

Some Physical Characteristics of the Antarctic and Western Indian Oceans

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ABSTRACT

Expendable bathythermograph (XBT) and hydrographic observations made along the transects through Antarctic and western Indian Oceans on board M. V. *Polar Circle* during the First Indian Antarctic Expedition have been analysed and presented in this paper. A wide north-south variation in the physical oceanographic parameters has been noticed along the transects. Maximum sea surface temperatures have been observed between latitudes 6-10°S and a sharp fall of temperature has been found near the convergence zones particularly between latitudes 40-50°S. The surface temperatures ranged between 28.7°C and -1.7°C. The depths of the isothermal (mixed) layer in the Antarctic waters to the south of latitude 68°S extend to as deep as 200-400 m while at other regions, they are found to be within 100 m. The data clearly shows that a convergence process is taking place around 60°S with the Antarctic surface water slipping below and mixing with the subantarctic surface water. T-S analysis shows characteristic changes in T-S relations of Antarctic intermediate water as the distance from the Antarctic convergence increases.

INTRODUCTION

The exploration of the Antarctic Ocean (Southern Ocean) receives much attention by oceanographers of various disciplines, because the ocean supports all the animal life and has a tremendous influence on meteorology and geophysical problems. During the First Indian Antarctic Expedition (Dec. 1981 - Feb. 1982), a preliminary study of various aspects of Antarctic Ocean waters have been undertaken. On board M.V. *Polar Circle*, expendable bathythermograph (XBT) and hydrographic observations have been made in the area of interest (Fig. 1). The cruise track covered a very long stretch from Mormugao port on India's west coast to the continent of Antarctica. The expendable bathythermograph records in the depth range (0-760 m) have been obtained at 154 stations along the cruise track using the system developed by Sippican, USA. Seventeen hydrographic stations have been covered between latitudes 70-30°S and the water samples collected from standard depths have been analysed for salinities on board the ship using the Autosal, laboratory salinometer. In the present paper some of the hydrographic features of the region covered during these cruises are studied in relation to physical oceanographic conditions.

GENERAL OCEANOGRAPHY OF THE ANTARCTIC AND WESTERN INDIAN OCEANS

Waters within the zone from the coast of Antarctica northward to the Antarctic convergence (an arbitrary limit at approximately 52°S latitude) have been termed as Antarctic waters. The waters within the zone between this convergence and the subtropical convergence have been termed as subantarctic waters.

The basic structure of Antarctic and subantarctic waters have been extensively studied during *Discovery* Expedition (Deacon 1937, 1963 and 1964). The main flow is zonal, westward south of Antarctic divergence and eastward north of the divergence. The surface and bottom watermasses here are Antarctic in origin in that their characteristics are acquired south of the Antarctic convergence. The northward and downward component of motion is compensated by a southward and upward flowing of deep watermasses. This results in a meridional exchange of oceanographic properties and as a consequence heat and nutrients are supplied to the surface of Antarctic waters from lower latitudes (Gordon, 1971).

The Antarctic convergence (Oceanic polar front zone) is the region separating Antarctic and subantarctic watermasses. It has characteristics that suggest alternate convergence, divergence or a combination of both. Some of the Antarctic surface water sinking in this region forms the low salinity Antarctic intermediate water (AAIW). The rest mixes into the subantarctic surface water.

Oceanographically, the southern boundary of the Indian Ocean has been placed in the region of subtropical convergence, approximately extending to 40°S. In the region of subtropical convergence,

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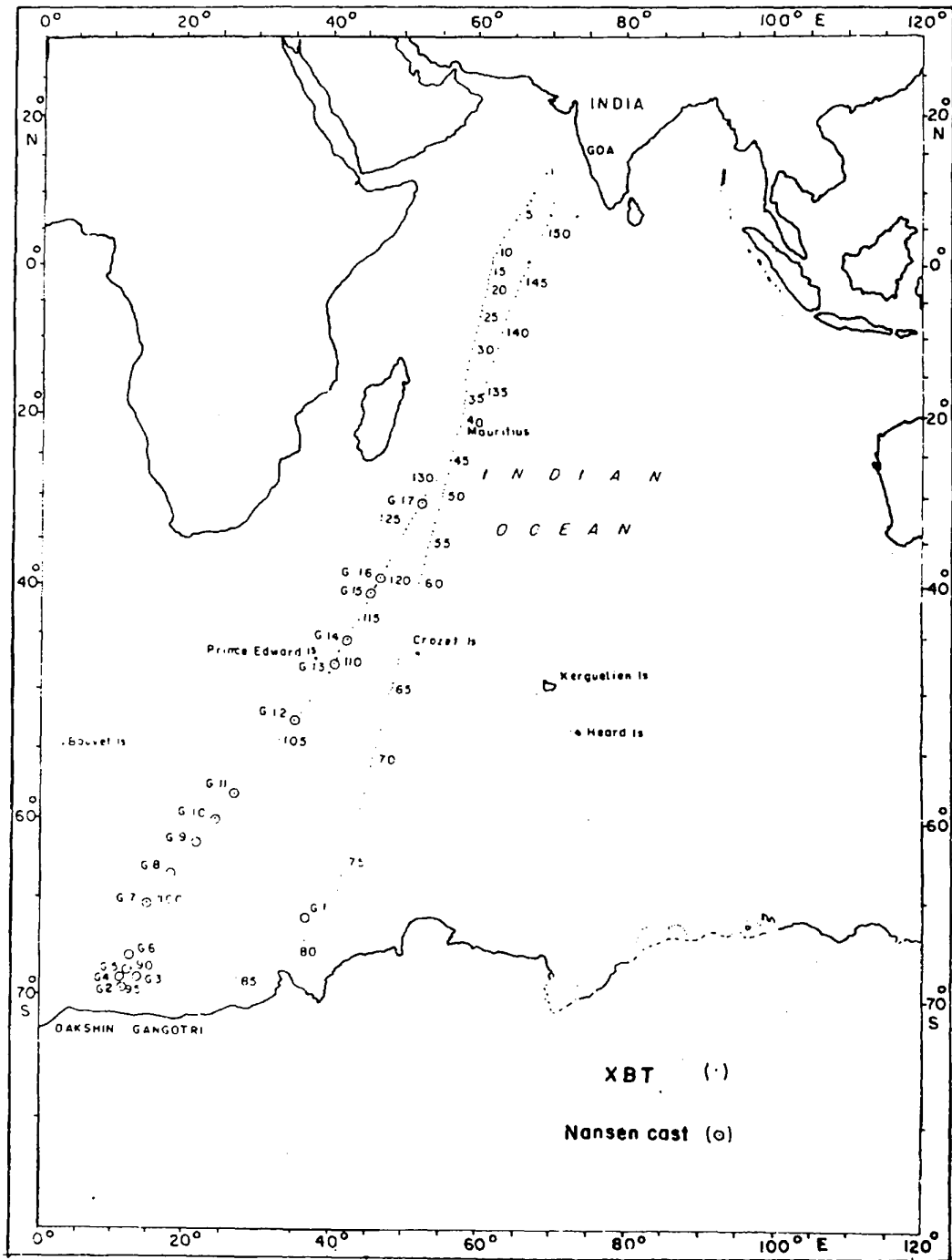


Fig. 1 : Location of stations XBT (·), Nansen cast (○)

surface temperature and salinity vary rapidly with latitude. The T-S relationship of the water sinking at the subtropical convergence has been reported to be that of the central watermass of the Indian Ocean. Hence, the origin of the central watermass of Indian Ocean may probably be considered to be from region of subtropical convergence. STC (Sverdrup, 1942).

In the southern part of the Indian Ocean, a great anticyclonic circulation system of currents prevail. Between South Africa and Australia the current is directed from west to east. To the north of 20°S, the south equatorial current flows from east to west. North of 10°S during the southern summer, the north equatorial current is well developed and an equatorial countercurrent is present with its axis at approximately 7°S.

PROCEDURE AND METHODS

Fig. 2 shows a sample XBT record obtained using the Sippican system, which covers the depth range 0-760 m. A large number of such records has been analysed for parameters like sea surface temperature, (SST), mixed layer depth and temperatures at 200, 300, 750 m depths. The variation of sea surface temperature along the cruise track has been plotted and shown in Fig. 3. Fig. 4 depicts the vertical profiles of temperature from 10°N to 70°S along the cruise track. Hydrographic data have been processed and analysed to construct vertical sections of temperature, salinity, Sigma - θ in the depth range 0-2000 m, along the cruise track between latitudes 69°-39°S (Fig. 5). Due to technical reasons observations were restricted to 2000 m. In preparing these diagrams an exaggeration of 1:1000 has been introduced to represent the vertical scale. The T-S curves for selected stations have been plotted and shown in Fig. 6.

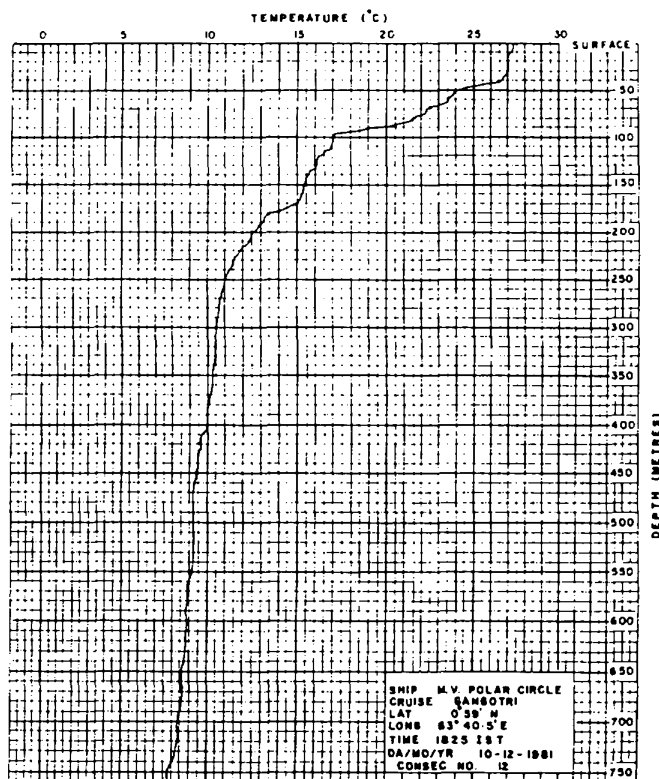


Fig. 2 : A sample expendable bathythermograph (XBT) record

RESULTS AND DISCUSSION

Fig. 2 shows a sample temperature profile obtained from Sippican XBT system. The temperature axis ranges from -2 to 35°C and depth axis from 0 - 760 m. Each division represents 0.5°C on temperature axis and 10 m on depth axis. Fig. 3 depicts the variation of sea surface temperature from 10°N to 70°S during the period of study (austral summer). The maximum sea surface temperature 28.7°C has been noticed between latitudes 6 and 10°S . A sharp fall of temperature near the zones of convergence is also clear from the diagram.

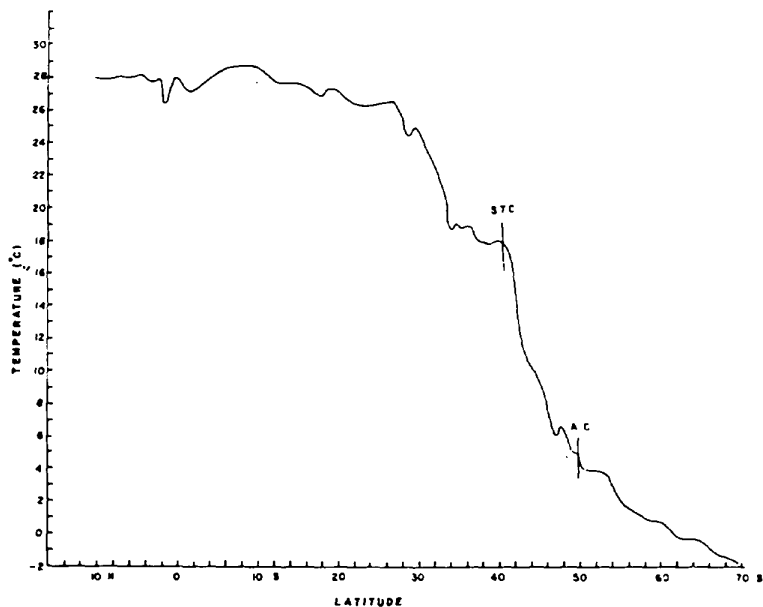


Fig. 3 : Chart showing variation of sea surface temperature observed along the cruise track.

The vertical temperature profiles along the cruise track extending from 10°N to 70°S have been plotted and shown in Fig. 4. The entire length is divided into 4 parts (10°N - 10°S , 10 - 30°S , 30 - 50°S and 50 - 70°S) for easy comparison. The temperature scale has been shown at the top-left, while the depth scale shown separately for each part. A suitable reference temperature $15^{\circ}/10^{\circ}/5^{\circ}/0^{\circ}\text{C}$ has been taken and shown by the vertical line intersecting each of the profiles and the corresponding temperature noted above the vertical line (first row). Latitude is demarcated by a small mark (second row). The respective station numbers of the profiles have been given right above the vertical line (third row) representing the reference temperature.

TABLE 1

Characteristic features of temperature structure

Feature	SST			T ²⁰⁰ m			T ³⁰⁰ m			T ⁷⁵⁰ m		
	°C	Lat	Long	°C	Lat	Long	°C	Lat	Long	°C	Lat	Long
Max	28.7	06°57'S	58°52'E	20.6	18°05'S	57°36'E	17.5	17°50'S	57°38'E	11.2	35°45'S	53°01'E
Min	-1.7	69°23'S	11°27'E	-1.7	69°24'S	17°11'E	-2.0	68°59'S	13°41'E	-0.5	67°46'S	12°06'E

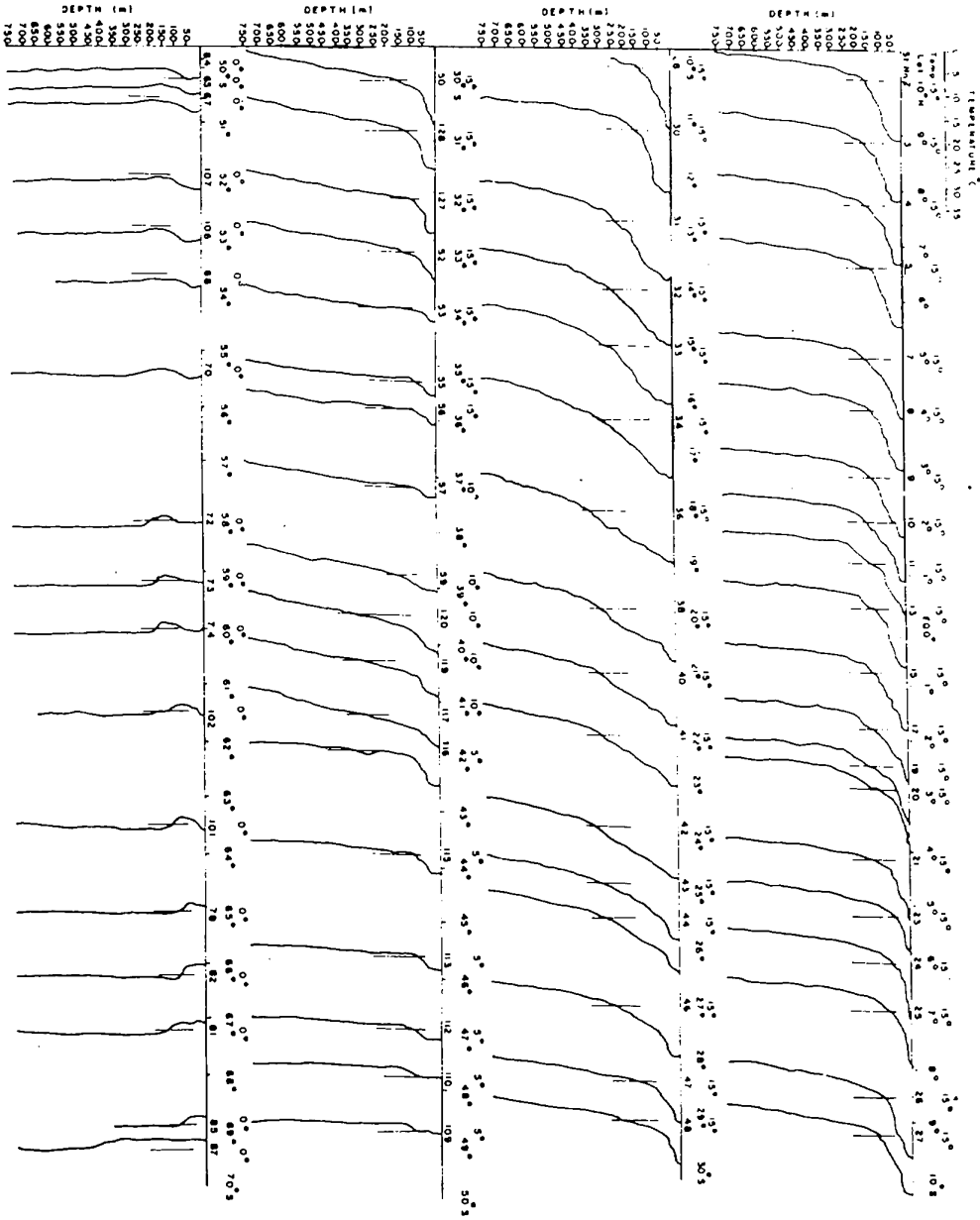


Fig. 4 : Vertical profiles of temperature along the cruise track between latitudes 10°N-70°S.

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The sea surface temperatures vary between 28.7 and -1.7°C for the entire stretch (Table 1); the maximum temperatures observed between latitudes 6-10°S while the minimum to the south of 69°S. The depths of the isothermal (mixed) layer in the Antarctic waters to the south of latitude 68°S extend to as deep as 200-400 m while at other regions, they are found to be within 100 m. In Fig. 4. a maximum mixed layer depth of 340 m has been observed at stn. 87 (69°24'S, 17°1'E) which is clear from the last profile.

Analysis has been made to study the range of temperatures at depths 200, 300 and 750 m over the entire region of study and presented in Table 1. At 200 m, temperatures vary between 20.6°C at stn. 36 (18°05'S, 57°36'E) and -1.7°C at stn. 87 (69°24'S, 17°11'E); at 300 m between 17.5°C at stn. 35 (17°50'S, 57°38'E) and -2.0° at stn. 96 (68°59'S, 13°41'E) and at 750 m between 11.2°C at stn. 56 (35°45'S, 53°01'E) and 0.5°C at stn. 99 (67°46'S, 12°06'E).

Vertical sections of temperature (A), salinity (B) and sigma - θ (C) along a hydrographic transect covered between latitudes 69-39°S is presented in Fig. 5. A wide variation of surface temperatures from -0.33°C (stn. 5) to 18.7°C (stn. 16) has been noticed. A tongue of cold water (temperature less than 0°C) above 300m depth has been found to extend towards north from near the Antarctic continent to about 60°S which may be considered as the northern boundary of the Antarctic surface water in the region. The data clearly shows the presence of a convergence process with the Antarctic surface water slipping below and mixing with the subantarctic surface water. North of 60°S temperature are positive in the entire depth and the isotherms are almost vertical. A sharp gradient of surface temperature (increasing towards north) has been observed north of 47°S, which starts from stn. 14 towards right where the isotherms are closely packed. At 400 m depth, south to north variation in temperature has been found to vary from slightly more than 0°C to nearly 10°C. At 1000 m depth, temperatures in the southern sector are more or less the same while they are about 3°C to the north. At 2000 m, temperatures have been found to be lower than 0°C in the south (south of about 60°S) and about 2°C in the northern region.

Thermal structure along this section may be used as a tool to identify the watermass structure. Following the analysis of Sverdrup, the subtropical convergence (STC) zone exists between stns. 14-15 and 10° isotherm may represent the mean position of STC. The zone of Antarctic convergence lies between 4-8° isotherms where Antarctic intermediate water forms by sinking of surface water from Antarctica. Isotherms 2-4° represent the depth layer of the Indian deep water which is a southward and upward flowing deep watermass. Antarctic bottom water penetrates northward below the deep water.

Surface salinities have been found to vary between 33.77‰ (stn. 12) to 35.16‰ (stn. 16). The isohalines in the upper 400 m are closely packed between stations 4 and 10 where the surface salinities are low owing to the melting of ice during this period (southern summer). A noted change in the horizontal salinity has been found between stations 14 and 15 with an increasing trend toward north. The 34.6‰ isohaline shows large oscillation in the vertical and below this depth salinity is more or less uniform.

The distribution of sigma - θ is very much similar to the salinity distribution, in that a prominent horizontal variation has taken place between stations 14 and 15 and the isopycnals are closely packed towards the northern end. The depth of occurrence of 27.8 sigma θ contour showed large variation between depths ranging from slightly less than 100 m at stn. 8 and about 2000 m towards the northern end. The shallowing feature of 27.8 contour at stn. 8 (63°30'S) coincides with the distribution chart of salinity which may represent the region of Antarctic divergence.

T-S profiles for selected hydrographic stations have been plotted and shown in Fig. 6 to study the structure of watermasses of different origins in the region of study. The Antarctic intermediate water (AAIW) appears in Fig. 6 as a salinity minimum at 830 m depth (T-S profile for stn. 15) and 1300 m (stn. 17). Salinity and temperature at the salinity minimum ranged from 34.39‰, 4.05°C (stn. 15) to 34.55‰, 3.04°C (stn. 17) The T-S profiles for stations 12 and 13 show the presence of low salinity (<34.0‰) in the upper 200m which is the characteristic feature of subantarctic water (SAW). The T-S profile for

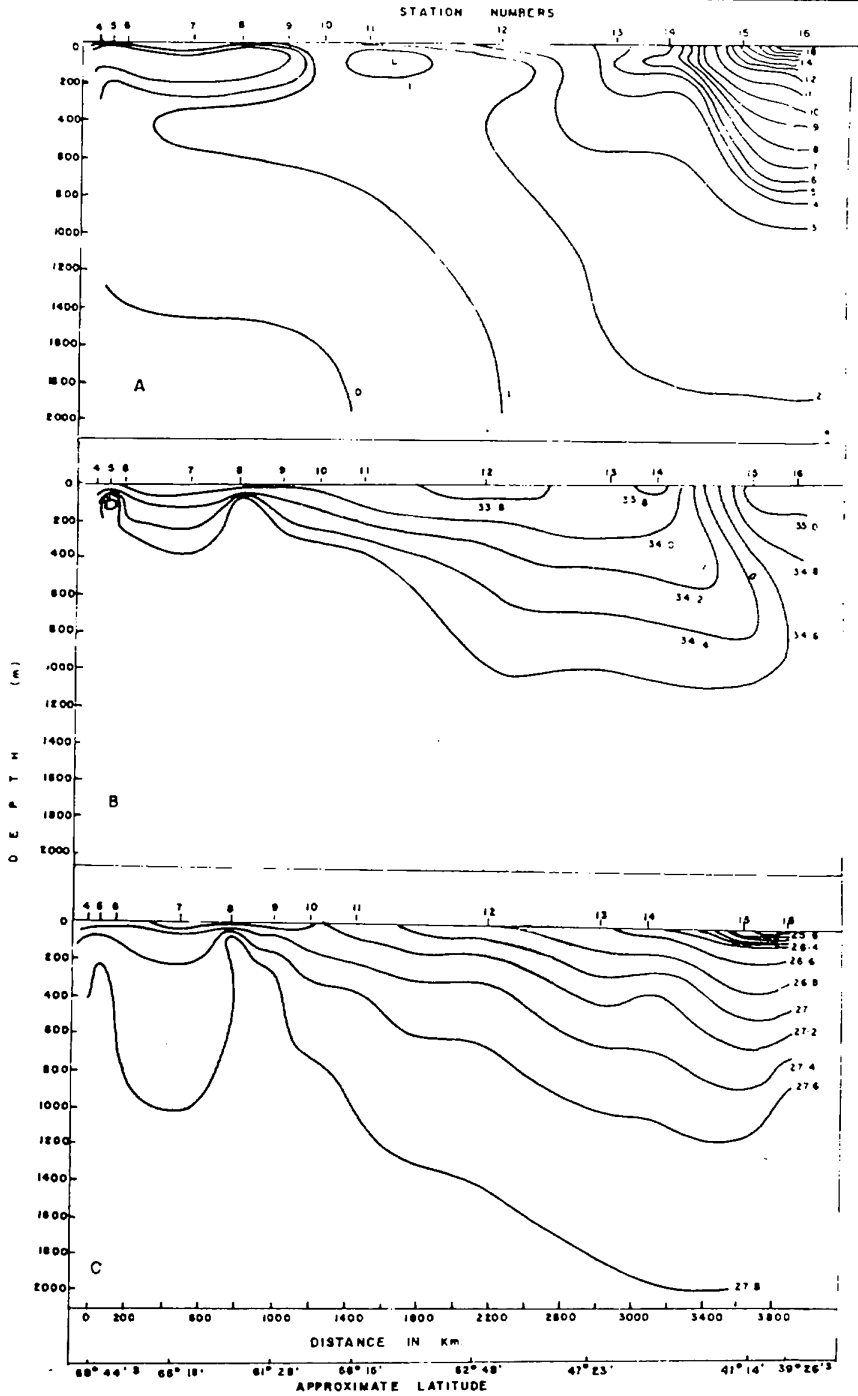


Fig. 5 : Vertical sections of temperature (A), salinity (B), Sigma - θ (C) along a transect between latitudes 69°-39°S.

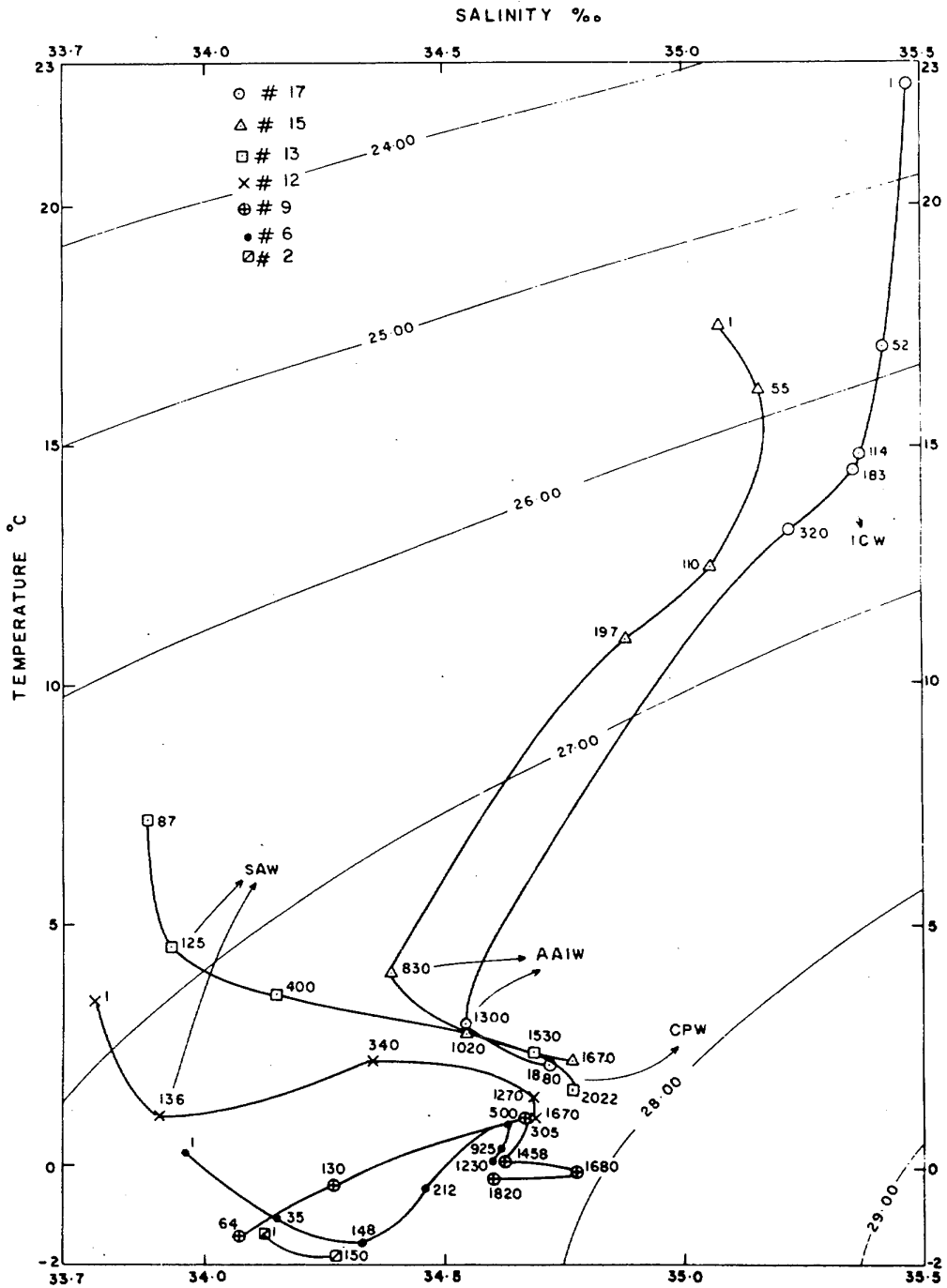


Fig. 6 : T-S profiles for selected stations.

station 17 indicates the presence of central watermass of the Indian Ocean (CIW) below 100 m depth with a limited vertical extension where σ_{θ} is around 26.5. Below the Antarctic intermediate water the T-S profiles indicate the presence of circumpolar water (CPW).

Close to the Antarctic continent, the existence of a polynya has been observed. Though it was austral summer, a cold strong wind blowing off the Antarctic ice shelf favoured the formation of the polynya. This zone of water surrounded by sheets of ice shows an increase in surface salinity resulted from the freezing of the surface sea water. XBT traces show step-like structures with limited vertical extent (stns. 90, 91) suggesting the influence of basal melting of ice. The increase of surface salinity caused by haline convection from freezing of sea water (Foster, 1972) has a prominent role in vertical transport mechanism and formation of watermasses in the Antarctic Ocean.

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REFERENCES

- Deacon, G. E. R.,
The hydrology of the Southern Ocean, *Discovery Report*, 15, p. 1-24, 1937
- Deacon, G. E. R.,
The Southern Ocean, Ideas and Observations on Progress in the study of the seas, in *The Sea*, vol. 2, edited by M. N. Hill, p. 281-296, Interscience, New York, 1963.
- Deacon, G. E. R.,
The Southern Ocean, in *Antarctic Research, A Review of British Scientific Achievement in Antarctica* edited by Sir Raymond Priestley, Ramond J. Adic and G. DE Q. Robin, London, Butter Worths (1964) p. 262-307.
- Gordon, A. L.,
Oceanography of Antarctic waters in *Antarctic Oceanology-I*, edited by Joseph L. Reid p. 169-203, Antarctic Research Series, vol. 15, published by American Geophysical Union, 1971.
- Sverdrup, H. U., M. W. Johnson and R. H. Fleming, 1942
The oceans, their physics, chemistry and general biology, Prentice-Hall, New York.
- Foster, T. D.,
Haline convection in polynyas and Leads, *Journal of Physical Oceanography* vol. 2, No. 4, 1972