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Deep Circulation in the Antarctic Ocean

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南極洋の深層循環流

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要旨

南極洋の鉛直南北断面内の循環流について，海鷹丸（東京水産大学練習船）の 1956 年 12 月～1957 年 3 月横断観測の資料に基き調べた結果，新しく見出した諸点を摘記し報告した．すなわち中冷水，溶在酸素極大層と極小層の分布，塩分極大層と極小層，燐酸塩極層等を図示した断面図，および中冷水水平分布地形図により考察した．

1） 亜熱帯収束は夏季 43°S 附近にあり，亜熱帯系水は塩分 35‰ 以上，水温 10°C 以上で，厚さ 400～600 m 深に及ぶ．

2） 南極収束は 49°～50°S 当季，極前線帯は 43°～49°S（偏西風暴風圏，西風漂流帯）にある．

3） 夏季南極圏（50°～70°S）は中冷水（−1.8°～+1.35°C）で明示され，中核深度は 66°～69°S で 75 m 深，58°～64°S で 100 m 深，50°S で 160 m 深と北上するほど深い．

4） 南極収束附近で，表層から降下した南極中間層水は亜熱帯系水の下で 1000 m 深に来ている．溶在酸素2次極大は中層流の軸にほぼ一致するか，塩分極小の中間層水の軸より浅い．（等密度面上の推算流速を試みに求めた．）

5） 極前線帯は酸素第 2 極大と塩分極小で識別される．

6） 上部深層水は 1500 m 深（45°S 以北）から南極圏内の 300～800 m 深の上層まで昇る．中暖水（水温中層極大）と酸素極小の層上部の燐酸塩極大層および，下方の塩分極大層（34.7‰ 前後）によって明示された．

7） 南極大陸に近い 64°～69°S では強盛な鉛直対流と水塊の沈降が低水温（0°C 以下）および酸素増多，塩分低下によって証示される．

8） 54°～64°S 間の湧昇水域は純南極洋圏内で最も生産力高く，鯨の最好良漁場帯に相当し，鯨餌のユーファウジアの最濃密帯と一致することを証示した．この水帯は南極収束線とパックアイス帯にはさまれて位置する．

9） 64°～69°S の沈降域は特殊水帯で真南極洋水帯ともいえよう．ここから底層水，底層流が各洋水に向って発源する．60°～68°S には南極洋表層水，深層水の鉛直混合が盛んに起る．

10） 54°～64°S の最良生産帯は中冷水 −1°C 以下の水域で，東風皮流と西風皮流の間の渦流の系列をみる渦度帯に相当する．

なお以上の調査には海鷹丸のデーターの外にディスカバリー号（英），プラテク号（ノルエー）のデーターも入れてしらべた．

Introduction

The general features of deep circulation in the Antarctic waters have already been illustrated by G. E. R. DEACON (1933, 1937) as well as A. DEFANT (1936) and D. WÜST (1932). The structure of whaling grounds depends on such hydrological conditions which vary year by year. The author intended to find a new approach to this problem.

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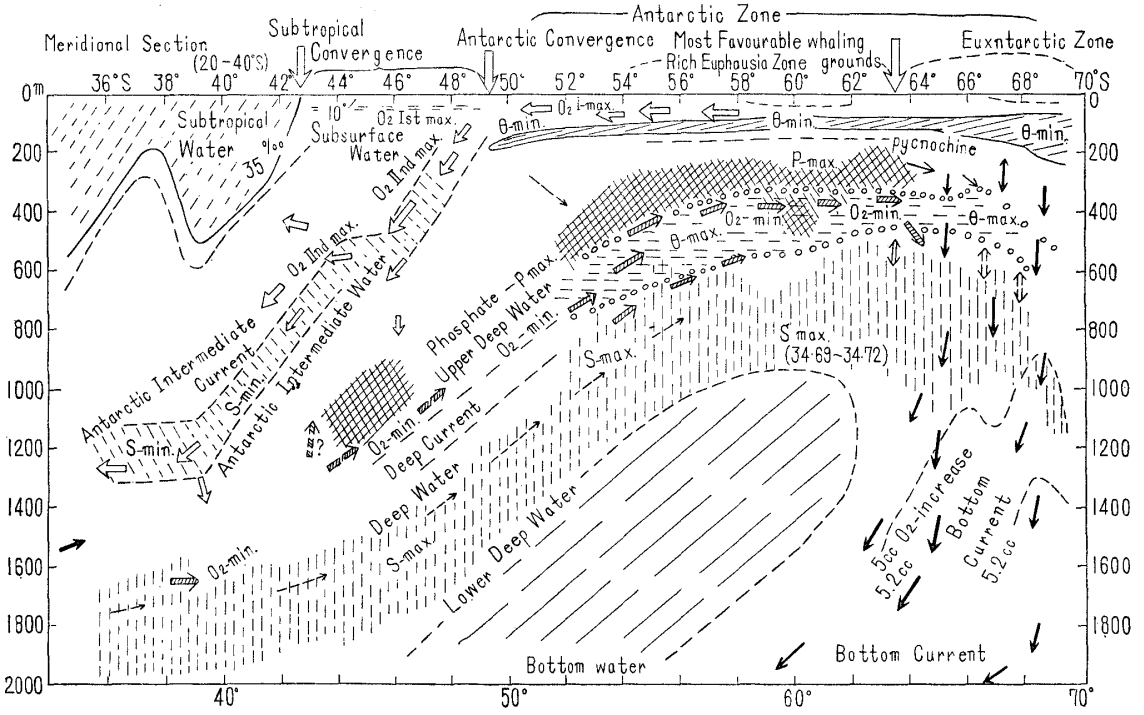
Meridional Section
(20-40°S)
Subtropical Convergence
Antarctic Convergence
Most Favourable whaling grounds
Rich Euphausia Zone
Antarctic Zone
Euxntarctic Zone
Subtropical Water
Subsurface Water
Antarctic Intermediate Current
Antarctic Intermediate Water
Upper Deep Water
Deep Current
Deep Water
Lower Deep Water
Bottom water
Bottom Current
pycnocline
Phosphate-P max.
S max. (34·69~34·72)
5cc O2-increase
5.2cc
Bottom Current
5.2cc

Fig. 1.

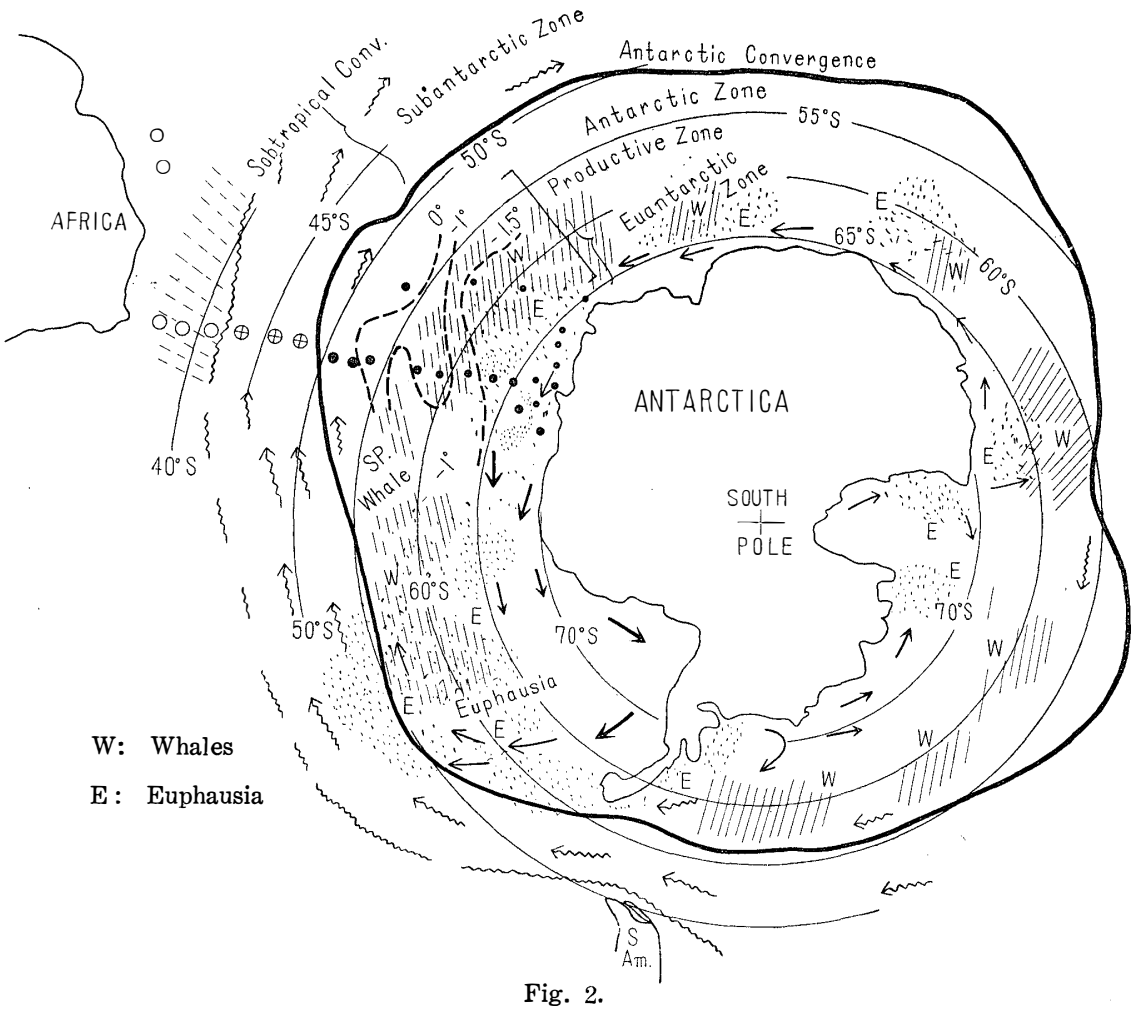
AFRICA
Subtropical Conv.
Subantarctic Zone
Antarctic Convergence
Antarctic Zone
Productive Zone
Euantarctic Zone
ANTARCTICA
SOUTH POLE
SP. Whale
Euphausia
S Am.
W: Whales
E: Euphausia

Fig. 2.

Basing his research on the oceanographic data collected by the Umitaka-maru (training boat belonging to the Tokyo University of Fisheries) during the period from Dec. 1956 to Mar. 1957 (M. ISHINO, Y. MORITA, Y. SAOTOME, 1958) the author studied the deep circulation in relation to fisheries.

First, the charts of the meridional sections for the water temperature, salinity, dissolved oxygen, phosphate-P and density *in situ* (σ_t) from Cape of Good Hope to Prince Harald Coast projecting those data within 20–40°E were constructed.

Next, the characteristic features such as dichothermal water (temperature minimum), oxygen maximum (the second maximum as well as the first maximum), the deeper oxygen minimum, salinity minimum (intermediate water) and the deeper salinity maximum of the deep water, phosphate-P maximum were compiled in the same map as shown in Fig. 1.

Secondly, the horizontal view of the boundaries of watermasses and the dichothermal topography related to the previously obtained results by other authors are indicated in Fig. 2. (G.E.R. DEACON, 1937, H. MOSBY, 1934, N.A. MACKINTOSH 1946, L. MIDTTUN and J. NATVIG 1959, J.L. HOLM and Å. JONSGÅRD 1959, J.W.S. MARR 1956, J.T. RUND, 1932).

Results

I. Refering to Fig. 1

(1) Subtropical Convergence was found to be nearly 43°S in summer (Dec.–Mar.). Subtropical water having temperature higher than 10°C and salinity higher than 35‰ indicated its thickness of about 400–600 m from the surface of the sea.

(2) Antarctic Convergence was found to be nearly at 49–50°S.
Consequently Polar Frontal Zone roughly between 43–49°S corresponds to stormy zone of prevailing westerlies and to West Wind-drift zone.

(3) Antarctic zone in summer lying in the higher south latitude (50°–70°S) is clearly defined by the existence of dichothermal water (intercooled water or winter water). However, the core depth comes down from south to north (75m depth in the 66–69°S, 100 m in the area of 58–64°S and 160 m depth at 50°S) and also its temperature minimum rises from south to north (−1.8°–−1.35°C). It shows vigorous convection in winter in the upper layer shallower than 300 m.

(4) Profiles indicate clearly the descent of Antarctic Intermediate Water from the surface layer near the Antarctic Convergence to about 1000 m depth beneath the subtropical water mass.
Second maximum of dissolved oxygen coincides nearly to the axis of Intermediate Current slightly shallower than the depth of salinity minimum (Intermediate Water). The same has been already confirmed in the case of

the north Pacific (M. UDA, 1960a, 1960b).

Following L. MIDTTUM and J. NATVIG and using the simplified equation,

$$\frac{A}{v_x}=\frac{\Delta z^2(s_A-s_B)}{\Delta x\cdot(s''+s'-2s_\sigma)} \quad \text{of} \quad v_x\frac{\partial s}{\partial x}=\frac{A}{\rho}\frac{\partial^2 s}{\partial z^2}$$

between Station A52 and A53 on the isentropic surface corresponding to depths of 278 m and 600 m respectively and assuming $A=10$,

we have $v_x=0.5$ cm/s.

(5) Hence, the polar frontal zone is defined by the limit of the salinity minimum and the second maximum of dissolved oxygen.

(6) In the Antarctic zone the ascending upper deep water from about 1500 m depth or deeper in latitudes lower than 45°S to the upper layer 300–800 m depth denoted by the mesothermal layer (temperature maximum) as well as the coincided oxygen minimum layer the upper phosphate-P maximum layer, and the deeper salinity maximum layer (34.69–34.72‰).

(7) Nearer to the Antarctic, between 64–69°S the pattern shows vigorous vertical mixing and sinking water masses by the evidence from the distributions of water temperature (very cold below 0°C) to the bottom, salinity (diluted lower value), dissolved oxygen etc.

(8) The upwelling area between 54–64°S corresponds to the most productive zone in the Antarctic Ocean i.e. most favourable whaling grounds (e.g. J. L. HOLM and Å. JONSGÅRD, 1959) and to the rich zone of *Euphausia superba* (J.W. S. MARR, 1956). Or in other words, the above zone lies between the pack-ice zone and Antarctic Convergence in summer.

(9) The sinking area between 64–69°S constitutes a peculiar zone adjacent to the Antarctic Continent, which may be called the Euantarctic zone in which the production of bottom water occurs and the bottom current starts. Vertical mixing between the surface water of Antarctic zone and deep water carried by deep current seems to occur most strongly, in the zone near the latitude 60–68°S around 64°S.

II. Refering to Fig. 2

(10) The above mentioned productive zone appears to be located around Antarctica, the latitudes of 55–65°S with the dichothermal water of temperature minimum below −1°C and in the eddy system between the warmer West Wind-drift and colder Easterly Wind-drift (Circum Polar Current).

Concluding remarks

The essential structure of the most productive zone in the Antarctic whaling grounds corresponds to the upwelling zone of Antarctic Ocean between 54–64°S in summer.

The mechanism in detail should be studied further. Also the characteristic features

of each sector within the Antarctic zone and its variation remain as our problem.

Lastly the author wishes to appreciate the surveys conducted by Mr. M. ISHINO *et al.* and the crew of Umitaka-maru (Captain T. KUMAGORI) as well as those splended works by "Discovery" and "Brateg" Expedstions etc.

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