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Intrayear variability of geostrophic circulation on the New England and Nova Scotia shelves

by

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Abstract

From the analysis of the charts of dynamic topography seasonal types of the geostrophic current fields on the New England and Nova Scotia shelves have been distinguished, and intrayear variations in the circulation field considered. 10 and 4 typical situations, accordingly for the New England and Nova Scotia areas, have been revealed. All these types are characterized by the availability of quasistationary gyres or the zones of rising and sinking water. The change of circulation types on the New England shelf during one year period occurs in a closed cycle.

Introduction

The water circulation is one of the most important abiotic factors in the mechanism of productive zone formation on the New England and Nova Scotia shelves. These areas are characterized by the interaction between the strong constant currents greately influenced by the processes of the seasonal variability. In the present paper the intrayear seasonal changes in the current structure on the shelf are studied based on the typification of the charts of dynamic topography and of qualitative relation between the peculiarities of the current fields and some biological phenomena annually observed in certain shelf parts. Such parts are, for example, the northern and southern slopes of Georges Bank, the East and South Channels, the Nantucket Shoals etc. The northern slopes of the Bank are traditional spawning grounds for herring, while along the southern slopes the silver and red hake spawning occurs annually. The Nantucket Shoals are commonly inhabited by the youngs of many fish species and invertebrate. In this connection, it may be important to find out the causes of timing of the fishing objects at different stages of their life span to definite shelf parts based on the circulation analyses.

Material and Methods

To distinguish between the types of geostrophic circulation on the New England and Nova Scotia shelves, a comparative analyses of 58 charts of dynamic topography drawn according to the temperature and salinity measurements taken during the hydrological surveys was made. The data obtained in the Atlant-NIRO expeditions in 1962-1975 were used.

The charts of dynamic topography were drawn according to the traditional dynamic method (Zubov N.N., Mamaev O.I., 1956); the peculiarities of its application are indicated by the author in his paper (I.K.Sigaev, 1975). Following from the essence of the method only surface circulation is analysed, as most close to the actual current pattern unlike the underlying horizons.

The construction of the types of geostrophic current fields is based on the principle of including of most frequently reiterated situations from the charts of dynamic topography related to the same month and area into one or another type. Thus, in the New England area it was possible to reveal typical situations for 11 months excluding February, while on the Nova Scotia shelf - only for 5 months. June-July (New England area), and April-May (Nova Scotia area) were represented by a single type, since the charts of dynamic topography show similar situations for both months in each pair.

Results

At the first stage of studies conducted in 1974 (I.K.Sigaev, 1975) the possibility of application of the dynamic method as the first approximation in the study of water circulation on the shelf has become evident. The summer-fall type scheme for the New England area was then designed based on the data from the analyses of the charts of dynamic topography drawn for 1972-1973.

At the second stage an attempt was made to reveal the types of current fields by month and to trace their intrayear variability. The results are given below.

Types of current fields on the New England shelf

It seems reasonable to begin from the description of the August type, which is formed under the conditions of most developed stratification of the water in terms of density, weakened wind force in the density field and maximum developed processes of the summer convection. The peculiarity of these conditions lies in the fact that they exert influence on the formation of the geostrophic circulation type with the features persisting through the most of the year, showing in other circulation types for a long time.

August. In August (fig. 1) the geostrophic circulation type is characterized by well developed anticyclonic gyres or the zones of rising and sinking water over the central part of Georges Bank, in the Nantucket Shoals area and in the southern Georges Bank, where the first gyre has the largest square. In addition, there is observed an anticyclonic gyre over the Wilkinson-Basin depression. During August in the Georges Bank area there also exist the cyclonic gyres and the zones of rising water. The rising zone in the East Channel is most developed. More zones of rising water are also observed north of the South Channel, and along the northern and southern slopes of Georges Bank. The development of such zones along the northern slopes of Georges Bank is timed to the spawning grounds of herring, as indicated by the author (I.K.Sigaev, 1975). The zones observed in August along the southern slopes of the Bank were weakened.

September. In September (fig. 2) the circulation field does not ungergo any significant changes compared to August. In this month the cyclonic gyres along the northern slopes of

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Georges Bank are most clearly pronounced. In the East Channel the rising zones are divided into single gyres and spread northwards to the eastern part of the Gulf of Maine, while the process of rising north of the South Channel is intensified with the eastward shift. The anticyclonic gyres over the Wilkinson-Basin depression and in the Georges Bank area are further developed. In the Gulf of Maine in general a cyclonic gyre is recorded with the eastward shifted centre. The anticyclonic gyre over Georges Bank is well developed.

October. The main peculiarity of geostrophic circulation on the October charts of dynamic topography is the appearance of the first features of destruction of the anticyclonic gyre over Georges Bank. As is seen from fig. 3, the northern limit of the gyre looks like being compressed by the zones of rising water both from the east and north; the latter are increased in square owing to merging with the adjacent zones (South Channel zone) and strengthening (East Channel zone). Besides, the sinking zone over the central part of the Bank is divided into two gyres. Its destruction in the south-east part of the gyre is promoted by the intensified rising of the water in the Corsair Canyon area. Significant changes occur in the Nantucket Shoals area, where the anticyclonic gyre is marke dly shifted westwards replaced by a weak rising zone. The anticyclonic gyre is well developed around the south-west extremity of the Nova Scotia peninsula..

November. In November (fig.4) the main anticyclonic gyre over the Bank is still well pronounced, although its

destruction is continued. The intensification of the zones of rising water from the south Bank and the East Channel area is a clear feature of destruction. In the Wilkinson Basin depression area a rising zone is formed, while the sinking zone is shifted southward. Other dynamic formations in general do not undergo any significant changes.

December. In December (fig. 5) important changes occur in the gyre over the central Georges Bank. The sinking zone over the shallow water shifted to the south-west is indicative of its existence. The rising zones are intensified on the slopes. In the East Channel area the rising zone is slightly reduced from the north, however, in the Gulf of Maine its extension formed in November is further developed. Between these the zone of sinking water is formed. On the Nantucket Shoals the situation is similar to that in November.

January. In January (fig. 6) the anticyclonic gyre over Georges Bank becomes considerably deformed, a latitudinally extended loop shifted to the south is generated. The shallow water of the Bank is occupied with the rising zone which evidentely represents a region of the intensified rising zone of the East Channel. North of the South Channel the zone of sinking water or anticyclonic gyre is further developed instead of the traditional rising zone observed in August-October. On the Nantucket Shoals predominates the zone of rising water. The sinking zone area around the south-west extremity of the Nova Scotian peninsula is extended.

March. In March (fig. 7) the structure of the current field is considerably different from that observed in January. The anticyclonic gyre over Georges Bank is completely destructed. It is replaced by the extended zone of rising water bordered on the local sinking zones from the east and south. In this period in the eastern Gulf of Maine a large cyclonic gyre and an anticyclonic gyre in the western Gulf of Maine region are formed. The anticyclonic gyre is well developed west of the Nantucket Shoals. The gyre around the south-west extremity of the Nova Scotian peninsula is intensified in March.

April. In April (fig. 8) the anticyclonic gyre is absent over Georges Bank. The central part is occupied with the rising zone stretched from the west in the eastward direction; south of the latter the sinking zone is observed. In the eastern Gulf of Maine there still exists the sinking zone or the anticyclonic gyre which is reduced compared with that observed in March. In the Nantucket Shoals area the zone of sinking water is again formed in April, while the rising zone persists in the East Channel. The sinking zone in the Browns Bank area is well developed.

May. The circulation type in May (fig. 9) is characterized by the beginning of the main gyre formation process over Georges Bank. This can be suggested from the appearance of the current with the general westward direction along the southern slopes of the Bank. The northern region of the Bank is occupied with the unstable gyres with the circulation in opposite direction. The sinking zone in the western Gulf of Maine becomes less intensive. The rising zone in the East Channel and the sinking zone in the Nantucket Shoals area are well developed. A sharp intensification of vorticity along the southern slopes of Georges Bank most likely caused by the intensive advection of the water from the frontal Gulf Stream zone is one of the characteristic features of the current field structure in May.

June - July. As mentioned above the current structure in these months (fig. 10) is similar on the whole, therefore, a single circulation type is given both for June and July. This type is characterized by formation of a new anticyclonic gyre over Georges Bank which, although somewhat deformed, is newly developed. Another peculiarity lies in the fact that the vorticity is further developed along the southern slopes of Georges Bank, where clearly pronounced local zones of rising and sinking water are formed. The spawning concentrations of silver and red hake are timed to their borders, as indicated by the author (I.K. Sigaev, 1975).

From the above data on the intrayear variations of geostrophic population in the Georges Bank area it can be concluded that during a year period the structure of the circulation field undergoes considerable changes which occur in a closed cycle. The main dynamic formations revealed during a year are observed at different phases of their development. Some formations, for example, the anticyclonic gyre over Georges Bank persists for a long time and is the main component of the current structure in the area.

Its formation is likely to begin in May, completely developed in August-September following by the period of its gradual destruction. In March the anticyclonic gyre over Georges Bank enters the phase of complete destruction and is replaced by cyclonic gyres over the considerable Bank region. These gyres have provided for most intensive influx of nutrient salts (biogenes) in this period to the upper zones. In this respect the circulation structure in February is of interest, however, since no hydrological surveys were made in February it may only be suggested that the current field structure in the period studied is of intermediate character as compared to that in January and March.

Current field types on the Nova Scotian shelf

August. A cyclonic gyre in the deepwater part of the shelf, anticyclonic gyres over Emerald and Middle Banks, and over Misaine and Banquereau Banks are characteristic dynamic formations for the Nova Scotian shelf in this period (fig. 11). A zone of rising water is observed in the area of Galli Deep. The same phenomenon was also recorded in the Lourenshan Channel similar to that in the East Channel and on Georges Bank.

October. The zone of rising water in the deepwater part of the shelf is divided into two parts by a well developed anticyclonic gyre (fig. 12). One part is adjacent to the north--eastern slopes of La Have Bank and another to the western border of Middle Bank. A vast zone of sinking water observed around Emerald and Middle Banks is also divided into two local zones. The rising zones occupy the areas northward of Misaine Bank in the Galli Deep and on the southern slopes of Emerald Bank. Powerful rising zone is also recorded in the Laurenshan Channel.

January. No significant changes in the current field occur in January (fig. 13) with the exception of marked intensification of the rising zone in a deepwater part of the Nova Scotian shelf, and of the sinking zone in the area of Emerald Bank - Sable Island.

April - May. In this time of the year the current structure is characterized by still more intensive rising zones in the deepwater part of the shelf, by destruction of the sinking zone over Emerald Bank and intensified vorticity along the seaward shelf border.

Thus, both in the Nova Scotian shelf and Georges Bank areas the intrayear variations in the current field structure are observed.

As a matter for discussion, it may be useful to consider the circulation patterns reported earlier for the Georges Bank and Nova Scotian shelf areas, and any differences between those and the types given in the present paper.

The earliest of the known schemes is the circulation pattern suggested by Bigelow (Bigelow H.B., 1927) for July and August and describing the cyclonic gyre of the water in the Gulf of Maine and the anticyclonic gyre of Georges Bank. This is a tentative scheme which represents the summer circulation type in general and is lacking many significant details shown in our schemes. Day (Day G.C., 1958) presented most possible directions of the main currents in February - June deduced from drift bottles used in 17 cruises by the USA R/V ALBATROSS III during 1931-34 and 1953-56. He showed that during the period from February to June certain variations are observed in the surface circulation structure, which are especially marked in February-March when " the gyre on Georges Bank is difficult to determine". According to the author these variations are caused by wind pattern of the area. So, the data of bottle mail allowed for consideration of the actual drift situation together with the wind conditions during each survey, and to tentatively assess the conditions which stipulated the plankton drift in the period as a whole. However, the lacking data on bottle recovery and inaccuracy in interpritation of their drift ways do not give evidence on current directions over considerable parts of Georges Bank and the Gulf of Maine thus excluding the possibility of detailed comparison with the types presented here. From the charts of dynamic topography Alekseev (Alekseev A.P. et.al,1971) presented the pattern of geostrophic circulation for the Georges Bank and Nova Scotian areas, which characterize the summer and winter seasons on the average for a period 1961 to 1966. The main dynamic formations in the summer and winter seasons are shown. However, due to a large time scale in averaging a rather smoothed pattern of currents was obtained lacking a number of characteristic eddies shown in our schemes. Nevertheless, the above authors suggested more complex structure of currents on the shelf compared to the known scheme by Trites and Banks (R.W. Trites and R.E. Banks, 1958) for the Nova Scotian shelf water from the data of bottle mail.

From the above said it follows that unlike the schemes or types given in the present paper where the variability of current fields was traced by season and by month, earlier schemes of current fields were based either on the bottle mail information which did not cover the whole investigation area, or on a dynamic method. A large time scale in averaging of the observation data in the latter method gave only a smoothed current pattern lacking the characteristic quasistationary eddies.

In discussing the reasons of intrayear variations in the density circulation on Georges Bank and Nova Scotian shelf one should agree with the authors stating a considerable influence of wind activity (Day G.C., 1958; R.W. Trites and R.E. Banks, 1958) and, therefore, of the processes of atmospheric circulation on the current field. In addition, advection processes are also likely to impose a considerable influence on the current field structure formation.

Conclusion

1. The results of studies have confirmed the applicability of dynamic method in calculation of geostrophic circulation on the Northwest Atlantic shelf region under the conditions of sharply pronounced density stratification and complex bottom contour.
2. The circulation field structure on Georges Bank undergoes considerable changes during the year and is recorded as a single closed cycle. The formation of anticyclonic gyre on Georges Bank and of cyclonic gyre (first phase) in the Gulf of Maine in August, a complete destruction of the first one and division of the second into two anticyclonic eddies in February-March (second phase) are the main phases of that cycles. During the year a gradual transition from the first phase to the second and then again to the first is observed.
3. A number of characteristic quasistationary eddies and zones is revealed to which different biological zones are timed.
4. Against the cyclonic gyre development and destruction of anticyclonic gyre over Georges Bank most intensive influx of biogenous elements to the surface layer is likely to occur in February-March.
5. In the geostrophic field current on the Nova Scotian shelf significant intrayear variations are also traced.
6. Wind activity, the processes of atmospheric circulation and advection process are likely to cause the intrayear variability in geostrophic circulation.

References

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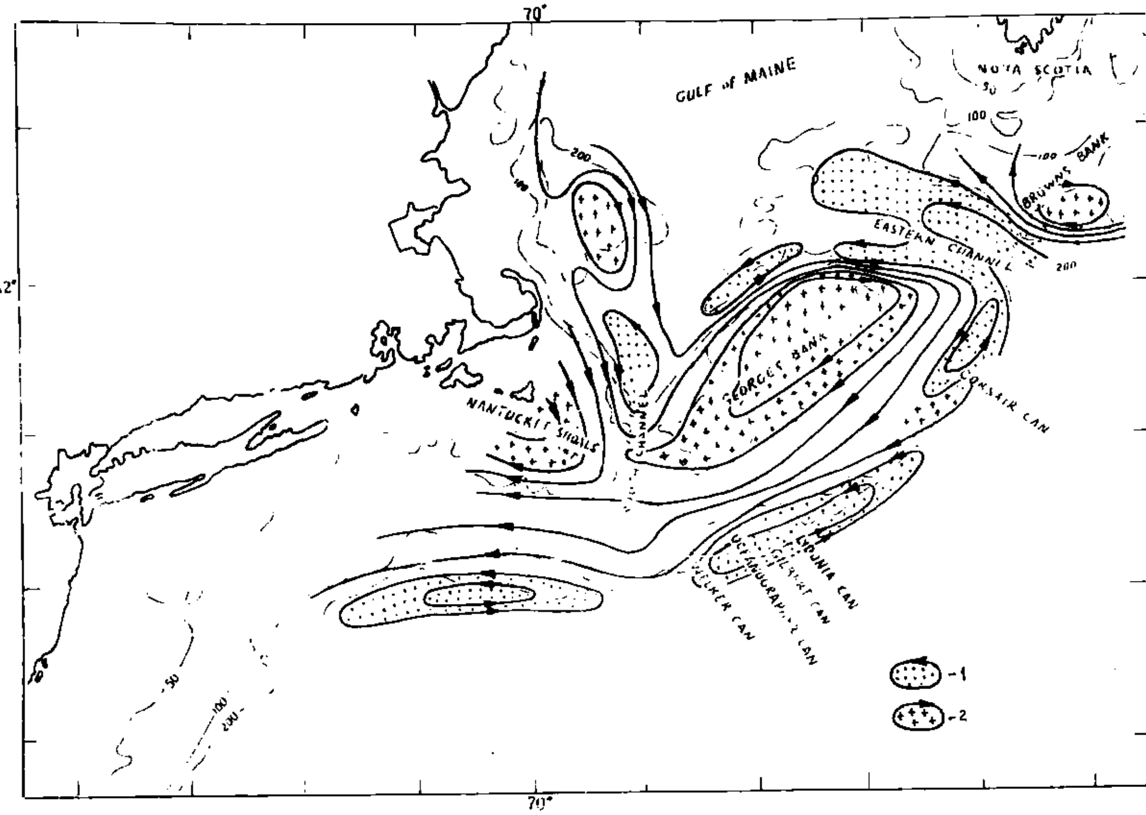

Fig. 1. Geostrophic circulation scheme on the New England shelf in August.

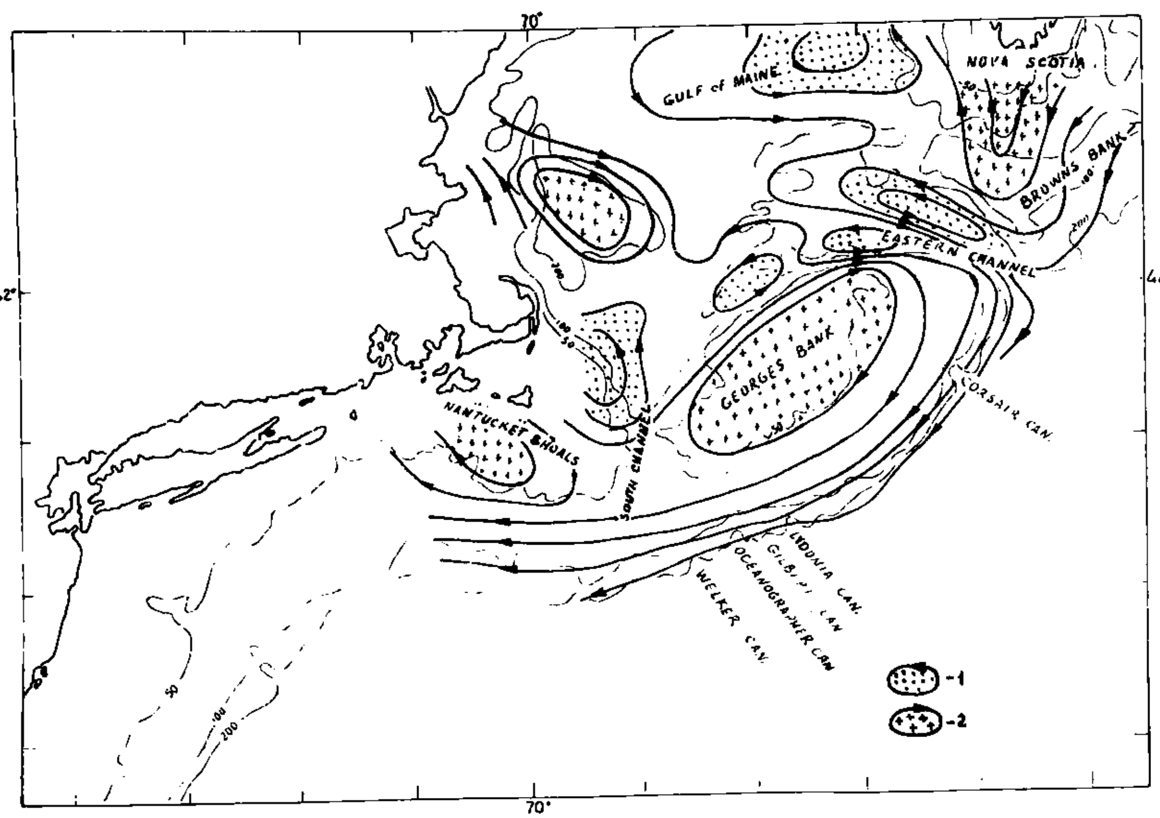

Fig. 2. Geostrophic circulation scheme on the New England shelf in September.

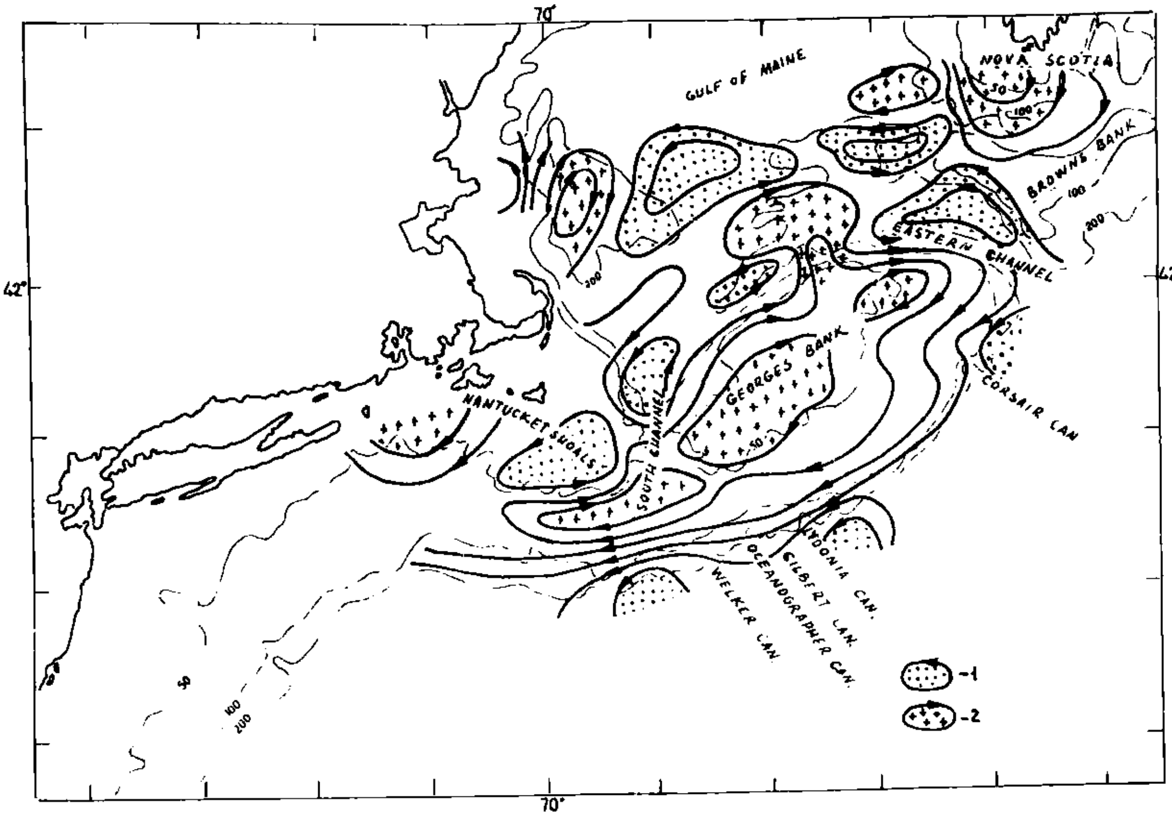

Fig. 3. Geostrophic circulation scheme on the New England shelf in October.

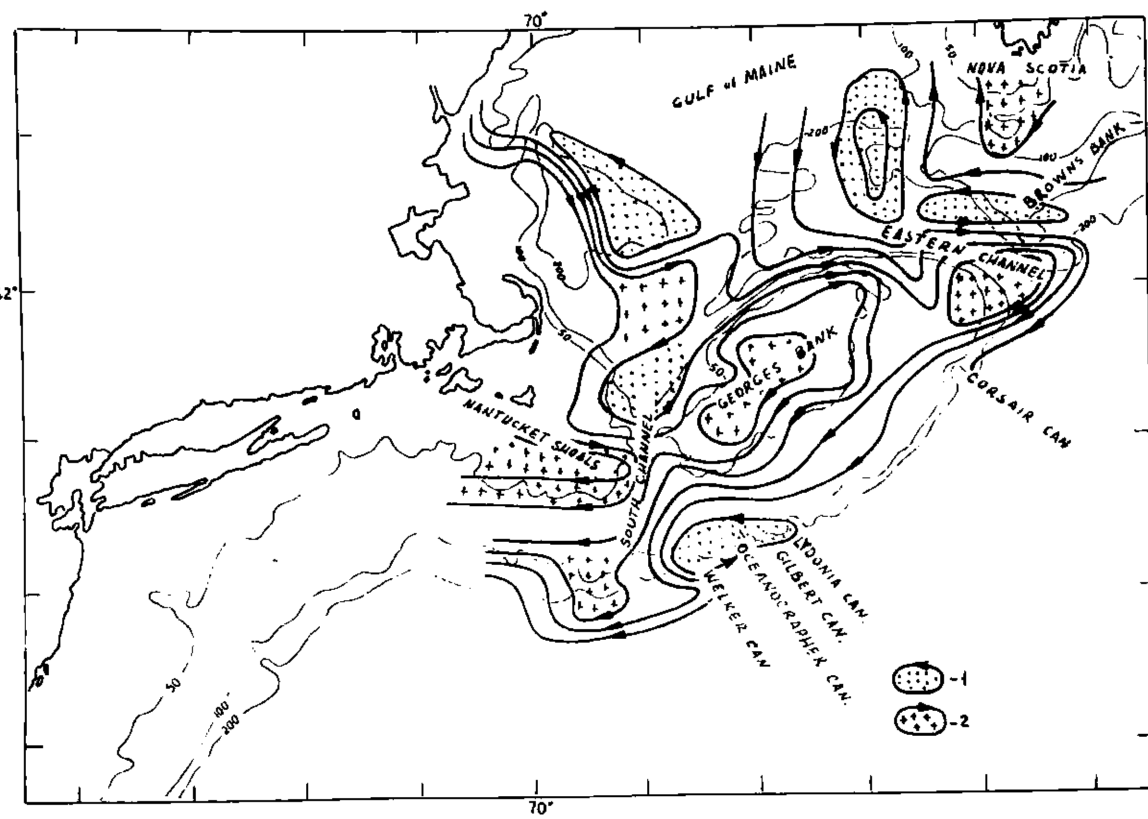

Fig. 4. Geostrophic circulation scheme on the New England shelf in November.

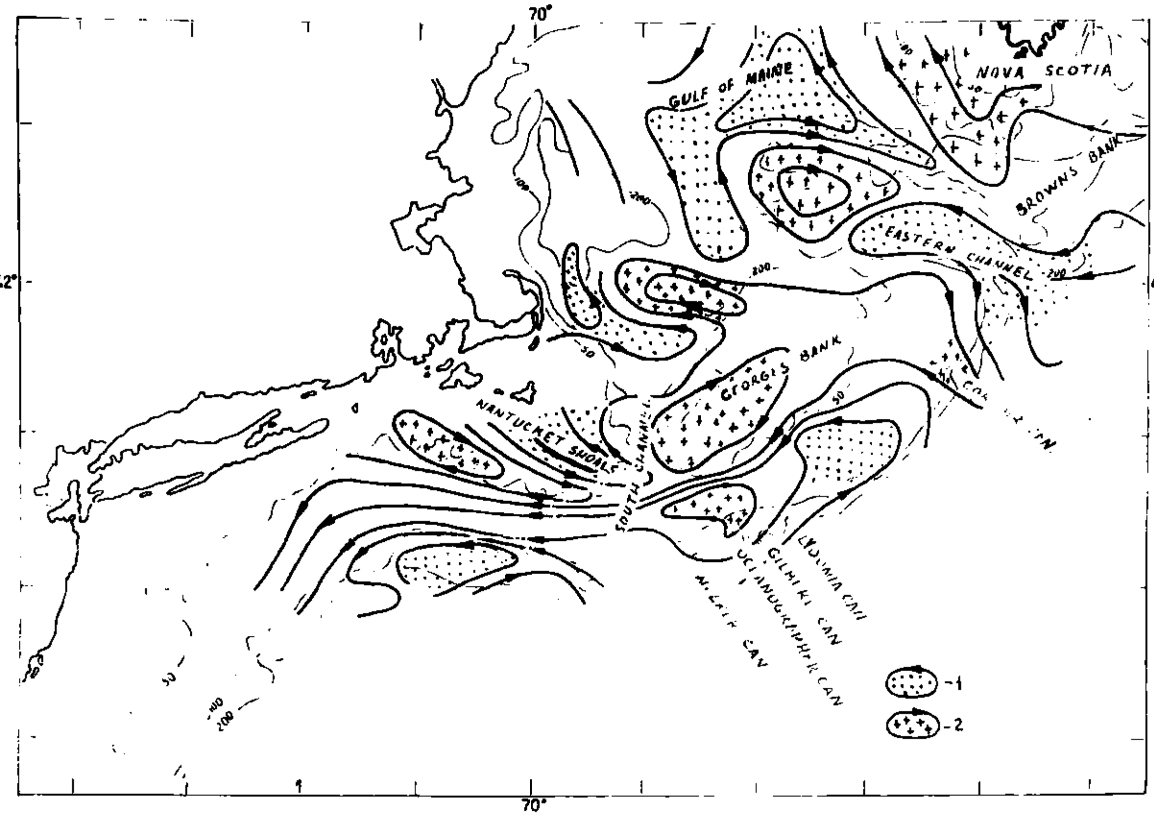

Fig. 5. Geostrophic circulation scheme on the New England shelf in December.

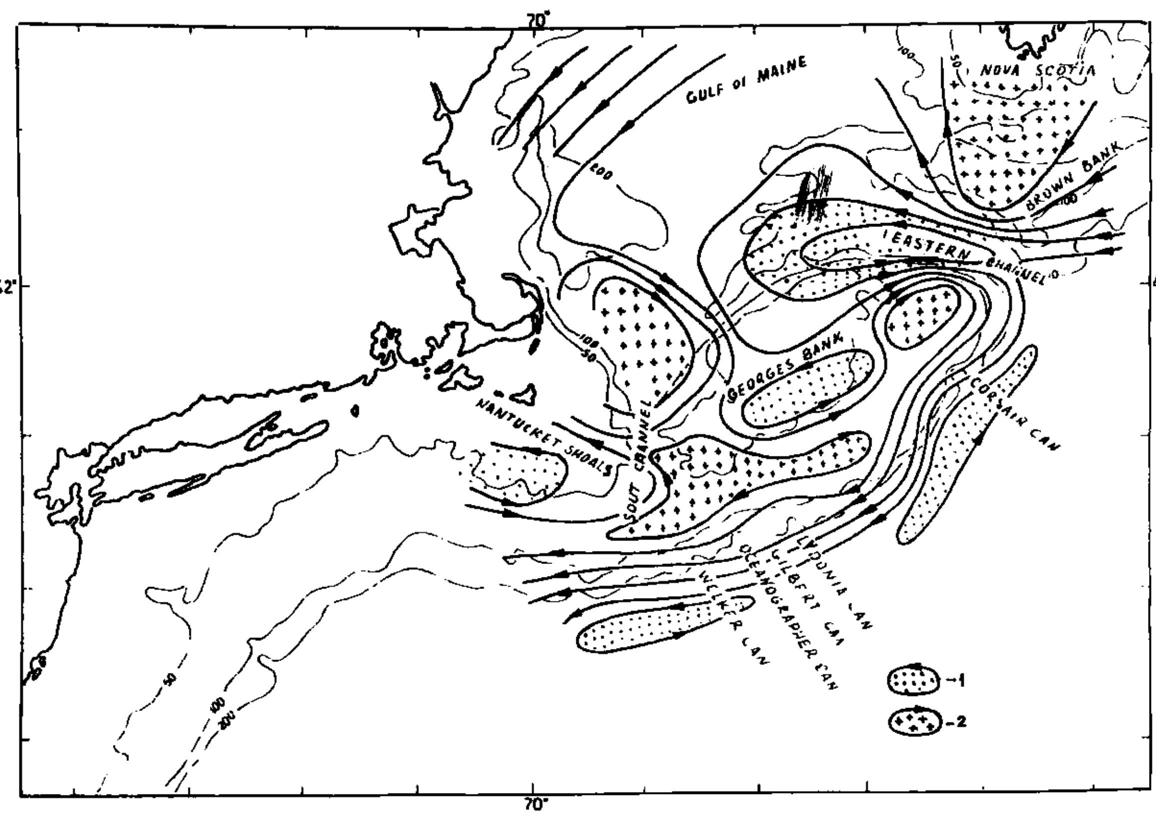

Fig. 6. Geostrophic circulation scheme on the New England shelf in January.

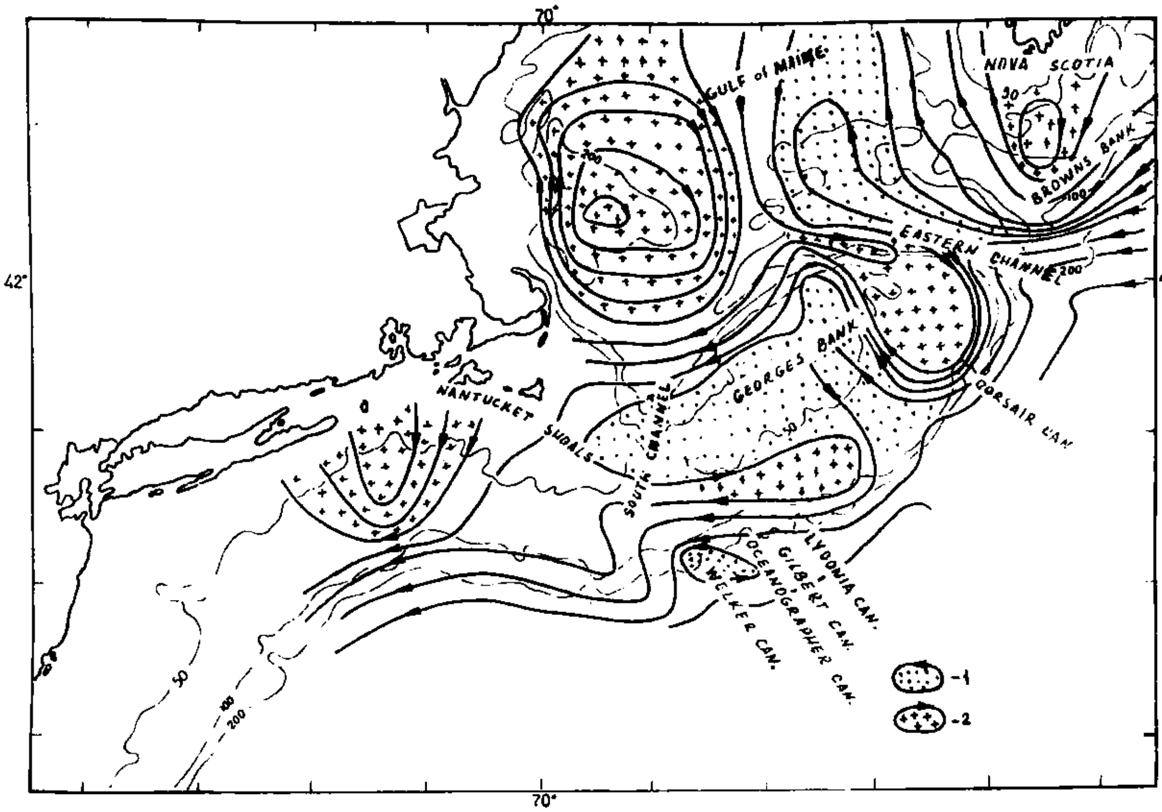

Fig. 7. Geostrophic circulation scheme on the New England shelf in March.

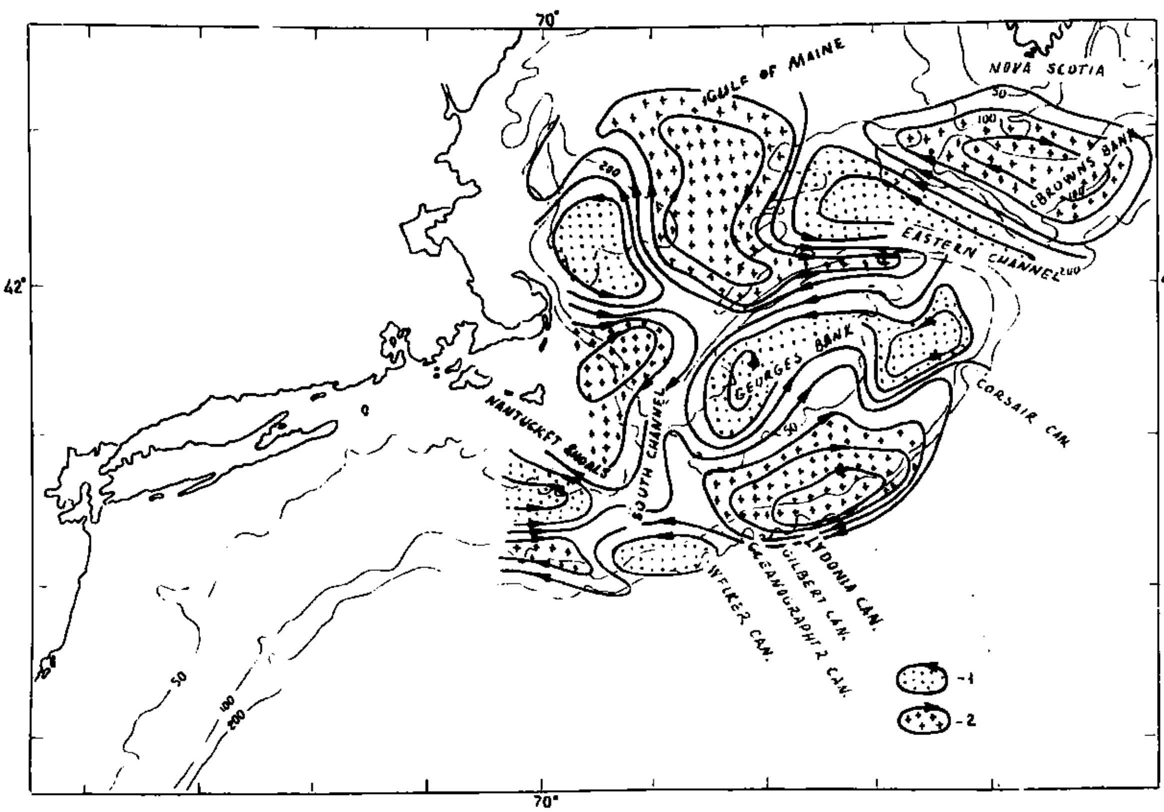

Fig. 8. Geostrophic circulation scheme on the New England shelf in April.

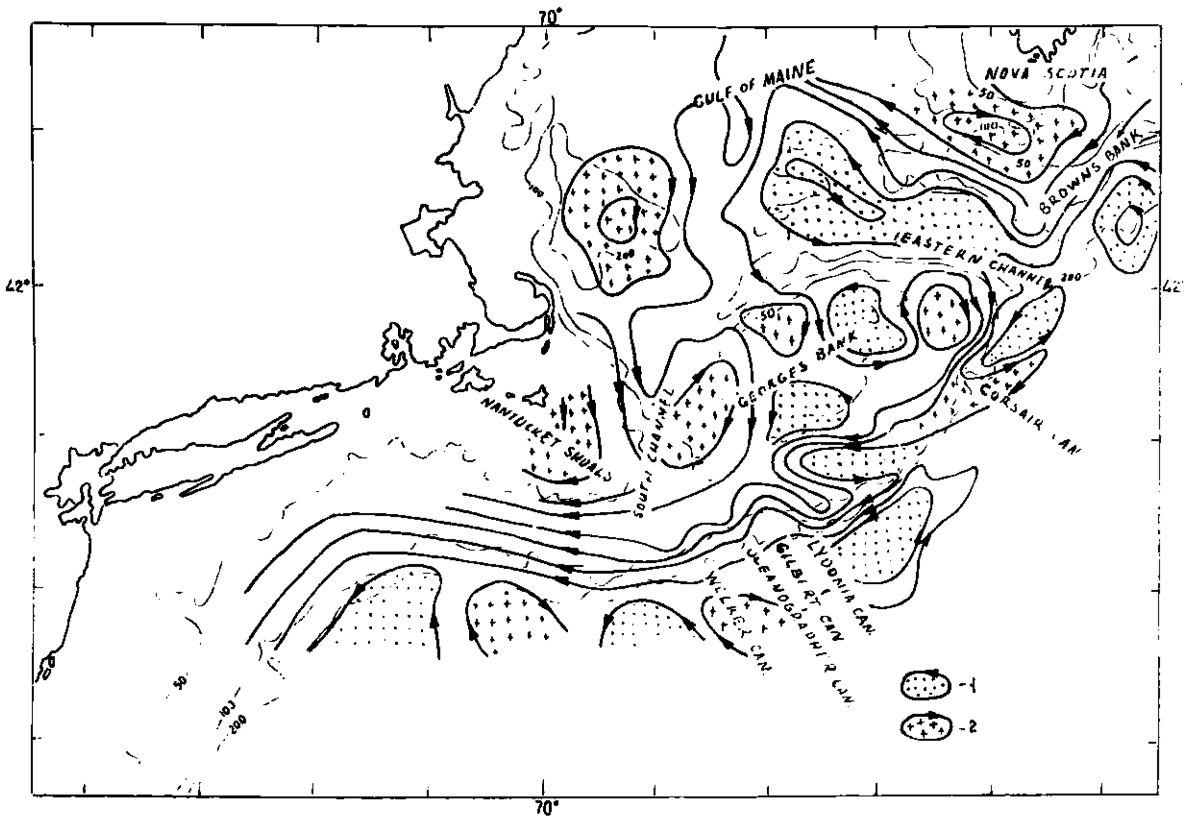

Fig. 9. Geostrophic circulation scheme on the New England shelf in May.

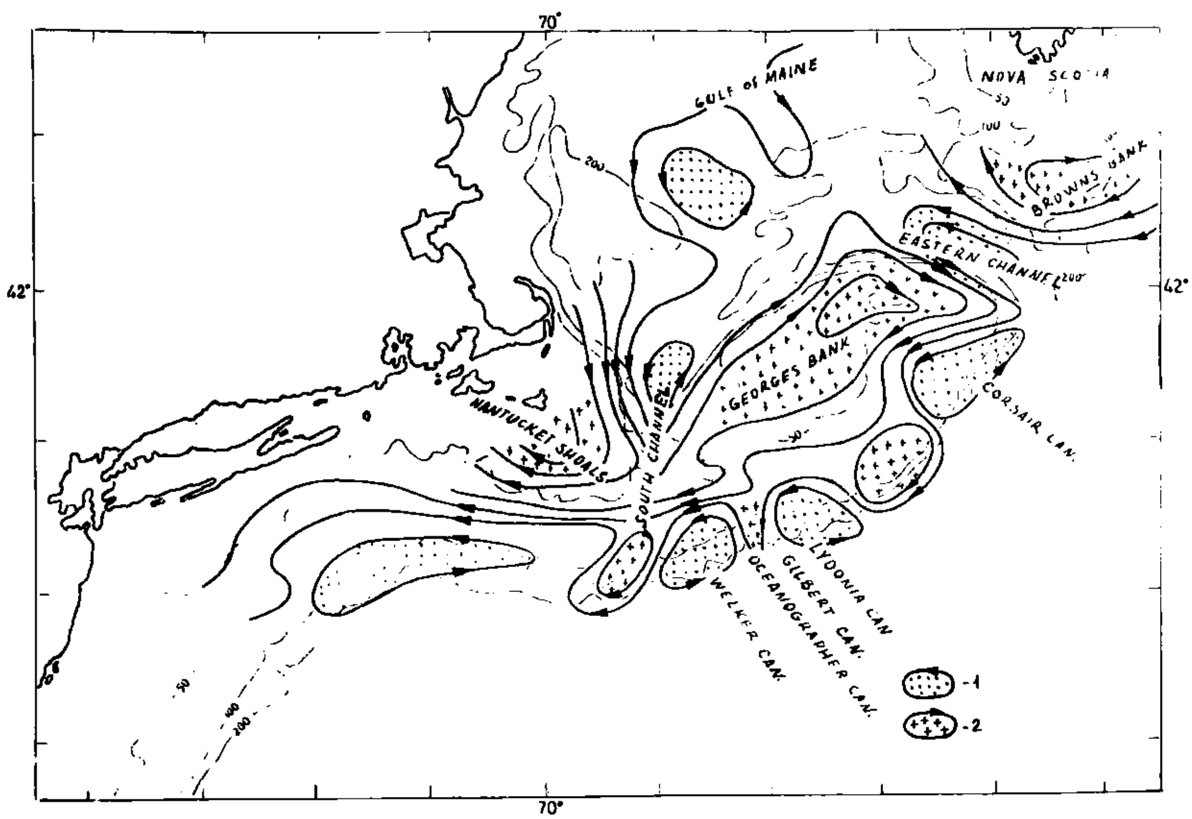

Fig. 10. Geostrophic circulation scheme on the New England shelf in June-July.

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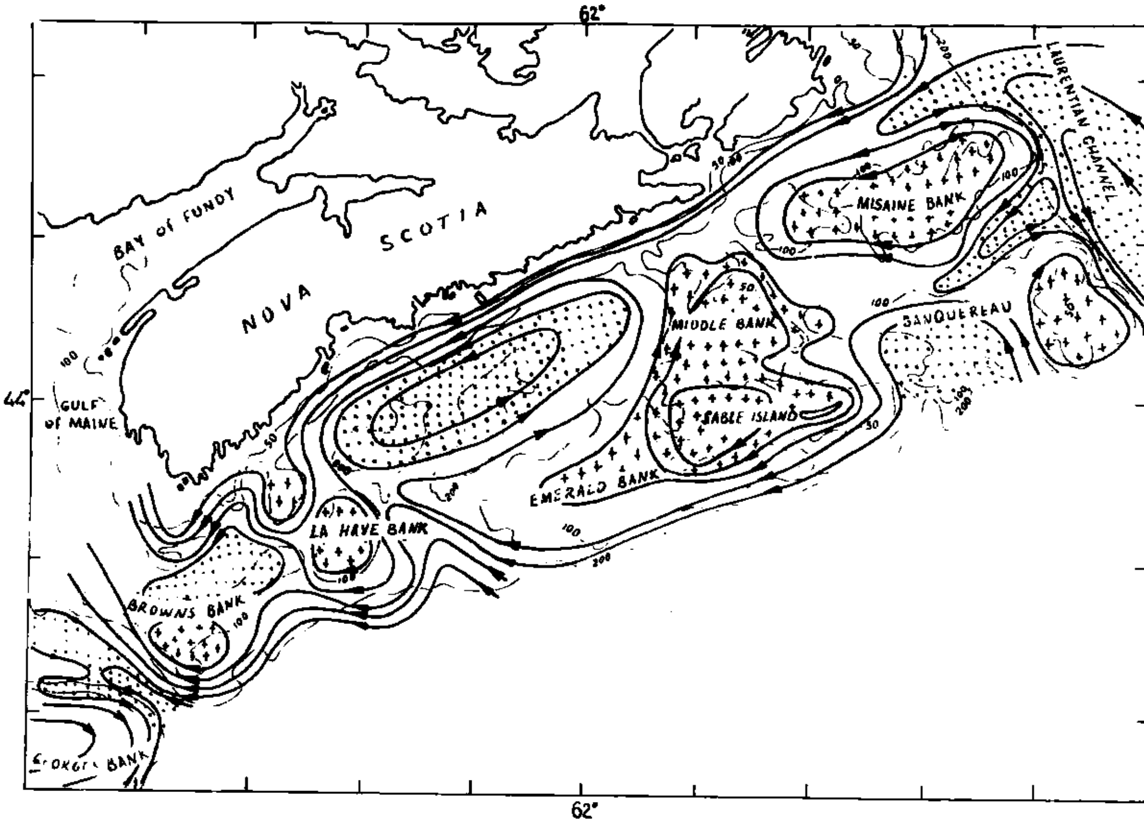

Fig. 11. Geostrophic circulation scheme on the Nova Scotia shelf in August.

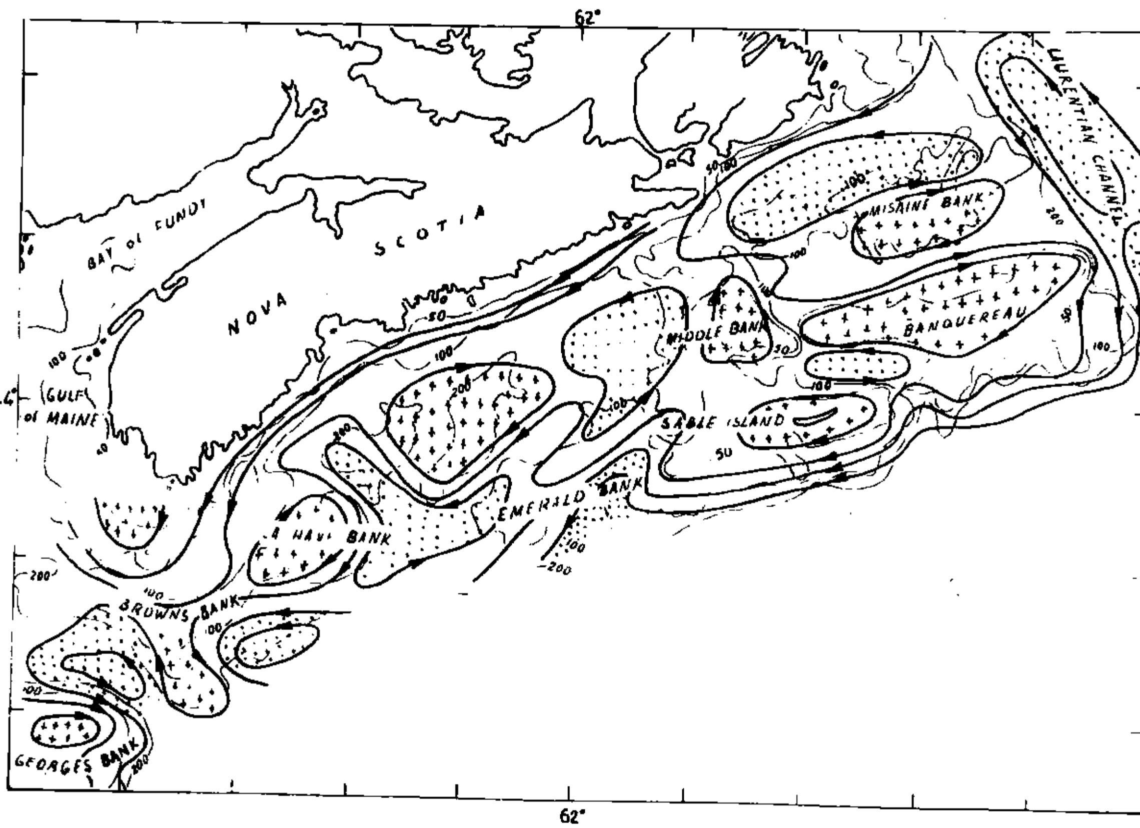

Fig. 12. Geostrophic circulation scheme on the Nova Scotia shelf in October.

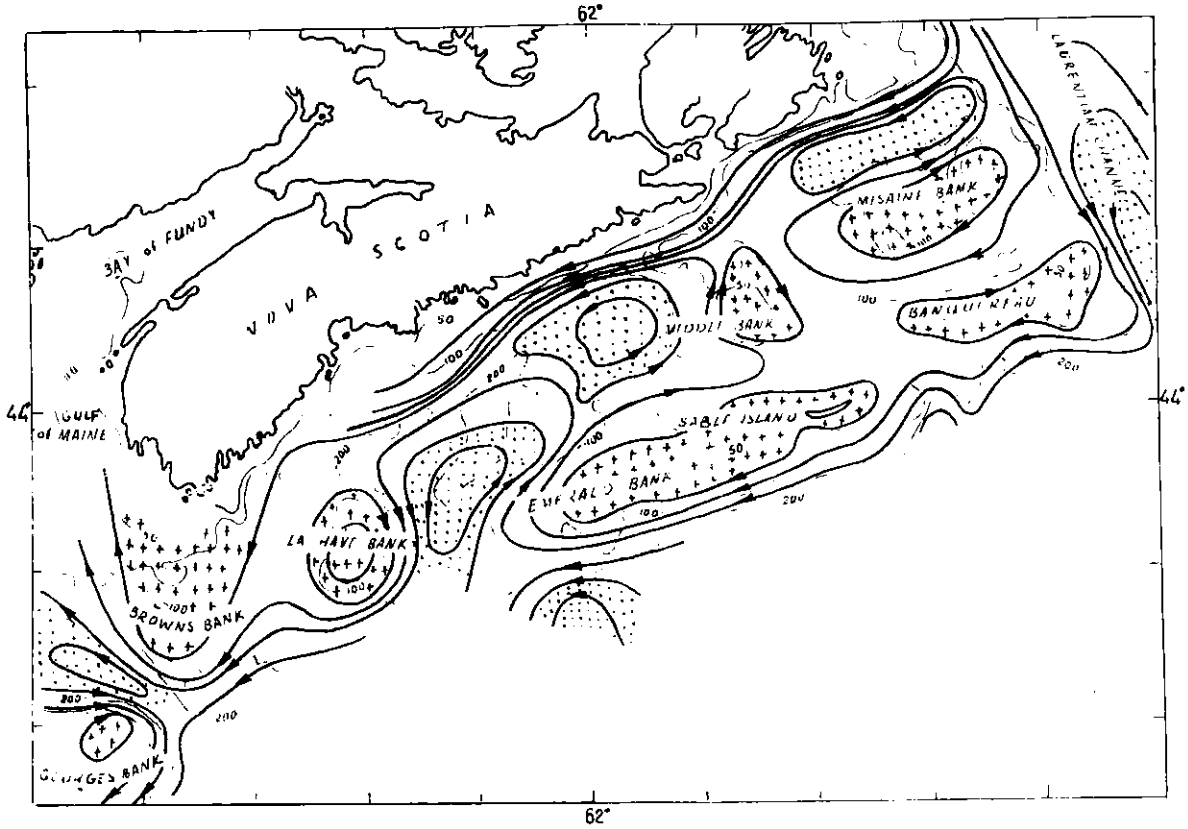

Fig. 13. Geostrophic circulation scheme on the Nova Scotia shelf in January.

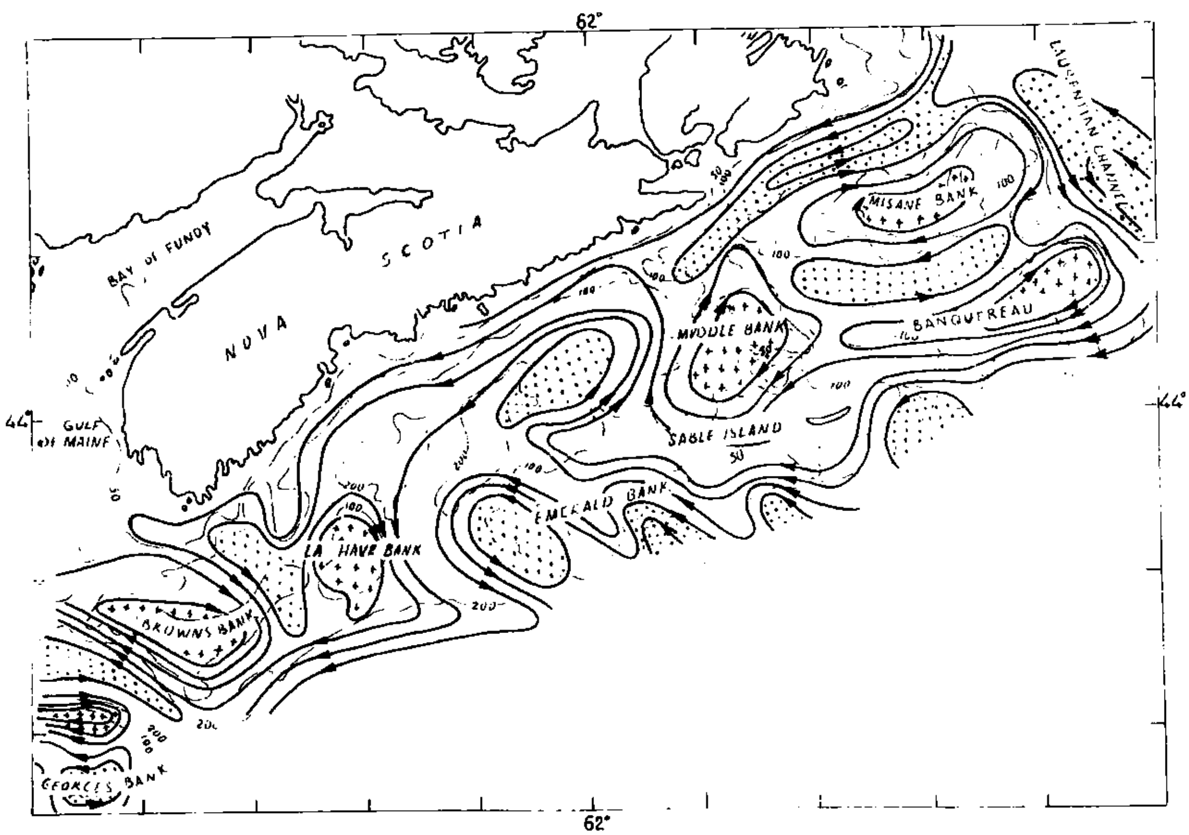

Fig. 14. Geostrophic circulation scheme on the Nova Scotia shelf in April-May.