J. D. GILARDI

Figure 1 **Blue-headed parrots (*Pionus menstruus*) at a clay lick in Manu, Peru. Gilardi *et al.*[10] have shown that minerals in the clay detoxify the birds' plant diet.**

tent of alkaloids and other toxins renders them bitter and even lethal to humans and other animals. Because many of these chemicals are positively charged in the acidic conditions found in the stomach, they bind to clay minerals bearing negatively charged cation-exchange sites[2,3,5,9]. That's why experienced tourists visiting destinations with poor sanitation carry medicines such as kaopectate (high in clay minerals) to adsorb the toxins. That's also why peasant farmers and hunter–gatherers throughout the world often mix bitter but otherwise nutritious plant foods (like acorns and wild potatoes) with selected soils before consumption[1–3].

Peruvian parrots behave like sophisticated human tourists and hunter–gatherers. Their preferred soils were found to have a much higher cation-exchange capacity than adjacent bands of rejected soils — because they are rich in the minerals smectite, kaolin and mica. In their capacity to bind quinine and tannic acid, the preferred soils surpass the pure mineral kaolinate and surpass or approach pure bentonite. Clearly, parrots would be well qualified for jobs as mining prospectors.

Gilardi *et al.* confirmed this hypothesis with two sets of bioassays. First, they exposed brine shrimp (the toxicologist's test animal of choice) to extracts of seeds routinely consumed by macaws. Many of the brine shrimp died, confirming the toxicity of the parrots' diet. But mixing the solutions or extracts with soil preferred by parrots reduced the effective toxin loads by 60–70% and improved shrimp survival. Second, Amazon parrots were given an oral dose of the alkaloid quinidine with or without preferred soil, and quinidine levels were measured in the parrots' blood for three hours as absorption took place from the gut. Providing soil along with the quinidine reduced absorbed quinidine blood levels by 60%.

What is the evolutionary significance of plant toxins and animal anti-toxin behaviour? From a plant's evolutionary perspective, a seed should be high in nutrients to support germination and seedling growth; the ripe fruit around the seed should also be nutrient-rich and attractive to animals, encouraging them to pluck and eat the fruit and disperse the seed. On the other hand, the seed itself should be repulsive to animal consumers, inducing them to regurgitate or defaecate it, and the unripe fruit should be repulsive, lest animals harvest it before the seed is viable. From an animal's evolutionary perspective, an ability to defeat the plant's toxin defences would enable it to obtain the nutrients in the seed as well as those in the ripe fruit, and to outcompete other animal consumers by harvesting the fruit while it is unripe and still unpalatable to them.

Any textbook of animal biology describes the resulting evolutionary arms race, in which plants evolve increasingly potent toxins (such as strychnine and quinine), and animals evolve increasingly potent means of detoxification. While enzymatic detoxification has previously received the most attention, the work of Gilardi *et al.*[10] and the wide distribution of geophagy among animal herbivores suggest an additional important means of detoxification by adsorption on ingested soil minerals.

A host of interesting questions now comes into focus. How do parrots discover the best soils — can they discriminate among soils immediately by texture and taste, or must they experiment with various soils mixed with toxic food and discover which soil assuages their upset stomach? Might the availability of suitable geophagy sites limit herbivore distributions and merit concern from conservation biologists? Only certain species of local herbivores are reported as visiting geophagy sites: why? To return to our youthful dirty habits, do curious dirt-licking babies deserve our encouragement for their experiments with self-medication?

Jared M. Diamond is in the Department of Physiology, University of California Medical School, Los Angeles, California 90095-1751, USA.
e-mail: jdiamond@mednet.ucla.edu.

1. Johns, T. *J. Chem. Ecol.* **12,** 635–646 (1986).
2. Johns, T. *With Bitter Herbs They Shall Eat It: Chemical Ecology and the Origins of Human Diet and Medicine* (Univ. Arizona Press, Tucson, 1990).
3. Johns, T. & Duquette, M. *Ecol. Food Nutr.* **25,** 221–228 (1991).
4. Abrahams, P. W. & Parsons, J. A. *Geogr. J.* **162,** 63–72 (1996).
5. Hladik, C. M. & Gueguen, L. *C. R. Acad. Sci.* **279,** 1393–1396 (1974).
6. Jones, R. L. & Hanson, H. C. *Mineral Licks, Geophagy, and Biogeochemistry of North American Ungulates* (Iowa State Univ. Press, Ames, 1985).
7. Kreulen, D. A. *Mamm. Rev.* **15,** 107–123 (1985).
8. Gionfriddo, J. P. & Best, L. B. *Condor* **97,** 57–67 (1995).
9. Mahaney, W. C. *et al. Primates* **37,** 121–134 (1996).
10. Gilardi, J., Duffey, S., Munn, C. & Tell, L. *J. Chem. Ecol.* **25,** 897–922 (1999).

Daedalus

Creep and anti-creep

Many substances — ice is perhaps the best known — can crystallize in lots of different ways, many of them stable only under high positive pressure. Daedalus is now exploring the converse field, that of crystals stable only under negative pressure, that is, tension. Engineering components are routinely stressed to thousands of atmospheres of tension: usually in one or two dimensions only, but isotropic three-dimensional tension is possible. Even liquids, if clean and degassed, can be tensioned to many hundreds of negative atmospheres. Indeed, the sap in trees taller than ten metres is thought to be under permanent tension.

So DREADCO physicists are melting numerous solids, putting the liquid under strong tension, and letting them resolidify again. They are also submitting crystalline samples to sustained three-dimensional tension, and looking for a slow phase-change to some expanded, negative-pressure crystal habit. The pilot experiments are largely empirical; it is hard to guess which substances form distinctive negative-pressure phases. But Daedalus hopes that at least some of these phases will continue to exist metastably at atmospheric pressure, at least for a while.

His ultimate goal is a new engineering material. Many such materials, he points out, creep under load. For a component in tension this is a dangerous vice. But for one in compression it can be a virtue. If overloaded, it creeps plastically away from the load, thickening as it does so, and sharing its burden with more lightly loaded members nearby. A compression structure is often usefully 'self-designing'.

Metastable expanded materials should bring the same self-optimization to tension structures. While it remains tensioned, a component of such a material will be quite stable. But if the tension slackens, it will become metastable. It will slowly contract to its denser phase, restoring the tension and relieving nearby members of some of their load. In fact it will show 'anti-creep'.

DREADCO's anti-creep alloys will be widely welcomed. Bridges, bicycles, power lines, aerospace frames, all will exploit anti-creep technology for greater safety and efficiency. Self-tightening anti-creep fasteners and connectors will transform the small-scale details of engineering. Over the whole field, designers will gratefully allow self-optimizing anti-creep materials to lift some of their lonely burden.

David Jones