# CHARACTERISTICS AND FLOW PATHS OF THE INTERMEDIATE DEPTH WATERS OF THE SOUTHEAST INDIAN OCEAN

By

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## ABSTRACT

For the southeast Indian Ocean, isentropic analysis of salinity and oxygen distributions on the 27.20 and 26.80 $\sigma_t$ surfaces showed that mixing of sub-Antarctic intermediate water with poorly oxygenated bottom water of Arabian Sea origin was confined to the region west of about 90° E, east of which there was sinking and movement of oxygenated waters from tropical and subtropical convergences and from the Banda Sea. The seasonal change of properties on the 27.20 and 26.80 $\sigma_t$ surfaces off Fremantle gave some indication of the seasonal flow paths of these different waters.

## INTRODUCTION

Between 1947 and 1951 the F.R.V. WARREEN occupied hydrological stations to depths of 1000 m off southwest Australia between Shark Bay and Albany. In August 1950 and in January 1951 R.R.S. DISCOVERY II sampled waters between the Great Australian Bight and Fremantle (Fig. 1). Thereafter this Laboratory's oceanic hydrological programme in southwest Australia was terminated.

TABLE I. SOURCES OF DATA UTILIZED

| *Year* | *Month* | *Vessel* | *Reference* |
|---|---|---|---|
| 1929 | IX–X | DANA | 1 |
| 1929 | I–XI | SNELLIUS | 13 |
| 1932 | IV–V | DISCOVERY II | 2 |
| 1948 | III–IV | ALBATROSS | 5 |
| 1948–50 | — | WARREEN | 6 |
| 1950 | VI | DISCOVERY II | 3 |
| 1950 | VIII | DISCOVERY II | 3 |
| 1951 | I | DISCOVERY II | 8 |
| 1951 | IX–X | DISCOVERY II | 3 |
| 1951 | — | WARREEN | 7 |
| 1956 | I | LAPÉROUSE | 4 |
| 1956 | II–III | NORSEL | 12 |

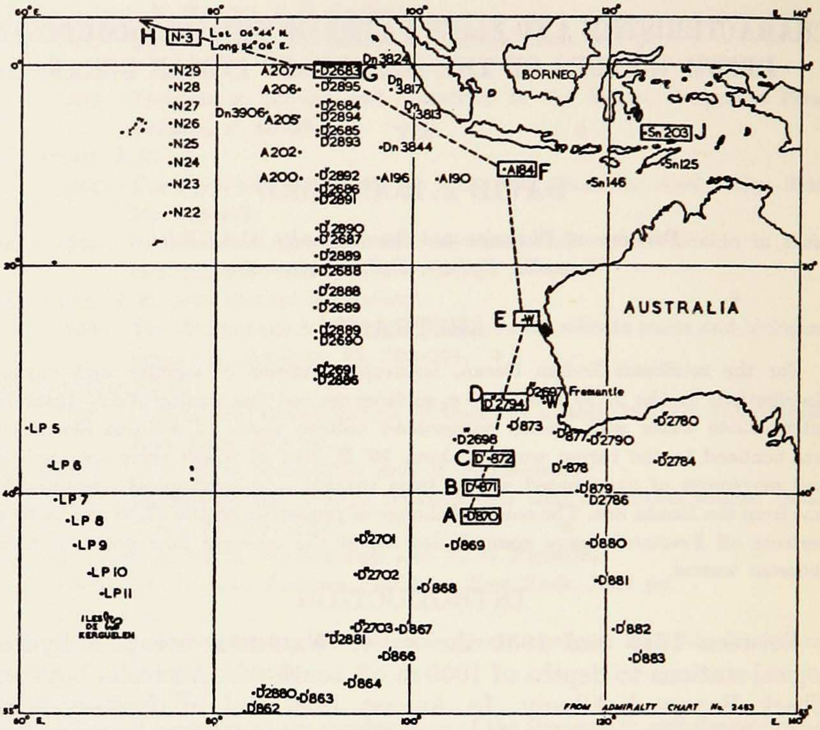


Figure 1. Location of stations:

| *Symbol* | *Vessel* | *Month* | *Year* |
|---|---|---|---|
| A | Albatross | III–IV | 1948 |
| Dn | Dana | IX–X | 1929 |
| DI | Discovery II | IV–V | 1932 |
| DII | Discovery II | VI | 1950 |
| DIII | Discovery II | VIII | 1950 |
| DIV | Discovery II | I | 1951 |
| DV | Discovery II | IX–X | 1951 |
| L.P. | Lapérouse | I | 1956 |
| N | Norsel | II–III | 1956 |
| Sn | Snellius | X–XI | 1929 |
| W | Warreen | XII | 1948 |

Lettered stations within squares are those used in Fig. 15.

The hydrological properties of this region varied considerably within the 500–1000 m levels. This paper examines the seasonal nature of these variations and shows their probable relationship to the intermediate circulation of the southeast Indian Ocean.

Table I lists the published sources of data from which the stations shown in Fig. 1 were selected. The method originally used by Montgomery (9) for interpreting flow patterns from the bathymetry and distribution of properties on isopycnal or near-isentropic surfaces was followed. The assumptions in his method have been accepted.

## VARIATIONS IN HYDROLOGICAL PROPERTIES OF WATERS OFF FREMANTLE

The salinity-temperature relationship of waters west of Fremantle (Fig. 2) showed the presence of two types of water to the limit of sampling depths. The water with the higher salinity and temperature on corresponding $\sigma_t$ surfaces (Fig. 2) had a higher oxygen saturation (Fig. 3) and lower total phosphorus content (Fig. 4) than the other.

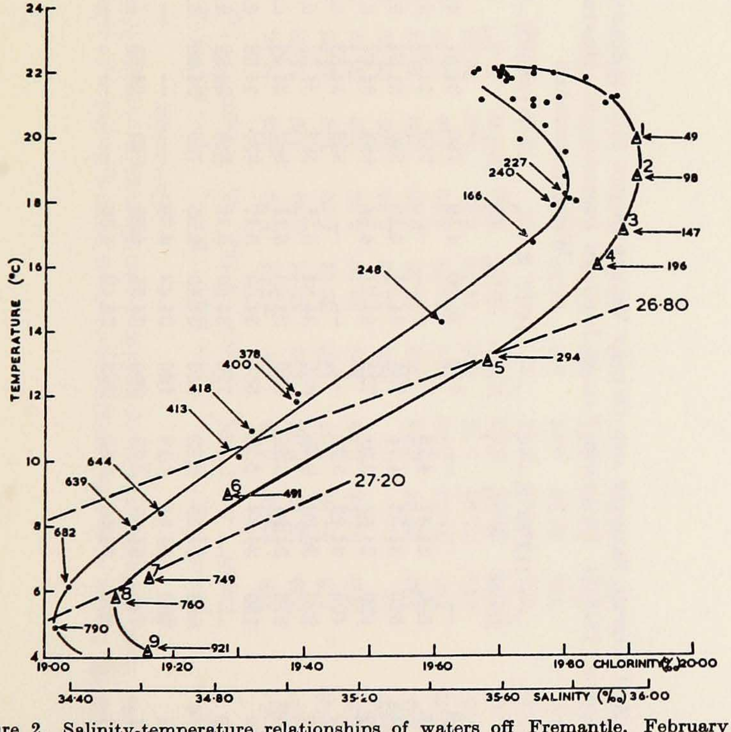


Figure 2. Salinity-temperature relationships of waters off Fremantle, February 1951. The numbered triangles enclose points which are referred to in Figs. 3 and 4. Selected depths are also given.

TABLE II. Depth, Salinity and Oxygen Values on the 27.20 $\sigma_t$ Surface at a Series of five Longitudes West of Fremantle, 1948–51. Boldface Values Indicate Stations and Months when high Salinity, well Oxygenated Waters occurred

| *Date* | 113°30′ E | | | 114°17′ E | | | 114°41′ E | | | 114°53′ E | | | 115°05′ E | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Depth* | *S* ‰ | $O_2$ | *Depth* | *S* ‰ | $O_2$ | *Depth* | *S* ‰ | $O_2$ | *Depth* | *S* ‰ | $O_2$ | *Depth* | *S* ‰ | $O_2$ |
| 16/4/48 | — | — | — | 710 | 34.50 | 4.59 | 780 | 34.51 | 4.80 | — | — | — | — | — | — |
| 24/8/48 | 800 | 34.47 | 4.79 | — | — | — | 750 | 34.79 | 5.30 | — | — | — | — | — | — |
| 11/12/48 | 520 | 34.52 | 4.74 | 735 | 34.47 | 4.39 | 580 | 34.67 | 5.14 | — | — | — | — | — | — |
| 6/4/49 | 830 | 34.63 | 5.04 | 735 | 34.71 | 4.94 | 693 | 34.67 | 5.05 | 735 | 34.67 | 4.73 | — | — | — |
| 7/6/49 | 405 | 34.92 | 5.72 | — | — | — | 809 | 34.53 | 4.74 | — | — | — | — | — | — |
| 22/7/49 | **324** | **35.88** | **5.76** | 650 | 34.88 | 5.21 | 587 | 34.77 | 5.09 | 755 | 34.42 | 4.68 | — | — | — |
| 9/11/49 | 872 | 34.38 | 4.80 | 856 | 34.53 | 5.11 | 862 | 34.49 | 4.96 | — | — | — | — | — | — |
| 23/2/50 | 780 | 34.68 | 5.20 | 656 | 34.48 | 5.17 | 850 | 34.38 | 4.65 | — | — | — | — | — | — |
| 21/6/50 | — | — | — | 770 | 34.66 | 5.12 | **520** | **35.01** | **5.66** | — | — | — | — | — | — |
| 5/10/50 | 696 | 34.55 | 4.83 | 840 | 34.45 | 4.55 | 760 | 34.50 | 4.76 | — | — | — | **583** | **34.93** | **5.68** |
| 18/1/51 | 900 | 34.41 | 4.18 | 790 | 34.48 | 4.39 | — | — | — | — | — | — | — | — | — |
| 23/2/51 | 735 | 34.62 | 5.28 | 790 | 34.36 | 4.23 | 752 | 34.53 | 4.84 | — | — | — | — | — | — |
| 6/7/51 | 850 | 34.43 | 4.63 | 893 | 34.42 | 4.56 | — | — | — | — | — | — | — | — | — |

TABLE III. Depth, Salinity and Oxygen on the 26.80 $\sigma_t$ Surface at a Series of five Longitudes West of Fremantle, 1948–51. Bold Face Values show Stations and Months in which Waters with Salinities greater than 35.00 $^0/_{00}$ Occurred

| Date | 113° 30′ E | | | 114°17′ E | | | 114°41′ E | | | 114°53′ E | | | 115°05′ E | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Depth* | *S* $^0/_{00}$ | $O_2$ | *Depth* | *S* $^0/_{00}$ | $O_2$ | *Depth* | *S* $^0/_{00}$ | $O_2$ | *Depth* | *S* $^0/_{00}$ | $O_2$ | *Depth* | *S* $^0/_{00}$ | $O_2$ |
| 16/4/48 | **278** | **35.25** | **5.76** | **400** | **35.05** | **5.25** | 490 | 34.84 | 5.70 | **260** | **35.02** | **5.51** | **430** | **35.06** | **5.47** |
| 24/8/48 | **280** | **35.17** | **5.66** | **410** | **35.11** | **5.90** | 525 | 34.83 | 5.62 | 460 | 34.99 | 5.93 | **460** | **35.09** | **5.91** |
| 11/12/48 | 275 | 34.84 | 5.65 | **260** | **35.11** | **5.53** | **310** | **35.06** | **5.57** | 476 | 34.65 | 5.65 | 410 | 34.97 | 5.60 |
| 6/4/49 | **320** | **35.06** | **5.90** | 300 | 34.99 | 5.79 | **360** | **35.18** | **5.48** | 440 | 34.93 | 5.57 | **385** | **35.06** | **5.48** |
| 7/6/49 | — | — | — | 460 | 34.69 | 5.75 | **380** | **35.00** | **5.60** | **330** | **35.19** | **5.56** | — | — | — |
| 18/7/49 | **230** | **35.87** | **5.64** | **260** | **35.25** | **5.86** | **250** | **35.39** | **5.85** | **290** | **35.29** | **5.79** | — | — | — |
| 9/11/49 | 380 | 34.65 | 5.95 | 430 | 34.93 | 5.92 | 490 | 34.87 | 6.01 | **410** | **35.05** | **5.87** | 460 | 34.75 | 5.92 |
| 23/2/50 | 410 | 34.98 | 5.76 | 420 | 34.75 | 5.82 | 440 | 34.73 | 5.80 | 500 | 34.60 | 5.80 | 470 | 34.65 | 5.78 |
| 21/6/50 | **400** | **35.18** | **5.83** | **350** | **35.28** | **5.60** | — | — | — | **220** | **35.84** | **5.37** | **480** | **35.28** | **5.69** |
| 5/10/50 | 430 | 34.61 | 5.32 | — | — | — | **430** | **35.02** | **5.72** | **360** | **35.31** | — | — | — | — |
| 18/1/51 | 290 | 34.90 | 5.92 | 423 | 34.78 | 5.92 | — | — | — | 450 | 34.81 | 5.49 | **375** | **35.51** | **5.31** |
| 23/2/51 | **290** | **35.57** | **6.21** | **380** | **35.00** | **5.48** | 520 | 34.84 | 5.48 | 530 | 34.62 | 5.52 | — | — | — |
| 6/7/51 | 470 | 34.74 | 5.87 | 500 | 34.81 | 5.85 | 360 | 34.88 | 5.91 | 460 | 34.80 | 5.93 | **340** | **35.22** | **5.72** |

The 27.20 $\sigma_t$ surface passed through the intermediate salinity minimum (Fig. 2) while the 26.80 $\sigma_t$ lay at about the depth of maximum variation in total phosphorus (Fig. 4) and of large variations in oxygen saturation (Fig. 3). The 26.80 $\sigma_t$ surface marked the lower boundary of subtropical waters. These two surfaces were chosen to show the magnitude and characteristics of seasonal changes in intermediate depth waters off Fremantle.

27.20 $\sigma_t$ SURFACE

On this surface the salinity-oxygen relationships (Fig. 5) showed that mixing of relatively high salinity, well oxygenated water with

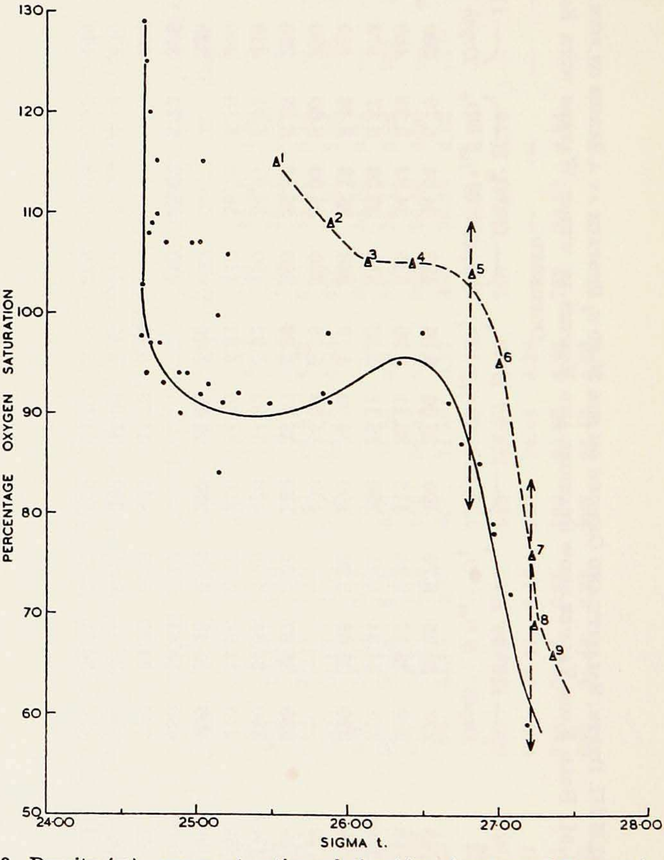


Figure 3. Density ($\sigma_t$)-oxygen saturation relationships of waters off Fremantle. February 1951.

low salinity, poorly oxygenated water determined the magnitude of these properties during 1948–1951. Table II shows that the high salinity, well oxygenated water occurred between June and October, generally at depths of 500 m or less. The maximum occurrence of the low salinity, poorly oxygenated water was found in January 1951 (Table II) at a depth of 900 m.

26.80 $\sigma_t$ Surface

The salinity-oxygen relationships on this surface (Fig. 6) were variable, partly because of its occasional shallow depth (Table III) which permitted local surface exchanges to occur; the oxygen supersaturation on this surface in February 1951 (Fig. 3) certainly indi-

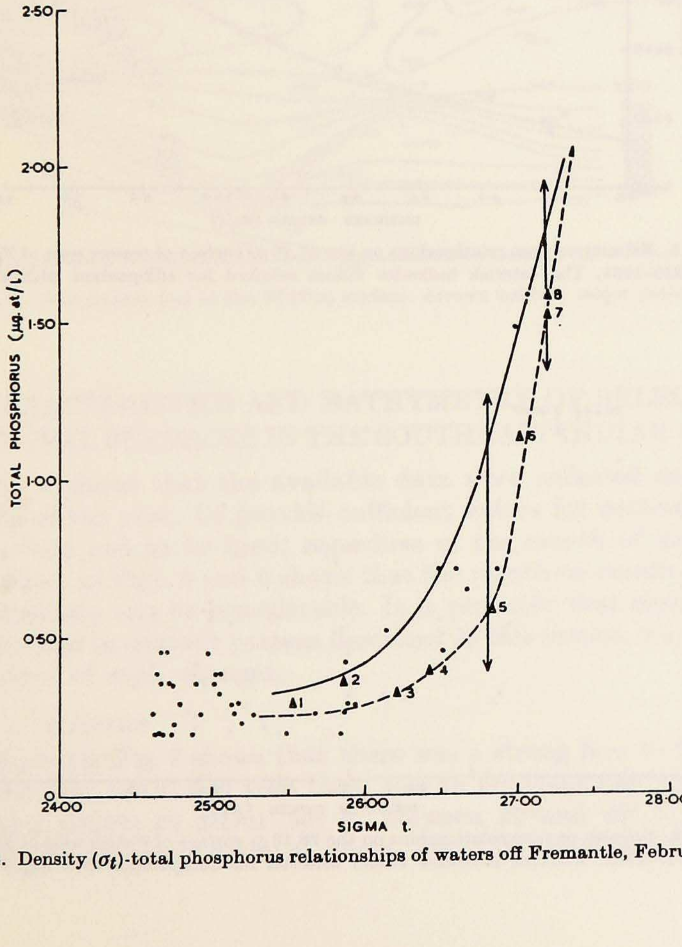


Figure 4. Density ($\sigma_t$)-total phosphorus relationships of waters off Fremantle, February 1951.

cated this. Salinities of less than 35.00 $^0/_{00}$ were found at 60 $^0/_0$ of the stations between November–February 1948–1950, those greater than 35.00 $^0/_{00}$ at 73 $^0/_0$ of the stations between April–August 1948–1951. The magnitude of the oxygen variation was much reduced on this surface compared with the 27.20 $\sigma_t$ surface.

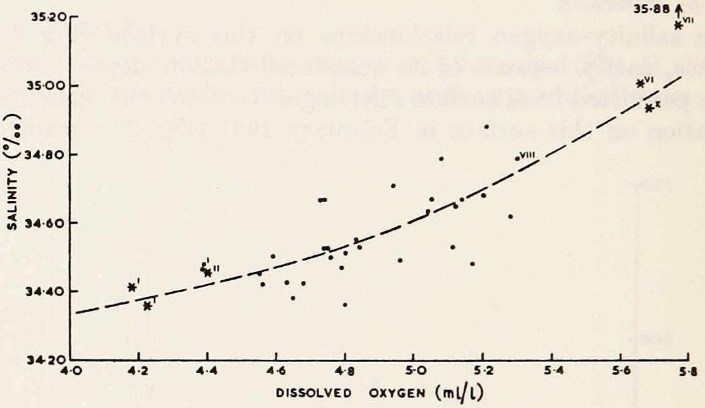


Figure 5. Salinity-oxygen relationships on the 27.20 $\sigma_t$ surface of waters west of Fremantle during 1948–1951. The asterisk indicates values selected for comparison with Fig. 10.

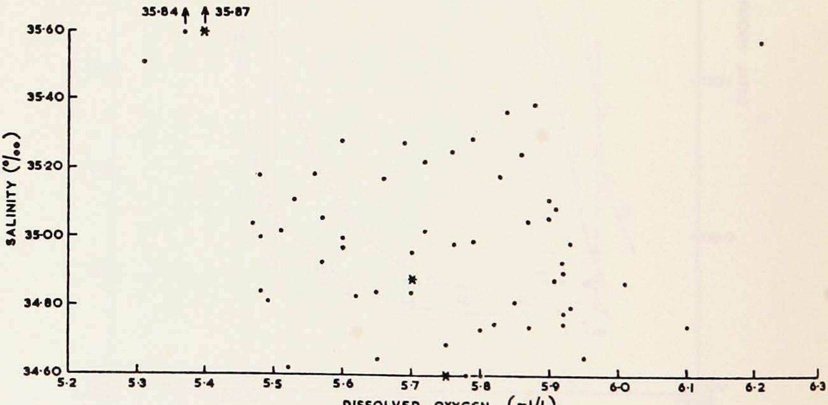


Figure 6. Salinity-oxygen relationships on the 26.80 $\sigma_t$ surface of waters west of Fremantle during 1948–1951. Asterisk indicates values selected for comparison with Fig. 14.

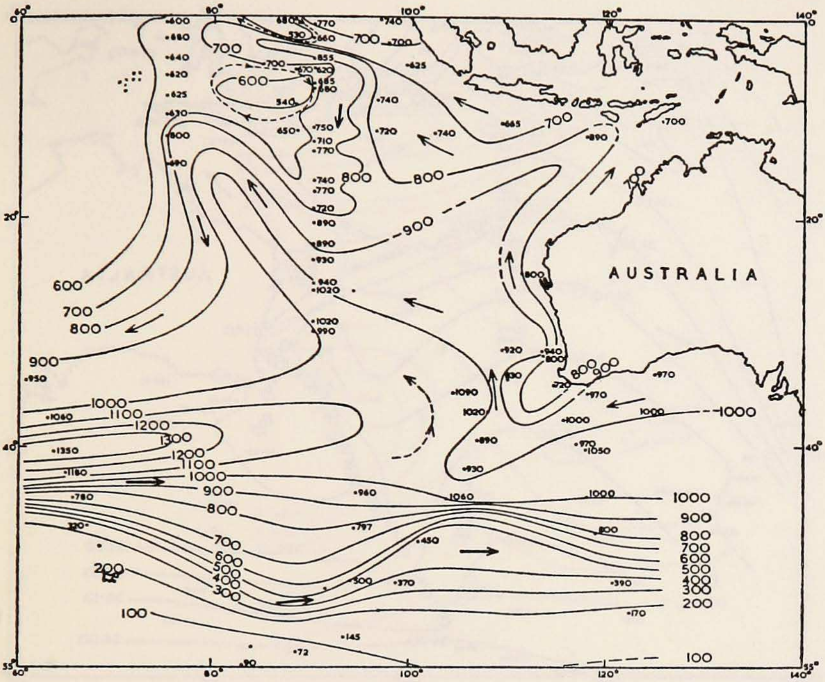


Figure 7. Bathymetry (m) of the 27.20 $\sigma_t$ surface. Arrows indicate major paths of flow.

## CHARACTERISTICS AND BATHYMETRY OF SELECTED ISOPYCNAL SURFACES IN THE SOUTHEAST INDIAN OCEAN

Table I shows that the available data were collected during all months of the year. To provide sufficient values for contouring, all of the data had to be used, regardless of the month of collection. The scatter in Figs. 5 and 6 shows that the month-to-month changes off Fremantle can be considerable. It is probable that some of the complexities in contour pattern described in this section may be due to neglect of such changes.

### 27.20 $\sigma_t$ Surface

*Bathymetry.* Fig. 7 shows that there was a strong flow to the east, south of Lat. 40° S, and that there was an anticlockwise movement around a centre at about 90° E, between 20 and 40° S; several smaller gyrals occurred to the north. Zonal flow was general south

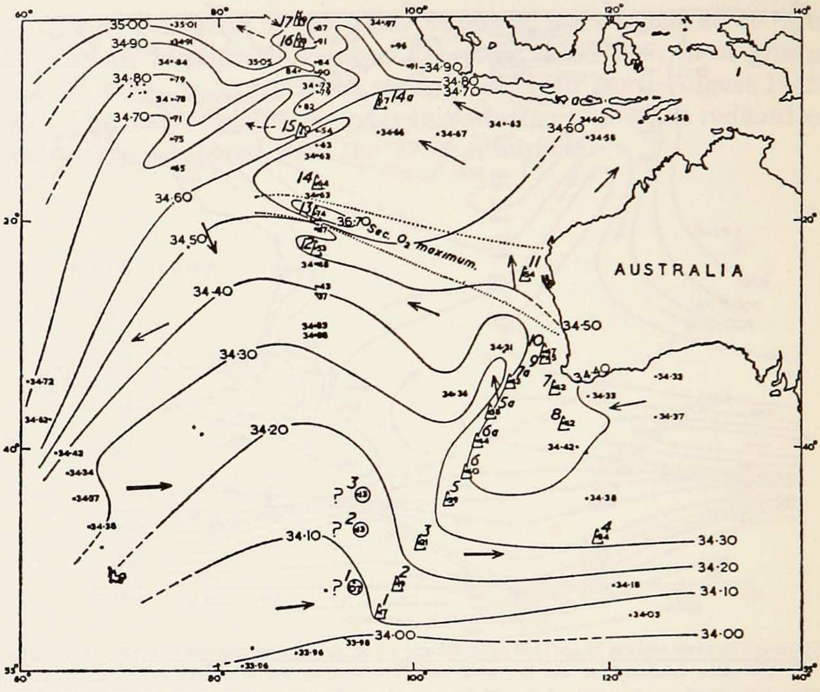


Figure 8. Distribution of salinity on the 27.20 $\sigma_t$ surface.

of 40° S and north of about 10° S, with quasimeridional movements between.

*Salinity*. South of Lat. 20° S, low salinity waters were found to the north along the 80° E meridian (Fig. 8). However, the DISCOVERY II data, from which the southernmost contours have been determined, are suspect (see *Salinity-Oxygen Relationship* below), hence the extent of these low salinity waters to the south of 40° S may have been much less than is indicated in Fig. 8. High salinities on the western side of the region were due to a southerly flow (Fig. 7) of waters of relatively high salinity from the Equator; low salinities on the eastern half of the region between 20 and 40° S must have been due in part to the northerly movement (Fig. 7) of low salinity waters from the south along this side.

*Oxygen*. Between Lat. 20–40° S the oxygen content of waters on this surface was less on the western than on the eastern side (Fig. 9).

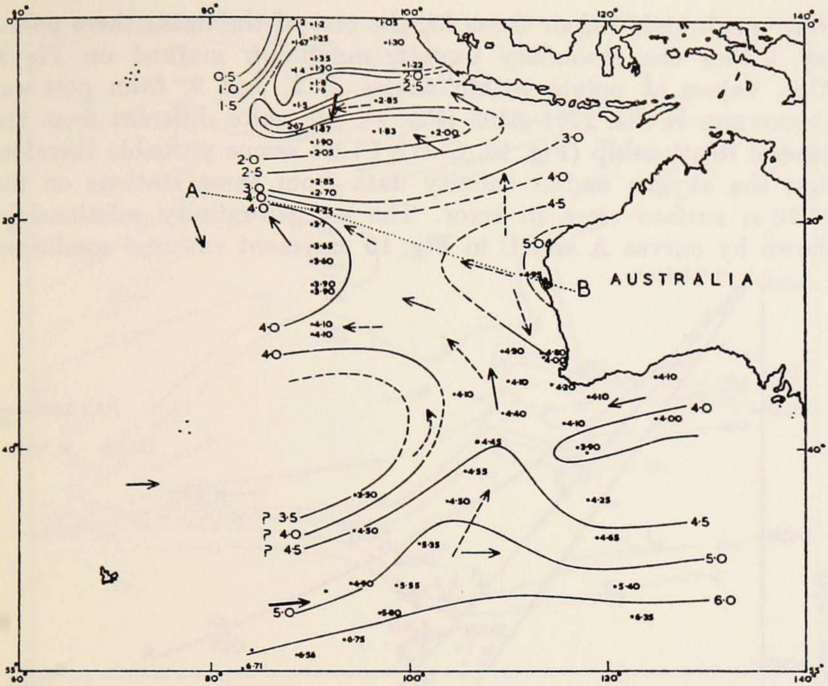


Figure 9. Distribution of oxygen on the 27.20 $\sigma_t$ surface. Full arrows, showing major paths of flow, are from Fig. 7. Dashed arrows indicate paths of flow of the more oxygenated waters.

The low oxygen values in the region west of 90° E, in about Lat. 45° S, were based on data from DISCOVERY II Sts. 2701–2703 (Fig. 1); it is possible that these values are too low (see *Salinity-Oxygen Relationship* below) and that no great significance can be attached to them. North of 20° S the oxygen distribution indicated zonal flow in agreement with previous evidence (Figs. 7 and 8). The WARREEN station off Shark Bay (Fig. 1) showed richer oxygen waters on this surface than elsewhere at the same latitude. Line AB of Fig. 9 indicates the probable centre of zonal movement of these oxygen-rich waters; however, north and south displacement also occurred. North of 20° S there was a sharp transition from waters of more than 4.0 ml/l oxygen to those of 2.0 ml/l or less.

*Salinity-Oxygen Relationships.* Fig. 10 shows the extent of oxygen variations in relation to salinity on the 27.20 $\sigma_t$ surface. Relative to salinity, oxygen values at points within triangles 10, 11, and 13 were much higher than those for the rest of the data; these points lay within the secondary oxygen maximum marked on Fig. 9. Also, values at points within circles 1, 2, and 3, from post-war DISCOVERY II Sts. 2701–2703 (Fig. 1), are quite different from the general relationship (Fig. 10, Curve C). It seems probable therefore that the oxygen and/or salinity data from these stations on the 27.20 $\sigma_t$ surface were in error. The oxygen-salinity relationships shown by curves A and C in Fig. 10 represent extreme conditions

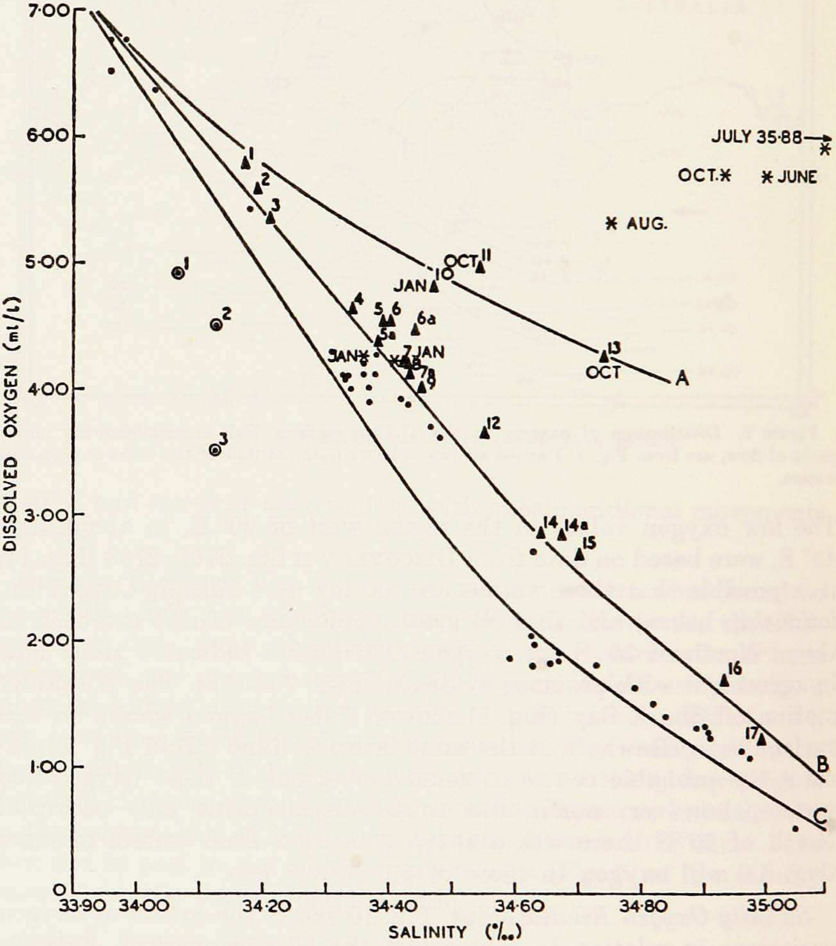


Figure 10. Salinity-oxygen relationships on the 27.20 $\sigma_t$ surface. Position of values within the numbered triangles and circles are given in Fig. 8. Asterisk values are taken from Fig. 5.

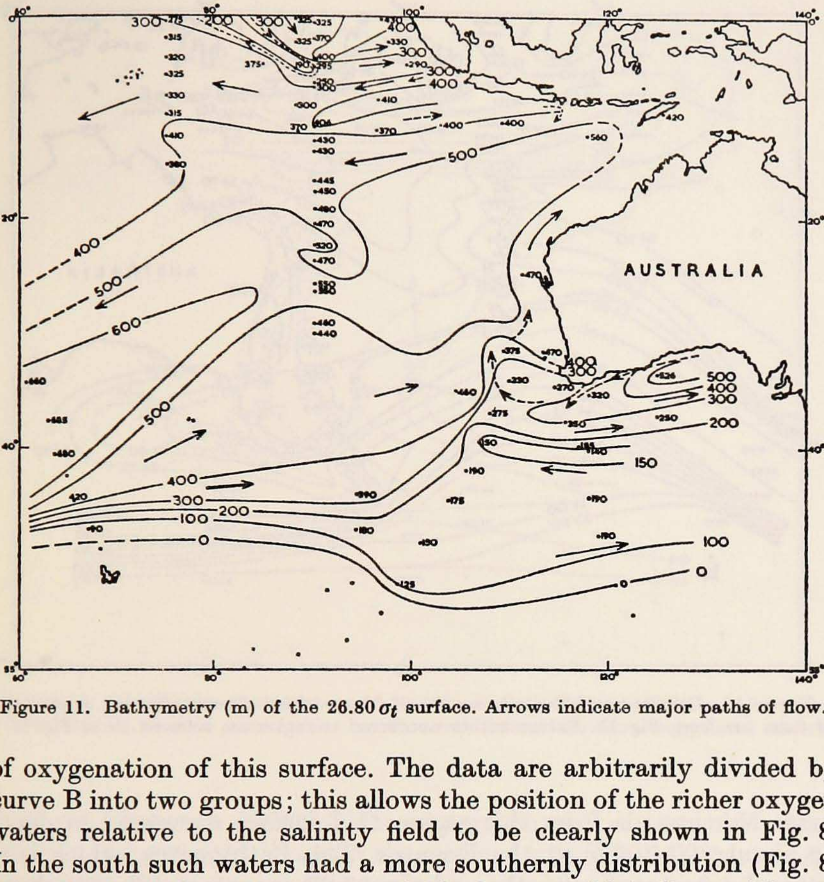


Figure 11. Bathymetry (m) of the 26.80 $\sigma_t$ surface. Arrows indicate major paths of flow.

of oxygenation of this surface. The data are arbitrarily divided by curve B into two groups; this allows the position of the richer oxygen waters relative to the salinity field to be clearly shown in Fig. 8. In the south such waters had a more southernly distribution (Fig. 8, triangles 5–8) than the oxygen field alone would indicate (Fig. 9). In the northern section the movement of these rich oxygen waters (Fig. 8, triangles 16 and 17) towards the Equator was more clearly demonstrated by this means than by the salinity (Fig. 8) or oxygen fields (Fig. 9). The high salinity, well oxygenated waters on this surface off Fremantle (Fig. 10, asterisk values) were not common, although values around line A (Fig. 10) were probably derivatives of such waters.

### 26.80 $\sigma_t$ Surface

*Bathymetry.* This $\sigma_t$ surface (Fig. 11) deepened from the surface, at about 45–50° S, to a maximum depth of 500–600 m along a region from about 40° S in the west to 15° S in the extreme east of the

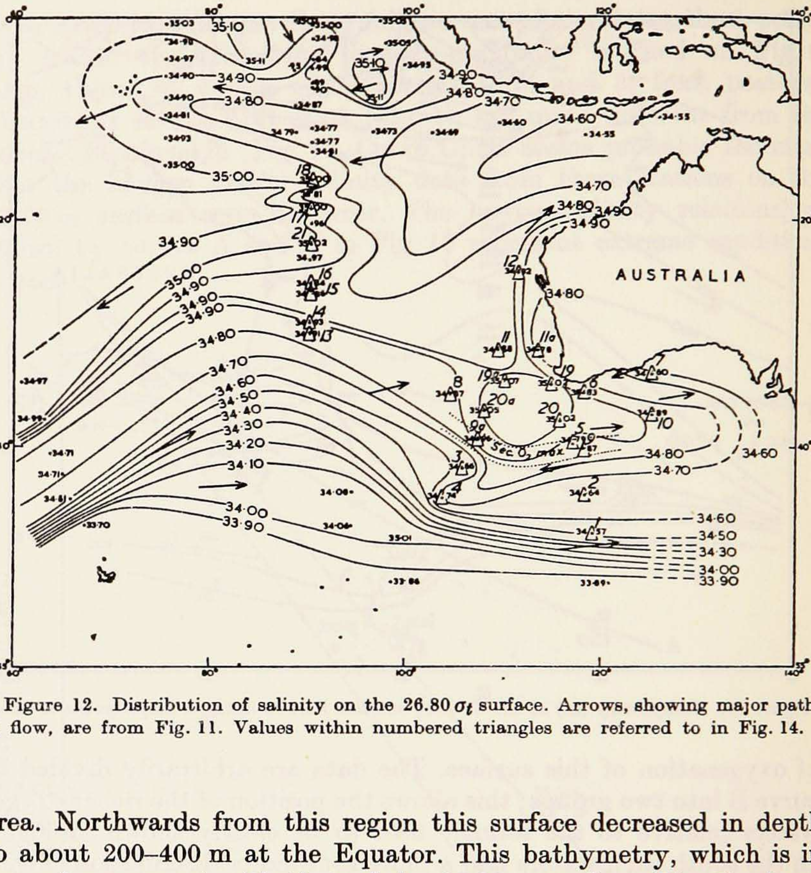


Figure 12. Distribution of salinity on the 26.80 $\sigma_t$ surface. Arrows, showing major paths of flow, are from Fig. 11. Values within numbered triangles are referred to in Fig. 14.

area. Northwards from this region this surface decreased in depth to about 200–400 m at the Equator. This bathymetry, which is in general agreement with that of the 27.20 $\sigma_t$ surface (Fig. 7), shows zonal flow to the east, south of 40° S, and an anticlockwise circulation around the region of maximum depth (Fig. 11). North of about 10° S there was an irregular boundary between eastward and westward movements at about 5° S.

*Salinity*. Maximum salinity gradients were found south of Lat. 40° S (Fig. 12) at a salinity of about 34.30 $^0/_{00}$. Off the southwest corner of Australia a region of high (near maximum) salinities was found. Between 0–20° S the salinity distribution was governed by the relative amounts of high salinity water from the west and north and by low salinity water from the region between northwest Australia and the Indonesian Archipelago.

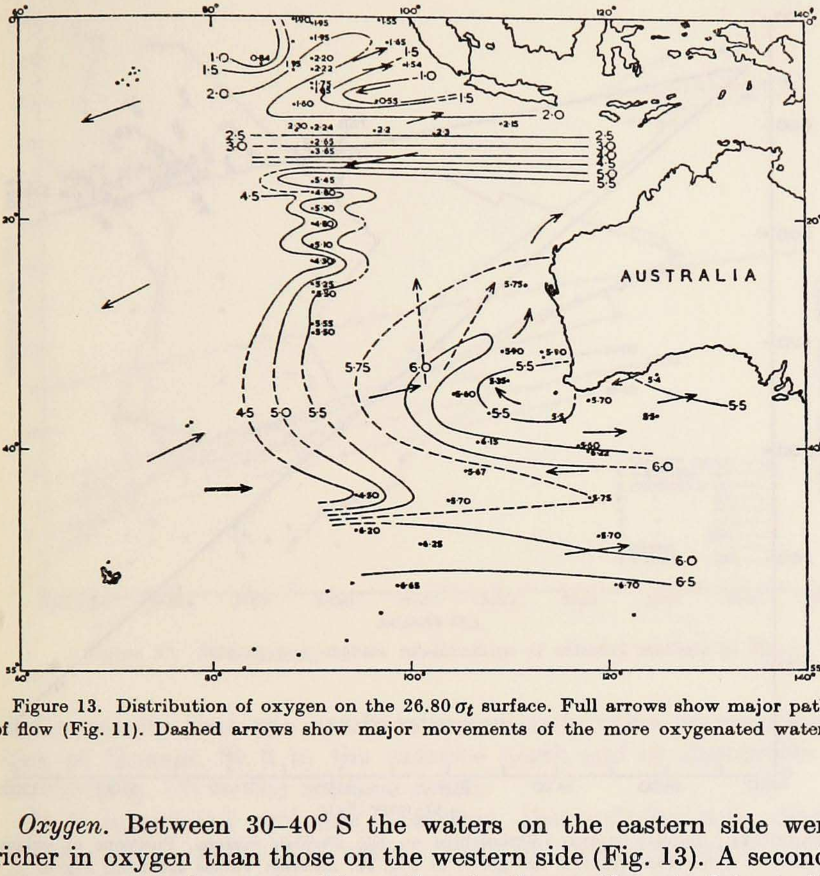


Figure 13. Distribution of oxygen on the 26.80 $\sigma_t$ surface. Full arrows show major paths of flow (Fig. 11). Dashed arrows show major movements of the more oxygenated waters.

*Oxygen.* Between 30–40° S the waters on the eastern side were richer in oxygen than those on the western side (Fig. 13). A secondary oxygen maximum on this surface to the southwest of Australia seemed to be the cause of this difference. North of 20° S there was a sharp transition from rich (greater than 4.0 ml/l) to poor (less than 2.0 ml/l) oxygenated waters.

*Salinity-Oxygen Relationship.* On this surface, oxygen values varied somewhat independently of salinity (Fig. 14). Lines AC and BC indicate that three kinds of water with different salinity-oxygen properties could have mixed around points A, B, and C (Fig. 14) and could have caused these variations in oxygen. Mixtures of A and C have been differentiated (Fig. 12, triangle values) and were found around the region of high salinity off southwest Australia, extending northwestwards to about 20° S and eastwards to the

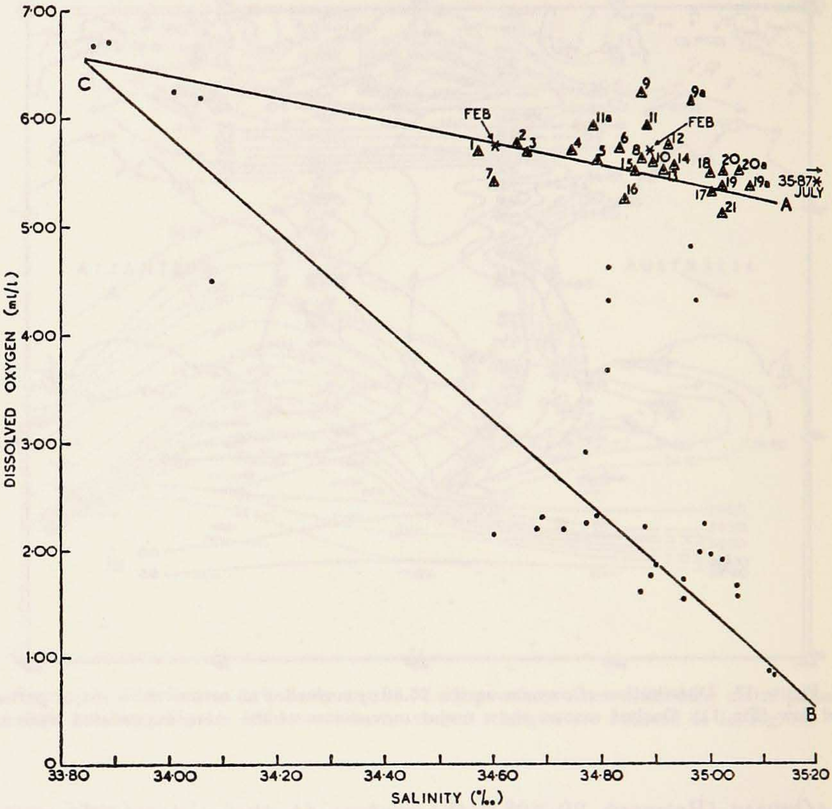


Figure 14. Salinity-oxygen relationships on the 26.80 $\sigma_t$ surface. Positions of values within the numbered triangles are given in Fig. 12. Asterisk values are from Fig. 6.

Australian Bight. Mixtures of B and C (Fig. 12, dot values) were found around the Equator and at all latitudes to the west of about 80° E.

## DISCUSSION

Salinity on the 27.20 $\sigma_t$ surface increased to the north of the region under investigation (Fig. 8). Fig. 15 shows the salinity-temperature characteristics of waters along the quasimeridional section (Fig. 1) selected to show the origin of these high salinity waters on this surface. Discovery II St. 2683 at the Equator (Fig. 1) had an oxygen content of 1.20 ml/l (Fig. 9) on the 27.20 $\sigma_t$ surface

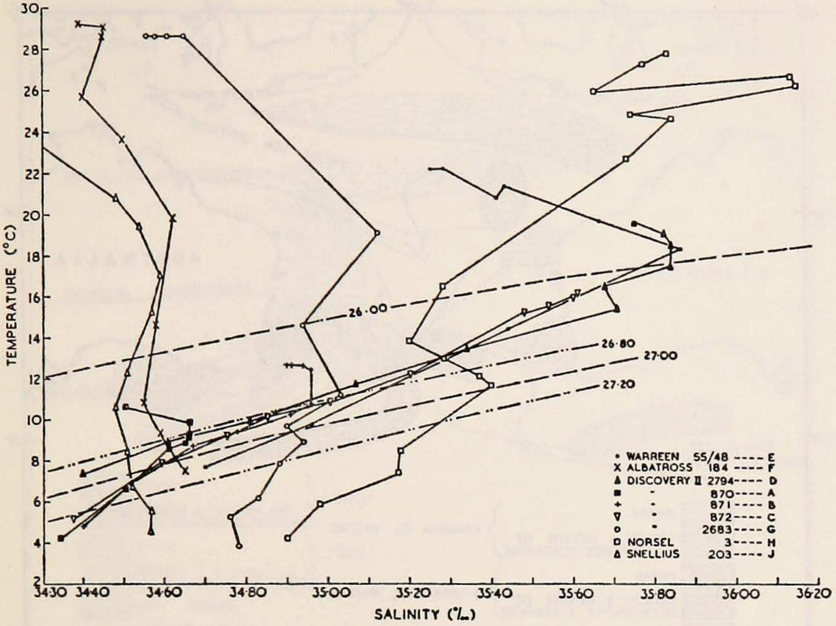


Figure 15. Salinity-temperature relationships of selected stations in Fig. 1.

and a salinity that was nearly intermediate in value between salinities at NORSEL St. 3 in the extreme north and at DISCOVERY II St. 870 (Fig. 15) in the extreme south.

It is considered probable, therefore, that salinity and oxygen characteristics of St. 2683 were formed by mixing between waters of the type found at the two extreme stations. The source region of the high salinity intermediate depth water at NORSEL St. 3, according to Tchernia (12), is the Arabian Sea. Tschernia also demonstrated the continuity of these Arabian Sea waters southwards of the Equator in the central Indian Ocean. The high salinity waters at the northern limits of the region under investigation will therefore be called Arabian Sea waters.

On the 26.80 $\sigma_t$ surface, high salinity waters poor in oxygen (Fig. 13) also occurred along the Equator (Fig. 12). These are also considered to be of Arabian Sea origin. However, on this surface, in intermediate latitudes, these were waters with a salinity minimum around 34.50 $^0/_{00}$ in the Banda and Timor Sea regions (Figs. 1 and 15, F and J). Thus the lowering of salinity on this surface was

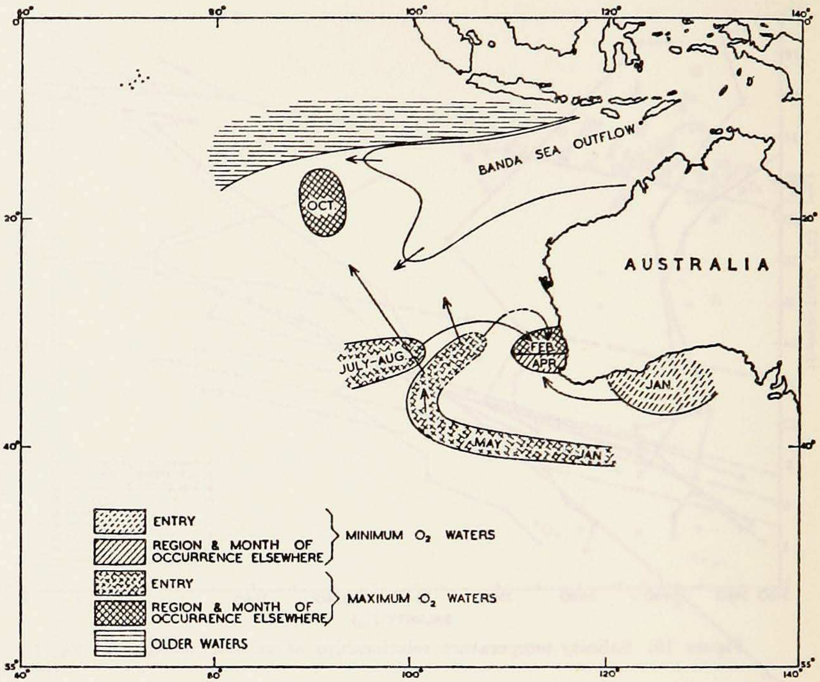


Figure 16. Seasonal movement and distribution of the principal types of water on the 26.80 $\sigma_t$ surface. Position of convergences from Schott (11).

caused not only by the introduction of upper sub-Antarctic intermediate waters (Fig. 15, DISCOVERY II St. 870) but by the outflow of low salinity waters from the Banda Sea (Fig. 15, SNELLIUS 203).

The dissolved oxygen of waters on the 27.20 and 26.80 $\sigma_t$ surfaces decreased rapidly at about Lat. 15° S (Figs. 9 and 13). This region formed a boundary between waters containing a high proportion of relatively recent surface waters (new) and those with a high proportion of relatively long isolated subsurface waters (old). With 4.0 ml/l as a boundary value, it is shown (Fig. 16) that on the 26.80 $\sigma_t$ surface the region from 90° to about 130° E, south of 15° S, contained new water.

On the 27.20 $\sigma_t$ surface, a similar distribution of new water was found, except westwards in Lat. 20–30° S (Fig. 17) and eastwards in Lat. 38–40° S into the Australian Bight. However, it is probable that the reduction in oxygen on this surface in the Australian Bight

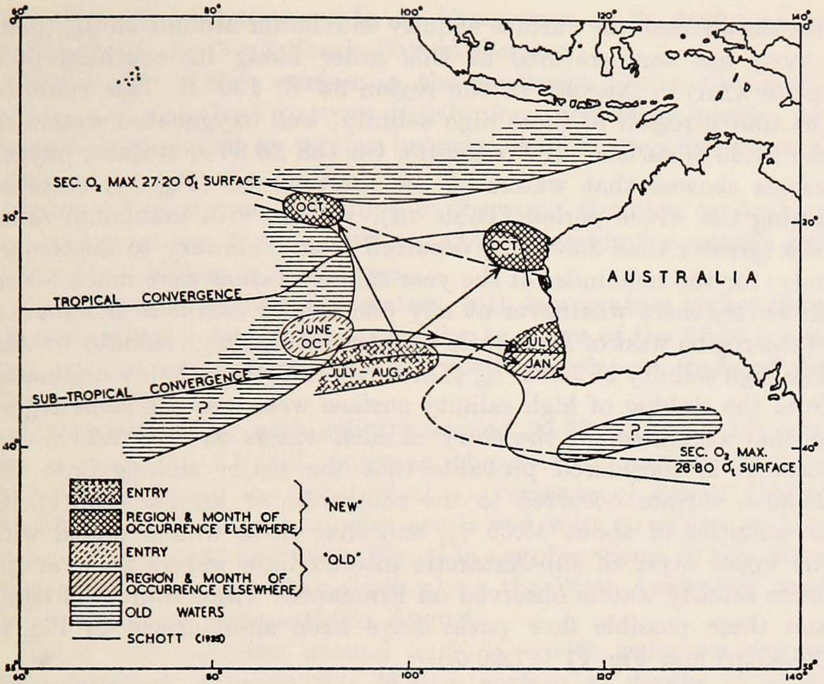


Figure 17. Seasonal movement and distribution of the principal types of water on the 27.20 $\sigma_t$ surface. Position of convergences from Schott (11).

was due to local oxygen demand and that these waters have no continuity with the old waters west of 90° E.

Fig. 4 indicates that new waters would contain less total phosphorus than the old. Upwelling or deep mixing down to 500–750 m in the region dominated by these new waters would enrich the nutrient level of surface waters less than such processes in regions with intermediate depth old waters. This, in part, may be the reason for the reduced nutrient level of the upper 500 m of waters off Fremantle compared with those off Sydney, noted previously by Rochford (10).

Salinities and oxygen values on the 27.20 $\sigma_t$ surface for waters west of Fremantle were minimal in January 1951 and maximal in July 1949 (Table II). In the former case these waters belonged to the low oxygen group of southeast Indian Ocean waters, and in the latter case to the high oxygen group (Fig. 10).

At a maximum salinity of 35.88 ‰, temperature of 12.5° C would be required at the surface to provide a source region. Schott (11) has shown that the surface salinity maximum around 36 ‰ (plate XXVII) has temperatures of this order along its southern limit (plate XXII) in August, in the region 32° S, 100° E. This could be the source region of these high salinity, well oxygenated waters on the 27.20 $\sigma_t$ surface off Fremantle. On the 26.80 $\sigma_t$ surface, oxygen values showed that waters of the mixture AC (Fig. 14) occurred during the whole period (Table III). Waters with maximum salinities (greater than 35.00 ‰) occurred from February to September only; for the remainder of the year salinity values were much lower. However, there was never at any one time a complete domination of the region west of Fremantle by either low or high salinity waters. The high salinity of 35.87 ‰ (Table III) 18/7/49 probably originated from the sinking of high salinity surface waters in the same region as that suggested for the entry of such waters on the 27.20 $\sigma_t$ surface. It is considered probable that the major sinking onto the 26.80 $\sigma_t$ surface occurred to the southwest of Fremantle (Fig. 12) at salinities of about 35.00 ‰ and that these waters mixed with the upper layer of sub-Antarctic intermediate waters to form the lower salinity waters observed off Fremantle. These sources of entry and these possible flow paths have been summarized in Fig. 16 (26.80 $\sigma_t$) and Fig. 17 (27.20 $\sigma_t$).

## CONCLUSIONS

(1) In the southeast Indian Ocean the distribution of salinity and dissolved oxygen on the 27.20 $\sigma_t$ surface is governed by mixing between the following three types of water:

High salinity (35.00–35.10 ‰), poorly oxygenated (0–1 ml/l) water of Arabian Sea origin which moves south (east of 80° E) and east (north of 10° S).

Sub-Antarctic intermediate water proper, with a surface salinity of less than 34.00 ‰ and an oxygen content greater than 6.0 ml/l, which moves strongly to the east, south of Lat. 40° S, but which has a significant northwards movement to the southwest and west of southwest Australia.

Water with a salinity greater than 35.00 ‰ and an oxygen content of about 5.50–6.00 ml/l which possibly enters the 27.20 $\sigma_t$ surface during July–August in the region southwest of Fremantle (Fig. 16), whence it apparently flows northeast to Fremantle by

July (Fig. 16) and then north to DISCOVERY II St. 2889 and to WARREEN St. 40/48 off Shark Bay in October.

(2) On the 26.80 $\sigma_t$ surface in the southeast Indian Ocean the salinity and dissolved oxygen distribution (neglecting surface exchanges) is governed by mixing between the following five types of water:

Arabian Sea waters, spreading in the same direction as Arabian Sea waters on the 27.20 $\sigma_t$ surface, and having similar oxygen and salinity but higher temperatures.

Sub-Antarctic intermediate waters, with temperature higher than, but with salinity characteristics similar to, those of the 27.20 $\sigma_t$ surface, moving east and north along paths similar to those of the 27.20 $\sigma_t$ surface.

Subtropical water with salinity around 35.00 $^0/_{00}$ and with oxygen content 5.5–6.5 ml/l, entering the 26.80 $\sigma_t$ surface between July–August along the subtropical convergence of Schott (11) to the east of 110° E, and moving north and west to arrive at DISCOVERY II Sts. 2889 and 2890 (Fig. 1) in October. Some of this water apparently recurves to the south along the West Australian coast and is found off Fremantle in August.

Water with salinities around 34.60 $^0/_{00}$ (with unknown oxygen characteristics), entering the 26.80 $\sigma_t$ surface at depths of about 500 m off Timor, moving west along the 10° S parallel, and becoming entrained in the path of the westward flowing subtropical waters at Lat. 15° S.

Water with salinities around 35.80 $^0/_{00}$, sinking along the eastern extremity of the maximum salinity region of the Indian Ocean (Fig. 17), and spreading eastwards.

(3) Off Fremantle, waters with a high proportion of Arabian Sea water are found on the 27.20 $\sigma_t$ surface in January–February (Fig. 10). For the greater part of the year, however, conditions on this surface are governed by mixing of sub-Antarctic intermediate water with high salinity waters entering this surface to the southwest of Fremantle.

(4) On the 26.80 $\sigma_t$ surface off Fremantle, only waters of recent sinking in the southwest Australian region occur. Waters of the low oxygen type found to the north of 20° S do not enter the Fremantle region.

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