Eq. 2 represents cation-exchange behavior in sea water for aragonite and high-magnesium calcite, it is apparent that the outer surface of carbonate-sediment grains immersed in sea water should be enriched in Mg relative to the interior of the grains. Surface ratios of Mg:Ca in exchange sites, calculated from Eq. 2, should be approximately 3 in sea water, compared to bulk values of 0.16 and <0.01 for high-magnesium calcite and aragonite, respectively.

In sea water some of the exchange sites may be occupied by sodium as well as calcium and magnesium because of the high concentration of Na^+ in the water. Exchange experiments analogous to those described, involving Ca, Mg, and Na, indicate, however, that at the Na:(Ca+Mg) ratio of sea water no more than 20 percent of the total exchange sites are occupied by Na^+. This percentage must be a maximum because much of the exchange Na^+ may be associated with organic matter (see *11*). Because Na^+ is not a lattice ion in $CaCO_3$ and is univalent, it would not be expected in general to contribute heavily to exchange with Ca and Mg on $CaCO_3$ surfaces.

It is probable that Mg^{++} on or near the surfaces of particles of carbonate sediment immersed in sea water shows a range of reactivities from unexchangeable, strongly bonded Mg^{++} (incipient dolomite?), through slowly reversible Mg^{++} exchangeable only for Ca^{++}, to rapidly exchangeable, weakly bonded Mg entering readily into exchange not only with Ca^{++} but also with Na^+ and other cations of sea water. Which type of Mg may be able to inhibit carbonate grains from reacting to form low-magnesium calcite or dolomite remains unknown.

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Foraminiferal Evidence of a Shallow Calcium Carbonate Solution Boundary, Ross Sea, Antarctica

Abstract. *In the Ross Sea, Antarctica, distributions of calcareous Foraminifera and other calcareous microorganisms are dominantly controlled by a shallow calcium carbonate solution boundary that occurs at depths of about 500 meters. Possible causes of substantial undersaturation of Ross Sea bottom waters in calcium carbonate are very low temperatures and high salinities, which favor the solution of calcium carbonate and, possibly, high concentrations of carbon dioxide.*

Foraminifera from 48 ocean-bottom samples collected within the Ross Sea between 1959 and 1961 by the New Zealand Oceanographic Institute during two cruises by H.M.N.Z.S. *Endeavour* have been studied. Of these samples, 37 were collected by orange-peel or Dietz-La Fonde grabs; 11, by Devonport dredge. No preservative was added to the foraminiferal samples and thus no post-collection solution of calcium carbonate could have occurred. Information from these samples has been supplemented by data from 60 earlier samplings by others (*1–3*). Ross Sea environmental factors and the distribution and foraminiferal content of Ross Sea samples studied by me are detailed elsewhere (*4*).

The presence of two greatly contrasting types of microfaunas are indicated: (i) Calcareous faunas made up of abundant calcareous Foraminifera, less-abundant Ostracoda, Bryozoa, and minute Mollusca, and other calcareous organisms, with relatively few arenaceous Foraminifera; (ii) dominantly noncalcareous and more-sparse faunas made up of arenaceous Foraminifera (> 85 percent benthonics), diatoms, and silicious sponge spicules (Fig. 1).

Most calcareous faunas are restricted to depths less than 550 m, while all the dominantly noncalcareous faunas occur deeper than 430 m. Abundant planktonic Foraminifera occur in all the calcareous faunas and generally constitute between 5 and 86 percent of the foraminiferal sample; they are generally absent from the arenaceous faunas and, in all but two samples, are very rare, constituting less than 3.2 percent of the foraminiferal sample (Fig. 2). The planktonics steadily increase in abundance to about 500 m; their sharp decrease at greater depths is associated with the appearance of dominant arenaceous faunas (Fig. 2).

The waters from which the samples were taken range in temperature as little as 2°C (+0.4 to −2°C) and in salinity less than 1 per mille (34.52 to 35.08 per mille); they are almost isothermal and isohaline, and the benthic faunas seem little affected by the small variations. There are no published data on the distribution of carbon dioxide in the Ross Sea.

Study of five cross sections across the Ross Sea (*4*) showed important relations between certain environmental factors and foraminiferal trends, of which the most striking is correlation between bathymetry and test (shell) composition; on the whole there is no definite relation between texture of bottom sediment and test composition. Although most calcareous faunas were associated with coarse sediment and most arenaceous faunas with fine sediment, the reverse was true for a reasonable number of stations—for example, stations A644 and A645, Mowbray Bay: A644 (530 m) is represented

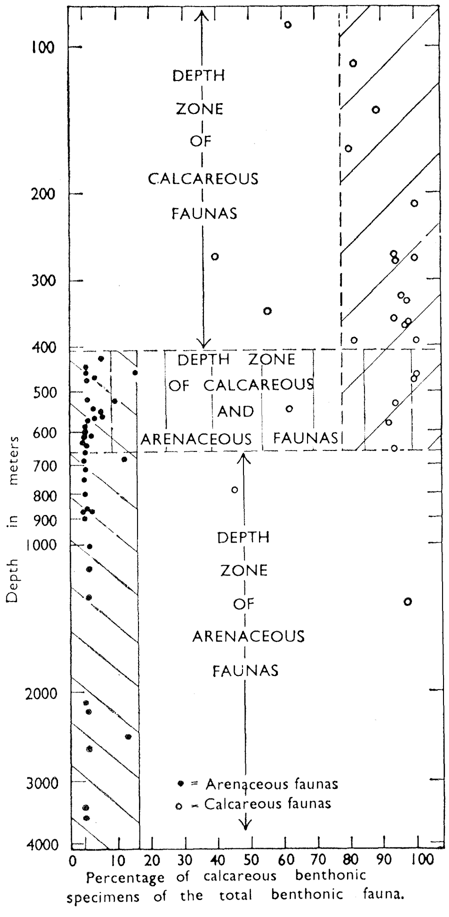

Fig. 1 (left). Percentages of calcareous benthonic specimens in the total benthonic fauna in Ross Sea samples counted by me, McKnight (*1*), and Pflum (*2*). Arenaceous faunas have less than 15 percent calcareous benthonic specimens; most calcareous faunas have more than 75 percent calcareous benthonic specimens. Most calcareous faunas are restricted to depths less than 550 m; all arenaceous faunas occur deeper than 430 m.

by black mud (median diameter, 14 μ) and has a calcareous fauna, whereas A645 (720 m) is represented by black-brown fine sand (median diameter, 130 μ) and has an arenaceous fauna. Some degree of correlation between calcareous faunas and coarse sediments might be expected, since sediments tend to be coarse in shallow water, but there is no evidence that the nature of the sediment has any direct control over the fauna.

Calcium carbonate percentages in the sediment are often greatest in the regions of high foraminiferal percentages, but this is probably an effect of calcareous foraminiferal abundance rather than a controlling factor in distribution. Salinity and temperature of the bottom water showed no definite relations with faunal trends.

The distribution of calcareous faunas (benthonics and planktonics) shallower than 550 m and of arenaceous (dominantly noncalcareous) faunas at depths greater than 430 m, in addition to the evidence of solution effects on calcareous Foraminifera in arenaceous faunas, suggests the presence of a calcium carbonate solution boundary at a depth of 500 to 550 m.

There are partial solution effects on most of the calcareous Foraminifera occurring in the dominantly arenaceous faunas in some of which the sparse calcareous Foraminifera are often represented by casts; in others, specimens are thin-shelled, chalky in appearance, and easily broken. Similar but lesser effects are evident in the Mollusca. The well-known (*5*) solution of calcareous tests (shells) of Foraminifera in the deepest parts of the oceans results from the high concentration of carbon dioxide below certain depths, caused by increased hydrostatic pressure and lower temperature.

Solubility of calcium carbonate in sea water increases with increasing salinity and decreasing temperature (*6*, *7*). The effect of pressure, regarded by some authors as small (*7–9*), has been recently shown (*10*) to be an important factor; the apparent solubility product increases about threefold on exposure to 1000-atm pressure.

Outside the Ross Sea, in warmer, less-saline circumpolar water, calcareous benthonic foraminiferal faunas exist as deep as 4000 m (*2*, *11*); thus it follows that *effective* solution of calcium carbonate occurs only at greater depths, even though it has been shown that waters in the eastern South Pacific are generally undersaturated in calcium carbonate below the first few hundred meters (*12*).

A much shallower effective calcium carbonate solution boundary in the Ross Sea probably reflects several factors: low temperatures (0° to −2°C) and high salinites (34.75 to 35.00 per mille) of the bottom water, favoring solution of calcium carbonate; high content (increased solubility) of carbon dioxide, caused by the low temperatures; the presence immediately to the south, below the thick Ross Ice Shelf, of a considerable mass of water probably containing much carbon dioxide as a result of aphotic conditions and of an ice cover over the Ross Sea for much of the year, whereby the activity of phytoplankton is limited to short periods during the summer. The topography in the Ross Sea would to some

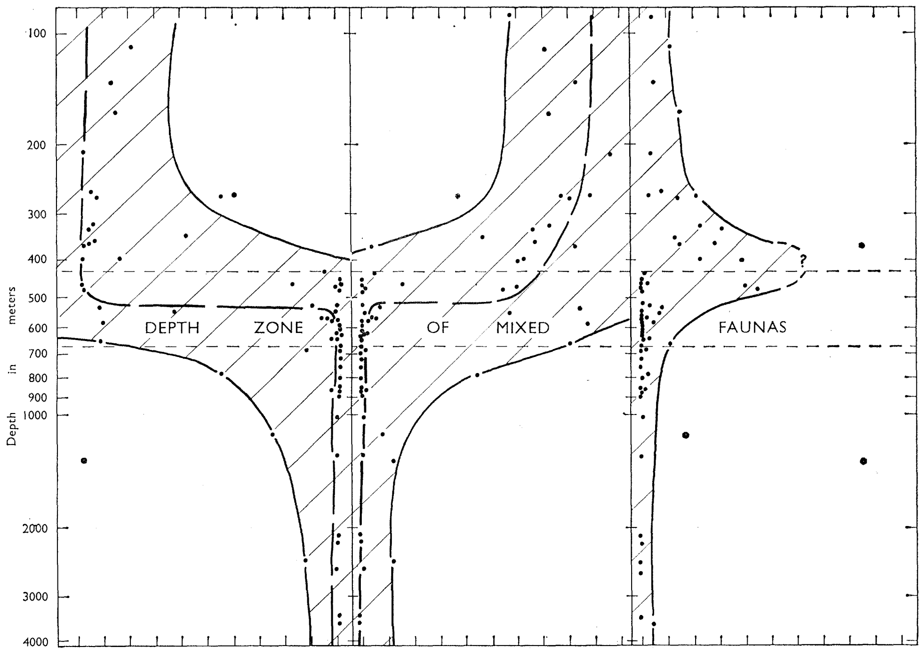

Fig. 2. Relative percentages of arenaceous benthonic, calcareous benthonic, and planktonic specimens in samples counted by me, McKnight (*1*) and Pflum (*2*). Arenaceous and calcareous benthonics show an approximately reciprocal relation, while planktonics increase in abundance down to about 500 m; deeper, a steep decrease reflects solution effects. Most samples from below 500 m contain very low percentages of calcareous Foraminifera.

extent help to retain the dense, highly undersaturated waters over the (bottom) shelf and reduce circulation (*13*).

Of the 108 samples studied by me and others, 46 with calcareous faunas are from depths less than 550 m; only nine are from more than 550 m and below the solution boundary. Two of McKnight's samples with high calcareous percentages can be disregarded because one (IBM 028, 576 m) contained only one specimen and the other (IBM 011, 740 m), only one calcareous species. Of the remainder, three are from the northeast of Pennell Bank, three are from McMurdo Sound to the west of Ross Island, and one is from 192 km east of Ross Island—all but the last from areas of steep slope. These atypical calcareous faunas possibly result from displacement of bottom sediments and calcareous faunas from shallower waters, a common phenomenon in Antarctic waters (*11*). Preservation of calcareous specimens not in chemical equilibrium with the surrounding water may also reflect rapid burial because of either high rates of sedimentation or burrowing by benthonic animals.

The distribution of the contrasting faunas has been explained by others, working with relatively few samples. McKnight (*1*) and, with modifications, Pflum (*2*) proposed a rather complicated mechanism involving a hypothetical current, with high arenaceous and low calcareous foraminiferal percentages, passing over the stations dominated by arenaceous Foraminifera; this bottom current swept almost all planktonic Foraminifera out of the areas dominated by the arenaceous forms. My work shows, however, that the calcareous faunas occur in shallow areas that are probably more exposed to current action. The distribution of calcareous and noncalcareous faunas in Ross Sea bottom sediments is more readily explained by invocation of a calcium carbonate solution boundary.

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Ambrosia Fungi: Extent of Specificity to Ambrosia Beetles

Abstract. *Experiments with developing ambrosia beetles and fungi indicate that beetles may feed on more than one species growing in their tunnels. The yeast-like ambrosia propagules in mycangia of beetles arise from conida and ascospores picked up by callow adults during their stay in tunnels.*

Despite earlier assumptions (*1–3*), each species of ambrosia beetle does not necessarily feed on a particular fungus throughout its life cycle; nor is it dependent on only one species of fungus. In nature, larvae feed usually on a primary ambrosia fungus while adults also eat one or more auxiliary ambrosia fungi. The primary fungus is brought into tunnels by females (rarely by males) at the time of burrowing (*2, 3*); it grows luxuriantly in tunnels and spreads from there to any cradles present. In some species the larvae are reared individually in cradles which they enlarge; other species do not construct such cradles. The mycelium ramifies into xylem, phloem, and ray elements, but usually sporulates only in the tunnels and larval cradles. By the time the first adult beetles emerge, auxiliary fungi may be growing throughout the entire tunnel system; one may sometimes grow beside the primary ambrosia fungus during the early stages of excavation of tunnels.

Most primary and auxiliary ambrosia fungi produce abundant conidia on short conidiophores of determinate length, and thus are well adapted to the limited space available in main tunnels and larval cells. Periodic removal of conidia by beetles ordinarily does not damage the growing point but rather appears to promote further sporulation.

Although larvae of several ambrosia beetles (*4*) were observed in the field feeding on the primary ambrosia fungus in their cells, young adults of the same brood may also feed on auxiliary fungi in the main tunnels. Such observations were confirmed in the laboratory in some instances by allowing callow adults access to auxiliary fungi. When eggs and young larvae were incubated on wood chips colonized by only auxiliary fungi (in some instances by fungi other than ambrosia) the larvae ate the fungi and matured (Table 1).

Adults usually contain in the gut partially digested conidia and fragments of mycelium of auxiliary and primary ambrosia fungi. Most of the auxiliary fungi so far isolated belong to either the yeast genera (*Hansenula, Saccharomyces, Oidium,* and *Torula*) or the filamentous hemiascomycete genera (*Ascoidea, Cephaloascus, Dipodascus, Endomycopsis,* and *Endomyces*). In some instances *Graphium* and *Leptographium* also serve as auxiliary fungi. The primary ambrosia fungus of one beetle may sometimes be an auxiliary fungus for other species of ambrosia beetles.

A large population of *Trypodendron scabricollis* just beginning a brood, with its primary ambrosia fungus already established in tunnels, was obtained from the field during early summer of 1962 (*2*). Thirty females (two groups of 15) were aseptically removed from naturally infested logs and identified with differently colored paints. One group was transferred into tunnels bored with an electric drill in wood that had been inoculated, after sterilization, with conidia of *Endomycopsis fasciculata,* a common auxiliary ambrosia fungus of many beetles. The second group was transferred to similar tunnels inoculated with conidia of *Ceratocystis minor,* a nonambrosia fungus commonly associated with bark beetles. A naturally infested log having 15 active burrows of approximately the same age and presumably lined with a palisade of primary and auxiliary fungi