Global water masses: summary and review

Water masses
Global distribution
Temperature
Salinity

Masses d'eau
Répartition globale
Température
Salinité

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ABSTRACT

Using published material the temperature-salinity characteristics of the world's water masses are defined for the upper, intermediate and deep/abyssal regions of the ocean. The global distributions and boundaries of these water masses are mapped along with indications of their formation regions. Representative temperature-salinity relationships are presented for each of the three major oceans.

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RÉSUMÉ

Les principales masses d'eau de l'océan mondial

Les caractéristiques température-salinité des masses d'eau de l'océan mondial ont été définies en compulsant les données publiées. Pour chacune des couches, superficielle, intermédiaire et profonde/abyssale, une carte indique la répartition globale, les limites et les zones de formation de ces masses d'eau. Les diagrammes température-salinité sont présentés pour chacun des trois grands océans.

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INTRODUCTION

It is surprising that while many oceanographic observations have been collected and analyzed since Sverdrup *et al.* (1942) published their familiar estimates of the global distributions of water masses very few new descriptions of these distributions have been attempted on a global scale. Many publications have examined the details of the water masses in particular regions but few have attempted to synthesize these regional studies into a comprehensive overview of the global distribution. As part of his treatise on TS analysis in the global ocean Mamayev (1975) reviewed the characteristic limits for the global water masses. In addition to his resulting table of global water mass characteristics Mamayev (1975) presents global maps of intermediate and deep water masses. Unfortunately these maps are reproduced on a very small scale and it is also difficult to determine the criteria used to define the water mass boundaries. The same problem arises in the characteristic TS values in his table of global water masses. This short note is an attempt to uptake the definitions and distributions of global water masses from the material presently available. The purpose is to present this updated global water mass summary in compact form rather than review all the regionally specific water masses that have been identified and studied.

In carrying out this effort two things were immediately apparent. First, as stated by Wright and Worthington (1970): "The nomenclature of the water masses in the North Atlantic Ocean has become bewilderingly confused in the past half century, although it is apparent that the water masses themselves have remained essentially the same."

This observation can be easily applied to other oceans as well and the abundance of water masses presently in use forces one to be selective and limit the description to what are, in broadest terms, the major water masses. The second most obvious fact is how well Sverdrup *et al.* (1942) did in estimating both the main water properties, in terms of their temperature-salinity (TS) characteristics, and in determining the global distributions of at least the upper layer waters. This is likely one of the main reasons why there has been no effort to improve on their earlier distribution which is widely available. Nevertheless, there are some important changes that have come to light through the analysis of both new and old data in the form of atlases and research papers. We draw upon these publications to first define temperature and salinity ranges for each of the major water masses for each ocean. Then we again turn to published presentations to estimate the horizontal distributions of these water masses for three vertical layers, the upper (0-500 m), the intermediate (500-1 500 m) and the deep/abyssal (1 500 m — bottom). It was decided to use the classical definition of vertical layers to separate the water masses since our goal was an update of existing distributions. Since most water masses trace their origin to the sea surface, this vertical separation is not going to hold everywhere and it may in general have been more appropriate to separate these water masses in terms of density.

A natural problem encountered in constructing our table and diagrams was the disparate nature of the data coverage in the northern and southern hemispheres. This is most acute in the South Pacific where few publications are available that treat the general water properties over this large, unsampled area. Here we were forced to use the few sections that were available to estimate our distributions. Fortunately, there are considerably more data and correspondingly more publications concerned with the South Atlantic. Nevertheless, it may be that the greater complexity in the North Atlantic, indicated for the water mass distribution (especially in the upper waters), reflects the greater degree to which the North Atlantic has been studied compared to the South Atlantic. Also the Antarctic or Southern Ocean, has been the focus of recent studies which greatly improved our knowledge of the water mass distribution in this important area. Finally, the Indian Ocean has been well summarized in the atlas by Wyrtki (1971) which provides a good description of the water properties.

WATER MASSES AND THEIR TEMPERATURE-SALINITY RANGES

The major water masses and their TS property ranges are presented here in the Table for the upper, intermediate and deep/abyssal waters. The surface waters of the Antarctic or Southern Ocean are treated separately in this table.

ATLANTIC OCEAN

Four dominant upper waters were identified for the Atlantic as shown in the Table. Farthest North the Atlantic Subarctic Upper Water (ASUW) was identified by Wright and Worthington (1970) in terms of source water for what they identified as Subarctic Intermediate Water and North Atlantic Intermediate Water (in our discussion all water mass names will be capitalized while only those we have listed in our summary table will receive an acronym title as well). Taking the values from these two components along with a TS diagram for the North Atlantic Intermediate Water by Wüst (1935) we arrived at the TS ranges of 0.0-4.0°C and 34.0-35.0. Here we note that neither the Subarctic Intermediate Water nor the North Atlantic Intermediate Water are identified in our summary. They have been replaced by the Eastern and Western Subarctic Intermediate Waters and the Mediterranean Water, as will be discussed later.

The main upper waters of the central North Atlantic were separated into the Eastern North Atlantic Central Water (ENACW) and the Western North Atlantic Central Water (WNACW). These water masses and their characteristics (Tab.) were selected from the maps of Worthington (1976) and Defant (1936), the sections of Fuglister (1960), the volume census of Wright and Worthington (1970), the TS curves of Emery and Dewar (1982), the study by Harvey (1982) and the recent analysis of Pollard and Pu (1985). Here Wright and Worthington (1970) point out that the Western North Atlantic Central Water (WNACW), with a temperature range from 7.0-20.0°C and salinities from 35.0-36.7, really corresponds to the North Atlantic Central Water identified by Sverdrup *et al.* (1942). The differentiation between Western and Eastern Central waters expresses the physically different characteristics of the eastern and western portions of the northern subtropical gyre circulation. In the western part, which is dominated by the intense recirculation of the Gulf Stream System, relevant isopycnals are generally deeper than in the eastern basin. Thus the Western North Atlantic Central Water (WNACW) is in closer contact with the fresher underlying subpolar intermediate water (the Western Atlantic Subarctic Intermediate Water, WASIW) while in the northeast winter convection is able to directly transfer salt from the surface layer into the central water resulting in salinities for the Eastern North Atlantic Central Water (ENACW) being on the average 0.1-0.2 higher. The higher salinity may also reflect the influence of the Eastern Atlantic Subarctic Intermediate Water (EASIW), which is saltier due to its proximity to Mediterranean Water (MW).

To the south the North Atlantic Central Waters transition into the South Atlantic Central Water (SACW) at about 15°N (Tomczak, 1984*a* and *b*). The TS characteristics of the SACW were taken from the maps of Defant (1936) and the sections of Wüst (1935) and Fuglister (1960). The resulting temperature range is 5.0 to 18.0°C with a salinity range of 34.3 to 35.8. This water mass is very similar to that identified for the South Atlantic upper layer by Sverdrup *et al.* (1942).

Five intermediate waters were identified in the Atlantic. Four can be identified as salinity minima, due to their formation in subpolar regions, and one signifies its presence as a salinity maximum due to its formation through high evaporation in a marginal sea. Among the fresh intermediate waters, coming from the north, the Arctic Intermediate Water (AIW) plays a special role since in the region of the Greenland-Scotland sill it becomes a major constituent of the Denmark Strait and Iceland-Scotland overflowes thus becoming a source for North Atlantic Deep Water (NADW). The two intermediate waters formed south of the Greenland-Scotland sill show significant salinity differences between the western and eastern basins. Whereas the TS characteristics of the Western Atlantic Subarctic waters flow unimpeded around Antarctica while in the Pacific the narrow Drake Passage forces Subantarctic Water (SSW) along the coast of South America.

Likewise in the North Pacific subarctic water flows south along the North American west coast. In the North Atlantic the analog subpolar water is bound up in the processes of intermediate and deep water formation.

All of the four intermediate waters in the Pacific are fresh in their origin and can be identified as salinity minima. The low salinities (33.8-34.3) of the Pacific Subarctic Intermediate Water (PSIW) are due to the input of surface fresh water from high levels of precipitation and runoff in the northern North Pacific (Royer, 1982). While this salinity range is similar to that of the Antarctic Intermediate Water (AAIW) in the Pacific (33.8-34.5) the Subarctic Intermediate Water (SIW) is somewhat warmer with temperatures between 5.0 and 12.0°C compared to 2.0 to 10.0°C for the AAIW.

The presence of two eastern intermediate waters is due to the existence of the eastern transition waters in the upper layers. Discussed by Tsuchiya (1968) the California Intermediate Water (CIW) again has temperature and salinity ranges (10.0-12.0°C, 33.9-34.4) contained within those of the Pacific Subarctic (PSIW) and Antarctic Intermediate (AAIW) Waters. On the basis of its TS relationship Kuska and Emery (1976) were able to identify this California Intermediate Water (CIW) in data collected as far away as Hawaii. The Eastern South Pacific Intermediate Water (ESPIW) is less documented; Mamayev clearly identifies an Eastern South Pacific Subtropical Intermediate Water, and Reid (1973) identifies an intermediate water, in the South Pacific, characterized by a salinity minimum. Again the TS characteristics of this intermediate water are found within the ranges of the other Pacific intermediate waters.

As mentioned earlier the deep and abyssal waters of the Pacific are lumped into the Circumpolar Deep Water (CDW) with the same characteristics (0.1-2.0°C, 34.62-34.73) as were assigned to the CDW in the Indian Ocean.

CIRCUMPOLAR SURFACE WATERS

Since they are found at the surface of all southern extensions of the three main oceans Subantarctic Surface Water (SASW) and Antarctic Surface Water (AASW) were considered as circumpolar surface waters and listed separately to save repetition. In their recent review of water masses in the Drake Passage, Sievers and Nowlin (1984) discuss the presence of both the SASW, which they associated with the Subantarctic Mode Water of McCartney (1977), and the AASW. The ranges of these water masses in the Drake Passage are smaller than, but are contained within, those given here in the Table. The continued presence of these water masses in other sectors of the Southern Ocean was suggested by Gordon *et al.* (1974) and by Emery (1977). Here it will be assumed that while the amounts of the water masses present may vary around the Antarctic these surface water masses can be identified in all sectors of the Southern Ocean. It should be noted that these upper waters can be distinguished primarily by their temperatures in that the Antarctic Surface Water (AASW) is much colder (—1.0-1.0°C) than the Subantarctic Surface Water (SASW) with temperatures from 3.2 to 15.0°C. Also the SASW is in general more saline than the AASW.

GLOBAL HORIZONTAL DISTRIBUTION

Before discussing the water mass distribution maps it should be mentioned here that some subjective judgement was exercised in selecting the precise distributions presented. It would not have been possible to achieve a global perspective if rigid water mass guidelines had been adopted since general conditions and data coverages vary so greatly. Instead an effort has been made to best represent, in a broad sense, what is known of water mass distributions from both recent and earlier studies. Thus it is not possible to define precisely the amount of the subject water mass present at the boundary shown nor estimate how much might extend beyond the boundary. An additional complexity occurs in areas where different water masses overlie each other within our selected depth ranges. For example the horizontal separation between Mediterranean Water and Eastern Atlantic Subarctic Intermediate Water does not take place at all depths. As we know the boundaries are in reality not single lines but rather relatively broad zones covering the final region of horizontal mixing of the candidate water mass characteristics. At present the information is not available to even approximately guess at the spatial coverage and distribution of these mixing zones.

UPPER WATERS (0-500 M)

Using a map projection similar to that employed by Sverdrup *et al.* (1942; Fig. 209A) we present our estimate of the distribution of the upper waters (Fig. 1) listed in the Table. Boundaries between water masses are indicated by a heavy solid line while formation regions are marked by hatching. The general areas, labelled with the names of the upper water mass, often in abbreviation form, and the formation regions are cross hatched and labelled with the corresponding acronymns. The source documents for determining this distribution are those listed above in discussing the definition of the water mass TS properties.

Comparison of this figure with that from Sverdrup *et al.* (1942) reveals how little this distribution of upper waters has changed in spite of the substantial amount of data collection and analysis that has taken place in recent years. Significant changes are seen in the Indian Ocean and important differences exist in the North Pacific and North Atlantic. In all three areas the research activity has provided us with improved resolu-

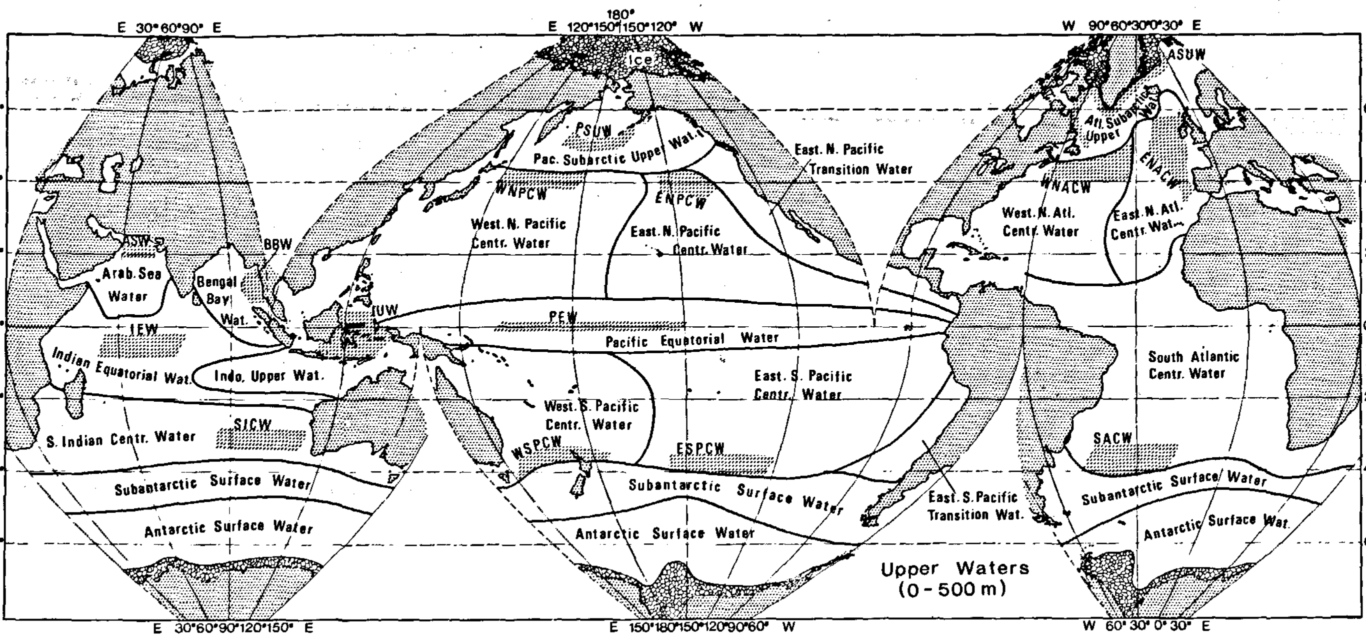

Figure 1

Global distribution of upper waters (0-500 *m*). *Water masses are labelled in abbreviated form with their boundaries indicated by solid lines. Formation regions for these water masses are marked by cross hatching and labelled with the corresponding acronym title.*

tion of these upper water masses and their formation mechanisms. Still it should be noted that many of these formation processes are not that clearly defined and we have been very general in assigning formation regions to the water masses.

In the broadest terms the upper layer water mass distribution corresponds to the mean circulation pattern at the surface. The western central waters are associated with the main subtropical gyres bounded by the polar surface waters at higher latitudes. Here fresh waters from precipitation, runoff and ice melt contribute to form the cold fresh surface waters that subsequently sink to form intermediate waters. Unique to the Pacific are the eastern boundary transition zones where somewhat different intermediate waters are also formed. In the Pacific and Indian Oceans there are distinct equatorial surface waters for which an analog cannot be found in the Atlantic. This is likely due to the influence of the nonsymmetrical geographic boundaries in the Atlantic contributing to strong cross-equatorial surface water exchange. Also in the northern part of the Indian Ocean geography plays the dominant role in the isolation of the salty Arabian Sea Water (ASW) and the fresh Bengal Bay Water (BBW). At its southeastern end this Bengal Bay Water (BBW) is difficult to distinguish from the Indonesian Upper Water (IUW) intruding from the east. In Wyrtki's (1971) maps of upper layer properties this Indonesian Upper Water (IUW) is expressed as a tongue of low salinity and high silicate.

In the Southern Ocean the circumpolar surface waters are defined by the Subantarctic Surface Water (SASW) being north of the Subantarctic Front and the Antarctic Surface Water (AASW) being south of the Polar Front. Here a separate formation region has not been identified since the SASW forms all along this area just north or the Subantarctic Front. The transition water of the variable zone between the Subantarctic and Polar fronts (Emery, 1977; Sievers, Emery, 1978) has not been identified as a separate water mass nor is it indicated on Figure 1. The Antarctic Surface Water (AASW) farthest south, forms all along the ice margin of the Antarctic and thus is also not shown with a separate formation region.

INTERMEDIATE WATERS (500-1 500 M)

Using the same map projection as Figure 1 the distribution of intermediate waters is presented here in Figure 2. Unfortunately Sverdrup *et al.* (1942) did not provide a map of the intermediate waters and the only map we could locate for comparison was in Mamayev (1975, Fig. 103). While there are many similarities between Mamayev's figure and our Figure 2 the correspondance is nowhere near as favorable as was found between our Figure 1 and the map of upper waters from Sverdrup *et al.* (1942).

In general the boundaries of the intermediate waters were identified by the scatter and spread in the TS curves (Emery, Dewar, 1982 for the North Pacific and North Atlantic and Wyrtki, 1971 for the Indian Ocean). In the South Atlantic the TS curves, sections and horizontal maps of Wüst (1935) were helpful while in the South Pacific estimates were roughly made from the sections in Reid (1965) and Warren (1973). The existence of the Eastern South Pacific Intermediate Water (ESPIW) was argued mainly by analogy with the North Pacific and the distribution inferred from that of Mamayev (1975) who also identified an Eastern Pacific Intermediates Water. The formation region of the Antarctic Intermediate Water (AAIW) corresponds roughly to the transition zone between the Subantarctic and Antarctic Polar Fronts called the Antarctic Polar Front Zone by Gordon (1971). From the property

Intermediate Water (WASIW) are 3.0-9.0°C, 34.6-35.0, the salinity of the Eastern Atlantic Subarctic Intermediate Water (EASIW) is higher by 0.2, TS ranges 3.0-9.0°C, 34.8-35.3) due to enhanced contact with the underlying Mediterranean Water (MW).

The intermediate waters of the North Atlantic owe their wide range of salinities to contributions from a wide range of latitudes, a consequence of the asymmetry of the northern subtropical gyre circulation, and to the large number of source waters (Labrador Sea, Norwegian-Greenland Sea, Mediterranean and South Atlantic Intermediate Water) contributing to them. There is a geographical separation between the Arctic Intermediate Waters which represents the formation region of other components of the North Atlantic Deep Water (NADW). Thus these various regional waters (Irminger Sea Intermediate Water, Labrador Sea Intermediate Water, *etc.*) occupy the intermediate portion of the water column; this detailed structure is beyond the scope of our general review. It should, however, be mentioned here that much of the Western Atlantic Subarctic Intermediate Water (WASIW) is composed of Labrador Sea Water which forms north of the WASIW formation region, spreads south at intermediate depths, and can be Atlantic-Indian Ocean basin and the south Sandwich trench. They further say that no single abyssal water type exists around Antarctica and the range of temperatures and salinities for AABW correspond to mixtures of these circumpolar bottom waters.

We have to consider the deep and bottom water of the Norwegian-Greenland Seas and the Arctic Ocean System as a distinctly separate water mass (Arctic Bottom Water, ABW). Locked off from the rest of the world ocean by the Greenland-Scotland ridge system the Arctic Bottom Water TS characteristics are severely limited to −1.8 to −0.5°C and 34.88 and 34.94.

Table
Temperature-salinity characteristics of the world's water masses.

Layer	*Atlantic Ocean*	*Indian Ocean*	*Pacific Ocean*
Upper waters (0-500 m)	Atlantic Subarctic Upper Water (ASUW) (0.0-4.0°C, 34.0-35.0)	Bengal Bay Water (BBW) (25.0-29°C, 28.0-35.0)	Pacific Subarctic Upper Water (PSUW) (3.0-15.0°C, 32.6-33.6)
	Western North Atlantic Central Water (WNACW) (7.0-20.0°C, 35.0-36.7)	Arabian Sea Water (ASW) (24.0-30.0°C, 35.5-36.8)	Western North Pacific Central Water (WNPCW) (10.0-22.0°C, 34.2-35.2)
	Eastern North Atlantic Central Water (ENACW) (8.0-18.0°C, 35.2-36.7)	Indian Equatorial Water (IEW) (8.0-23.0°C, 34.6-35.0)	Eastern North Pacific Central Water (ENPCW) (12.0-20.0°C, 34.2-35.0)
	South Atlantic Central Water (SACW) (5.0-18.0°C, 34.3-35.8)	Indonesian Upper Water (IUW) (8.0-23.0°C, 34.4-35.0)	Eastern North Pacific Transition Water (ENPTW) (11.0-20.0°, 33.8-34.3)
		South Indian Central Water (SICW) (8.0-25.0°C, 34.6-35.8)	Pacific Equatorial Water (PEW) (7.0-23.0°C, 34.5-36.0)
			Western South Pacific Central Water (WSPCW) (6.0-22.0°C, 34.5-35.8)
			Eastern South Pacific Central Water (ESPCW) (8.0-24.0°C, 34.4-36.4)
			Eastern South Pacific Transition Water (ESPTW) (14.0-20.0°C, 34.6-35.2)
Intermediate waters (500-1 500 m)	Western Atlantic Subarctic Intermediate Water (WASIW) (3.0-9.0°C, 34.0-35.1)	Antarctic Intermediate Water (AAIW) (2-10°C, 33.8-34.8)	Pacific Subarctic Intermediate Water (PSIW) (5.0-12.0°C, 33.8-34.3)
	Eastern Atlantic Subarctic Intermediate Water (EASIW) (3.0-9.0°C, 34.4-35.3)	Indonesian Intermediate Water (IIW) (3.5-5.5°C, 34.6-34.7)	California Intermediate Water (CIW) (10.0-12.0°C, 33.9-34.4)
	Antarctic Intermediate Water (AAIW) (2-6°C, 33.8-34.8)	Red Sea-Persian Golf Intermediate Water (RSPGIW) (5-14°C, 34.8-35.4)	Eastern South Pacific Intermediate Water (ESPIW) (10.0-12.0°C, 34.0-34.4)
	Mediterranean Water (MW) (2.6-11.0°C, 35.0-36.2)		Antarctic Intermediate water (AAIW) (2-10°C, 33.8-34.5)
	Arctic Intermediate Water (AIW) (−1.5-3.0°C, 34.7-34.9)		
Deep and abyssal waters (1 500 m — bottom)	North Atlantic Deep Water (NADW) (1.5-4.0°C, 34.8-35.0)	Circumpolar Deep Water (CDW) (0.1-2.0°C, 34.62-34.73)	Circumpolar Deep Water (CDW) (0.1-2.0°C, 34.62-34.73)
	Antarctic Bottom Water (AABW) (−0.9-1.7°C, 34.64-34.72)		
	Arctic Bottom Water (ABW) (−1.8- −0.5°C, 34.88-34.94)		
		Circumpolar Surface Waters	Subantarctic Surface Water (SASW) (3.2-15.0°C, 34.0-35.5)
			Antarctic Surface Water (AASW) (−1.0-1.0°C, 34.0-34.6)

INDIAN OCEAN

In the Indian Ocean the information on the water mass structure has improved dramatically due largely to the international Indian Ocean Expedition and the resulting oceanic atlas by Wyrtki (1971). In his table of upper ocean waters Mamayev (1975, Table XV) lists four water masses for the Indian Ocean. We have increased that to five (Tab.) to include Arabian Sea Water (ASW) with its high salinities between 35.5 and 36.8 over a temperature range of 24.0 to 30.0°C. The surface layer fresh water component is Bengal Bay Water (BBW) having salinities from 35.0 down to 28.0 over a similar temperature range. Both of these upper layer water masses are absent in the description by Sverdrup *et al.* (1942).

The two Indian Ocean upper layer waters that were identified by Sverdrup *et al.* (1942) are in the Indian Equatorial Water (IEW) and South Indian Central Water (SICW) which they called Indian Central Water. Both of these water masses have the same temperature range of 8.0-25.0°C but the equatorial water is somewhat less salty with a salinity range from 34.6 only up to 35.2 while the central water goes up to 35.8. Also in this range is the Indonesian Upper Water (IUW) which Mamayev (1975) called Timor Sea Water and Wyrtki (1971) generally classified as Indonesian waters.

Again the intermediate waters can be separated into those with a fresh water signature and those that are salty. The salinity maximum Red Sea-Persian Gulf Intermediate Water (RSPGIW) salinities range from 34.8 to 35.4, which is a much smaller range than for Mediterranean Water (MW) in the Atlantic. The temperature range of the RSPGIW is higher than that of the MW. The Antarctic Intermediate Water (AAIW), in the Indian Ocean, has a slightly smaller and colder temperature range but the same salinity range as the Antarctic Intermediate Water (AAIW) found in the Atlantic (Tab.). Intruding from the east is Indonesia Intermediate Water (IIW) with its temperatures from 3.5 to 5.5°C and salinities from 34.6 to 34.7. It is often difficult to distinguish the horizontal distribution of this water mass in the mid-depth plots by Wyrtki (1971) on the basis of salinity but similar maps of silicate clearly define the distinct distribution of this water mass.

Deep and abyssal water is a mix between deep and bottom waters from other regions which we have lumped together here under the title of Circumpolar Deep Water (CDW) with temperatures from 0.1 to 2.0°C and salinities from 34.62 to 34.73. Since this is the most abundant water mass in the world's ocean, Montgomery (1958) gave it the name common water. More recently, Broecker *et al.* (1985) has used chemical evidence to suggest that the common water is produced by the mixing of waters entering the Antarctic region, at mid-depths, from the Indian, Pacific and Atlantic with Weddell Sea bottom water. They conclude that the common water is composed of 45% Weddell Sea water, 30% Pacific and Indian Ocean intermediate waters and 25% deep water from the north Atlantic. Since almost half of the CDW is comprised of Weddell Sea water, the source also of AABW, we don't list it (CDW) as an Atlantic water mass. As demonstrated by Warren (1981) it is possible to resolve details in the component deep and abyssal waters but this is beyond the goal of the present study.

PACIFIC OCEAN

While, in the absence of northern source regions, the deeper waters of the Pacific are again lumped together into a single water mass the surface and intermediate waters are more numerous and complex. This reflects the larger extent of this ocean, its symmetry and the corresponding clearer zonality in the formation and spreading of upper layer water masses. In addition the eastern Pacific, in both hemispheres, is the location of unique upper layer transition waters and the formation of intermediate waters along the eastern boundary. Both these upper and intermediate waters are the products of subpolar waters advected equatorward along the eastern boundary (Sverdrup *et al.*, 1942) mixed with coastal waters influenced by upwelling.

In the upper layer the North Pacific contains the relatively fresh (32.6-33.6) and cold (3.0-15.0°C) Pacific Subarctic Upper Water (PSUW) along with its consequent Eastern North Pacific Transition Water (ENPTW). Representing a transition from the fresh cold subarctic waters to the warmer, saltier, central waters the Eastern North Pacific Transition Water (ENPTW) has a salinity range from 33.8 to 34.3 and a temperature range from 11.0 to 20.0°C (Emery, Dewar, 1982; Roden, 1972). The Eastern North Pacific Central Water (ENPCW) and the Western North Pacific Central Water (WNPCW) both have similar temperature and salinity ranges but can be distinguished by their TS relationships (Emery, Dewar, 1982). Also identifiable by its TS characteristics is the Pacific Equatorial Water (PEW) with its relatively high salinities (34.5-36.0) in its subsurface salinity maximum.

In the South Pacific the published material is decidedly sparse due to the relative lack of data coverage and we relied heavily on the sections in Reid (1965) and Warren (1973). Following the pattern in Sverdrup *et al.* (1942) an Eastern South Pacific Transition Water (ESPTW), with temperatures of 14.0-20.0°C and salinities of 34.6-35.2, was identified to represent the transition between salty (34.4-36.4) Eastern South Pacific Central Water (ESPCW) and the influence from the fresher Subantarctic Surface Water (listed here as SASW under circumpolar surface waters). The Eastern South Pacific Central Water (ESPCW) is separated by a surface salinity minimum from the somewhat cooler (6.0-22.0°C versus 8.0-23.0°C) and fresher 34.5-35.8 *versus* 34.4-36.4) Western South Pacific Central Water (WSPCW). The unique presence of these transition waters, in the eastern Pacific, reflects the strong connection between the subtropics and the subpolar region. In the South Atlantic and Indian Oceans the subantarctic distributions and sections in the atlas by Wyrtki (1971) the strong front between the fresh AAIW and the salty RSPGIW could be clearly identified and located.

DEEP AND ABYSSAL WATERS (1 500 M-BOTTOM)

Since a single Circumpolar Deep Water (CDW) covers the deep regions of both the Pacific and Indian Oceans these basins display no separate deep water. Instead we have used Figure 3 to primarily show the distribution of abyssal water as suggested by the near-bottom silica distribution given by Mantyla and Reid (1983). This abyssal water distribution reflects the influence of bottom topography in dictating the flow paths for this near bottom water mass. This bottom water distribution is consistent with that given much earlier for the Atlantic by Wüst (1935) and that developed more recently for the global ocean by Broecker and Peng (1982). In the Atlantic the formation region for the north Atlantic Deep Water (NADW) is shown and then a dashed line is drawn around the Antarctic suggesting the latitude at which the NADW ascends to mix with Antarctic waters and is transported around the Antarctic to become the primary constituent of Circumpolar Deep Water (CDW).

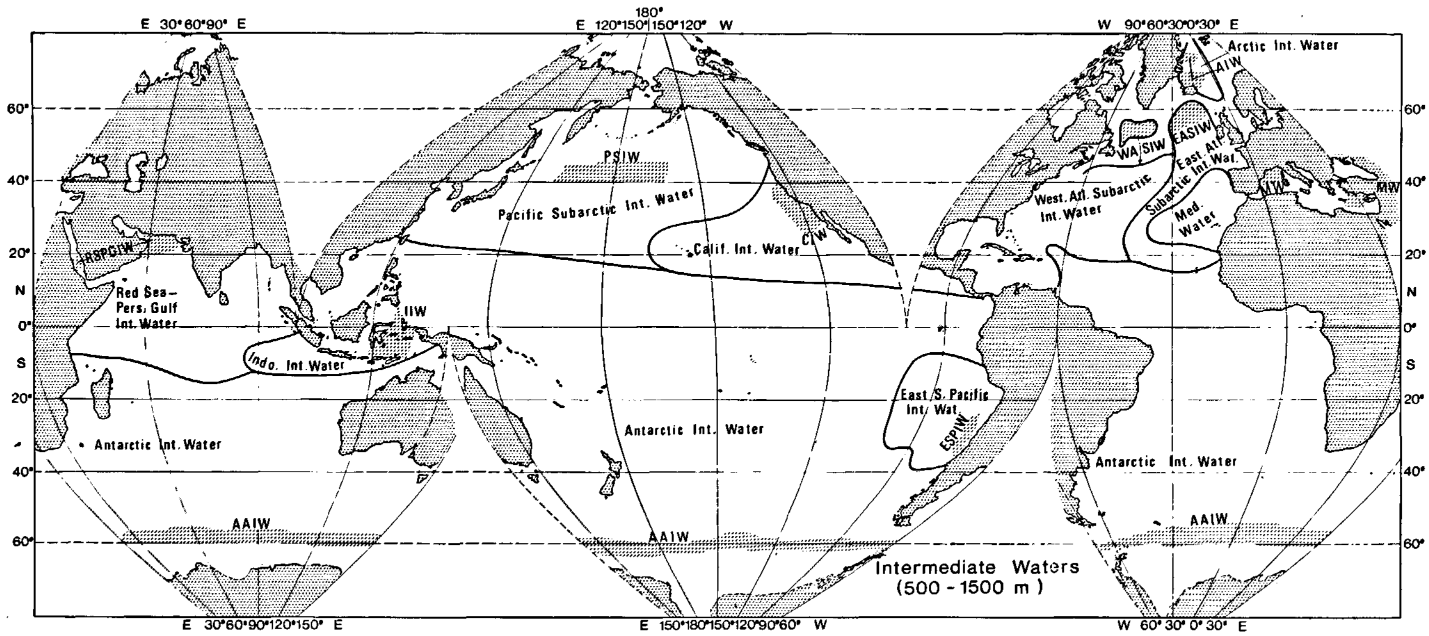

Figure 2
Global distribution of intermediate water (550-1 500 m). Lines, labels and hatching follow the same format as described for Figure 1.

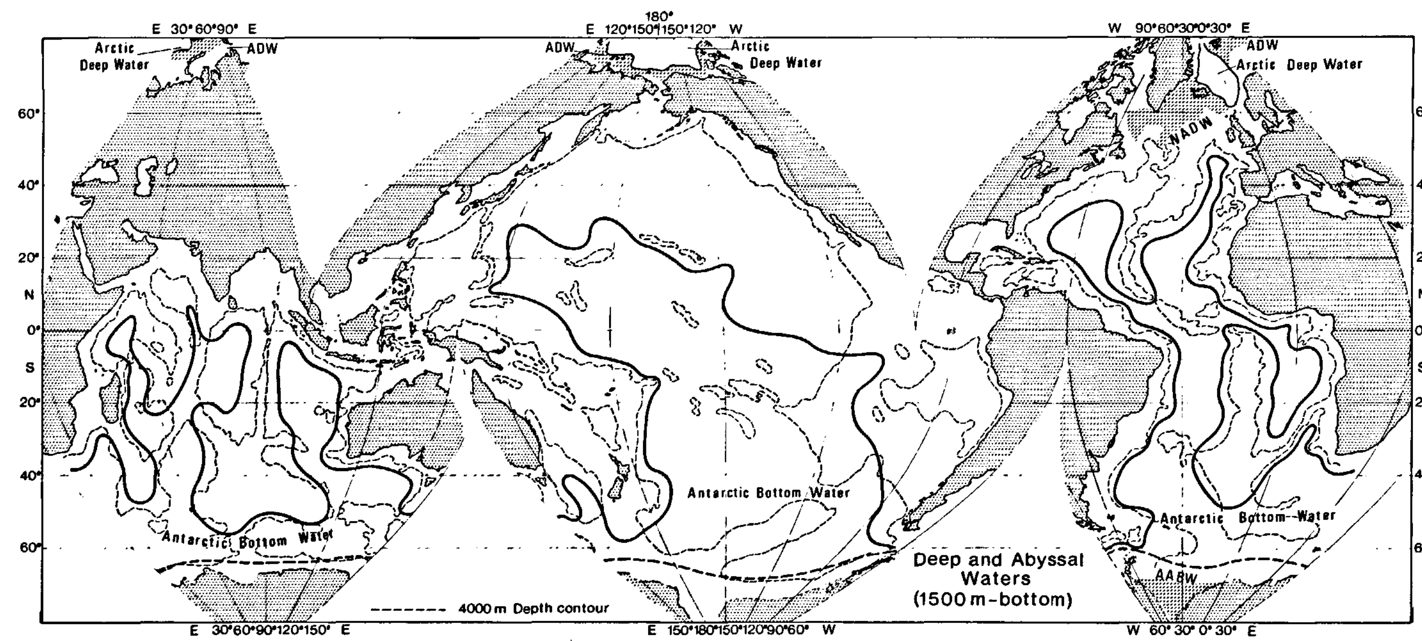

Figure 3
Global distribution of deep and abyssal waters (1 500-bottom). Contour lines describe the spreading of abyssal water (primarily AABW). The formation of NADW is indicated again by hatching and its spreading terminus, near the Antarctic, by a dashed line which also suggests the global communication of this deep water around the Antarctic. The formation and distribution of CDW is not shown since it overlies the abyssal water in both the Pacific and Indian Oceans.

TEMPERATURE-SALINITY DIAGRAMS

For completeness characteristics TS relationships are shown here in Figures 4-6 for each of the three main ocean basins. These summary TS curves are intended to just roughly portray the general character of the water masses and do not reveal the details that were used to determine the properties of the Table or the distributions of Figures 1-3. Here individual curves are presented as solid lines rather than in the form of curve ranges as used by Sverdrup *et al.* (1942) and follow the form of the summary TS curves in Pickard and Emery (1982). In an effort to minimize confusion and keep the diagrams as clean as possible the water masses expressed have been restricted to the primary constituents for each ocean. Thus in the Atlantic, for example, the ASUW, AIW, ABW, SASW and the AASW are not included in the TS diagram (Fig. 4). Also no specific account has been taken of the mixing mechanisms, as discussed by Mamayev (1975), and the connections between source waters and salinity extrema only suggest the relationship between formation region and subsequent salinity extremum.

Another important caution is the absence of property extrema produced by marginal seas. One example in Figure 5 is the arrow indicating the salinity range of Bengal Bay Water which goes off scale in the TS diagram. The greater complexity in the TS curves from the Pacific (Fig. 6) reflects the absence of deep and bottom water varieties and the abundance of upper water masses.

DISCUSSION

The specification of temperature, salinity water mass characteristics and the global distribution of upper, intermediate and deep waters presented here represents an update and an extension of the description of these properties and their distributions found in Sverdrup *et al.* (1942). In addition this effort brings together in a single document wide spread information that is difficult to find easily in summary form. It is hoped that this effort at a synopsis of existing information in a useful format will be appreciated for the ease it provides in gaining an overview of these water masses and their distributions.

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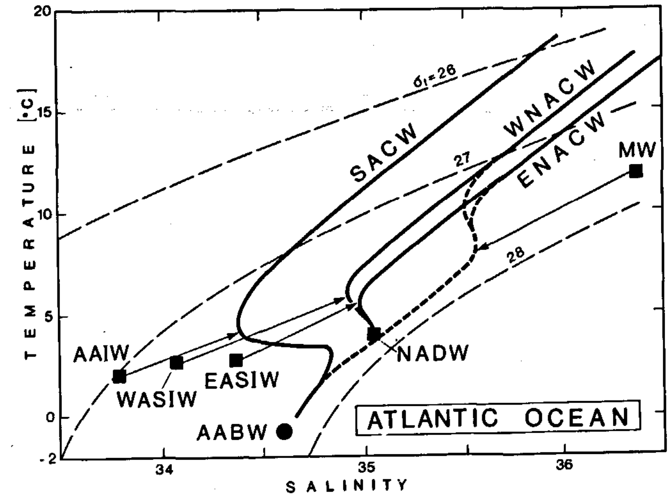

Figure 4
Characteristic temperature-salinity (TS) curves for the main water masses of the Atlantic Ocean. Water masses are labelled by the appropriate acronym and core water properties are indicated by a dark square with an arrow to suggest their spread. The cross isopycnal nature of some of these arrows is not intended to suggest a mixing process but merely to connect source waters with their corresponding characteristic extrema.

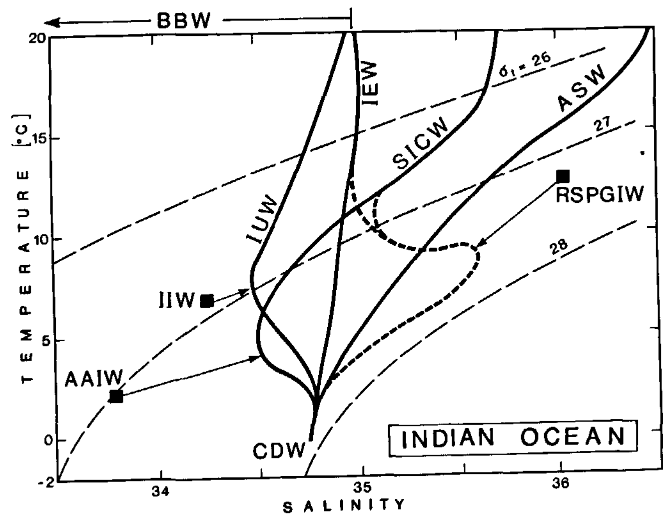

Figure 5
Characteristic temperature-salinity (TS) curves for the main water masses of the Indian Ocean. All labels as in Figure 4.

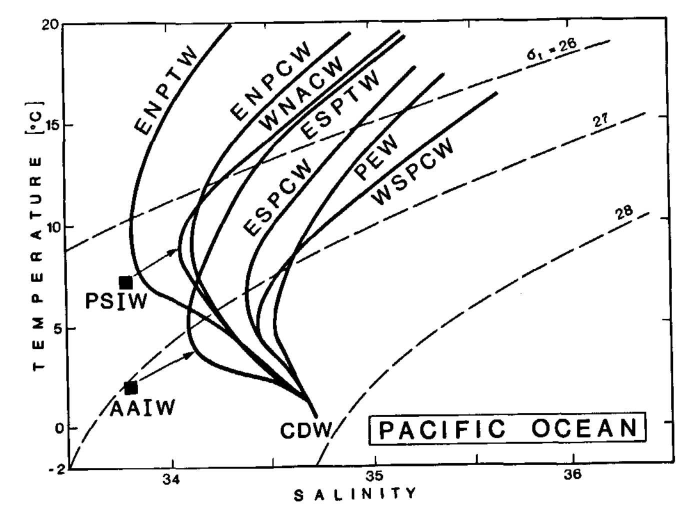

Figure 6
Characteristic temperature-salinity (TS) curves for the main water masses of the Pacific Ocean. All labels as in Figure 5.

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