# Weddellite in a Marine Gastropod and in Antarctic Sediments

Abstract. *The calcium oxalate dihydrate mineral, weddellite, has been identified in a microarchitectural component of the gizzard plates from the deepwater gastropod* Scaphander cylindrellus. *This is the first indication of nonpathologic precipitation of this mineral by an animal species. A new occurrence of weddellite in sediments from the Weddell Sea, Antarctica, is also reported, lending support to the earlier interpretation that the mineral is an authigenic constituent of the sediments in this area.*

Most gastropod species have a calcareous shell which is secreted by the mantle and is composed of aragonite, calcite, or vaterite. Additional tissues are involved in mineral secretion in some superfamilies. In the Patellacea, the superior epithelial cells of the radular sac secrete the mineral geothite ($\alpha$FeOOH) on the denticles of the teeth in all species examined to date (*1*). The gizzard plates found in species of the tectibranchian family Scaphandridae show a different tissue as the site of mineralization. According to the literature, the gizzard plates of *Scaphander* species are calcareous, implying strengthening by a carbonate mineral similar to that of their shell (*2*).

I had the opportunity to study the mineralogy of the gizzard plates of a *Scaphander* species through recovery of a live individual of the deepwater species *Scaphander cylindrellus*. The specimen was dredged by the Magdalena Bay Expedition from a depth between 3389 and 3594 m off Baja California (24° 45.2′N, 113°25′W to 24°21.3′N, 113° 1618′W) and was kept in a solution of 75 percent alcohol. This species was found to have three equidimensional, narrow, biconvex gizzard plates, which become flattened at their anterior and posterior ends. The central portion of the plates which face into the gizzard is free from enclosing tissues, and its surface is strongly convex and shows signs of mechanical wear.

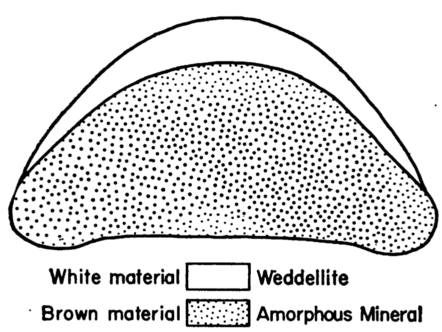


Fig. 1. Distribution of two microarchitectural units as seen in a median transverse cut through a gizzard plate of *Scaphander cylindrellus* Dall. Dimensions: width of dark brown unit at base, 1.1 mm; thickness of dark brown unit, 0.47 mm; thickness of white unit, 0.14 mm.

The plates are composed of two color-distinct structural components, of which one is an opaque, dark reddish brown and the other is white semitranslucent. The white component is confined to the strongly convex part of the plates that project into the gizzard cavity.

A median transverse cut through a gizzard plate was prepared for elemental determination with an electronprobe microanalyzer. The cross section (Fig. 1) shows the distribution relation of the white and dark brown structural components in the plane where the white compound attains its greatest thickness. The contact between the two structural units is sharply defined by their color differences and the abrupt termination of the growth lines seen in the brown component against their common boundary.

The electroprobe analyses show that, in the white component, calcium is the major constituent (average, 32.2 percent), and phosphorus, fluorine, iron, strontium, and magnesium are present in trace amounts (totaling 0.5 percent). In the dark brown component, iron, calcium, and phosphorus were found to be major constituents; manganese, barium, magnesium, and sulfur are present in intermediate amounts; and chromium, nickel, and chlorine are present in trace amounts (*3*).

Samples of the two microarchitectural units were mechanically separated from another gizzard plate. The samples were finely ground, and the powders were investigated separately by x-ray diffraction (Norelco instrument) with a (Debye-Scherrer) camera and nickel-filtered copper radiation.

A sample of the mineral weddellite ($CaC_2O_4 \cdot 2H_2O$) was included in the study for comparison with the white component. The weddellite sample was isolated from the coarse fraction of sediments recovered by the Eltanin Expedition at Station 517 at a depth of 4196 m in the Weddell Sea (66°26′S, 45°45′W to 66°23′S, 45°49′W) (*4*). The mineral occurs in the sediments as single crystals which are transparent, colorless, tetragonal dipyramids. Identification of the crystals as weddellite was made from their optical data and x-ray powder diffraction patterns (*5*).

Figure 2 shows the powder-diffraction pattern obtained from the white component of the gastropod gizzard plates and of the weddellite crystals from the Antarctic sediments. The pattern of the mineral from the white component indicates that it is crystallochemically identical in spacings and intensities to the reference weddellite. The nature of the dark brown component of the gizzard plates is not revealed by the x-ray

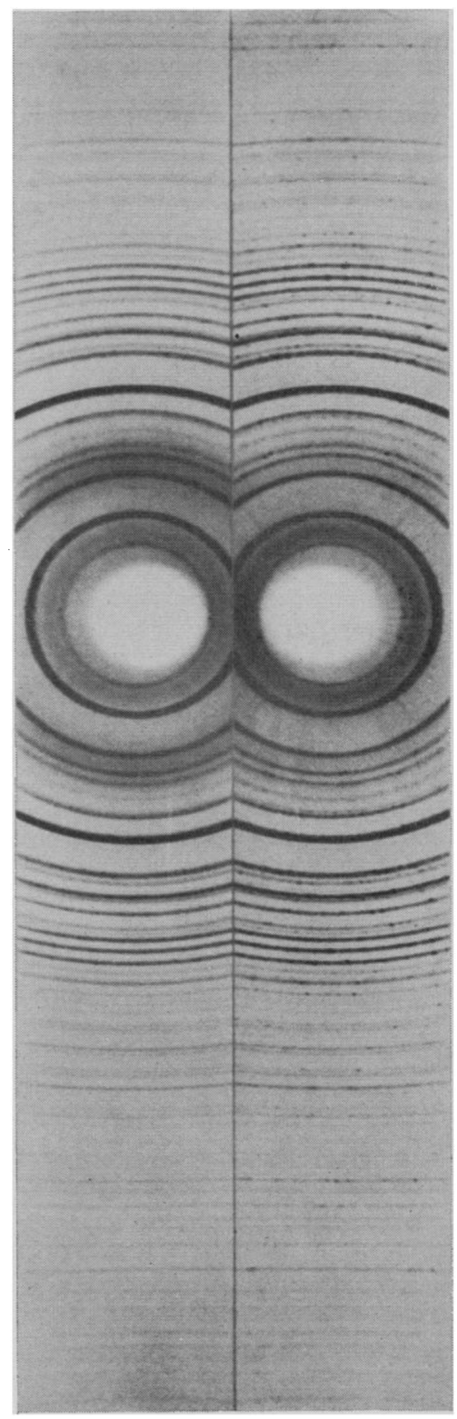

Fig. 2. (Left) White material from the gizzard plate of *Scaphander cylindrellus*; (right) reference weddellite.

diffraction pattern, indicating that it is an amorphous substance; its mineralogical composition remains an enigma.

The calcium oxalate hydrate, weddellite, is a common constituent of urinary calculi in man and other mammals and has been with question identified in waste products of plants (*5*). Bannister and Hey (*6*) also identified weddellite crystals in sediments of the Weddell Sea and concluded from the perfectly developed form of the crystals and their lack of mechanical abrasion that they were an authigenic mineral constituent of the sediments. The bottom deposits containing the weddellite crystals were stored in containers originally used for provisions on shipboard and mostly were allowed to dry before being analyzed for their mineral content. Hence, questions have been raised concerning the origin of the crystals (*7*). Recovery of the weddellite crystals from bottom sediments geographically close to the Antarctic stations where the original samples were found, and the fact that this mineral has not been reported from marine deposits elsewhere, favor the original interpretations that it is an authigenic mineral of the deepwater sediments in the Weddell Sea.

The data presented here extend the range of weddellite precipitation in biologic systems from the mammals to an invertebrate species. The localization of the mineral in discrete microarchitectural units, at homologous sites in the gizzard plates of the gastropod, indicates that for the first time we are dealing with a normal biochemical precipitate. This is in contrast to the occurrence of weddellite in renal calculi of mammals, which are pathologic mineral secretions. The weddellite crystals of *Scaphander cylindrellus* are initially enclosed in an organic matrix. Mechanical wear of the weddellite-bearing surface of the plates brings the crystals in direct contact with the gizzard contents. The gizzard plates of the *Scaphander* species serve as mechanical crushers of the exoskeletons of invertebrate prey, which consist of calcite and aragonite. The hardness of the weddellite is about 4 (*8*); whereas that of the mineral phases of the carbonate found in the skeletons of the prey is 3 to 3.5. Hence, the tipping of the crushing surface of the gizzard plates in *S. cylindrellus* with weddellite is of mechanical advantage in its functional use by the organism.

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**References and Notes**

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3. The preliminary qualitative data on the elemental composition of the brown structural component are presented here solely to indicate the gross chemical composition of the mineral which borders the weddellite-bearing components. The precise chemical composition of the brown structural component is still under investigation.
4. The sediment sample containing the weddellite crystals was preserved in a solution of 70 percent alcohol.
5. The crystals are uniaxial positive, $\omega = 1.5237 \pm 0.0006$, $\epsilon = 1.5434 \pm 0.0012$. The *d*-spacings and line intensities of the powder diffraction patterns for the crystals match those listed for the mineral weddellite in the American Society for Testing Materials catalog.
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9. Contribution No. 1552 from the Division of Geological Sciences, California Institute of Technology. Supported by NSF grant GB-6707X. I thank M. Dekkers, A. Chodos, and B. Carter, for technical assistance; C. Hubbs, for facilitating my participation in the Magdalena Bay Expedition; and M. Keen, for identification of the specimen.

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## Neuronal Coding by Cortical Cells of the Frequency of Oscillating Peripheral Stimuli

Abstract. *One class of neurons in the somatic sensory cortex of unanesthetized monkeys is rhythmically entrained by sinusoidal mechanical stimulation of the skin of the hand at low frequencies. A second class, which is linked to Pacinian afferents, increases its rate of discharge in response to high-frequency peripheral stimuli but is not entrained. The vibratory sense is served by two distinct classes of cortical cells. The code for the group sensitive to low-frequency stimuli is the temporal order of impulses; for the high-frequency group the code is the labeled line.*

One objective in the study of central neural mechanisms in sensation and perception is the elucidation of the patterns of activity of central neurons in relation to peripheral stimuli that vary with time; another is to learn how certain properties of the latter are coded in the discharge patterns of the neurons. In somesthesis this correlation is based on the neural activity evoked throughout the somatic afferent system by sine-wave oscillatory stimulation of the skin. The idea is that the perception of vibration must be related to neural mechanisms at a high level of the nervous system which provide cues to the location, frequency, and intensity of the vibratory stimuli. Identical vibratory stimuli have been applied to the hands of humans for psychophysical studies and to those of monkeys for the study of activity in single peripheral nerve fibers (*1*). Two sets of fibers signal with precision the frequency of vibratory stimuli: the quickly adapting afferents which terminate in the dermal ridges of the glabrous skin and those which originate in the subcutaneous Pacinian corpuscles. At intensities comparable to human thresholds, low-frequency stimuli (5 to 50 hz) drive the cutaneous movement detectors, and high-frequency stimuli (50 to 400 hz) drive the Pacinian afferents. At the threshold tuning points the frequencies of the stimuli are replicated by periodic discharges in the first-order afferent fibers.

We here describe the way in which neurons of the somatic sensory area (the postcentral gyrus) of the cerebral cortex respond to vibratory stimuli in the unanesthetized monkey (*Macaca mulatta*). With the animal under pentobarbital anesthesia the skull was opened, and a Lucite chamber was fixed above the target area. The scalp wound was sutured, and the animal was allowed to recover overnight in a primate chair. The next morning gallamine triethiodide was injected intraperitoneally, and respiration was maintained by means of a face mask. The tissues about the trachea were infiltrated with a permanent local anesthetic, Efocain. An endotracheal tube was inserted and connected to a positive-pressure respirator. Expired $CO_2$ was kept at about 4 percent. The head was fixed by gripping the Lucite chamber; the animals rested on soft padding. They appeared to be free of pain, for they alternated between sleep and wakefulness, as indicated by pupillary and electroencephalographic signs. The dura beneath the skull opening within the chamber was excised, and the area of the postcentral gyrus associated with the hand was detailed by mapping of the evoked potential. Tungsten microelectrodes were inserted into the cortex by way of the hydraulically sealed chamber (*2*). An electronically controlled skin-displacement stimulator delivered sine-wave stimuli, of various frequencies and amplitudes, superimposed on a step indentation of the skin of 560 $\mu$m. A LINC computer was used for stimulation, data collection, and data analysis (*1*).

More than 1000 neurons in Brodmann's areas 3 and 1 were studied,