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Evidence for an anticyclonic circulation on Faroe Bank

by

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Abstract

It has been known for a long time that biological populations on Faroe Bank, including plankton and fish species, are isolated from the neighbouring Faroe Plateau. Existing data from hydrographic surveys and current observations are reviewed and are found to be consistent with a closed anticyclonic circulation on the bank similar to that proposed for other banks. More conclusive evidence is obtained from an experiment where two drogued satellite-tracked drifters were deployed on the bank in March 1986. The results of this experiment support the hypothesis and at the same time give some information on the disruptions of the typical circulation.

Introduction

Faroe Bank is the easternmost of the three banks in the northeast corner of the Rockall Plateau (Fig.1). Its shallowest part is less than 100m deep which is somewhat shallower than the two other banks in the group: Bill Baileys Bank and Lousy Bank. Towards the east it is separated from the Faroe Plateau by the narrow (20 km) and deep (850 m) Faroe Bank Channel while the saddle depth between the Faroe Bank and Bill Baileys Bank is less than 400m. Towards the southeast the Wyville Thomson Ridge with depths around 500m connects the Faroe Bank to the Scottish shelf. Thus the topography around the bank is quite complicated and to some degree it is debatable to consider Faroe Bank a separate entity.

The question of a separate circulation on the Faroe Bank isolating it partly from the surrounding waters is an old hypothesis suggested mainly on the basis of biological data. Thus Paulsen (1909) states that: "*...the water on the bank is somehow prevented from having free communication with the surrounding water.*" He bases this on plankton investigations done in 1904. This problem was touched upon from the hydrographic side (Nielsen 1907) and in the following years the problem was discussed by Knudsen (1911), Nansen (1913), and Jacobsen (1915). They presented hydrographic evidence to support the hypothesis and suggested three different mechanisms: *Winter cooling; upwelling; and mixing*. Originally the hydrographic evidence was to a large extent confined to surface observations from merchant vessels. With time the number of hydrographic sections made by research vessels across the bank increased and they have tended to support the isolation hypothesis.

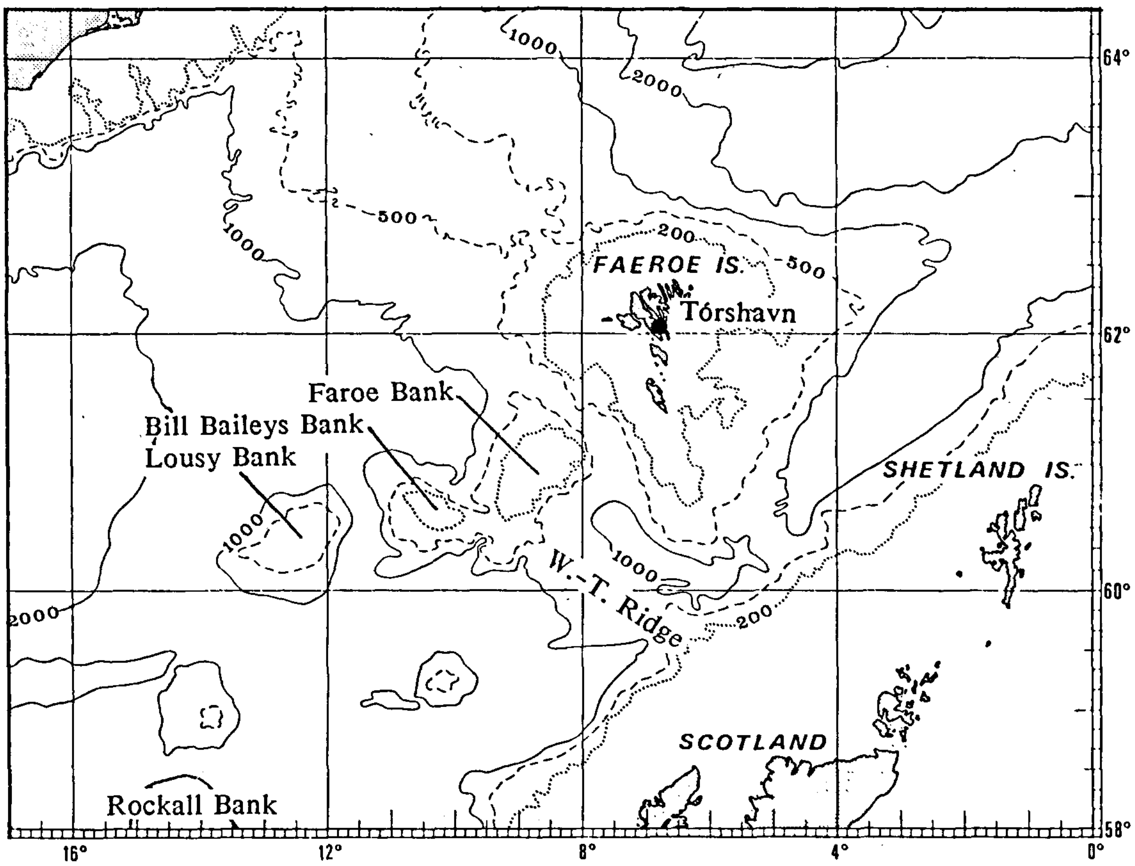


Fig.1 Bottom topography around Faroe Bank.

Further evidence was however found also from biology. It is well known that growth of cod on Faroe Bank is much faster than on the Faroe Plateau or indeed any other investigated area (Taaning, 1943, Jones, 1966) and Schmidt (1930) showed that the number of vertebrae differed for the two stocks, indicating different races. This was confirmed by genetic investigations on blood sera of the two cod stocks (Jamieson and Jones, 1967). This is a convincing argument for an isolation between the Faroe Bank and the Faroe Plateau. On the other hand the knowledge on fish stocks of Bill Baileys Bank and Lousy Bank is too scarce to warrant any conclusions as to isolation between Faroe Bank and these two banks (J.S.Joensen pers. comm.).

In later years evidence has been accumulating that more or less closed anticyclonic circulation is a common feature of oceanic banks. Georges Bank is perhaps the best known example, but Dooley (1984) has proposed the same feature for Rockall Bank. He attributes this to a *Taylor column* established on the bank. According to Dooley the retention of water on the Rockall Bank by this mechanism is variable in response to external factors which might be responsible for some of the variability in fish recruitment on that bank. The close proximity of Faroe Bank to Rockall Bank and the similarity in external forcing argues that the circulation schemes be similar on the two banks but the more complicated bottom topography around Faroe Bank weakens this argument.

On the other hand an understanding of the circulation and its implications for the retention time is much needed, especially if indeed variations in the circulation may explain some of the variability in recruitment of the Bank stocks. These stocks are heavily exploited and very dependent on single yearclasses, but as yet estimation of yearclass strength is mere guesswork until the recruits reach fishable size, at which time regulatory actions are too late. It is therefore of considerable importance to establish whether there is a closed circulation system on Faroe Bank and what is its variability.

A better understanding of the horizontal circulation and its driving mechanism might also yield a better understanding of upwelling around the bank. There are too few measurements on the bank to make any quantitative estimates of its primary productivity, but it appears to be high as indicated both by plankton observations and fish production. Nutrient enrichment from deeper waters may conceivably be a contributory factor and the vertical water movement responsible for this must be coupled to the horizontal motion.

With the number of hydrographic sections across the bank now available it would of course be possible to calculate geostrophic velocities, but the use of the dynamic method over a bank is a rather futile effort as has been demonstrated for Rockall Bank where dynamically calculated and measured currents tend to give opposite circulation directions. The final test of the isolation hypothesis therefore requires direct flow measurements either Lagrangian or Eulerian. This was attempted early in the century by Jacobsen (1915) and again in the mid-sixties, as reported by Lee (1974). The results were not very conclusive, since all the measurements were over quite short periods and by inaccurate techniques.

In this paper we will present results of flow measurements both from a moored current meter and from two sattelite-tracked drifters. Before that, however, it is appropriate to survey the available hydrographic data on the Faroe Bank.

Hydrography

All the water on and around the Faroe Bank down to depths about 500m comes from the West. The flow pattern in the area was described by Helland-Hansen and Nansen (1909) (Fig.2). Thus the main watermass surrounding the bank is not the NAW (North Atlantic Water) found in the southern part of the Rockall Channel (Ellett and Martin 1973) but rather MNAW (Modified North Atlantic Water) which is the generally used name for the water mass flowing eastward over the central and northern part of the Rockall Plateau and along the southern flank of the Iceland Basin (Hansen, 1985).

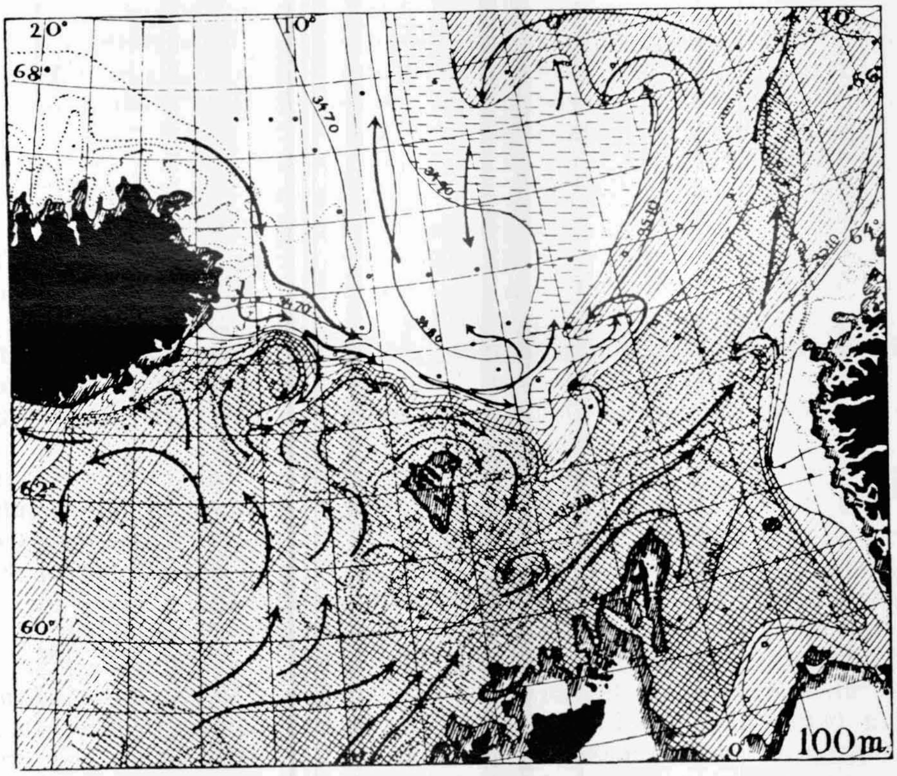


Fig.2 Horizontal distribution of salinity at 100m and probable circulation pattern, May 1904 according to Helland Hansen and Nansen (1909).

This flow sends one branch south of the bank and one north of it but there is a zonation of the flow with increasing temperatures and salinities towards the south.

This is evident in Fig.3 which shows temperature and salinity variations across the bank on an approximately north-south-going section in different months of the year. The figure was prepared from 14 occupations of this standard section made by Scottish research vessels in the years 1949-1958. The data was picked out of the ICES data bank. Nine of the stations on this section are considered here (Fig.3a). In each of the five months March, May, June, July and September there were taken two or three sections from 1949 to 1958 and in the figure average temperature and salinity at the surface and at 75m are shown for each of these five months. Also one section from Nov.-Dec. 1957 has been included. The figure shows for all seasons a clear trend of higher temperatures and salinities at the southern end of the section than at the northern.

More interesting perhaps is the minimum over the top of the bank evident for temperature every month and for salinity almost every month. The fact that the surface water on top of the bank is colder than the surrounding water during summer is well known and is evident in satellite infrared pictures. The generally accepted explanation for this is the difference between the well mixed vertically homogeneous water on the bank and the stratified water outside, heated during summer (Jacobsen, 1915).

This mixing hypothesis does explain the surface temperature minimum over the bank in summer, but it does not explain the minimum also in March when the sea is at its coldest. In fact, mixing can hardly explain that the temperature at 75m, just above the crest of the bank, also has a minimum on the bank in most of the months.

There can be little doubt that the mixing mechanism of Jacobsen is to a large degree responsible for the temperature minimum above the bank in summer, but it can hardly be the sole cause even at this season, as we would then at 75m depth expect a temperature maximum above the bank rather than a minimum.

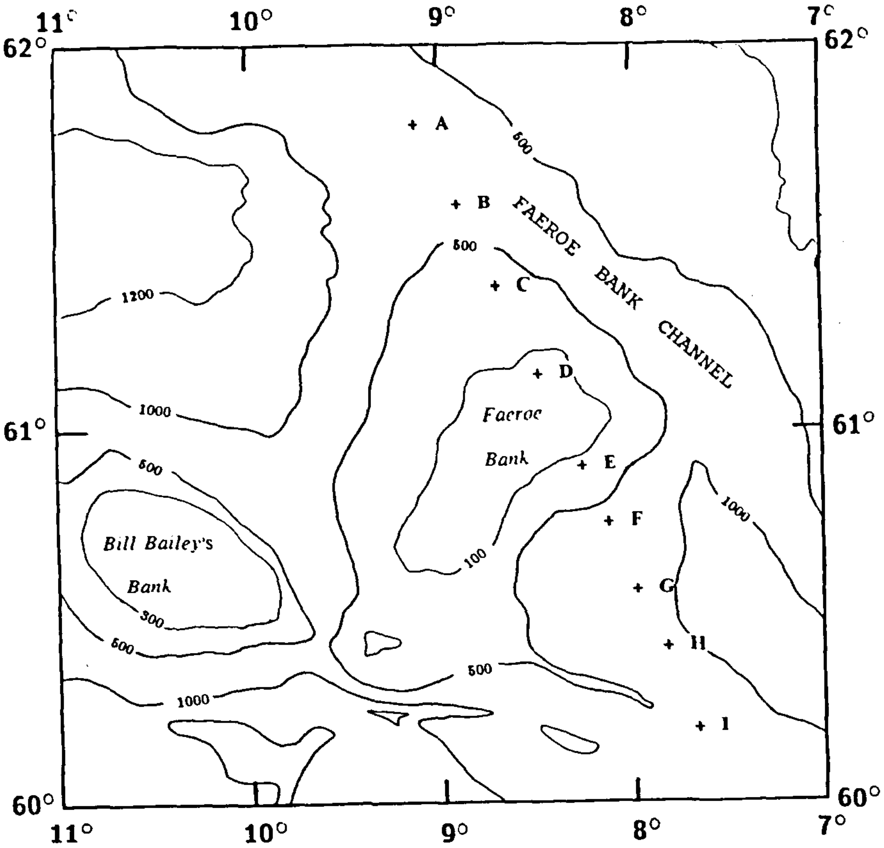


Fig.3a Standard section occupied by Scottish research vessels across Faroe Bank from 1949 to 1958.

In winter, the difference in mixing rates on the bank and off it should lead to more effective cooling of the water on top of the bank, and the existence of a minimum in March may be due to this winter cooling over the bank. This is corroborated by the absence of any clear salinity minimum over the bank in March.

Thus the two mechanisms proposed early in this century, mixing and winter cooling, can explain the temperature variations in Fig.3 if the residence time of water on the bank is large enough (that is some months), so that an appreciable part of the winter water stays on the bank until the summer.

This can, however, hardly explain the salinity variations observed. From May to September Fig.3 shows a salinity minimum of the surface water above the top of the bank. To explain that fact one needs either upwelling or a long residence time combined with lower salinities during the time September to March. Malmberg and Magnússon (1982) have discussed the seasonal variation in salinity in the southern Iceland Basin and their work does not support that hypothesis. On the other hand upwelling on Faroe Bank was suggested already by Knudsen (1911) mainly on the basis of surface observations. This hypothesis finds some support in Fig.3, but the salinity signal is not as clear as the temperature signal and is only evident in the surface, not very convincingly at 75m.

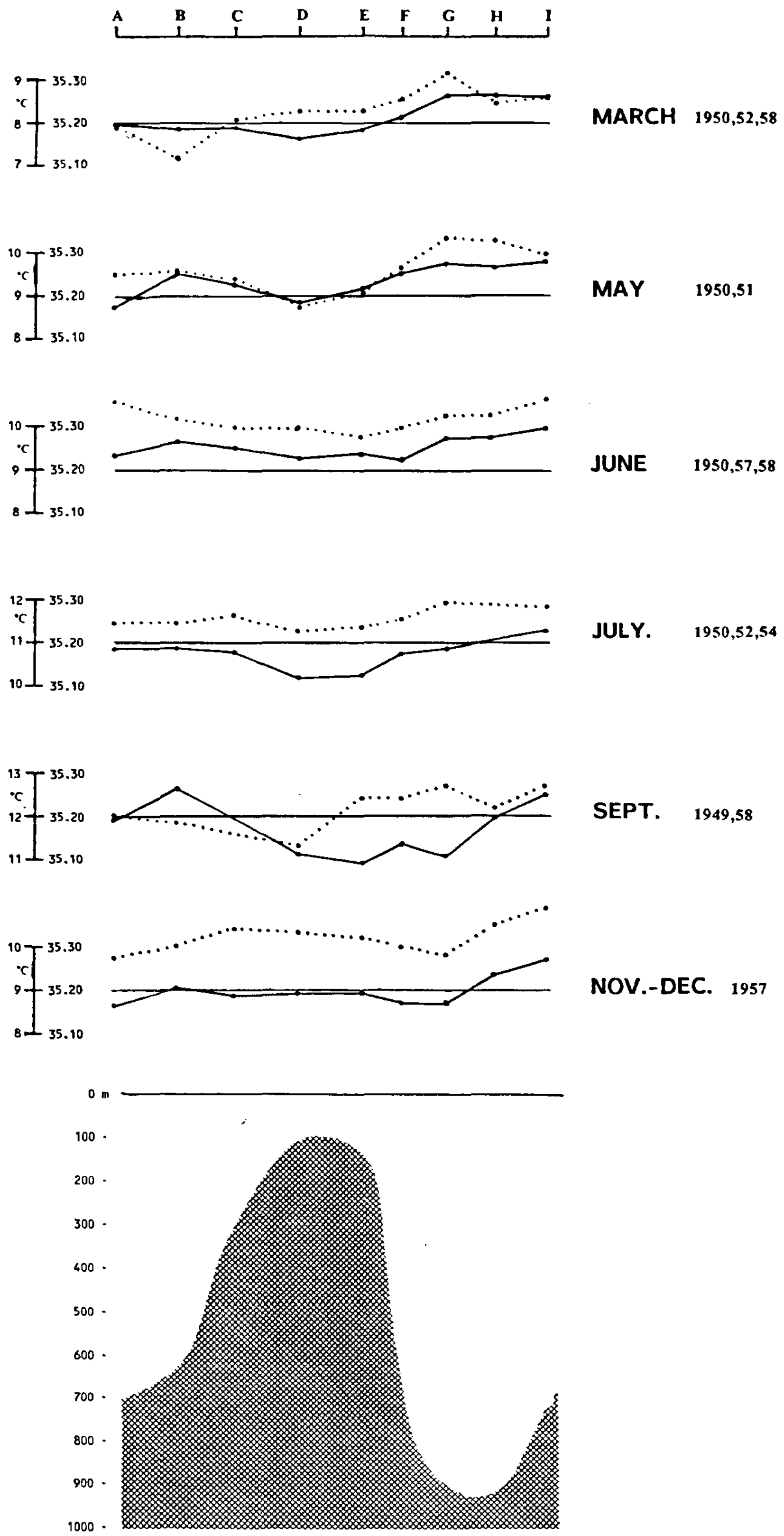


Fig.3b Variation in surface temperature (full line) and salinity (dotted line) across Faroe Bank. Letters refer to stations on the standard section shown in Fig. 3a. Bottom topography of section shown below.

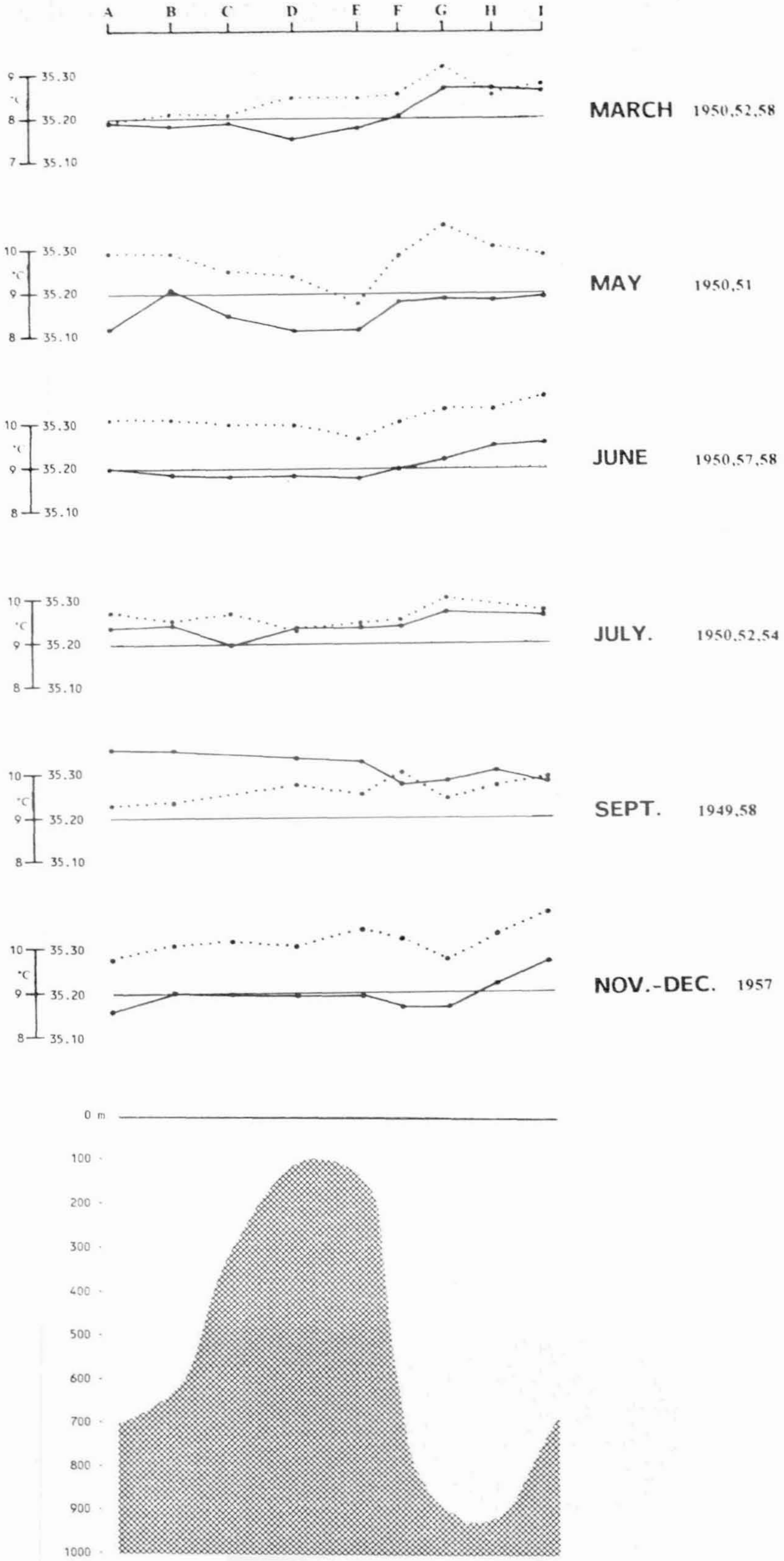


Fig.3c Variation in temperature (full line) and salinity (dotted line) at 75 m depth across Faroe Bank. Letters refer to stations on the standard section shown in Fig. 3a. Bottom topography of section shown below.

Altogether it must be confessed that the statistics of Fig.3 do not allow one to reach any very certain conclusions, but from the discussion above it would appear that all three of the mechanisms proposed early in this century to explain the biological isolation of Faroe Bank may apply for some parts of the year. All three of them give rise to a radial density gradient which again should lead to an anticyclonic circulation around the bank. An alternative possibility is the one that the flow of the Atlantic water past the bank combined with the earth's rotation creates a Taylor column on the bank; this increases the residence time of water on the bank, and may give rise to the winter cooling, the summer mixing difference and may create secondary vertical flow, giving upwelling.

These qualitative arguments can not clarify what is cause and what is effect in this problem, but we can conclude that the hydrography of Faroe Bank indicates that the water on top of the bank has a long residence time not only in summer, but also during the spawning period in late winter of several important fish stocks, e.g. cod, and associated with this we expect an anticyclonic circulation on the bank. The magnitude of the residence time, the strength of the circulation and the variability of both these we can not find from hydrography alone and they require direct flow measurement.

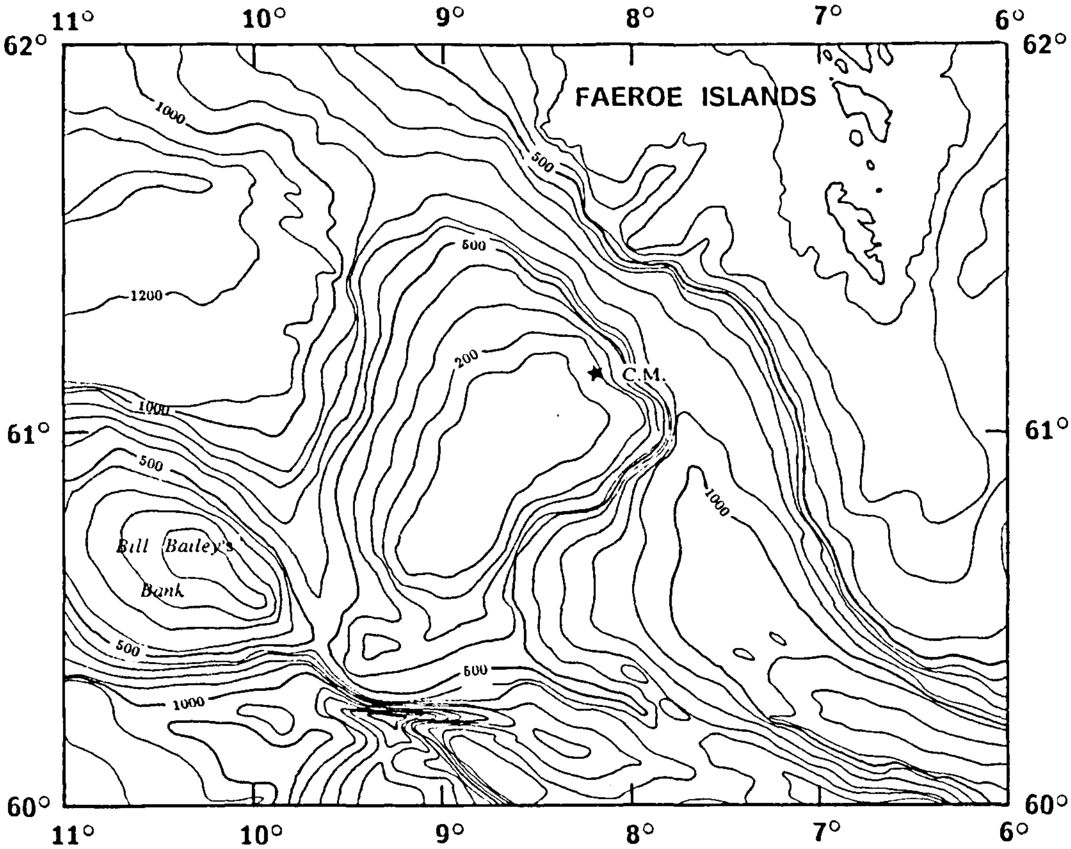


Fig.4 Current meter moored on Faroe Bank spring 1981.

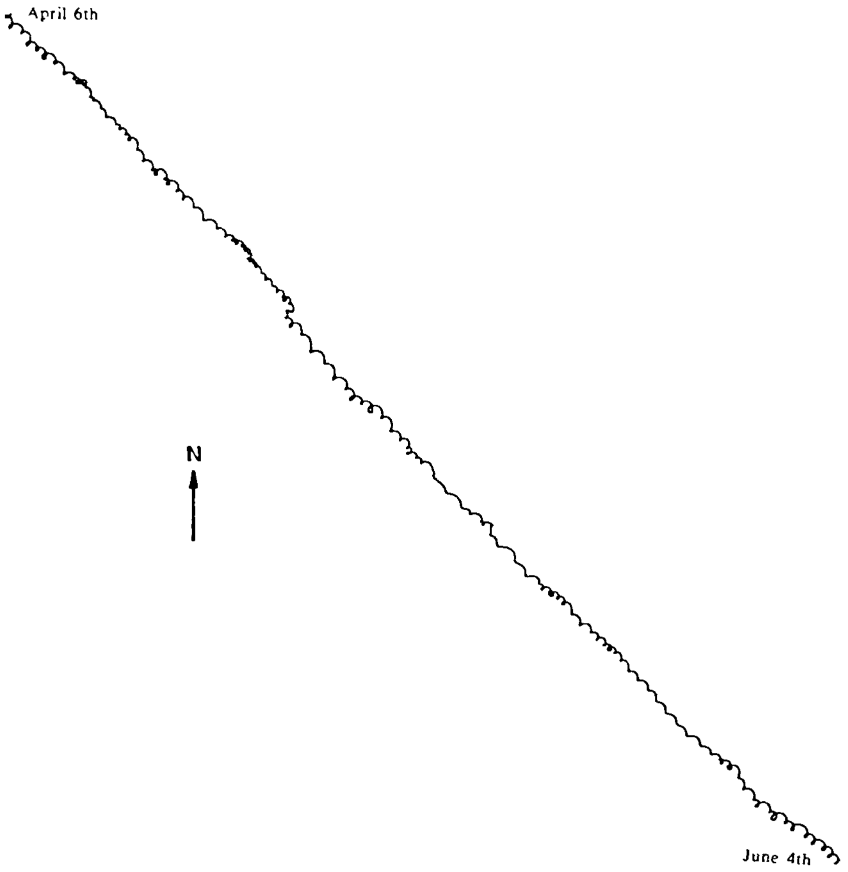


Fig.5 Progressive Vector Diagram from April 6th to June 4th 1981 at location shown in Fig.4

Flow measurements

As mentioned in the introduction there are old current measurements on the Faroe Bank which are, however, of too short duration to give reliable residual currents, but we have one Eulerian current measurement on the bank with modern instrumentation. This was an Aanderaa current meter moored at 120m bottom depth on the northeastern corner of the bank (Fig.4) in the period April 6th to June 4th 1981. The instrument which was at 40m depth was deployed and recovered by the Faroese Coast Guard (Vaktar og Bjargingartænastan).

In Fig.5 is shown the progressive vector diagram for the whole period and it shows a striking directional stability along the bottom topography towards southeast. The mean and maximum speeds were 19cm/s and 75cm/s respectively.

The flow shown by this current meter is consistent with an anticyclonic circulation around the bank, but with just one mooring the evidence is still questionable. To get more conclusive evidence on the circulation system the SMBA Dunstaffnage Marine Research Laboratory at Oban and the Fisheries Laboratory in Tórshavn decided to make a joint experiment deploying two satellite-tracked drifters on the Faroe Bank. The drifters have been developed at the SMBA Laboratory (Booth and Ritchie, 1983) and have been used with great success in North European offshore waters (Booth and Meldrum, 1986). Especially they seem to have small wind drag when deployed with a sufficiently large drogue.

The two drifters used in this experiment were drogued as shown in Fig.6 so their track should represent fairly well the flow pattern at about 60m depth, just shallower than the top of the bank. The drifters were deployed on March 10th (day 69) by the Faroese research vessel Magnus Heinason. Drifter no. 3979 was deployed at position 60°56.67 N 9°00.90 W while drifter no. 3973 was deployed at position 60°49.81 N 8°45.1 W.

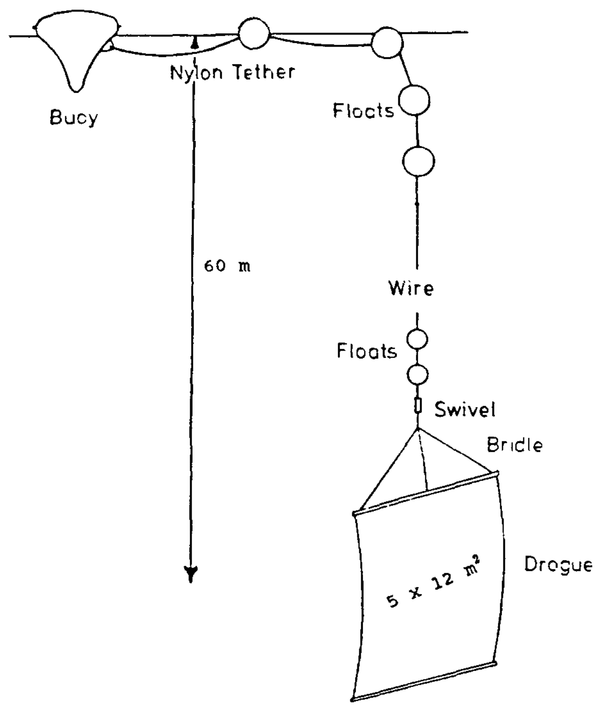


Fig.6 Rigging of the sattelite-tracked drifters.

Both drifters functioned properly for the first 12 days, but on March 22nd drifter 3979 began to move very rapidly indicating that it had lost its drogue. This drifter was recovered on April 6th and it was verified that the lug, where the drogue is fastened to the buoy, was broken. The other drifter, 3973, behaved reasonably and stayed on the bank until the end of April at which time it moved northwards off the bank. This drifter was picked up on May 3rd and it was verified that it still had its drogue in apparently good condition.

During this period CTD data was furthermore collected on two cruises. One cruise was by R/V Charles Darwin in the period 16-17 March while the other one was by R/V Magnus Heinason from April 25th to May 4th.

The track of the two drifters (Fig.7) gives strong support for the hypothesis that there was an anticyclonic circulation around Faroe Bank at the time of the experiment. Drifter 3979 moved quite regularly along the 100m isobath approximately and during the 12 days it retained its drogue it completed 1/3 to 1/2 of the circumference of this isobath. Assuming constant speed this gives a rotational period of about 1 month for that water. Drifter 3973 also started inside the 100m isobath. It tended to move into deeper and deeper water, but it circled the bank and completed about 2/3 of its circumference in nearly two months, giving a rotational period around this contour of approximately 3 months. The speed of this drifter was however not very constant. In the first two weeks, moving southwestwards over the southern flank of the bank, its residual drift averaged something like 5cm/sec. This increased to about 15cm/sec. on the northeastern flank which matches well with the 20cm/sec. measured by the Aanderaa current meter in the northeastern corner of the bank at the same time of year in 1981.

The resulting track of this drifter was almost a closed anticyclonic path around the bank, but it reversed its circulation direction significantly twice and moved cyclonically for about a week in each case, after which it continued the anticyclonic path.

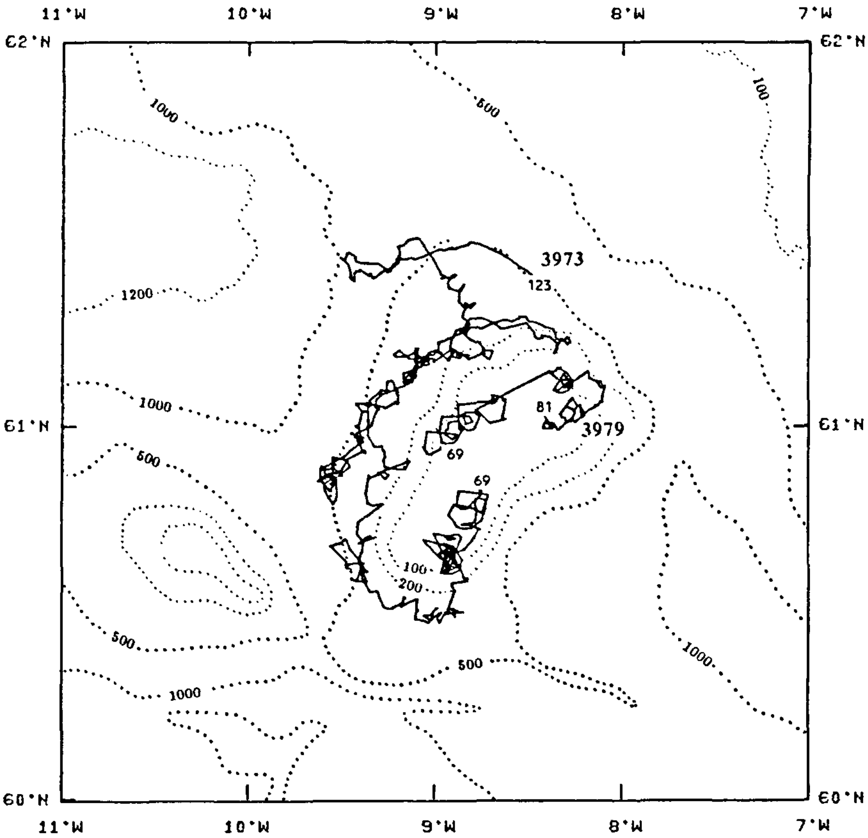
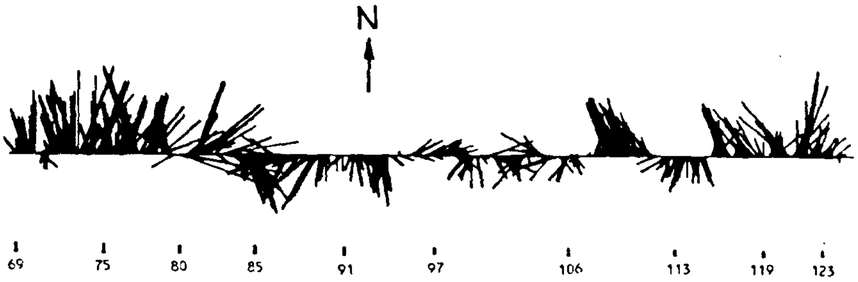


Fig.7 Paths of the two sattelite-tracked drifters in relation to the bottom topography around Faroe Bank. The numbers 3973 and 3979 indicate drifter. Small numbers close to paths indicate time as number of day in the year.

The question arises, to what extent the movement of the two drifters was influenced by wind either directly on the drifter or on the water. The question is twofold: 1. Could the local wind be responsible for the resultant anticyclonic movement of the drifters? 2. Could it be responsible for the flow reversals? In Fig.8 the overall path of both drifters is shown by plotting the positions for a few key dates labeled by the number of the day in the year. Above this map is shown the wind in Tórshavn sampled every 3 hours by a stick diagram labeled in the same way. No statistical correlation between the data sets has been made, but a visual comparison does not indicate any causal effect of the local wind neither on the overall movement, nor on the occasional flow reversals.

At the end of the experiment drifter 3973 moved off the bank towards N-NW. This excursion was not along the isobaths and took the drifter into considerably deeper water. It appeared as if it was about to return to its original path when it for logistical reasons was picked up. During this excursion there were strong southeasterly winds which could be partly responsible for a flow disruption, but looking in detail at Fig.8 the influence of the wind is not obvious.

The results of the hydrographic survey by R/W Charles Darwin are shown in Fig.9. We will not discuss these in any detail, but just note that they look typical for the bank with slightly denser water over the crest. Thus the drifter experiment apparently took place during normal conditions.



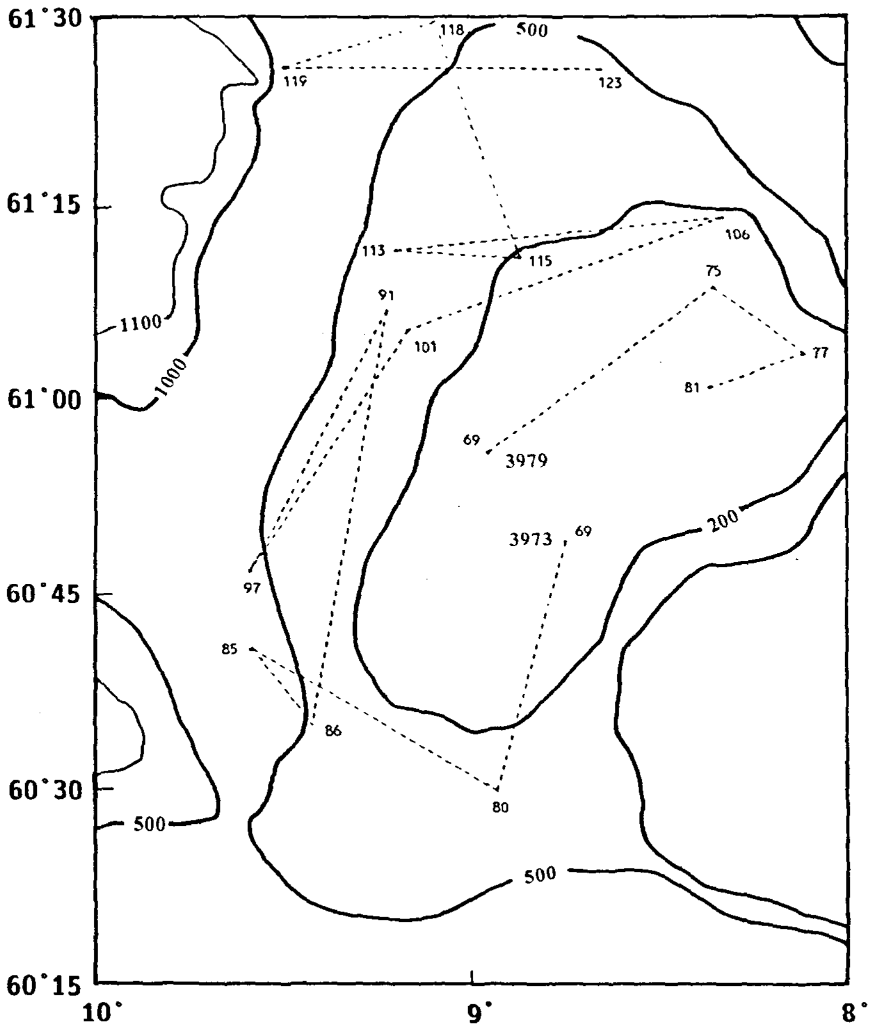
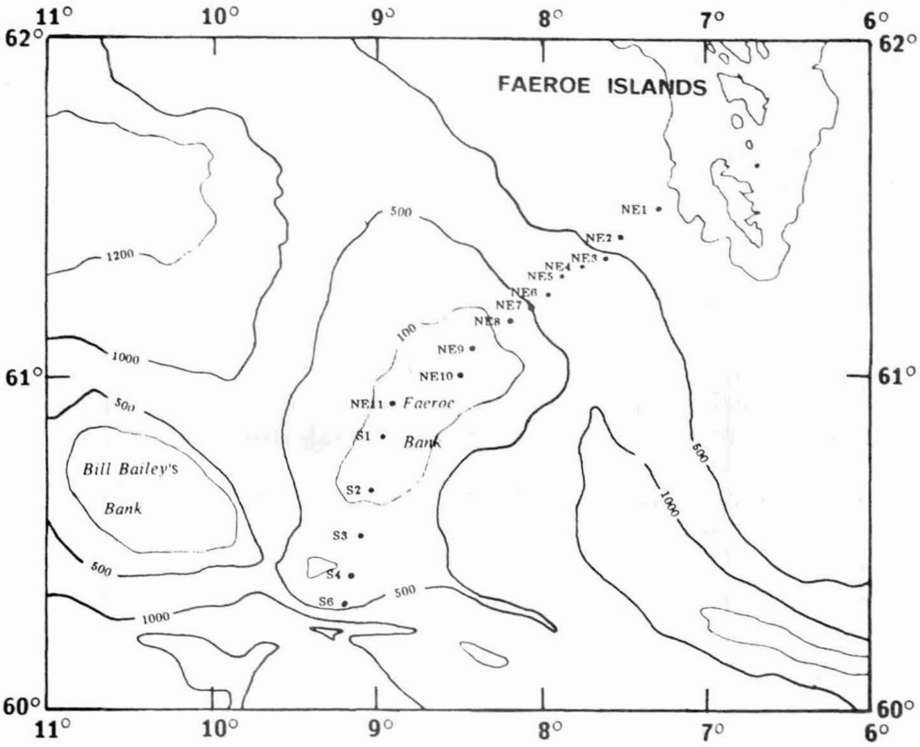


Fig.8 *Overall movement of the two drifters (bottom figure) as defined by a few key dates labeled by number of day in the year and wind in Tórshavn (upper figure) as stick diagram labeled in the same way.*



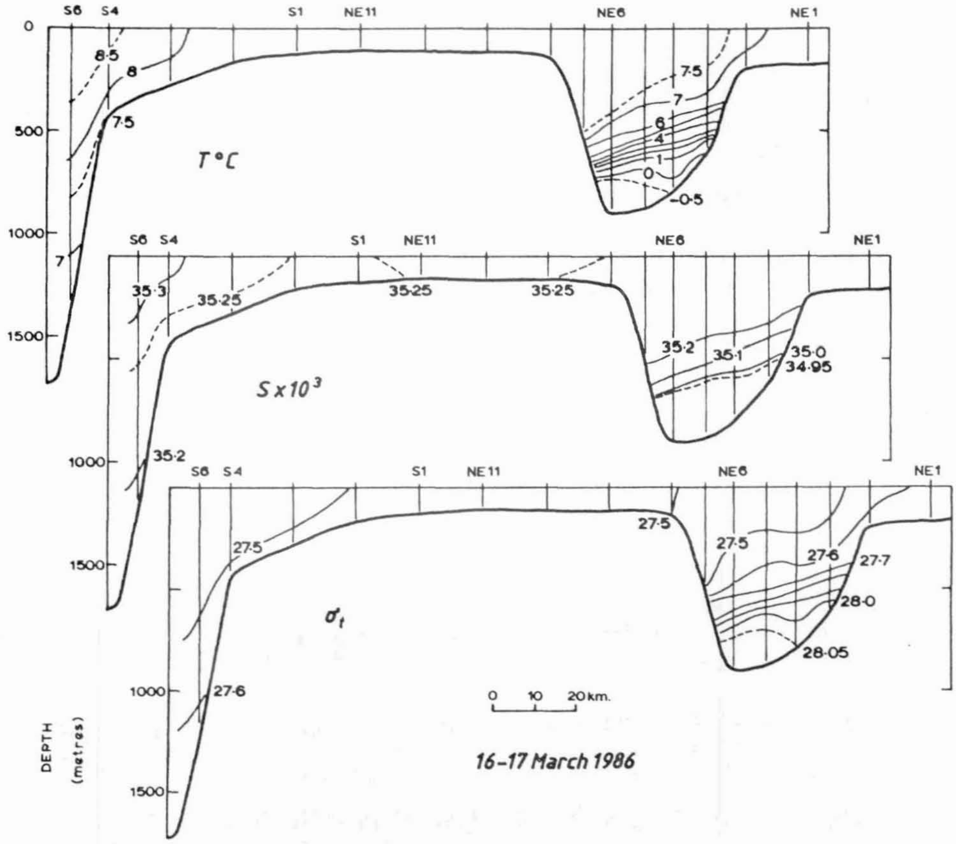


Fig.9 Hydrographic section across Faroe Bank by R/V Charles Darwin.

Conclusions

Summarizing the discussion on the hydrography, temperature variation across the bank indicates that the water on top of the bank has a relatively long residence time not only during summer when surface heating off the bank could create a closed circulation, but at least from March to September. This could be created either by winter cooling on the bank combined with summer heating off it, by upwelling of cold water, or by a Taylor column on the bank. Whatever the reason, the hydrography indicates that throughout the period from early March, when the cod spawns, and well through the period when the larvae go to bottom around June the water on top of the bank has a high residence time, and associated with this an anticyclonic circulation around the bank.

This indirect evidence is borne out by the drifter experiment which shows very clearly that during the period from early March to early May 1986 there was a persistent anticyclonic circulation around the bank, at least out to depths of about 200m. The direction of flow reversed a couple of times, but the drifters did not leave the bank until at the end of the experiment.

The isolation of biological stocks on the bank which was suggested early in this century can therefore be explained by the flow pattern over the bank. Also the drifter experiment shows a variability which may contribute to the recruitment variability of the bank stocks. More observations are, however, needed on the statistics of these variations and on the persistence of the circulation throughout the year.

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