Cometary organic matter still a contentious issue

SIR—Hoyle and Wickramasinghe[1] question certain aspects of our model of the 3.4-μm feature in the coma of comet Halley as thermal emission from organic grains[2]. Our basic contention is that if the infrared spectra of freeze-dried bacteria do acceptably match the cometary spectra — a matter in dispute — this is because of simple organic functional groups that are present in many abiogenic organics. We therefore do not believe, as Hoyle and Wickramasinghe charge, that our preference for a non-biological explanation is due to our "strongly-held cultural prejudice that there is no life outside the Earth". (Indeed, one of us has made a considerable effort over three decades to seek evidence relevant to such life.) We do concede, however, that we should not have described the fit between the bacterial model and the 3.4-μm feature as providing "no" evidence for cometary biology; rather, we should have said that it provides no persuasive evidence as much more plausible alternatives exist. The recent comparison[3] of 'bacterial' and 'abiotic' models leaves unanswered such questions as how the bacterial emission model somehow fits the 3.05-μm absorption feature, or whether this model implies emission features at longer wavelengths where none is observed.

Hoyle and Wickramasinghe ask what "definite observation" we can cite for our "belief in the production of a specific mixture of organic materials in significant quantity" from irradiated C- or N-bearing ices. The production of organics from such ices has an experimental history extending over a quarter of a century[4-6], and was recently the subject of an international workshop[7]. The application of such experiments to the outer Solar System has recently been surveyed[8].

Most points raised by Greenberg and Zhao[9] with reference to our original correspondence[10] are addressed directly in our subsequent letter[2]; indeed, several of their points are possibilities which we explicitly endorsed. They object to "the assumption that a methane ice clathrate has any relevance to the comet nucleus." But recent work based on *in situ* data from the Giotto ion mass spectrometer indicates that CH_4 is present in the Halley coma with a production rate about 2% that of H_2O[11]. In cometary ices, clathrates are thermodynamically favoured[12]. By no means, however, did we argue that CH_4 clathrate is the only plausible candidate ice yielding radiation-processed organics, and our group has examined a range of alternatives[8,13]. However, interstellar dust particles of probable cometary origin provide "nothing resembling the Greenberg model "[14] (see ref. 15). Nor did we claim that only post-accretion cosmic-ray processing is important for the formation of organics. Rather, we concluded[2] that most organic Halley dust "is probably jetted from the interior, with organics thus due mainly to processing by radionuclides and pre-accretion irradiation".

Greenberg and Zhao note that "no published laboratory residue spectrum provides a perfect fit to the Halley dust emission". But no single model can yet hope to encompass the entire range of complexity of the formation and time-variable infrared emission of cometary organics. It is not even certain that the 3.4-μm feature is wholly due to thermal emission from organic grains[2], rather than, for example, gas-phase fluorescence. As is often the case in science, the present debate is not about which mechanism is 'the' answer, but rather about the relative merit of competing models.

Our model makes specific testable predictions for the heliocentric evolution of cometary emission features, to be tested by observations planned for comet Brorsen–Metcalf in 1989 (C.C. and C.S., preprint). We hope the infrared astronomy community will take full advantage of this apparition. Only further experimental work, tested against such observations, can sift through the range of alternative models.

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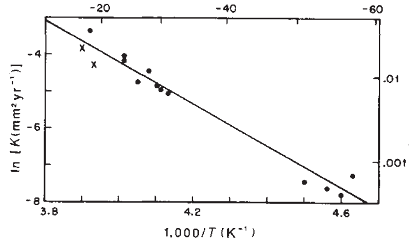
Long-term climate changes from crystal growth

SIR—In a recent letter to *Nature*[1], Petit *et al.* proposed that the small grain sizes in Wisconsinan ice from Vostok Station and Dome C, East Antarctica, were caused by the cold surface temperatures at the time of deposition. A further analysis of the relevant data indicates that their proposed temperature 'memory' can last only hours rather than thousands of years, and that the small grain sizes in Wisonsinan ice are probably caused by the drag effect of the soluble impurities in that ice[2].

Petit *et al.*[1] proposed that the grain-growth rate is controlled by the concentration of self-interstitials in the ice lattice near grain boundaries, and that this concentration becomes fixed soon after deposition and does not change until the onset of recrystallization near the glacier bed. Formation of self-interstitials is thermally activated, and free surfaces (bubbles or pores) serve as sources or sinks for self-interstitials during temperature changes[3]. The proposal of Petit *et al.*[1]



Temperature dependence of grain growth in polar ice. Impure coastal sites are shown by crosses. Data include all points from ref. 1, plus further points from refs 5 and 9.

thus requires that the diffusion distance for self-interstitials over time $t \approx 10^4$ yr is small compared with the spacing between pores ($\approx 10^{-3}$ m), so that equilibrium is not established. At −60 °C (the approximate temperature of Vostok and Dome C) the diffusion coefficient for self-interstitials is $D = 3 \times 10^{-10}\,m^2\,s^{-1}$ (ref. 3). Estimating the diffusion distance as $(Dt)^{1/2}$ excess interstitials will diffuse 10^{-3} m in about 1 h. (A more exact calculation for diffusion to a spherical bubble[4], using data for Wisconsinan ice from Dome C, shows that excess interstitials quenched into ice by an instantaneous cooling from −10 °C to −60 °C would be reduced to less than 1 per cent of the equilibrium concentration at −60 °C in less than a day.)

A similarity between the activation energy for volume diffusion in ice and that for grain growth, calculated from an Arrhenius plot of growth rates at different polar sites, is cited as evidence[1] that volume diffusion of self-interstitials controls grain growth. But similarity of activation energies is not sufficient to demonstrate equality of mechanisms. Furthermore, reanalysis of available data shows that the activation energies are significantly different in this case. Petit *et al.*[1] combined data corrected for the section effect (the difference between the average cross-sectional area of a grain on a plane of section and the true cross-sectional area) with uncorrected data. The figure shows an Arrhenius plot similar to that of Petit *et al.*[1], in which available data have been corrected in a geometrically consistent manner to match Gow[5] as closely as