of heavy minerals in the upper sand and gravel unit is greater and many readily-weatherable minerals are included. This suggests that the heavy minerals in the upper sand and gravel unit have been enriched from a new source, such as would be associated with a glacial event. Also the frequency of volcanic rocks, quartz, and quartzite is much greater in the lower sand and gravel unit than in the till. Thus it is impossible to argue that these materials could have been derived either from the till or from the ice which deposited the till.

(6) We are interested to know on what basis active ice in the Thames would affect outwash drainage as far away as Bury St. Edmunds.

(7) Anglian glacial deposits are restricted because most of the melt-water beneath the ice was concentrated in 'tunnel valleys' related to a low sea level³. The relative scarcity of glacial deposits in an ice-marginal location is not peculiar to southern East Anglia. It is also characteristic of the southern margin of the Devensian ice sheet.

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¹ Rose, J. & Allen, P. J. *geol. Soc. Lond.* (in the press).

² Lake, R. D., Ellison, R. A. & Moorlock, B. S. P. *Nature* 265, 663 (1977).

³ Woodland, A. W. *Proc. Yorks. geol. Soc.* 37, 521-577 (1970).

The cause of Forbush's 20-year wave

LEVY¹ has suggested an explanation of Forbush's² 20-yr wave in the galactic cosmic-ray diurnal anisotropy. Levy states he knows of no other way to account for the variation. This note discusses a previously known alternative mechanism and provides a calculation for the thickness of the heliosheath.

Any mechanism to explain Forbush's 20-yr wave must use the 20-yr oscillatory solar cycle vector dipole field (B_{SD}). To obtain a sinusoidal wave from this vector, it is necessary to have a mechanism which basically takes the

product of B_{SD} with a stationary vector. Levy's mechanism utilises the azimuthal twisting of the interplanetary magnetic field (IMF) lines to obtain an enhanced radial $\nabla \times B$ drift between the positive and negative field of the extended solar dipole. The azimuthal twisting of the field as a result of the solar rotation is important because the perpendicular drift in a radial field would only result in an azimuthal drift of the cosmic rays³ with no outward 20-yr wave. Thus Levy's mechanism takes the product between B_{SD} and the angular velocity vector of the Sun to obtain an effect.

Schatten and Wilcox⁴, however, take the product between B_{SD} and the nearby galactic magnetic field (GMF) vector to obtain their effect. In this model, cosmic rays either gain access to the heliosphere at high (or low) heliographic latitude depending on whether the extended IMF connects to (or is closed from) the GMF. This causes a 20-yr streaming of cosmic rays away from (or toward) the Sun along the IMF of the type Forbush observes, and Duggal and Pomerantz⁵ confirm.

Matters arising

Matters Arising is meant as a vehicle for comment and discussion about papers that appear in *Nature*. The originator of a Matters Arising contribution should initially send his manuscript to the author of the original paper and both parties should, wherever possible, agree on what is to be submitted. Neither contribution nor reply (if one is necessary) should be longer than 300 words and the briefest of replies, to the effect that a point is taken, should be considered.

It is interesting that this latter view, if correct, enables a calculation of the thickness of the heliosheath. The cosmic rays producing the Forbush effect have an energy of around 25 GeV (refs 1 and 2). Thus their rigidity is $R/V = 300 \text{ H}\rho$ (H in gauss, ρ in cm).

The heliosheath fields are most effective at filtering cosmic rays with gyro-radii comparable to the heliosheath thickness $\rho \sim d$. An extension of the Archimedean spiral IMF suggests H may be as low as $6 \times 10^{-7} \text{ G}$ whereas the galactic magnetic field is nearer 10^{-6} G (ref. 6). Equating ρ to d in the above equation, we find for d , a value of $1.4 \times 10^{14} \text{ cm} \sim 10 \text{ a.u.}$ This is in fact approximately the value suggested for the heliosheath thickness⁷. Undoubtedly Pioneer missions to the outer planets may add to our knowledge about what is happening in this interesting region of space.

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¹ Levy, E. H. *Nature* 261, 394 (1976).

² Forbush, S. E. *J. geophys. Res.* 72, 4437 (1967).

³ Fisk, L. A. & Schatten, K. H. *Solar Phys.* 23, 204 (1972).

⁴ Schatten, K. H. & Wilcox, J. M. *J. geophys. Res.* 74, 4157 (1969).

⁵ Duggal, S. P. & Pomerantz, M. A. *Proc. 14th Int. Cosmic Ray Conf.* 4, 1209 (1975).

⁶ Allen, C. W. *Astrophys. Quantities*, 2nd ed. (Athlone Press, London, 1963).

⁷ Axford, W. I., Dessler, A. J. & Gottlieb, B. *Astrophys. J.* 137, 1268 (1963).

LEVY REPLIES—The suggestion put forward by Schatten and Wilcox⁴, that the solar-magnetic-cycle wave in the diurnal variation of energetic cosmic rays results from alternating connection and disconnection of the interplanetary and galactic magnetic fields, is an interesting one that deserves quantitative discussion. Although this is not the place to discuss the idea in detail, one remark does seem in order.

As I understand Schatten's present calculation, particles with cyclotron radii that are small compared with the characteristic length scales in the magnetic-field reconnection region will efficiently follow the field lines and thus will show the largest effect of field line topology. Particles with increasing energy, and thus increasing cyclotron radii, will be less inhibited in their motion by the details of the field-line topology in the heliosheath reconnection region. Thus it seems to be a natural consequence of Schatten's and Wilcox's proposal, in its present form, that the amplitude of the variable anisotropy is a monotonically decreasing function of particle energy. The existing, but sparse, information on this point² suggests that this is not the case. The amplitude of the varying anisotropy seems to increase with energy in the range below 20-30 GeV and to decrease at larger energies. This behaviour is consistent with that predicted as a result of particle drifts³ in a large-scale coherent interplanetary magnetic field⁴.

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¹ Schatten, K. *Nature* 265, 664 (1977).

² Duggal, S. P. & Pomerantz, M. A. *Proc. 14th Int. Cosmic Ray Conf.* 4, 1209 (1975).

³ Levy, E. H. *J. geophys. Res.* 81, 2082 (1976).

⁴ Levy, E. H. *Nature* 261, 394 (1976).