Meteoric smoke concentration in the Vostok ice core estimated from superparamagnetic relaxation and some consequences for estimates of Earth accretion rate

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[1] We measured the magnetization of glacial and interglacial ice from the Vostok core to estimate the meteoric smoke concentration in Antarctic ice. We have found that, within the uncertainty of the method, the smoke concentration in ice in Antarctica is equivalent to that previously measured in Greenland ice. The virtually identical smoke concentrations despite the different ice accumulation rates in Greenland and Antarctica suggest that wet deposition is the main deposition mechanism for such ultra-small particles. Given the typical scavenging ratios for atmospheric aerosols, this would imply that previous estimates of accretion rate based on dry deposition are likely to be appreciably overestimated. Citation: Lanci, L., D. V. Kent, and P. E. Biscaye (2007), Meteoric smoke concentration in the Vostok ice core estimated from superparamagnetic relaxation and some consequences for estimates of Earth accretion rate, Geophys. Res. Lett., 34, L10803, doi:10.1029/2007GL029811.

2. Measurement Procedure and Results

[3] We performed IRM measurements following previously described procedures [Lanci et al., 2004; Lanci and Kent, 2006] on 70 ice samples from the Vostok ice core (78°28′S, 106°48′E; Figure 1) at 10 levels between 140 m and 500 m depth that represented the Holocene and the last glacial maximum (Figure 2). An IRM was induced in each sample (typically ~50 g) with a pulse magnetizer up to the maximum field of 1 T and the magnetizations were measured immediately after each step, all the while maintaining the sample close to liquid nitrogen temperature (77 K). After the measurements, the samples were allowed to re-equilibrate to storage freezer temperature (about 255 K) for a few hours and were measured again immediately after re-immersion in liquid nitrogen. The resulting IRM of the ice samples had decreased compared to their previously measured value, suggesting the relaxation of remanence of the finest (i.e., superparamagnetic or SP) particle fraction, between ~5 nm and 30 nm diameter [Lanci and Kent, 2006]. The contribution of the SP fraction was computed for each sample by subtracting the IRM remaining after relaxation at 255 K (ST, stable magnetization) from the IRM attained just after exposure to the maximum field. The exponential dependence of relaxation time with respect to magnetization and temperature makes the determination of the SP and ST components relatively insensitive to the elapsed time for temperature re-equilibration.

[4] A comparison of magnetization (SP and ST) and dust measurements for Vostok [Petit et al., 1999] indicates that they are clearly correlated (Figure 2), which is the same pattern observed in the NorthGRIP results [Lanci and Kent, 2006]. Moreover, the variability of the ST magnetization as indicated by the standard deviations is comparable to that of the dust concentrations, although the lower resolution of the available dust data does not allow a detailed comparison. A relatively high SP fraction was found in Vostok ice, with a relatively large background value that is actually higher than ST magnetization when dust concentrations are low during the Holocene (to ~350 m) although SP values are less elevated than ST magnetization when dust concentrations are generally high in the last glacial maximum.
(~350–500 m). We cannot exclude the possibility that part of the magnetic relaxation may be due to large multi-domain grains (>1000 nm for magnetite), which can lose some of their magnetization by warming through the Verwey transition [e.g., Dunlop and Özdemir, 1997]. However, most of them (those larger than 1300 nm) are recognized in grain-size analysis, and thus, they are not included in the offset of dust magnetization [Lanci and Kent, 2006]. For interglacial samples, the loss of magnetization is so large that it would require an unrealistically large fraction of large multi-domain grains that somehow escaped detection by grain size analyses; for glacial samples, large multi-domain particles are likely to be included in the dust measurements and this will tend to factor out their influence on the relaxation magnetization that is uncorrelated to dust concentration.

[5] We assume that the terrestrial dust component has a constant ST/SP ratio, which is supported by the linear correlation of the ST and SP magnetizations (Figure 3), and that the concentration of meteoric smoke is constant over glacial and interglacial times. We neglect any significant climatic control on the grain-size distribution of the magnetic particles, based on the qualitative linear correlation between dust and ST magnetization (Figure 2) and by the linear correlation of ST and SP magnetizations (Figure 3). We also disregard the possibility that the meteoritic component contributes significantly to the ST magnetization (i.e., it has a grain size larger than 30 nm) on the basis of the zero intercept obtained from regression of the stable magnetization versus dust concentration in North-GRIP ice [Lanci and Kent, 2006] as well as the very low stable (ST) magnetization values for Holocene ice at Vostok (Figure 2). The linear correlation between SP and ST (Figure 3) thus reflects a common terrestrial dependence, whereas the significant positive offset in the linear regression is explained as the uniform meteoric contribution to SP magnetization. The best estimate of the meteoric smoke magnetization, calculated on the basis of mean values of SP and ST magnetization at each level and taking into account errors in both coordinates in the linear regression, is $8.1 \pm 2.7 \times 10^{-9} \text{Am}^2\text{kg}^{-1}$ (1 $\sigma$ uncertainty of the regression line); a similar magnetization is obtained using single-sample values of SP and ST in the regression.

[6] The concentration of meteoric smoke can be estimated from the ice magnetizations by assuming that all available iron in the meteoritic source was oxidized to magnetite ($\text{Fe}_3\text{O}_4$), which for the average composition of ordinary chondrites, the most common type of meteorite [Lodders

Figure 1. Location of Vostok ice core.

Figure 2. Ice magnetizations (stable and superparamagnetic) compared with dust concentration [Petit et al., 1999] in the Vostok ice core over the last glacial and interglacial (Holocene) intervals. ST magnetizations (samples as closed diamonds, interval averages as open diamonds) more closely follow the changes in dust concentration than the SP magnetizations (open circles), which include a significant contribution from meteoric smoke. Age scale from Petit et al. [1999].
3. Discussion and Conclusions

Meteoric smoke flux can be computed at the Vostok ice compared to NorthGRIP ice in Antarctica, even though the 64 ± 18 kt/yr estimated from NorthGRIP ice is greater than the 40 ± 20 kt/yr range proposed by Love and Brownlee (1993) from direct satellite measurements and suggest that previously computed accretion rates from Greenland ice (≈78 kt/yr [Gabrielli et al., 2004] or ≈64 kt/yr [Lanci and Kent, 2006]) are likely to be overestimated by at least a factor of two.

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References


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