Panama Basin Deep Water— Properties and Circulation[1]

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ABSTRACT

Temperature, salinity, and dissolved-oxygen data from the deep waters of the Panama Basin suggest that water enters the Basin through a single pass near Ecuador and subsequently spreads to the north and west. The flow is blocked in places by subsills, and warming occurs through mixing and geothermal heating. The bottom water appears to have a residence time of about 175 years, and heat flow is believed to be important in the renewal process in the bottom water.

Introduction. The upper waters in the Gulf of Panama have been studied by numerous investigators. Stevenson (1970) has summarized near-surface circulation and its apparent seasonal variation, and Wyrtki (1967) has described the circulation and water masses at depths from the surface down to about 1000 m. Wooster and Cromwell (1958), using Shellback data, provided temperature and oxygen profiles to a depth of 2500 m for stations along 85°W, but for north of the equator they showed only one station that reached 2500 m. Until recently it has been difficult to study the deep layers because relatively few data from deep observations have been available.

Using the few existing deep-water data, Laird (1969) noted the presence of horizontal temperature gradients in the bottom water. When compared with nearly isothermal bottom water in similar basins, these gradients were considered to be anomalous. Two explanations have been presented: (i) heat flow through the sea floor modifies the bottom water along its path of flow, or (ii) an uncharted topographic barrier separates the Panama Basin into two parts, with one side being filled from a higher level than the other. Salinity and oxygen data were not precise enough to be conclusive, but bottom salinity did not appear to vary. A sill depth for the Basin and the circulation paths were also suggested.

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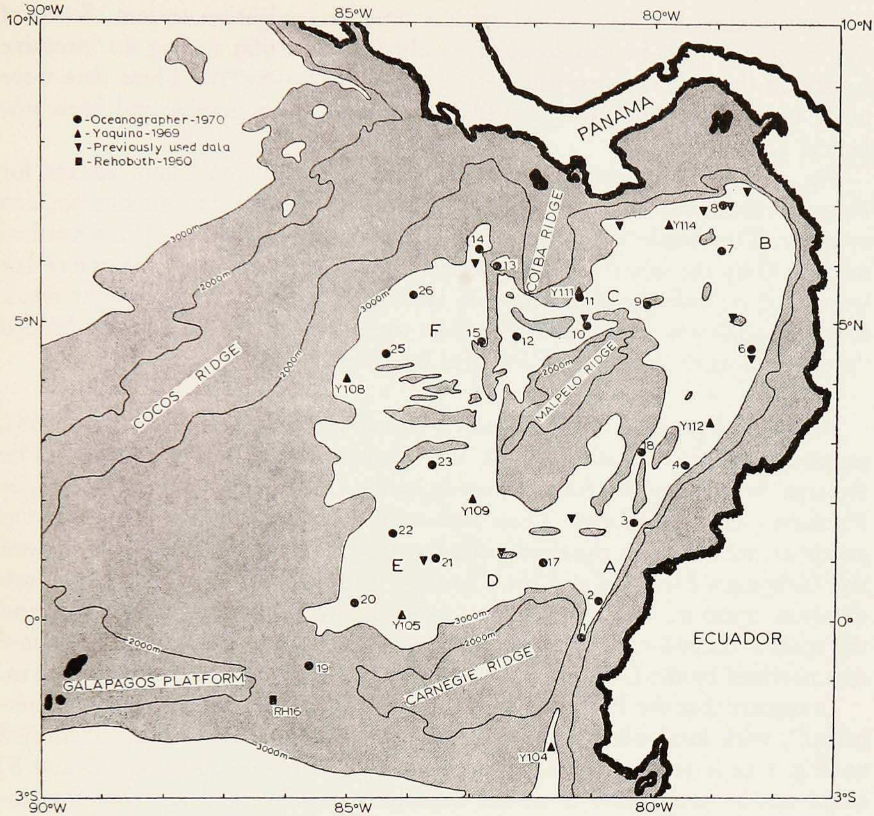

Figure 1. Bathymetry of the Panama Basin and the oceanographic stations used. Shaded areas indicate depths of less than 3000 m.

During April 1970, measurements were made from the NOAA Ship Oceanographer to improve the description of the distributions of temperature, salinity, and oxygen. This improved description has been used to determine the cause of horizontal temperature gradients and to further delineate the bottom circulation. Twenty-four Nansen-bottle casts were made, with emphasis on the deep and bottom waters. A pinger was used to place the deepest bottle about 10 m above the bottom. At most stations, the deepest three bottles had thermometers ranging from $-2°$ to $3°C$. An intercomparison of these low-range thermometers indicates that their measurement precision is approximately $\pm .005°C$. The salinity was determined with an inductive salinometer, the dissolved oxygen with a modification of the Winkler method. In situ temperatures were converted to potential temperatures according to Fofonoff (1962).

Limited bathymetric data were acquired with a narrow-beam echo sounder, and positioning was determined with a satellite navigation system. Some of the soundings used in this study were obtained in 1969 during an intensive survey on the OCEANOGRAPHER between 3–6°N, 80–85°W. These data were made available by Paul Grim (NOAA, Atlantic Oceanographic and Meteorological Laboratories).

Fig. 1 shows the location of the stations in the Panama Basin. Except for REHOBOTH-16 and OCEANOGRAPHER-19, the depth at all stations was 3000 m or more. The shoaler stations are shown because they were used in a vertical section. Only the salinity and oxygen data taken aboard the OCEANOGRAPHER were used in order to avoid possible systematic differences that might result from the different methods used by the investigators. Those stations labeled "previously used" have been identified by Laird (1969).

Bottom Topography. The bathymetry shown in Fig. 1 is from Chase (1968), supplemented and modified with the OCEANOGRAPHER's soundings. The Panama Basin is isolated from the ocean by the Cocos Ridge and the Galapagos Platform—Carnegie Ridge. These features form a barrier below about 2000 m except at two places on the south side. Sounding lines across the saddle between the Galapagos Platform and the Carnegie Ridge indicate a maximum depth of about 2300 m. The deepest pass exists between the Carnegie Ridge and the coast of Ecuador. The sill depth is somewhat approximate, but the limited data obtained by the OCEANOGRAPHER in 1970 suggest that it is 2700–2800 m.

It appears that the Panama Basin is divided into at least six regions or "sub-basins", with local sills deeper than 3000 m. These sub-basins are identified on Fig. 1 as A through F. The true sill depths at some sub-basins (D and F) could not be ascertained from the available soundings and are therefore inferred from water properties.

Deep-water Properties. Fig. 2 shows the distribution of bottom potential temperature at depths greater than 3000 m. Most of the measurements are within 10 m of the bottom. The coldest water is found along the coast of South America, the warmest in sub-basin F to the northwest. A range in bottom potential temperature of about 0.2°C is evident. Within the precision of the data, the water is homogeneous below the local sill depth in sub-basin F and at Sts. 13 and 18, which are located in isolated deeps. A slight negative vertical gradient in potential temperature is found at the other stations. At depths greater than 3000 m, the largest vertical gradients (1.3×10^{-4}°C/m) are at stations near the pass off Ecuador.

Fig. 3 shows the horizontal distribution of the bottom salinity and the contours of the bottom dissolved oxygen at depths greater than 3000 m. Bottom salinities have a range of only 0.005‰, which is approximately the precision of measurements; the changes in salinity, however, do correlate with the changes in potential temperature, the higher salinities being associated with

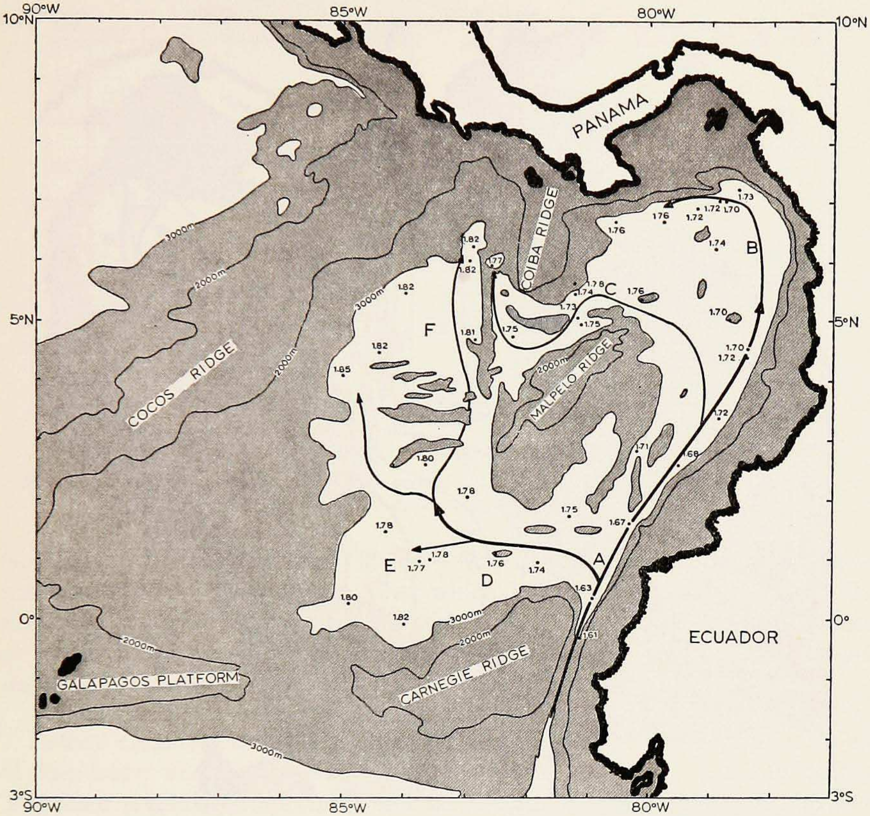

Figure 2. Horizontal distribution of potential temperature (°C) at depths of more than 3000 m and within 200 m of the bottom. Arrows represent the inferred bottom-water paths of flow.

the colder water. This correlation suggests that the small range is a real feature. Bottom salinities in each sub-basin are nearly constant and deviate about each mean by less than ±.002‰. There is a slight vertical salinity gradient in the deep and bottom water, except where the water was previously noted as being homogeneous. The oxygen content of the bottom water shows a systematic decrease of about 0.45 ml/L across the Basin from the southeast to the north and northwest. Although oxygen generally increases with depth, the largest increase below 3000 m is less than 0.15 ml/L. Thus the vertical gradients, coupled with the depth differences of the measurements, do not seriously affect the pattern shown in Fig. 3.

Deep-water Flow. It is apparent from Figs. 2 and 3 that the coldest water with the greatest salinity and oxygen content is present at the pass near Ecuador. An examination of the water properties north of the saddle (sub-basin E,

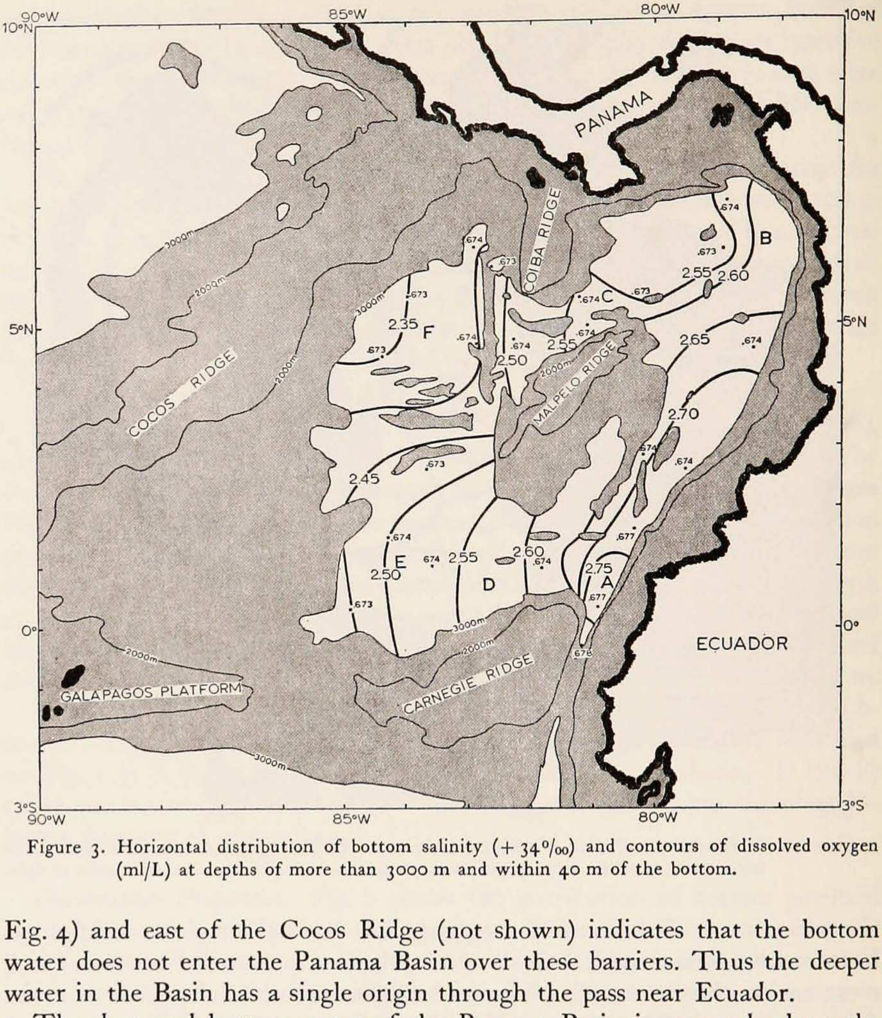

Figure 3. Horizontal distribution of bottom salinity (+ 34‰) and contours of dissolved oxygen (ml/L) at depths of more than 3000 m and within 40 m of the bottom.

Fig. 4) and east of the Cocos Ridge (not shown) indicates that the bottom water does not enter the Panama Basin over these barriers. Thus the deeper water in the Basin has a single origin through the pass near Ecuador.

The deep and bottom water of the Panama Basin is warmed, along the paths of flow, by vertical mixing and by heat flow through the sea floor. Salinity is decreased through mixing; oxygen is decreased through biological processes and mixing. Similar changes in the water properties have been used by numerous authors to infer deep and bottom circulation (see Wooster and Volkmann 1960, Knauss 1962).

The flow paths of bottom water that are consistent with the changes in the water properties are shown in Fig. 2. Two major paths are suggested. One follows the coast of South America northward through sub-basin B. A branch of this flow, which appears to move westward between the Coiba and Malpelo ridges (sub-basin C), eventually fills an isolated deep located at St. 13

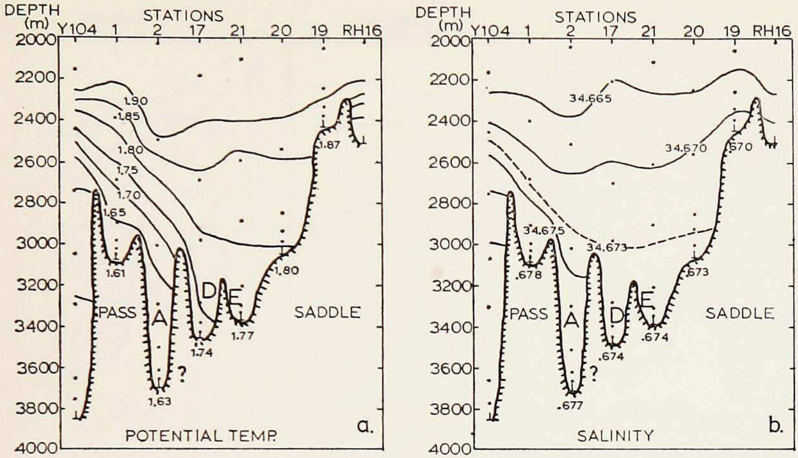

Figure 4. Vertical sections of potential temperature (°C) and salinity (‰), which illustrate the source of bottom water. See Fig. 1 for station locations.

(see Fig. 1). Farther westward, the deep flow is blocked by a ridge that trends north-south. The other major flow, which is westward from the pass, fills sub-basins D and E and northward to sub-basin F. The horizontal distribution of the water properties on level surfaces above the bottom suggests that all water below about 2700 m has the same circulation pattern.

Factors Causing Observed Distribution. Figs. 5 and 6 are vertical sections of deep-water and bottom-water properties along the two major flow paths. The deep potential-temperature and salinity isolines slope downward to the north. The isolines of oxygen slope downward more rapidly, probably as a result of oxygen utilization. Ocean water that sinks to the bottom and to the deep levels in sub-basin A (> 3100 m) is blocked by sills from further advection to sub-basins B and D. Sub-basin B has a sill that is about 100 m deeper than that at sub-basin D, consequently colder temperatures, higher oxygens, and slightly higher salinities are present along the eastern flow path. Along the western flow path, at least one more sill to sub-basin F blocks the flow of bottom water.

All observed horizontal gradients in the bottom salinity are probably related to the presence of internal sills. It appears, however, that other factors produce additional change in the potential temperature. On deep isohaline surfaces, the potential temperatures increase about 0.03°C along the paths of flow. Bottom potential temperatures also increase about the same amount in sub-basins that have constant salinity (Fig. 5). A temperature increase without a corresponding decrease in salinity suggests that little vertical mixing occurs in the deep and bottom water and that the potential-temperature increase is caused mainly by geothermal heating.

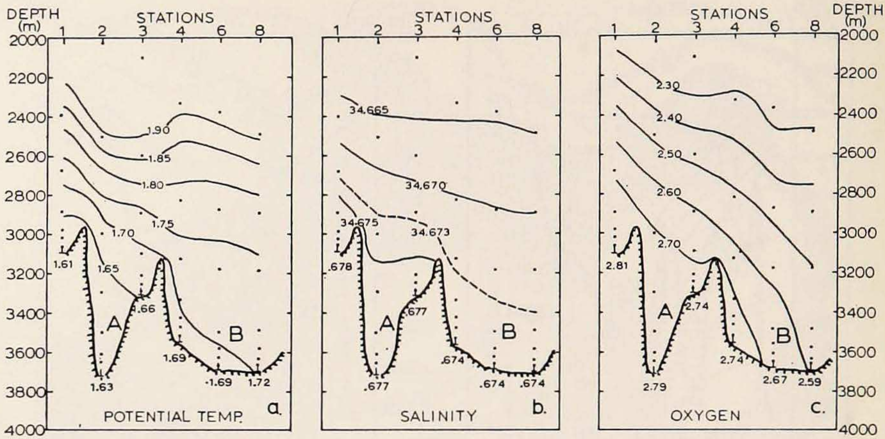

Figure 5. Vertical sections of potential temperature (°C), salinity (‰), and dissolved oxygen (ml/L) along the eastern flow path. See Fig. 1 for station locations.

Renewal. Renewal of the water in the Panama Basin requires a driving force to sustain flow; otherwise the Basin would in time become filled with the densest water that could flow over the sill. It would also become depleted in dissolved oxygen. The increasing dissoved oxygen with depth indicates renewal, and the lack of significant changes in the bottom potential temperatures over a 40-year period suggest that renewal is a continuous process.

The heat flow through the earth's crust and the vertical mixing by currents and tidal forces have been recognized as factors that cause bottom-water renewal (Kuenen 1943, Postma 1958). Postma felt that the renewal of the deepest water in some basins is due mainly to heat flow. Therefore, from studies of other basins and in the absence of any major baroclinic flow at these depths (Reed, in press), it seems reasonable to assume that vertical mixing by tidal currents and heat flow are the driving forces that cause renewal in the Panama Basin.

If it is assumed that the warming of the deep water is caused by geothermal heating alone, then it is possible to estimate the maximum time needed for complete renewal of the Basin water (Postma 1958, Von Herzen 1964). Water enters this Basin, excluding sub-basin A, at a potential temperature of about 1.68°C and appears to leave at about 1.90°C over the surrounding barriers (possibly the saddle between the Galapagos Platform and Carnegie Ridge at a depth of about 2300 m). With an average Basin depth of 3300 m, the column of water heated is 1000 m high. As the geothermal flux is about 100 cal/cm²/year (Laird 1969), about 220 years are required for renewal.

If an oxygen-consumption rate is known for the deep and bottom water, a renewal time can also be estimated. Various authors have suggested consumption rates for particular locations. Arons and Stommel (1967) used

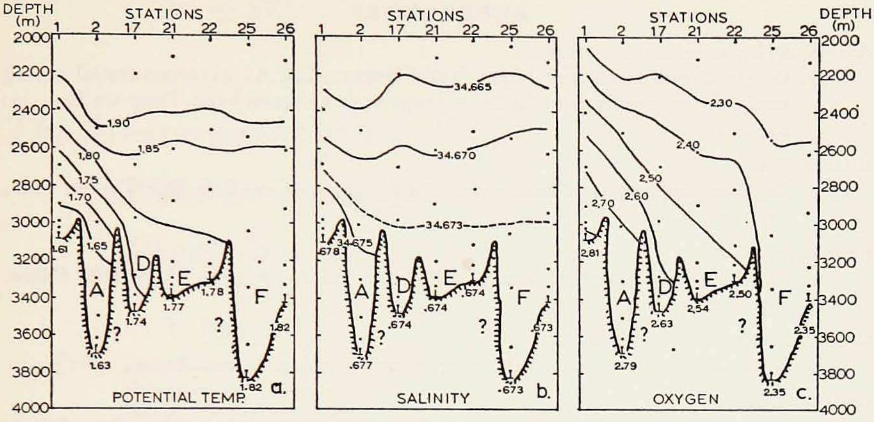

Figure 6. Vertical sections of potential temperature (°C), salinity (‰), and dissolved oxygen (ml/L) along the western flow path. See Fig. 1 for station locations.

values of $2\text{–}2.5 \times 10^{-3}$ ml/L/year for the North Atlantic, and Gordon and Gerard (1970) used a value of 2×10^{-3} ml/L/year for the North Pacific. This latter value is used in the following discussion.

The oxygen content of the source water and the bottom water in sub-basin F is shown in Fig. 6. The source water available for advection has about 2.70 ml/L of dissolved oxygen. A difference of 0.35 ml/L between the source and the oldest water indicates that renewal takes place in about 175 years.

The agreement between two independent estimates of the renewal period is remarkably good and gives confidence to the estimate that about 175 years are needed for complete renewal of the water in the Panama Basin. This agreement, along with the suggestion that vertical mixing appears negligible, leads to the tentative conclusion that geothermal heat flow is an important factor causing bottom-water renewal in the Panama Basin.

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