Geomagnetic Oscillations and Excursions and Upper Pleistocene Chronology

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The global character of geomagnetic reversals throughout geological time enables them to be used as parameters for correlation and chronology. The most accurate application to date of magnetostratigraphy has been in the study of the late Cenozoic, especially through the palaeomagnetic record of lake sediments. This article reviews the approach used in determining secular variations and oscillations and presents new data from France for the past 30,000 years.

Introduction

The geomagnetic polarity time scale for the last 5 Ma is based on reliable chronological and palaeomagnetic data obtained from many lava flows sampled all over the world. However, the frequency of reversals is inadequate for high resolution stratigraphy and chronology in the Middle and Upper Pleistocene. Some events of short duration have been pointed out in the Brunhes epoch (0.73 Ma to the present) though they need to be confirmed, but the most recent development in magnetostratigraphy is the study of high frequency markers: geomagnetic secular variations and excursions.

Analysis of magnetic vectors involves the use of instruments such as the cryogenic magnetometer. Samples are inserted between sensors that have been cooled down to the critical temperature at which, in the absence of a magnetic field, they become superconducting. The flux change created by the sample induces a circulating current that can be analysed for each of the sample axes to yield the orthogonal components X, Y, and Z, which characterize the magnetic moment of the sample.

Depositional Remanent Magnetization is acquired during deposition of sediments as magnetic grains align themselves with the Earth's magnetic field; realignments that originate during compaction constitute Postdepositional Remanent Magnetization. Comparison between the palaeomagnetic record of recent lake sediments and archaeomagnetic data clearly indicates that the Depositional and Postdepositional Remanent Magnetizations are reliable processes in recording short period (1,000–5,000 year) geomagnetic variations.

Palaeo-secular variations are attributed to non-dipolar components of the geomagnetic field, which are assumed to be generated by sources located in the outer core near its

boundary with the mantle. Although the number and the behaviour of these sources are still speculative, the analysis of the shape of the declination and inclination curves, and the comparison between type curves computed for different regions allows the secular variations to be modelled in terms of drifting and oscillating sources with an overall westward drift (Creer and Tucholka, 1983; Creer, 1983).

Secular Variations and Excursions as Chronostratigraphic References

The most complete and precise curves yet defined describe secular variations over the last 20,000 years for western Europe (Creer, 1974; Creer et al., 1980), North America (Dodson, Fuller, Kean, 1977), South America (Creer et al., 1983) and Australia (Barton and McElhinny, 1981). Correlation between records that show regular oscillations without any characteristic feature can be drawn from counting successive cycles. Of course, if very specific features are recognized in curves from different sites, these can be used as magnetostratigraphic markers.

Figure 1: Regional geology of the Massif Central, showing the location of Lac du Bouchet and Puy de Laschamp.

Inclination curves obtained for Europe and North America have identical shapes, but when chronological controls are applied, a systematic phase shift appears with the inclination peaks occurring in America 300-450 years later than in Europe. This shift is due to the westward drift of the non-dipole field sources at a rate of 0.24 degrees per year, and when this is taken in account, correlations can be made possible between distant regions. In contrast, curves obtained from South America and Australia show no similarity between these two regions, or with the northern hemisphere curves.

Geomagnetic excursions are frequently reported from palaeomagnetic studies of Upper Pleistocene lavas and sediments. They consist of large departures (more than 40°) of the Virtual Geomagnetic Pole (computed from the directional parameters of the mean remanent magnetization and the geographical coordinates of the site) from the geographical pole without complete reversal.

One of the first excursions discovered was detected by Bonhommet and Babkine (1967) in the Laschamp and Olby lava flows of the Chaîne des Puys in the Massif Central of France (Fig. 1). The Laschamp excursion has been dated by thermoluminescence, K/Ar and U/Th techniques between 30,000 and 50,000 yBP (Guerin et al., in press). Since the Olby flow is 3,000 to 10,000 years older than the Laschamp, the excursion might have been a unique one lasting a few thousands of years, or the data may represent two successive excursions separated by a similar period of time. However, no excursion or event has been seriously confirmed elsewhere during the 30,000-50,000 year interval, and the existence of the excursion has been contested after thermal experiments showed self reversal behaviour in samples of the two flows. This suggests that the reverse direction of magnetization may not reflect the geomagnetic field direction during the cooling of the lava but may rather be due to special proper-

Figure 2: Variations in declinations and inclination of the geomagnetic field recorded in Core BS from Lac du Bouchet. Each sample gives one declination and one inclination value. Full lines are fitted curves computed using 50 equally spaced knots along the depth scale; each knot represents 10 samples.

ties of the rock's magnetic domains (Heller and Petersen, 1982). This controversy will remain open until the directions of magnetization in continuous sedimentary formations of the same age are studied in detail.

The second well known excursion occurs at Mono Lake, California (Liddicoat and Coe, 1979) and is dated at around 24,000 yBP. Similar patterns have also been found at other sites in Nevada and Oregon (Negrini et al., 1984), though other studies of contemporaneous sequences in the west-central U.S.A. show no indication of this excursion.

Since what appear as magnetic excursions could result from sedimentological disturbances, burrowing or even deformation, their reliability must be proved by many tests on continuous sections of the same age and showing sufficiently high sedimentation rates to record any excursion. The existence of an excursion can be neither affirmed nor denied from the study of only one or two cores.

The question, therefore, is whether geomagnetic excursions have global or regional effects. If they result from perturbations of the local non-dipolar field due to one or two sources, they can be assigned to large-amplitude secular variations with no more than a regional chronostratigraphic significance.

Recent Results Obtained in Western Europe

After preliminary study on 6 m sedimentary cores (Bonifay et al., in press) a detailed record of geomagnetic secular variations from over the last 30,000 years has now been

Figure 3: Comparison of the inclination curves recorded at Lac du Bouchet and Meerfelder Maar (Germany). Minima and maxima are labelled 1 to 13. The similarity between the two curves permits Meerfelder Maar to be calibrated according to the dates obtained for Lac du Bouchet.

obtained from 9 m cores collected from Lac du Bouchet, a maar lake in the Massif Central. Chronological control was given by five ^{14}C dates and five palynological markers. The inclination pattern shows a characteristic succession of large amplitude (40° peak to peak) oscillations from 17,000 to 12,000 yBP occurring at the same time as large amplitude (50° peak to peak) declination oscillations (Fig. 2). This specific pattern of secular variation has also been found at other European sites: Black Sea (Creer, 1974), Lac de Joux, Switzerland (Creer et al., 1980), and Meerfelder Maar, Germany (Haverkamp, 1984). In the last case the shape of the inclination feature is remarkably similar to that found at Lac du Bouchet (Fig. 3). This obvious correlation is the best evidence that we are dealing with a geomagnetic signature, which can clearly be used as a regional magneto-stratigraphic marker. Precise time control even permits its use as a chronological reference.

The European records do not show any succession of anomalous directions assignable to a geomagnetic excursion in the time interval 0-30,000 yBP. The Mono Lake excursion cannot therefore be considered as a global geomagnetic

event. The Lac du Bouchet sediments are, however, appropriate for studying the 30,000-50,000 yBP Laschamp excursion. An excursion recorded in the Chaîne des Puys would have been necessarily recorded at a 100 km distant site like Lac du Bouchet. Its duration was certainly long enough to be recorded by sediments deposited with an average rate of about 0.3 mm/yr. The study of 12-meter cores collected in Lac du Bouchet in April 1985 is now underway and should resolve the matter. Assuming that sedimentation was continuous, the absence of anomalous directions clearly assignable to this event would provide definitive evidence that a self-reversal mechanism was responsible for the anomalous directions recorded in the Laschamp and Olby lavas.

In conclusion, provided that the magnetic directions recorded in sedimentary sequences over a wide area are stable, there appear to be some very significant geomagnetic features in the last 50,000 years that can be used as chronostratigraphic references. Reliable chronological data given by different methods can lead to the establishment of regional curves of absolute chronological value.

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