Highlights and Breakthroughs:

At the Blurry Edge of Mineralogy

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When discussing logic in legal matters, Abraham Lincoln liked to pose the following riddle: "How many legs does a calf have if we call its tail a leg?" When his audience inevitably responded with the answer "Five," Lincoln reminded his listeners that the answer was four, because *calling* the tail a leg does not *make* it a leg (Rice 1909). A recent article in *Biology Letters*, however, reports that kangaroos routinely plant their tails on the ground for propulsive purposes when they are walking slowly, and the tail exerts as much mechanical force as the front and back legs combined (O'Connor et al. 2014). Do we call a tail a leg when it engages in pentapedal ambulation?

These kinds of questions form the basis of a recent exploration of human cognition by Douglas Hofstadter (author of *Gödel, Escher, Bach*) and Emmanuel Sander. In *Surfaces and Essences* (2013), Hofstadter and Sander consider how the human mind apprehends the world, and they argue that classification lies at the heart of all thinking. "Without the ceaseless pulsating heartbeat of our 'categorization engine'," they argue, "we would understand nothing around us, could not reason in any form whatever, could not communicate with anyone else, and would have no basis on which to take any action." In their view, when humans are confronted with anything new, we first analogize the thing within the inventory of our mental impressions. Then we contextualize the novel item among a set of similar entities to frame it within a conceptual grouping. That is how we make sense of an ever-changing reality.

Whether this thesis is genuinely profound or too self-evident to justify 530 pages of philosophizing may depend on the degree to which one has had to categorize objects that lie at the taxonomical fringe. Over the last two decades, mineralogists have increasingly challenged the conceptual envelope that has distinguished minerals from non-minerals. For much of the twentieth century, we were happy to exclude teeth from the mineral sodality because of their explicitly organic origin, but the rise of geomicrobiology has forced us to ask whether we really intend to excommunicate biogenic metal oxides in soils. Similarly, new techniques of crystallographic interrogation have emerged to characterize materials that lie at the fuzzy edge between crystals and glasses, leaving us to scratch our heads over the best way to classify objects that are atomically ordered at the nanoscale.

When our metaphors fail us, we can simply throw up our hands and dismiss the exercise as both impossible and useless. For example, an associate editor at *Scientific American* opined in *The New York Times* this spring that defining *life* is "futile" and "unnecessary" (Jabr 2014). As with minerals, living things are differentiated from non-living things by a series of characteristics rather than through a simple definition: *Metabolism*, *reproduction*, and *capacity for evolution* typically are included in this list. The nettlesome problems always arise at the boundaries – brine shrimp that can maintain dormancy for years, viruses that are capable of both replication and crystallization, prionic proteins that can propagate their misfolded topologies in ways that are not yet fully understood.

Alternatively, one can perform the yeoman's labor of pinning down what we really know about these twilight zones, and nobody is better suited to navigate the murky haze of nanominerals than are the authors of this Outlook piece. These scientists have themselves made seminal contributions to nanomineralogy, and they provide a timely synopsis of the state-of-the-art. The article is neatly divided into four sections: 1) some historical background on our evolving sense of crystallinity; 2) a review of the technologies that are enriching our understanding of the gray area between amorphous and crystalline phases; 3) a discussion of models that discriminate among short-, medium-, and long-range order; and 4) a defense of the need to develop a language that adequately captures variations in non-crystallinity.

Is it time to dispense with crystallinity as a criterion of "minerality"? My reading of this Outlook article is that the authors favor a functional approach – crystallinity depends on both the length-scale of the technique that you are using to measure it and of the mineral process being studied. Definitive answers don't come cheap in this territory, but Caraballo et al. have succeeded in sharpening our understanding of issues that are inherently blurry.

References Cited

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