plex head and body movements in the unrestrained cat and monkey. Only in restrained animals does the stimulation effect appear to be restricted to eye movement (*10*). Lesions in this area produce gross deficits in posture and head movements, as well as disturbing eye movements (*11*).

Eye and head movements are normally coordinated and therefore it should not be surprising that eye movement relations have been found in cells related to head and other movements. Indeed, as Bizzi *et al.* (*12*) have pointed out, neck muscles are activated prior to eye muscles in coordinated movements. Neck muscle activation can also be detected in head-restrained animals. Most studies of eye movement relations in PRF cells have been performed in head-restrained animals. Therefore, correlations between activity in head movement cells and EOG in these preparations might speciously suggest that these cells were triggering eye movements. Conclusions from studies that examine the relationship of unit discharge to only one isolated behavior must be cautiously interpreted and cannot confirm general conclusions about the cells' functional role.

We have now examined a large portion of the medial brainstem reticular formation in unrestrained, behaving cats in a variety of behavioral situations and find cells related to specific movements throughout this area. The correlations between PRF activity and habituation and conditioning processes (*13*), pain and escape behavior (*14*), treadmill stepping (*15*), REM sleep (*3*, *6*, *16*), and eye movements can be viewed as a consequence of the involvement of these movements in a variety of behaviors.

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Nautiloid Uroliths Composed of Phosphatic Hydrogel

Although it has been known for more than a century that nautiloid uroliths are composed chemically of phosphate of calcium with lesser amounts of magnesium, the true nature of this inorganic bioprecipitate was not known (*1*). We have investigated by x-ray diffraction the characteristics of these concrements, have related the nature of this inorganic substance to a theory governing the crystallization of phosphatic hydrogels, and have suggested a possible relation between these uroliths and "conodont pearls" described by Glenister *et al.* (*2*).

It was surmised that the uroliths might be francolite (carbonate fluorapatite) inasmuch as this is the crystallochemical nature of marine phosphorites (*3*) and the shells of inarticulate brachiopods (*4*, *5*). However, no interference maxima were observed in an attempt to obtain a powder-diffraction pattern by x-rays (*6*). Furthermore, the chemical composition was found to be inconsistent with that of francolite, the carbon dioxide and fluorine being too low (*7*).

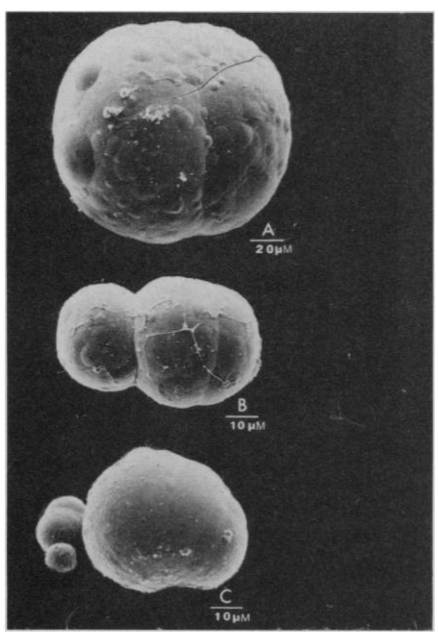

Fig. 1. Scanning electron photomicrographs of *Nautilus* concrements. Specimens A and B are from *N. macromphalus* from New Caledonia; specimen C is from *N. pompilius* from Fiji.

A similar amorphous, calcium-phosphate hydrogel was reported as a component of gizzard plates of a gastropod (*Scaphander lignarius*), but this was complicated by the presence of another crystalline phase (fluorite), and the water content was not determined (*8*). Lowenstam (*5*) subsequently found the gizzard plates of another species (*S. interruptus*) to produce no pattern prior to heating, after which the pattern of whitlockite was obtained.

Prior experience with phosphatic hydrogels had indicated that some of them, at least, could be induced to crystallize by heating them—thus reducing the water content—and thereby bringing them into consistency with a kinetic hypothesis for crystallization which proposes that an energy barrier exists that is directly dependent on the product of some functions of the cationic and anionic concentrations, but is inversely proportional to some function of the hydrogen concentration per volumetric unit (*9*). This hypothesis, to be sure, contains no clue concerning the crystal structure that will form; we had supposed that it might be dahllite.

When a small sample of pink spherules from *Nautilus pompilius* was heated for 24 hours at 600°C, it lost 21 percent of its weight and turned dark gray—presumably through carbonization of organic matter. The x-ray diffraction pattern of this heated substance was then found to be virtually identical with patterns of two analyzed samples of whitlockite (*10*). This result is consistent with the relatively high magnesium content of the nautiloid spherules (*12*).

Naturally occurring, amorphous, phosphatic substances seem to be unknown among fossilized materials. From the sizes and shapes (Fig. 1), the small nautiloid concrements described here might have counterparts as "conodont pearls" (*2*) within older sedimentary formations. Glenister *et al.* (*2*) were able to show merely a stratigraphic association with conodonts, aside from similarities in chemical composition. Their suggested relation to conodonts fails to account for the rarity or absence of "pearls" in some strata, such as those of the Baltic Platform and of the Appalachians where some of the greatest concentrations of conodonts are found (*12*).

In contrast, leaching of magnesium and crystallization of such spherules of phosphatic hydrogel would be expected to yield francolite within a marine environment. Provided that such uroliths were excreted by the cephalopods, it would be unnecessary to assume that the shells of cephalopods would be abundant in the same strata.

Surely these tiny spherules (up to 0.1 mm) are adequately abundant in extant *Nautilus* to appear as fossils in ancient strata, although their crystallochemical characteristics might have changed during the fossilization process from a phosphatic hydrogel to a more stable form, francolite.

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5. See H. A. Lowenstam [*Chem. Geol.* **9**, 153 (1972)], where it is stated that *Pelagiodiscus atlanticus* produces an x-ray pattern similar to dahllite. However, it is not possible to distinguish between francolite and dahllite by this method, and the fluorine content (~3 percent) surely indicates that the substance of the shell is francolite.
6. Although negative evidence of crystallinity is not usually unequivocal, several attempts to obtain diffraction lines were unsuccessful despite careful control of the density of packing of the specimen that was exposed to the x-ray beam and sufficient exposure time. Such methods have proved successful in the discovery of crystallinity among substances previously reported as "amorphous" by other laboratories. Electron diffraction was attempted also, and a few "spotty" rings were obtained, but these rings may have resulted from incipient crystallization produced by energy from the electron beam or loss of water in the vacuum system, or both.
7. A qualitative estimate indicted distinctly less CO_2 than bone (that is, less than 5 percent), and a quantitative determination of fluorine was 0.03 percent. We thank Dr. Leon Singer (University of Minnesota) for these analyses.
8. H. A. Lowenstam and D. McConnell, *Science* **162**, 1496 (1968).
9. D. McConnell, *Mineral. Mag.* **40**, 609 (1976), wherein it is indicated that, in a series of hydrated aluminum phosphates $f(P) \cdot f(Al)/f(H)$ must exceed some minimum value in order for crystallization to take place.
10. The samples of whitlockite used for comparison were topotype material from New Hampshire and analyzed material from near Sabinas Hidalgo, Nuevo Leon, Mexico. We thank C. Frondel (Harvard University) and W. L. Hill (deceased) (formerly with the U.S. Department of Agriculture) for these samples.
11. Through correspondence with A. W. Martin (University of Washington), we learned that the Mg content exceeded the Ca content of some of these nautiloid uroliths, thus indicating an unexpectedly great tolerance for Mg in the crystal structure of whitlockite. However, the (Ca + Mg)/P ratios are still below the theoretical value (1.5), ranging from 1.31 to 0.84 for five determinations by a commercial laboratory.
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McConnell and Ward (*1*) report that sand-sized phosphatic concretionary bodies, long known to be abundant in the urinary tract of extant *Nautilus*, are converted from an amorphous hydrogel to the mineral whitlockite when heated to 600°C for 24 hours. They suggest a possible relationship between these nautiloid uroliths and the phosphatic dimpled spheres, which, on the basis of mineralogy, ultrastructure, morphology, and occurrence we interpreted as possible conodont pearls (*2*).

Phosphate compounds are present in every animal cell, and a wide variety of invertebrates and vertebrates secrete phosphatic structures for protection and support. Additionally, many organisms eliminate metabolic waste as laminated phosphate [for example, (*3*)], and concentrically banded phosphatic concretions are known to form in association with degradation of organic tissue [for example, (*4*)]. In view of this ubiquitous occurrence of phosphate, the suggestion, based mainly on chemical similarity, that uroliths of *Nautilus* have counterparts as "conodont pearls" is subject to critical evaluation.

A notable feature of "pearls" is their regular, smooth, spherical form in which the dimpled base is replicated precisely in successive growth stages. *Nautilus* uroliths are comparable in size and concentric growth, but almost all are compound, some as irregular clusters but most as beaded rods (*5, 6*). Unlike the "pearls," uroliths display an uneven varicose surface and lack a regularly replicated dimple.

McConnell and Ward note that ". . . amorphous, phosphatic substances seem to be unknown among fossilized materials," but speculate that nautiloid uroliths may have been converted during diagenesis from a phosphatic hydrogel to a more stable form, francolite, the mineral species of both conodonts and "pearls" (*2*). When preserved unaltered, conodonts and "pearls" are translucent and honey-colored. Progressive and irreversible color change from yellow to black occurs with increasing depth and duration of burial and geothermal gradient (*7*) and reflects fixation of carbon. Subjection of conodonts and "pearls" to the experimental conditions reported necessary to convert *Nautilus* uroliths to whitlockite (*1*) renders them black and opaque [figure 3 in (*7*)].

The rarity or absence of "pearls" in some strata containing abundant conodonts was noted by us and raised subsequently (*1*) to question our suggestion that these "pearls" were secreted by the conodont-bearing animal. But sporadic occurrence characterizes the pearls and shell blisters formed by diverse living invertebrate groups. Uroliths may also be expected to occur sporadically. However, neither "pearls" nor uroliths are known from the Upper Carboniferous to the Holocene, an interval when nautiloids and other cephalopods were extremely abundant. This apparent hiatus casts doubt on the abundance or preservability (or both) of cephalopod uroliths.

In conclusion, we interpret differences in morphology, mineralogy, and distribution between "pearls" and nautiloid uroliths as evidence that they are unrelated biologically. Available data still tend to support our suggestion that the dimpled spheres described by us are pearls secreted by the conodont-bearing animal as a response to an organic or particulate irritant.

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31 October 1977