FEATURES OF THE THERMAL AND DYNAMIC STRUCTURES OF THE ACTIVE OCEAN LAYER IN THE REGION OF BANKS

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Results are presented on the dynamic and thermal structures of the active ocean layer in the regions of the Ampere and Whale Banks, which were obtained on the eleventh voyage of the R/V *Academician Petrovskii*. The field observations indicate that there are regions above the crests of the bank that differ substantially from the surrounding water masses in thermal and dynamic characteristics. The features are given a qualitative explanation in terms of Taylor's column theory.

Increasing attention is being given to researching hydrodynamic anomalies over ocean-floor relief features, because many countries have introduced 200-mile economic zones, which has greatly reduced the number of fishing regions.

Theoretically speaking, there are two lines of research here: the first is to examine the currents over topographic features and the second is that of examining the transformation of long waves and the generation of internal waves above submerged obstacles.

Basic results from the first approach have been given in [1]; that paper also contains an extensive bibliography. The second approach is also developing vigorously: in [2-4], we find various models for long-wave generation and transformation over banks.

The field observations also indicate hydrophysical anomalies over local perturbations in the ocean-floor relief, such as over the underwater mountains Altair [5], Atlantics II [6], Great Meteor [7], and certain others. In some recent papers [8,9], field observations were used to show that one of the possible dyanmic anomalies over banks is that there are trapped anticyclonic vortices, which are known in the theory as Taylor vortices.

Here we present field studies on the effects of high underwater mountains on the structure of the hydrophysical fields in the active ocean layer.

Comprehensive studies were performed on three polygons in the Atlantic and Mediterranean in order to examine the dynamic and thermal structures of the active layer above relief features during the eleventh voyage of the R/V *Academician Petrovskii*. The polygon in the Atlantic covered underwater Mount Ampere, while that in the Mediterranean covered the Emil Bodo and Whale banks (41°06'N, 10°56'E). The studies were made in January-March 1981.

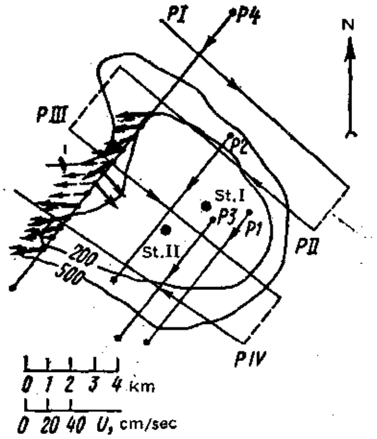

Fig. 1. Scheme for the spatial sections and mutlihour stations at Ampere Bank and velocity distribution along section P4: h = 40 m (dashed arrows) and 90 m (solid arrows).

In all the polygons, the hydrophysical parameters were measured at multihour stations and on spatial sections. With the ship anchored, we measured the vertical temperature and electrical-conductivity profiles, the current speed and direction, as well as various meteorological data, including the wind speed and direction, the air temperature and humidity, and the atmospheric pressure. The same measurements were made on the spatial sections.

The vertical temperature and conductivity profiles were measured by continuous sounding each 15 min. The vertical current speed and direction profiles were measured every 30 min, and the meteorological observations were also made at 30 min intervals. The depth step in the velocity measurements was 5-10 m. The hydrophysical measurements were made with nonstandard apparatus [10]; the meteorological observations were made with standard instruments and by standard methods.

In the region of the Ampere Bank, we organized two multihour stations and eight spatial sections, of which four were in the drift direction and four perpendicular to it. Figure 1 shows the scheme for the sections and the positions of these stations.

The temperature and conductivity measurements showed that the salinity varies only slightly in the top 150 m layer (about 0.02°/₀₀), whereas the temperature distribution showed a pronounced stepout layer with a gradient of about 0.3 deg/m. This confirms earlier conclusions that the temperature distribution in the active layer makes the decisive contribution to the density distribution.

We found that the position of the thermocline was dependent on the floor topography. For example, at the first multihour station, where the ocean depth was 70 m, the mean depth of that layer was 40-45 m, while it was 60 m at the second multihour station, where the ocean depth was 115 m.

Fuller information on the relationship was obtained from the spatial sections. Figure 2 shows the vertical temperature distributions from the spatial section in the drift P1; above the top of the bank, the depth of the thermocline

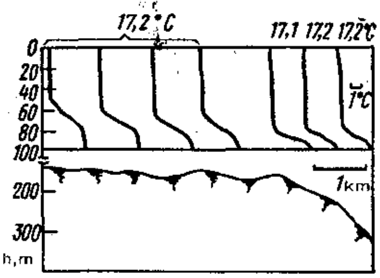

Fig. 2

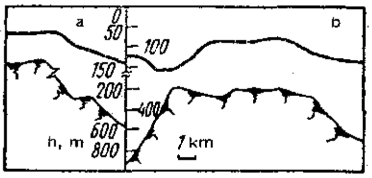

Fig. 3

Fig. 2. Vertical temperature profiles above the top of Ampere Bank (from data on section P1).

Fig. 3. Depth of the thermocline above Ampere Bank: a) from section P3; b) from section P4.

was minimal (about 45-55 m), while the thickness was maximal (about 25 m). As the flank of the bank was approached, the thermocline descended to 90-110 m, while its thickness decreased to 10 m. Figure 3 shows how the depth of the thermocline is dependent on the relief as indicated by the drift section P3. Here the thermocline depth increases from 70 to 140 m down the flank of the bank.

Drift section P4 was the most interesting, which covered the floor rise region and the flank.

Figure 3b shows that the depth of the thermocline increases from 120 m in the deep ocean to about 150 m as the bank is approached and then decreases sharply to 70 m over the top. Then it descends smoothly to about 120 m. The same sections show an interesting anomaly in the current speed under the thermocline. Figure 1 shows the velocity distributions along the P4 sections at the 40 and 90 m horizons. It is evident that at 40 m, which always lies above the thermocline, there are no changes in the distribution, whereas at 90 m the velocity shows considerable direction deviations. The thermocline at that time was at 60 m. There were similar anomalies in the distribution of the current speed along the section at the 70 and 80 m horizons.

It was supposed that there was an anticyclonic vortex over the bank during the measurements, which deformed the density field, and this caused the thermocline to rise over the bank crest.

Theory shows [1,11,12] that an anticyclonic vortex is formed on flow around an underwater obstacle of medium extent by a stationary current in the f plane, with the shape of the region and the intensity of the vortex dependent on the topographic parameter $G=h_0fL(HU)^{-1}$, which is proportional to the height h_0 of the obstacle, and on the stratification parameter $Q_i=(N_iH)^2(fL)^{-2}$, which is proportional to the square of the Brent frequency N_i^2 (H is the ocean depth, L the characteristic horizontal dimension of the obstacle, U the incident flow speed, and f the Coriolis parameter). The field data gave the values of these for the lower layer ($i = 1$) and the thermocline layer ($i = 2$): $G = 9.5$, $Q_1 = 0.16$, and $Q_2 = 160$, which showed that the region of anticyclonic vorticity lies [11] in the layer of moderate stratification between the crest of the bank and the thermocline, while the vorticity decreases considerably in the latter.

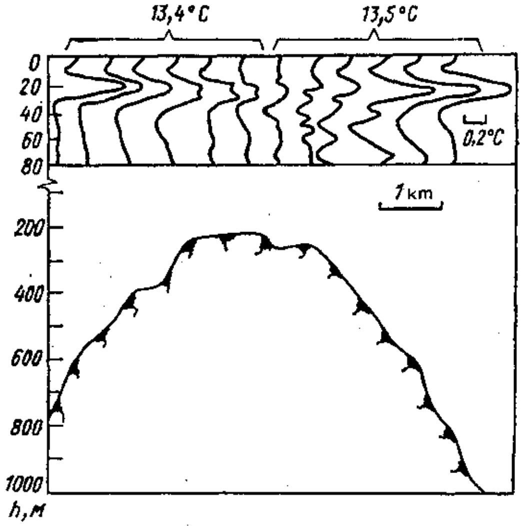

Fig. 4. Vertical temperature profiles above the crest of Whale Bank (from spatial section data).

This conclusion agrees with the current speed measurements, since there were deviations in the velocity vector from the incident flow direction only below the thermocline, whereas there were no substantial changes in velocity distribution above it.

The force balance in the vortex region implies that the Coriolis force should be balanced by a gradient in the dynamic pressure related to the tilt in the thermocline. It can be shown [1] that in the case of an anticyclonic vortex, the slope of the interface is negative from the center of the region to the periphery, which corresponds to the thermocline rising over this region.

Numerical calculations [12] indicate that the occurrence of an anticyclonic vortex over the crest indicates a stratification anomaly in the form of a cold-water dome. The field observations indicate such a feature. Therefore, the anomalies found in the region of Ampere Bank are explained by Taylor's column theory.

On this voyage we also examined the structure of the active layer in the region of the Whale Bank. Here there were also multihour stations and spatial sections, but the measurement methods were altered: the current speed and direction were measured at the 20 and 40 m horizons. At the 20 m horizon, the measurements were made with a nonstandard probe at intervals of 2 min, while at 40 m they were made with a BPV-2 instrument with intervals of 5 min. Also, the structure of the surface currents was determined in calm weather by tracking freely drifting buoys by radar. The vertical temperature profiles were measured in the top 80 m layer with time intervals from 1 to 15 min.

There was much greater temperature homogeneity in the active layer in this polygon than in that in the region of Ampere Bank. The temperature fluctuations in the top 80 m layer did not exceed 0.6°C. At the same time, there were one or more inversion layers of thickness about 10-20 m, whose position and extent depended on the relief. For example, Fig. 4 shows that there is a fairly pronounced inversion layer above the regions of substantial depth, which gradually degenerates above the crest. Similar patterns were observed on two other spatial sections examined in the same period.

The current and buoy-drift measurements revealed a further feature: the current speed was considerably reduced over the bank. At the same time, the current speed was 25 ± 5 cm/sec at both horizons 5-7 nautical miles from the crest of the bank, while the direction varied a little between 225 and 245°, whereas near the crest and in the northern part of the bank the speed was not more than 15 cm/sec, while the direction showed substantial changes. The buoy observations also indicated that the drift speed far from the bank was substantially larger than that near the crest, and there were areas where there was virtually no movement. The drift of one of the buoys was characteristic in that respect, which was tracked at intervals of 0.5 hr for 45 hr. During this time, the buoy traversed the bank along a path resembling a segment of an unwinding spiral, with its speed minimal in the region of the crest, and increasing considerably away from the center.

These data show that there was a region above the top of the bank during the measurements that was substantially distinct from the surrounding water in thermal and dynamic respects. This region is undoubtedly related to the topographic feature, and although it is very difficult to give anything approaching a complete theoretical explanation of the anomalies, the following qualitative explanation is possible on the basis of Taylor's column theory, which implies that the flow around a reasonably high underwater obstacle by a homogeneous liquid with vanishingly small viscosity takes up a limiting stationary state for $t \to \infty$ in which the flow above the obstacle produces a columnar stagnant region.

However, it is unlikely that the flow would reach such a state under real conditions because of the long settling time (estimates [1] show that this is about 1.5 months). It is therefore most likely that under natural conditions one would find some intermediate situation, where the motion within the Taylor column has not died away completely because of friction on the floor, but the particle speed within it is much less than that of the surrounding flow.

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