multaneous, spatial sensor arrays, such as the one described here, in conjunction with detailed process and stratigraphic studies of lacustrine environments, should provide such information and improve our understanding of the general laws of motion governing density currents and their deposits.

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References and Notes

1. General summaries of studies undertaken may be found in: V. A. Vanoni, Ed., *Sedimentation Engineering* (Report 54, American Society of Civil Engineers, New York, 1975), pp. 278–285; G. V. Middleton and M. A. Hampton, in *Marine Sediment Transport and Environmental Management*, D. J. Stanley and D. J. P. Swift, Eds. (Wiley, New York, 1976), pp. 197–218; J. S. Simpson, *Annu. Rev. Fluid Mech* **14**, 213 (1982); W. E. Galloway and D. K. Hobday, *Terrigenous Clastic Depositional Systems* (Springer-Verlag, New York, 1983), pp. 168–175 and 185–201; J. R. L. Allen, *Sedimentary Structures: Their Character and Physical Basis*, vol. 1, *Developments in Sedimentology 30A* (Elsevier, New York, 1982), pp. 47–56.
2. W. R. Normark, *Bull. Am. Assoc. Pet. Geol.* **62**, 549 (1978).
3. S. D. Ludlam, *Limnol. Oceanogr.* **12**, 618 (1967); F. P. Agterberg and I. Banerjee, *Can. J. Earth Sci.* **6**, 625 (1969); I Banerjee, *Geol. Surv. Can. Bull.* (Part A) **226**, 1 (1974); S. D. Ludlam, *Limnol. Oceanogr.* **19**, 656 (1974); D. Mankiewicz, *J. Sediment. Petrol.* **45**, 462 (1975); S. S. Harrison, *ibid.* **43**, 738 (1975); G. M. Ashley, *Soc. Econ. Paleontol. Mineral. Spec. Publ. 23* (1975), p. 304; W. H. Theakstone, *Sedimentology* **23**, 671 (1976); A. Lambert and K. J. Hsu, *ibid.* **26**, 453 (1979); R. A. Pickrill and J. Irwin, *ibid.* **30**, 63 (1983).
4. T. C. Gustavson, *Soc. Econ. Paleontol. Mineral. Spec. Publ. 23* (1975), pp. 249–263; A. M. Lambert, K. R. Kelts, N. F. Marshall, *Sedimentology* **23**, 87 (1976); N. D. Smith, *Can. J. Earth Sci.* **15**, 741 (1978); M. Sturm and A. Matter, in *Modern and Ancient Lake Sediments*, A. Matter and M. E. Tucker, Eds. (Special Publication No. 2, International Association of Sedimentologists, Liége, Belgium, 1978), pp. 147–168; R. Gilbert and J. Shaw, *Can. J. Earth Sci.* **18**, 81 (1981); N. D. Smith, *Arct. Alp. Res.* **13**, 75 (1981); J. Irwin and R. A. Pickrill, *N.Z. J. Mar. Freshwater Res.* **16**, 189 (1982).
5. W. R. Normark and F. H. Dickson, *Sedimentology* **23**, 815 (1976).
6. This work was funded by the National Research Council of Canada and the Canadian Department of Energy, Mines, and Resources. The loan of equipment by D. C. Ford and J. A. Davies of the Department of Geography at McMaster University; B. Goodison of the Canadian Atmospheric Environment Service; the Environmental Institute of the University of Toronto; and the Department of Geography of the University of Toronto is gratefully acknowledged. The support and encouragement of A. V. Jopling of the Department of Geography of the University of Toronto was crucial to the conduct of this work.

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Congruent Paleomagnetic and Archeomagnetic Records from the Western United States: A.D. 750 to 1450

Abstract. *Two independently dated, high-resolution paleomagnetic records, one lacustrine and one archeological, record the passage across western North America of the same nondipole feature of the geomagnetic field during the time interval from A.D. 750 to 1450. Although these sequences indicate that correlation between paleomagnetic and archeomagnetic records is feasible under certain conditions, differences between the records underscore the difficulty of dating accurately an archeological site by correlation of a single archeomagnetic direction with a secular variation curve.*

Since the first paleomagnetic measurements of varved sediments from western New England were reported (*1*), the study of fine-grained lacustrine sediments has held the promise of providing long, continuous histories of the geomagnetic field and, eventually, a master curve to which shorter archeomagnetic records could be compared. It has also been suggested that the age of an undated archeological site or lava flow might be determined by correlating its paleomagnetic direction to a master curve of secular variation. However, the correspondence between paleomagnetic features observed in lacustrine sediments and contemporaneous archeomagnetic records has been disappointing; only the broadest trends in lacustrine records have been correlated to the archeomagnetic data (*2, 3*).

We have compared two independently dated, high-resolution paleomagnetic records from western North America, one lacustrine and one archeological, and have found that they contain the same nondipole feature of the geomagnetic field during a 700-year interval. The lacustrine record is from Fish Lake, a small lake in Steens Mountain of southeastern Oregon. The record is part of a 8.93-m composite section composed of nine overlapping 10-cm diameter cores representing a total length of 16 m and spanning the last 13,000 radiocarbon years before the present (B.P.). The presence of six tephra layers and other thin, distinctive bands allowed us to align the overlapping segments of different cores with an uncertainty of less than 0.3 cm. Age control for the composite section came from 18 radiocarbon dates from the Fish Lake cores as well as 19 radiocarbon dates from two nearby lakes containing the same tephra layers (*4*). Two of these tephra layers are from Mount Mazama (Crater Lake) Oregon (*5, 6*).

Core samples were collected in plastic boxes (2.5 by 2.5 by 1.8 cm) which were placed as close together as possible to obtain a nearly continuous record. Each box was fully oriented with respect to the axis of the core segment. Magnetic analyses indicated that the magnetic carrier was pseudo–single-domain magnetite with no hematitic component. This was not surprising because most detritus coming into Fish Lake is derived from Miocene basalt. Upon alternating field demagnetization the paleomagnetic directions were found to be extremely stable, and the intensities had median destructive fields of 200 oersteds.

The declination record from the two core segments that span the interval from 450 years B.P. to 3500 years B.P. (A.D. 1450 to 1950 B.C.) is shown in Fig. 1. Unlike many other paleomagnetic records from lake sediments, the Fish Lake record has low scatter and a high degree of serial correlation within each core as well as excellent agreement between the corresponding segments of different cores. Although the cores were not azimuthally oriented, the overlap and precise stratigraphic correlation between the cores made it possible to align them, one with another, to obtain a single (unoriented) composite record. The absolute orientation of this composite record was then determined by matching the declination at the level of the upper of the two Mazama tephras in the composite core with the declination of the corresponding Mazama tephra measured in the field at various sites in Oregon (*7*). Various checks for consistency showed that the cores had penetrated the sediment vertically and had not twisted during penetration.

Comparison of the inclination at the level of the upper Mazama tephra in the composite section with the inclination measured in the field as well as comparison of the inclination at the top of the core with the corresponding inclination determined from historical records showed that there was an inclination error in the lake sediments. From observations of sediment grain size and the absence of apparent bioturbation, this error was to be expected (*8*), and the composite record was corrected for it. The data were then combined and smoothed by a Gaussian weighting function corresponding to an 80-year moving "window" (*9*). The virtual geomagnetic poles (VGP's) corresponding to the smoothed and corrected data for the time interval A.D. 600 to 1450 are shown in Fig. 2A.

The archeomagnetic record for the interval A.D. 750 to 1450 was developed by Sternberg from archeological sites in the southwestern United States (*10*). His sequence is based on 73 independently

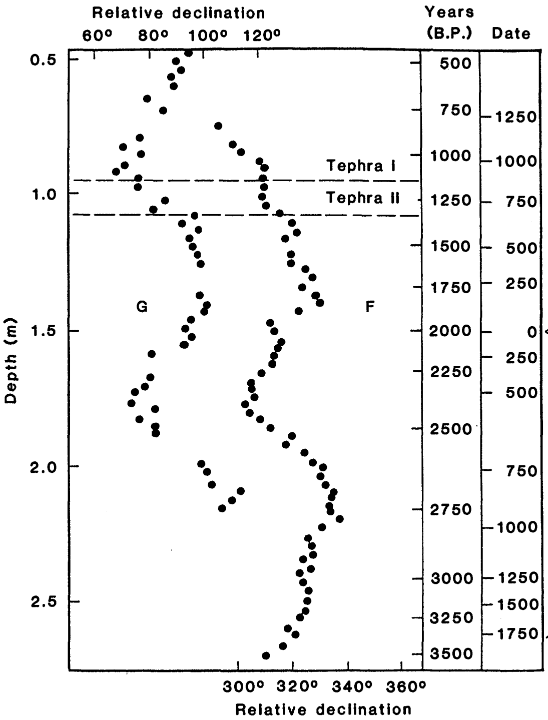

Fig. 1. Declination record of two cores (F and G) from Fish Lake, Steens Mountain, Oregon, spanning the interval from 450 years B.P. to 3500 years B.P. (A.D. 1450 to 1950 B.C.). The samples have been demagnetized in an alternating field of 200 oersteds. Because the cores were not azimuthally oriented, only relative values of declination could be determined initially. The nonlinear relation between radiocarbon years and depth is caused by variations in sedimentation rate which can be resolved from the 37 radiocarbon dates. For the calendar dates, the nonlinearity is compounded by variations in the radiocarbon calibration curve (*14*).

dated features (mainly hearths), and the primary dating technique was dendrochronology. The VGP's corresponding to each feature were combined by a moving-window weighted Fisher statistic technique (*11*). A 100-year window was used before A.D. 1000 and a 50-year window was used after that time. The resulting VGP path is shown in Fig. 2B. The windows represented by successive points overlap by 50 percent. Cones of 95 percent confidence for points more recent than A.D. 1100 are about 1.5°; those for points between A.D. 1000 and 1100 are about 2.5°, and those for points older than A.D. 1000 are about 4° (*10*).

The two VGP paths appear to record the passage of the same nondipole feature of the geomagnetic field. For the lacustrine record, the path of the feature begins near the geographic North Pole and moves southward toward the 180° meridian along an arc that is concave toward the west. After a relatively tight turn near 75°N latitude and 170°W longitude, the path follows along another arc that is concave in the opposite direction. The path ends near 85°N and 90°W. All the motion is generally clockwise, which is consistent with that observed for the past 8000 years in North America (*12*).

With respect to the lacustrine sediments, the archeological record appears to be translated toward the south and rotated slightly counterclockwise. Such a displacement might be expected since a well-defined westward-drifting center of nondipole activity with a diameter on the order of 1200 km would not be seen in the same way at sites with a north-south separation of 900 km. In addition, the center of activity would be a dynamic feature of the geomagnetic field so that as it drifted across the western United States, its evolution through time would lead to additional variations in direction and timing from one observation point to another. Some displacement may also be caused by uncertainties inherent in the correction for the inclination error and the determination of the absolute declination. With these factors taken into account, the overall agreement between the two curves appears to be better than that between any other published pair of records.

An analysis of the details of the agreement is more difficult because of the uncertainties associated with each data point. For example, the radiocarbon calibration curve allows us to convert each radiocarbon date only to a range of calendar dates. The dendrochronological age of an archeological dwelling may represent its initial construction or repair, whereas the paleomagnetic direction from an associated hearth may represent the last fire that burned in that hearth. Thus, the tree ring age could represent the earliest occupation of a site, and the paleomagnetic direction, the latest occupation. Also, there is the statistical uncertainty associated with each paleomagnetic direction. Within the constraints of these uncertainties, the detailed agreement between the two curves is excellent. In Fig. 2A, the age ranges shown correspond to the end, crossover point, turning point, and beginning of the corresponding archeomagnetic VGP path. The archeomagnetic ages of these points are A.D. 1400, 1300, 1025, and 750, respectively. For the first three points the age range in Fig. 2A includes the corresponding archeomagnetic date in Fig. 2B. Only the fourth point is discordant because of the large change in the archeological pole path occurring between A.D. 1000 and 1025. It is possible that this change does not represent actual motion of the geomagnetic vector and arises instead from a systematic offset in sites with ages earlier than A.D. 1000 (*13*). On the other hand, the lacustrine record also begins with a significant change in pole position so that both changes may reflect rapid evolution of the center of nondipole activity as noted earlier. Minor fluctuations in the sedimentation rate at Fish Lake or a systematic error in radiocarbon dating could also cause these apparent differences. In view of these uncertainties, we

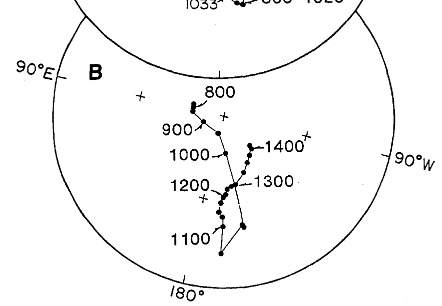

Fig. 2. Stereographic projections of paths of virtual geomagnetic poles from the western United States. The bounding circle is 20° from the pole. (A) Paleomagnetic record from Fish Lake, southeastern Oregon, for the interval from A.D. 600 to 1450. The arrows mark calendar ages at intervals of 100 radiocarbon years beginning with 1400 years B.P. for the arrow nearest the geographic pole. The corresponding calendar age ranges (*14*) are shown for the beginning, turning point, crossover point, and end of the VGP feature. For the other points, only the midpoints of the calendar age ranges are given. (B) Archeomagnetic record from sites in the southwestern United States for the interval from A.D. 750 to 1450 (*9*). This stereographic projection has been rotated clockwise 15° to emphasize the similarity between the shapes of the paths.

consider the close agreement in space between the VGP paths to be far more significant than the partial discrepancy in time between the paths.

The presence of the same feature of the geomagnetic field in independently dated paleomagnetic and archeomagnetic records indicates that correlation of paleomagnetic and archeomagnetic records is feasible when certain conditions are met for both types of records. For lake sediments, the minimum conditions require the collection of overlapping cores that can be dated independently and correlated precisely as well as the measurement of closely spaced paleomagnetic samples that can be shown to contain a stable magnetic signal in which the geomagnetic field has been accurately recorded. For archeomagnetic studies, there must be sufficient sites to provide a record of accurate directions from many samples extending over several hundred years. In addition, during the time interval of interest, there must be some distinct feature in the VGP path of the geomagnetic field. These conditions imply that it is possible to correlate only between features in paleomagnetic and archeomagnetic VGP paths and that, in general, it is not yet possible to determine the age of an undated archeological site or an undated lava flow from a single paleomagnetic direction associated with the site or the flow.

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References and Notes

1. E. A. Johnson, T. Murphy, O. W. Torreson, *Terr. Magn. Atmos. Electr.* **53**, 349 (1948).
2. C. E. Barton and M. Barbetti, *Earth Planet. Sci. Lett.* **59**, 375 (1982).
3. M. Kovacheva, *Philos. Trans. R. Soc. London Ser. A* **306**, 79 (1982).
4. P. Mehringer, Jr., J. Sheppard, L. Kittleman, C. Knowles, in preparation.
5. C. R. Bacon, *J. Volcanol. Geotherm. Res.*, in press.
6. E. Blinman, P. J. Mehringer, Jr., J. C. Sheppard, in *Volcanic Activity and Human Ecology*, P. D. Sheets and D. K. Grayson, Eds. (Academic Press, New York, 1979), pp. 393–425.
7. D. Champion, personal communication.
8. M. A. Payne and K. L. Verosub, *Geophys. J.* **68**, 625 (1982).
9. The smoothing was done with a seven-point weighted vector mean in which the primary contribution came from the three central points. The weighting factors were 0.037, 0.230, 0.692, 1.000, 0.692, 0.230, and 0.037, and they correspond to a Gaussian filter [J. L. Holloway, *Adv. Geophys*, **4**, 351 (1958)]. The average time interval spanned by the three central points was 79.6 years, with a standard deviation of 22.4 years.
10. R. S. Sternberg, in *Geomagnetism of Baked Clays and Recent Sediments*, K. M. Creer, P. Tucholka, C. E. Barton, Eds. (Elsevier, Amsterdam, 1983), pp. 158–167.
11. R. S. Sternberg and R. H. McGuire, *Eos* **62**, 852 (1981).
12. K. M. Creer and P. Tucholka, *Philos. Trans. R. Soc. London Ser. A* **306**, 87 (1982).
13. The difference in VGP between the moving window centered at A.D. 1000 and the one centered at A.D. 1025 is 8.9°. This difference corresponds to a rate of change of VGP position of 0.36° per year, which is 30 times greater than the average rate for the Holocene and 6 times greater than the fastest observed rate (R. Thompson, *ibid.*, p. 103). Furthermore, this difference in VGP is greater than the sum of the cone of 95 percent confidence of the pole position for A.D. 1000, which is 4.4°, and that of the pole position for A.D. 1025, which is 3.2° (*9*). Thus the cones do not overlap even though the pole position for A.D. 1000 is determined from sites dated between A.D. 950 and 1050 and that for A.D. 1025 is determined from sites dated between A.D. 1000 and 1050.
14. J. Klein, J. C. Lerman, P. E. Damon, E. K. Ralph, *Radiocarbon* **24**, 103 (1982).
15. We thank D. Champion for paleomagnetic data on the Mazama tephra; J. C. Sheppard for radiocarbon dates; R. Sternberg for a preprint of his paper; K. L. Petersen, P. E. Wigand, and R. Negrini for assistance in sampling cores; and P. Waterstraat for computer programs to analyze the data. Supported in part by NSF grants EAR 78-23559, EAR-82-13332, BNS-77-12556, and BNS-80-06277.

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Initiation of Angiogenesis by Human Follicular Fluid

Abstract. *Angiogenesis was observed and measured after injection of human follicular fluid into rabbit corneas. Undiluted human follicular fluid stimulated angiogenesis in every case, with new blood vessels visible 3 days after injection and extending 2.0 millimeters from the corneal scleral limbus into the injection site by day 15. Stimulation of angiogenesis was lost by heating or diluting the follicular fluid but was retained after charcoal stripping or dialysis. Human follicular fluid contains an angiogenic factor that may be associated with perifollicular neovascularization during folliculogenesis.*

Angiogenesis plays a major role in a variety of important biological processes, including wound healing, collateral circulation, tumor growth, and embryonic development. Angiogenesis also occurs during maturation of the preovulatory follicle and subsequent formation of the corpus luteum, suggesting that the follicle complex may produce an angiogenic factor. Here we report the presence of an angiogenic factor in human follicular fluid (hFF).

Human follicular fluid was pooled from follicles (> 16 mm; N = 30) in 12 spontaneously cycling women 16 days after the onset of menses. The women had been treated with clomiphene citrate (days 5 to 9), luteinizing and follicle-stimulating hormones (150 IU/day; days 10 to 14), and human chorionic gonadotropin (hCG) (5000 IU; day 16). Each hFF sample was mixed with an equal volume of a solution containing 10 percent Hydron, 60 percent ethanol, and 1 percent polyethylene glycol. The hFF was sterile-filtered and serially diluted (1:0, 1:2, 1:3, 1:4, 1:9, and 1:27) with phosphate-buffered saline (0.05M; pH 7.4) for dose-response studies. The supernatant (600g for 30 minutes) of hFF treated in 10 percent dextran-coated charcoal (24 hours at 4°C) and the retentate of dialyzed (molecular weight cutoff, 8000) or heated (62°C) hFF were also tested (20 μl).

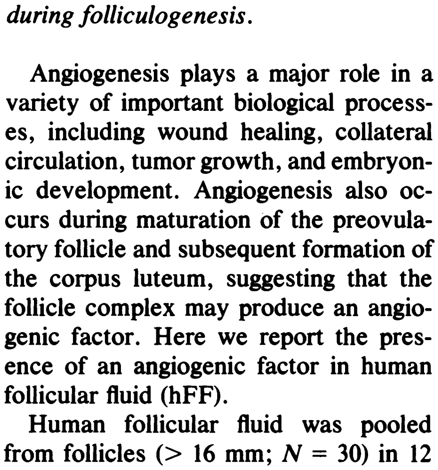

Fig. 1. Angiogenesis 12 days after injection of hFF into the cornea of a rabbit eye. Vascularization extends across the sclera and 2 mm into the cornea.

The effects of the hFF-Hydron solution on angiogenesis were assessed in 44 New Zealand White female rabbits (1.5 to 2 kg) anesthetized with ketamine hydrochloride (20 mg/kg, intravenously). A 20-μl portion of the solution was introduced into the right cornea by aseptically creating a pocket 2 mm proximal to the superior limbus (*1*). To evaluate the effects of hCG at concentrations typically found in follicular fluid after hCG treatment, 20 μl of a solution of hCG (1 mIU/ml) and Hydron was similarly injected into the cornea of three New Zealand White female rabbits. The left cornea of each animal was injected with Hydron and saline as a control.

Corneas were evaluated daily for 15 days. Sustained growth of well-defined new capillaries from the limbus toward or into the corneal implant was considered a positive angiogenic response (Fig. 1). Responses were graded qualitatively as follows: 0, no angiogenesis; 1, plexus of blood vessels seen at the limbus; 2, intracorneal vessels present; 3, intracorneal vessels extending more than 1.0 mm from the limbus toward the injection site;