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Distribution of Available Potential Energy, Geostrophic Circulation and Biological Productivity Indices in Two Areas of the North Atlantic

by

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Abstract

Distribution of available potential energy (APE) in the Gulf Stream and Mid-Atlantic Ridge regions is considered. The comparison of APE distribution in the two regions showed that horizontal gradients of APE in the subpolar front region are five times lower than in the Gulf Stream front region.

Judging from general peculiarities of the APE distribution in the above regions the change of APE to kinetic and vortical kinetic energy takes place along hydrological fronts. Also, it is suggested that the eddy forming processes can develop both in slackened and strengthened currents.

A comparison of APE and the geostrophic circulation field showed a close agreement between them.

A characteristic feature in the APE, seston and phosphates distribution was revealed showing in that the maximum concentrations of the biological productivity indices chiefly occurred in the regions with the surplus APE.

Introduction

In the recent years the role of available potential energy (APE) in the eddy forming processes in the ocean is being studied. As is evident from the papers by Kozlov et al.(1979), Korotaev et al.(1977), Barret (1971), Gill et al.(1974) and Huppert and Bryan (1976), a part of the kinetic energy of the flow moving in stratified liquid can be changed to APE, which in its turn changes to vortical kinetic energy. The APE thus can be realized due to the baroclinic instability mechanism. In the regions with not uniform bottom relief the change of APE to whirling kinetic energy may take place both at slackening or strengthening of the flow running against obstacles. The Azores Banks area is one of the regions where, according to Tsyganov and Lebedev (1981), there exists a close correlation between the APE distribution and mezoscale eddy formation. In the regions with a relatively uniform bottom relief but with a powerful continuous flow the formation of eddies due to realization of APE is likely to be governed by the same mechanism of baroclinic instability, when the equilibrium of the system becomes disturbed (for instance, weakening of external strengths).

In this connection the computation of the APE distribution allows for revealing the regions of intensive formation of eddies, which often include the zones of high biological productivity.

The main objective of the present paper is to analyse the APE distribution in two significantly differing regions of the North Atlantic by means of comparing the peculiarities of water circulation and biological productivity indices.

The investigated areas were the open part of the ocean adjacent to the New England shelf between 57° and 65°W and involving the frontal Gulf Stream zone in the south, and a part of the Mid-Atlantic Ridge area between 45°-56°N and 22°-38°W including a region of the subpolar oceanic front dividing the waters of the North Atlantic Drift and the subarctic waters. These areas were selected due to clearly pronounced frontal zones, stable powerful flows, active eddy formation processes, the highest gradients of hydrophysical characteristics and relatively great depths.

Materials and Methods

The data for the first area were collected during the ecological survey conducted by RTM "Belogorsk" in the second half of November of 1974. The main results of this survey presented earlier by Noskov et al.(1977) involved the analysis of the temperature fields, geostrophic circulation and seston. A geostrophic circulation field shown in Fig.1 was calculated by a dynamic method. The 800 db level was taken as a reference zero surface. A section along 57°W omitted in calculations is not shown on the chart of dynamic topography, which did not affect the general character of the circulation field. The APE distribution is shown in Fig.2, and that of the seston biomass in the 200-m layer in Fig.3. All the fields are given as the isolines of standardized values for more convenient and correct comparison with the APE field. Standardization was made according to the formula

$$\tilde{A}_i = \frac{A_i - \bar{A}}{\sqrt{\frac{\sum_{i=1}^{n}(A_i - \bar{A})^2}{n}}} \qquad (1)$$

where A_i is a value in the field point;

$\bar{A}$ is the mean value;

$\tilde{A}_i$ is the standardized value in a point;

n is the number of points

For the second area the hydrological survey data collected on RV "Ajaks" during the period of February to May, 1980, were analysed. The APE distribution is shown in Fig.4. The phosphate (PO_4) distribution at the 250 m depth was taken as a biological productivity index (Fig.5). Non-uniformity of the phosphate distribution at that depth was the highest.

APE for both areas was computed according to a simplified method suggested in the paper by Tsyganov and Lebedev (1981). Keeping in mind that the sea water is practically non-compressible, the calculations for a water column with the H height and a unity base were made by means of numerical integration of the expression for APE

$$APE_i = 10^{-3} g \int_H^0 (G_{iz} - \bar{G}_z)\, z dz \qquad (2)$$

where g is the acceleration of gravity

G_{iz} and $\bar{G}_z$ are the conventional density for a given depth calculated in a point and the mean for the field

Results

In the first area a standardized field of geostrophic circulation at the surface (Fig.1) has a number of characteristic features. One of these is well developed parts of the Gulf Stream meanders with the axes running along 62°W and, possibly, along 57°W. Negative values of standardized estimates of dynamic hights are placed to the left of the meanders. A boundary between the negative and positive values, i.e. a zero isoline, is shifted to the left edge of the meandering flow. Some upwelling regions as cyclonic eddies, are also located along the left edge of meanders. Parts of anticyclonic eddies centered at 65°W-40°N and 63°W-43°N are well seen on the chart. They might be the left-side rings of the Gulf Stream.

The comparison between the fields of geostrophic circulation and seston biomass distribution (Fig.2) revealed a good qualitative agreement. The regions with the highest biomass were found in the upwelling zones, i.e. in cyclonic eddies and in the left periphery of the meandering flow.

The APE field (fig.3) nearly coincided with the geostrophic circulation field, when compared. Evidently, the zero equipotential line is consistent with the Gulf Stream axis position. To the left of this line, looking downstream, the seston patches with the maximum biomass were recorded.

According to computation, the APE resource is concentrated in the northern part of the area, i.e. on the left side of the meandering stream, while in the southern part the APE is deficient. A clearly pronounced division of the regions with the surplus and deficient APE along the boundary between the water masses-subarctic and subtropical, i.e. along the subpolar front is characteristic of the APE distribution over the Mid-Atlantic Ridge. Also, the zero isoline of the APE level coincides with the front line. The highest APE level was observed in the subarctic waters, and the lowest in the North Atlantic Drift waters. Thickened isolines showing the APE level indicate separate jets of the North Atlantic Drift crossing the Ridge at 52°-53°N and 46°-47°N. In the area of Gibbs Break (51°-52°N)a vast region with the minimum APE can be distinguished. There is a close correlation between the field of geostrophic currents and the APE distribution. In principle, the phosphate distribution at the 250 m depth (fig.5) is similar to that of APE. The maximum content of phosphates coincides with the highest APE level in the subarctic waters, and their lowest content is reported from the southern part of the area, i.e. from the North Atlantic Drift waters. The correlation analysis of the fields of the APE and phosphate distribution at the 250 m depth revealed a linear dependence with the correlation factor of 0.74 ± 0.03.

As is evident from the comparison of APE in the two areas, the APE horizontal gradients in the subpolar front are on the average 5 times below those in the Gulf Stream front area. This is indicative of the fact that the eddy forming processes and water exchange across the Gulf Stream front producing right-and left side rings are more intensive there than in the Mid-Atlantic Ridge area. A striking balance in the distribution of the kinetic and available potential energy indicates that the changes of APE into kinetic and vertical-kinetic energies occur in frontal regions. The eddy formation processes are likely to be effective in cases when the balance of the system is disturbed, i.e. at slackening or strengthening of the flow. A good qualitative agreement between the biological productivity indices and the APE distribution makes it possible to use the value of the latter as an indicator of the physical environment for preliminary assessment of biological productivity of various regions of the ocean.

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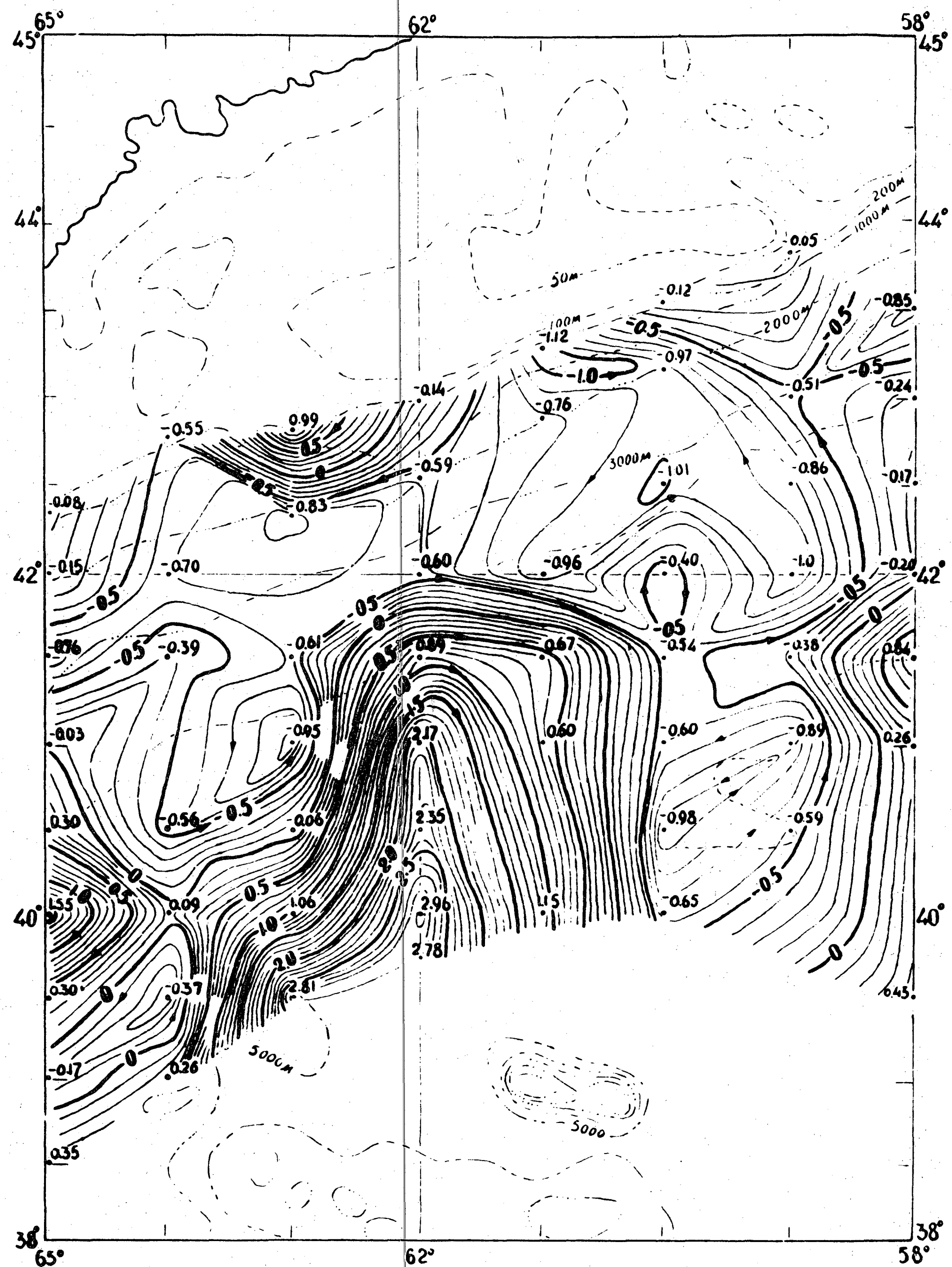

Fig. 1. Geostrophic circulation field in the Gulf Stream area, 14-30 November 1974.

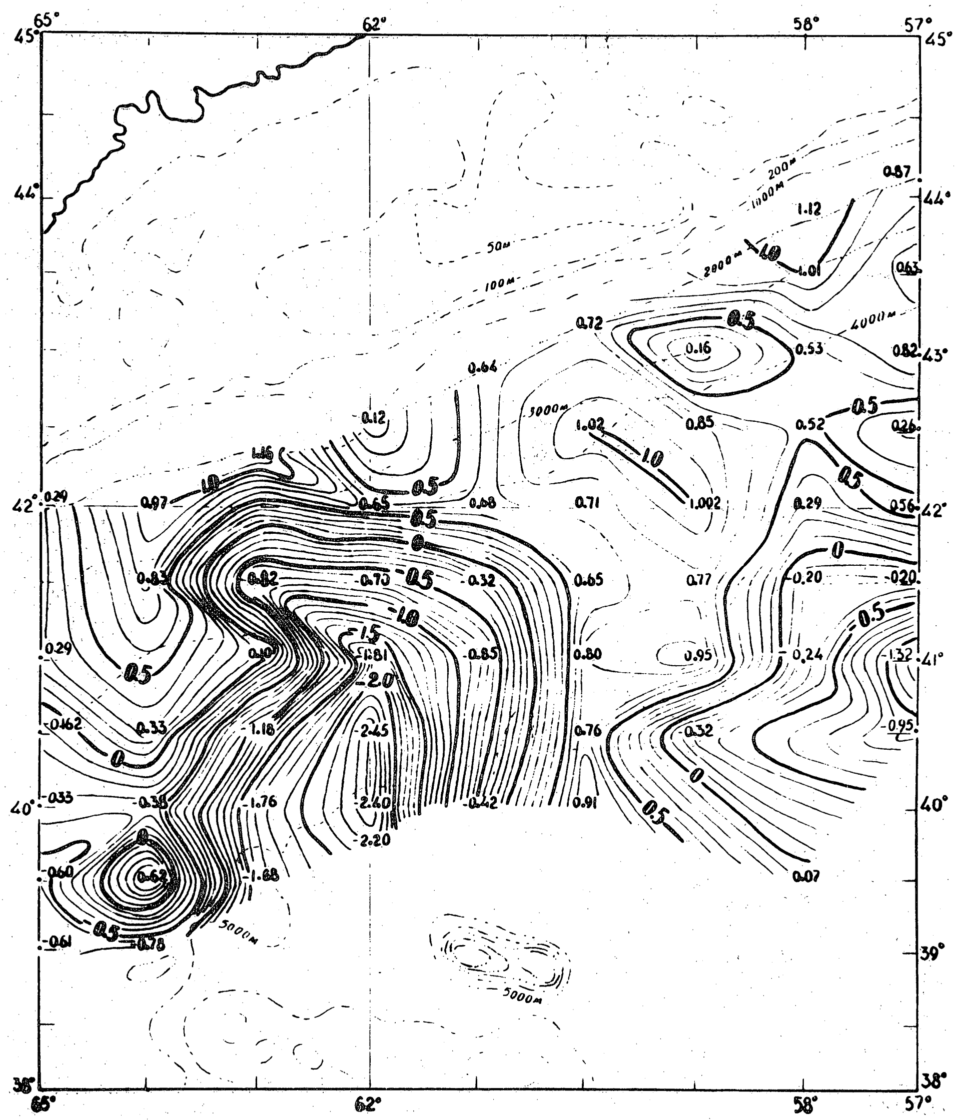

Fig.2. Distribution of available potential energy in the Gulf Stream area, 14-30 November 1974.

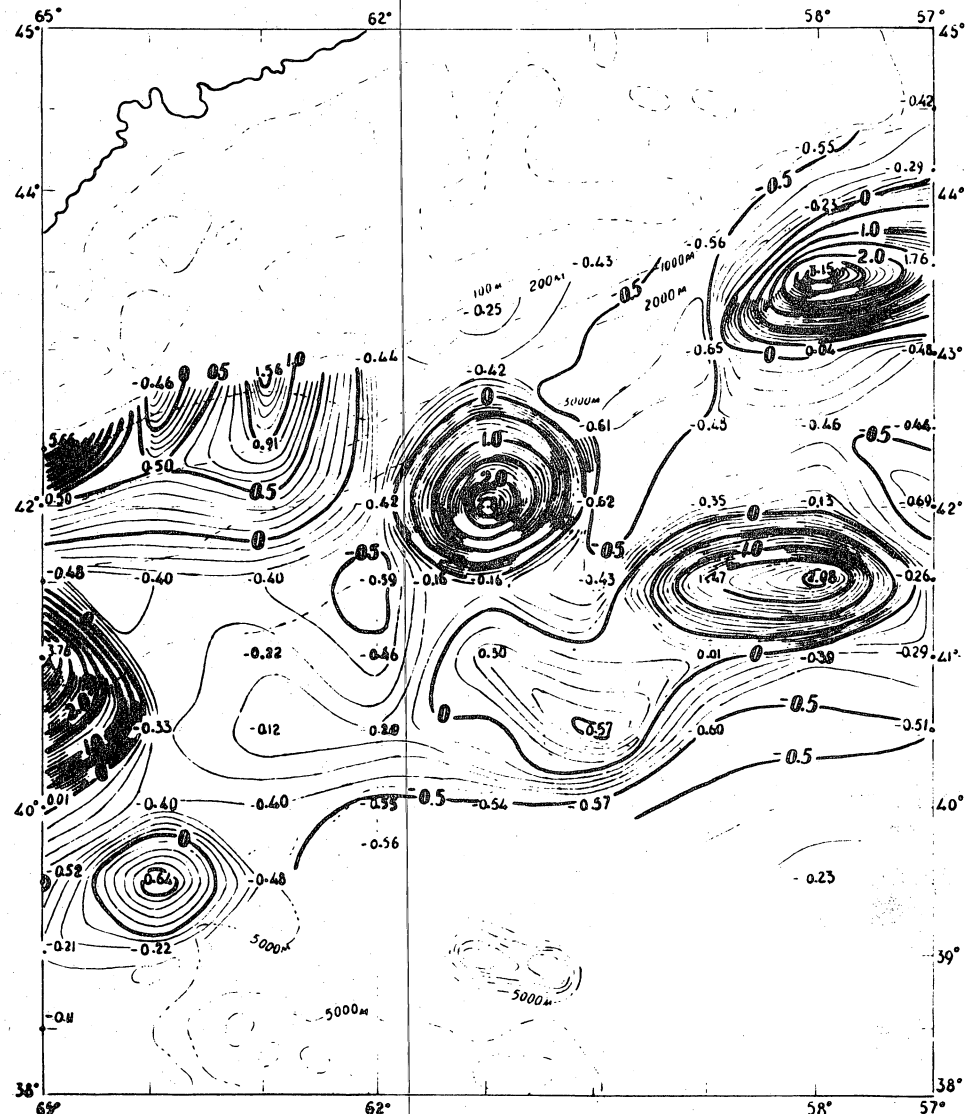

Fig.3. Distribution of seston biomass in the Gulf Stream area, 14–30 November 1974.

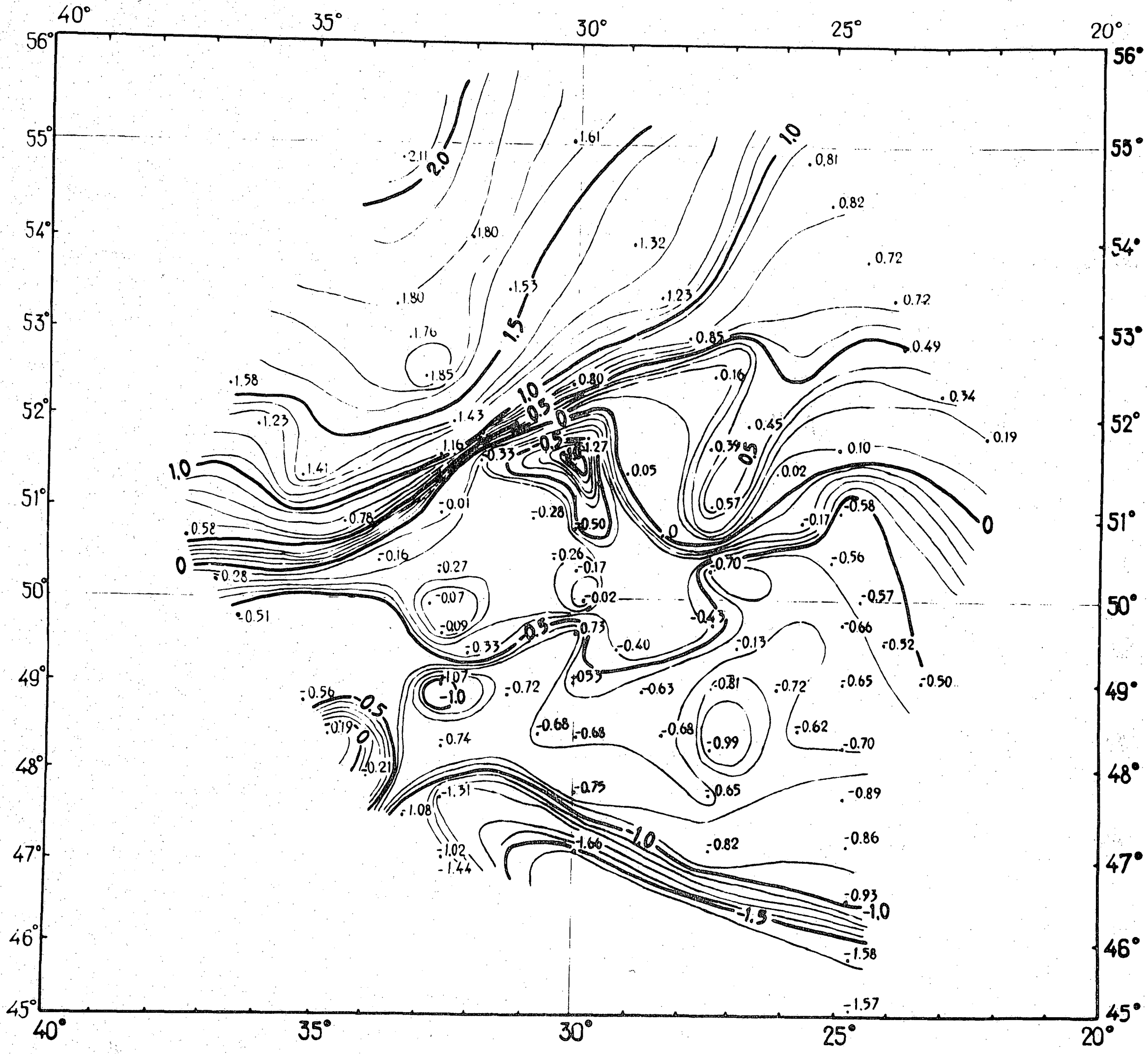

Fig.4. Distribution of available potential energy in the Mid-Atlantic Ridge area, February–May 1980.

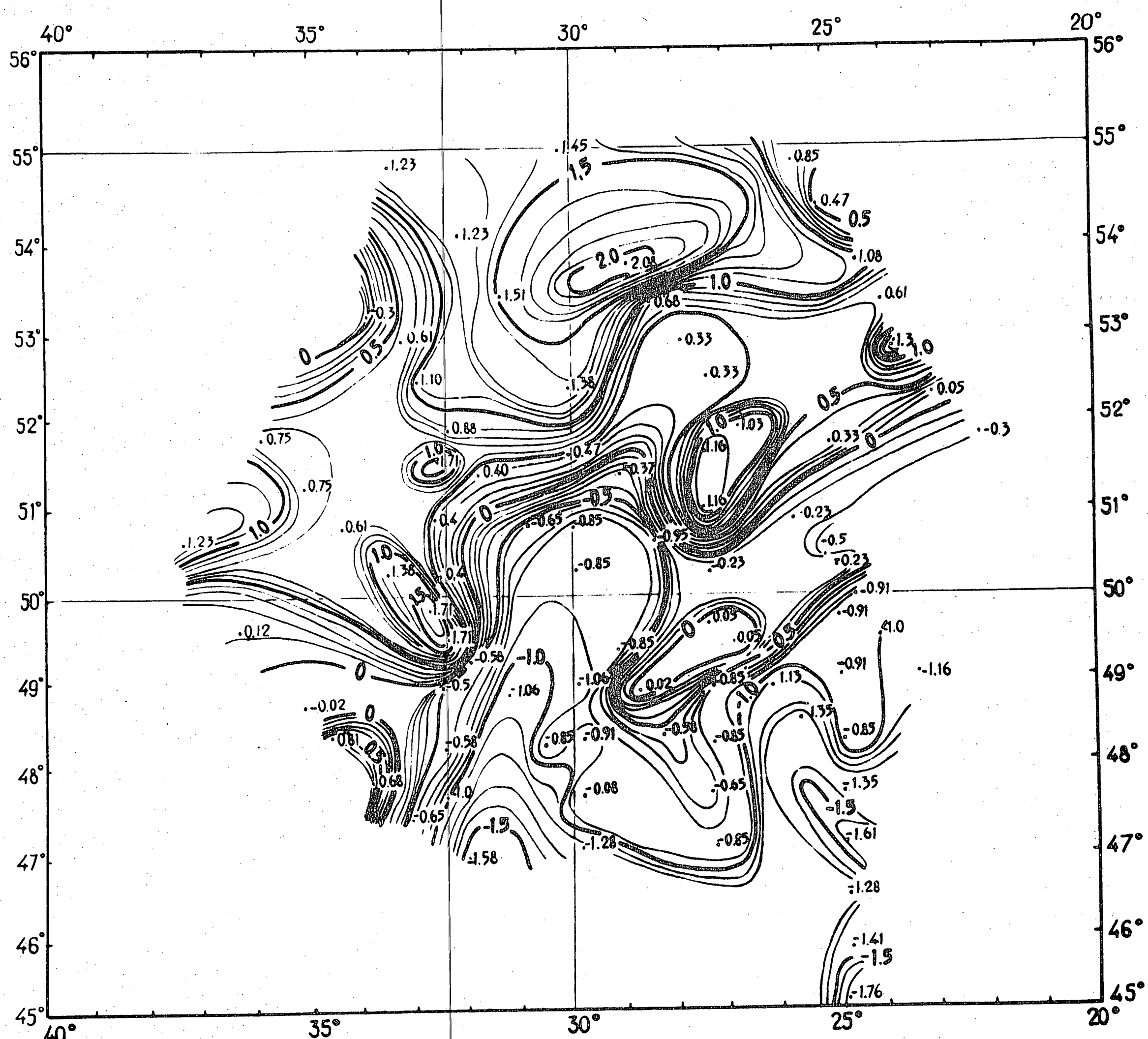

Fig.5. Distribution of phosphates (PO_4) in the Mid-Atlantic Ridge area at the 250 m depth, February-May 1980.