distances in the atmosphere. This does not, however, rule out the possibility that the high Se concentrations found in the atmosphere are the result of the emission of volatile Se compounds from natural sources such as volcanism or terrestrial vegetation (*12*).

It is impossible at this time to ascribe the high enrichment values of Zn, Cu, Sb, Pb, Se, and Br in atmospheric particles over Antarctica to any particular natural or anthropogenic process. We know of no measurements in snow samples of any of the anomalous elements or the other elements for comparison with the atmospheric concentrations presented here. Possible sources such as extraterrestrial material could be expected to account for a small portion of the concentrations of some elements such as Fe (*4*) but cannot account for the anomalous elements. However, the relative volatility of these anomalous elements relative to elements which show no enrichment over Antarctica suggests strongly that some vapor-phase condensation or high-temperature dispersion process is responsible for the enrichments found.

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References and Notes

1. J. T. Peterson and R. A. Bryson, *Science* **162**, 120 (1968); J. M. Mitchell, Jr., in *Global Effects of Environmental Pollution*, S. F. Singer, Ed. (Springer-Verlag, New York, 1970), p. 139; *Inadvertent Climate Modification: Report of the Study of Man's Impact on Climate* (SMIC) (MIT Press, Cambridge, Mass., 1971).
2. *Man's Impact on the Global Environment: Report of the Study of Critical Environmental Problems* (SCEP) (MIT Press, Cambridge, Mass., 1970); *Marine Environmental Quality* (National Academy of Sciences, Washington, D.C., 1971).
3. J. Brocas and R. Delwiche, *J. Geophys. Res.* **68**, 3999 (1963); C. Boutron, M. E. Chevin, C. Lorius, *Geochim. Cosmochim. Acta* **36**, 1029 (1972); A. A. Matveev, *J. Geophys. Res.* **75**, 3686 (1970); M. Murozumi, T. J. Chow, C. Patterson, *Geochim. Cosmochim. Acta* **33**, 1247 (1969); T. J. Peterle, *Nature (Lond.)* **224**, 620 (1969); J. A. Warburton and L. G. Young, *Antarct. J. U.S.* **5**, 115 (1970).
4. J. Brocas and E. Picciotto, *J. Geophys. Res.* **72**, 2229 (1967).
5. K. K. Bertine and E. D. Goldberg, *Science* **173**, 233 (1971).
6. C. E. Junge, *Air Chemistry and Radioactivity* (Academic Press, New York, 1963).
7. N. A. Esmen and M. Corn, *Atmos. Environ.* **5**, 571 (1971).
8. E. S. Gladney, W. H. Zoller, A. G. Jones, G. E. Gordon, *Environ. Sci. Technol.*, in press; R. E. Lee, Jr., S. S. Goranson, R. E. Enrione, G. B. Morgan, *ibid.* **6**, 1025 (1972).
9. K. A. Rahn, thesis, University of Michigan (1971).
10. R. A. Duce, W. H. Zoller, J. L. Moyers, *J. Geophys. Res.* **78**, 7802 (1973).
11. H. V. Weiss, M. Koide, E. D. Goldberg, *Science* **172**, 261 (1971).
12. B. G. Lewis, C. M. Johnson, C. C. Delwiche, *J. Agric. Food Chem.* **14**, 638 (1966).
13. S. R. Taylor, *Geochim. Cosmochim. Acta* **28**, 1273 (1964).
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Temporal Bone Preservation in a 2600-Year-Old Egyptian Mummy

Abstract. *Perforated eardrums in the preserved temporal bones of a mummified Egyptian male in otherwise normal middle ears offer new evidence of acute otitis media and probable defective hearing among ancient Egyptians.*

Although many Egyptian mummies have been examined, evidence of temporal bone disease has been noted in only seven cases (*1*). In these mummified remains, evidence of bone destruction from antemortem mastoiditis was found in various regions of the mastoid, antrum, and external meatal walls. However, diseases or other abnormalities involving the auditory structures of the middle and inner ears were not evident in any of these specimens. Following a recent autopsy on a 2600-year-old Egyptian male mummy [PUM-II (*2*)] by Cockburn and his colleagues (*3*), we removed cylindrical temporal bone plugs containing the middle and inner ears from the mummy's skull and examined them for evidence of past diseases and other physical abnormalities. This report describes our observations and some abnormal findings not previously documented.

An examination of the external ears before the temporal bones were removed revealed that the auricles were displaced forward almost perpendicular to the plane of the skull. The outer portions of the external auditory canals were packed with material and covered with resin. X-rays with polytomography taken previously revealed normal mastoid pneumatization, intact malleus and incus without evidence of dislocation or deformity, normally patent oval window, and normal-looking cochlear and vestibular structures. The internal auditory canals were patent and symmetrical. In all details, the x-rays of both temporal bones were similar in appearance with no indication of premortem disease.

Plugs from both temporal bones were removed with the Gigli saw and Schuknecht temporal bone plug cutter (*4*) through a transverse opening (6 by 10 cm) in the parietal bones. Each specimen was 3.7 cm in diameter and 5.0 cm long and included the medial portion of the external canal, tympanic membrane, middle and inner ears, mastoid air cell system, and entire internal auditory canal. A thin layer of resin covered the petrous portion of each temporal bone and dural membrane. When the arcuate eminence was removed from the superior surface of the petrous bone of each specimen, we found large amounts of resin in the lumen of the posterior and superior semicircular canals. The presence of this resin in the inner ears seems to be related to the method of embalming. X-rays and autopsy confirmed that Egyptian embalmers placed an instrument far into the left nostril and punched a hole through the cribriform plate of the ethmoid bone into the cranial cavity. After removing the brain through the nares, the Egyptians then injected molten resin into the cranial vault which settled into the posterior cranial cavity, filling about 25 percent of the total volume. Apparently, this resinous material also entered the internal auditory canals at the same time and from there found its way into the inner ears.

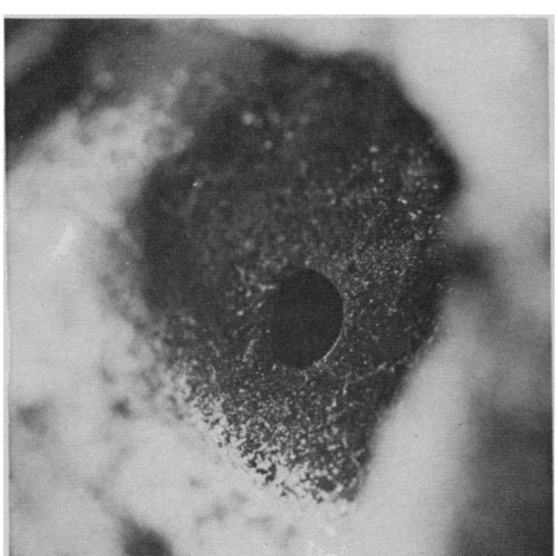
The posterior aspect of the roof of the middle ear of each specimen was removed with fine rongeur forceps to facilitate inspection of the middle ear structures with a Zeiss operating microscope.

Examination of the right temporal bone revealed that the air cells of the mastoid were well pneumatized and showed no evidence of previous mastoiditis. No trace of resin could be seen in the mastoid cells of this bone. The walls and air cells of the antrum appeared to be lined with a thin coating of resin but otherwise were well developed and looked entirely normal in appearance. The ligamentous articulation of the malleus and incus, superior ligament of the malleus, body and short process of the incus, and promontory of the lateral semicircular canal were clearly visible and looked normal. The incudostapedial articulation was intact and a portion of the stapes could be seen. The medial end of the external ear canal was patent and the color of the walls was dull gray-black. There was only a minimal amount of resin lining the canal walls and covering the tympanic membrane. The entire ear drum was visualized. The umbo (center of the cone-shaped eardrum) and the region of the annular ligament around pars tensa (central portion) were identified. The manubrium of the malleus with its lateral process was faintly outlined on the lateral surface of the drum membrane. The superior region of the eardrum (pars flaccida) was intact. All landmarks of the tympanic membrane were in their normal position. A small irregular oval perforation with smooth and concise margins was observed in the posteroinferior quadrant of pars tensa, occupying about 5 to 10 percent of the entire drum surface (Fig. 1).

Examination of the left temporal bone revealed considerable shiny black resin in the middle ear cleft filling many of the air cells of the mastoid and antrum. The mastoid process was well developed and showed no evidence of past disease. The ossicular chain was intact. The head of the malleus, superior mallear ligament, and body of the incus were covered with a thin coating of resin with a reddish hue. The short process of the incus was embedded in a thick accumulation of resin. Scattered over the surface of the ossicular chain and walls of the middle ear cavity were tiny crystal-like deposits resembling salt. These deposits were probably the remains of the natron used during the early drying phase of mummification since, according to Lucas (*5*), Egyptian natron always contained salt impurities, often in considerable proportion. The lumen of the external auditory canal was almost completely filled with resin, which obstructed the eardrum from view. Most of the resin was dissolved with a solution of equal parts of chloroform and ether in order to expose the eardrum. A perforation in the posterosuperior region of the tympanic membrane was found, occupying about 20 percent of its entire surface. This perforation was filled with resin giving the appearance that the preservative may have flowed into the middle ear cavity and antrum through this opening. The umbo and the manubrium of the malleus were identified and noted to be in normal position.

A beetle larva measuring about 1.5 by 0.2 mm was found in the left canal embedded in resin at the medial end of the anterior canal wall close to the rim of the eardrum in its superior region. The larva was removed and prepared for examination by scanning electron microscopy. The insect was coated with carbon and gold palladium alloy, examined in a JEOL scanning electron microscope, model JSM-2, and photographed with a 25-kv scanning electron beam on Polaroid P/N film (Fig. 2). The larva was later identified as Staphylinidae, genus probably *Atheta* (*6*). Beetles of this family are often found associated with carrion. It appears likely that this larva is an interesting postmortem artifact that entered the ear canal during the early drying phase of mummification before resin was introduced into the canal and before the body was wrapped in linen.

The external and middle ear structures of the temporal bones of this 2600-year-old Egyptian mummy were in a remarkable state of preservation. There was no radiographic or macroscopic evidence of previous chronic middle ear disease involving the external meatus, mastoid, antrum, or middle ear structures. The small perforations of the tympanic membranes were the only significant abnormal findings. Unfortunately, details of the attic perforation of the left eardrum were obscured by the presence of resin and it was not possible to tell whether this perforation was the result of disease or a postmortem artifact. However, the location and oval shape of the central perforation of the right eardrum with its smooth and well-circumscribed margins suggests an etiology of acute otitis media occurring sometime during life. This unhealed perforation is very similar in appearance to the persistent perforations encountered today in patients who have had acute middle ear infections. The eardrum perforation observed in this Egyptian mummy offers



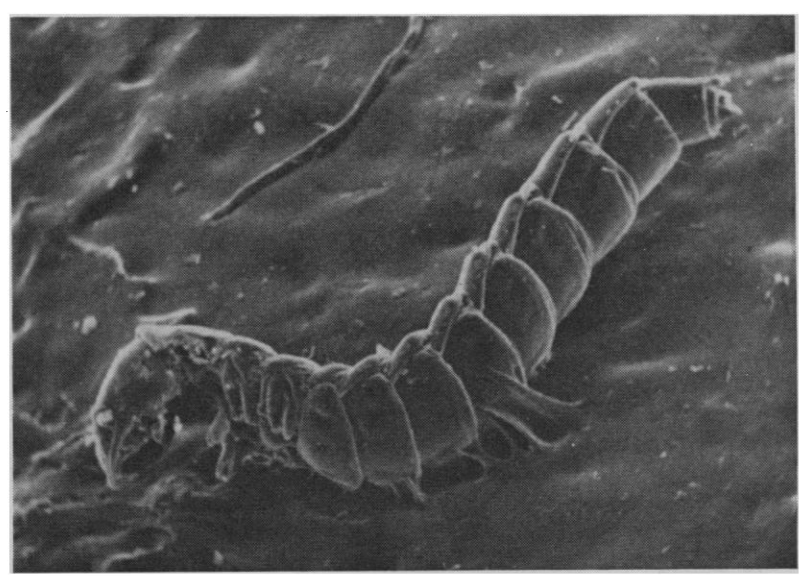


Fig. 1 (left). Posterior portion of the right tympanic membrane with oval perforation in the posteroinferior region. Fig. 2 (right). Scanning electron micrograph of the beetle larva, Staphylinidae, found in the left external auditory canal close to the eardrum (× 60).

new evidence of middle ear disease and probable defective hearing among ancient Egyptians. Histologic study of these temporal bones is under way.

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References and Notes

1. W. McKenzie and D. Brothwell, in *Diseases and Antiquity*, A. T. Sandison, Ed. (Thomas, Springfield, Ill., 1967), p. 464.
2. PUM-II is the Pennsylvania University Museum's second mummy autopsied.
3. A. Cockburn, *Science* **181**, 470 (1973).
4. H. Schuknecht, *Arch. Otolaryngol.* **87**, 33 (1968).
5. A. Lucas, *Ancient Egyptian Materials and Industries* (Arnold, London, 1962), p. 275.
6. D. M. Anderson, Systematic Entomology Laboratory, U.S. Department of Agriculture, identified the larva.
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Toxic Trace Elements: Preferential Concentration in Respirable Particles

Abstract. *The toxic trace elements arsenic, antimony, cadmium, lead, selenium, and thallium were found to be most concentrated in the smallest respirable particles emitted from coal-fired power plants. These elements, or their compounds, are probably volatilized during combustion and preferentially adsorb or condense onto the small particles which can most easily pass through conventional control equipment.*

Possibly one of the most dangerous, and certainly one of the most insidious, forms of pollution arises from the mobilization of toxic trace elements, such as Be, Cd, As, Se, Pb, Sb, Hg, Tl, and V, in our environment (*1, 2*). The majority of living organisms possess little or no tolerance for these elements whose presence in the environment is unseen and often undetected.

It is now well established (*3*) that many trace elements are mobilized in association with airborne particles derived from high-temperature combustion sources such as fossil-fueled power plants, metallurgical smelters and blast furnaces, municipal incinerators, and automobiles. It is also established that many elements, notably Pb, Cd, Zn, Cr, V, Ni, Mn, and Cu, are found at highest concentrations in the smallest particles collected from ambient air (*3–5*).

This finding has considerable significance in terms of environmental health because it is these same small particles from which trace elements are most effectively extracted into the human bloodstream (*1, 6, 7*). Thus, particles less than about 1 μm in equivalent aerodynamic diameter deposit predominantly in the alveolar regions of the lung where the absorption efficiency for most trace elements is 50 to 80 percent. Larger particles, on the other hand, deposit in the nasal, pharyngeal, and bronchial regions of the respiratory system and are removed by cilial action to the stomach where absorption efficiency is commonly only 5 to 15 percent for most trace elements (*1, 7*). The natural size distribution of particles in ambient air ensures that about one-third of the total particulate mass retained during respiration is deposited in the lung (*1*), and it is clear that this organ constitutes the major gateway to the bloodstream for toxic elements that are present in airborne particles.

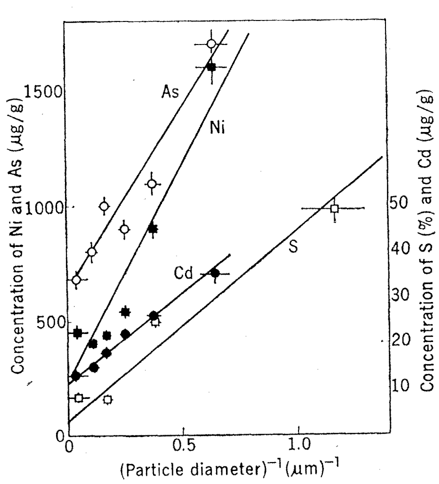

Fig. 1. Dependence of the average concentrations of As, Ni, Cd, and S on airborne particle size in coal fly ash.

Consequently, attention should be focused sharply on the chemical composition and physical form of submicrometer-sized respirable particles. In particular, the reasons why many toxic elements are most concentrated in the smallest ambient airborne particles require elucidation. This could simply be the result of the mixing of particles from a variety of sources, each with its own characteristic particle size distribution. Alternatively, the effect may be determined by combustion characteristics at the particle source. The work reported herein was designed to test this latter suggestion for the case of fly ash derived from coal-fired power plants.

Fly ash samples were collected from eight power plants in the United States. A variety of coal types are represented. The samples can be divided into two classifications which represent (i) fly ash retained in the precipitation system of a plant and (ii) airborne fly ash leaving a plant. The retained material was collected in bulk and differentiated both physically, by sieving, and aerodynamically, with a Roller particle size analyzer (*8*), into a range of particle size fractions. Airborne fly ash samples were collected inside the plant stacks, and the sizes were differentiated aerodynamically in situ with an Anderson stack sampler (*9*).

Solid particulate material was analyzed directly by means of spark-source mass spectrometry, d-c arc emission spectrometry, and wavelength-dispersive x-ray fluorescence spectrometry. The particles were also digested in a mixture of 3.5 parts of aqua regia and 1.5 parts of 48 percent hydrofluoric acid in a Teflon-lined Parr pressure bomb at 120°C for 2 hours. The neutralized solution was then analyzed by atomic absorption spectrometry, differential pulse anodic stripping voltammetry, and colorimetrically, with a Weisz ring oven. Each element was determined by at least two techniques to establish the reliability of the data.

Results representative of our findings are presented in Table 1 for particles derived from a single representative coal-fired power plant equipped with cyclonic particle collectors. For comparative purposes results obtained for the major matrix elements Al, Si, Fe, K, and Ca are listed in Table 2. Raw analytical data are presented for the method considered most reliable for each element. Comparison of the results obtained with different techniques