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- 2. E. C. LaFond, in Encyclopedia of Oceanog-raphy, R. W. Fairbridge, Ed. (Reinhold, New
- York, 1966), pp. 402-408. 3. Hueneme Canyon is located directly off the artificial Navy harbor at Hueneme. The canyon crosses the narrow shelf, terminating at a depth of about 550 m. It is cut into soft formations.
- 4. Santa Cruz Canyon has steep rocky walls and a twisting axis. It extends diagonally down the slope into Santa Cruz Basin about 22 km and terminates at a depth of 1350 m.
- 5. Carmel Canyon has steep granite walls. It heads a stone's throw from the beach at the head of an embayment. It extends seaward past the Monterey Peninsula, joining Monterey Canyon at a depth of about 2000 m.
- 6. Monterey Canyon, the largest on the California

coast, has walls of unconsolidated sediments in the inner portion where we worked, but is rock-walled at greater depths. The axis is essentially meandering and can be traced for more than 100 km. E. C. LaFond, personal communication. F. P. Shepard, N. F. Marshall F

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Atmospheric Concentrations and Sources of Trace Metals at the South Pole

Abstract. The chemical composition of atmospheric particulate material collected at the geographic South Pole indicates that Al, Sc, Th, Sm, V, Mn, Eu, Fe, La, Ce, Co, Cr, Na, K, Mg, and Ca are derived from either crustal weathering or the ocean. The relatively volatile elements Zn, Cu, Sb, Se, Pb, and Br are apparently derived from other sources. Because of their volatility, vapor-phase condensation or a high-temperature dispersion source is suspected for these elements or their compounds.

Considerable interest has been directed recently toward measurements of the distribution and composition of atmospheric particles in remote regions of the earth. This interest has developed largely out of concern that man might inadvertently modify the earth's climate by changing the distribution of particles in the atmosphere on a global basis (1) and also as a result of the need to determine, for both geochemical and environmental reasons, the atmospheric input of many substances into the oceans (2).

The Antarctic polar plateau offers one of the best locations on earth for studying the composition of the background aerosol since it is isolated, both geographically and meteorologically, from the major sources of anthropogenic emissions in both the Northern Hemisphere and the Southern Hemisphere. Most measurements of trace substances of atmospheric origin from Antarctica have been confined to snow and ice (3, 4). The primary advantage of direct atmospheric collection is that the investigator is aware of, and has some control over, the history of the sample being collected. On the basis of current meteorological conditions and local activities, he can determine whether or not a sample is truly representative of a background aerosol.

In October 1970, extensive atmo-

spheric sampling was begun in Antarctica at Amundsen-Scott (or South Pole) Station at 90°S, 2800 m above sea level. We collected the atmospheric particulates on polystyrene filters (20.3 by 25.4 cm Delbag, type 99/97), using high-volume pumps (Gelman Hurricane) at a sampling rate between 1 and 2 standard cubic meters (SCM, 298°K, 1 atm) per minute. Samples were also collected on 47-mm and 90mm filters (Millipore Celotate type EA, $0.5-\mu m$ pore radius). The filter holders for all filter types were constructed entirely of polyethylene or Teflon and were located approximately 8 m upwind from the pumps. Typical sample volumes ranged from 10,000 SCM for the Delbag filters to 100 SCM for the 47-mm Millipore filters. The samples were collected about 400 m upwind of South Pole Station. The winds were predominantly (over 90 percent of the time) from the 0° to 90°E longitude quadrant during the 7-week period of sample collection. Continuous records of wind speed and direction were obtained from the U.S. Navy weather station during each sampling interval. Four samples were collected simultaneously over each 3-day period, two on Delbag filters and one on each size of the Millipore filters. Numerous filter blanks were measured to correct for filter impurities and collection contamination. Although the Millipore blanks were generally higher, their variability was considerably less than that for the Delbag filters, and the agreement between samples collected on the two types of Millipore filters and samples collected on the Delbag filters was good.

One of the two Delbag filters was used for analyses of Pb, Na, Mg, Ca, and K by atomic absorption, the acidsoluble fraction having been removed from the polystyrene filter matrix with nitric acid prior to analysis with an atomic absorption spectrophotometer (Perkin-Elmer model 303). For the Pb analysis we used a heated graphite atomizer (Perkin-Elmer HGA-70) and for Na, Mg, Ca, and K we utilized standard flame techniques. The other filters were analyzed by nondestructive instrumental neutron activation analysis (INAA) for as many elements above the blank value as possible. Filters were pressed into pellets in a Ninylon die before being irradiated in the National Bureau of Standards reactor $(\phi_{
m thermal}=6 imes10^{13}$ neutron cm^{-2} sec^{-1}) along with standards for each element determined. After appropriate decay periods, radiation from the samples was measured with Ge(Li) γ -ray detectors of large volume and high resolution (full width at half maximum, 2.2 kev for the 1.33-Mev γ -ray of ⁶⁰Co). The γ -ray spectra were analyzed by computer, with the small peaks being checked by manual integration to obtain the final concentrations.

There were ten 3-day sampling periods during which the winds were favorable for the collection of atmospheric samples without contamination from the camp. The results presented below are confined to these ten sampling periods only. For virtually all the elements measured by INAA, the final result for each sampling period represents the average of the analyses of two Millipore and one Delbag filter that were collected in parallel.

The average trace element concentrations and concentration ranges for the ten sampling periods are presented in Table 1. The uncertainty given for the concentrations is the standard deviation of the mean concentration found for each element in the ten sampling periods.

There are two major obvious natural sources for trace elements in atmospheric particulates-crustal weathering and the sea. In an effort to ascertain whether either of these sources is re-

Table 1. Mean atmospheric concentrations and concentration ranges of trace elements at South Pole Station; 1 ng = 10^{-9} g; 1 pg = 10^{-12} g; 1 fg = 10^{-15} g.

Ele- ment	Mean concentration*	Concen- tration range
Na	$7.2 \pm 3.8 \text{ ng/SCM}$	2.7-12
Mg	$1.0 \pm 0.7 \text{ ng/SCM}$	0.32-2.0
Fe	0.84 ± 0.21 ng/SCM	0.51-1.19
Pb	$0.63 \pm 0.30 \text{ ng/SCM}$	< 0.19-1.2
Br	0.63 ± 0.33 ng/SCM	0.38-1.41
Al	$0.57 \pm 0.17 \text{ ng/SCM}$	0.32-0.81
Ca	$0.5 \pm 0.4 \text{ ng/SCM}$	0.15-1.1
K	$0.3 \pm 0.1 \text{ ng/SCM}$	0.14-0.5
Cu	$36 \pm 19 \text{ pg/SCM}$	25-64
Zn	$30 \pm 11 \text{ pg/SCM}$	18-51
Mn	$10.3 \pm 5.5 \text{ pg/SCM}$	4.4-19
Se	$5.6 \pm 1.2 \text{ pg/SCM}$	4.2-8.2
Cr	$5.3 \pm 3.0 \text{ pg/SCM}$	2.5-10
Ce	$2.3 \pm 1.6 \text{ pg/SCM}$	0.8-4.9
Sb	$1.7 \pm 0.6 \text{ pg/SCM}$	1.0-3.1
v	$1.5 \pm 0.6 \text{ pg/SCM}$	0.6-2.4
Co	$0.84 \pm 0.27 \text{ pg/SCM}$	0.36-1.21
La	$0.51 \pm 0.37 \text{ pg/SCM}$	0.21-1.4
Sc	125 \pm 48 fg/SCM	59-212
Th	$59 \pm 21 \text{ fg/SCM}$	18-83
Sm	55 \pm 23 fg/SCM	28-89
Eu	$17 \pm 4 \text{ fg/SCM}$	4-24

* The uncertainty reported is the standard deviation of the mean concentration in the ten sampling periods.

sponsible for a particular trace element in the atmospheric samples, we have calculated the ratio of the concentration of that element to the concentration of a reference element present in high concentration in the source of interest and then compared the atmospheric ratio with the corresponding ratio in the source. The reference elements used were Al for the earth's crust and Na for the sea. An enrichment factor for each element in the atmosphere, relative to the crust, can be calculated as follows:

$$EF_{\text{crust}} = \frac{(X/Al)_{\text{air}}}{(X/Al)_{\text{crust}}}$$

where X refers to the concentration of the trace element of interest and Al refers to the Al concentration. If EF_{crust} is close to unity for any element X, this element may have a crustal source.

Mean EF_{erust} values for the South Pole samples are presented in Table 2 in order of increasing enrichment. The enrichment factors indicate that the first group of 15 elements, including Sc, Th, Al, Sm, V, Mn, Eu, K, Fe, La, Ca, Ce, Co, Mg, and Cr, are likely associated with a source largely derived from crustal material. The weathering rates and relative abundances of various types of rocks in the vicinity of the sampling area may cause the ratio of crustal source elements in atmo-

18 JANUARY 1974

spheric particles to differ somewhat from the mean crustal ratio. The second group of elements, however, including Na, Zn, Cu, Sb, Pb, Se, and Br, have such high values for EF_{crust} that a normal crustal weathering source for these elements must be ruled out.

If we may assume from Table 2 that 98 percent of the atmospheric Na is attributable to sea salt, the marine contribution of sea salt to the concentration of each of the other trace metals (in percentages) may be calculated and is significant only for the following elements: Na, 98; Mg, 90 to 95; K, 60 to 80; Ca, 50 to 80; and Br, ~ 8. When these percentages are taken into account in new computations of $EF_{\rm crust}$, the numbers in parentheses in Table 2 are obtained.

With the exception of Na, the remaining elements with very high values for EF_{crust} are more difficult to explain. Most of these elements are relatively volatile. If we consider all the elements in Table 2 with the exception of the alkali and alkaline-earth elements, the volatility, as measured by the elemental boiling points, decreases in the order Br>Se>Zn>Eu>Pb>Sb>Sm>Mn > Al > Cu > Cr > Fe > Sc > Co >Ce > V > La > Th. Five of the six most volatile elements listed above are included in the group of elements with high enrichment factors in Table 2. A similar order of volatility is found for many inorganic compounds of these elements (5).

The volatility of these elements may well be associated with their high atmospheric enrichment relative to less volatile elements. One possible source for these volatile elements in the atmosphere is high-temperature processes, either natural or anthropogenic. Bertine and Goldberg have recently pointed out (5) that volatile elements may be selectively introduced into the atmosphere during the combustion of fossil fuels, especially coal. Selective volatilization would also be expected from such natural processes as volcanism. In both processes the more volatile elements are emitted either in the gas phase or on very small particles. Gas-phase condensation and coagulation of the very small particles ultimately results in particles with radii on the order of a few tenths of a micrometer in a very few days (6). Particles in this size range have significantly longer atmospheric residence times than larger particles (7). They will also obviously be considerably enriched in the volatile elements relaTable 2. Mean atmospheric enrichment factors at the South Pole relative to crustal values of Taylor (13). The enrichment factor of the reference element, Al, has been normalized to unity.

Element	EFerust
Sc	0.8
Th	0.9
Al	1.0
Sm	1.3
V	1.4
Mn	1.4
Eu	1.9
K	2.0 (0.6)*
Fe	2.1
La	2.2
Ca	2.2 (0.8)*
Ce	4.4
Со	4.7
Mg	6.7 (0.7)*
Cr	6.9
Na	49 (1.0)*
Zn	69
Cu	93
Sb	1,300
Pb	2,500†
Se	18,000
Br	44,000 (40,000)

* Enrichment factors after correction for the oceanic component with Na used as the reference element. † Based on an atmospheric Pb concentration of 0.2 ng/SCM, which we believe to be more reliable because of possible contamination of the samples by exhaust emissions.

tive to larger particles produced by abrasional processes such as normal crustal weathering. At remote sites, such as the South Pole, far from particle source areas, the submicrometer particle population will suffer a much smaller concentration decrease during transport from the source area than the larger particle population, resulting in high enrichment factors for the more volatile elements on the total aerosol population collected at this site. Measurements of the variation of the concentration of many of these trace elements with particle size in urban air (8) and in northern Canada (9) support the concept above.

On the basis of Br/Pb ratios observed in this study (1.1/1) and in urban air, it would appear that most of the particulate Br in the atmosphere over the polar plateau is not associated with particles formed directly from the burning of ethyl fluid (10).

A recent study of Se and S in Greenland ice cores showed that the S content of the ice has increased in recent decades but that the Se content has remained relatively constant (11). The increase in the S concentration has been attributed to fossil fuel burning. If this is true, then the lack of a Se increase suggests that any Se injected into the atmosphere during the burning of fossil fuels is not being transported great 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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200

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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 2600year-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