5. The D and L enantiomers of amino acids can be separated by the usual amino acid analytical techniques only after a series of complicated derivates are synthesized.
6. At equilibrium, the concentration of alloisoleucine is slightly greater than that of isoleucine [S. Nakaparksin, E. Gil-Av, J. Oró, *Anal. Biochem.* **33**, 374 (1970)]. For most other amino acids the equilibrium constant for the racemization reaction is 1.0.
7. J. D. Phillips, W. A. Berggren, A. Bertels, D. Wall, *Earth Planet. Sci. Lett.* **4**, 118 (1968).
8. W. A. Berggren, personal communication.
9. Several of the reagents used in the isolation procedure have been found to contain minute amounts of amino acids. To substantially reduce this source of contamination, only distilled and freshly prepared reagents were used in the analyses.
10. After the $NH_4OH$ solution had been reduced to about half the original volume, a white precipitate formed (believed to be aluminum hydroxide). This was filtered off, and the evaporation was completed without the formation of any additional precipitate.
11. In order to achieve good separation of methionine, alloisoleucine, and isoleucine, a 150-cm column filled with Aminex Q-150S resin obtained from Bio-Rad Laboratories was used for the analyses.
12. The small amounts of racemization observed in the first 200 cm of the core are not due to racemization during the acid hydrolysis of the sediment sections. In 200-cm sections hydrolyzed for 24 and 48 hours, the ratios of alloisoleucine to isoleucine were the same within experimental error.
13. Since the surface layers of the sediment may contain small amounts of alloisoleucine, the constant of integration is not zero.
14. The 25- and 100-cm values were not used in the calculations. The value determined for the constant in Eq. 3 was 0.007.
15. Equation 3 cannot be used to estimate the depth of 50 percent racemization because it is valid only when the amount of racemization does not exceed 15 to 20 percent. Integration of Eq. 2 would yield

$$\ln \frac{\text{alloisoleucine} + \text{isoleucine}}{\text{isoleucine} - \text{alloisoleucine}} = 2k'_{\text{rac(Iso)}} \text{ (depth of burial)}$$

if the equilibrium ratio of alloisoleucine to isoleucine was 1.0. At 140°C the observed ratio is 1.25 (*6*). The temperature variation of the ratio is not known, however; a value of 1.0 is therefore assumed for 2°C. The uncertainty arising from this assumption is probably less than 10 percent. The equation used in the text for the depth of 50 percent racemization was obtained by substituting alloisoleucine/isoleucine = 0.33 into the above equation.
16. C. Emiliani, *J. Geol.* **63**, 538 (1955); *ibid.* **66**, 264 (1958); W. Dansgaard and H. Tauber, *Science* **166**, 499 (1969).
17. T. L. Ku, *J. Geophys. Res.* **70**, 3457 (1965).
18. The natural remanent magnetization and the remanent magnetization after demagnetizing in an alternating field at 115 and 250 oersteds were determined. The core was cut at 218 cm after top and bottom halves were oriented with respect to one another; thus, the declination data should be internally consistent for the entire core.
19. A. Cox, *Science* **163**, 237 (1969).
20. We thank Drs. Raymond Siever and J. D. Phillips for helpful discussions, and Dr. Frank Westheimer for the use of the amino acid analyzer, which was purchased and maintained by grant GM-04712 from the National Institute of General Medical Sciences of the National Institutes of Health. We also thank Dr. Phillips for access to his paleomagnetics laboratory and equipment, and Captain C. Davis and the crew of the *Chain* for their assistance during sampling operations. This research was supported by the Committee on Experimental Geology and Geophysics at Harvard University and NSF grant GA-12865. Cruise 96 of the *Chain* was supported by the Office of Naval Research (contract N 00014-66-C0241). J.B.M. is a NSF predoctoral fellow. Contribution 2086 of the Woods Hole Oceanographic Institution.
* Present address: Scripps Institution of Oceanography, University of California at San Diego, La Jolla 92037.

10 August 1970

# Aboriginal Trephination: Case from Southern New England?

Abstract. *The skull of a young adult male Amerind from a grave at a coastal site in southern Connecticut bears a largely cicatrized elliptical anomaly near bregma. Some evidence suggests deliberate antemortem trephination of the scraping type. The specimen is of interest since perhaps fewer than twenty human skulls have been advanced as putative cases of trephining by North American aborigines.*

A human burial at Spruce Swamp, a site of former Indian occupancy at Norwalk, Fairfield County, Connecticut (*1*), was vandalized by road workers who discovered it after my formal field work was completed. The individual was a young adult, probably male, whose age at death was estimated to be between 20 and 25 years on the basis of absence of tooth wear and suture closure. He had apparently been buried semiflexed, on his side, head to east, and about 0.5 m deep in loam above a glacial terrace on Long Island Sound. Quartz *debitáge*, scattered marine shell fragments, and, notably, a clay sherd in the grave fill relate the burial tenuously to the Woodland Period. Apparently there were no deliberate grave offerings or mortuary furniture. I designated the find Spruce Swamp Burial 1 (B. 1).

By sifting the disturbed soil in the vicinity of the grave with a 7-mm screen, I recovered about 50 percent of the postcranial skeleton and 90 percent of the cranium. The cranium was reconstructed and stabilized by immersion for several days in Alvar 7/70 solution. At that time it became apparent that a peculiar condition obtained near bregma.

Specifically, there is an only slightly elliptical cavity, which is 35 mm long by 33 mm wide and is a maximum of 7 mm deep, with the long axis parallel to the long axis of the skull and overlying the superior sagittal sinus. A thin, bony floor, varying from 1 to 3 mm in thickness, covers more than 90 percent of the bottom of the cavity. A ridge of bony growth, which opens posteriorly, partially surrounds the cavity on the outer table in a shape rather like a horseshoe (see Fig. 1A).

The remainder of the cranium is normal. Wormian bones are present in the lambdoid suture. Deformation by earth pressure is not marked. Sand grains and drusy mineral crusts on the inner table probably record transient groundwater penetrations.

The general appearance suggests trephination. A search of the literature fails to disclose references to trephining for this region. The practice is worldwide at many time levels but is most marked in the New World, especially among the highland Incas of Peru (*2*). Stewart (*3*) lists fewer than 20 instances of putative cases of trephining in North America and admits to a dissatisfaction with evidence and arguments advanced in the literature. He cites a specimen from Maryland as the best example yet found in North America, but he feels it is suspect since it was an isolate among unmodified skulls.

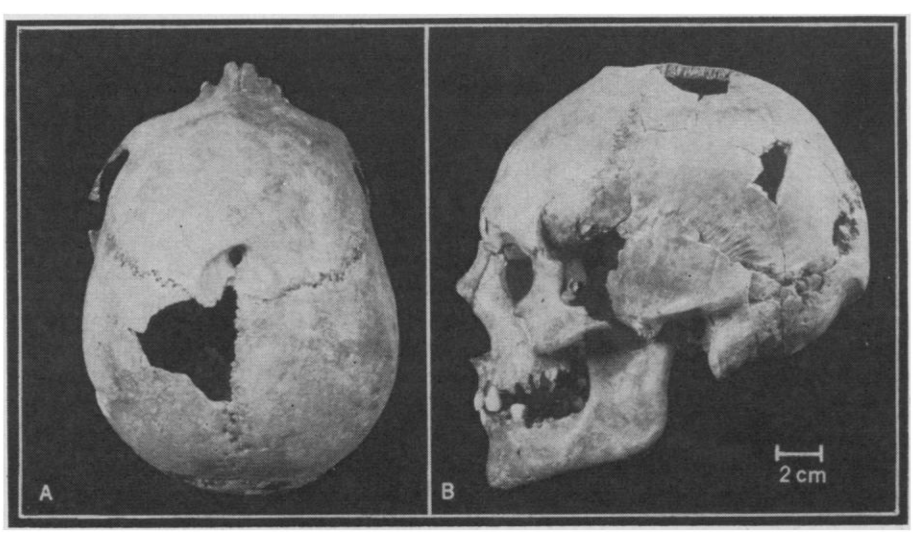


Fig. 1. (A) Superior aspect of B. 1 cranium from the Spruce Swamp site. A large portion of the left parietal is missing. (B) Left lateral aspect of B. 1. Note angular bony ridge apparent anteriorly to anomaly in profile.

However, Stewart concedes that "according to modern pathological knowledge, no other diagnosis fits as well" (*3*, p. 476). Other locales cited by him include Alaska, Arkansas, British Columbia (five specimens), Georgia, Kodiak Island, Mexico, Michigan, and New Mexico. Trephining may be postmortem or antemorten; many writers fail to make this distinction.

Postmortem trephining is thought to be largely thaumaturgic in origin and is responsible for the rondelles frequently cited for the European Paleolithic. Such disks, both in the Old and New Worlds, were often further modified by boring and scraping, presumably to serve as amulets, personal charms, and fetishes.

Antemortem trephination is thought to be largely therapeutic in origin, and the presence or absence of bony replacement records whether individuals survived the operation. Different appearances of "green" and dry bone when cut or broken help distinguish valid postmortem trepanning from antemortem trepanning followed by immediate death. In a classic study of trephining among the Peruvian Yauyos, Tello (*4*) reports 250 cicatrices among a total of 400 skulls with antemortem trephining. The presence of cicatrization in the B. 1 cranium indicates that the anomaly was not an immediate cause of death.

Natural holes in human skulls may be caused by diseases, notably osteoperiostitis, rarefying osteitis from lesions of the periosteum, and syphilis; by anomalies such as congenital aperture with hernia of the brain and meninges; and by genetic conditions such as parietal fenestrae ("Catlin marks") (*4, 5*). Placement (bilaterally symmetrical holes in parietals for Catlin marks) and presence of ancillary conditions (stellar gumma cicatrices in syphilis; everted edges in hernia; and other diseased conditions) help eliminate cases otherwise referable to trephining. There are no such conditions for the B. 1 cranium. Wells (*6*) illustrates "horns" from sebaceous cysts, which he says leave marks on the skull "indistinguishable" from healed trepans. Presumably this condition is rare.

Scraping, boring, and sawing, as well as a lesser known rubbing technique, were all used in primitive trephining. Scraping often yielded ellipsoid cavities with their long axes in the direction of the scraping. Boring left buttons of bone and round holes in skulls; it is the method of modern neurosurgeons. Sawing, usually accompanied by elevating individual bone polygons freed by the kerfs, was a common method among the Inca. Of these techniques, the B. 1 specimen most suggests the scraping technique, which may have stopped short of complete removal of all bone (Fr. *raclage* trephine).

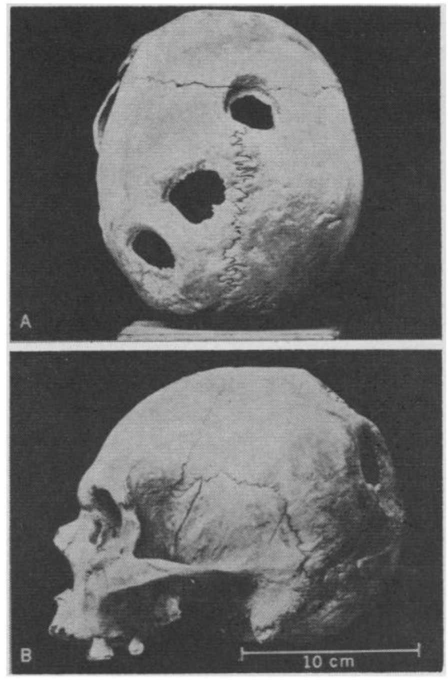


Fig. 2. (A) Superior aspect of cranium 18, a triple-trephined skull of a middle-aged Inca from Cuzco. (B) Left lateral aspect of cranium 18. Note angular bony ridge apparent posteriorly in profile around uppermost aperture. [From plates XXXVII and XXXVIII, Muniz and McGee (*9*)]

Fractures are probably the most common motive for trephining; primitive warfare and daily hazards might be expected to result in a fair number of such wounds. One authority, Fletcher (*7*), notes that the well-defined, beveled edges of trephined apertures contrast to the "blows of stone hammers or axes [which] resulted generally in necrosis, or death of the bone, and often disruption or bulging of the inner table of the skull for some distance from the seat of the injury." He cites examples of the latter condition from a prehistoric cemetery near Madisonville, Ohio. Radiating fractures, in contrast to depressed fractures, show radial cracks around the point or points of impact. If a fracture preceded the B. 1 anomaly, no evidence is discernible on the inner table, and the presumptive trephination and healing have obliterated any evidence on the outer table and diploe.

Fletcher (*7*) says further of trephined apertures that they are nearly always elliptical; they fall within a range of 35 to 50 mm in length and 6 to 10 mm in width; and they show oblique edges at the expense of the outer table. The B. 1 cranium fulfills these criteria, save for that of width. This size range, however, seems restrictive to me, judging from relative appearance of illustrated Inca remains.

In a study of perforated crania from southern Michigan, Hinsdale and Greenman (*8*) indicate a point near bregma as a preferred locus for perforations (again like B. 1), but the Michigan specimens were postmortem trephinations. They postulated cultural connections south and east of Michigan.

The B. 1 cranium shows striking parallels to a known triple-trephined skull of a middle-aged Inca (Fig. 2) designated as cranium 18 by Muniz and McGee (*9*). These parallels are a trephination near bregma; bony ridges in profile around the trephination (see Fig. 1B and Fig. 3); an inner table with visible suture remnant; and a horseshoe shape, opening posteriorly. This last condition prompted the authors to posit that the operation was done by a right-handed individual with the patient's head between his knees and the patient supine before him, with both patient and operator facing the same direction.

It would seem that the B. 1 cranium might be advanced as a case of antemortem trephining on the following grounds: absence of bone erosion or rarefaction as in disease; no evidence for either a depressed or a radiating fracture; well-defined, beveled exterior edges, oblique at the expense of the outer table; ellipsoid shape; length within a cited range for primitive trephination; evidence of bony regrowth; and general similarity in appearance and in orientation to a verified Inca trepan.

T. Stewart, who has examined many trepans on skulls in the U.S. National Museum collections, suggested that the B. 1 cranial aperture might be from a cyst or tumor. He conceded, however, that he had never seen anything quite like this specimen. Of five pathologists who examined the skull, four were flatly of the opinion that it was a trephination and not meningioma or other disease; the fifth, M. Helpern, a specialist in forensic medicine, suggested that a downward invasion of a basal cell tumor of the scalp *could* cause the condition, but he declined ultimately to say definitely what the lesion represented. H. Jaffee may have effected a marriage of the opposed viewpoints of disease and trephining; he raised the possibility

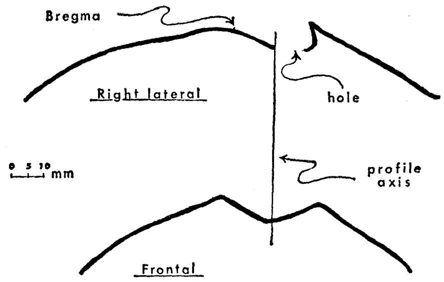


Fig. 3. Cranial profiles of B. 1 anomaly. (Top) Right lateral view. (Bottom) Frontal view.

that the anomaly might result from a long-standing lesion which prompted attempts to scrape or treat it.

What a trephined skull might mean at the Spruce Swamp site is unclear. Both generalized regional Archaic and Woodland levels have been postulated here (*1*), with only tenuous suggestion of exotic elements. These include an artifact of plasma (a stone material identified as originating in Georgia or Alabama) and an enigmatic incised paintstone (*10*), which may record Southern cult motifs.

The presumptive trephination may be an isolate, or it may relate to cultural practices or influences inadequately recorded in the literature. Certainly the unskilled and fragmentary recovery of most Indian burials in this region plus unrestricted "pothunting," may have destroyed much evidence.

BERNARD W. POWELL
*Stonebridge Road,*
*Wilton, Connecticut 06897*

**References and Notes**

→ B. Powell, *Amer. Antiquity* **30**, 460 (1965).
2. J. Daland, *Ann. Med. Hist.* **7**, 550 (1935).
3. T. Stewart, in *Smithsonian Institution Annual Report of 1957* (Government Printing Office, Washington, D.C., 1958), pp. 469–491.
4. J. Tello, *Prehistoric Trephining among the Yauyos of Peru* (Harrison, London, 191-), pp. 75–83.
→ W. Goldsmith, *Amer. Antiquity* **10**, 348 (1945).
6. C. Wells, *Bones, Bodies, and Disease* (Praeger, New York, 1964), plate 82.
7. R. Fletcher, in *Contributions to North American Ethnology* (Government Printing Office, Washington, D.C., 1882), pp. 5–30.
8. W. Hinsdale and E. Greenman, *Perforated Indian Crania in Michigan* (Univ. of Michigan Press, Ann Arbor, 1936), pp. 1–15.
9. M. Muniz and W. McGee, in *Sixteenth Annual Report of the Bureau of American Ethnology* (Government Printing Office, Washington, D.C., 1897), pp. 11–72.
→ B. Powell, *Amer. Antiquity* **30**, 98 (1964).
11. I thank T. Stewart, United States National Museum; M. Helpern, Chief Medical Examiner, and his staff, New York City; and H. Jaffee, Hospital for Joint Diseases, New York City, for their examinations of, and comments on, the cranium from B. 1. I also thank R. Colmers, Medical Examiner of Stamford, Connecticut, and J. Gifford of the Department of Anthropology, Temple University, for encouragement and other assistance in carrying out this project.

17 August 1970

# Stratospheric Ozone with Added Water Vapor: Influence of High-Altitude Aircraft

Abstract. *Simple, steady-state models for ozone photochemistry, radiative heat balance, and eddy-diffusive mass transport can be combined to estimate water-induced changes in the stratospheric ozone concentrations and temperatures, the integrated ozone column, the solar power transmitted to the earth's surface, and the surface temperature. These changes have been computed parametrically for mixing fractions of water vapor between* $3 \times 10^{-6}$ *and* $6.5 \times 10^{-6}$*. With added water from the exhausts of projected fleets of stratospheric aircraft, the ozone column may diminish by 3.8 percent, the transmitted solar power increase by 0.07 percent, and the surface temperature rise by 0.04°K in the Northern Hemisphere. Due to a cancellation of terms, temperatures in the lower stratosphere remain essentially unchanged. These results are sensitive to the form of the water profile and emphasize the potential role of convective transients near 30 kilometers.*

Several authors have expressed concern that exhausts from fleets of stratospheric aircraft may build up to levels sufficient to perturb weather both in the stratosphere and on the surface (*1–3*). Indeed, calculations indicate that the quantity of added water vapor may become comparable to that naturally present; projected fleets of high-altitude aircraft may add 0.6 part per million (ppm) to the mixing ratio of water above 15 km in the Northern Hemisphere, relative to the natural ratio of about 3 ppm (*4, 5*). Similarly, the added mixing ratio of carbon dioxide may be about 0.6 ppm in the presence of a natural ratio of 320 ppm.

Manabe and Wetherald (*2*) have examined the atmospheric radiative-convective balance and concluded that an increase of water vapor from 3 to 15 ppm, in *both* the stratosphere and troposphere, would produce temperature changes of + 2°K at the surface and about − 7°K at 20 km. As these authors pointed out, this large increase in the water column exceeds that anticipated from stratospheric aircraft.

Hampson (*3*) has suggested that water added from commercial supersonic transports may interact significantly with the photochemical cycle of ozone. This interaction might be expected to disturb both the stratospheric temperature gradients and the total solar power transmitted to the earth's surface. It is the purpose here to describe a quantification of Hampson's hypothesis, consistent with simple models of water distribution, ozone photochemistry, and radiative heat balance (*6*).

Leovy (*7*) has given a simplified treatment of the photochemical steady-state equations for stratospheric ozone concentrations. Leovy's model, with the assumption that the photochemical rate constants are slowly varying integral functions of ozone concentrations, implies that for small changes of water vapor:

$$\frac{\delta [O_3]}{[O_3]} \simeq -\frac{1}{3}\frac{\delta [H_2O]}{[H_2O]} \qquad (1)$$

The unperturbed stratospheric mixing ratio of water is approximately 3 ppm (*5*). Added water from projected fleets of high-altitude aircraft may assume a steady-state value of approximately 0.6 ppm (*8*). For these numbers $\delta [H_2O]/[H_2O]$ is approximately ⅕, and therefore Eq. 1 implies an aircraft-induced depression of the ozone column by about 7 percent. For a better estimate, it is necessary to solve the equations with explicitly altered water concentrations. This was done (*6*) with, for consistency with Leovy, the same solar fluxes, chemical rate constants, and photoabsorptive cross sections (*7*). Water mixing ratios were varied between 3 and 6.5 ppm by volume. The solar zenith angle was taken to be 45°. Ambient stratospheric temperatures were those of the 1962 standard atmosphere for all computations (*9*), but independent temperatures were also computed by a very approximate method of Lindzen and Goody (*10*):

$$T = \frac{\eta\phi + 9 \times 10^{-5}\ {}^\circ\mathrm{K\ sec}^{-1}}{5 \times 10^{-7}\ \mathrm{sec}^{-1}} \qquad (2)$$

where $\phi = [O_3]/$[total atmospheric concentration]. This equation follows from the assumptions that the only heating term, $\eta\phi$, is due to direct absorption of solar energy by ozone, and that the only cooling term is radiation in the 15-$\mu$ band of $CO_2$. For internal consistency, the heating coefficients $\eta$ were computed for the work reported here with the same cross sections and solar fluxes as those used for the parent computation of perturbed ozone concentrations; however, the resulting coeffi-