Extraterrestrial Material and Stratospheric Aerosols

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ABSTRACT

The composition of stratospheric aerosols has been measured for about 40 years, with some of the most intense efforts during the 1960s. A recent technique, particle analysis by laser ionization mass spectrometry, has shown that many stratospheric sulfuric acid aerosols also contain ablated material from meteors. Meteoritic material may affect the size distribution of aerosols in parts of the stratosphere. The amount of meteoritic material in stratospheric aerosols is not consistent with the upper end of estimates of the flux of extraterrestrial material into the Earth's atmosphere. Transport of stratospheric aerosols into the troposphere will preferentially deposit ablated meteoritic material at middle latitudes compared to the tropics or poles.

HISTORY

Extraterrestrial material from the ablation of meteors has been considered as a possible constituent of stratospheric aerosols for almost 40 years. However, this consideration has been sporadic, with meteoritic material often ignored in the literature on stratospheric aerosols. At the same time, the literature on extraterrestrial matter in the stratosphere has sometimes focused on interplanetary dust particles to the exclusion of the much larger mass of meteoritic material that ablates in the upper atmosphere and then recondenses to form aerosols.
The existence of a layer of aerosols in the lower stratosphere at about 16–25 km altitude was established around 1960 by Junge (1963). The question of whether extraterrestrial material was a major constituent of these stratospheric aerosols was quickly answered in the negative as the aerosols were found to be composed largely of sulfate. Some major features of stratospheric aerosols were presented in a remarkable paper by Junge et al. (1961):

The particles between 0.1 and 1.0 μm were collected in sufficient concentration to permit detailed investigation. They were found to be very hygroscopic and, by electron microprobe analysis, were found to contain sulfur as a major constituent, with traces of iron and silicon. Those particles between 0.1 and 1.0 μm are most likely formed within the stratosphere, possibly by oxidation of SO₂ and H₂S gas traces. Fall speed considerations make it very likely that the majority of particles larger than one micron are of extra-terrestrial origin.

The only significant change to this in our current understanding is that the oxidation of carbonyl sulfide is probably the largest source of sulfate in the stratosphere. It was also some years before it was established that the sulfate is mostly sulfuric acid rather than ammonium sulfate (Rosen, 1971; Lazrus and Gandrud, 1974).

Research in the 1960s continued to consider the possibility of extraterrestrial material (Rosen, 1969). Solid inclusions seen in electron micrographs of sulfate aerosols were considered to be extraterrestrial (Mossop, 1963). Solid inclusions in aerosols collected from balloons above the main sulfate layer at altitudes of up to 37 km were ascribed to meteoritic material (Bigg et al., 1970). Yet measurements of the Fe/Na ratio in filter samples of stratospheric aerosols indicated that meteoritic material was either absent or present only in very small quantities (Shedlovsky and Paisley, 1966). However, out of their three published samples there were no Fe values and only one Na value more than 2 standard deviations above variability in the blanks.

The 1960s also saw tremendous efforts to understand the fate of radioactive material that was injected into the stratosphere by bomb tests and became attached to aerosols (e.g., special section of *J. Geophys. Res.* on Heidelberg conference, 1970; CIAP, 1974). The eruption of Mt. Agung in 1963 as well as the later eruptions of El Chichón and Mt. Pinatubo provided clear evidence of the sporadic domination of the stratospheric aerosol layer by volcanic ash and sulfate derived from volcanic SO₂ (Mossop, 1964). The abundances of trace elements can distinguish volcanic particles from interplanetary dust particles on a single particle basis (e.g., Flynn and Sutton, 1990; Rietmeijer, 1995) and could do so for bulk samples as well using chemical mass balance techniques.

Experimental searches for extraterrestrial material in sub-micron stratospheric sulfate aerosols seem to have ended in the 1960s, although work did continue on altitudes above the aerosol layer (e.g., Herrmann et al., 1978; Krieger and Arnold, 1992). One experiment in 1985 that collected stratospheric particles at 34 to 36 km found mostly volcanic material, almost certainly from the eruption of El Chichón two years earlier (Testa et al., 1990; Rietmeijer, 1993). Several review papers on stratospheric aerosols published in the 1980s and 1990s never mention extraterrestrial material. Whether this was because the knowledge that sulfate was the dominant constituent was considered satisfactory or because the extraterrestrial component of stratospheric aerosols had been underestimated is hard to judge. The meteorite community seems