rate. The mean life of ^{238}U is 6.4×10^9 yr, or twice the time required for homogenisation of abundances. The homogenised background of this nuclide may thus be about 50% of the total, with local fluctuations in abundance of the order of a factor two. The mean life of ^{235}U is 1.02×10^9 yr. The homogenised background abundance level is thus only about 4% of the average, and local fluctuations may be an order of magnitude about the mean. There will be some correlations between the abundance fluctuations of ^{235}U and ^{238}U. I estimate the fluctuations that may occur in the radiogenic ^{207}Pb/^{206}Pb ratio to be of order 20Δ, but not even the sign of these can be predicted, because a region with excess r-process production might or might not have had a recent contribution within the homogenisation time, and thus the ^{235}U might be high or low when there is an r-process excess.

For what it is worth, the difference in ^{207}Pb/^{206}Pb ratios between Angra dos Reis and the other two basaltic achondrites implies an order of magnitude $\Delta \sim 0.019/20 \sim 10^{-3}$. Since in this case it seems that ^{235}U is in excess in Angra dos Reis, it is perhaps not surprising that this meteorite also has a large component of the fission decay products of ^{244}Pu, an extinct radioactivity with a half-life of 82×10^6 yr (ref. 14).

Thus it seems that a case can be made that the isotopic differences between Angra dos Reis and other basaltic achondrites may be due to real fluctuations between the relative abundances of s-process and r-process nucleosynthesis products at a level $\Delta \sim 10^{-3}$. These differences are at a level which is subject to detection by careful mass spectrometry. The optimum ranges of elements in which to seek such effects are those in which there are comparable abundances from the two processes. Elements of even atomic number in the range from germanium to tellurium are probably most suitable for these measurements. If such differences should be found, this would provide a new tool for finding difference source regions in which Solar System materials have accumulated.

After this letter was submitted, I learned of the important work of R. N. Clayton, L. Grossman, and T. K. Mayeda (personal communication) showing that individual minerals in carbonaceous chondrites contain variations in oxygen isotope ratios that must represent different mixtures of separate nucleosynthetic processes. The general theoretical considerations given here should also provide an explanation of these effects.

A. G. W. CAMERON

Center for Astrophysics,
Harvard College Observatory/Smithsonian
Astrophysical Observatory,
Cambridge, Massachusetts 02138

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Post-depositional Remanent Magnetisation in Deep-sea Sediment

SEDIMENTS of various lithologies cored from most parts of the deep ocean floor have been found to contain a record of the past behaviour of the Earth's magnetic field, especially the sequence of reversals over at least the past 5 m.y. (ref. 1). The mechanism by which these sediments acquired their natural remanent magnetism (NRM) is, however, still poorly understood. We have recently conducted experiments that indicate that post-depositional remanent magnetisation[2] is a viable mechanism of magnetisation of deep-sea sediments.

Laboratory studies of the most obvious mechanism, depositional or detrital remanent magnetism (DRM), have shown that the remanent inclination is usually shallower than the field inclination in which the sediment was deposited[3,4]. The difference is thought to be due to the effects of gravity overcoming magnetic-orienting couples of the magnetised grains at the instant of deposition[5]. The NRM inclinations of deep-sea sediments generally agree, however, with the expected axial dipole field inclinations[6]. It has been suggested[7] that these sediments may acquire their remanent magnetism shortly after deposition, by the post-depositional mechanism observed in synthetic sediment[2]. The physical origin of this remanence is likely to be closely related to Brownian motion[8]. In deep-sea sediments, a remanence may be acquired as a result of sediment disturbance by benthic organisms[9]. The natural remanent magnetism of some sediment may also be of chemical origin as a result of *in situ* authigenic growth of ferromagnetic minerals[10].

Deep-sea sediment was obtained from the bottom of a Lamont core, RC14-14, the magnetic properties of which have been reported[11]. The NRM was of a stable type; alternating fields necessary to randomise 50% of the original NRM (median destructive fields) averaged 200 oersted. The average magnetic inclination of the core was not significantly different from the axial dipole field inclination at the core site. The dominant magnetic minerals were essentially magnetite and titanomagnetite (compositional parameter, $x = 0.53$) which were incorporated in a matrix of diatomaceous clay.

A quantity of the sediment was thoroughly dispersed in a sufficient amount of distilled water to form a thick slurry,
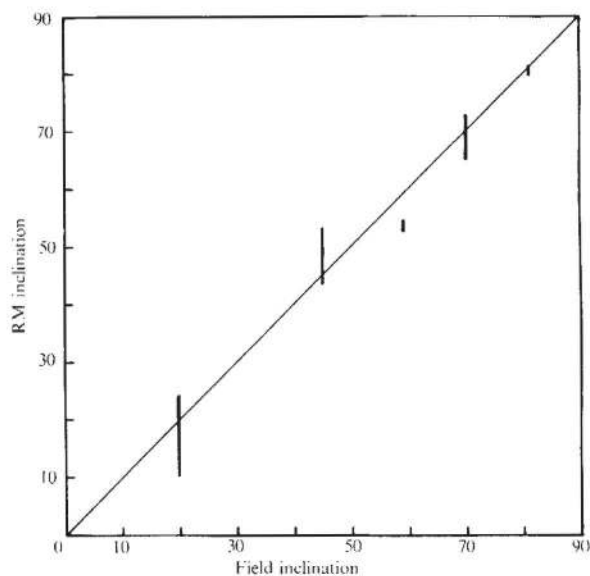

Fig. 1 Inclinations of the control field and the remanent magnetisation of the reconstituted sediment. Error bars represent range of remanent inclinations for each sample; the line of perfect agreement is shown. Successively steeper inclinations were produced in fields of 0.20, 0.28, 0.38, 0.59 and 1.20 oersted, respectively.
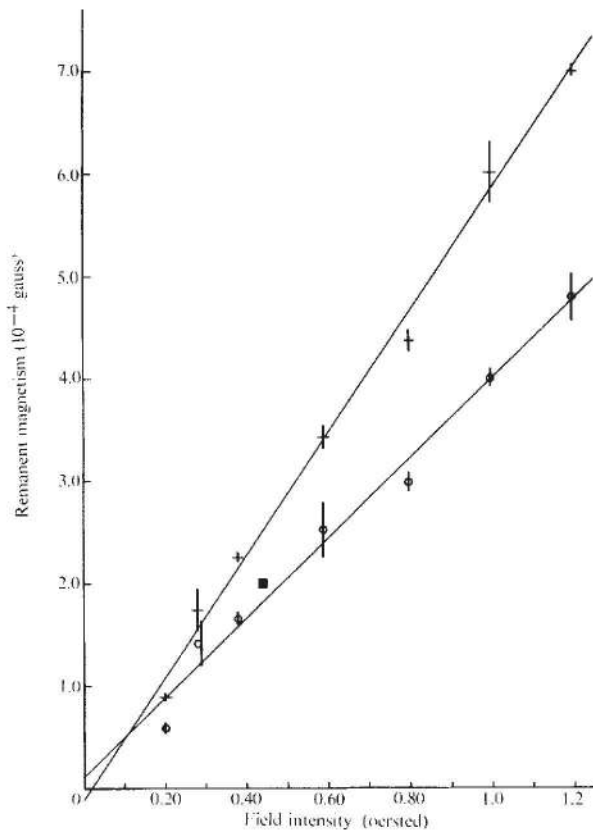
Fig. 2 Intensities of the control field and the remanences of the reconstituted sediment, before (+) and after (⊕) 100 oersted a.f. demagnetisation. Regression line slopes are 5.96 ± 0.19 ($\times 10^{-4}$ gauss oersted^{-1}) and 3.87 ± 0.20 ($\times 10^{-4}$ gauss oersted^{-1}), respectively. ■, Average remanent intensity of RC14–14, after 100 oersted a.f. demagnetisation[11], plotted against the present axial dipole field intensity at the core site.

similar in consistency to that normally found near the tops of piston cores immediately after coring. The sediment slurry was spooned into plastic cylinders (diameter 7 cm, height 5 cm) that had perforated bottoms covered with paper towelling to prevent sediment loss. Helmholtz coils were used to provide various field intensities and directions. The sediment slurry was thoroughly stirred in the presence of a known field and allowed to dry in this same field. Two or three specimens were cored from each sample with a plastic cylinder after the sediment became cohesive yet not completely dry (generally after 4 to 7 d). The remanent magnetism of each specimen and that remaining after partial alternating field (a.f.) demagnetisation[12] were measured with a slow-spin magnetometer. Unreliable results were obtained if the sediment was too wet.

The remanent inclinations agreed reasonably well with the inclinations of the control fields (Fig. 1). No systematic deviation of the remanent magnetism direction from that of the control field, such as inclination error[4,13], was observed. The scatter of directions among specimens from an individual sample is attributed chiefly to specimen orientation errors and, more important, to visible deformation of the sediment resulting from partial desiccation.

The remanent intensity was linearly proportional to the intensity of the control field, at least up to 1.2 oersted (Fig. 2). The regression line through either the remanent intensities or the partially demagnetised remanences intersects the ordinate at a value not significantly different from zero magnetisation intensity. Only 35% of the remanence was randomised by 100 oersted a.f. demagnetisation as illustrated by the different slopes of the two lines. Alternating field demagnetisation curves of individual specimens show median destructive fields of about

200 oersted, with corresponding directional changes of less than 10°.

The process of stirring the sediment in the presence of a magnetic field may be analogous to the activities of benthic organisms at, or just beneath, the sediment-water interface on the ocean floor[14]. Core RC14-14 shows evidence of benthic organism activity or bioturbation over most of its length[11]. The NRM of the core and the remanence of the reconstituted sediment are similar in intensity (Fig. 2), in stability against alternating fields and in their apparent lack of systematic inclination error. This evidence suggests that the stable NRM is a post-depositional remanent magnetisation acquired in conjunction with physical disturbance by benthic organisms in most sections of the core.

Mixing of deep-sea sediment by benthic organisms is seen from photographs to be a common feature of the ocean bottom environment[15] and evidence of it is found in many sediment cores[16,17], which often contain good magnetic records[18,19]. Therefore, a substantial portion of deep-sea sediment may have acquired an NRM as a result of a sediment-mixing process. This is not to say that mixing is a prerequisite for the acquisition of post-depositional remanence in sediment. Preliminary results show that the same sediment acquires a stable remanence in the direction of an applied field without stirring. It has no inclination error but has a somewhat lower intensity. Even if the DRM mechanism is also a factor in the original magnetisation of deep-sea sediment, realignment of this type of remanence may occur after deposition. The small grain diameters of magnetic minerals often encountered in deep-sea sediment (generally $40\% < 1$ μm)[20], coupled with the field dependence and lack of inclination error of this post-depositional remanence, support the Brownian motion model of magnetic grain alignment in a field in the sediment[8,21].

The extent to which the sediment and its observed remanent magnetism are contemporaneous must vary with depth of faunal activity and other factors controlling the immobilisation of magnetic grains in the sediment. These include grain size, grain magnetic moment and sediment-water content. The mean burrowing depths are apparently only about 5 cm in deep-sea sediment, although some burrows can infrequently extend deeper[17,22,23]. Preliminary laboratory observations indicate that only a small decrease in water content is necessary to lock-in a post-depositional remanence in the sediment. This suggests that the difference in depth between acquisition of remanence and the sedimentation surface may not be excessive.

The applicability of such sediment reconstitution studies to palaeofield intensity measurements in deep-sea sediments is now being investigated.

DENNIS V. KENT

*Lamont-Doherty Geological Observatory
of Columbia University,
Palisades, New York* 10964

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Flocculation of Latices by Low Molecular Weight Polymers

POLYELECTROLYTES are increasingly being used as flocculants for electrostatically stabilised dispersions of colloidal particles in such diverse fields as water treatment and mineral processing[1]. Suitable polyelectrolytes, which are usually effective at low concentrations ($\leqslant 10$ p.p.m.), invariably have a high molecular weight[2] (a viscosity average molecular weight $M_V > 10^5$). They seem to function by a bridging mechanism whereby the flocculant interferes with the free movement of the particles[1-6].

We now report that even low molecular weight non-ionic polymer molecules ($M_V \geqslant 10^3$ to 10^4) are able to flocculate some polymer latices. They also seem to function by a bridging mechanism but require the presence at the particle surfaces of suitable groups with which the flocculant can interact specifically.

The new phenomenon was first discovered with an apparently electrostatically stabilised aqueous polystyrene latex (mean radius 24 nm), prepared by the method of Ottewill and Shaw[7]. Figure 1a displays the course of flocculation, which was followed turbidimetrically, on addition of poly(ethylene oxide) (PEO) to the latex at 35° C. (The initial light scattering was compensated for.) Several samples of low molecular weight PEO (ex Union Carbide Australia Ltd) were examined using the latex at a particle concentration of $\sim 10^{12}$ cm^{-3}. In the absence of PEO the particles exhibited long term stability, whether or not 0.2 M HCl was present (line 1). When low molecular weight PEO was added in the absence of 0.2 M HCl no flocculation could be detected at any polymer concentration. But the addition of PEO, at 20 p.p.m., of either $M_V = 4,000$ or 23,000 in the presence of 0.2 M HCl resulted in rapid flocculation of the latex (curves 2 and 3). The higher molecular weight polymer was the more effective. Very high molecular weight polymer $M_V = 1 \times 10^6$ was also an effective flocculant at concentrations of only a few p.p.m.

Polystyrene latices prepared by the method of Ottewill and Shaw[7] possess surface carboxylic acid groups[8,9]. To investigate the role of these groups, polystyrene latices were prepared at low temperatures (<30° C); as we have shown elsewhere[10], such latices possess no detectable surface carboxylic acid groups. Interestingly these latices failed to flocculate on addition of PEO in the presence of 0.2 M HCl. On the other hand, polystyrene latices sterically stabilised[11] by poly(acrylic acid) (PAA) of $M_V = 19,300$ were also found to be flocculated by low (and high) molecular weight PEO (Fig. 1b). Again 0.2 M HCl was necessary for flocculation. We note that in the absence of PEO these latices exhibit long term entropic stabilisation[11] (line 4).

The foregoing experiments point to the central role played by the surface carboxylic acid group in promoting flocculation. They suggest the following mechanism for flocculation by low molecular weight polymers: At suitably low pH the surface carboxylic acid groups are predominantly unionised and so can H bond with the ether oxygens of the PEO chains. The occurrence of such H bonding is forcefully demonstrated by the phase separation of mixtures of PAA and PEO from aqueous solutions at low pH (refs 12 and 13). For the conditions relevant to curve 3 in Fig. 1a, the centres of the particles were separated, on average, by ~1,000 nm, if a cubic array is assumed. The r.m.s. end-to-end length of the PEO chains was calculated[14] to be only ~10 nm. Obviously on average the polymer chains could not possibly span the distance between the particle surfaces. Therefore the PEO chains may reasonably be inferred to have become attached to one particle by H bonding to the surface carboxylic acid groups and to have become attached to a second (or more) particle(s) in subsequent Brownian collisions. Free movement of the latex particles was thus prevented, corresponding to bridging flocculation. According to this postulated mechanism, no flocculation would be expected at higher pH values because the ionised carboxylic acid groups would be unable to H bond with the PEO. Also no flocculation would be expected in the absence of surface carboxylic acid groups. Both expectations were realised.
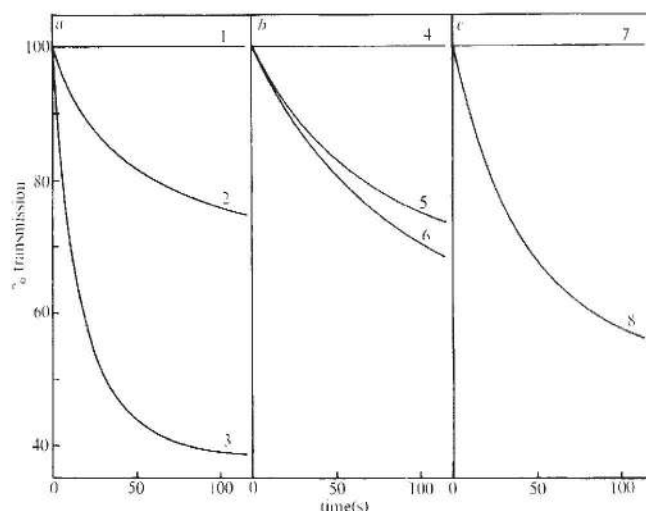

Fig. 1 The % transmission as a function of time for polystyrene latices. a, Curves for latices containing surface carboxylic acid groups: 1, no PEO added; 2, PEO of $M_V = 4,000$ added; 3, PEO of $M_V = 23,000$ added. b, Curves for latices stabilised by PAA: 4, no PEO added; 5, PEO of $M_V = 4,000$ added; 6, PEO of $M_V = 23,000$ added. c, Curves for latices stabilised by PEO: 7, no PAA added; 8, PAA of $M_V = 19,300$ added. Flocculant added at 20 p.p.m. in a and c and 50 p.p.m. in b.

If this explanation is correct then it is also predicted that low molecular weight PAA should be able to flocculate latices stabilised solely by PEO chains. Figure 1c shows the flocculation induced by the addition of PAA ($M_V = 19,300$) to a polystyrene latex sterically in this case enthalpically stabilised by PEO ($M_V = 23,000$). Again no flocculation was evident unless 0.1 M HCl was also present to convert most of the carboxylic acid groups into the unionised form.

The phenomenon seems to be closely analogous to the bridging flocculation observed with high molecular weight polyelectrolytes. Both are characterised by the intervention of the polymeric flocculant by promoting 'sticky' collisions between the particles, the flocculated particles often being separated by some distance[15]. There is thus no need to reduce to near zero the repulsive potential energy between