does not. His argument is analogous to a defense of laissez-faire capitalism by saying "but surely you don't prefer Maoist communism"; this enthymematic argument is not valid even if laissez-faire capitalism is eminently desirable.

Paleontologists will never be in a position to decide which of these hypotheses is correct, although we may be able to rule out extreme hypotheses such as phyletic gradualism and its counterpart $P(S,S_i) = 1$ [or $P(C,C_i) = 1$], an extreme version of the Eldredge-Gould hypothesis, by providing counterexamples. The frequency at which we might expect new species to originate by gradual changes in ancestor-descendant sequences of large established populations over geologic time must be determined, if it is determined at all, by population geneticists.

CHARLES W. HARPER, JR.
School of Geology and Geophysics, University of Oklahoma, Norman 73069

References and Notes

1. N. Eldredge and S. J. Gould, in *Models in Paleobiology*, T. J. M. Schopf, Ed. (Freeman, Cooper, San Francisco, 1972).
2. N. Eldredge, *Evolution* **25**, 156 (1971).
3. E. Mayr, *Animal Species and Evolution* (Harvard Univ. Press, Cambridge, Mass., 1963), p. 513; L. Brundin, in *Current Problems of Lower Vertebrate Phylogeny*, Tor Ørvig, Ed. (Almqvist & Wiksell, Stockholm, 1968), p. 473; L. Croizat, G. Nelson, D. E. Rosen, *Syst. Zool.* **23**, 265 (1974) (see pp. 269 270 and 279 280).
4. F. Bernard [*Éléments de Paléontologie* (Baillière, Paris, 1895)], L. A. Nevesskaya [*Paleontol. J.* **1** (No. 4), 1 (1967)], and V. N. Ovcharenko [*ibid.* **3** (No. 1), 57 (1969)] cite examples to document the origin of fossil species through speciation in peripheral isolate populations, although Nevesskaya does not regard this as necessarily the main mechanism of speciation. V. Ruzhentsev [*Int. Geol. Rev.* **6**, 2204 (1964)] postulates that fossil species originated rapidly (in less than 1000 years) and subsequently changed little, if at all, so that transitional forms should be rare in the fossil record; he did not restrict their origin to small peripheral isolates.
5. H. Reichenbach, *The Theory of Probability* (Univ. of California Press, Berkeley, 1971).
6. For the purpose of this discussion, I assume that (i) all (known and unknown) ancestor-descendant sequences of fossil populations with distinctive end members have been divided into species comparable in scope to modern-day species, in the manner suggested by A. L. McAlester [*J. Paleontol.* **36**, 1377 (1962)] and T. R. Waller [*ibid.* **43** (part 5 Suppl.), 8 (1969)], and (ii) all reproductively isolated populations (known and unknown) existing in any given time interval have been divided into separate species.
7. S. M. Stanley, *Proc. Natl. Acad. Sci. U.S.A.* **72**, 646 (1975).
8. For the purpose of this discussion, we will assume that all of the changes occurring, including those in continuous variates such as the ratio of orbit size to skull width in vertebrates, have been characterized as occurring in small, discrete steps; this could easily be accomplished for a continuous variate in any particular case by defining class intervals.
9. A. M. Ziegler, *Palaeontology* **9**, 542 (1966).
10. W. B. N. Berry and A. J. Boucot, *Geol. Soc. Am. Spec. Pap. 102* (1970), p. 28.
11. On *Stricklandia* evolution see A. Williams, *Q. J. Geol. Soc. Lond.* **107**, 85 (1951); T. W. Amsden, *J. Paleontol.* **40**, 1012 (1966); and W. B. N. Berry and A. J. Boucot (*10*). A recent study of Siluro-Devonian *Gypidula* species [J. H. Makurath and E. J. Anderson, *Evolution* **27**, 303 (1973); J. H. Makurath, *ibid.* **28**, 481 (1974)] purports to document gradual change in ancestor-descendant lineages, but the available data are limited and, in contrast to those for *Eocoelia* and *Stricklandia*, only local in scope.

12 June 1975

Paleomagnetic Excursions as Magnetostratigraphic Horizons: A Cautionary Note

Abstract. *Sediments from certain environments with high rates of deposition are not remagnetized after they have been deformed. The paleomagnetic signature from a zone of deformation can be misinterpreted as evidence for globally coherent fluctuations in the earth's magnetic field.*

Recent paleomagnetic studies of sediments from environments with high rates of deposition have provided evidence that, at one or more times during the past 50,000 years, the earth's magnetic field may have exhibited large-scale fluctuations in direction. In view of the lack of a standard terminology, I shall use the term "paleomagnetic excursion" to designate this anomalous behavior. Several investigators (*1, 2*) have proposed that paleomagnetic excursions record synchronous, worldwide geomagnetic phenomena and therefore represent important magnetostratigraphic horizons that could be used as chronological markers in many areas of late Pleistocene research, including sedimentology, archeology, climatology, paleontology, and palynology.

However, despite many studies (*3*), the nature of the paleomagnetic excursions remains uncertain. In particular, proposed paleomagnetic excursions do not yet satisfy the requirements of internal consistency within a given sedimentary basin as well as spatial and temporal consistency on a global scale. In this report I will briefly review these inconsistencies and then provide field evidence that demonstrates that at least some anomalous paleomagnetic results may be explained in terms of other processes.

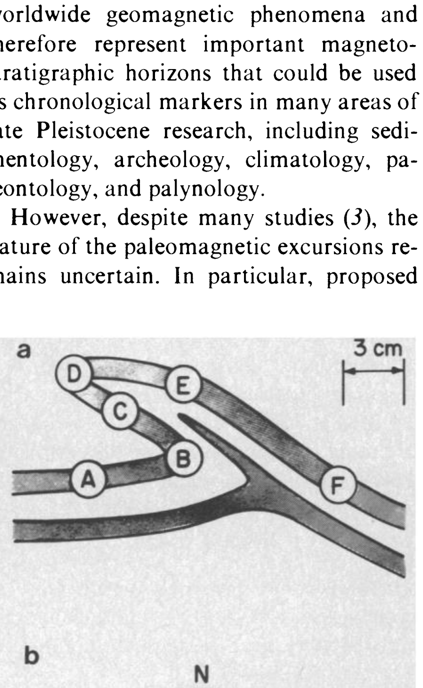

Fig. 1. (a) Vertical cross section showing the location of samples from a fold in varved sediment. The shaded portion represents the winter (clay) layer; the unshaded portion represents the summer (silt) layer. (b) Remanent magnetic directions of samples plotted on a stereographic projection. Samples were demagnetized in a 350-oersted alternating field.

The geomagnetic field is generated by a dynamo within the earth's core. If paleomagnetic excursions represent geomagnetic phenomena, they must arise from instability in the fluid motions of the core. In this case magnetic potential theory requires that paleomagnetic excursions have a coherent variation on a scale of at least several hundred to a thousand kilometers. We expect therefore that evidence for a paleomagnetic excursion should be internally consistent within sedimentary basins the size of lakes or small seas. Most anomalous paleomagnetic directions represent the results of a study of a single piston core from a given sedimentary basin. When multiple cores have been taken, the results have not always been internally consistent. For example, of 15 cores taken from the Gulf of Mexico (*4*), only eight appeared to record the excursion. More importantly, the magnetic signature, that is, the precise variation of declination and inclination, varied markedly from core to core.

Difficulties are also encountered when paleomagnetic excursions are examined for spatial consistency on a global scale. A set of paleomagnetic anomalies from northern and central Europe, eastern Canada, the Gulf of Mexico, and New Zealand, with dates clustering around 12,500 years before the present (B.P.), has been interpreted as a global geomagnetic fluctuation and has been named the Gothenburg flip (*1*). However, the event is apparently not recorded in sedimentary sequences of the same age in southern Europe (*5*), the Mediterranean Sea (*6*), and western North America (*7*).

Finally, there is a lack of temporal consistency in the ages of paleomagnetic excursions. In addition to the cluster of dates around 12,500 B.P., other excursions have been reported in the intervals 15,000 to 20,000 years B.P. (*8*), 24,000 to 25,000 years B.P. (*9*), 28,000 to 30,000 years B.P. (*10*), and 38,000 to 40,000 years B.P. (*11*).

If each of these represents a distinct excursion, then the geomagnetic field is much less stable than has been assumed in the past. Such a high degree of instability, extended back over geological time, would produce a paleomagnetic record far more complex than has been observed.

Thus the present evidence for globally coherent paleomagnetic excursions is not conclusive. In view of the problems with internal consistency as well as spatial and temporal consistency, it seems appropriate to consider alternate explanations for anomalous magnetic directions. One characteristic of the excursions reported in sedimentary sequences is that the samples have been obtained almost exclusively by piston coring. Only the excursion in the interval 24,000 to 25,000 years B.P. (*9*) represents a terrestrial sampling of a sediment sequence. In most cases it has not been possible to apply the standard paleomagnetic field tests for stability (*12*) to the sediments in which the excursions are found. I now present evidence to show how vitally important such a test can be to the question of paleomagnetic excursions.

I have been studying the remanent magnetism of sediments from now-drained glacial Lake Hitchcock in western New England. The sediments are studied in outcrop and consist of alternating layers of silt and clay. Each silt-clay couplet is called a varve and represents a single year of depositional history. The winter (clay) and summer (silt) layers are easily distinguished so that any postdepositional deformation of the sediment is readily apparent. The average rates of sediment accumulation in different parts of the lake ranged from 0.5 to 10.0 cm per year.

A paleomagnetic fold test (described below) was applied to two exposures of varved sediments. The first exposure in Chicopee, Massachusetts, consists of a 16-m sequence of 250 varves. All of the varves are flat-lying with the exception of a disturbed zone consisting of 15 varves in the middle of the sequence. Within the disturbed zone is a series of folds which developed shortly after deposition. A single varve was sampled along the fold as shown in Fig. 1a. In addition, suites of samples were taken from horizontal varves overlying and underlying the disturbed zone. Pilot studies indicated that the samples possessed a very stable remanent magnetization but that magnetic cleaning in a demagnetizing field of 350 oersteds was needed to remove viscous components which could alter the directions by at most 10°. In a typical varve overlying the zone the declination was 7.5° and the inclination was 53.2° (with a 95 percent cone of confidence of 2.4° and a precision parameter of 775 for six samples). In contrast to this

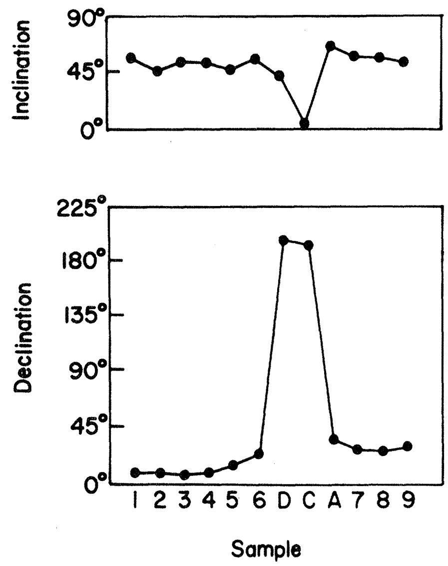

Fig. 2. Apparent paleomagnetic excursion obtained by an imaginary piston core through a fold including points D, C, and A of Fig. 1a.

tight clustering, the samples from the folded zone gave the scatter of directions shown in Fig. 1b. The axis of the fold was east-west, and "unfolding" the fold caused the points to cluster roughly around the direction found for the undisturbed varves. This is the paleomagnetic fold test of Graham (*13*), and from it I can conclude that the sediment was not remagnetized after deformation. The varve to which the fold test was applied was located five varves down from the top of the deformed zone. There was no evidence for an erosional unconformity between the deformed zone and the overlying horizontal varves. I conclude that the deformation occurred 5 years after the varve in question was deposited. Hence the remanence was already locked in the sediment 5 years after deposition.

At a second site, in South Deerfield, Massachusetts, a deformed zone with a north-south axis of folding also produced a scatter in the remanent magnetic directions. Using the variation in the thickness of the varves in the sequence (*14*), I could correlate with two other sites in which there was no disturbed zone. From this correlation, I can conclude that the deformed zone incorporated material that had been deposited at most 3 years before deformation. Thus the remanent magnetism of these glacial lake sediments is either true depositional remanence or postdepositional remanence acquired within a very few years.

In contrast to this situation, in the slow-depositional environment of the deep sea, the presence of bioturbation (*15*) precludes true depositional remanent magnetization. Laboratory experiments (*16*) have shown that postdepositional magnetization is a feasible mechanism. The actual process is probably very complex and dependent upon bioturbation, water content, rate of deposition, and subsequent diagenesis. The lock-in time for the remanence may be hundreds or even thousands of years (*17*). In such a case postdepositional deformation would have little effect on the remanent magnetism due to subsequent remagnetization. It has been generally assumed that this situation prevails in all sedimentary environments. The results presented here demonstrate that the acquisition of remanence in environments with high sedimentation rates may be distinctly different from that in environments that are characterized by low sedimentation rates and subjected to bioturbation and slow dewatering (*18*).

I have shown that, in some sedimentary environments, the sediments will not be remagnetized after deformation. The implication of this conclusion for paleomagnetic excursions is significant. If a deformation in the sediments is obscured because the sediment is not laminated or if the sediment is sampled by coring and the deformed structures are not recognized, then an anomalous remanent magnetic direction will be observed. For example, let us assume that the site at Chicopee, Massachusetts, is sampled from above by a piston corer and that the core includes points D, C, and A of Fig. 1a as well as overlying and underlying horizontal varves. The remanent magnetism shown in Fig. 2 would be observed. Now let us assume either that the sediments are homogeneous rather than varved or that the core is not large enough to reveal the fold. The results might then be erroneously interpreted as a paleomagnetic excursion characterized by a 180° fluctuation in declination accompanied by a sharp reduction in inclination. Clearly other types of folds and orientations of fold axes can be combined to mimic any observed excursion. Cores through different portions of the same deformed zone will record the spurious excursion with a variety of magnetic signatures.

The spurious paleomagnetic excursion described above should serve to sound a note of caution. Not every set of anomalous paleomagnetic directions represents a genuine, large-scale geomagnetic field fluctuation (*19*). Sedimentary environments are susceptible to deformation and disturbance on a scale ranging from centimeters to kilometers. Among possible mechanisms are seismic activity, turbidity flows, density currents, and glacial and periglacial activity. In environments characterized by depositional remanence or rapidly acquired postdepositional remanence, these deformations can produce a paleomagnetic record that can be misinterpreted as an excursion. Genuine global paleomagnetic excursions can only be confirmed by evidence of spatial, temporal, and internal consistency in replicate cores or sampled sections from each of several areas. Until such evidence is available, it is premature to advocate the use of paleomagnetic excursions as magnetostratigraphic horizons.

KENNETH L. VEROSUB*

Departments of Geology and Physics, Amherst College, Amherst, Massachusetts 01002

References and Notes

1. N. A. Morner and J. P. Lanser, *Nature (Lond.)* **251**, 408 (1974).
2. M. Noel and D. H. Tarling, *ibid.* **253**, 705 (1975).
3. A complete review of all reported paleomagnetic excursions would require knowledge of the type of sediment sampled, the method of sampling, the signature of the excursion, the age and duration of the excursion, and the age and duration of overlying and underlying normal intervals. Such a review is not possible at present. Many reports are available only as abstracts of papers presented at meetings. In a few cases information has been disseminated solely as "personal communications" to other authors.
4. H. C. Clark and J. P. Kennett, *Earth Planet. Sci. Lett.* **19**, 267 (1973).
5. K. M. Creer, *ibid.* **23**, 34 (1974).
6. N. D. Opdyke, D. Ninkovich, W. Lowrie, J. D. Hays, *ibid.* **14**, 145 (1972).
7. J. C. Liddicoat and R. S. Coe, *Eos Trans. Am. Geophys. Union* **54**, 1075 (1973); *ibid.* **55**, 1109 (1974).
8. R. Nakajima, K. Yaskawa, N. Natsuhara, N. Kawai, S. Horie, *Nature (Lond.)* **244**, 8 (1973); K. L. Othburg, *EOS Trans. Am. Geophys. Union* **54**, 1075 (1973).
9. C. R. Denham and A. V. Cox, *Earth Planet. Sci. Lett.* **13**, 181 (1971).
10. M. Barbetti and M. W. McElhinny, *Nature (Lond.)* **239**, 327 (1972).
11. N. D. Opdyke, N. J. Shackleton, J. D. Hays, *EOS Trans. Am. Geophys. Union* **55**, 237 (1974).
12. M. W. McElhinny, *Paleomagnetism and Plate Tectonics* (Cambridge Univ. Press, London, 1973), pp. 83–89.
13. J. W. Graham, *J. Geophys. Res.* **54**, 131 (1954).
14. E. Antevs, *Am. Geogr. Soc. Res. Ser.* **11**, 1 (1922).
15. N. D. Watkins, *Earth Planet. Sci. Lett.* **4**, 341 (1968).
16. D. V. Kent, *Nature (Lond.)* **246**, 32 (1973); R. Løvlie, *Earth Planet. Sci. Lett.* **21**, 315 (1974).
17. J. Dymond, *Earth Planet. Sci. Lett.* **6**, 9 (1969).
18. An intermediate case of 50 percent remagnetization in a fold has been reported by N. Niitsuma, International Union of Geological Sciences International Geological Correlation Program Conference on Late Cenozoic Magnetostratigraphy, Tokyo and Otsu, Japan, 1974.
19. The importance of the "reinforcement syndrome" [N. D. Watkins, *Geol. Soc. Am. Bull.* **83**, 551 (1972)] should not be underestimated. The initial report of a paleomagnetic excursion will encourage other workers to reexamine previously unexplained or disregarded "curious" results and to reinterpret sedimentation rates so that the anomalous behavior seen by them is contemporaneous with the paleomagnetic excursion. Subsequent work will also focus on sediments of the same age. Reported excursions will then tend to cluster around a single date, whereas negative results showing no anomalous behavior will tend to remain unpublished because they are "not interesting." Thus the initial reports exert considerable leverage on the direction of future research.
20. Supported by NSF grant GA-43344. I thank Dr. C. E. Helsley and his colleagues at the University of Texas-Dallas and Dr. J. deBoer at Wesleyan University for the use of their paleomagnetic facilities. I thank Dr. C. R. Denham for useful criticisms of the manuscript.
* Present address: Department of Geology, University of California, Davis 95616.

24 March 1975

Greenhouse Effect Due to Chlorofluorocarbons: Climatic Implications

Abstract. *The infrared bands of chlorofluorocarbons and chlorocarbons enhance the atmospheric greenhouse effect. This enhancement may lead to an appreciable increase in the global surface temperature if the atmospheric concentrations of these compounds reach values of the order of 2 parts per billion.*

It has recently been suggested (*1, 2*) that atmospheric concentrations of chlorofluorocarbons (CF_2Cl_2 and $CFCl_3$) may increase by as much as 20 to 30 times the present-day value, 0.1 part per billion (ppb) by volume, if the present level of injection into the atmosphere is maintained. The primary reason for this expected buildup seems to be the lack of any significant tropospheric removal mechanisms for these compounds. In addition, Lovelock's (*3*) recent measurements indicate substantial concentrations ($\approx$ 0.1 ppb) of CCl_4 within the troposphere, and Lovelock suggests the presence of other chlorocarbons ($CHCl_3$, CH_3Cl, and CH_2Cl_2) within the atmosphere. The consequences of a significant buildup of these compounds for the chemical balance of the atmosphere has already been investigated (*1, 2, 4*). In this report I examine another important aspect of the problem, the impact on the overall thermal energy balance of the earth-atmosphere system due to a significant buildup in the concentrations of the chlorofluorocarbons and chlorocarbons.

The chlorofluorocarbons and chlorocarbons have strong infrared bands (*5–8*). The infrared bands of these compounds would absorb radiation from the surface and emit it at the atmospheric temperature. Since the atmosphere is at a lower temperature than the earth's surface, these bands would cause a reduction in the net infrared radiative flux (F, watts per square meter) emitted to space by the earth-atmosphere system. This trapping of the surface radiation by the infrared bands, also known as the greenhouse effect, would tend to increase the surface and atmospheric temperature. The strongest bands of these compounds are located in the spectral region 8 to 13 μm where the atmosphere is relatively transparent. Because of this relative transparency, the atmospheric and surface temperatures are most sensitive to constituents that have absorption bands in this spectral region. In order to estimate the increase in the surface temperature (T_s), the reduction in F due to the infrared bands of the chlorofluorocarbons and chlorocarbons is computed first. The procedure for the flux calculation is described only for chlorofluorocarbon bands since the same procedure can be applied to the chlorocarbon bands.

Table 1. Chlorofluorocarbon band positions and intensities.

Species	Band: Assignment	Band: Center (μm)	Band: Intensity (cm/mole)	Reference
CF_2Cl_2	ν_1	9.132	2.98×10^7	(*5*)
	ν_6	8.681	2.0×10^7	(*5*)
	ν_8	10.93	3.07×10^7	(*5*)
$CFCl_3$	ν_1	9.217	1.75×10^7	(*6*)
	ν_4	11.82	3.75×10^7	(*6*)

For this analysis I consider only bands in the region 8 to 12 μm, since these bands are stronger by two orders of magnitude than bands located elsewhere in the infrared spectrum (*5–8*). Table 1 shows the band centers and intensities. Radiative transfer within infrared bands can be conveniently formulated in terms of the total band absorptance, A (reciprocal centimeters) (*9, 10*). This is the total spectrally integrated absorption by the band, and for the present analysis the bands are optically thin (*11*), so A can be written as

$$A = SX \qquad (1)$$

where S is the band intensity and X is the amount of absorber. The formulation of F in terms of A is given by Cess and Ramanathan (*9*). Pertinent details of the flux calculations are given in (*12*).

The model atmosphere—that is, the vertical distribution of temperature, H_2O, and clouds—is adopted from Rasool and Schneider (*13*) and reflects the present-day globally averaged conditions. The mixing ratio, q, of CF_2Cl_2 and $CFCl_3$ is prescribed by

$$\begin{aligned} q &= K; & 0 \leqslant z \leqslant 12 \text{ km} \\ &= K\exp[(12 - z)/H]; & z > 12 \text{ km} \\ && H = 3 \text{ km} \qquad (2) \end{aligned}$$

where z is the altitude with $z = 0$ denoting the surface, H is the prescribed scale height, and K is the tropospheric mixing ratio (parts per billion, by volume) which has been assumed constant. The shape of the mixing ratio profile given by Eq. 2 is consistent with the model predictions of Cicerone *et al.* (*2*).

When Eqs. 1 and 2 are combined with