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Pathways of Antarctic Bottom Water Propagation in the Atlantic †

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Abstract: This is a review paper based on the literature and author's measurements in the abyssal channels of the Atlantic, which are continuing. Antarctic Bottom Water (AABW) that propagates in the Atlantic up to the latitudes of Europe is formed in the Weddell Sea. Potential temperature of AABW increases and the thickness of its water layer decreases during propagation. The flow propagates to the north in the South Atlantic and then splits into the eastward current through the equatorial fractures of the Mid-Atlantic Ridge and to the northwestern current to the North American Basin. An important part of the flow passes through the Vema Fracture Zone (11° N) and fills the deep basins of the Northeast Atlantic.

Keywords: Antarctic Bottom Water; abyssal channels; fracture zones; bottom water circulation

Antarctic Bottom Water (AABW) is formed in the Weddell Sea over the Antarctic slope. Cold and dense Antarctic Surface Water cools during cold weather. When surface water freezes, salt brine flows down from ice. Thus, Antarctic Shelf Water is formed. During downwelling of the shelf water, it mixes with less dense, warmer, and more saline Circumpolar Deep Water. Thus, Weddell Sea Deep Water is formed, which is the coldest part of Antarctic Bottom Water.

The pathways of AABW propagation follow the depressions in bottom topography. The flow of AABW in the deep basins is slow, but accelerates in the abyssal channels and fracture zones between the basins. The thickness of the layer of Weddell Sea Deep Water in the Weddell Sea exceeds 3000 m. The coldest part of AABW from the Weddell Sea propagates to the Scotia Sea through four passages in the South Scotia Ridge. The deepest of them is the Orkney Passage 3600 m deep. The main portion of the coldest AABW propagates through this passage while the whole volume overflows the South Scotia Ridge [1]. The coldest potential temperature after exiting the Orkney Passage measured in 2022 is −0.54 °C. A smaller part of AABW flows through the South Sandwich Trench. The first analysis of AABW propagation was reported in [2].

Antarctic Bottom Water flows from the Scotia Sea to the north into the Argentine Basin. Potential temperature of the flow in the Argentine Basin increases to −0.19 °C. The current continues through the Falkland Gap in the Falkland Ridge. Then the flow propagates along the southern and western margin of the Argentine Basin as the western intensification of bottom circulation. The main flow from the Argentine Basin is directed through the Vema Channel (34°–27° S) to the Brazil Basin. The water enters the Vema Channel with a temperature of −0.13 °C and leaves it with a temperature of −0.08 °C. The transport to the north is approximately estimated as 3 Sv.

The depths of the Vema Channel exceed 4660 m over the background depths of the Santos Plateau, which are approximately 4200 m. The Vema Channel is a narrow conduit in the Rio Grande Rise between two terraces. Its width is about 18 km. The flow of AABW

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in the deep-water Vema Channel occurs as a well-mixed jet. The coldest and less saline part of the flow is displaced to the eastern slope of the channel. This displacement is caused by the Ekman bottom friction [3].

The upper warmer part of AABW also flows through the Hunter Channel and over the Santos Plateau. The flows in these channels are not direct and subjected to eddy activity. In the Brazil Basin the flow continues as the western boundary current [4]. A strong weakening of the flow is observed in the Brazil Basin. The total transport of AABW in the Brazil Basin is approximately 2–3 Sv. In the northern part of the basin the flow splits into the equatorial transport through the Romanche and Chain fracture zones and the flow to the northwest into the North American Basin. Antarctic waters propagate to the western part of the North Atlantic through the Equatorial Channel located to the northwest of the Brazil Basin. Whitehead and Worthington [5] report that the coldest and densest Antarctic waters with temperature less than 1 °C do not propagate through this channel.

From the Northwest Atlantic, Antarctic Bottom Water propagates to the East Atlantic through fractures in the Mid-Atlantic Ridge: Vema, Romanche, and Chain. Potential temperature of bottom waters entering the Romanche Fracture Zone is 0.5 °C [6]. Due to the existence of many sills along the Romanche and Chain fracture zones and intense mixing potential temperature increases to 1.69 °C while the current of bottom water reaches the eastern exit from the fractures. Here, potential temperature is as high as 1.69 °C. The transport in both fracture zones exceeds 1.2 Sv [7].

The flow directed to the northwest from the Brazil Basin reaches the Vema Fracture Zone at 11° N. Then the flow through the Vema Fracture Zone is directed to the basins of the Northeast Atlantic. The transport through the Vema Fracture Zone is approximately 1 Sv (1 Sv = 10^6 m^3/s). In addition, several other tropical fractures in the Mid-Atlantic Ridge also allow the bottom water propagation to the East Atlantic at amounts smaller than 1 Sv [8]. Potential temperature of bottom waters flowing from the Vema Fracture Zone is 1.66 °C. We emphasize that potential temperature of AABW that propagated through the Romanche Fracture Zone is almost the same (1.69 °C).

Among the fractures in the tropical North Atlantic, the transport of the coldest Antarctic waters into the Northeast Atlantic basins occurs through the Vema Fracture Zone. These waters fill the deep basins of the Northeast Atlantic and occupy the Gambia Abyssal Plain and Canary Basin [9]. This scheme of AABW spreading was described by McCartney et al. [10], later it was confirmed in [11] based on the newest data. The waters that were not entrained in the flow to the East Atlantic continue flowing in the North American Basin to the north and reach the region of the Newfoundland Bank.

The bottom waters that passed the Romanche Fracture Zone spread only in the Sierra Leone and Guinea basins. Waters from the Vema and Romanche fracture zones arrive to the Kane Gap with potential temperature close to 1.85 °C. Further flows of the bottom waters from the Guinea Basin penetrate the Angola Basin; however, only the warmer upper part of AABW fills the abyssal depths of the Angola Basin because the passages in the surrounding ridges are not very deep. Hence a strong difference between bottom waters in the Brazil and Angola basins exist. Potential temperatures at the same latitude in the Brazil Basin are about 0 °C, whereas in the Angola Basin they are 1.84 °C.

The bottom topography in the Vema Fracture Zone is much smoother than in the Romanche Fracture Zone. This is the cause that potential temperature does not increase so strongly while passing the Vema Fracture Zone as compared to the Romanche Fracture Zone. After exiting the fractures, the bottom water flow mixes under the influence of internal waves, which are much stronger in the eastern part of the Romanche Fracture Zone and Kane Gap than in the region of the Vema Fracture Zone [12].

Even though the transports of bottom water in the Vema Fracture Zone and equatorial fractures are approximately the same (1.0–1.2 Sv) the basins of the Northeast Atlantic are filled with water from the Vema Fracture Zone as was initially suggested in Mantyla and Reid [13]. Strong internal waves in the region of the Romanche Fracture Zone and Kane Gap prevent further propagation of AABW from these abyssal channels [14].

The flow in the East Atlantic reaches the Discovery Gap and Western Gap in the East Azores Ridge with temperatures close to 2.0 °C. This region is considered the terminal point of the AABW flow.

Thus, we have summarized the analysis of abyssal circulation in many publications. A scheme of AABW flow in the abyssal Atlantic is shown in Figure 1.

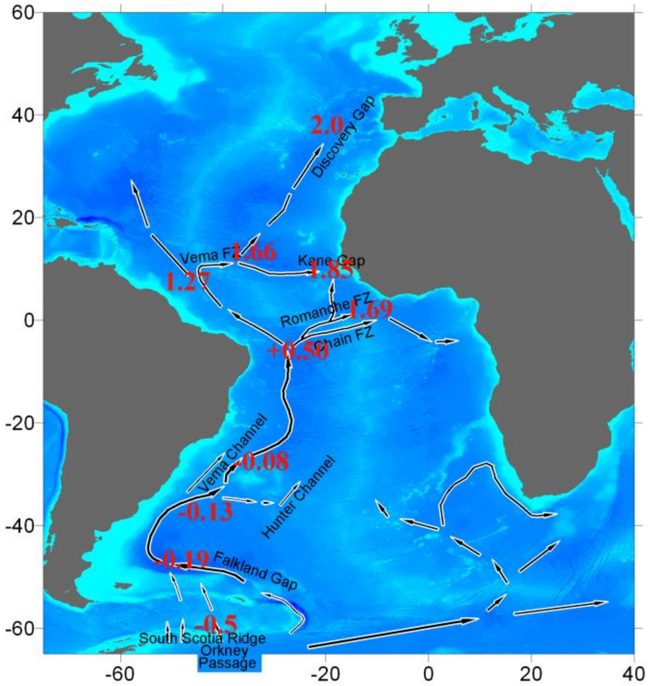

Figure 1. Scheme of Antarctic waters spreading in the bottom layer of the Atlantic and distribution of potential temperature (°C) at the bottom based on WOD18 data. The figure is based only on the data deeper than 4 km. Numerals on the map (red color) indicate potential temperatures at key points of AABW propagation.

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