Speaking of Science

It Isn't Easy Being King

To be royalty in the Middle Ages wasn't easy. Internecine feuds and intrigue were common, and crowned heads and lesser luminaries had to be constantly on guard against physical attacks, poisoning, and other forms of mayhem. A ruler's most valuable possessions were a loyal retinue and his bezoar stones, which were used to remove arsenic—the most common type of poison then in use—from wine and other drinks. The mystery of how these "magic" stones work has only recently been unraveled at the Scripps Institution of Oceanography in San Diego. In the process, the investigators have provided some interesting new information about arsenic in the environment.

True bezoar stones are calcareous concretions that develop in the alimentary tracts of the Persian mountain goat, but similar stones can be obtained from antelopes, goats, llamas, and other ruminant animals. The word "bezoar" itself comes from two Persian words meaning "to protect" and "against poison." Among the royalty who used the stones was King Eric XIV of Sweden, a suitor of Queen Elizabeth I who wore a stone set in silver rings on his fingers, as did Elizabeth herself. Napoleon received a gift of the stones from the Shah of Iran, but threw them into the fire; arsenic poisoning was later considered to be a factor in his death. The stones were widely used from the 11th to the 18th century and gained repute for magical powers beyond all rational possibility, including the ability to cure jaundice, plague, epilepsy, and fatigue.

King Eric XIV of Sweden. [Courtesy of the Swedish Information Service]

Bezoar stones may, in fact, remove both toxic forms of arsenic, arsenate and arsenite, from solutions in which they are immersed. About a decade ago, Gustaf Arrhenius of Scripps suggested that arsenate is removed by exchange with phosphate in the crystalline mineral brushite, which is found in the stones. How the arsenite is removed remained a mystery until late last year when Andrew A. Benson of Scripps used a radioactive isotope of arsenic to demonstrate that arsenite binds to sulfur in the protein of the partly digested animal hair in the stones. In effect, he says, the hair can act as a chemical sponge for arsenite.

The clue to this finding came from Benson's studies of the effects of arsenic on marine plant life. He had previously observed that algae in tropical waters off Baja California can absorb and chemically process arsenic, whereas similar algae in nontropical waters off British Columbia are poisoned by it. On closer examination, he found that algae and other plants in tropical waters absorb dissolved arsenate—the form of arsenic produced by most natural sources, such as volcanic activity, submarine hot springs, and the slow dissolution of sediments—convert it into arsenite, and then transform it, through several previously unknown chemical reactions, into a nontoxic phospholipid that dissolves in fats and membranes of the plants. Arsenic, he says, replaces the nitrogen of a conventional phospholipid. This bezoar action prevents the plants from being poisoned. But why do plants in tropical waters possess this ability while those in more northern climates do not?

The key, Benson says, is not the climate, but the concentration of phosphate in the waters. The concentration of phosphate, which has a chemical structure similar to that of arsenate, in tropical waters, he says, is often only a few parts per billion, slightly lower than the concentration of arsenate. Because of the similarity in concentrations, plants absorb both elements from the water and, through evolution, those that could reduce and methylate the arsenate survived and reproduced. In the northern waters, in contrast, phosphate levels are much higher than those of arsenate, plants do not absorb significant quantities of arsenate, and there is no evolutionary pressure to select those that can process the toxic element.

If arsenic were introduced into this environment in significant quantities now, Benson says, the plants would absorb it but would not be able to detoxify it. Bound arsenite compounds would accumulate in their protein and kill or greatly weaken them, and marine animals grazing on the plants would accumulate potentially dangerous levels of arsenic in their tissues.

Clearly, then, industrial activities that produce relatively large amounts of arsenic as a by-product (most notably, smelters of copper, lead, and zinc ores) should be located in regions where the indigenous plant life could detoxify the wastes. Benson is also seeking species that could be transplanted to industrial and agricultural areas to detoxify wastes and the residues of arsenic-containing pesticides. We should learn from Napoleon, Benson says, and not ignore this bezoar activity of nature, but use it to keep from poisoning ourselves and our environment.

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