DEVONIAN PLANTS FROM SOUTHERN QUEBEC AND
NORTHERN NEW HAMPSHIRE AND THE AGE OF
THE CONNECTICUT VALLEY TROUGH

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ABSTRACT. The gray metasedimentary rocks of the Connecticut Valley trough extend from the east end of the Gaspé Peninsula southwest and south across Quebec and western New England. In northern New England, these rocks belong to the Waits River Formation and Standing Pond Volcanic Member and to the Gile Mountain Formation and its Meetinghouse Slate and Northfield Members (in ascending order). Ages based on reports of fossils in these rocks in New England have long been controversial and range from Middle Ordovician to Early Devonian. Many of the fossils have been proven to be inorganic, some misidentified, and others severely questioned.

Following a review of the earlier “fossil” finds, we herein present descriptions of Early Devonian fossil plants found in rocks of the upper part of the stratigraphic section composing the Connecticut Valley trough. We also present U-Pb data from analyses of zircons from a dike near Springfield, Vt., indicating a Silurian age for some rocks of the trough. Four groups of plants have been recovered from eleven sites: Nematophytales; Zosterophyllumophytina; Lycophyta; and Trimerophyta. The best preserved and most numerous specimens occur in southern Quebec in very low grade metaturbiditic rocks of the Compton Formation (correlative with the Gile Mountain Formation). One site in northern New Hampshire contains fragmental Prototaxites. Farther south near Montpelier, Vt., and down section, poorly preserved echinoderm fragments and “pseudograptolites” that may be interpreted as plant fragments (inertae sedis) occur in the Waits River Formation. The presence of plant fossils in northern New Hampshire and southern Quebec supports a late Early Devonian (Emsian) age for the Gile Mountain Formation and its equivalent, the Compton Formation; the equivocal paleontological data in Vermont and the radiometric data indicate a Silurian age for the Waits River Formation. We conclude that the rocks of the Connecticut Valley trough accumulated continuously beginning as early as the Silurian and extending into the latest Early Devonian.

INTRODUCTION

The Connecticut Valley-Gaspé synclinorium (Cady, 1960), or Connecticut Valley trough (Hatch, 1988), is a distinctive belt of rocks that
extends from the east end of the Gaspé Peninsula southwest and south across Quebec and New England to Long Island Sound (fig. 1). The rocks of the trough are about 95 percent gray metasedimentary rocks of the Waits River and Gile Mountain Formations: the remaining few percent are metavolcanic rocks, most assigned to the Standing Pond Volcanic Member of the Waits River Formation. On the basis of facing criteria, Hatch (1987, 1988) has demonstrated that the stratigraphic order is different from that shown by Doll and others (1961; fig. 2). In this revised sequence the Waits River Formation forms the base of the

Fig. 1. Map of New England and adjacent parts of Quebec (QU) and New Brunswick (NB) showing the location of the Connecticut Valley trough (patterned). Also shown are locations of areas mapped in figures 3, 4, and 6.
HISTORY OF STRATIGRAPHIC AND AGE ASSIGNMENTS

VERMONT SEQUENCE (or equivalents in Quebec)

- Meetinghouse Slate
- Gile Mountain Formation
- Waits River Formation
- Northfield Slate
- Shaw Mountain Formation

* Fossil control ("*" discredited)
/ Fault boundary

SOURCES

1861, 63 Hitchcock, Logan
1906-29 Richardson
1941 Currier and Johns
1950 Cady
1951 Doll
1956a Billings
1956b Dennis
1957 Cooke
1961 Doll and others
1963 Goodwin
1986a Hatch
1986b Bothner and Finney
1989 This report

Fig. 2. Diagram showing the history of stratigraphic sequence and age assignments of the rocks of the Connecticut Valley trough.

Section and grades upward into the Gile Mountain Formation (as earlier recognized by Fisher and Karabinos, 1980). The Gile Mountain in turn passes upward and laterally into the Northfield Member as a more distal western facies equivalent. The top of the section on the east side of the trough is the Meetinghouse Slate Member of the Gile Mountain Formation, interpreted as stratigraphically equivalent to the Northfield. The grade of metamorphism in the rocks of the trough in Vermont, New Hampshire, and southern Quebec ranges from chlorite to sillimanite; most of the rocks have been strongly folded and cleaved at least twice, and, especially in northern Vermont and southern Quebec, they have been intruded by many Devonian and a few Mesozoic plutons.

Although the rocks of the trough have long been recognized as a lithologically distinct sequence, the age of the sequence, particularly in Vermont and northern New Hampshire, has remained unknown or disputed. The purpose of this paper is to review briefly the past record of reported fossils and to present some new fossil evidence and radiometric age data that we feel bear strongly on the resolution of this problem.
PREVIOUS REPORTS OF FOSSILS

Richardson (1902, 1906, 1908, 1916, 1918, 1924, 1929) reported graptolites from a number of localities in the trough rocks in Vermont. He sent the material to Rudolph Ruedemann who assigned the rocks to the Ordovician. In the fall of 1927, however, all Richardson’s samples were lost when a major flood of the Winooski River destroyed the State Museum at Montpelier. Shortly thereafter, Foyle (1931) reported that at one of Richardson’s localities, the “graptolites” were merely streaks of compressed mica flakes, a conclusion that cast some doubt on the validity of all of them. Clarke (1934) reported graptolites from the Tomfobia Formation in southern Quebec in the same strike belt as Richardson’s localities. The validity of these fossils was reviewed by Boucot and Drapeau (1968), who concluded (p. 14) that they were not fossils. Billings and Lyttle (1981) recorded those results as the “pseudo-graptolite belt” on their map of Paleozoic fossil localities in New England.

Boucot and Drapeau (1968) reexamined Clark’s (in Cooke, 1937) faunal assemblage of brachiopods, trilobites, crinoids, and corals from the base of the St. Francis Group near the eastern shore of Lac Saint-François in southern Quebec. An Upper Silurian age was assigned to those rocks in a recent compilation by Sivitsky and St. Julien (1985).

Doll (1943a) reported finding echinoderms in the trough rocks indicating a Silurian or Devonian age and a single brachiopod indicating a “lower Devonian (Oriskanian) age” (1943b, p. 676). Neither of these fossils has been widely accepted. Doll (1984) has since summarized all his information on fossils in the Connecticut Valley trough.

Cady (1950) reported seven localities of cup corals from the trough rocks just east of Montpelier, Vt. Professor V.J. Okulitch (University of British Columbia), to whom Cady sent the material for identification, said “...my impression is that the corals are probably Streptelasma [which is] very common in the Middle and Upper Ordovician of North America” (Cady, 1950, p. 495). Despite this work, however, and apparently on the basis of regional relations, Cady (1956) assigned a Silurian(?)-Devonian age to the very same rocks. In 1979, N.L. Hatch, Jr., recovered Cady’s locality 7, his major locality. Numerous color slides and some large slabs containing the “corals” were examined by William A. Oliver, Jr. (U.S. Geological Survey), who reported (written commun., December 3, 1979) that “None of the specimens at hand appear to be corals and none have any markings or structure that suggest an organic origin, although this is a possible origin of the objects.”

In addition to a review of the fossil data available through 1950, Dennis (1956) reported the presence of microfossils from black slates in the Waits River Formation. These microfossils were examined by L.R. Wilson (New York University), who identified Hystrichosphaerida and Chitinozoa and suggested “that the beds are younger than Cambrian in age and that since no Silurian or Devonian forms were encountered in
association with this sparse fauna, the formation could most easily be assigned to the Ordovician” (Dennis, 1956, p. 31–32). Unfortunately, his sample locality has not been relocated, and the material has been lost. As did Doll and Cady, Dennis (1956) also assigned these rocks to the Silurian and Devonian, presumably for the same reasons.

Thus, at the time of the compilation of the Vermont State bedrock map (Doll and others, 1961), none of the reported fossils in the trough rocks was generally accepted as reliably indicating their true age. Doll and others (1961), based in part on regional relations, called the trough rocks Silurian and Devonian, which assignment has been broadly, though not universally, accepted since. For a graphic historical review of the stratigraphic nomenclature and age assignments, see figure 2.

In 1985, Bothner and Berry reported “upper Ordovician graptolites” from rocks of the trough about 2 km west of La Patrie, Quebec (fig. 3). F.M. Hueber soon thereafter identified Early Devonian, probably Emsian, plants from identical rocks a few kilometers on strike to the northeast and not far from fossil localities near Ste. Cecile, Quebec (fig. 3), noted on maps by St. Julien (1970) and Kelly (1975). Bothner and Finney (1986) then reported “Middle to Upper Ordovician biserial graptolites” from Richardson’s localities near Montpelier, Vt. Well-preserved echinoderm fragments and crinoid columnals (confirmed by Julian Green, Harvard University, written commun., January 10, 1988) occur in the same outcrops but unfortunately are not age specific (Bothner, 1987).

In August 1988, an expedition was organized to get the involved geologists and paleontologists into the field together to look at the critical outcrops with the hope of solving the dilemma of whether we were dealing with Devonian plants or Ordovician graptolites. Most of the remainder of this paper discusses the results and conclusions from that expedition. Localities examined are described in table 1, and plant fossils found are summarized in table 2.

**PSEUDOCKERATOLITES**

A revisit to Bothner’s original locality near La Patrie, Quebec (fig. 3; U.S. National Museum locality 14290) and careful examination of the “graptolites” resulted in agreement that these forms were plants and definitely not graptolites. Four localities (figs. 4 and 5) with possible graptolites were visited in the Montpelier area of Vermont. Sabin quarry (USNM locality 14293), Catholic Cemetery (USNM locality 14294), and Valley Lake (USNM locality 14291) are areas from which Richardson (1916, 1918; in Ruedemann, 1947, p. 63) reported Ordovician graptolites. Berlin Corners (USNM locality 14300) is a recent roadcut for Interstate 89 in the vicinity of Richardson’s Berlin Mountain locality.
Fig. 3. Map of southern Quebec and northernmost New Hampshire showing localities (black dots) from which plant fossils were recovered; italicized numbers are the last three digits of USNM locality number listed in tables 2 and 3 (USNM 14---).
### Table 1

**Fossil localities in the Connecticut Valley trough**

<table>
<thead>
<tr>
<th>U.S. NATIONAL MUSEUM LOCALITY NUMBER</th>
<th>AGE</th>
<th>STRATIGRAPHIC UNIT</th>
<th>QUADRANGLE</th>
<th>LATITUDE</th>
<th>LONGITUDE</th>
<th>DETAILED LOCATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>14290</td>
<td>Devonian, Emsian</td>
<td>St. Francis Group, Crompton Formation</td>
<td>LaPatrie, PQ, 21E/E6, 1:50,000</td>
<td>45° 23.86' N</td>
<td>71° 17.05' W</td>
<td>Low cutouts, south side of Rt. 212, 2.5 km west of LaPatrie, Compton County, Quebec, Canada</td>
</tr>
<tr>
<td>14291</td>
<td>Late Silurian? Devonian</td>
<td>Waits River Formation</td>
<td>Plainfield, VT, 1:62,500</td>
<td>44° 26.77' N</td>
<td>72° 26.15' W</td>
<td>Valley Lake, 1.7 km west northwest of Woodbury, Washington County, VT</td>
</tr>
<tr>
<td>14292</td>
<td>Devonian, Emsian</td>
<td>St. Francis Group, Crompton Formation</td>
<td>Megantic, PQ-ME, 21E/10, 1:50,000</td>
<td>45° 40.35' N</td>
<td>70° 55.30' W</td>
<td>Farm of Jacques LaCroix, on road 2.2 km NE of town of St. Cecile de Whiston, Frontenac County, Quebec, Canada</td>
</tr>
<tr>
<td>14293</td>
<td>Late Silurian? Devonian</td>
<td>Waits River Formation</td>
<td>Montpelier, VT, 1:24,000</td>
<td>44° 15.32' N</td>
<td>72° 33.65' W</td>
<td>Sabin Quarry, 0.4 km east of Vermont College, Montpelier, Washington County, VT</td>
</tr>
<tr>
<td>14294</td>
<td>Late Silurian? Devonian</td>
<td>Waits River Formation</td>
<td>Montpelier, VT, 1:24,000</td>
<td>44° 15.78' N</td>
<td>72° 33.82' W</td>
<td>Catholic Cemetery, 0.15 km north of Main Street along Lincoln Street, Montpelier, Washington County, VT</td>
</tr>
<tr>
<td>14295</td>
<td>Devonian, Emsian</td>
<td>St. Francis Group, Crompton Formation</td>
<td>LaPatrie, PQ, 21E/E6, 1:50,000</td>
<td>45° 25.82' N</td>
<td>71° 15.75' W</td>
<td>Low roadside exposure 1.75 km north of LaPatrie, and 0.3 km west on Petit Quebec Road from Rt. 257, Compton County, Quebec, Canada</td>
</tr>
<tr>
<td>14296</td>
<td>Devonian, Emsian</td>
<td>St. Francis Group, Crompton Formation</td>
<td>LaPatrie, PQ, 21E/E6, 1:50,000</td>
<td>45° 25.82' N</td>
<td>71° 15.76' W</td>
<td>Low roadside exposure 1.75 km north of LaPatrie, and 0.31 km west on Petit Quebec Road from Rt. 257, Compton County, Quebec, Canada</td>
</tr>
<tr>
<td>14297</td>
<td>Devonian, Emsian</td>
<td>St. Francis Group, Crompton Formation</td>
<td>Megantic, PQ-ME, 21E/10, 1:50,000</td>
<td>45° 39.85' N</td>
<td>70° 56.25' W</td>
<td>Low exposure, northeast side of road, Rt. 263, 0.4 km southeast of St. Cecile de Whiston, Frontenac County, Quebec, Canada</td>
</tr>
<tr>
<td>14298</td>
<td>Devonian, Emsian</td>
<td>St. Francis Group, Crompton Formation</td>
<td>Megantic, PQ-ME, 21E/10, 1:50,000</td>
<td>45° 40.27' N</td>
<td>70° 56.87' W</td>
<td>Road cuts, both sides of road, Rt. 263, 0.7 km northwest of St. Cecile de Whiston, Frontenac County, Quebec, Canada</td>
</tr>
<tr>
<td>14299</td>
<td>Devonian, Emsian</td>
<td>Gil Mountain Formation</td>
<td>Indian Stream, NH, 1:62,500</td>
<td>45° 02.75' N</td>
<td>71° 26.65' W</td>
<td>Road cut, west side of Rt. 3, and west of the bridge crossing Indian Stream, Coos County New Hampshire</td>
</tr>
<tr>
<td>14300</td>
<td>Late Silurian? Devonian</td>
<td>Waits River Formation</td>
<td>Berlin West, VT, 1:24,000</td>
<td>44° 12.70' N</td>
<td>72° 35.03' W</td>
<td>Road cut, 0.62 km west northwest of Berlin Corners, Washington County, VT, on access road west of southbound lane, Route 1-89</td>
</tr>
</tbody>
</table>
### Analysis of the fossils at localities in the Connecticut Valley trough

<table>
<thead>
<tr>
<th>PLANT GROUP</th>
<th>Vermont Localities</th>
<th>New Hampshire Locality</th>
<th>Quebec Localities</th>
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<tbody>
<tr>
<td>Nematophytales</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Zosterophyllophyta</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Axes</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Sporangium</td>
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<td></td>
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<tr>
<td>Lycophyta</td>
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<tr>
<td>Leafy axes</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Decorticated axes</td>
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<tr>
<td>Trimerophyta, s.l.</td>
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</tr>
<tr>
<td>Axes</td>
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</tr>
<tr>
<td>Dichotomous</td>
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<tr>
<td>Pseudomonopodial</td>
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<td></td>
</tr>
<tr>
<td>Ornamented</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Smooth</td>
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<td></td>
<td></td>
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<tr>
<td>Grooved</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Regularly</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Irregularly</td>
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<td></td>
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<tr>
<td>Large, Dia. &gt;10 mm</td>
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</tr>
<tr>
<td>Conducting strand</td>
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<td>Incertae sedis</td>
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<td>Axes</td>
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<tr>
<td>Large</td>
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<tr>
<td>Dia. &gt;10 mm</td>
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<td></td>
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<tr>
<td>Dia. 5 - 10 mm</td>
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<tr>
<td>Smooth</td>
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<tr>
<td>W/Narrow strand</td>
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<tr>
<td>Narrow, Dia. &lt;1 - 5 mm</td>
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<td>Smooth</td>
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<tr>
<td>ANIMAL GROUP</td>
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<td></td>
</tr>
<tr>
<td>Echlnoderm fragments</td>
<td></td>
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<tr>
<td>Arthropod fragment</td>
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</tbody>
</table>
Fig. 4. Map of the vicinity of Montpelier, Vt., showing the localities (black dot) of the "pseudograptolites." Italicized numbers as in figure 3; Dn-Northfield Member of the Gile Mountain Formation, DSw-Waits River Formation, Om-Moretown Formation.
Fig. 5. Pseudograptolites from Catholic Cemetery (USNM locality 14294; see fig. 4). A. B. V-shaped specimen (USNM 422533) resembling *Isogaptus*, X 2, X 1, respectively. B. C. Straight, parallel-sided specimens (USNM 422534) resembling diplograptid graptolites, X 1, X 2.

Possible fossils were discovered at the Sabin quarry and Catholic Cemetery localities (fig. 4; USNM localities 14293 and 14294, respectively), but they are not graptolites. The specimens (fig. 5) consist of black, flattened layers that are distinct from the enclosing metamorphic matrix. In shape and size, the specimens resemble rhabdosomes of diplograptids *Phyllogaptus* and *Isogaptus*, but the specimens display no detailed morphological features of graptolites. Thecal apertures, siculæ, and spines cannot be recognized on the margins of the specimens, and interthecal and median septa cannot be discerned on the surfaces of the flattened layers.

Possible fossils from the Valley Lake locality (fig. 6; USNM locality 14291) consist of straight, parallel-sided depressions and slightly rusty streaks 2 to 5 mm wide and several centimeters long. The sizes and shapes are comparable to those of stipe fragments of many different Ordovician graptolites, but the possible fossils are not graptolites. Although the specimens are poorly preserved, the margins, where visible, are perfectly straight and without any indication of thecal apertures.
Fig. 6. Map of the environs of Valley Lake, Vt., showing “pseudograptolite” locality (black dot); italicized number as in figure 3; Dn-Northfield Member of the Gile Mountain Formation, DSw-Waits River Formation, Ssm-Shaw Mountain Formation, Om-Moretown Formation.

Parallel-sided streaks comparable in size and shape to Ordovician diplograptid graptolites are abundant on numerous large bedding surfaces at Berlin Corners (figs. 4, 7; USNM locality 14300). The streaks consist of low ridges of pyrite. In places, the irregular margins of the streaks resemble thecal apertures, but few could be found on the multitude of streaks examined. A metamorphic origin of the streaks is indicated by the fact that they are all perfectly aligned not only on each individual bedding surface, but also on all bedding surfaces. Graptolites have never been reported to occur with such a consistent unidirectional orientation on one bedding surface, let alone many.

Finney’s initial identification (Bothner and Finney, 1986) resulted from a desire to find graptolites in small samples studied only in the laboratory. The opportunity to examine large samples and to view them
Fig. 7. Pseudograptolites (arrows) from Berlin Corners (USNM locality 14300; see fig. 4) resembling diplograptid graptolites. A, B. USNM 422555 and USNM 422536, both X 1.

in their geologic setting provided the insights to conclude confidently that these possible fossils in the rocks of the Connecticut Valley trough are not graptolites.

ISOTOPIC DATA

New U-Pb zircon data have been obtained from a dike cutting the Standing Pond Volcanic Member of the Waits River Formation just southeast of Springfield, Vt. (fig. 1). In addition Spear and Harrison (1989) and Harrison and others (1989) have recently reported $^{40}\text{Ar}/^{39}\text{Ar}$ isochron and plateau ages on hornblendes from the Gile Mountain Formation and Standing Pond Volcanic Member and $^{40}\text{Ar}/^{39}\text{Ar}$ ages from muscovite, biotite, and K-feldspar from rocks of the trough, respectively.

Zircons from the dike near Springfield, Vt. (fig. 1) are clear to light brown, euhedral, and stubby (length-to-width ratio of 1:2). Most grains have at least one pyramidal termination, most faces are somewhat pitted, and no distinct cores are visible; this morphology is suggestive of an igneous origin. No detrital zircons were found in this sample. Eight size
TABLE 3

Uranium-lead concentration and composition data from zircon from a dike cutting the Standing Pond Volcanic Member of the Waits River Formation, southeastern Vermont (zircons are from sample VT/Sp I-85 collected at lat 43° 16' 14" N., long 72° 27' 23" W. Constants used in determining ages:
\( ^{235} \lambda = 9.8485 \times 10^{-10} \) yr; \( ^{238} \lambda = 1.55125 \times 10^{-10} \) yr; \( ^{238} U / ^{235} U = 137.88 \) (Steiger and Jäger, 1977))

<table>
<thead>
<tr>
<th>Fraction*</th>
<th>Wt (mg)</th>
<th>Concentration (mg)</th>
<th>Pb composition**</th>
<th>Ratio (% error)**</th>
<th>Ages (Ma)***</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>U</td>
<td>Pb</td>
<td>Pb</td>
</tr>
<tr>
<td>150NM</td>
<td>5.81</td>
<td>316.9</td>
<td>27.82</td>
<td>306.09</td>
<td>9.7006</td>
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<tr>
<td>150+250NM</td>
<td>6.57</td>
<td>361.9</td>
<td>26.51</td>
<td>454.00</td>
<td>17.096</td>
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<td>150+250NM</td>
<td>13.44</td>
<td>306.4</td>
<td>22.62</td>
<td>529.4</td>
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<td>200+350NM</td>
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<td>250+350NM</td>
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<td>23.78</td>
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<td>320NM</td>
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<td>309.7</td>
<td>22.94</td>
<td>518.75</td>
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<td>320Mag</td>
<td>4.92</td>
<td>421.2</td>
<td>32.05</td>
<td>1978.3</td>
<td>15.966</td>
</tr>
</tbody>
</table>

*Numbers refer to mesh sizes, Abbreviations: NM (non-magnetic), Mag (magnetic), A (abraded).
**Corrected for 1 ng blank and mass fractionation of 0.14 ± 0.05 percent/atomic mass unit.
***2 σ errors.
****Common lead corrected for using appropriate values from Stacey and Kramers (1975).

fractions were analyzed for uranium and lead isotopes, including two abraded splits (table 3). The Pb/U and \(^{207}\text{Pb} / ^{206}\text{Pb}\) ages are similar (ranging from 395–413 and from 418–429 Ma, respectively). A standard best fit regression of all eight points has concordia intercept ages of 428 ± 32 and 90 ± 230 Ma. However, because of the narrow spread of \(^{207}\text{Pb} / ^{206}\text{Pb}\) ages, a meaningful concordia intercept age is determined by forcing the regression through a lower intercept of 0 ± 50 Ma (fig. 8). According to this method, the age of crystallization of the dike is 423 ± 4 Ma. Another approach, calculating the weighted average of the \(^{207}\text{Pb} / ^{206}\text{Pb}\) ages, yields an age of 422 ± 2 Ma. J. N. Aleinkoff concludes that this dike is Silurian, thereby suggesting a minimum age for the Standing Pond Volcanic Member of the Waits River Formation and, thus, also for the rest of the Waits River.

The hornblende \(^{40}\text{Ar} / ^{39}\text{Ar}\) release spectra reported by Spear and Harrison (1989) from one Gile Mountain Formation locality in Vermont yielded isochron ages of 451 ± 27 and 425 ± 5 Ma, and spectra from one exposure of the Standing Pond Volcanic Member at Saxtons River yielded an isochron age of 440 ± 10 Ma. Four other samples from the Standing Pond have an average plateau age of 372 Ma. Their isochron analysis of the older ages "strongly suggests" (1989, p. 183) the preservation of Late Ordovician cooling in the Connecticut Valley trough. That suggestion is interpreted by them as an indication of pre-Acadian
Fig. 8. Concordia plot (dashed) of U-Pb data from zircons from a dike cutting the Standing Pond Volcanic Member of the Waits River Formation, Rt. 11, about 3 km southeast of Springfield, Vt. (see fig. 1). Regression of 8 points, forced through 0 ± 50 Ma, yields upper intercept age of 423 ± 4 Ma.

metamorphism and leads them to the conclusion that the ages of the Gile Mountain Formation, the underlying Standing Pond Volcanic Member, and, hence, the Waits River Formation as well are Late Ordovician or older.

NEW FOSSIL DATA

The field expedition in August 1988, besides refuting the Ordovician graptolites reported by Bothner and Berry (1985) and Bothner and Finney (1986), produced at least five localities from which identifiable (by F.M. Hueber) fossil plants were recovered and others from which non-age-specific plants or echinoderm fragments were recovered.

Echinoderm Fragments

At the west end of the Berlin Corners locality (fig. 4; USNM locality 14300), a gray 2 to 5 mm-thick layer of calcareous metasiltstone of the Waits River Formation contains numerous 1 to 2 mm chalky white to pink subrounded carbonate clasts that under the hand lens and in thin section are clearly crinoid columnals and other echinoderm fragments. In thin section (fig. 9) the columnals and/or cirri and other fragments are composed to optically continuous single-crystal calcite. Some have pores filled with carbonaceous material, but neither axial canals nor
Fig. 9(A and B) Photomicrographs of echinoderm fragments (USNM locality 14300).
(C and D) Specimen USNM 422570), plane polarized light.
other features that might provide further identification were recognized. These fragments, unfortunately, do not aid in the resolution of the age of the basal unit of the Connecticut Valley trough but do lend credence to Doll's (1943a) earlier report.

**Fossil Plants**

When the first collections of fossil-bearing rocks from USNM localities 14290, 14292, and 14295 were received and examined closely, there was no doubt that the fossils were fragmented remains of land plants. Variety of morphology, relatively large individual stems, and occasional traces of conducting strands all were clearly evident. A comparison with assemblages of similar composition indicated a strong correlation with the flora found in upper Emsian sedimentary rocks at Gaspé Bay, Quebec, as well as other sites approximating the same age. Unfortunately, the fragmentary condition and state of preservation of the fossils precluded assignment of specific names to most of the specimens. On the other hand, reasonable interpretations could be made as to the relation of the remains to major, early land-plant groups as well as to their relative position in the evolution of the plant kingdom.

Subsequent collections, obtained during the expedition in 1988, have supplied larger numbers of specimens both from the very productive sites and from those sites where plant remains are less abundant. These recent collections have been the source of additional evidence of the general diversity and the age of the fossil plants preserved in the rocks of the Connecticut Valley trough.

Unfortunately, the usual techniques used in the preparation of fossil plant material for anatomical studies are of limited or no use on the specimens at hand. Metamorphism and tight folding of the enclosing sedimentary rocks have converted the carbonized plant remains to minutely fractured, high-grade, coal films, or, in many instances, the plants have been nearly totally replaced by micaceous minerals. Very rarely and at only two localities, some permineralization of tissues by pyrite or quartz has been found. This form of preservation apparently occurred prior to metamorphism. Internal and external molds of fragments of stems are relatively common at some of the localities (USNM localities 14290, 14292, and 14298).

The fossils are observed best by bright, low-angle, reflected light. However, before a particular specimen is photographed, the surface of the matrix is flooded for a few seconds with concentrated hydrofluoric acid, thoroughly rinsed with water, and then air dried. This treatment results in better contrast between the fossils and the surrounding matrix. The best photographs are then obtained by using carefully selected film and developing, processing, and printing methods, which, in concert, increase the contrast to an even higher degree.

An analysis of the variety of plant remains found at eleven sites in the Connecticut Valley trough is presented in table 2. Primarily, the
assignment of specimens to particular plant groups is based on interpretive judgments and field experience. In only three instances can generic or specific identifications be given with reasonable confidence of accuracy. We are dealing with the remains of relatively delicate land plants, which were fragmented, transported from their sites of growth, and buried in sediments of fluvial origin. Subsequent metamorphism erased many of the characteristics that are useful in the description of species but did not obliterate the remnants of morphological detail that aid in the identification of plant groups in early floras. The plant groups and the representative fossils collected at the sites in the Connecticut Valley trough are described next in the order in which they are listed in table 3.

Nematophytales.—The Order Nematophytales, comprising four genera, ranges in age from late Wenlock (Middle Silurian) (Etheridge, in Hicks, 1881) through the Late Devonian (Arnold, 1952). Specimens from USNM localities 14298 and 14299 (fig. 10A), exhibiting details of anatomy characteristic of the Order, are best compared with the genus Prototaxites, the longest ranging of the four genera. Prototaxites is characterized by its anatomy comprising a meshwork of large, smooth-walled tubes surrounded by smaller, branched, hyphae-like tubes. The genus for more than a century has been compared with the brown algae; however, the anatomy is more comparable to that of certain fungi.

At USNM locality 14298, the specimens occur as considerably compressed, rounded pellets ranging from 0.5 to 3.5 cm in diameter. When the enclosing sediments were folded and metamorphosed, the carbonized remains were fragmented into small rectangular blocks, and the spaces between the fragments were infilled by micaceous minerals. Freshly broken surfaces of the blocks show fine, undulating striations that are seen as suggesting smooth tubular cells forming a tissue typical of the genus. Finer structural details, unfortunately, were not preserved. At USNM locality 14299, the specimens were two rounded cobbles embedded at slightly different levels in a section of otherwise barren metagraywackes. This type of occurrence parallels in appearance that which one can observe in the cliffs along the north and south shores of Gaspé Bay, even though the matrix in the cliffs has a different texture.

The specimens at USNM locality 14299 were apparently permineralized by quartz before the surrounding matrix was metamorphosed. The fibrillar structure of the tissue is still reasonably intact (fig. 10A). Such would not be the case if the tectonic forces had acted on purely carbonaceous remains. Prototaxites is almost invariably preserved by quartz permineralization while other plants with which it is associated remain as mere carbonized compressions. As yet, this characteristic is not explained.

Zosterophylliphytina.—The Zosterophylliphytina (Banks, 1968) was a group of plants that arose in the Late Silurian (sensu Douglas and Lejal-Nicol, 1981), reached its acme during the Early Devonian, and disappeared from the record in the early Late Devonian (in the
Fig. 10. Nematophytales, Zosterophyllphytina, and Lycophytina. (A) Prototaxis sp., slightly contorted fibrilar cell structure in longitudinal section, X 10, USNM 422537, USNM locality 14299. (B) Sporangium with morphology typical of zosterophylls, upper arrow defines the distal line of dehiscence, the lower arrow defines the stalk, X 5, USNM 422538, USNM locality 14298. (C) Fragment of stem of Sawdonia ornata (Dawson) Hueber, arrow defines remnants of spines, lateral branch is typical of the species, X 5, USNM 422539, USNM locality 14292. (D) and (E) Part and counterpart of lycopod stem referable to the genus Drepanophyceus, arrow in (E) defines leaf in side view, X 2, USNM 422540 A and B, USNM locality 14296. (F) and (G) Part and counterpart of small lycopod stem, arrow in (G) defines attenuated apex of leaf, X 5, USNM 422541, USNM locality 14298.
Frasnian, according to Hueber and Grierson, 1961). Specimens attributable to the group have been found at only two of the localities included here. One, at USNM locality 14292, is a small stem (fig. 10C) that exhibits branching and ornamentation typical of the species *Sawdonia ornata* (Dawson) Hueber. The branching is pseudomonopodial, and the lateral branch departs at an angle of approx 60 degrees and then assumes a position that would result in growth parallel to the central axis. Remnants of spines are apparent on the central axis. The apex of the lateral branch exhibits circinate vernation, and the outer margin of the spiral is directed toward the central axis.

The second occurrence of Zosterophyllophytina is from USNM locality 14298. The specimen is a sporangium characteristic of the zosterophylls (fig. 10B). It is reniform in outline, 3.4 mm wide and 2.2 mm high, borne on a short stalk, 1 mm long and 1.4 mm wide. The presence of a distal line of dehiscence is indicated by the thickened outer margin of the compression. The paucity of specimens representing the zosterophylls may be a reflection of the delicate nature of the plants. Most of the species had very little heavily thickened supportive tissue. As a result, large fragments could rarely have survived the rigor of the currents and turbulent mixing with sediments during transport and subsequent deposition.

*Lycophytina.*—The Lycophytina is a group of plants still represented in our modern floras. The origin of the group may be traced, with some debate, to the species *Baragwanathia longifolia* Lang and Cookson in the Late Silurian of Victoria, Australia (*sensu* Garratt, 1978; Douglas and Lejal-Nicol, 1981; Garratt and Rickards, 1984). This purported earliest representative of the group was a fleshy, herbaceous plant having a well-developed, cauline, vascular strand which, in an orderly sequence, supplied single vascular traces to each of its many leaves. Each trace, as a single vein, extended along the full length of the individual leaf. The sporangia in fertile specimens were borne in the axils of the leaves. On both fertile and vegetative stems, the leaves were arranged in steeply inclined, contiguous helices. Although fleshy and to some extent delicate, large specimens of *Baragwanathia* are found preserved apparently as a result of gentle rafting of the stems into a marine basin where they settled and were buried in fine sediments. Such gentle conditions were not experienced by the specimens representing the Lycophytina at the sites in the Connecticut Valley trough. At this time, only two leafy stem fragments have been found.

The better specimen was collected at USNM locality 14296 (fig. 10D, E) and consists of a fragment of a stem 3.2 cm long and 1.2 cm wide. The leaves are directed vertically along the margin of the stem and are arranged in a low-angled, open helix. The best preserved leaf is 9.5 mm long, and the average width of the leaf-bases is 2.5 mm. In lateral view, the leaves appear to be thickened, perhaps keeled, rather than flattened into a blade-like lamina. Although the taxonomy of Devonian lycopods is in considerable flux at this time, the genus to which this
specimen may be referred is *Drepanophyкус*. Most of the discussions center on the definition of the species, but this genus is still treated as a lycophyte by most workers on the floras of the Devonian. *Drepanophyкус* ranged from the Pragian to the Frasnian, and its fossils are most abundant in species and number of occurrences in lower Lower Devonian rocks (Pragian-Emsian).

The second leafy lycophyte stem (fig. 10F, G) was found at USNM locality 14298. It is a very small fragment 8.8 mm long, but in that length there are 10 leaves. They are helically arranged and are unusual in that each appears to have a broadly ovate entire lamina and a caudate apex. The margins are slightly overlapped in the sequence around the stem. The narrow spine-like apices are nearly as long as the lamina and are directed away from the stem. Each leaf is perhaps 2.2 mm long including the spine-like apex. It is not possible to determine if the leaves are petiolate or attached along the broad bases of their expanded laminae. Thus, a meaningful measurement is not possible. The literature at this time has no description of a Devonian lycophyte with leaves of the form seen on this specimen. Those with expanded laminae as in *Haskinsia* Grierson and Banks (1983) and *Archaeosigillaria* (Goeppert) Kidston (1901, *pro parte*) differ in other features of their leaf morphology. In *Haskinsia* the leaves are hastate, entire, and acuminate, whereas in *Archaeosigillaria*, the leaves are lanceolate-deltoid, serrate, and acuminate, terminating in a hair. The leaves of these two genera are also described as petiolate; however, this characteristic is not determined for the specimen described and illustrated here (fig. 10F, G). *Haskinsia* ranges from the Givetian to the Frasnian; *Archaeosigillaria* ranges from the Givetian to the Viséan.

The specimens included in the Lycophytina here and noted as decorticated axes are essentially Lycophytina *incertae sedis*, because they represent compressions of defoliated and retted stems which reflect only the original helical arrangement of appendages. No species can be named, and the classification within this category is based simply on the morphology of the specimens at hand. Specimens are rare at USNM localities 14292 and 14297, and they are somewhat common at USNM locality 14298. None was found at the other collecting sites. The specimen illustrated here (fig. 11A) from USNM locality 14297 is a fragment of an unusually large stem 21.5 cm long and 5.5 cm wide. It is best compared with the rhizomes of *Baragwanathia* or defoliated stems of *Drepanophyкус*, particularly *D. spinaeformis* Goeppert. The openings marked by the oval areas on the stem probably represent the points of attachment of roots or of leaves. Stems of *Baragwanathia* of this size can be seen in the flora of the Upper Plant-Graptolite Horizon, as defined by Garratt and Rickards (1984), which is of Pragian age in Victoria, Australia. Stems of *Drepanophyкус* of similar appearance to the specimen at hand and of Emsian age are available along the north and south shores of Gaspé Bay, Quebec, and the banks of the Abitibi River, James Bay Lowland, Ontario, Canada. The small fragments from USNM localities 14298 and 14292 have been particularly difficult to photograph, but
Fig. 11. Decorticated lycopods. (A) Large stem with lenticular openings in the epidermal layers marking sites of leaf attachments, X 0.75, USNM 422542A and B, USNM locality 14297. (B) Fragment of a stem with pattern of openings suggesting points of attachment of small leaves, X 5, USNM 422543, USNM locality 14298. (C) Fragment of stem with large lenticular openings, one defined by arrow on left suggesting points of attachment of leaves, X 2, USNM 422544, USNM locality 14292.

two specimens are illustrated as well as possible in figure 11B and C. The helically arranged openings in the compressed cuticular material are the only characters useful in defining these specimens.

Trimerophytina.—Banks (1968) established the Trimerophytina as a group of Devonian plants characterized by complex branching patterns, massive xylem strands relative to the Rhyniophytina, and large,
freely branching lateral trusses of sporangia. Most of the robust fossil plants that reflect some or all of these characteristics and that are described from many sites rich in Devonian plants have been placed in the Trimerophytina. The group now contains a variety of plants having an even wider range of morphological characteristics than those originally proposed. In table 3, under the category of Trimerophytina, s. l., are listed some of the characteristics attributed to various members of the group. These were used in the analysis of specimens collected in the Connecticut Valley trough. Axes may be dichotomously and/or pseudomonopodially branched (figs. 12, 13), ornamented with spine bases or tubercles (figs. 14, 15), or uniformly smooth (figs. 12, 13B, C, D) or grooved (fig. 15B). The regularly grooved condition usually reflects the form of the xylem strand or thickenings in the cortex (fig. 14D). The thinner and softer cortical tissues have been compressed, but a probable ribbed xylem strand or cortical thickenings were firmer and more resistant to compression. The irregularly grooved stems generally indicate the presence of randomly aligned stomata on the stem surfaces wherein the outer, thickened, cortical layers are thinner and more susceptible to compression. Axes of Trimerophyton, the genus that forms the basis of the group, have been found up to 2.5 cm in diameter and 2 m tall in a single specimen at the type locality on the north shore of Gaspe Bay. Fragments of large stems as shown in figures 12A and 13E are common at USNM localities 14296 and 14298. The presence of a vascular strand, as seen in compressions of stems, may be interpreted from regular surficial grooves as mentioned above or by the presence of a thicker layer of carbonized tissue traversing the length of the stem (figs. 12A, 14C).

Where anatomy has been observed in permineralized specimens of some of the species in the Trimerophytina, it is clear that the plants were structurally stronger than their contemporaries. Most had a larger volume ratio of xylem to stem and had well-developed, multi-celled layers of thick-walled cells forming the outer cortex of the axis. These characteristics, in concert with turgor pressure within the layers of thin-walled cells composing the inner cortex, increased the potential for robust growth forms. The heavier cell structure in the axes lent itself to better preservation of larger and more meaningful fragments in the fossil record. This is probably one of the factors partly responsible for our finding representative fragments assignable to the Trimerophytina at all but one of the localities from which fossil plants were collected. Another factor, however, is the broad range of characters that can be used to define the group. Unfortunately, no sporangia or sporangial trusses were found that could further corroborate the presence of the group. However, the absence in the collections of fossils of trimerophyte sporangia may be directly due to the fragile nature of the structures and their inability to withstand the rigors of rough transport and subsequent tectonic pressures. Additional searching at USNM localities 14296 and 14298 may eventually yield specimens.
Fig. 12. Trimerophytina s.l. (A) Large, probably dichotomously branched stem, the right limb showing remnants of a median vascular strand, X 1, USNM 422545, USNM locality 14298. (B) Slender, smooth, dichotomously branching stem, X 1, USNM 422546, USNM locality 14298. (C) and (D) Part and counterpart of a small, dichotomously branching stem, X 2, USNM 422547, USNM locality 14298.
Fig. 13. Trimerophytina s.l. (A) Distorted, pseudomonopodially branched stem with tuberculate surface detail, X 1, USNM 422548, USNM locality 14292. (B), (C), and (D) Acutely to obtusely, dichotomously branched stems characteristic of the trimerophytes. (B) X 2, USNM 422549, USNM locality 14294; (C) X 1, USNM 422550, USNM locality 14294; (D) X 2, USNM 422551, USNM locality 14290. (E) Two relatively large, smooth, dichotomously to pseudomonopodially branched stems in association with compressed mudballs (dark, ovoid bodies), USNM 422552, USNM locality 14298.
Fig. 14. Trimerophytina s.l. Branched and ornamented stems. (A), (B), and (C) are pseudomonopodially branched stems; (C) shows evidence of a median conducting strand. (A) X 1, USNM 422553, USNM locality 14298. (B) X 2, USNM 422554, USNM locality 14296. (C) X 1, USNM 422555, USNM locality 14298. (D) Longitudinally striated stem, the striae reflect structural thickenings of probable significance in the support of the stem, X 1, USNM 422556, USNM locality 14292. (E) Stem with tubercles which may represent raised pores or bases of fine spine-like appendages, X 2, USNM 422557, USNM locality 14298. (F) Small fragment of stem on which the punctae may represent the eroded bases of small spines, X 1, USNM 422558, USNM locality 14298.

_Incertae sedis._—The principal purpose of this section in table 2 is to point out the presence of structures in the “pseudograptolite” localities that may be interpreted as plant fragments. The fragments in most instances are so badly altered that only the most noticeable characteristics such as branching are definable. No surface ornamentations are evident, although they may have been present originally. The alignment
Fig. 15. Trimerophytina *s.l.*, ornamented stems, some with median conducting strands. (A) Part and counterpart of relatively large stem with tubercles and a median conducting strand at the arrow, X 1, USNM 422559, USNM locality 14296. (B) Fragment of an irregularly grooved stem (groove at arrow) probably indicating the arrangement of stomata on the surface of the stem as evidenced in permineralized stems having similar morphology, X 2, USNM 422569, USNM locality 14290. (C) Narrow, smooth stem showing evidence of a median conducting strand, X 2, USNM 422561, USNM locality 14298. (D) Relatively large stem having a well-defined median conducting strand, X 1, USNM 422562A and B, USNM locality 14298.
of fragments (fig. 16A, B) at these particular sites can be duplicated at other sites where the matrix is not so highly metamorphosed (fig. 16C). The specimens from USNM locality 14291 (fig. 17A) are apparently plant axes that initially were permineralized by pyrite soon after burial. The pyrite subsequently has been oxidized, and now only amorphous hydrous iron oxide minerals form casts of the original axes. No cell structures are present.

**Arthropod Pellicle**

At USNM locality 14298, a fragment of organic remains was found which may be compared to the scale-like surface structure of an arthropod, particularly that of some of the species in subclass Merostomata, Order Eurypterida (fig. 18). The presence of such fragments along with the general size and variety of plant debris found at this locality parallels similar occurrences observed in the Campbellton “beds” along the banks of the Restigouche River in northern New Brunswick, Canada. Occasional eurypterid fragments are also found associated with the plant remains along the north and south shores of Gaspé Bay, Quebec. The association of the pellicles with an abundance of plant debris is therefore significant in the analysis of the fossil record contained in the Connecticut Valley trough.

**DISCUSSION AND CONCLUSIONS**

Unlike some shelly fossils reported from scattered localities in highly folded rocks in the sillimanite zone of western New Hampshire (Boucot and others, 1958; Boucot and Thompson, 1963), plants and graptolites seem unable to survive metamorphism much above chlorite grade; middle- to high-grade metamorphism and polydeformation affected the Connecticut Valley trough rocks south of about 45° north latitude. Along the northwest margin of the trough, some 125 km northeast of the international border. Upper Silurian-Devonian shelly fauna in correlative low grade metamorphic rocks provide an age constraint near the base of the Connecticut Valley—Gaspé sequence (Slivitsky and St. Julien, 1987; Boucot and Drapeau, 1968).

We have relied on the moderately well-preserved plants in southern Quebec and northernmost New Hampshire in reaching our conclusions on the paleontological age of the Connecticut Valley trough rocks. Although the fossils are not spectacular, sufficient details of morphology are preserved for a few specimens to be assigned to known genera, and those genera, when viewed with the overall mass of plant material available, are sufficient corroboration to date the Gile Mountain and Compton Formations as late Early Devonian (Emsian). The age is in agreement with the Devonian age for rocks on the Gaspé Peninsula reported by Bourque (1977) and Bourque and LaChambre (1980). These outer Gaspé rocks have long been mapped as continuous along strike with the trough rocks of southern Quebec and western New England (fig. 1).
Fig. 16. Stems aligned by currents or oscillatory motion of water, specimens from three separate localities. (A) X 1, USNM 422566, USNM locality 14294. (B) X 1, USNM 422567, USNM locality 14293. (C) X 1, USNM 422568, USNM locality 14298.
Fig. 17. *Incertae sedis.* (A) Two unornamented stems probably originally permineralized by pyrite which has subsequently been replaced by hydrous iron oxides, no cell structures are clearly evident, X 1, USNM 422563, USNM locality 14291. (B) Internal cast of stem common at this locality, X 2, USNM 422564, USNM locality 14290. (C) Highly altered fragments of large stems lacking identifying characteristics, X 1, USNM 422565, USNM locality 14294.
The plant fossils represent an early land flora that lived during the early Emsian and extended into the Eifelian over much of the geographic area that is now eastern North America. Very well-preserved comparable floras of Early Devonian age occur in the Trout Valley Formation of northern Maine (Andrews and Kasper, 1970), the Campbellton "beds" and associated outcrops along the Restigouche River in New Brunswick (Gensel and Andrews, 1984, Index), the Sextant Formation along the Abitibi River, Ontario (Lemon, 1953; Banks, Leclercq, and Hueber, 1975; Hueber, 1983), and the Battery Point Formation on the shores of Gaspé Bay, Quebec (Dawson, 1859, 1863, 1871; Gensel and Andres W., 1984, index). A rather poorly preserved assemblage paralleling the assemblage of fossils in the Connecticut Valley trough is found in beds of the Bay du Nord series in the LaPoil-Cinq Cerf area of Newfoundland (Dorf and Cooper, 1943).

We are also confident that these gray slates and quartzites of the Compton Formation in Quebec trace without interruption southward into the eastern belt of the Gile Mountain Formation in northeastern Vermont and northwestern New Hampshire (Bothner and Jahrling, 1984; Slivitzky and St. Julien, 1987). The correlation of the western belt of the Gile Mountain with the eastern belt is well established by the
mapped connection (Doll and others, 1961; Goodwin, 1963) of the two belts in northern Vermont near Island Pond. The depositional continuity of the Waits River and Gile Mountain Formations is supported by the gradational nature of their mutual contact and the fact that both formations contain the same rock types, but in different proportions (Fisher and Karabinos, 1980; Hatch, 1988). Furthermore, no one has yet reported significant faults or unconformities within the sequence (see list of sources in Doll and others, 1961). The dominant turbidite component in both the Waits River and Gile Mountain implies rapid deposition for the thicker graded beds, slower deposition for the interlayered pelitic beds, and perhaps slowest for the dominant pelitic rocks of the Northfield and Meetinghouse Members. What remains unknown is the time interval between turbidite flows. If that interval is short, then a good reliable date on one part of the Connecticut Valley trough sequence should effectively date the whole sequence. On the other hand, if the interflow interval is long, then the lower parts of the sequence could be significantly older.

Somewhat less compelling, but still potentially significant, evidence for an Early Devonian age for the upper part of the trough rocks is the striking resemblance between some of the trough rocks and rocks of the fossiliferous Early Devonian Littleton Formation in New Hampshire (Billings and Cleaves, 1934; Billings, 1937; Boucot and Arndt, 1960) and the fossiliferous Early Devonian Seboomook Formation in the Moose River synclinorium of western Maine (Boucot, 1961). The Littleton Formation rocks at Slate Ledge, Littleton, N.H., are remarkably similar to rocks of the Meetinghouse Slate Member of the Gile Mountain Formation 14 km to the northwest (Billings, 1937; Eric and Dennis, 1958). Rhythmically graded-bedded rocks of the Littleton Formation on Garnet Hill in the northeast corner of the Moosilauke quadrangle (Billings, 1937) are essentially indistinguishable from the Gile Mountain Formation rocks of the Townshend-Brownington syncline in Vermont (Hatch, 1988). Such striking resemblance between two rock units does not prove stratigraphic correlation, but it may provide support for a Lower Devonian age for at least the Meetinghouse Slate Member and the Gile Mountain Formation of the Connecticut Valley trough.

The second type of new evidence bearing on the age of the Connecticut Valley trough is the U-Pb zircon age on the dike cutting the Standing Pond Volcanic Member of the Waits River Formation and the $^{40}$Ar/$^{39}$Ar data from hornblendes in the Standing Pond Volcanic Member and in the Gile Mountain Formation (Spear and Harrison, 1989). These isotopic data argue against an Early Devonian age for some of the trough rocks. The zircon data yield a clear Silurian age of 423 ± 4 Ma and, thus, indicate a minimum age for the Waits River Formation, a unit that is traceable throughout eastern and central Vermont. The lateral and vertical stratigraphic continuity and lack of structural discontinuity within the section, as discussed above, imply accumulation during 30 to 40 my by intermittent rapidly deposited turbidites.
Spear and Harrison (1989) suggest a pre-Taconian age for the Gile Mountain and Standing Pond Volcanic Member (and presumably also for the stratigraphically underlying Waits River Formation) because of isochron ages that span the Late Ordovician to Silurian. The Late Ordovician isochron ages are inconsistent with the fossil data reported herein. Both their hornblende plateau ages (avg 372 Ma) and those for micas and K-feldspar (ranging from 345–310, respectively) in eastern Vermont (Harrison and others, 1989) span a larger age range that includes the Middle Devonian and reflect Acadian cooling.

On the basis of combined field, paleontologic, and radiometric data, we conclude that the age of the Connecticut Valley trough sequence (Waits River Formation and its Standing Pond Volcanic Member, Gile Mountain Formation and its Northfield and Meetinghouse Slate Members) ranges from the Silurian continuously through the late Early Devonian (Emsian). Additional radiometric work will be necessary to evaluate fully the implications of Spear and Harrison (1989) that the sequence is older than Silurian.

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