VERMONT GEOLOGY

JUNE 1984 VOLUME 3

FOSSILS FROM THE METAMORPHIC ROCKS OF THE SILURIAN-DEVONIAN MAGOG BELT IN NORTHERN VERMONT

Charles G. Doll

VERMONT GEOLOGICAL SOCIETY, INC.
P.O. BOX 304
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FOREWORD

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2) contributing to the public education of the geology of Vermont and promoting the proper use and protection of its natural resources; and
3) advancing the professional conduct of those engaged in the collection, interpretation and use of geologic data.

This issue is the third in the Vermont Geology series. Vermont Geology was initiated in 1980 to publish information about research in Vermont and Vermont related geology. Volume 1, papers from a symposium, The Geology of the Lake Champlain Basin and Vicinity, February 1980, and Volume 2, papers from the February 1982 winter meeting, are still available from the Society.

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Cover: Pelmatozoan stem in schist.
After Plate 2, Figure 4a.

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PREFACE

Fossil localities in Vermont outside of the Champlain Valley are rare. Metamorphism and multiple deformational events in Vermont rocks have all but obliterated recognizable fossil remains. Charles G. Doll, former State Geologist of Vermont (1947-1976) and Professor Emeritus of the University of Vermont, has a keen eye for recognizing fossils in these deformed rocks.

Over the past forty years, Charles Doll has collected and catalogued numerous fossils from the Silurian-Devonian metalimestones and metaclastic rocks of northern Vermont. The area has been his outside laboratory for geological research which spans five decades. He has contributed tremendously to our present day understanding of the stratigraphy, structure and petrology of rocks in this area.

The fossils reported in this paper display a wide range of preservation. Some (as Charles Doll himself will readily admit) have been, and probably will continue to be, considered suspect by paleontologists accustomed to working with better preserved materials. Other specimens are readily identifiable even to the untrained eye.

The Editorial Committee of Vermont Geology has urged Charles Doll to get these fossils "out of hiding". The committee did not subject this paper to its established review procedures. We hope that in publishing the entire collection of Charles Doll's fossils, including many considered "controversial", we will stimulate field geologists to intensify the field search for additional fossils in Vermont rocks.

This paper provides previously unpublished information on paleontological controls of the Silurian-Devonian rocks of northern Vermont. The catalogued collection described in this paper will be maintained as part of the permanent paleontology research collection at the University of Vermont.

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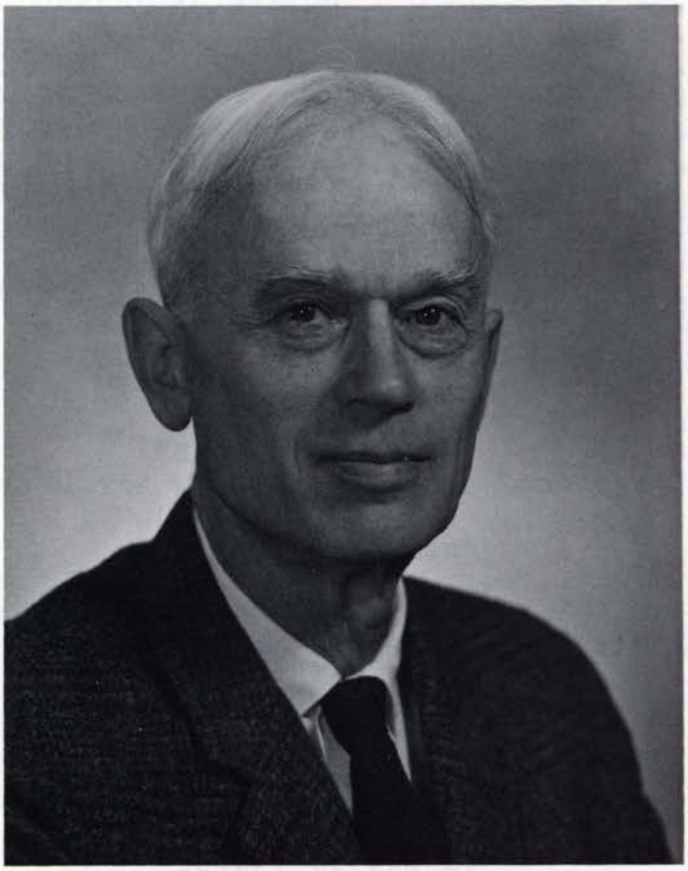

Charles G. Doll was born in Providence, Rhode Island in 1898. He received his Ph.B. and A.M. degrees in geology at Brown University in 1924 and 1926 respectively, received a second A.M. degree at Harvard University in 1931 and his Ph.D. at Columbia University in 1951. His dissertation was published as Vermont Geological Survey Bulletin No. 3: "The Geology of the Memphremagog Quadrangle and the southeastern portion of the Irasburg Quadrangle, Vermont" (1951). His publications, beginning in 1927 ("Notes on Mineral Localities in Rhode Island", American Mineralogist, v. 12, p. 427-436), include many popular and scientific geological studies. He joined former State Geologist Eldridge Jacobs at the University of Vermont in 1927, becoming the sole member of the Geology Department after Professor Jacobs' retirement from the University in June 1944. Charles Doll was given a continuing appointment to serve as State Geologist in July 1947 and served in this post for 29 years, 12 years beyond his retirement from teaching in 1964. The climax of Professor Doll's career as State Geologist is the publication of the Centennial Geologic Map of Vermont in 1961, followed 9 years later by publication of the Surficial Geologic Map of Vermont. Vermont Survey Bulletins published under his direction include, besides the well-respected bedrock geology series, series on economic geology, environmental geology, state forests and parks, and popular publications for the amateur geologist. Although officially in retirement, Professor Doll continues with his writing about a wide range of geological topics accumulated after more than 50 years of trekking Vermont foothills and mountains.

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FOSSILS FROM THE METAMORPHIC ROCKS OF THE SILURIAN-DEVONIAN MAGOG BELT IN NORTHERN VERMONT

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ABSTRACT

Seven fossil localities bordering extrusive and intrusive igneous rocks in the Memphremagog, Irasburg, Lyndonville and Hardwick map areas in northern Vermont are described. Five of these localities are identified as Seaver Branch, Ware Brook North, Clyde Dam, Stony Brook and Lake Willoughby, and the remaining two as adjuncts to the Seaver Branch and Clyde Dam localities. At all sites the fossils occur in metalimestones ranging in metamorphic intensity from middle to high grade. The fossils are Silurian-Devonian in age and consist mostly of echinoderms, with a few corals, brachiopods, graptolites, bryozoans, sponges, a trilobite glabella, and a single cephalopod.

INTRODUCTION

At the time the writer first published on fossils from the metamorphic rocks of eastern Vermont (Doll, 1943a and b), some paleontologists received these reports with a great deal of skepticism. The fossil forms were regarded by some as of inorganic origin, suggesting that they were concretions or merely inorganic "objects", in spite of discernible organic features displayed by the specimens. It is the experience of the writer that prejudices in the past against finding fossils in metamorphic rocks and consequent negative attitudes toward searching for them still linger among some professionals. This philosophy leads to mistaken identification of a specimen or ends with the platitudinous and noncommittal word "object". This is unfortunate, as it could account for the loss of important paleontological information. Quoting from Walter Bucher (1953, p. 293): "Now paleontologists do not care for poorly preserved fossils, and narrowly trained "hard-rock geologists" do not care for fossils. Since those who know where to find fossils are unwilling to look, and most of those who are looking at the metamorphic rocks do not know what to look for and where, much valuable material must remain undiscovered". Fortified with research of the paleontological literature and having a working acquaintance with the subject, the non-paleontologist would do well to have some input of his own. Stromatolites discovered in the Proterozoic marbles of St. Lawrence County, New York, have been reported on recently (Isachsen and Landing, 1983).

The prevailing thought among geologists in the past was that the intensity of metamorphism is universally the same, and that, as a consequence, all fossils were completely destroyed. Fortunately, time and a greater familiarity with metamorphic environments have brought about a better understanding among some paleontologists of the processes of diagenesis and metamorphism relative to the preservation of organic remains and the fossils themselves, which seems to signal that now may be a safe and appropriate time to induce a miscellany of fossils to come out of hiding.

PREVIOUS WORK

Early workers in the region (Adams, 1845, p. 15; 1846, p. 167; Thompson, 1848, p. 13-26) placed the rocks in the Primary (Azoic) on the basis of their crystalline appearance and absence of fossils. Hitchcock was the first geologist to determine the age of the rocks by means of fossils ("encrinal stems") as probable Devonian (Hitchcock and others, 1861, v. 1, p. 46-47, 486-487). The fossils were found in limestone dipping under a granite cliff in the town of Derby, possibly on the west side of Salem Hill (ibid., p. 47, Fig. 19; Doll, 1951, p. 98, Pl. 10, Fig. 1, shows limestone strata dipping into a granite cliff 2.25 miles south of Salem Hill). Samuel R. Hall, a member of the Hitchcock mapping party, reporting on the Orleans County area, concurred essentially with Hitchcock's age determination for the rocks, regarding them as Silurian-Devonian (Hall, 1870, p. 71-72). These assignments of the crinoidal limestone in Derby to the Devonian were largely the result of lithological comparisons with the fossiliferous Devonian rocks at Owls Head Mountain on the west side of Lake Memphremagog in Canada.

Richardson pioneered mapping by townships extending from the Canadian to the Massachusetts border in eastern Vermont in the early part of the century. During his mapping he sequentially reported graptolites, which, determined by Ruedemann to be of Middle Ordovician age (Richardson, 1908, p. 290-291, and subsequent reports of the Vermont State Geologist), served as a basis for his correlation of the rocks with those at the Castle Brook locality near Magog, Quebec.

In addition to his reporting on graptolites from the rocks of almost all the towns mapped by him, Richardson also mentions other invertebrate fossils found by him (Richardson, 1912, etc.), but with such cautious phrases as "merely a suggestion" or "suggestive material", which indicates some skepticism of his own discoveries, in light of some geological thinking among his colleagues at the time. Instead of placing so much stress on his graptolites, Richardson might have been more successful in dating the rocks in eastern Vermont, had he given greater prominence to his "suggestive material", even from the Seaver Branch locality alone, from which the writer believes Richardson collected his fossils. It is the writer's belief that the citations repeated in Richardson's reports amount to much more than merely doubtful material, some of which must actually have been identifiable as fossils, especially his collections from the Stony Brook and Seaver Branch localities. Richardson could hardly have escaped finding identifiable fossils at either locality, the latter in particular.

It is somewhat surprising that paleontologists to whom he submitted his specimens for identification were so unenthusiastic and problematical about them and often dismissed them as inorganic because of the lack of an organic feature, which could have been destroyed by metamorphism, while the specimen in its entirety possessed the requisites of a fossil. Some specimens, however imperfect, have undoubtedly been unknowingly discarded in the past.

Jacobs (1922, p. 101) reported "crushed graptolites in limestone" in the bed of Trout Brook in Brownington, agreeing with the graptolite-based Ordovician of Richardson. Crinoid stems found by Currier and Jahns in the limestone of the Shaw Mountain Formation were identified as of Middle Ordovician age (Currier and Jahns, 1941, p. 1501). In 1943, the writer reported on crinoid and cystoid calyces, collected by him, from limestone beds near Westmore village. Their identification as fossils belonging to the Middle Silurian and possibly Early Devonian called for a revision of the age of the rocks in the area generally (Doll, 1943a). A second paper (Doll, 1943b) in the same year reported on a large brachiopod found by the writer near South Strafford in mica schist of the Devonian Gile Mountain Formation.

Rugose corals discovered in the Waits River Formation in the East Montpelier-Calais area were reportedly suggestive of a Middle Ordovician age, with the possibility of revision in the future (Cady, 1950). Since underlying and overlying formations in a stratigraphic section from the Shaw Mountain up through the Gile Mountain, both north and south of the above area, are now believed to be Silurian-Devonian in age, it has become necessary to reconsider the paleontologic aspects of the locality. With reference to Cady's paper, the writer proposes a Silurian-Devonian age for the fossils described therein, based on a probable *Cystiphyllid* type (ibid, p. 493, Fig. 2, sketch of specimen showing silicified dissepiments which fill the whole interior of the calyx) and a *Zaphrenthid* type, a possible *Syringaxon* (ibid., Pl. 2, Fig. 1). *Zaphrentis* (*Zaphrenthis*)* and *Cystiphyllum vesiculosum* have been reported from the rocks of the Eastern Townships, Quebec (Boucot and Drapeau, 1968, the latter on p. 33). Zaphrenthids and cystiphyllids were characteristic of the Devonian, the time of culmination of the rugose corals (Easton, 1960, p. 186). Field occurrences of these corals show that they existed in both colonial and solitary forms.

Konig and Dennis (1964, p. 19) reported fossils, determined to be of probable Silurian-Devonian age, from the Shaw Mountain Formation near Albany. Billings and Lyttle (1981) have presented a thorough list, from the literature, on fossil localities in New England, with accompanying maps. In Table 2, listing the doubtful fossil specimens, it is surprising to find the fossils of Doll (1943a and b) and those of Cady (1950) from eastern Vermont in this list, still unaccepted after more than 30 years.

The results of the basic bedrock mapping program of the Vermont Geological Survey, directed by the writer, have made possible the placing of fossil localities with formations, and not only with lithologies in the region, as was the case at an earlier time (Doll, 1951; Dennis, 1956; Konig, 1961; Konig and Dennis, 1964). State-wide correlations of fossil-bearing formations became more facile with the appearance of the Centennial Geologic Map of Vermont (Doll, and others, 1961), which afforded a regional mosaic.

*The writer follows corrected spelling of *Zaphrentis* by Easton (1960, p. 179).

PURPOSE OF PAPER

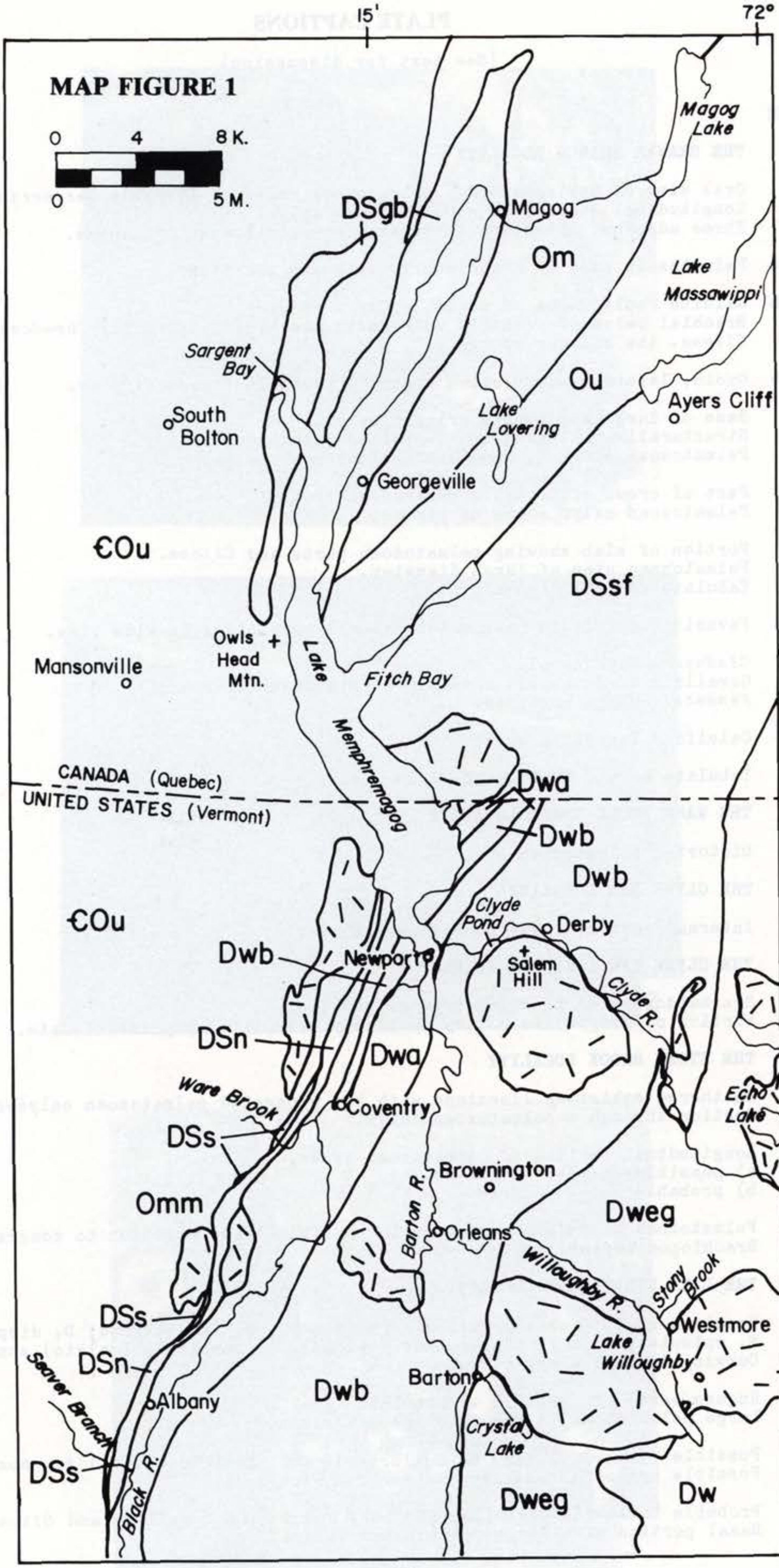
The purpose of this paper is to describe additional fossil localities, discovered by the writer, which have yielded a greater variety and better preserved specimens than previously reported. Some among them permit reasonably conclusive age determinations for the formations of the Vermont portion of the Magog belt.

GEOLOGIC SETTING

The fossiliferous portion of the Magog belt, composed of Middle Paleozoic metamorphic rocks in northern Vermont, is located in the core area of the Connecticut Valley - Gaspe Synclinorium, in which three in a series of five formations are pertinent to this study, namely, the fossil-bearing Shaw Mountain, Waits River - Barton River, and Westmore - Gile Mountain formations (Cady, 1960, Pl. 1; Doll, and others, 1961). The Northfield and Ayers Cliff lying between the Shaw Mountain and Waits River - Barton River formations, have, as yet, no record of having yielded fossils. The area is delimited on the west at the base of the Shaw Mountain Formation by the Supra-Ordovician unconformity marking the upper surface of the Moretown Member of the Missisquoi Formation and on the east by the west flank of the Willoughby Arch.

Assemblages of coarse- to fine-grained, largely argillaceous, arenaceous, and calcareous mixtures comprise thick sections of metasedimentary rocks with volcanics in the western portion (Shaw Mountain Formation). Extensive Middle and Late Devonian granitic plutons have spawned a preponderance of sills over dikes (Doll, 1951). Structurally the fossiliferous beds of the Shaw Mountain and Waits River - Barton River formations occur in the steeply dipping, overturned west limb of the Brownington Syncline, while the fossiliferous beds in the Westmore - Gile Mountain Formation are located on the northwest flank of the Willoughby Arch. The Willoughby Arch is recorded as a development subsequent to that of the Brownington Syncline (Konig and Dennis, 1964, p. 38; Hall, 1959, p. 8), which indicates that the fossils in the area have undergone multiple periods of disturbances and metamorphisms, culminating in the emplacement of the plutons.

Map Figure 1. Geologic Index Map. €Ou, undifferentiated; Ou, undifferentiated; Om, Magog Formation; Omm, Missisquoi - Moretown Formation; DSgb, Glenbrooke Formation; DSsf, St. Francis Formation; DSs, Shaw Mountain Formation; DSn, Northfield Formation; Dwa, Waits River - Ayers Cliff Formation; Dw, Waits River Formation; Dwb, Waits River - Barton River Formation; Dweg, Westmore - Gile Mountain Formation. Hachured areas are plutons. Geology in Quebec adapted, in part, from Boucot and Drapeau, 1968, Map 1607A.



MAP FIGURE 1
0 4 8 K.
0 5 M.
15'
72°
45°
Magog Lake
Magog
DSgb
Om
Lake Massawippi
Sargent Bay
Ou
Ayers Cliff
South Bolton
Lake Lovering
Georgeville
ЄOu
DSsf
Owls Head Mtn.
Mansonville
Lake
Fitch Bay
Memphremagog
CANADA (Quebec)
UNITED STATES (Vermont)
Dwa
Dwb
Clyde Pond
Derby
Salem Hill
Clyde R.
Newport
DSn
Ware Brook
Coventry
Echo Lake
DSs
Brownington
Omm
Dweg
Barton R.
Orleans
Willoughby R.
Stony Brook
Westmore
Lake Willoughby
Barton
Albany
Seaver Branch
Black R.
Crystal Lake
Dw

PLATE CAPTIONS

(See text for discussion)

PLATE	FIGURE	
		THE SEAVER BRANCH LOCALITY
1	1	Oral view of hemispheroidal pelmatozoan calyx, a possible *Caryocrinites*.
	2	Longitudinal section of a pelmatozoan calyx.
	3	Three adjoined limestone slabs showing pelmatozoan columnals.
2	4a-c	Pelmatozoan stem in structurally delicate position.
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	30a,b	Brachiopod resembling *Gypidula*.
		THE LAKE WILLOUGHBY LOCALITY
17	31	Specimen showing metamorphic mineral zones. G, garnet zone; D, diopside zone; E, epidote group, P, plagioclase (calcic), A, amphibole (calcic) zone. Curving lines are saw marks.
18	32	Rugose coral of probable zaphrenthid type.
	33	Large pelmatozoan, a probable *Caryocrinites*.
19	34	Possible *Sphaerocystites* or *Coelocystis* and possible crinoid *Scyphocrinites*.
	35	Possible cystoids *Sphaerocystites* or *Coelocystis*.
20	36	Probable trilobite glabella, possibly *Phacops*; a corallite and *Cliona* sponges.
	37	Basal portion of a large pelmatozoan calyx.

SEAVER BRANCH LOCALITY

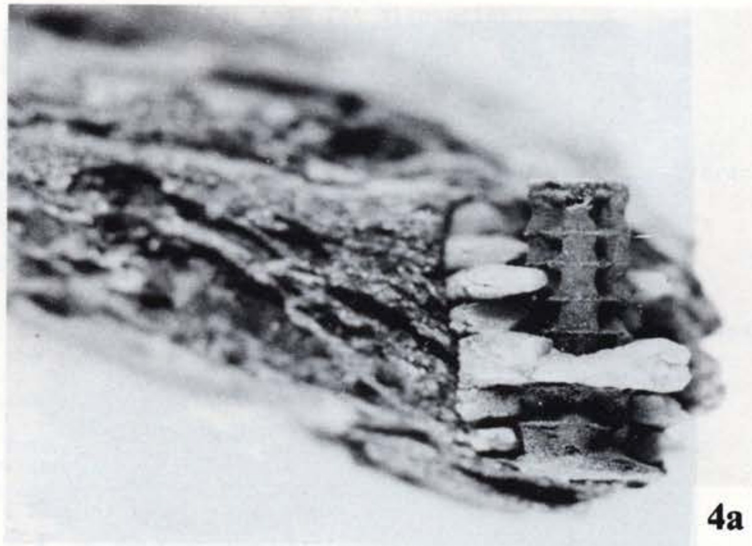
1

2

3

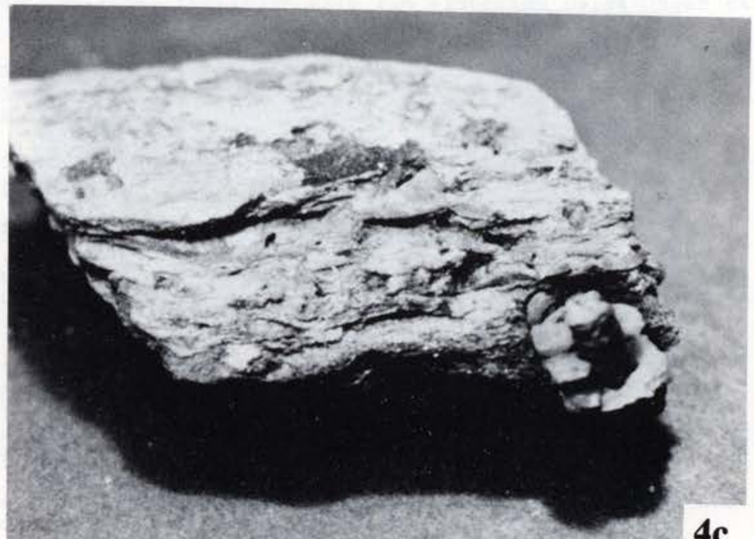
PL.2

SEAVER BRANCH LOCALITY



4a

4b



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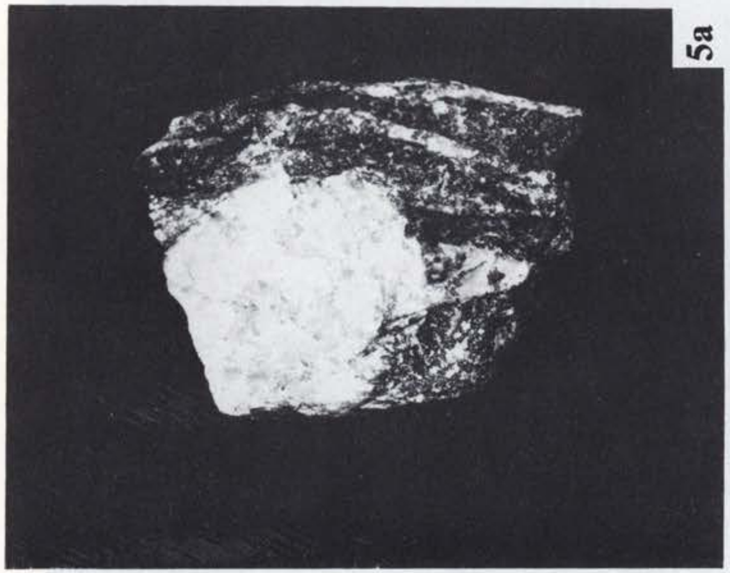
PL.3

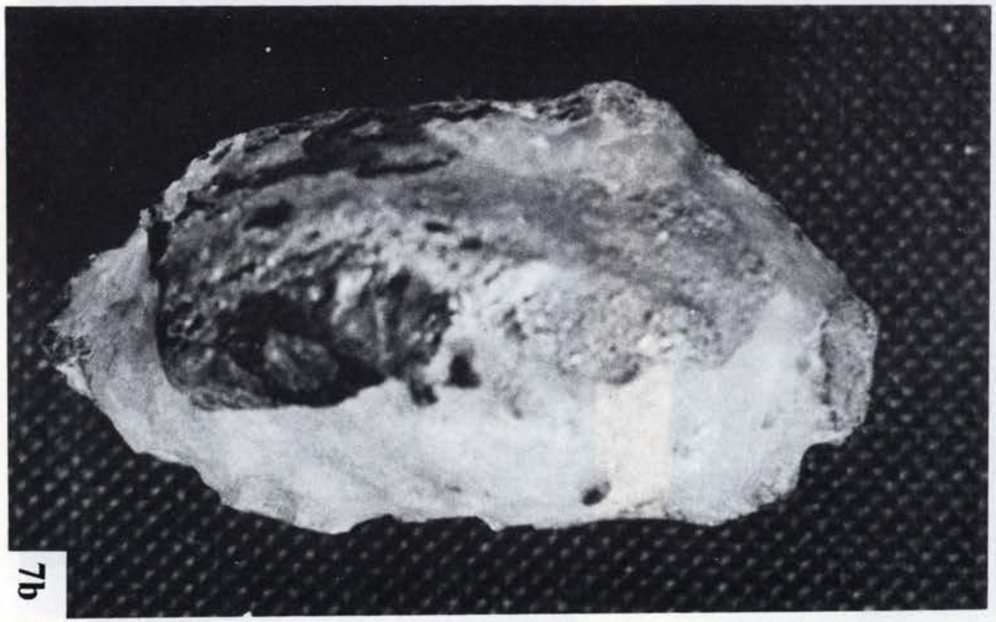
SEAVER BRANCH LOCALITY



5a

5b

6



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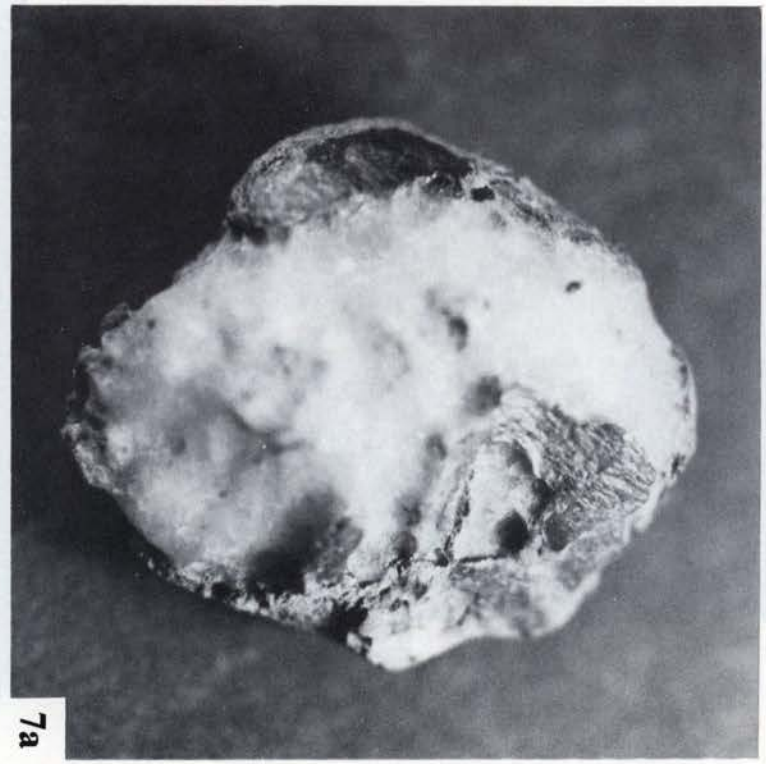
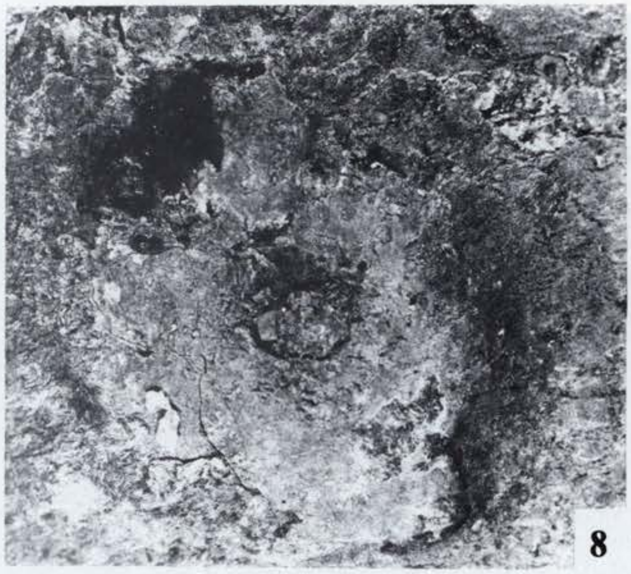


7a



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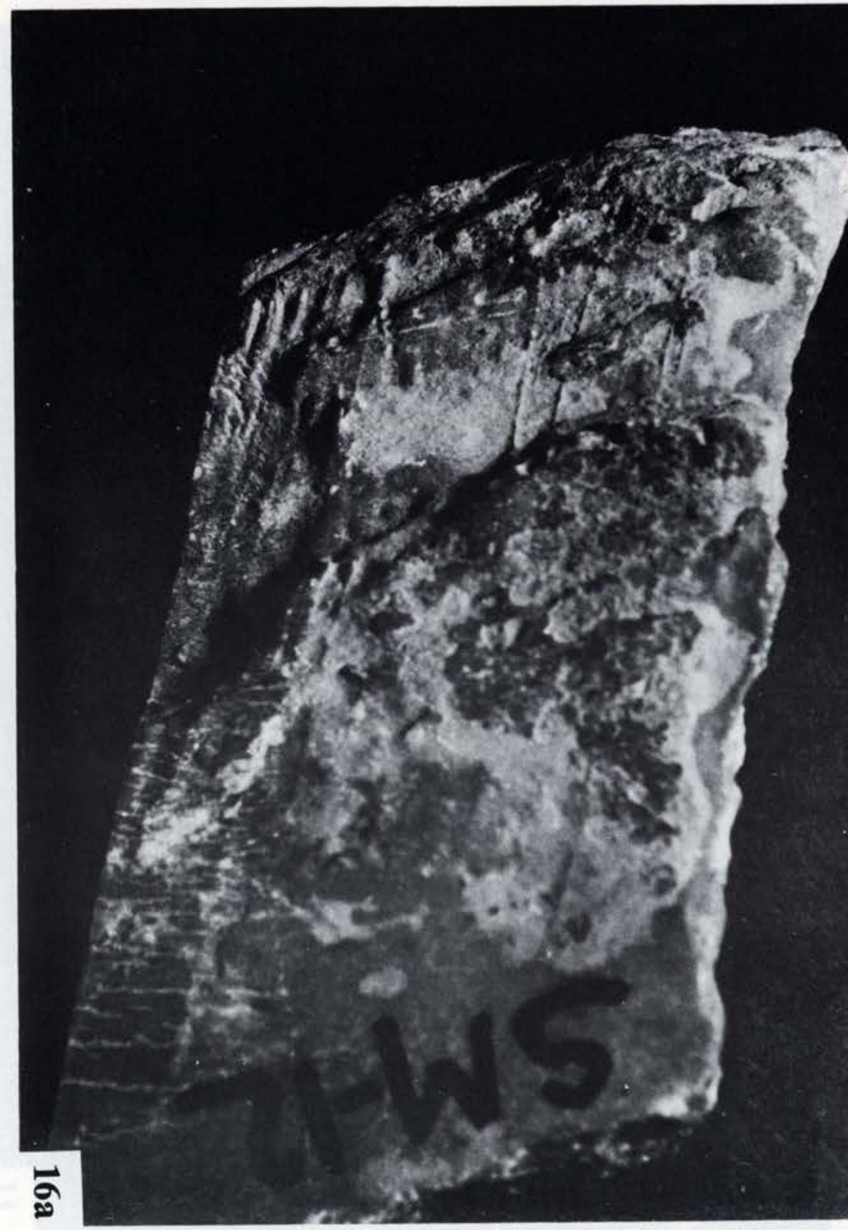
SEAVER BRANCH LOCALITY

13

14

15

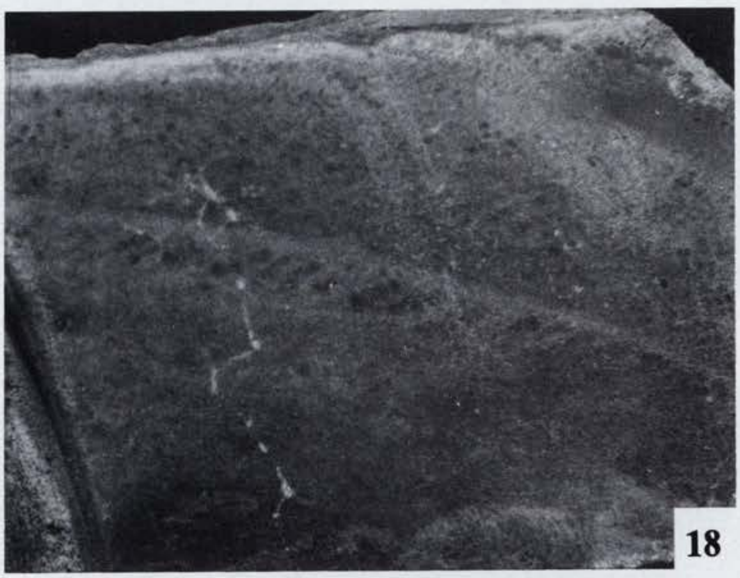
16b



16a

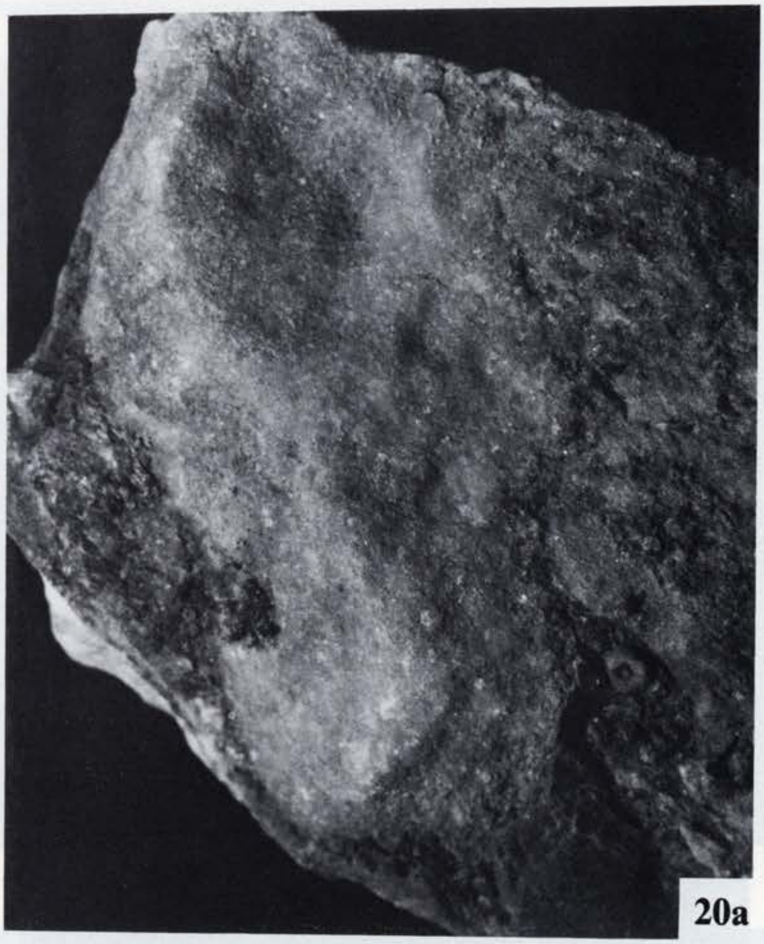
SEAVER BRANCH LOCALITY

17



18

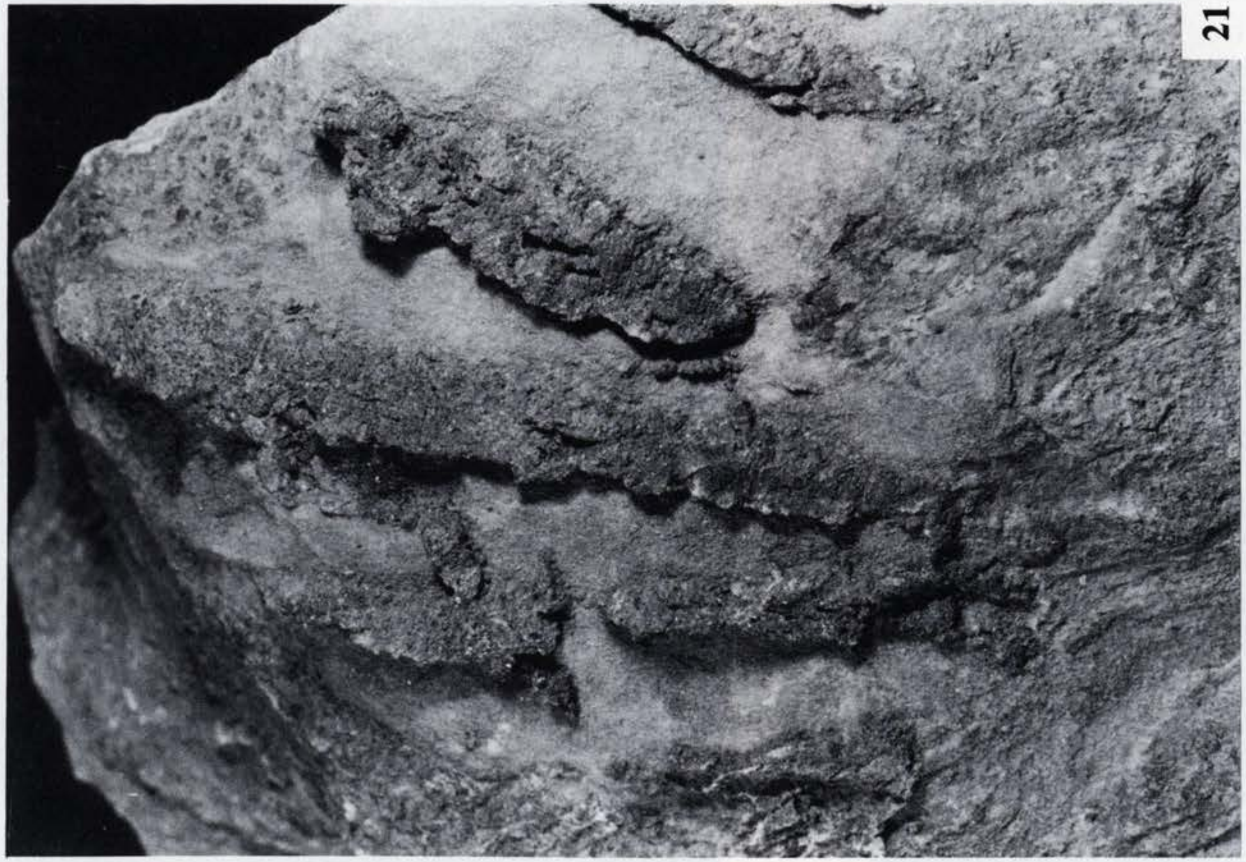
19



20a

20b

SEAVER BRANCH LOCALITY

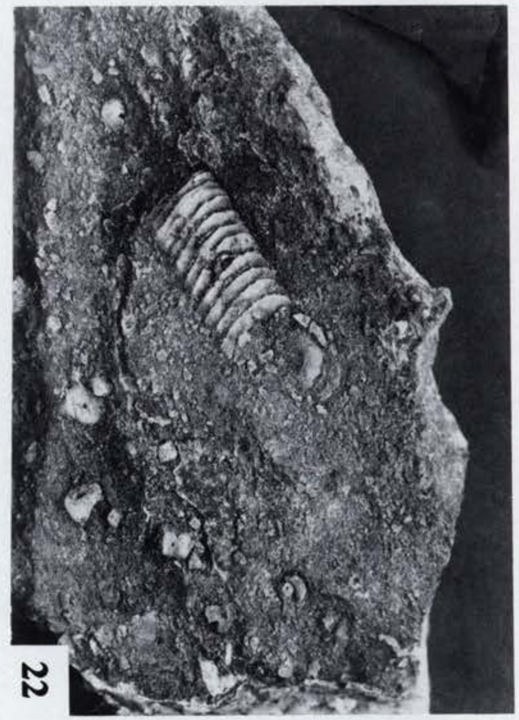


21

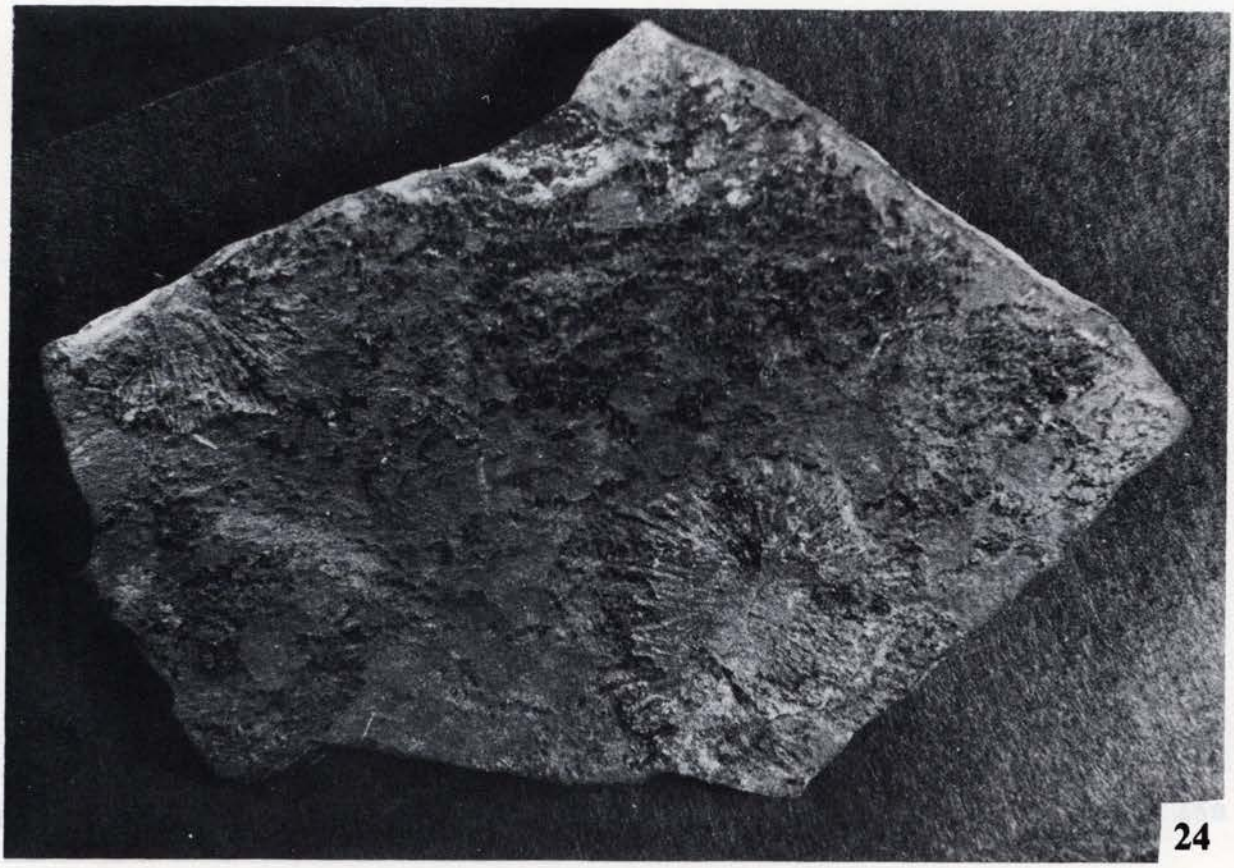
CLYDE DAM LOCALITY

23

WARE BROOK NORTH LOCALITY



22



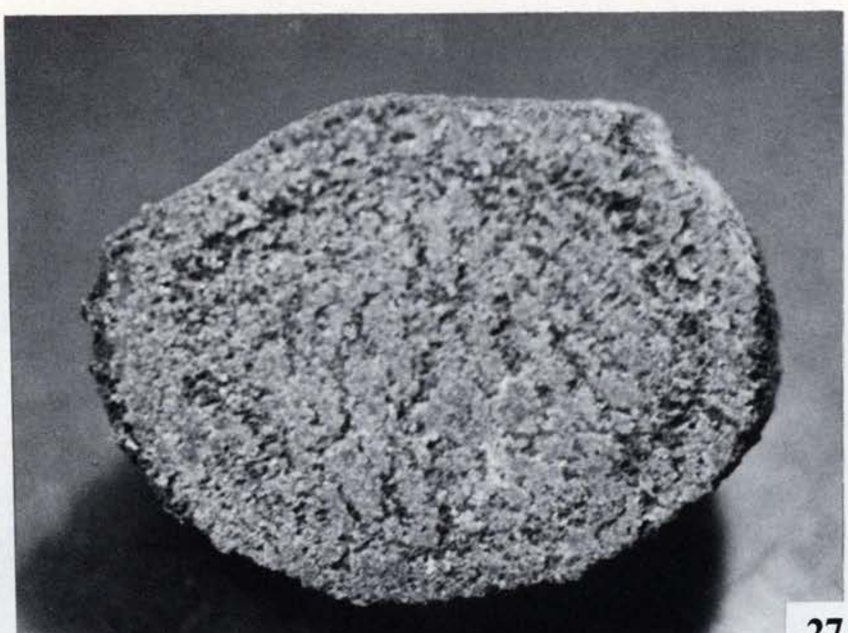
24

25

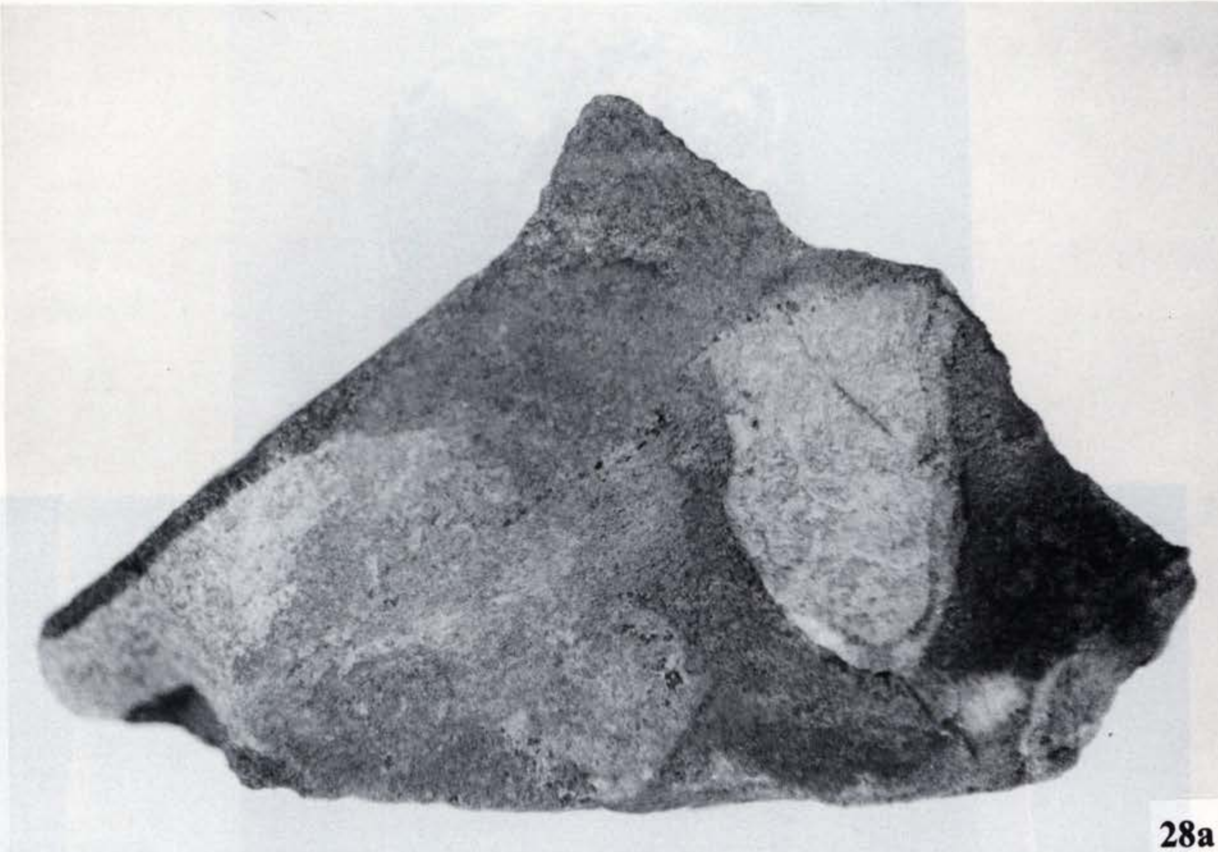
PL.14

STONY BROOK LOCALITY

26



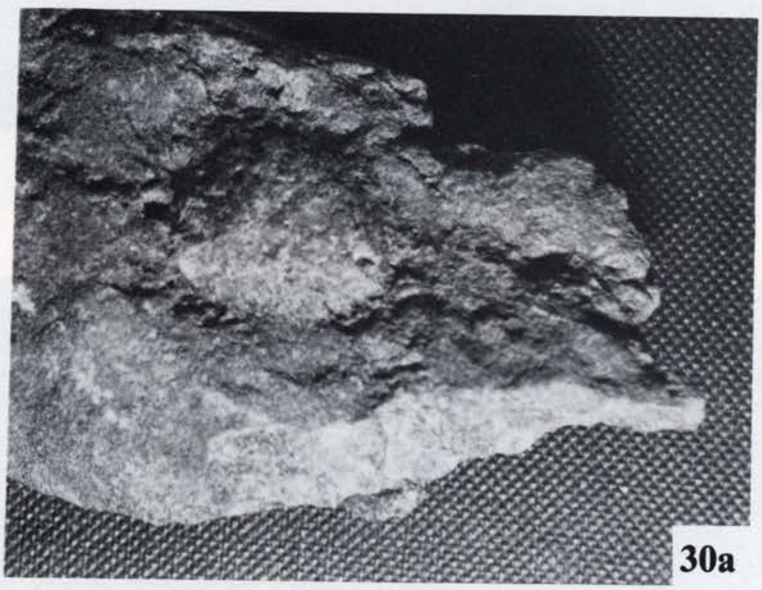
27



28a

28b

29

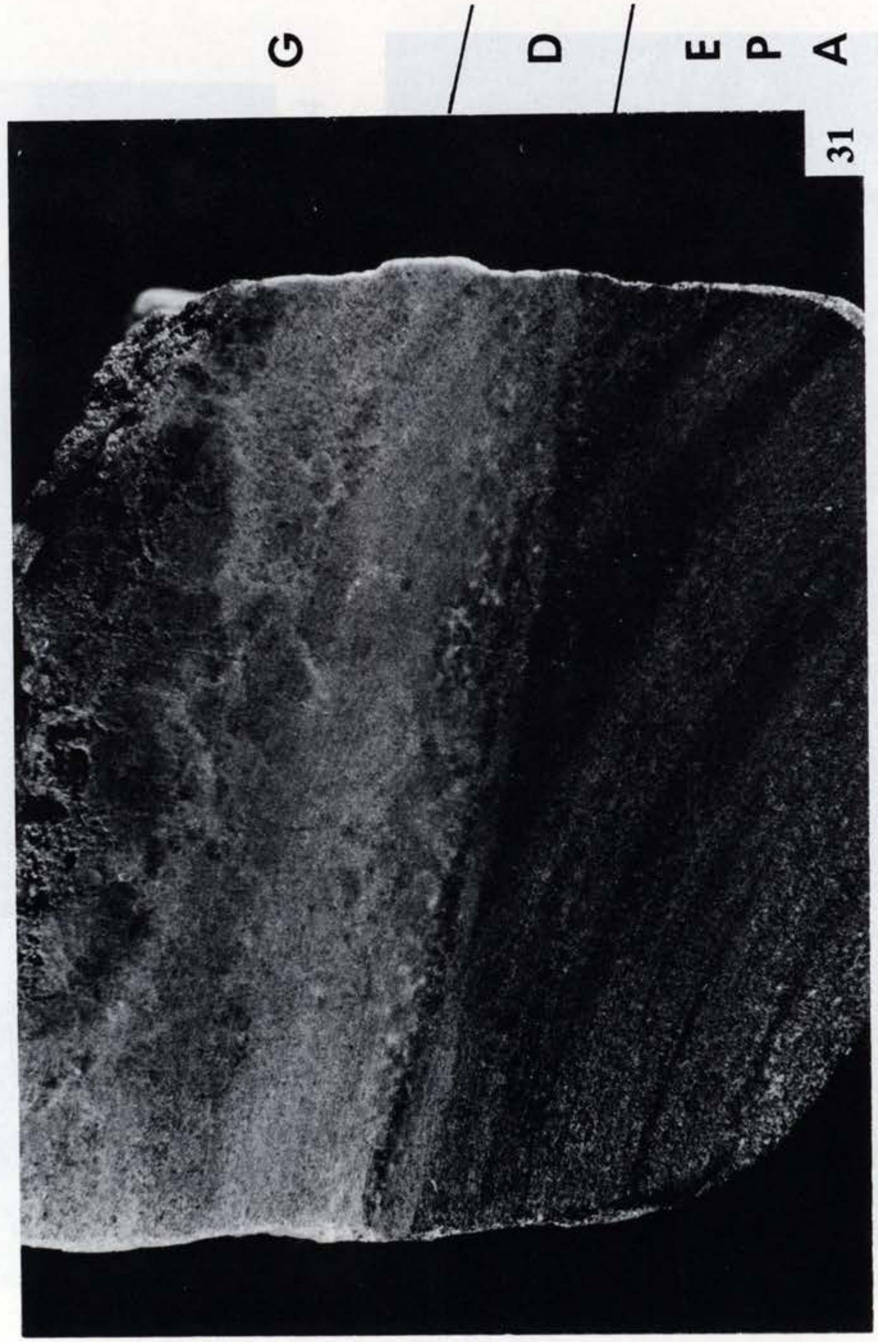


30a

30b

PL.17

LAKE WILLOUGHBY LOCALITY



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MIDDLE PALEOZOIC ENVIRONMENT

Noteworthy is the fact that all fossil localities described herein occur contiguous to igneous rocks, the fossils occurring in significant concentrations at three localities, probably as biostructures of some kind. This observation raises the question: Why are the fossils in such close proximity to the igneous rocks in contrast to their apparent absence in the more remote metasedimentary rocks in the area generally? Is it that contact metamorphism is not as drastic as regional metamorphism mechanically, even though it is usually of higher grade? An explanation might be found in the marine environment in which the living forms of these fossils existed and the diagenetic-metamorphic conditions to which the fossils were exposed.

The fossil localities all lie within a terrane along the western limb of the Connecticut Valley - Gaspe Synclinorium, within the realm of the Magog eugeosynclinal belt (Kay, 1951, p.49-60; Doll, 1951, p. 74-77). The Magog eugeosynclinal belt comprises thick sections of metasedimentary rocks and volcanic rocks of early to middle Paleozoic age, with extensive Middle to Late Devonian granitic intrusives. The Silurian-Devonian section includes the Shaw Mountain, Waits River - Barton River, and Westmore - Gile Mountain formations which are younger eastward in that order, and unconformably overlie the Ordovician rocks to the west (Doll, and others, 1961). The metasedimentary rocks are largely clastic, considerably argillaceous, and locally thick carbonate units. Carbonate rocks give way to dominantly siliceous types southeastward.

The rocks in the area reveal a time of great eugeosynclinal instability in which sedimentation was frequently interrupted by crustal movements and accompanying vulcanism in a belt of island arcs (Kay, 1951; Wilson, 1953; Cady 1960, 1968, 1969). It was probably in this kind of environment that the Shaw Mountain, Waits River - Barton River, and Westmore - Gile Mountain formations, the three fossil-bearing units described in this paper, were deposited, during the time of closure of the Proto-Atlantic (Iapetus) Ocean in the Late Devonian by the convergence of North America with Africa and Europe (Wilson, 1966, 1971).

During the existence of the Proto-Atlantic, the New England area was close to the equator, as studies of Paleozoic climates have shown (Bain, 1960; Seyfert and Sirkin, 1979). Life was abundant in the warm seas in which conditions were favorable for a liberal supply of calcium carbonate, making possible the construction of organic reefs and "gardens" of organisms on the sea floor. It has already been stated at the beginning of this section that noticeably large assemblages of fossils occur at three localities, namely, Seaver Branch, Stony Brook and Lake Willoughby, all of which are probably biostromes.

SILURIAN-DEVONIAN AGE

In 1861, Hitchcock (Hitchcock and others, 1861, p. 451) wrote:

> The upper Helderberg, as seen on page 54, is in the lower part of the Devonian system. It is better known to some as the Onondaga limestone. It is a remarkably persistent group in its distribution, as it is often developed where both the shales above and the sandstones below are wanting. How remarkable that this limestone can be recognized among these azoic rocks, and especially that it can be traced as far as Montpelier, in the very heart of what, a few years ago, was universally conceded to belong to the oldest series of strata upon the globe! We confidently expect that the progress of knowledge will ere long develop the age of every azoic rock in New England.

Thus began the revision of Adams' Primary (Azoic) rocks with this statement prophetic of a Devonian age for the rocks of the Magog belt in Vermont.

The respective formations include the Shaw Mountain, Waits River - Barton River, and Westmore - Gile Mountain, which contain fossils indicating a Silurian-Devonian age, with some emphasis on the Devonian. The age problem is further discussed in Lyons, 1955, p. 111; Billings, 1956, p. 89-99; Dennis, 1956, p. 30-34; Cady, 1960, p. 555-556; and Boucot and Drapeau, 1968, p. 13-18.

Chief among the diagnostic fossils newly reported from the Seaver Branch locality (Shaw Mountain Formation) are pelmatozoans, corals, bryozoans, sponges, and a brachiopod. Fossils newly reported from the Clyde Dam locality and its adjunct (Waits River - Barton River Formation) are graptolites and a single cephalopod, both of which contribute importantly to an age determination for these strata. The remaining Stony Brook and Lake Willoughby localities (Westmore - Gile Mountain Formation) have yielded pelmatozoans, corals, sponges, a brachiopod, and a trilobite part. Where possible, the probable age and range of the fossil from an extensive study of the literature and specimens is given in the section on fossil descriptions.

FOSSIL DESCRIPTIONS — PART 1

FOSSILS FROM THE SHAW MOUNTAIN FORMATION

The Seaver Branch Locality

LOCATION

The Seaver Branch locality is situated 3.6 km south-southwest of the village of Albany (Map Fig. 1) in a low cut (coordinating with Richardson's description, page 6 this paper) at the southern terminus of an abandoned road at the junction of an east-west road, also abandoned. The portion of the east-west road shown on the 15-minute Hardwick quadrangle, north rectangle, terminates at the fossil locality. It may also be seen that the Seaver Branch locality is in the extreme northwest part of the town of Craftsbury.

GENERAL STATEMENT

The writer, accompanied by Robert B. Erwin, field assistant, first collected fossils from the Shaw Mountain Formation at the Seaver Branch locality during reconnaissance in the area, in the early 1950's. The fossils represented by cystoids, crinoids, corals, bryozoans, sponges, and a brachiopod, are embedded in a gray to bluish gray, crystalline limestone in relatively thin layers and lenses of white marble parallel to the bedding. The calcareous beds are intercalated with paper-thin, shiny to dull, smooth to finely crinkled, and where weathered, pale greenish gray to brown phyllitic tuff, the metamorphic derivative of a tuff (Currier and Jahns, 1941).

The fossil-bearing limestone is subjacent to a greenstone which appears to have the requisites of an extrusive. Approximately 400 m to the south of the Seaver Branch locality, pelmatozoan stem-bearing, blue-gray crystalline limestone is infolded with greenstone (adjunct to Seaver Branch locality). This stratigraphic and structural association indicates a probable extrusive origin for the greenstone here. It would have been difficult and destructive to attempt to extract the stems from the outcrop because of its massiveness and low profile and, it might be added, an unnecessary effort in light of the wide variety of meaningful specimens already obtained from the Seaver Branch locality just to the north.

Konig and Dennis (1964, p. 16) describe greenstone "features which are suggestive of deformed pillow structures", but not "well enough defined to verify this conclusion". They also mention greenstones "which are oriented parallel or subparallel to adjacent bedding planes". In his report on the geology of the Plainfield quadrangle (1961, p. 31), Konig cites "lenticular bodies" of greenstone interbedded with quartz conglomerate and with random distribution in the formation. He further reports bedded greenstones in the Moretown Member of the adjacent Missisquoi Formation. It is the writer's opinion, on the basis of the above information and his own observations in the field, that the greenstones, in large part, are volcanic in origin and have been altered by metamorphism.

At the Seaver Branch locality, as is the case generally in the Shaw Mountain Formation, the fossils occur in crystalline limestone beds, often disconnected as lenses in bedded tuffs in the upper part of the formation (Currier and Jahns, 1941; Doll, 1951). Close examination of the limestone and contained fossils discloses a very intimate association between them and the tuffs. The tuffs are all-pervading in the limestone, wrapping around the fossils in paper-thin, lustrous schistose layers (e.g. see Pl. 3, Fig. 5), the lattermost apparently the result of metamorphism. It occurred to the writer that this saturation of the fossiliferous limestone with tuff could have been the effect of extrusive ash falls during the eruptions of island arc volcanoes, the volcanic ash and dust raining down on the sea, covering the bottom of the relatively shallow water and suffocating the invertebrate populations. Although the evidence for such an event may be circumstantial, there is still a possibility that a catastrophe could have happened. It is known that sessile animals cannot live under conditions of rapid deposition in which they would be smothered and buried by murky waters propelled over the sea bottom by currents. In a few places where the slates of the Northfield Formation are in direct contact with the Shaw Mountain Formation, in the absence of the tuffs (Currier and Jahns, 1941, p. 1499), mud-laden waters could have played the same suffocating role as the volcanic ash. The tuffs greatly exceed the limestone, both in thickness and breadth of outcrop. Because of their fine texture, tuffs provide excellent conditions for fossilization. The Onondaga Limestone has at least three ash layers in New York and the Helderberg (Kalkberg) has one ash bed radiometrically dated (zircons) as 395 ± 5 mya (D.W. Fisher, 1983, written communication).

Subsequent diagenesis followed by metamorphism of these deposits resulted in the fossilization of the hard parts by replacement. The writer believes that the diagenetic transition during the conversion of the ash to tuff conditioned the fossilizing organisms for the preservation of at least some organic detail during the succeeding metamorphism. Fossils in tuffs have been reported in Maine (Williams and Gregory, 1900, p. 123; Neuman and Whittington, 1964). Without any attempt at time correlation with the Shaw Mountain Formation, it is interesting to note that in a table on page 119, Williams and Gregory have shown the tuffs also at the top of the stratigraphic list of Silurian-Devonian lithologies. The writer recently was shown a brachiopod from Maine completely enclosed in tuff by Prof. B.L. Doolan of the Department of Geology, University of Vermont.

In the Biennial Report of the Vermont State Geologist for 1911-1912, on page 192, C.H. Richardson wrote the following: "A diligent search for fossils was made by the authors of this article in the area that appears to be the most promising in the cut near the saw mill at West Albany. A considerable amount of material was collected for laboratory examination, but nothing could be identified with absolute certainty. The evidences are suggestive of an orthoceras, corals, and crinoid stems. It is hoped as more of this limestone is removed for road material or other purposes less decomposed areas will be made available for examination and that here type fossils will be discovered". In the opinion of the writer, the above quotation is a description of his Seaver Branch locality, and Richardson's evaluation as "most promising" and "that here type fossils will be discovered" has since proved him to be correct. However, contrary to his suggestion in the last sentence, it is the weathering of the limestone that has exposed the fossils and, moreover, it is reasonable to conclude that the unweathered rock must be teeming with them, judging from their abundance in the decomposed rock. Not only does this locality yield the greatest number, but also the widest variety of fossils in the Shaw Mountain Formation to date. With reference to "West Albany" in the quotation above, the village name was changed to Albany in 1865 (Swift, 1977, p. 339).*

THE FOSSILS

Plate 1

Figure 1. Oral side of hemispheroidal pelmatozoan calyx with pitted arm bases on upper edge of body wall. Note domed roof (tegmen) of calyx. Breach in calyx wall on left side is more likely a solution channel than an organic structure. Not visible in the photograph are three scale-like plates at the left end of the straight side of the calyx. The hemispheroidal shape could represent an underdeveloped or a misshapen *Caryocrinites*. Cystoid tests may be globular, ovoidal, or hemispheroidal (Twenhofel and Shrock, 1935, p. 159). Magnification is 1.5 times.

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*Research has disclosed that Richardson's township maps in the reports of the Vermont State Geologist had their source in the Atlas of Lamoille and Orleans Counties by F.W. Beers and Company, 1878. His use of "West Albany", when the village name had been changed to Albany in 1865, is an indication that Richardson borrowed from the Atlas for his base maps. It may be that local inhabitants were slow in becoming accustomed to the name change to Albany, which, incidentally, antedated the Atlas by 13 years.

Figure 2. Longitudinal section of a pelmatozoan calyx, the prominent left wall showing occasional thecal pores, and sutures between plates. The flaring right wall is faintly traceable as a bead-like arrangement of thecal pores. Close inspection of the interior of the calyx reveals a structure resembling a spadix of a flower, which is probably an anal sac. A brachiole with its brush-like fringe may be seen paralleling the left wall of the calyx externally. Arm segments are discernible in the pelmatozoan matrix, as well as a short piece of stem at the aboral side of the calyx. A possible *Caryocrinites* (Silurian). Magnification is 1.5 times.

Figure 3. Three limestone slabs adjoined to show pelmatozoan columnals with circular, stellate, and quinquelobate axial canal contours, embedded in echinoderm debris.

Students of pelmatozoan stems have recorded their evolutionary characteristics (Stukalina, 1967, 1968; Moore and Jeffords, 1968; Shimer and Shrock, 1944), ascribing great importance to the outline of the axial canal. In the evolutionary development of the stem, the axial canal becomes progressively restricted and accompanied by reduction in thickness of the columnals, resulting in a consequent increase in their number. The higher forms have lobate ligamental areas.

In Figure 3 the columnals are round, among which transverse sections of two columnals display quinquelobate and stellate axial canal areas. Columnals possessing these characteristics have been assigned to the Silurian-Devonian, with greatest expansion in the Devonian (Stukalina, 1968). Magnification is 1.25 times.

Plate 2

Figure 4. Portion of a pelmatozoan stem in a delicate position in calc-chlorite schist (metatuff). The mud-filled axial canal and ligamental areas between columnals are strikingly preserved and appear as though machine-tooled (Fig. 4a). One complete columnal has survived the effects of solution. A top and side view in Figure 4b reveals the lobate nature of the ligamental area and restricted axial canal, and, in addition, the tops of three visible lobes have a "dot" at the center of each pentalobate lumen, which appears to indicate pinhole size canals parallel and subsidiary to the axial canal, probably to compensate for the restricted axial canal. Figure 4c is a top view showing whole specimen, parts of columnals, cast of ligamental area, and relationship of stem to schistosity of enclosing rock, which last is also demonstrated in Figures a and b. The probable age is the same as that stated in a discussion of the stems in Plate 1, Figure 3. Magnification is 6.5 times.

This is truly a remarkable preservation, considering the detail shown by a rather delicate fossil in a metamorphic rock exhibiting schistosity normal to the axis of the stem.

Plate 3

Figure 5. Calcite replacement of a calyx and tapering stem of a cystoid in a gray calcareous schist, the bedding schistosity both wrapping around the calyx and terminating at its bottom (Fig. 5a). Apparent plates and sutures are visible on calyx. Figure 5b is a view of the circular top of the calyx flattened or sheared off on one side by pressure of the enclosing schist. The shape of the calyx is very similar to that of *Caryocrinites*. Magnification is one.

Figure 6. Brachial valve of a probable spiriferid brachiopod, possibly *Theodossia hungerfordi* Nalivkin (Upper Devonian). Originally known as *Spirifer hungerfordi* Hall in the writer's student days, the brachiopod was described as having a straight hinge line with cardinal extremities, valve longer than wide with rounded contour, and weak to no fold or sinus. The shell in Figure 6 fits this description reasonably well (Hall, 1858, p. 501; Fenton and Fenton, 1924, p. 146; Shimer and Shrock, 1944, p. 321; Nalivkin, 1925, p. 358). The shell appears also to possess some of the characteristics of *Stropheodonta* (Middle Devonian). In either case, we are dealing with a Devonian brachiopod, the geologic date of which is further supported by the perforations in the shell.

The many borings in the shell may be correctly termed *Clionolithes*, as the boring sponge *Cliona* (Devonian to recent) is "caught in the act" on the anterior and right margins of the shell to substantiate this determination (Fenton and Fenton, 1932; Thomas, 1911; Shimer and Shrock, 1944, p. 57 and Pl. 17, Figs. 18, 20). *Cliona* is also "off stage" in the fossil matrix, especially the specimen at the left end of the shell's hinge line and at its anterior. Four spiralia are readily observable in the matrix and a possible sponge in the upper right hand corner. The presence of an appreciable number of spiralia and sponges within the limited scope of the shell might be suggestive of a widespread distribution of the spirifers and *Cliona* sponges in the sea of Shaw Mountain time. According to Fenton and Fenton (1924, p. 24), *Cliona* borings are found mostly on brachial valves, which would appear to indicate that they were made during the lifetime of the brachiopod. Boucot and Thompson (1963, p. 1318) have identified the brachiopod *Howellella* from the Shaw Mountain Formation near Albany. Magnification is one.

Plate 4

Figure 7. An ovoid, laterally compressed cystoid showing a few probable spines or pointed solution remnants linearly arranged on the antanal side of the calyx (Fig. 7a). Not visible in the illustration is a circular stem attachment area. The lateral view (Fig. 7b) shows the protruding anal pyramid with a circular periphery and two of the pyramid plates. Ambulacra are faintly perceptible along the encircling edge of the calyx. The fossil has undergone complete calcite replacement. The dark areas are paper-thin chlorite schist.

In the writer's opinion, the specimen closely resembles *Pseudocrinites* (Silurian-Devonian, Shimer and Shrock, 1944; Devonian, W. Va., Easton, 1960, p. 595, Fig. 14.7.4). Magnification of 7a is 2 times; of 7b, 2.6 times.

Plate 5

Figure 8. Base of large monocyclic crinoid calyx in full relief showing prominent basal plates surrounding depressed stem connection area with part of columnal. A probable camerate crinoid of the Order Monobathrida, which were widely dispersed in Silurian-Devonian time. Magnification is one.

Figure 9. Structurally flattened and distorted pelmatozoan calyx with granular crystalline surface retaining probable plates, well displayed in the white area near the center of the calyx. Circular columnal is observable on aboral side of calyx. Close inspection discloses a lobate lumen. Specimen is a probable cystoid. Magnification is 2.5 times.

Figure 10. Pelmatozoan remnant (on left); an anal sac? On right, pelmatozoan calyx framed by gray mica schist; the frame's shape is accidental. The recrystallized, granular calyx is similar in texture to that in Figure 9. Magnification is 1.5 times.

The calyces in Figures 9 and 10 probably show the outermost of the internal structure or filling.

Plate 6

Figure 11. Part of crown of a probable *Barrandeocrinus* with broken arm showing free pinnules suture along the arm. Immovable pinnules of arm describe a triangular cross section with a hollow center containing possible tubular structure of the water vascular system. At right, outer "pavement" of pinnulars which surround crown. In a well-preserved specimen, the tight-fitting arms hang downward, concealing the calyx (Moore, ed., 1978, p. T154,-T155, Fig. 128; Moore and others, 1952, p. 631-632, Fig. 18-23; Ubaghs, 1956). The white, calcified appendage has the shape of a complete arm in a normal hang-down position, as viewed from the side, without preservation of structural detail. At left, a probable arm part and stem fragments in matrix.

The writer believes the specimen described above to be *Barrandeocrinus* sp. (Middle Silurian). Magnification is 1.5 times.

Figure 12. Calcite replacement of pelmatozoan calyx with a portion of stem at base, in sawed section. Plates with parallel orientation, at left of calyx, appear to have been disjoined from it by possible strong currents, leaving a jagged border of the calyx. It may be seen that the disjoined plates decrease in thickness upward in the enclosing sediments, keeping an apparent normal sequence from heavier basal to thinner radials. Magnification is 2.33 times.

Plate 7

Figure 13. Portion of slab, photographed at the locality, of crystalline limestone composed largely of echinoderm debris, the prominent fragments consisting of stem and arm parts, and the sponge *Cliona* an inch from the right side in the upper right corner. Magnification is 2 times.

Figure 14. Crinoid stem of large diameter (13mm). Close observation will reveal crenellae appearing as minute tooth-like structures between relatively thin columnals on left side of stem. Stem of Silurian-Devonian vintage. Magnification is 3 times.

Figure 15. Tabulate favositid coral with tabulae and mural pores visible in prismatic corallites which are somewhat distorted. The features present indicate a probable *Favosites* sp. Most *Favosites* occur in Devonian strata. Various species of *Favosites*, including "probable helderbergie", occur in the lists of fossils from the Eastern Townships, Quebec, in Boucot and Drapeau, 1968. Magnification is one.

Plate 8

Figure 16. A favositid coral showing tabulae and outlines of corallites in side view (Fig. 16a) and ends of corallites in top view (Fig. 16b). Magnification is 1.5 times.

Plate 9

Figure 17. *Cladopora*-type coral in a matrix of fossil debris; corallites with apparent tabulae. Magnification is 2.5 times.

Figure 18. Sawed surface of crystalline limestone exposing corallite of favositid coral with distorted tabulae. A few saw marks may be seen to cross the fossil at high angles. Magnification is 2 times.

Figure 19. A fenestellate bryozoan. Pelmatozoan stems at immediate left. Silurian to Permian (Shimer and Shrock, 1944; Moore, ed., 1953, pt. G, p. G120-G127). Magnification is one.

Plate 10

Figure 20. Calcified favositid coral. Branching corallites apparent in low relief in Figure 20a. Top view in Figure 20b shows pressure-flattened coral with long axis parallel to the schistosity. Magnification is 1.5 for Figure 20a; 2.33, for Figure 20b.

Plate 11

Figure 21. Fossil suggestive of the coral *Syringopora*; the corallites converge toward the base as though to join a common root system. What appear to be remnants of lateral connecting processes are apparent on corallites on left side of illustration. The relatively thick-walled corallites, although greatly distorted, show constricted hollow centers at intervals. The planed surfaces of the corallites, especially the long one, and its neighbor on the left, give the appearance of having been sheared. *Syringopora* ranges from the Silurian to Permian, as a widespread form (Easton, 1960, p. 161). Magnification is 1.33 times.

The Ware Brook North Locality

LOCATION

The Ware Brook North locality has an easterly exposure on a gentle slope about .8 km north-northeast of where the Shaw Mountain Formation and Ware Brook intersect (Doll, 1951), and 2.8 km southwest of the village of Coventry, in the southeast rectangle of the 15-minute Irasburg quadrangle (Map Fig. 1).

GENERAL STATEMENT

Pelmatozoan stems occur in crystalline limestone lenses and layers embedded in pinkish to tan-weathered, paper-thin tuffs near the top of the formation. The fossils were revealed in a trench silo that was bulldozed across the strike of the soft tuffs. When the writer originally mapped in the area the easily eroded tuffs scarcely surfaced, consequently his report (1951) was published without fossil evidence for this portion of the Shaw Mountain Formation. It is quite possible that more exploratory effort at this locality will unearth other invertebrates in addition to pelmatozoan stems.

THE FOSSIL

Plate 12

Figure 22. Distorted pelmatozoan stem in matrix of echinoderm debris. Columnals are thin, showing erosional effects in sharpened perimeters where exposed at the surface. Recognizable in the debris are several arm segments and an arm base. Stem illustrates a middle Paleozoic demonstration of the domino theory. Magnification is one.

FOSSILS IN THE PLUTON CONTACT ZONES

PART 2

The fossils at the Clyde Dam, Stony Brook, and Lake Willoughby localities occur in the contact aureoles of granite plutons. Their presence in all these sillimanite zones of high-grade metamorphism (Doll and others, 1961; Doll, 1951,p.71) appears notable, especially at the Lake Willoughby locality where silication of the fossiliferous limestone by the process of diffusion has produced a coarse-textured, highly crystallized rock (Thompson, 1975). That the surviving fossils retained their forms and varying degrees of organic detail while the enclosing rock was undergoing strong recrystallization during the emplacement of an extensive magmatic body, is again notable.

The rocks in the area generally appear to be recrystallized under low pressure metamorphic conditions (andalusite-sillimanite type, Miyashiro, 1961; Doll, 1951). Fossil occurrences in igneous contact aureoles have been reported elsewhere (Dodge and Beecher, 1892; Bucher, 1953, p. 288-291). In an earlier paper, Dodge (1881, p. 435) reported "...fossil beds about the Katahdin granite", with greenstone nearby. Pavlides and Berry (1966, p. B51) have called attention to fragile graptolite preservation in "thermal aureoles" in the following statement: "Despite the thermal metamorphism that these rocks have undergone, graptolites are locally preserved within them". Their geologic map shows a frequency of plutons with intervening metasedimentary rocks, much like the terrane in northeastern Vermont.

Invertebrate life must have had a wide distribution in the seas of middle Paleozoic time, yet fossil representatives at the three abovementioned eastern Vermont localities appear to be preserved in narrow tracts adjacent to granite plutons where the intensity of long-continued metamorphism would be expected to destroy them completely. That this is not always the case is evidenced by the fossils described in this paper. In his report on the Stony Brook locality, the writer (Doll, 1943a, p. 59) suggested that hydrothermal metamorphism played an important part in the preservation of the fossils. Further consideration of the specimens from this locality indicates that the alteration and preservation mechanism was silication as well, judging from the silicate minerals composing the fossils which occur in the same metamorphic aureole as those at the Lake Willoughby locality. The writer believes that it is the process of diagenesis that prepares a fossil to survive metamorphism and not so much its size.

FOSSILS FROM THE WAITS RIVER-BARTON RIVER FORMATION

The Clyde Dam Locality

LOCATION

The site of the Clyde Dam locality is at the dam impounding the waters of Clyde Pond at the Newport City limits, between the road and the dam. Its location on the 15-minute Memphremagog quadrangle is in the northwest rectangle (Map Fig. 1). Had it not been for the diversion of the water for hydropower, the locality would have been covered by the flow of the Clyde River.

GENERAL STATEMENT

A single fossil cephalopod was found here on the weathered surface of a metalimestone bed of the Waits River - Barton River Formation in the contact aureole of a large granite pluton, on the west flank of Salem Hill, the northernmost of several prominent granitic eminences. The formation here comprises interbedded metalimestones, phyllites, and slates, all cut by a series of granitic dikes which are well exposed downstream from the bridge. This locality is illustrated in Doll, 1951, p. 106, showing the edges of the steeply dipping beds. Hitchcock (Hitchcock and others, 1861, p. 47) has reported "encrinal stems" on Salem Hill in the town of Derby, in limestone of "Devonian age".

THE FOSSIL

Plate 12

Figure 23. Internal cast of a spyroceroid cephalopod showing transverse, sharply-defined, widely separated annulations, slightly inclined. First camera (protoconch) is deformed. *Spyroceras* sp. fits the above description and is Silurian-Devonian in age (Shimer and Shrock, 1944). Magnification is one.

Spyroceras has been reported from the Eastern Townships, Quebec (Clark, 1942; Tolman, 1936) as of Devonian age.

Clyde Dam Locality Adjunct

LOCATION

This locality can be seen a short distance downstream from the bridge at an old ruptured dam, where the metasedimentary rocks vie for space with granitic dikes in the stream bed and rise high on the east side of the gorge. They are especially prominent on the downstream side of the abandoned dam (Map Fig. 1).

GENERAL STATEMENT

The fossils are graptolites of the floating type, occurring in very thin-bedded, platy limestone seamed contrastingly gray and black in section, the graptolites preserved on the smooth, black surface (Plate 13, Fig. 24). Graptolites are found also in black, fine-grained, finely crinkled, semi-lustrous calcareous phyllitic slate (Plate 13, Fig. 25). The occurrence here conforms well with the media in which graptolites are most common (Ruedemann, 1894, p. 52; 1947, p. 22-23; Moore, ed., 1955, p. V16; Moore and others, 1952, p. 729; Grabau and O'Connell, 1917, p. 961). The graptolites are confined to the black seam of the shaly metalimestone, whereas the gray, silty calcareous portion is barren of fossils. Both dark graptolite-bearing and light-colored barren seams are visible on the thin upper right side of the slab (Plate 13, Fig. 24).

THE FOSSILS

Plate 13

Figure 24. Complete fossil: A colony or synrhabdosome of a floating type graptolite in low relief showing stipes and thecae. Visible in depressed area at center is part of the perimeter of the float (pneumatocyst) with indistinct nodes, the float apparently shifted. Thecae appear as chambers in stipes, some in circular and others in oval transections. A few stipes, upon close inspection, show the customary saw-tooth outline. The stipes are of varying lengths.

A smaller specimen may be seen at the lower left edge, concealed largely by the matrix but for a few radiating portions of stipes. Of particular note here is the group of round impressions seen by close observation in the area of the pneumatocyst, very possibly gonangia (Ruedemann, 1894, p. 250 and Pls. 1 and 2; 1947, Pl. 68, Fig. 1) or immature pneumatocysts (Easton, 1960, p.135, Fig. 4.5.4) of a graptolite possessing a floating apparatus. The gonangia impressions are of a lighter color than the surrounding material, the color resembling somewhat that of chitin. The broken colony at the upper edge of the shale piece displays stipes and other organic features resembling those already described. At the immediate right of the complete specimen are two smaller graptolites partly concealed by the matrix. Magnification is 1.5 times.

Figure 25. Stipes of part of a graptolite colony on a finely crenulated surface of black phyllitic slate, with features corresponding to those in Figure 24. Magnification is 1.5 times.

It is the opinion of the writer that these graptolites probably belong to the *Diplograptidae* (Lapworth) and are possibly *Diplograptus* (McCoy), *Orthograptus* (Lapworth) and/or *Glyptograptus* (Lapworth). *Diplograptus* and subgenera *Orthograptus* and *Glyptograptus* range from Ordovician to the Llandoverian of the Silurian. However, a hiatus occurs in the succession of *Diplograptus* and *Glyptograptus* as recorded by Moore (1955, p. V72-V73, V19, Fig. 5) in the following: "Attention should be called to the break in continuity of *Glyptograptus* and *Diplograptus* (*Diplograptus*) between the Ordovician and Silurian (Fig. 5), which may indicate that forms assigned to these genera have originated more than once". From this it would seem that the upper range limit of these genera is, as yet, unknown and could extend beyond that shown.

Graptolites have been reported by Cooke (1937, p. 42-43; 1950, p. 32) in "fine-grained blackish sandstone" from the St. Francis Series in Adstock Township, Quebec, and were identified by Ruedemann as "comparable with *Diplograptus* (*Glyptograptus*) *euglyphus* Lapworth...". He also mentions two other species of *Diplograptus* as possibilities.

FOSSILS FROM THE WESTMORE-GILE MOUNTAIN FORMATION

The Stony Brook Locality

LOCATION

The Stony Brook site is located 1.2 km due north of Westmore village on the south bank of the brook. The brook is unnamed on the 15-minute Memphremagog quadrangle, southeast rectangle, but is shown on the map alongside a farm road which terminates just short of the locality (Map Fig. 1). Directions to this locality are also given in Doll (1943a).

GENERAL STATEMENT

The Stony Brook locality, in the Westmore - Gile Mountain Formation, has already been described (Doll, 1943a). Subsequent visits to the locality were rewarded with additional specimens. As originally reported, the fossils are concentrated at the border of a dike which is an apophysis of the near-by Goodwin Mountain pluton. The fossils occur in crystalline limestone intercalated with mica schist and consist of cystoids, crinoids, and a brachiopod. The pelmatozoan calyces are so crowded in the limestone as to leave little space for the matrix; where weathered, the fossils can be easily freed from the rock. With this abundant mixture of identifiable pelmatozoan calyces and concretionary forms at the same horizon, it should not be difficult to envision the transformation of the calyces to concretionary shapes, some still retaining organic features, however vaguely visible, in an environment of progressive metamorphism, noticeably the globose calyx of *Caryocrinites*.

THE FOSSILS

Plate 14

Figure 26. Weathered specimen of schistose limestone with two somewhat elongated pelmatozoan calyces, one showing the calyx wall section and the other the stem connection area with a perimeter suggestive of a columnal. They are probably crinoids, possibly a *Eucalyptocrinus* type (Doll, 1943a). Silurian. Magnification is 1.33 times.

Figure 27. Section through a pelmatozoan calyx showing wall and probable structure of the interior, both containing multitudinous very small circular forms possibly representative of tubes along with numerous canals constituting a part of the water vascular system. Magnification is 2.75 times.

Plate 15

Figure 28a. Longitudinal section of pelmatozoan crown and part of stem inclined to right. The incurve of the left wall of the specimen appears to mark the upper margin of the calyx and the base line of the arms, the last sparsely and vaguely determinable and terminating in the fringed oral side. Its shape is suggestive of *Eucalyptocrinites*. *Eucalyptocrinites* has been described from this locality (Doll, 1943a). Magnification is one.

Figure 28b. Surface subjacent to (a), on which several pelmatozoan calyces, some with stems attached, are well exposed and reveal important detail permitting reasonable identification of genus.

The largest calyx at the immediate right of center has the bulbous shape of a *Caryocrinites* with the perimeter of the oral area determinable. The calyx walls are layered with transverse pore tubes. Extending vertically in the center of the calyx is a columnar, chimney-like organ which increases in diameter upward and ends near the center of the oral area with a circular opening bordered by a plate with several radiating projections discernible. The above description conforms well with that of an alimentary canal (here calcified), a circular mouth at the center of a ring canal with several radial canals preserved.

Adjacent on the left of the above-described specimen is a similar but smaller calyx distorted on its right side and showing the outline of the oral area. From the aboral side the segmented stem can be seen curving upward toward the left border of the illustration and crossing another stem extending downward from a small calyx to a calyx with its interior exposed in the lower left corner, the latter with its encircling wall and portion of pentameral stem in center. Magnification is 1.75 times.

The writer believes the pelmatozoans described above belong to the Caryocrinidae of the Rhombifera. Middle Ordovician - Late Devonian, (Moore, ed., 1967, p. S153, Fig. 71), possibly *Caryocrinites*.

Plate 16

Figure 29. Pelmatozoan calyx exhibiting several perforations at arm bases in perimeter (wall) of depressed oral area, and stem connection aboral side. An example of a stage in the transformation of a fossil to its end product, a concretion, the result of advancing metamorphism. Magnification is 2.66 times.

Figure 30a. Brachiopod. Shell thin, carbonaceous at anterior margin, a few plications vaguely visible on surface of a pedicle valve and in serrations at its anterior edge. Shell globose with incurved beak. Magnification is 1.75 times.

Figure 30b. Shape of valve in section closely resembles that of *Gypidula*, possibly *Gypidula* sp. of Early Devonian age. *Gypidula* has been reported from several localities in the Eastern Townships, Quebec (Boucot and Drapeau, 1968, *Gypidula galeata* on page 31). Magnification is 1.5 times.

The Lake Willoughby Locality

LOCATION

This locality is situated approximately 4 km south of Westmore village on State Highway 5A, in the northeast rectangle of the 15-minute Lyndonville quadrangle and in the metamorphic aureole of the Goodwin Mountain pluton (Map Fig. 1).

GENERAL STATEMENT

The fossils are ubiquitous in the garnet zone of well-defined metamorphic mineral zones in a calc-silicate rock of the Westmore - Gile Mountain Formation, in the contact aureole of the Goodwin Mountain pluton. Macroscopically, the indicator minerals by zone colors are the cinnamon-colored grossularite garnet zone adjacent to the thinner, pale green diopside zone, followed by the fine-grained, gray gneissic-schistose zone of chiefly epidote group, calcic plagioclase, and calcic amphibole, the zonal sequence being in the direction of the igneous rock. All zones exhibit sharp borders and are the result of diffusion in a high-grade metamorphic zone (Pl. 17, Fig. 31, magnification is 3 times). The mechanism of the metamorphic alteration here has been described in some detail by Thompson (1975).

Harker (1932) has stated that fossils are destroyed where diffusion in a high grade of metamorphism gives rise to perceptively coarse crystallization, stating that "fossil remains of the larger and more robust organisms are exceptionally preserved up to the garnet stage". The garnet zone at the Lake Willoughby site is coarsely crystalline. One can wonder where he drew the line, since he made no mention of the smaller and more robust organisms which are represented by the surviving fossils at this locality. Boucot and Thompson (1958, p. 362) report fossils in Croydon Township, New Hampshire, in coarsely crystalline calcite in a matrix of quartz, diopside, grossularite and hornblende, a mineral assemblage somewhat like that at this locality.

The fossils found at the Lake Willoughby locality consist of corals, crinoids, cystoids, and a trilobite glabella, all replaced by calc-silicate minerals and distorted to varying degrees, and the probable sponge, *Cliona*. The garnet zone, to which the fossils are confined, has an appreciable amount of porosity expanded to voids permitting the fossils to stand out in bold relief. The space may have been inherited from an original biostrome stage. The fossil beds appear to be repeated and are inclined at high angles.

THE FOSSILS

Plate 18

Figure 32. A rugose coral showing a columella at both ends of specimen, and several septa. The theca is cuneate, probably due to pressure. The columella is vesicular. Close observation reveals a fine, reticular pattern on the coral. The extension of the columella beyond the apex of the coral probably served as an attachment organ; in any case, its preservation is significant considering the metamorphic environment in which it occurs. The coral conforms to a *Zaphrenthis*-type which ranges from Silurian to Mississippian. *Zaphrentis* (*Zaphrenthis*) is listed from a number of localities in the Eastern Townships, Quebec (Boucot and Drapeau, 1968). Magnification is 1.75 times.

Figure 33. A large pelmatozoan with well-defined calyx wall whose inner surface is dentate with pore tubes of a rhombiferan cystoid. The calyx is globose with a thick stem curving downward from the aboral side. Visible and slightly out of focus are brachioles. The description indicates a possible *Caryocrinites*. The round form at lower right is a probable cystoid, to be given attention in Plate 19, Figure 34. Magnification is 2 times.

Plate 19

Figure 34. Group of cystoid calyces, which in flattened, wider-than-high shape, could represent *Sphaerocystites* or possibly *Coelocystis*; cross sections of two calyces visible near left border of illustration. Openings in calyces probably indicate place of periproct. The white disc-shaped forms with fine denticles at their

perimeters, in lower left corner of photograph, appear to be plates on an elongated calyx whose facing aboral end displays a circular stem attachment area. The plates resemble those of the crinoid *Scyphocrinites* (Lower Devonian) (Moore and others, 1952, p. 632). Both cystoid genera cited above are of Middle Silurian and Early Devonian age, respectively. Magnification is one.

Figure 35. Cystoid calyces of *Sphaerocystites* or *Coelocystis* types with apparent periproct apertures. Magnification is 1.5 times.

Plate 20

Figure 36. A probable trilobite glabella with either glabellar or occipital lobe attached on right side, at center of illustration. Glabella swollen, widens forward, and shows a number of surviving tubercles distributed over its surface, including that of the attached glabellar or occipital lobe. From a study of the literature it was found that by far most glabellae having a shape like that of the specimen under study, occur in Silurian and Devonian strata. "In progressive genera it (glabella) may become inflated or globose..." (Moore, ed., 1959,p. 046). The glabella could have belonged to a member of the phacopids, possibly *Phacops* sp.

Phacops has been reported from the Cranbourne locality in the Eastern Townships, Quebec (Tolman, 1936, p. 15), and it has been noted that all trilobite fossils from locations in the rocks of the Eastern Townships have middle Paleozoic (Silurian-Devonian) affiliations. With a few Silurian exceptions, *Phacops* is a Devonian fossil with its greatest expansion during that period (Shimer and Shrock, 1944, p. 651). Additional identifications are a corallite, slightly out of focus, at upper left margin of the illustration, and possibly two sponges of the genus *Cliona*, one at right of the corallite and the other on the reader's side of the glabella. Undeterminable fossil fragments compose much of the matrix. Magnification is 2 times.

Figure 37. Basal portion of a large pelmatozoan calyx exhibiting basal plates and stem, in form of wye, in pelmatozoan matrix. Stem shows columnals and lumen. Magnification is 1.5 times.

CANADIAN EASTERN TOWNSHIPS CORRELATIONS

Boucot and Drapeau (1968) have compiled an exhaustive list of fossil localities in the Eastern Townships, from Cranbourne to the International border, assembled from the Canadian reports. The writer, upon examining these lists and those in the various reports on the region, has noted many genera related to those from Vermont localities and that they also have Silurian-Devonian labels attached to them.

Among the fossils listed from the localities in the Eastern Townships, the corals appear to be most common, particularly the genus *Favosites*. Next to the corals in abundance are the brachiopods and trilobites. Least abundant are the cephalopods, bryozoans, and "crinoidal fragments", the last group apparently having been overlooked because it is not conspicuous.

The fossil genera common to both the Eastern Townships and Vermont localities are the corals, *Favosites*, *Zaphrenthis*, *Syringopora*, and *Cladopora*; the brachiopods *Gypidula*, and a possible *Stropheodonta*; the cephalopod *Spyroceras*; the bryozoan *Fenestella*; the probable trilobite *Phacops*; and crinoidal fragments. The brachiopod *Howellella* has been identified from both Vermont and Eastern Townships by Boucot (from Vermont, Boucot and Thompson, 1963, p. 1321, 1332; from Eastern Townships, Boucot and Drapeau, 1968, p. 29). In Vermont, pelmatozoans have the most abundant representation, followed by the corals, and all other fossils are less common.

Of the Vermont fossil localities, four are situated in the area designated as unfossiliferous by Boucot and Drapeau (1968, Map 1607A) which includes the writer's Stony Brook locality reported on in 1943 and apparently still not recognized by the above-mentioned writers. The four localities are the Clyde Dam and its adjunct (Waits River - Barton River Formation), Stony Brook and Lake Willoughby (Westmore - Gile Mountain Formation). Boucot and Drapeau (1968) have correlated the Waits River - Barton River Formation with the upper part of the Lower St. Francis Formation and the Westmore - Gile Mountain with the upper St. Francis Formation, which is also shown as unfossiliferous on Map 1607A. In this connection, Cooke (1937, p. 42-43) has reported graptolites, identified as *Diplograptus* by Ruedemann, from the St. Francis Formation.

DISCUSSION

Fossil localities have been widely recognized in the crystalline metamorphic rocks in all the New England states, even within touching distance of their igneous benefactors in eastern Vermont (Hitchcock and others, 1861, v. 1, p. 486, v. 2, p. 719; Doll, 1943a, p. 59; Cady, 1950, p. 492, and this paper).

Emboldened by these observations in eastern Vermont and in a moment of fossil-oriented enthusiasm, the writer ventures to suggest that it might not be entirely beyond the realm of possibility to find a fossil specimen, embedded in a weak matrix, that unfortunately or perhaps fortunately, chanced to be so close to the widening contact zone of a cooling pluton, and to have survived, at least in part. Some eastern Vermont fossils appear to be preserved under these conditions. The plutons in eastern Vermont show evidence of forceful injection and stoping (Doll, 1951, p. 44). In addition, fossils have been caught up in lava flows or rapidly buried in ash fall tuff deposits. It might also be possible that individual fossils may be preserved on the pluton side of the contact with metamorphic rocks, possibly during the late stages in a cooling pluton and in numbers locally sufficient to permit at least some to survive assimilation. Fossil-containing xenoliths are, of course, known. The writer recalls the easy and clean release of echinoderm calyces from their contact metamorphosed matrices at the Stony Brook locality. The prolific yield of silicified and silicated concretionary forms, some still retaining organic features, however vague, in the flow-structured metalimestone at this same locality, may be due, in some measure, to their spherical shape (Stony Brook, Pl. 16, Fig. 29).

Putting oneself out on a limb, so to speak, in the refreshing breeze of progress with a field-inspired, speculative proposal, however untenable it might appear at the time, should not be regarded as an unscientific posture, but, on the contrary, it should serve as a stimulus to further research on the basis of the discovery already made. "A plurality of suffrages is no guarantee of the truth where it is at all difficult of discovery." - Descartes.

An alternative view of the close proximity of the fossils to igneous rocks could also be their attraction in life to warm waters and food in the neighborhood of molten rock with attendant thermal springs. Invertebrate life in the area, it is reasonable to believe, flourished in such an alluring environment and likewise was victimized by it. The modern analogues of these environments are sea water reaching the depth of magma chambers and recycled as ocean-bottom hot springs highly charged with mineral matter, in all respects hydrothermal (Edmond, 1980).

Conditions favorable for fossilization could be brought about in such an area of mineralizing thermal springs, in places or at intervals deficient in oxygen, and a shifting cover of bottom sediments resulting from circulating sea water induced by the undersea springs. Sulphides variously disseminated in metamorphic rocks might be suggestive of waters associated with thermal springs permeating the layers of sediments and resulting in discrete sulphide deposition. An influx of sulphide precipitation could seriously dilute the oxygen content of the sea water to the extent of causing the extinction of life and, at the same time, aid in the fossilization of its preservable remains. Disseminated sulphides are a common constituent at some horizons in the Silurian-Devonian metamorphic rocks in the Magog belt in northern Vermont (Doll, 1951).

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