the Central and Eurasian plates in East Anatolia. This stage coincided with the final separation of the Tethys ocean into two segments (the Mesopotamian and Mediterranean basins) which occurred during Miocene times (*14*). The combined effects of the geometry of the plates, the wedging-in mechanism, and the collision of the plates could supply a mechanism which caused the reshuffling of the active shear faulting within the crust.

At the same time, the driving forces that are manipulating the plate movements should not have changed. Therefore, exertion of lateral and vertical compressions, due to oblique collision along the Pelusium Line, are maintained. Hence, evidence for uplift and folding processes along both margins of the Sinai subplate described in this report, is not only explainable but is to be expected.

An eruption at the Volcano Santorini in the eastern Mediterranean, north of Crete, occurred at about 3400 years B.P., a date that coincides with the abrupt demise of the Minoan civilization on Crete (*15*). This event may perhaps have coincided with an earlier Holocene tectonic activity along the margins of the Sinai subplate; however, so far such an earlier event cannot be precisely determined.

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Copper in Aerosol Particles Produced by the Ocean

Abstract. *Measurements of particulate copper in the atmosphere near the island of Tasmania indicate that the ocean is a source of atmospheric copper. A biogenic agent may be responsible for the approximately 20,000-fold enrichment of copper during aerosol production from the ocean.*

Copper frequently is detected in atmospheric particles, even in those collected at locations far removed from anthropogenic sources. For instance, Duce *et al.* (*1, 2*) measured copper concentrations between 0.12 and 10 ng m^{-3} over the Atlantic Ocean north of 30°N and between 0.025 and 0.064 ng m^{-3} at the South Pole. These concentrations are much larger than those predicted for unenriched crustal weathering or oceanic production.

Because of the similar enrichments found over the North Atlantic and the South Pole, together with the short residence time of tropospheric particles compared with the mixing times between the Northern Hemisphere and the Southern Hemisphere, Duce *et al.* (*2*) argued that the enrichment may result from natural processes. Possible natural continental sources of anomalously enriched elements in aerosol particles include volcanism (*3*), low-temperature volatilization processes such as biological methylation (*4*), direct sublimation from the earth's crust (*5*), and emissions from plants (*6*). Fractionation at the air-sea interface can enrich elements in particles produced from the oceans (*7*). We present here evidence that the major source of copper in maritime particulate matter, collected at altitudes below 2000 m, is the ocean and that considerable enrichment must occur at the air-sea interface.

Atmospheric particles were sampled from a Cessna 402 aircraft flying near the island of Tasmania by direct impaction collection (*8*) on Whatman 542 filter papers. These samples were analyzed later by the ring oven technique for copper, sulfate, magnesium, calcium, aluminum, and other trace constituents. This technique allows better temporal and spatial resolution than is usually possible.

Aerosols collected near the surface (below 2000 m) have characteristics different from those collected above this altitude (*8*). Copper concentrations in aerosols collected at low altitudes in upwind conditions (so that local urban and industrial pollution was negligible) ranged from 0.3 to 190 ng m^{-3}. Most of the concentrations are comparable with those reported elsewhere, although the range is wider with some concentrations a little higher than usually observed. A wider range of values is expected because of the shorter sampling times and smaller sampling volumes (typically 10 to 20 m^3) in this work.

Magnesium in atmospheric particles is expected to arise from an oceanic source without enrichment at the air-sea interface (*7*). Aluminum, on the other hand, is derived from a crustal source. As expected, there is virtually no correlation between magnesium and aluminum concentrations in the samples. The correlation coefficient between log[Mg] and log[Al] is only 0.03 (*9*).

Evidence concerning the sources of the elements can be obtained from their correlations with magnesium and aluminum. The correlation coefficient between log[SO_4] and log[Al] was 0.02, indicative of negligible correlation, whereas that between log[Mg] and log[SO_4], based on 19 data points, was 0.71. The correlation between sulfate and magnesium is significant at above the 99 percent confidence level. The geometric mean of the ratio of the magnesium concentration to the sulfate concentration is 0.46 ± 0.09 (*10*). This ratio is essentially the same as the value for sea salt (0.48). The inferences are that the sea is the source of both magnesium and sulfate in these atmospheric aerosols, and that sulfate is not significantly enriched at the air-sea interface.

Because the precision of the measurements of the sulfate concentrations is greater than that for the magnesium concentrations and because sulfate is deduced to have an oceanic source, the correlation of copper concentrations with both magnesium and sulfate was estimated. A least-squares analysis of log[Cu] versus log[SO_4], based on 25 points, produces a gradient of 1.18 ± 0.29 and a correlation coefficient of 0.65. For log[Cu] versus log[Mg], based on 19 points, the gradient is 1.08 ± 0.35 and the correlation coefficient is 0.60. Both correlations are significant at above the 99 percent confidence level. The better correlation for copper with sulfate may result from the more precise sulfate measurements.

If two sources of copper, one independent of magnesium (and sulfate) and one linearly dependent on the magnesium concentration, contributed significantly to the overall copper concentration, a highly significant correlation coefficient could still result. However, in this case the gradient from the least-squares analysis would be less than unity. It seems, therefore, that the only significant source of copper in these aerosol samples also results in atmospheric magnesium and sulfate. For particles collected below 2000 m, the sea appears to be the only important source of copper particles. (For samples collected above the inversion layer, copper concentrations are much lower and there appears to be no positive correlation between copper and sulfate concentrations. However, the data are few in number.)

Further support for the view that the source of atmospheric copper in the samples collected below 2000 m comes from the variation of concentration with altitude. The aluminum concentrations show no significant variation with altitude, whereas the sulfate, magnesium, and copper concentrations decrease approximately exponentially with increasing altitude. The correlation coefficient between log[Cu] and height is −0.52 (16 points), a value significant at better than the 95 percent confidence level.

The geometric mean mass ratio of $[Cu]/[SO_4]$ is 0.018 ± 0.005 compared with the oceanic value of 1.1×10^{-6} (*11*). The enrichment factor for copper relative to an ocean reference constituent Y is given by

$$E_{\mathrm{sea}}(\mathrm{Cu}) = \frac{(\mathrm{Cu/Y})_{\mathrm{atm}}}{(\mathrm{Cu/Y})_{\mathrm{sea}}} - 1$$

where in this case Y is either sulfate or magnesium. Based on magnesium or sulfate, copper is enriched by a factor of 2×10^4 during aerosol production at the sea surface.

Enrichment at the sea-air interface is consistent with measurements by Duce *et al.* (*12*), who found that at Narragansett Bay, Rhode Island, enrichments of copper of about 50 occurred in the top 150 μm of the sea surface. If when a rising bubble bursts at the water surface only the top 0.025 to 0.75 μm of the surface is stripped off (*13*) and if all the enrichment of copper occurs in this surface layer, enrichment of copper in the atmospheric aerosol is estimated to be in the range 10^4 to 3×10^5. This range encompasses our measured enhancement.

Barker and Zeitlin (*14*) also found enrichments of copper as well as iron and zinc in surface layers and marine atmospheric samples gathered off the island of Oahu, Hawaii. Copper in the atmospheric aerosol was enriched by three to four orders of magnitude. Our measurements, which were made in the Southern Hemisphere and were removed from any direct coastal influence, corroborate these results.

The evidence strongly supports the contention that copper found in atmospheric aerosols collected near Tasmania and below the inversion layer originates from the ocean. The estimated enrichment of copper is rather large but is comparable to enrichments of other heavy metals (*7*) including silver (*15*). A biogenic agent (*12*) may be responsible for the approximately 20,000-fold enrichment of copper during aerosol production at the sea surface.

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Carbon-13/Carbon-12 Isotope Fractionation of Organic Matter Associated with Uranium Ores Induced by Alpha Irradiation

Abstract. *Analyses of stable carbon isotopes from two sample suites from sandstone uranium (tabular) ores show interesting variations. Organic carbon associated with high-grade uranium ore is heavy* ($\delta^{13}C$ = −*16.9 to* −*19.6 per mil, where* $\delta^{13}C$ = $^{13}C/^{12}C$ *relative to the Pee Dee belemnite standard) relative to the adjacent lower-grade samples (*−*22.7 to* −*26.4 per mil). It is suggested that the heavy isotopic values for the ore samples are related to a radiation and chemical isotope effect that has occurred mainly because of an alpha-radiation dose of* 10^{11} *rads.*

Stable carbon isotopic fractionation in noncarbonate materials occurs mainly as a result of biological processes (*1*), catagenesis (thermal cracking) of buried organic matter (*2*), and occasionally exotic reactions such as solar proton "stripping" (*3*). We report here on a radiation-induced isotope fractionation not previously observed.

To better understand the relationship between organic matter and uranium, we have analyzed two suites of five samples each from the Kerr McGee Corporation section 30 mine near Grants, New Mexico. The uranium ore occurs in medium- to fine-grained nonmarine sandstones of the Upper Jurassic Westwater Canyon member of the Morrison Formation (*4*). The ore is of the trend or tabular type, where the ore forms blankets that are lit-

Table 1. Uranium, organic carbon, carbonate carbon, and isotopic carbon data for samples from the Kerr McGee Corporation section 30 mine, New Mexico.

Laboratory number	Uranium (%)	Organic carbon (%)	Organic carbon $\delta^{13}C$	Carbonate carbon (%)	Carbonate carbon $\delta^{13}C$
359	0.008	<0.2*	−23.52	0.78	−12.63
360	0.39	0.4	−19.61	1.27	−11.93
361	0.69	0.8	−18.73	0.10	−13.62
362	1.08	1.4	−18.71	0.04	−16.05
363	0.016	<0.2†	−22.65	1.26	−15.74
824	0.038	0.2‡	−24.06	<0.01	
825	2.87	5.0	−17.76	<0.01	
826	2.78	4.3	−17.66‖	<0.01	
827	1.17	1.8	−16.87	<0.01	
828	0.016	<0.2§	−26.43	<0.01	

*Reanalyzed to give 0.30 by difference and 0.11 after acid leach. †Reanalyzed to give 0.23 by difference and 0.12 after acid leach. ‡Reanalyzed to give 0.19 by difference; 0.20 total combustion. §Reanalyzed to give 0.13 by difference; 0.12, total combustion. ‖Acid-treated replicate, −17.45 per mil.

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