Aragonite Inorganic Precipitation in a Freshwater Lake

IN Lake Balaton, Hungary, large quantities of fine grained, high-magnesian calcite are precipitated during the warmer seasons by a strong growth of phytoplankton^{1,2}. The formation of high-magnesian calcite instead of "normal" (that is, low-magnesian) calcite can be related to the high Mg/Ca ratio of the lake water which varies locally between about one and three. The electrolyte concentration of the lake water is less than 500 mg/l.

During July 1970 I collected carbonate crusts from leaves of *Potamogeton*, a common aquatic plant in eutrophic lakes. These crusts normally are built up of fine grained calcite which forms preferentially on the upper surface of the leaves during assimilation; CO₂ is extracted from the dissolved bicarbonate of the lake's water and calcium carbonate precipitates. This latter process is purely inorganic and the precipitates crystallize outside the tissues of the plants. X-ray investigations of the *Potamogeton* crusts show that aragonite is by far the chief constituent. Lesser amounts of high-magnesian calcite, traces of dolomite, quartz, and micaceous clay minerals are mechanically included in the aragonite crusts during growth because they are normal constituents of the suspended material of the lake water.

To my knowledge inorganic aragonite and high-magnesian calcite have not yet been reported from any other freshwater lake. Both metastable carbonates are well known under marine and some hypersaline conditions. Thus in the interpretation of the geological record, indications of the formation of inorganic aragonite and/or high-magnesian calcite need not necessarily mean that these minerals were formed in a marine or hypersaline environment.

The question why aragonite forms on *Potamogeton*, when at the same time and in the same location high-magnesian calcite is precipitated by a phytoplankton blossom in the lake, remains to be solved. There is little doubt, however, that the high Mg/Ca ratio of the lake water influences both the crystallization of aragonite and high-magnesian calcite as is the case under marine and some hypersaline conditions.

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¹ Müller, G., *Naturwissenschaften*, **56**, 606 (1969).

² Müller, G., *Nature*, **226**, 749 (1970).

Evidence for a Deep Western Boundary Current in the South Indian Ocean

SIMPLE models of the deep ocean circulation in the southern hemisphere require narrow, northward flowing currents along the western boundaries of the great ocean basins to transport cold, deep Antarctic water into low latitudes^{1,2}. The existence of one such current in the South Atlantic has been well known for many years through the results of the Meteor expedition³, and a similar current has been found in the South Pacific⁴, where direct velocity measurements have been made^{5,6}.

Although the deep Indian Ocean is also filled with water originating in the Antarctic, definite knowledge of the pattern of mean motion there has been lacking. LePichon⁷ found indications of northward movement of near bottom water in the south-western Indian Ocean, but too few data were available for him to specify the flow field. It therefore seemed desirable, both as a further test of the theoretical circulation models, and to improve the physical description of the world ocean, to make more measurements to determine whether a deep western boundary current exists in the South Indian Ocean.

An opportunity for such a project was afforded during a voyage of RV Chain from the South Atlantic to the Red Sea. Between July 11 and 26, 1970, two hydrographic sections were studied between Madagascar and the Mid-Indian Ridge (specifically to longitude 66–67° E), one along latitude 12° S, the other along 23° S. The sections were run to the east of Madagascar because the Mozambique Channel, separating Madagascar from East Africa, has a sill depth less than 3,000 m, so that the effective western boundary for the very deep South Indian Ocean really lies along the eastern slope of Madagascar, rather than along East Africa proper. The station spacing was usually 100 miles in the central ocean, but was reduced gradually to 20 miles or less close to Madagascar; below a depth of 1 km, observations were made 200–300 m apart in the vertical direction.

At depths greater than about 3,200 m, a boundary current is indicated clearly on both sections by a downward slope of isotherms away from Madagascar, the increase in depth of a given isotherm amounting to as much as 700 m. (The prevailing abyssal depth here is roughly 4,500 m.) In the deep water the minimum values of temperature (0.9–1.0° C) and salinity (34.71–34.72 ‰), and the maximum values of dissolved oxygen concentration (4.7–4.8 ml. l.⁻¹), were found close against the base of Madagascar, indicating intensified northward flow of Antarctic water along the western boundary. The width of the current, as measured by the band of sloping isotherms, is about 300 miles at latitude 12° S. The structure at latitude 23° S is less simple, because there seem to be two regions of relatively cold, northward flowing bottom water, one immediately adjacent to Madagascar, as at latitude 12° S, and one less pronounced in the central Mascarene Basin near longitudes 57°–62° E. This odd structure, which evidently disappears by the time the flow reaches latitude 12° S, may represent confirmation of LePichon's suggestion⁷ that deep Antarctic water could enter the Mascarene Basin from both the Madagascar Basin to the west and the East Crozet Basin to the east.

The sign of the zonal density gradient in the boundary current is such that the northward component of geostrophic velocity increases with depth. If one assumes zero meridional velocity at a depth of 3,000 m, just above the region of marked slope in isotherms, then the maximum values of geostrophic bottom velocity, as calculated from the measured density field, have a general magnitude of 6–7 cm s⁻¹. Speeds of this size are comparable with those estimated in the South Atlantic³ and measured in the South Pacific^{5,6} for the corresponding currents in those oceans. Nevertheless, this selection of a zero velocity level is essentially intuitive, and trustworthy figures for velocities and transports must await direct measurements of current speed at one level at least.

The deep salinity maximum found throughout the southern hemisphere lies at depths of 2,000–3,000 m in the South Indian Ocean, well above our assumed level of zero meridional velocity. Because the salinity maximum is formed through entrainment of North Atlantic deep water in the circumpolar current, such water must also enter the deep Indian Ocean from the south. The way in which this comes about is not entirely clear from the present two hydrographic sections. It happens that near Madagascar, and below 2,000 m, the calculated values of northward geostrophic velocity generally decrease with depth down to about the 3,000 m level, then increase again at greater depth; the assumption that the