Robinson

Comments to the Map User

A geologic map displays information on the distribution, nature, orientation and age relationships of rock and deposits and the occurrence of structural features. Geologic and fault contacts are irregular surfaces that form boundaries between different types or ages of units. Data depicted on this geologic quadrangle map are based on reconnaissance field geologic mapping, compilation of published and unpublished work, and photogeologic interpretation. Locations of contacts are not surveyed, but are plotted by interpretation of the position of a given contact onto a topographic base map; therefore, the accuracy of contact locations depends on the scale of mapping and the interpretation of the geologist(s). Any enlargement of this map could cause misunderstanding in the detail of mapping and may result in erroneous interpretations. Site-specific conditions should be verified by detailed surface mapping or subsurface exploration. Topographic and cultural changes associated with recent development may not be shown.

We recommend reading Reading Maps with a Critical Eye: Becoming an Informed Map Reader by the Maine Geologic Survey to make the best use of a geologic map (http://www.maine.gov/doc/nrimc/mgs/mapuse/informed/informed.htm).

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Citation:
Robinson P., 2008, Bedrock geologic map and cross sections of the Orange area, Massachusetts: Office of the Massachusetts State Geologist Open File Report 09-01. Scale 1:24,000. 5 sheets and digital product: Adobe PDF files.

This map was produced on request directly from digital files (PDF format) on an electronic plotter.

A digital copy of this map (PDF format), including GIS datalayers, is available at http://www.geo.umass.edu/stategeologist

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