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*Some Features of the Deep Water in the Gulf of Mexico*¹

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ABSTRACT

In the central Gulf of Mexico, 52 stations having depths greater than 1500 m were occupied within a seven-week period. The data for waters below sill depth (2000 m) show that the ranges of potential temperature and salinity are very limited, although weak vertical gradients indicate a slight positive stability. Water characteristics are consistent with the concept of flooding through the Yucatán Channel, but the data are inadequate to examine the possibility of present-day exchange. In contrast to the potential temperature and salinity, which show no horizontal variations, the dissolved oxygen content appears nonuniform on all horizontal surfaces below the sill depth.

Introduction. The central Gulf of Mexico, having depths in excess of 3400 m, is a basin isolated from the adjacent Caribbean Sea by a sill with a controlling depth of roughly 2000 m; the sill depth in the Yucatán Channel has not been determined with precision. Fig. 1 presents contours for depths below 1500 m, at 500-m intervals; this figure is based on U. S. Coast and Geodetic Survey Chart 1007 and on soundings filed at The A. and M. College of Texas, Department of Oceanography and Meteorology.

From 12 February to 31 March of 1962, the R/V HIDALGO occupied a pattern of 126 hydrographic stations in the Gulf of Mexico. In Fig. 2 (solid dots) are shown the 52 stations at which observations from depths greater than 1500 m were obtained. The samples taken during this cruise (62-H-3) were collected by classical methods, using Nansen bottles and reversing thermometers. The samples were analyzed for salinity with a shipboard conductive salinometer built at the University of Washington. Chemical analyses for dissolved oxygen were carried out aboard ship using a modification of the Winkler method.

It is with the characteristics and origins of the waters below 1500 m that we are concerned here.

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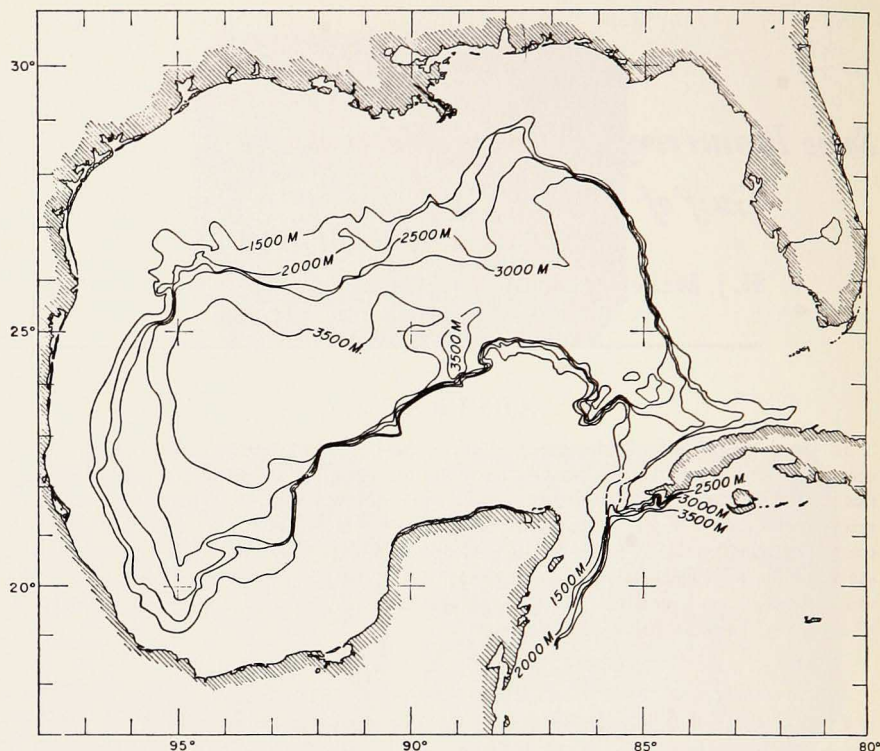


Figure 1. Bathymetry of the Gulf of Mexico Basin from available data. Contour interval 500 m. Contours inshore from the 1500-m isobath are omitted.

Salinity and Potential Temperatures. Fig. 3 shows a composite plot of salinity versus depth for all observed depths below 1400 m at the 52 stations in Fig. 2. This plot shows that, from 2000 m to the maximum depth sampled, the range in observed salinity was 0.008 ‰. All salinity observations from depths greater than 1500 m were fitted to both first- and second-degree polynomials (in depth) by the method of least squares. The resulting linear and quadratic forms, each with a standard error of 0.0015 ‰, appeared to be equally good. Salinity values and gradients at standard depths were obtained from the linear fit and are presented in Table 1. This trend line (omitted from Fig. 3 for clarity) indicates that, throughout this deep water, salinity continued to increase with depth, with a gradient of some 0.002 ‰ per 1000 m. Although the error claimed in the measurement of salinity by the conductive method is ± 0.003 ‰ or more, this gradient appears to be real rather than due to scatter. Even if this gradient is real, however, it may be a measurement of something other than salinity, as usually defined, e. g. a slight departure from constancy of composition.

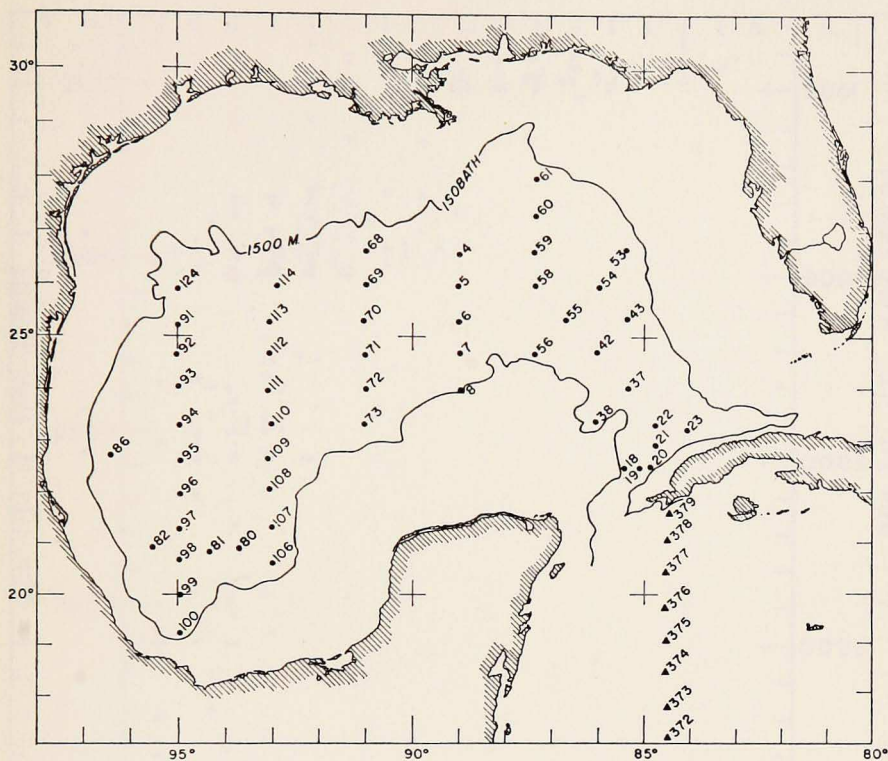


Figure 2. Location of stations occupied during Cruise 62-H-3 (solid dots) where observations at depths greater than 1500 m were made. Location of CRAWFORD Cruise 17, Sts. 372-379 (solid triangles), in the western Caribbean, are also shown.

TABLE I. THE MEAN STABILITY PARAMETER, \bar{E} , FROM MEAN VALUES AND GRADIENTS OF T AND S AT STATED DEPTHS.

Z (m)	\bar{T} (°C)	\bar{S} (‰)	$\frac{d\bar{T}}{dZ} \times 10^3$ (°C m ⁻¹)	$\frac{d\bar{S}}{dZ} \times 10^3$ (‰ m ⁻¹)	$E \times 10^8$ (m ⁻¹)
2000	4.23	34.971	0.034	0.002	1.3
2500	4.26	34.972	0.077	0.002	0.8
3000	4.31	34.973	0.120	0.002	0.2

In Fig. 4 it is seen that a general decrease in potential temperature (θ) with depth (Z) was observed from 1400 to 3000 m; these potential temperatures were computed from tables given by Helland-Hansen (1930). The potential temperatures for all observed depths greater than 1500 m were fitted to several functional forms. The form chosen was the second-degree polynomial in depth,

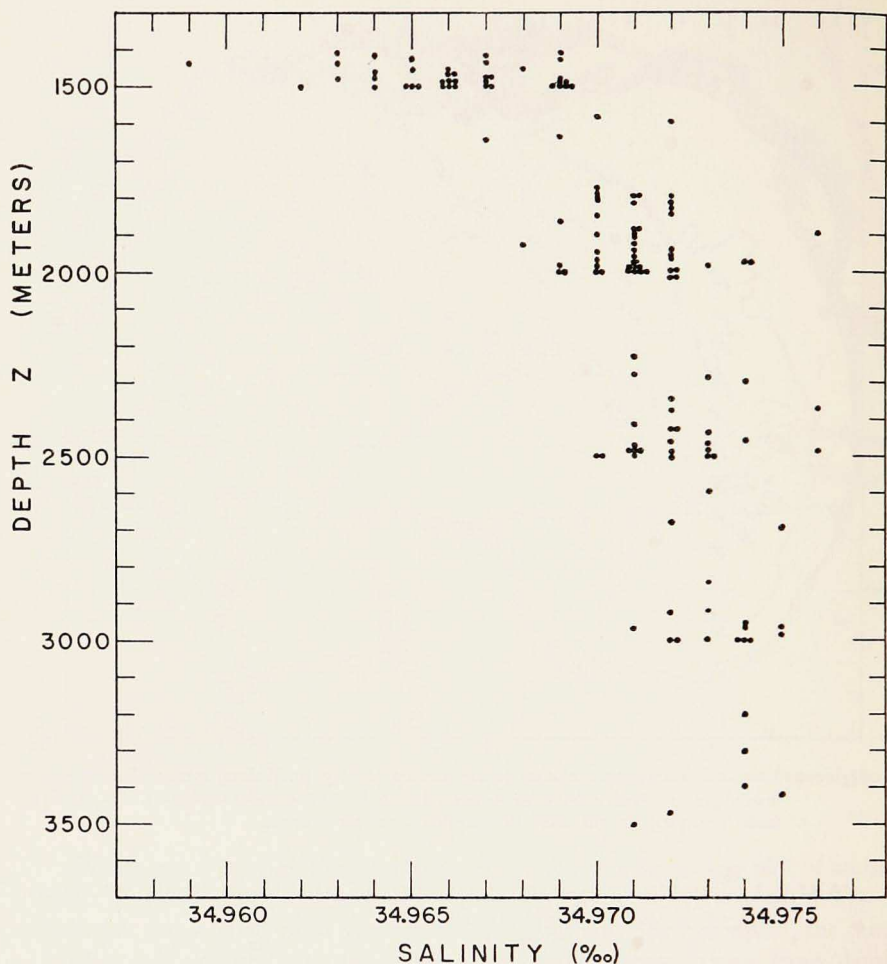


Figure 3. Salinity-depth relationships for all observations from deeper than 1400 m on Cruise 62-H-3, Gulf of Mexico.

$$\theta = 4.334 - 2.139 \times 10^{-4}Z + 3.596 \times 10^{-8}Z^2, \quad (1)$$

with θ in degrees Celsius and Z in meters; this gave a standard error of 0.012 C degrees. Resulting mean potential temperatures for selected depths are presented in Table 11; these values agree to three significant figures with the arithmetic means of the potential temperatures observed within a depth range of 50 m on either side of the tabulated depths. Although the number of observations below 3000 m is small, it may be said that the potential temperature does not appear to decrease further below this depth.

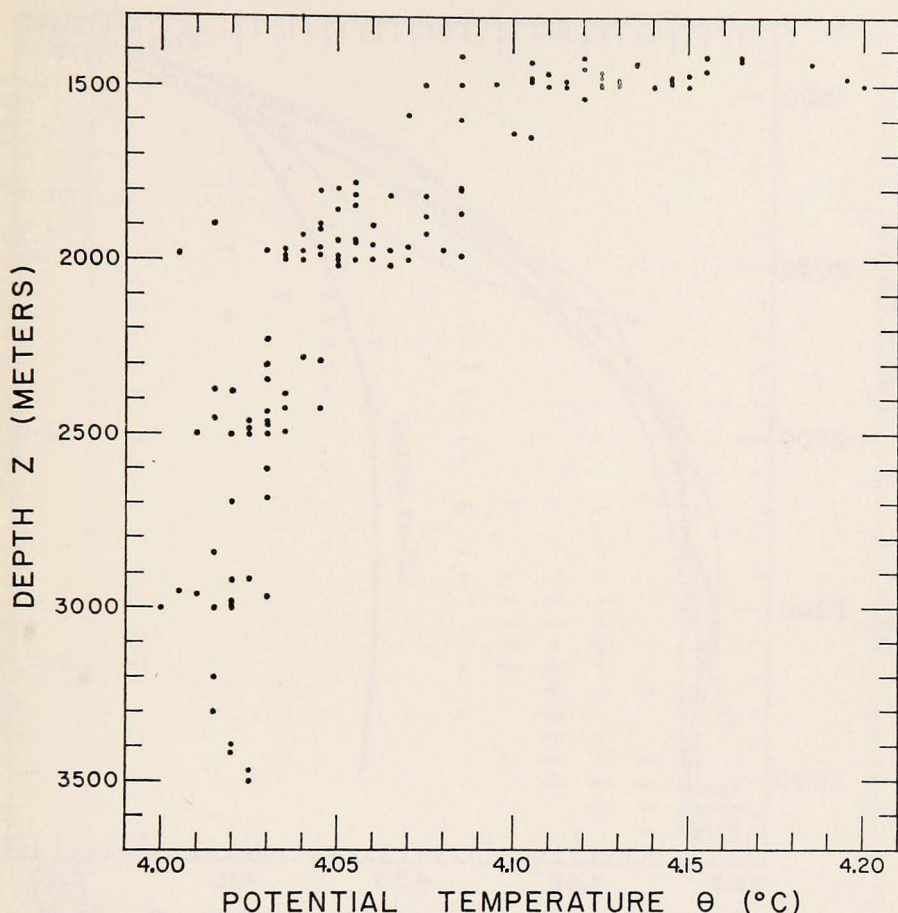


Figure 4. Potential temperature-depth relationships for all observations from deeper than 1400 m on Cruise 62-H-3, Gulf of Mexico.

That the vertical gradients of both potential temperature and salinity were observed to be small below the 2000-m depth is consistent with the concept of a basin isolated by a sill whose controlling depth is 2000 m or less. The observed vertical gradients indicate diffusion of salt (upward) and heat (downward at least to 3000 m). No significant pattern of horizontal variations in salinity or potential temperature was discernible below 2000 m.

The Stability of the Basin Waters. On the basis of the vertical distribution of po-

TABLE II. MEAN POTENTIAL TEMPERATURES (MPT) FOR GIVEN DEPTHS.

Depth (m)	MPT (°C)
2000	4.050
2500	4.024
3000	4.016
3500	4.026

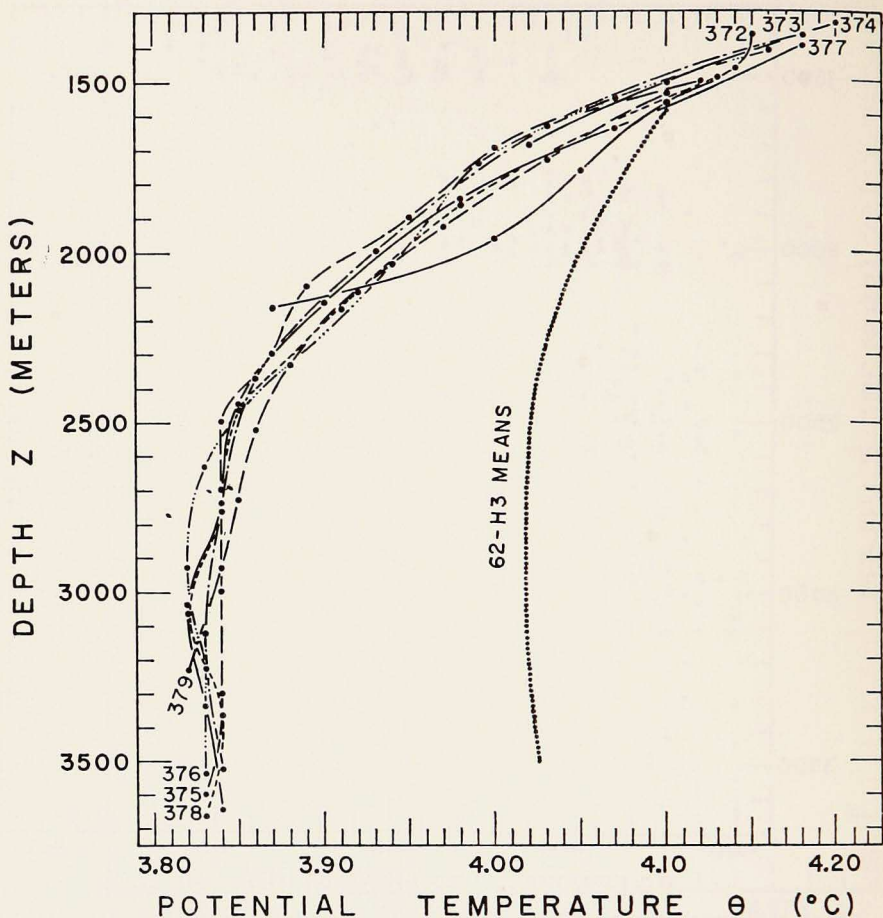


Figure 5. Potential temperature-depth relationships for CRAWFORD Cruise 17, Sts. 372-379. Range of Cruise 62-H-3 observations shown.

tential temperature, the waters of the basin appear to be stable down to 3000 m. Moreover, if the salinity gradient is to be accepted, this stability is enhanced, and it may be that the waters are stable to the bottom.

Since the ranges of both potential temperature and salinity in Figs. 3 and 4 are limited, it is easily possible to overestimate the degree of positive stability from a consideration of these figures. It seems worthwhile, therefore, to consider some parameter whereby the vertical stability of these waters may be quantitatively compared with that of waters in other areas. Such a quantitative measure is provided by the Hesselberg-Sverdrup (1915) stability parameter, E , an equivalent of which may be defined by

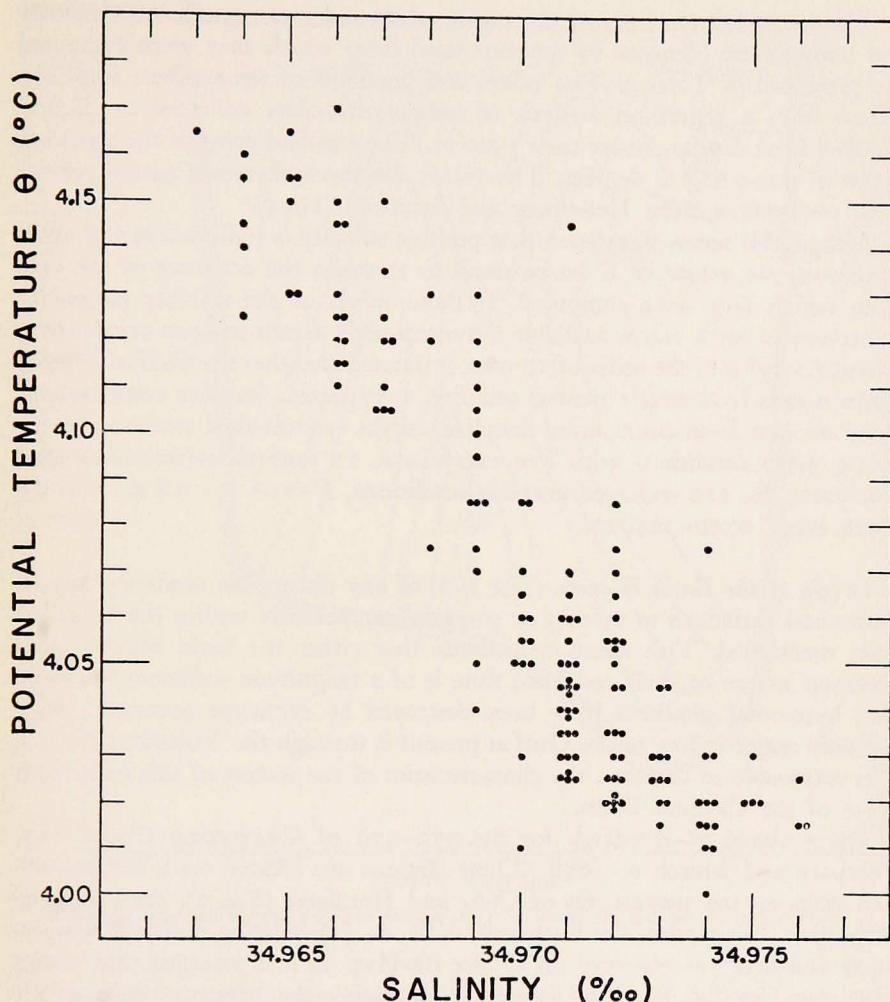


Figure 6. Potential temperature-salinity relationships for all observations from deeper than 1400 m on Cruise 62-H-3, Gulf of Mexico.

$$E = \frac{1}{\rho} \left[\frac{\partial \rho}{\partial S} \frac{dS}{dZ} + \frac{\partial \rho}{\partial T} \left(\frac{dT}{dZ} - \Gamma \right) \right], \quad (2)$$

where: ρ is density, S salinity, T temperature, and Z depth (increasing downward); dS/dZ and dT/dZ denote environmental gradients; $\partial \rho / \partial S$ and $\partial \rho / \partial T$ denote thermodynamic partial derivatives; Γ denotes the increase in temperature per unit increase in depth under adiabatic conditions.

The mean values of E and the mean values and mean gradients of salinity and temperature (denoted by superior bars) from which they were computed are presented in Table 1. The values and gradients of temperature were obtained from a regression analysis of temperature data collected on Cruise 62-H-3 from depths greater than 1500 m. The standard error of the resulting curve fit was 0.014 C degrees. The values for thermodynamic partial derivatives were taken from Hesselberg and Sverdrup (1915).

Although it seems significant that positive stability is indicated as the mean condition, the values of \bar{E} are so small as to strain the accuracy of the data from which they were computed. If these values of the stability parameter are compared with values available for comparable depths in open ocean areas, where $E \times 10^8$ is of the order of 10 m^{-1} , it is concluded that the Gulf of Mexico Basin waters have nearly neutral stability, as expected. Stability computations based on data from consecutive sampling depths at individual stations also indicate stable conditions with few exceptions: 11 stations evidenced neutral conditions; St. 110 indicated unstable conditions, $E \times 10^8 = -0.8 \text{ m}^{-1}$, in the depth range 2750-3250 m.

Origin of the Basin Waters. The lack of any discernible tendency toward horizontal variations in salinity or potential temperature within the basin has been mentioned. This seems to indicate that either the basin waters had a common source or their residence time is of a magnitude sufficient to insure that horizontal gradients have been destroyed by exchange processes. Since the only major inflow to the Gulf at present is through the Yucatán Channel, it is reasonable to compare the characteristics of the waters of this basin with those of the Cayman Basin.

Fig. 5 shows θ - Z curves for Sts. 372-379 of CRAWFORD Cruise 117, February and March of 1958. These stations are located on a north-south line between the western tip of Cuba and Honduras (Fig. 2). Also pictured (Fig. 5) is the graph of the least-squares fit, eq. (1), relating potential temperature and depth as observed on Cruise 62-H-3. If it is assumed that waters from the Cayman Basin are presently displacing the bottom waters of the Gulf of Mexico Basin, then consideration of potential temperatures leads to an estimated maximum controlling sill depth of between 1650 and 1900 m (less than 1800 m if CRAWFORD St. 372 is ignored). If it is assumed that the bottom waters of the Gulf Basin have a greater potential density than the present Cayman waters at the controlling sill depth, then Cayman waters may presently be flooding the Gulf Basin at some depth between 1500 m and the bottom. In this case the controlling sill depth must be less than 1900 m. It is seen, however, that this sill depth must be at least 1400-1500 m, for at these depths the θ - Z curves for the Cayman and Gulf waters coincide. Moreover, if the controlling sill depth is within this shallower range, the interpretation might be that the Gulf Basin was filled at some past time (when the

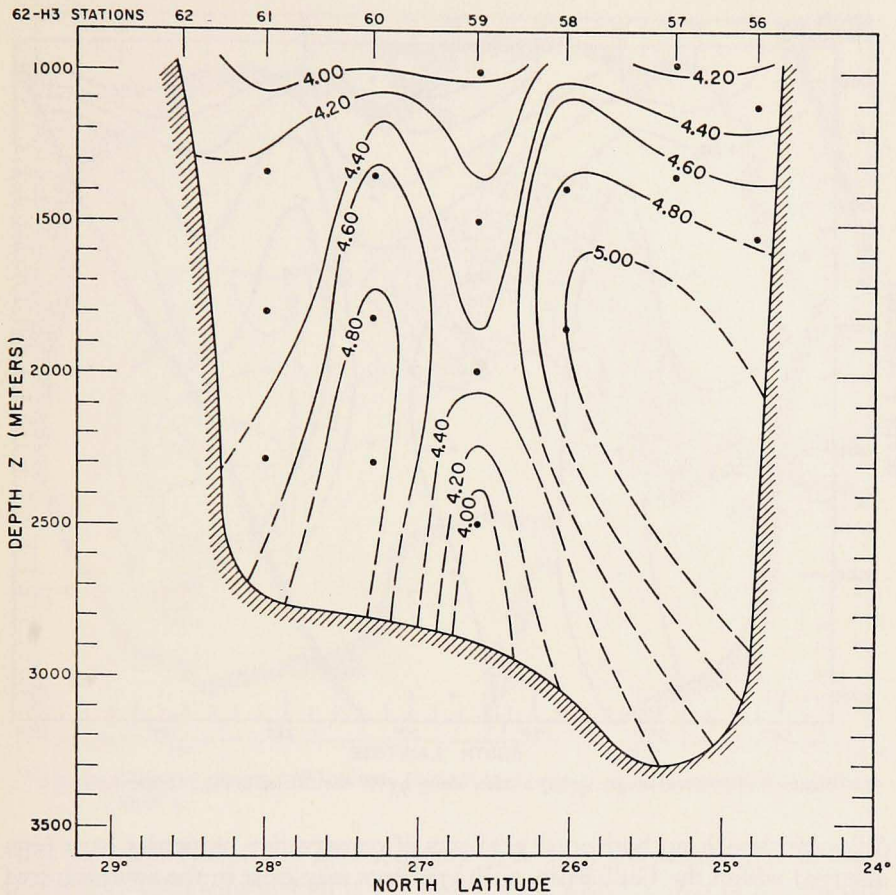


Figure 7. Dissolved oxygen (ml/l) in section along $87^{\circ}20'W$ for Sts. 56-62, Cruise 62-H-3.

distribution of temperature within the Cayman Basin differed from that evidenced by the CRAWFORD data).

It must be emphasized that the controlling sill depth as discussed is only an estimate. The difficulty of accurately relating the controlling sill depth to the available hydrographic data is reflected in the following statements: (i) unless isothermal surfaces are horizontal within the Cayman Basin in the 1400-2000 m depth range, the water found some hundreds of miles removed from the sill cannot be expected to represent the water available for inflow into the Gulf of Mexico at the same depth; (ii) since the northward currents through the Yucatán Channel are thought to extend practically to the bottom, it is possible that the intensity of this flow (not necessarily stationary) may determine the greatest depth from which Cayman waters enter the Gulf; and

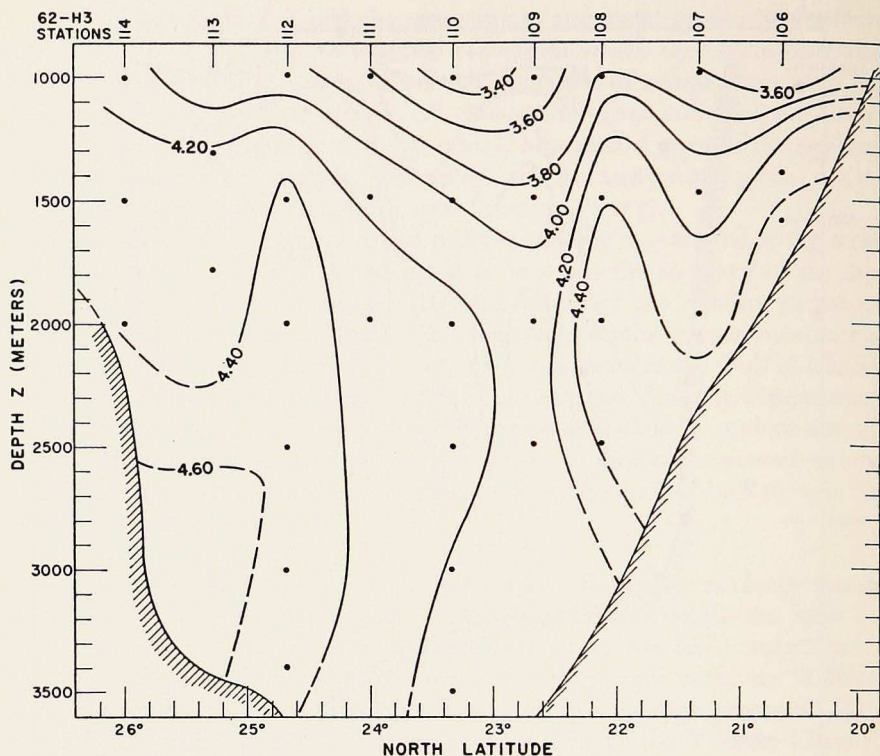


Figure 8. Dissolved oxygen (ml/l) section along 93°W for Sts. 106-114, Cruise 62-H-3.

(iii) even though no horizontal gradients of conservative properties have been observed within the Gulf Basin, such gradients may exist in the approach area if Caribbean waters are presently moving northward in a downslope flow and displacing the bottom waters of the Gulf Basin.

In the foregoing discussion no mention has been made of attempts to compare Cayman and Gulf waters on the basis of salinity or dissolved-oxygen content. Comparison of the θ - S plot for waters of the Gulf Basin (Fig. 6) with a corresponding plot for waters of the Cayman Basin (CRAWFORD Sts. 372-379) has shown us that at any given potential temperature in the range 4.01 to 4.15°C , significant differences in salinity between the waters of the two basins do not exist, i. e. the salinity differences do not exceed 0.006‰ , which is roughly twice the error claimed for the conductive measurement of salinity. With regard to dissolved-oxygen content, it is felt that no significant conclusions can be drawn from the comparison of Cruise 62-H-3 data with those available from the Cayman Basin because of the lack of intercalibration.

Unpublished data from preliminary investigations (D. W. Hood, personal communication) indicate, on the basis of radiocarbon dating, an age of 519 ± 76

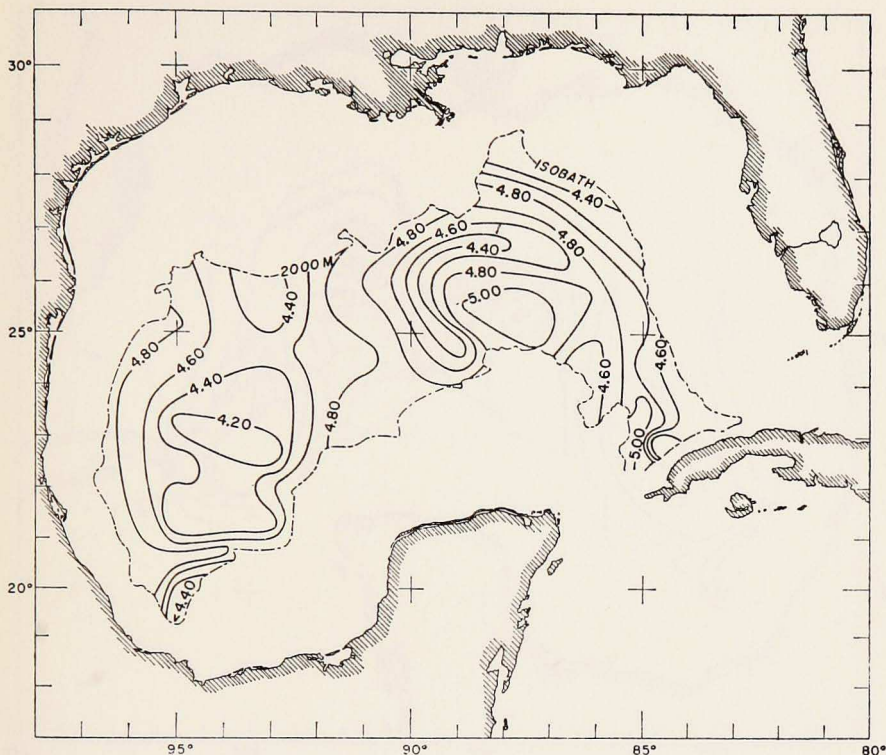


Figure 9. Dissolved oxygen (ml/l) in the Gulf of Mexico at 2000 m as observed during Cruise 62-H-3.

years for water collected at approximately 3400 m in the western central Gulf of Mexico. This information is not inconsistent with the idea of present-day displacement of Gulf bottom water by Cayman water. At present, estimates for the age of western North Atlantic and northern Caribbean waters at 1200 to 2500 m depths are roughly 350 ± 100 years (see, e. g., Broecker *et al.*, 1961).

Distribution of Dissolved Oxygen. In contrast to the horizontal uniformity of temperature and salinity, observations of dissolved oxygen and phosphate-phosphorous in the deep waters displayed considerable lateral variability. The small number of data points made it impossible to define unique patterns in the horizontal distribution at the lower levels, but the following subjective procedure was followed:

(i) Smooth oxygen-depth curves were drawn for each station, referring to adjacent stations for consistency as appeared warranted.

(ii) A set of vertical sections such as those in Fig. 7, along the $87^{\circ}20'W$ meridian, and in Fig. 8, along the $93^{\circ}W$ meridian, were contoured so as to

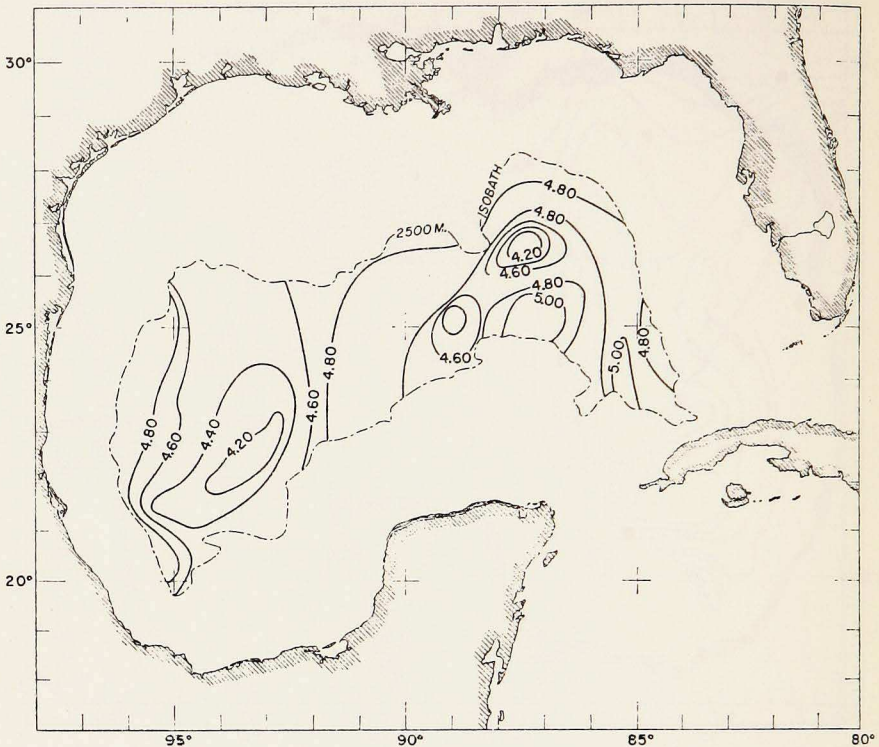


Figure 10. Dissolved oxygen (ml/l) in the Gulf of Mexico at 2500 m as observed during Cruise 62-H-3.

be consistent with individual station curves and with one another. All such vertical sections showed some evidence of low oxygen values near the center of the basin and of higher values along the scarps.

(iii) Isoline-isobath crossings were transferred from the vertical sections to the appropriate horizontal plots and contoured.

Thus displayed (Figs. 9, 10, 11), the horizontal distribution of dissolved oxygen indicates a cell of relatively low values in the south central portion of the western Gulf Basin. This cell seems to extend into the central and eastern portion of the basin at the deepest levels. Relatively high concentrations appear in the deep water near the Yucatán Channel and in a large cell just north of the Campeche Shelf in the eastern basin. The subjectivity (increasing with depth) of these presentations should be noted.

In the light of recent questions concerning the reliability of dissolved-oxygen determinations, a complete check was made on such things as operators involved, Nansen bottles used, reagent batches, etc. It is considered extremely unlikely that the pattern of O_2 distribution shown by these data has been gen-

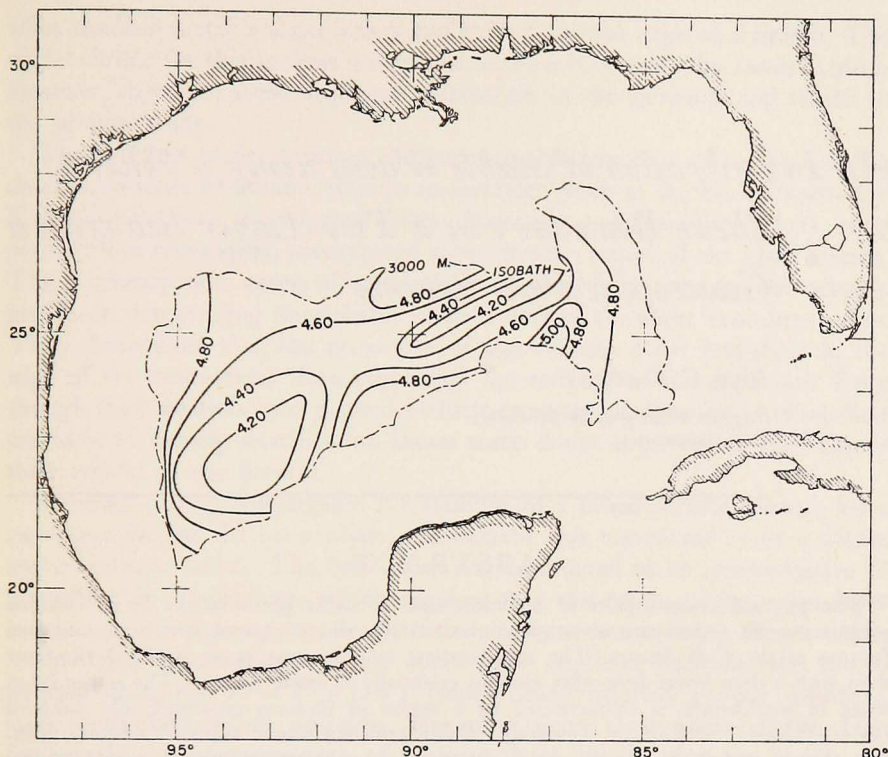


Figure 11. Dissolved oxygen (ml/l) in the Gulf of Mexico at 3000 m as observed during Cruise 62-H-3.

erated by fortuitous errors. Moreover, the determinations of phosphate-phosphorous made at the same time, while lacking in precision, show a correlation of high phosphate with low oxygen. This is consistent with the utilization of oxygen in oxidation of organic matter.

At present the authors do not wish to put forth any conjectures in an attempt to explain the observed distributions of nonconservative constituents.

REFERENCES

- BROECKER, W. S., R. D. GERARD, MAURICE EWING, AND B. C. HEEZEN
1961. Geochemistry and physics of ocean circulation. *Oceanography. Publ. Amer. Ass. Adv. Sci.*, 67: 301-322, Washington, D. C.
- HELLAND-HANSEN, BJORN
1930. Physical oceanography and meteorology. Rep. "Sars" N. Atlant. Deep-Sea Exped., 1; 217 pp.
- HESELBERG, TH., AND H. U. SVERDRUP
1915. Die Stabilitätsverhältnisse des Seewassers bei vertikalen Verschiebungen. *Bergens Mus. Årb.* (1914-1915), 15: 1-16.