W/cm^2) through a conventional gas-filled hollow capillary without damaging the walls (*17*). This possibility would open new directions in laser-plasma nonlinear optics, including laser-plasma acceleration of charged particles and laser-plasma Raman amplifiers that can withstand unprecedented intensities (*18*).

Benabid *et al.* report the first step toward these exciting possibilities for nonlinear optics with hollow-core fibers. A new era in the nonlinear optics of gases, and maybe even plasmas, is about to begin.

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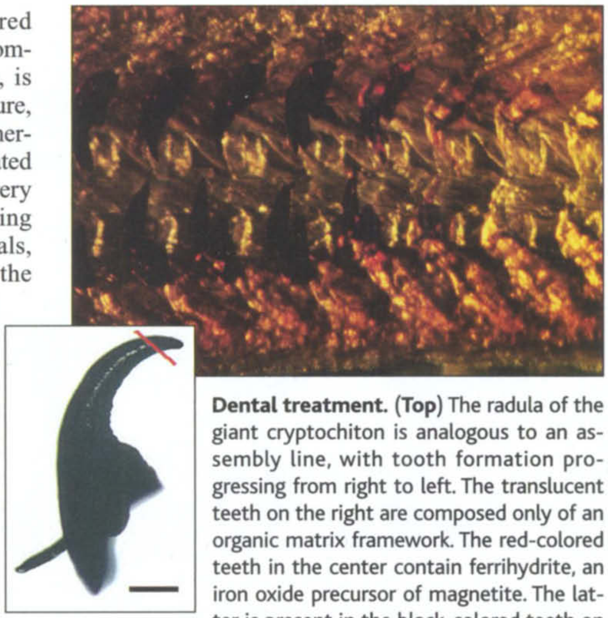
PERSPECTIVES: BIOMINERALIZATION

At the Cutting Edge

Steve Weiner and Lia Addadi

In 1962, Heinz Lowenstam discovered that the outer layer of the teeth of a common intertidal mollusk, the chiton, is composed of magnetite (*1*) (see the figure, top panel). This magnetic iron oxide mineral was then thought to form only at elevated temperatures and pressures. The discovery focused attention on the ability of living systems to produce unexpected minerals, and proved to be a turning point for the field then known as calcification.



Dental treatment. (Top) The radula of the giant cryptochiton is analogous to an assembly line, with tooth formation progressing from right to left. The translucent teeth on the right are composed only of an organic matrix framework. The red-colored teeth in the center contain ferrihydrite, an iron oxide precursor of magnetite. The latter is present in the black-colored teeth on the left [reviewed in (*9*)]. The chiton radula represents one of the best-documented examples of a preformed organic framework in which mineral subsequently forms. This basic strategy is widespread in biomineralization. It also demonstrates that transient mineral phases may be the first deposits during mineralization. **(Left)** The teeth of the bloodworm *Glycera*, shown by Lichtenegger *et al.* (*2*) to contain a copper mineral.

CREDIT: TOP PANEL, H. A. LOWENSTAM; LEFT PANEL, FROM (2)

Forty years on, Lichtenegger *et al.* (*2*) report more dental surprises. On page 389 of this issue, they show that a copper chloride mineral, atacamite, is formed in the teeth of the carnivorous marine worm *Glycera* (see the figure, left panel). It is the first copper mineral to be identified that is formed under controlled conditions in an organism (*3*), prompting the question of how they can scavenge enough copper from their surroundings to produce this mineral.

The mineral atacamite is the latest addition to the growing list of known biological minerals. This list, compiled and monitored periodically by Lowenstam for more than 30 years, has expanded from just over 10 in the early 1960s to almost 70 today (see table S1 for a full listing). Many of the minerals do not contain calcium, prompting a change in the name of the field to biomineralization.

Atacamite reinforces the very sharp tips of four teeth that are used by the worms as syringes to inject poisonous venom into their prey. There is no definitive explanation for why they use copper. Another, taxonomically related, worm (*4*), and quite a few arthropods, have high concentrations of zinc in their teeth and mandibles (*5*). The zinc is apparently not in the form of a mineral, but is associated directly with the organic framework. One intriguing possibility raised by the authors is that the copper may activate the venom as it is being injected. Lichtenegger *et al.* also point out that atacamite [$Cu_2(OH)_3Cl$] occurs in four different polymorphic forms. As the worm consistently forms only one, the process must be under strict chemical control.

The field of biomineralization straddles the organic and inorganic worlds. The "active site" equivalent of a mineralized tissue is the interface at which the biological macromolecules that control mineral formation interact with the mineral surfaces. The major component of the teeth of the worms studied by Lichtenegger *et al.* (*2*) is an unusual and uncharacterized protein (or protein mixture) rich in glycine and histidine (*6*). Histidine is a common ligand in metal-binding sites of metalloenzymes, including those containing copper. It will be most interesting to understand the nature of the interface between this structural protein and atacamite.

Many fundamental questions remain to be addressed regarding recognition and assembly in complex three-dimensional biological tissues such as teeth. Understanding these processes in the vertebrate skeleton and in tooth formation, and in the many forms of human pathology involving mineral formation, has much relevance to medicine.

About a decade ago, materials scientists began to look for new ideas for improving materials design inspired by biological materials. Lichtenegger *et al.* (*2*) elegantly show that the teeth of their worms have an extraordinary resistance to abrasion. This property is presumably related to the molecular structure of the mineral-reinforced fibrils that constitute the building block of the tooth. Such mineralized fibrils are common in biological tissues, including vertebrate bone and tooth dentin (*7*). Understanding the structural basis for this unusual mechanical property in the worm teeth could lead to new ideas for tool design. Many other scientific disciplines including paleoclimatology, archaeology, evolution, and paleontology, which extensively use biologically produced skeletons, may also benefit.

With the discovery of biogenic atacamite formed by a group of exotic blood worms, another fascinating window on the field of biomineralization opens up. Understanding how copper is scavenged, transported, and concentrated, and ultimately how this particular mineral is induced to form with its own

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unique shape and orientation, are all essential components for understanding tooth formation in these worms.

The discovery of magnetite in the teeth of chitons initiated a series of investigations that contributed significantly to our understanding of basic processes of biomineralization. The discovery of this copper chloride mineral in the teeth of another invertebrate may well do the same. There is still much to learn about the mechanisms involved in controlled mineral formation.

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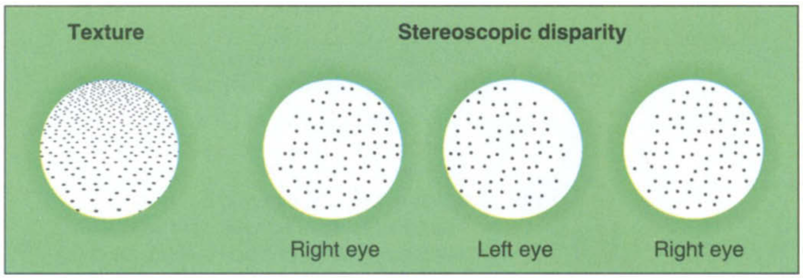
Supporting Online Material
www.sciencemag.org/cgi/content/full/298/5592/375/DC1
Table S1

PERSPECTIVES: NEUROSCIENCE

Reconstructing a 3D World

Charles E. Connor

Information in the visual system starts out as a two-dimensional (2D) pattern of neural activity across the retina. Yet the world we perceive is three-dimensional (3D). The neural mechanisms for reconstructing this 3D reality from 2D sensory inputs have long fascinated scientists. Much research has focused on stereopsis—inferring depth position from small image disparities between the right and left eyes. Neurons in the primary visual cortex (V1), V2, and many other visual areas are sensitive to such disparities, providing the signals that enable us to perceive depth stereoscopically (*1*–*3*). However, even without stereopsis—for example, when viewing photographs or movies—we still obtain vivid impressions of depth. This kind of nonstereoscopic 3D perception depends on other cues such as shading, perspective, texture gradients, and motion parallax. Two articles in this issue, one by Tsutsui *et al.* on page 409 (*4*) and one by Vanduffel *et al.* on page 413 (*5*), break new ground in understanding how the brain uses such cues to infer 3D structure.



Making 3D a reality. The figure shows how texture and stereopsis suggest the same surface orientation in different ways. **(Left)** The gradual bottom-to-top decrease in texture element size and spacing implies that the surface is slanting away toward the top. **(Right)** A random dot stereogram, with no changes in texture size or spacing, but with a bottom-to-top gradient in dot position disparity (between the right and left eye images). Readers can either uncross their eyes to view the right pair of circles or cross their eyes to view the left pair. This stereogram produces the same percept of surface slant.

Tsutsui and colleagues (*4*) used electrophysiological recording to study responses of single neurons in the caudal intraparietal sulcus (CIP) of the monkey brain. CIP is part of the dorsal visual pathway, which processes large-scale spatial information. This group has already shown that CIP neurons are tuned for 3D surface orientation defined by stereoscopic disparity and perspective cues (*6*, *7*). Here, they report that CIP neurons are also sensitive to texture-based depth cues. Texture gradients convey 3D orientation through gradual changes in the size, shape, and spacing of small surface elements (see the figure).

One striking aspect of the Tsutsui *et al.* results is that most cells showed identical tuning for surfaces defined by texture gradients and for surfaces defined by purely stereoscopic cues. The figure shows how texture and stereopsis suggest the same surface orientation in different ways. The majority of CIP neurons tested with both of these very different cues showed consistent selectivity for the same surface orientations. Such convergence of coherent information from different sources is unlikely to occur by chance. Thus, these investigators provide unusually strong evidence for CIP's involvement in 3D surface perception.

3D surface orientation tuning has also been demonstrated in region MT/V5, another dorsal visual pathway area, using random dot stimuli with stereoscopic disparity (*8*) and motion parallax (*9*) cues. In contrast, many neurons in area V4, part of the object-related ventral visual pathway, are tuned for the 3D orientation of elongated stimuli (rectangular bars) but not continuous surfaces (*10*). It may be that the dorsal (spatial) pathway is specialized for representing 3D surfaces, which can pertain to objects but can also define the large-scale spatial structure of landscapes and buildings. (The ground, for example, usually slants away from the viewer in the direction shown in the figure.) The ventral (object) pathway may be more concerned with 3D contours (edges and lines), which contain the most information about object shape.

The importance of electrophysiological studies in monkeys, exemplified by the Tsutsui *et al.* work, lies partly in their implications for human vision. Monkeys have long been considered a good model for human vision because of their similar visual capacities and evolutionary proximity. The relationship has turned out to be even closer, as shown by functional magnetic resonance imaging (fMRI) studies of visually evoked neural activity in humans. These studies reveal a similar arrangement of retinotopic maps (that is, retinal maps of visual space) and specialized responses across the surface of the visual cortex in the two species. As a result, there is a strong case for homology between monkey and human areas V1, V2, V3, V3A, VP, V4v (ventral V4), and MT/V5 (*11*, *12*). Thus, it is now possible to study detailed neural mechanisms in the monkey and point to specific areas of the human brain where the same processing may occur.

Such cross-species comparisons usually rely on electrophysiology in monkeys and fMRI in humans. Vanduffel and colleagues, in their study of motion-based 3D perception (*5*), have taken the more direct approach of using fMRI on awake subjects of both species. This has the obvious advantage of closer technical equivalence between experiments. It also overcomes the

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