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Richard H. Fillon et Allen S. Hunt

Volume 10, numéro 1, avril 1974

URI : https://id.erudit.org/iderudit/ageo10_1rep03

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Éditeur(s)

Maritime Sediments Editorial Board

ISSN

0843-5561 (imprimé)

1718-7885 (numérique)

[Découvrir la revue](#)

Citer cet article

Fillon, R. H. & Hunt, A. S. (1974). Late Pleistocene Benthic Foraminifera of the Southern Champlain Sea: Paleotemperature and Paleosalinity Indications. *Atlantic Geology*, 10(1), 14–19.

Late Pleistocene Benthic Foraminifera of the Southern Champlain Sea:
Paleotemperature and Paleosalinity Indications*

RICHARD H. FILLON

Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543

ALLEN S. HUNT

Department of Geology, University of Vermont, Burlington, Vermont 05401

Introduction

Lake Champlain (Fig. 1) is a long, narrow lake lying between New York and Vermont. It trends north-south and has a maximum depth of about 244 metres. The Champlain Valley was glaciated during the Woodfordian stage and between 14,500 and 11,500 years BP, the lake basin was gradually freed of ice. During this interval, pro-glacial lakes at several levels occupied the Champlain Valley (Chapman, 1937; Schafer and Hartshorn, 1965; Thomas, 1964; Connally and Sirkin, 1970). With the departure of the ice blocking the St. Lawrence lowland, which was then below sea level, the Champlain Sea penetrated into the Champlain Valley (Chapman, 1937; Gadd, 1964). This southern arm of the Champlain Sea gradually shallowed as glacio-isostatic uplift proceeded until the sill at its northern end reached sea level between about 8500 and 10,000 years BP (Fillon, 1970; and Chase and Hunt, 1972), and the present fresh-water lake was created.

Samples for this study were taken from five piston cores recovered from Lake Champlain by the research vessel U.V.M. MELOSIRA and from three sections exposed above lake level (Fig. 1). The coring program in Lake Champlain has been successful in providing sediment samples from the pro-glacial lake, Champlain Sea and Lake Champlain phases of sedimentation (Chase and Hunt, 1972). The cores are sampled at 50-cm intervals by removing 25-cc portions of sediment. The samples are then washed through a 61-micron sieve and examined for microfossils. In the Champlain Sea sediments these are largely benthic foraminifera with occasional ostracodes and juvenile pelecypods. No planktonic foraminifera have yet been found. Lake Champlain sediments are recognized by their abundant fresh water diatoms (Sherman, 1971) while pro-glacial lake sediments can be distinguished by their stratigraphic position, texture (Chase and Hunt, 1972) and lack of fossils.

Paleotemperature

Examination of southern Champlain Sea foraminiferal faunas has so far resulted in the identification of 21 species (Table 1). The most abundant forms are *Protelphidium orbiculare*, *Elphidium bartletti*, *E. clavatum*, *Islandiella teretis*, and *I. islandica*, one or several of which typically compose over 90 per cent of the total fauna. Zones representing the intervals of dominance of these species appear to be correlatable throughout the lake (Fig. 2).

The evident high degree of dominance and low diversity is characteristic of both very shallow

and very cold water foraminiferal faunas (Cushman, 1921). In fact, 60 per cent of the foraminiferal species (Table 1) from the southern Champlain Sea are not reported living today south of the Gulf of St. Lawrence. The remaining 40 per cent while not restricted to the Arctic have all been reported from there (Parker, 1952; Loeblich and Tappan, 1953; Cushman, 1948).

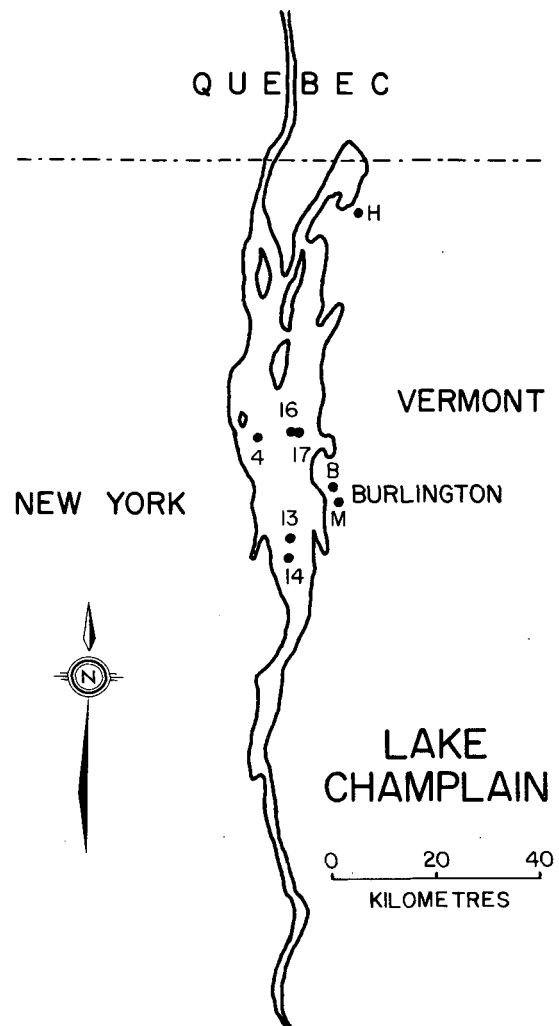


Fig. 1. Map of Lake Champlain showing sample locations.

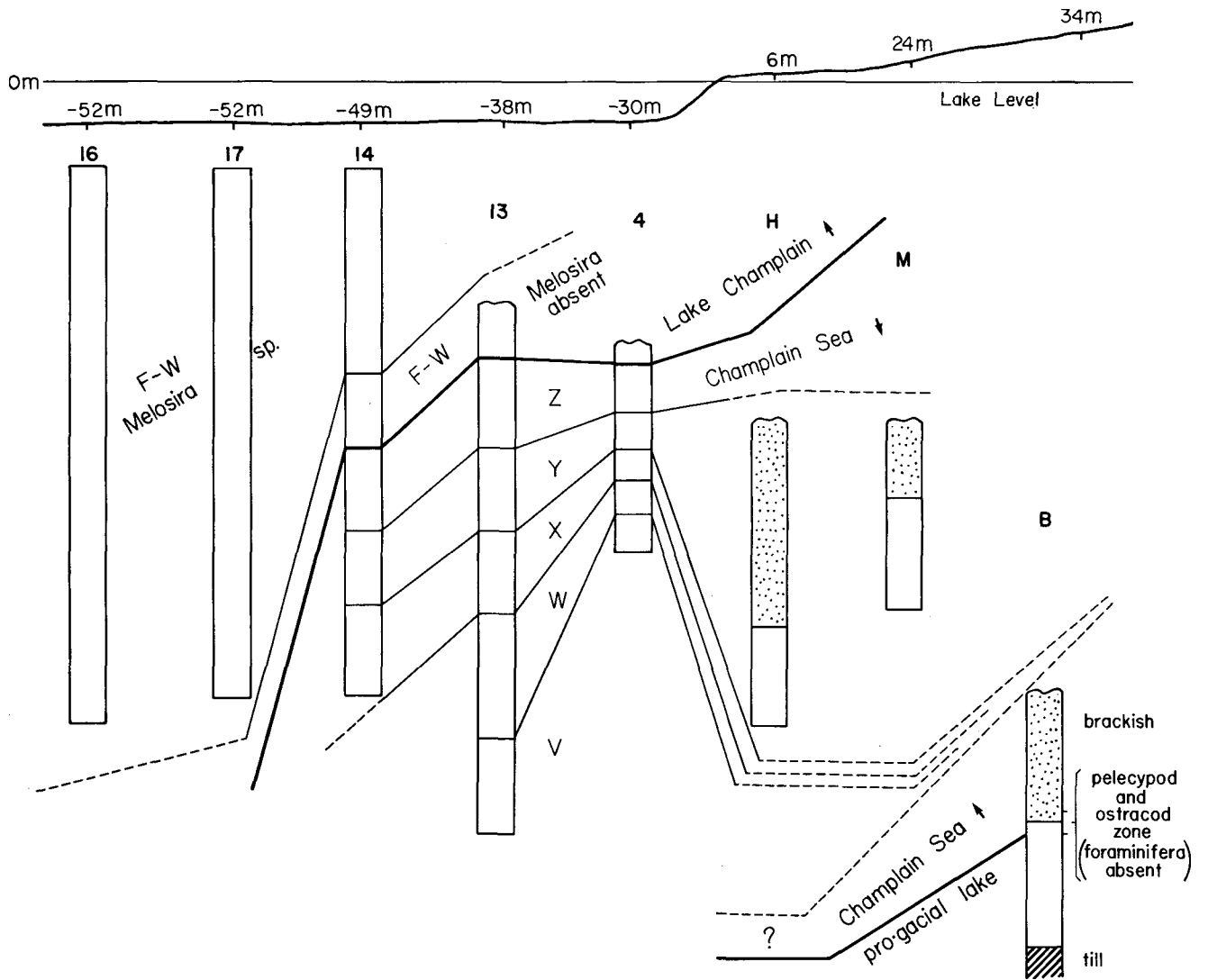


Fig. 2. Schematic cross section of the Champlain Valley with suggested faunal zonation based on the ranges of dominance of certain benthic foraminiferal species.

- z - *Elphidium clavatum*
- X - *P. orbiculare* and *E. bartletti*
- V - *I. teretis*
- Y - *E. clavatum* and *Protelphidium orbiculare*
- W - *Islandiella islandica* and *I. teretis*

Stippling represents deltaic sands which are generally barren of fossils. Core numbers are above columns, letters indicate terrestrial sections (Fig. 1). Lake level is at 30 m above sealevel. F - W equals fresh water.

TABLE 1

Foraminifera from southern Champlain Sea sediments

<i>Bolivina pseudopunctata</i>
<i>Buccella frigida</i>
<i>Cassidella complanata</i>
<i>Cassidulina crassa</i>
<i>Discorbis chasteri</i>
<i>Elphidium bartletti</i>
<i>Elphidium clavatum</i>
<i>Fissurina cucurbitasema</i>
<i>Fissurina laevigata</i>
<i>Fissurina marginata</i>
<i>Islandiella islandica</i>
<i>Islandiella teretis</i>
<i>Lingulina</i> sp.
<i>Nonionella auricula</i>
<i>Parafissurina fusuliformis</i>
<i>Parafissurina</i> sp.
<i>Protelphidium orbiculare</i>
<i>Pyrgo williamsoni</i>
<i>Quinqueloculina agglutinata</i>
<i>Quinqueloculina stalkerii</i>
<i>Spiroplectammina bifurcata</i>

Islandiella teretis, which was a dominant form during the early stages of the southern Champlain Sea has previously been found in abundance only in the northern Champlain Sea (Wagner, 1970), the Canadian Arctic (Loeblich and Tappan, 1953; and Vilks, 1969) and in the Gulf of St. Lawrence (Hooper, 1968 and Vilks, 1968). The Gulf of St. Lawrence occurrences are largely restricted to water depths of about 55 to 75 m and to temperatures which are constant throughout the year at about 0°C (Vilks, 1968). The salinity was reported to be about 32‰. In shallow waters of similar salinity in the Chuckchi Sea (<50 m) on the Arctic coast of Alaska, *I. teretis* is not reported to occur (Cooper, 1964). By contrast, *I. teretis* has been noted in extremely shallow water from other regions of the Arctic (Loeblich and Tappan, 1953; Cushman, 1948; Phleger, 1952a). Cooper's (1964) report that near-bottom summer temperatures in the Chuckchi Sea range from 11°C to 3°C provides a possible explanation. It appears that *I. teretis* may be limited to very cold water that does not rise much above 3°C during any portion of the year. If comparisons of water temperatures in other portions of the Arctic with the distribution of *I. teretis* bear this out, it must be concluded that bottom water during the first half of the 3,000-year history of the southern Champlain Sea was uniformly at or below about 3°C.

The other dominant species in southern Champlain Sea sediments appear to have been more tolerant of water temperatures in excess of 3°C. *Islandiella islandica*, *Elphidium clavatum*, *E. bartletti* and *Protelphidium orbiculare* are all abundant in the Chuckchi Sea (Cooper, 1964) and throughout the Canadian Arctic (Loeblich and Tappan, 1953) as well as in continental shelf sediments to Cape Cod and Martha's Vineyard, (Slessor, 1970; McRoberts, 1968; Harrington, 1955; Cushman, 1944; Hooper, 1968; and Phleger, 1952b). Nevertheless the Arctic nature of the total fauna implies that summer bottom-water temperatures never exceeded about 11°C which is the maximum recorded in the shallow Chuckchi Sea (Cooper, 1964).

The paleoclimatological findings of this study have demonstrated the strong Arctic affinity of the Champlain Valley foraminiferal fauna the probable existence for 1,000 to 2,000 years of uniformly cold (possibly < 3°C) bottom water is indicated. However, unambiguous conclusions cannot be drawn from this information alone, without knowledge of the salinities and water depths involved.

As glacio-isostatic rebound of the Champlain Valley region progressed, the area inundated by water of the Champlain Sea diminished and the marine limit retreated from an initial maximum of about 75 m ASL, to a minimum at the end of the marine episode of about 15 m ASL near Burlington, Vermont (Chapman, 1937). Continued elevation of the sill at the northern end of the basin then caused the newly created fresh-water lake to rise to its present level at 33 m ASL. Because the cores presented in this paper were taken at depths between 30 m and 60 m, Champlain Sea depths at these sites would have ranged from 100 m to 10 m approximately over the time-period sampled. Water depths in the deepest part of the basin were about 200 m.

Circulation and exchange with the Atlantic Ocean via the St. Lawrence Valley in the early stages of the southern Champlain Sea were relatively unrestricted, taking place across an opening approximately 200 m deep and 80 km across (Chapman, 1937). However, glacio-isostatic rebound gradually reduced the size of this connection causing circulation to become increasingly restricted, resulting in decreased salinities which are reflected by foraminiferal faunal changes.

Glacio-isostatically induced shallowing of the Champlain Sea would also eventually have facilitated thermal mixing, producing warmer summer bottom-water temperatures. These events may have caused the scarcity of *I. teretis* observed in southern Champlain Sea sediments deposited late in the marine interval. The warming effect on local climate, produced as Woodfordian ice retreated northward, may also have served to make it increasingly difficult for *I. teretis* to flourish.

Paleosalinity

Elphidium clavatum as defined by Loeblich and Tappan (1953) is a ubiquitous species. It is common throughout the Arctic in water depths from 0 to 150 m (Loeblich and Tappan, 1953; Cushman, 1948; Phleger, 1952a; Cooper, 1964). It is also common at these

depths on the continental shelf to the north (Slessor, 1970; McRoberts, 1968; Harrington, 1955; Cusham, 1944; Hooper, 1968; Phleger, 1952b) and south (Ronai, 1955; Todd and Low, 1961; Said, 1951, 1953; Parker, 1952; Weiss, 1954) of Cape Cod. However, faunas in which *E. clavatum* is an overwhelmingly dominant constituent are typically restricted to very shallow, low-salinity environments such as estuaries (Loeblich and Tappan, 1953; McRoberts, 1968). In Covehead Bay, Prince Edward Island, *E. clavatum* dominated faunas (> 35%) are reported living in less than 4 m of water with salinities ranging from 18 to 24‰ (Slessor, 1970). It is thus inferred that the last phase of the Champlain Sea in which *E. clavatum* dominates (> 75%) was relatively fresh (Ca. 18‰) and very shallow, probably less than 20 m in the regions we sampled.

Protelphidium orbiculare in the Canadian Arctic (Loeblich and Tappan, 1953) and on the continental shelf off eastern Canada (Vilks, 1968) occurs in greatest abundance at depths less than 100 m. In Bras d'Or Lakes, Nova Scotia, which taken together exhibit features of morphology and bathymetry similar in many respects to the terminal phase of the southern Champlain Sea, *P. orbiculare* is abundant in water with an average salinity of 22.5‰ at all depths from < 10 m to > 150 m (Vilks, 1967 and personal communication). It appears then that during the period of dominance of *P. orbiculare* in the Champlain Valley, bottom-water salinities at the depth we sampled may have been as low as 22.5‰.

A distribution with depth and salinity similar to that of *P. orbiculare* is indicated for *Elphidium bartletti* (Schafer, 1969; Hooper, 1968; Vilks, 1968; McRoberts, 1968; Harrington, 1955 and Slessor, 1970). However, variations in the ratio of abundance of these two species do not appear to follow a consistent pattern.

Islandiella islandica, which was co-dominant with *I. teretis* prior to the increase in *P. orbiculare* and *E. bartletti* (Fig. 2), overlaps the range of those two in the Canadian Arctic. *I. islandica* extends in abundance deeper than *P. orbiculare* and *E. bartletti* to > 500 m, (Loeblich and Tappan, 1953; Phleger, 1952; Cooper, 1964 and Vilks, 1969). Hooper (1968) and Vilks (1968) report that off eastern Canada *I. islandica* is most common below 58 m and extends in abundance to at least 317 m (Hooper, 1968). The species has not been reported from Bras d'Or Lakes which are deeper than 150 m but exhibit generally low (24‰) salinities (Vilks, 1967) nor from the shallow waters of Covehead Bay, which are characterized by similar salinities (Slessor, 1970). Salinities in the southern Champlain Sea while *I. islandica* was a dominant constituent of the fauna could not, therefore, have been less than 24‰ and were probably in the range of 30 to 33‰. These limits represent the range of salinities of coastal waters in which *I. islandica*, is known to be living (Cooper, 1964; Vilks, 1968).

In the present distribution of *I. islandica*, there also appears to be evidence that this species must have been restricted to water depths of greater than 30 m in the southern Champlain Sea. This is in agreement with the depth limits already estimated

by consideration of glacio-isostatic uplift. Therefore it is probable that portions of the *E. clavatum*-*P. orbiculare* zone which outcrop above lake level were deposited while *I. islandica* and *I. teretis* were dominant constituents of deeper faunas.

Less Common Species

The usually abundant and relatively diverse arenaceous foraminiferal faunas typical of arctic and sub-arctic regions are not found in southern Champlain Sea sediments. The very few arenaceous specimens found (exclusively *Spiroplectammina biformis*) were fragmentary and any handling produced additional breakage. We feel that diagenetic processes are probably at work in the sediments weakening the cementation of arenaceous foraminifers to the point that they are destroyed by normal sample disaggregation and sieving procedures. A similar phenomena was previously noted in the Ross Sea, Antarctica (Fillon, 1972).

There are 16 species of less common calcareous foraminifera found in southern Champlain Sea sediments (Table 1). They are all species that would be expected at the temperatures and water depths estimated according to the dominant forms. Their distributions are well referenced in Loeblich and Tappan (1953), Hooper (1968), Phleger (1952), Cushman (1948), and Wagner (1970).

Conclusions and Possibilities of Further Study

This investigation illustrates that benthic foraminifera provide a convenient and sensitive tool for investigating temperatures and salinities of the Late Pleistocene southern Champlain Sea. Salinities represented in the study area are as follows: less than 18‰ to less than 24‰ for the *E. clavatum* zone; between 22‰ and 28‰ for the *E. clavatum*-*P. orbiculare* through *E. bartletti*-*P. orbiculare* zones; and probably about 30‰ to about 33‰ for the *I. islandica*-*I. teretis* through *I. teretis* zones. Examination of additional cores and outcropping material above lake level will permit detailed mapping of the foraminiferal zones.

Planned C_{14} -calibrated paleomagnetic analysis of Lake Champlain cores by N.D. Watkins and K. Freed of the University of Rhode Island will hopefully provide an independent method of correlation between cores which will permit the development of paleo-environmental reconstructions for various synchronous horizons. These results should be directly comparable with Champlain Sea strand-line studies by Chapman (1937). The rate of shallowing as interpreted from inferred salinity changes and planned paleomagnetic correlations will provide useful supplementary information about eustatic sea level change and glacio-isostatic uplift rates.

Evidence showing the apparent affinity of *I. teretis* for bottom water colder than about 3°C throughout the year has been introduced. Further investigation of this relationship is certainly warranted and is planned. If *I. teretis* does prove to be a reliable indicator of bottom water temperatures, it could be of great value to studies of Pleistocene climatic change as recorded in near-shore sediments. Additionally two apparently distinct morphotypes of

I. islandica have been recognized which appear to favour different depths of water. We plan further work to clarify morphologic and ecologic differences between the two.

Acknowledgements

Thanks are due to the crew and student assistants for their help on board the U.V.M. MELOSIRA and to the Lake Champlain Studies Center of the University of Vermont for providing us with ship time. We are also grateful to G. Vilks for his valuable suggestions.

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