

MAGNETIC REMANENCE AND FABRIC PROPERTIES OF LABORATORY-DEPOSITED HEMATITE-BEARING RED SANDSTONE

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**Abstract.** Redeposition experiments of disintegrated hematite bearing sandstone have confirmed a tangent relationship between inclinations of the DRM and ambient magnetic field. Pronounced variations of DRM-intensities with field inclination are attributed to processes acting during the depositional formation of laminated sediments. Coinciding azimuthal distributions of remanence and maximum susceptibility directions reflect intrinsic properties of flaky hematite grains in which the magnetic moment is parallel to the direction of maximum susceptibility. This parallelism probably depends on magnetic domain configurations.

Introduction

The origin of remanent magnetization in red beds is generally attributed to either diagenetic formation of hematite, by which a chemical remanent magnetization is acquired, or to a "true" depositional remanent magnetization (DMR) acquired by rotation of detrital hematite grains into the direction of the ambient field. The recognition of DRM in red beds is still a matter of dispute, partly due to incomplete knowledge of the properties of DRM carried by hematite.

Bressler and Elston (1980) conducted redeposition experiments on naturally disintegrated red beds and found significant errors in the remanent inclinations, which appeared to be independent of the ambient field inclination. This result is at variance with previous experimental results on silt-sand sized magnetite-bearing deposits which demonstrated a tangent relationship between inclinations of DRM and ambient field (King, 1955). Recent experiments with hematite-bearing river sands (Tauxe and Kent, 1983) have confirmed the tangent relationship according to theory. The apparent discrepancy between these two sets of results probably elucidate the influence experimental conditions (grain by grain/dispersion) and the physical properties of redeposited materials may have on experimental results.

The present work reports on the properties of DRM and magnetic fabric of hematite-bearing red sand-siltstone which was deposited to form laminated layers. The magnetic fabric, described by the anisotropy of magnetic susceptibility (AMS), is well established for sand-silt-sized magnetite-bearing deposits (Hamilton and Rees, 1970). In the present context it is emphasized that these experimental results indicate that the directional distributions of the principal susceptibility axis appear to be dominated by depositional conditions rather than by ambient magnetic field directions. Since both DRM and magnetic fabric properties reflect the statisti-

cal orientation of magnetic grains, this observation suggests that remanence and fabric are related to different populations of magnetic grains.

Origin of AMS in hematite

The magnetic properties of hexagonal crystals of hematite are due to antiferromagnetic coupling between crystallographic c-planes within which the magnetic cation moments have a ferromagnetic coupling (parallel alignment). Above the Morin temperature (-10°C), imperfect antiparallelism between c-plane moments gives rise to a weak spontaneous magnetization which is constrained to lie in the basal plane (Stacey and Banerjee, 1974).

The low-field susceptibility of hematite is composed of an isotropic, antiferromagnetic contribution in addition to a dominant contribution from the alignment of the spontaneous moments. In single domain hematite the magnitude of the former is less than 1/5 of the latter (Stacey, 1963), implying that hematite in effect has an uniaxial magnetic susceptibility confined to the basal plane. The magnitude of the latter is of the order of  $10^{-4}$  emu, implying that the shape of hematite grains does not contribute to the AMS.

A relationship between the direction of maximum susceptibility and spontaneous magnetization, beyond the fact that both are confined to the basal plane, has been observed in natural crystals of hematite in which minimum susceptibility directions accurately defined the directions of the isothermal remanent magnetization (Schmidt and Fuller, 1970). They also confirmed and extended the observation that the low-field susceptibility in single crystals of hematite depend on both the magnitude and type of induced magnetization (Kobayashi and Smith, 1965). Directional coupling between magnetization and susceptibility is likely to be related to domain configurations. In hematite, the latter is recognized to be determined by physical conditions which depend strongly on the mode of formation of individual crystals.

Experimental methods

Redeposition experiments were performed with natural disintegrated flood-plain deposits of the Devonian red sand/siltstone of the Wood Bay Formation, Dicksonfjorden, Spitsbergen. Bulk magnetic properties are characterized by fine-grained hematite as indicated by the following results: IRM-H acquisition curves do not reach saturation in 0.9T fields and back-fields above 0.3T are necessary to reduce the  $IRM_{0.9T}$  to zero. Thermomagnetic curves reveal a single, reversible Curie-point around 670°C, indicative of substantial amounts of almost pure hematite, cf. Figure 1. By magnetic extraction procedures,

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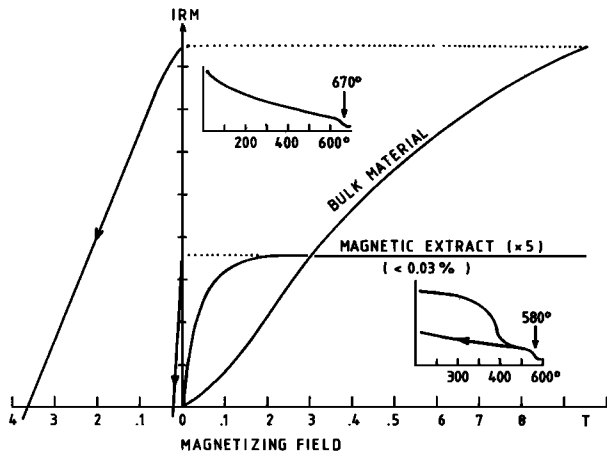


Fig. 1. IRM-H acquisition and back-field curves for bulk material and magnetic extract. Note 5 time magnification of the latter. Thermomagnetic curves for bulk material are reversible.

a small amount (<0.03%) of a strongly magnetic mineral was obtained. This low-coercive force ( $H_{SIRM} < 0.2T$ ) mineral revealed irreversible thermomagnetic curves characteristic of titanomaghemite in addition to magnetite, cf. Figure 1. Although the specific magnetization and susceptibility of magnetite are significantly larger than hematite, the absence of magnetite features on both the IRM-H and thermomagnetic curves suggest negligible contributions of this phase to the bulk properties. The occurrence of titanomaghemite within a red bed formation reflects moderate oxidizing conditions since deposition, favouring a detrital origin of the hematite present.

Grain-size determinations (settling) revealed bimodal distributions with peaks around  $15\mu$  and  $50\mu$ . Visual inspection by SEM showed a large proportion of  $<100\mu$  square to hexagonal flakes of presumably hematite coating larger grains, but mostly appearing as individual grains.

Redeposition experiments were performed by daily pouring 200 ml of a vigorously shaken 1:20 (sediment:water) dispersion into plastic tubes (D/L:9/20 cm) situated in the center of three mutually orthogonal Helmholtz coils (diam: 2.4m). After 5 to 7 days of daily deposition, the sediment was left to consolidate for 4 to 6 days before draining off excess water. Final drying for 2 to 3 days resulted in a rather wet, but highly cohesive deposit. 5 to 7 subsamples were obtained by pressing cylindrical plastic cups (D/L:17/16 mm) vertically into the laminated sediment (thickness: 2-2.5 cm). During six experimental runs, inclinations of the constant magnitude ambient field (0.26 Oe) varied between  $0^\circ$  and  $75^\circ$ .

### Experimental results

#### Remanence properties

Samples from each experimental run were subjected to progressive af-demagnetization to 60mT which revealed stable, single component directions with median destructive fields above 30mT. Thermal demagnetization could not be applied since drying resulted in complete disintegration of the samples. The directional distributions,

shown in Figure 2, are rather scattered, but mean declinations, cf. Table 1, coincides with the ambient magnetic field meridian. The large scatter in both directions and other parameters are rather unexpected taking into account that these samples were deposited and prepared under controlled laboratory conditions. We felt that significant noise was introduced by the experimental procedures, implying that the magnetic properties of these deposits are rather sensitive to physical disturbances against which no precautions have been made.

From Figure 2 it is apparent that inclinations of the DRM are significantly shallower than ambient field directions. The plot in Figure 3 indicates a systematic dependence between inclinations of the ambient field ( $I_H$ ) and DRM ( $I_{DRM}$ ). The experimental results alone would suggest a rather complex curve, due to the deviating result from experiment no. 3. By including results from in situ samples of the flood-plain deposit, probably laid down during the spring 1982, however, the results are seen to fit a tangent relationship between  $I_H$  and  $I_{DRM}$  of the form:

$$\tan I_{DRM} = f \cdot \tan I_H \quad (1)$$

Although the results admittedly have a poor precision, a best fit is obtained for a value of  $f$  around 0.4. DRM inclination errors may thus be accounted for by the classical theory which postulates contributions from two populations of magnetic grains, one oriented parallel to the magnetic field (spheres) while the other (discs) always remain in a horizontal position (King, 1955). According to this model the intensity of DRM ( $J$ ) depends on  $I_H$  of a constant magnitude field according to:

$$J = (f \cdot \sin^2 I_H + \cos^2 I_H)^{1/2} \quad (2)$$

on the assumption that  $f$  is independent on  $I_H$ . Theoretical curves for three values of  $f$  together with the intensity results are shown in Figure 3, which reveal large discrepancies. The experimental values indicate an almost exponential decaying relationship with  $I_H$ , by which  $J$ , for  $I_H=90^\circ$ , appear to reach a value some 10% of the intensity acquired in a horizontal field. This result can

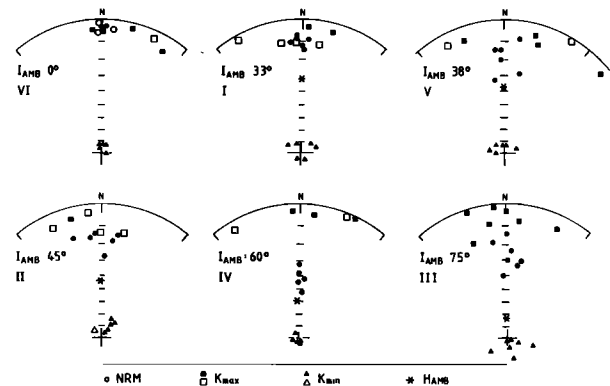


Fig. 2. Stereographic plots of directional results from experiments 1 to 6.  $I_{AMB}$ : inclination of 0.26 Oe ambient field.

TABLE 1. Results of Redeposition Experiments

N	H	n	D	I	Int	k	Q' <sub>n</sub>	(D/I) <sub>1</sub>	(D/I) <sub>3</sub>	P <sub>1</sub>	P <sub>2</sub>	P <sub>3</sub>	E
1	33	6	359	10	56.6	9.1	6.3	357/-4	24/84	1.014	1.081	1.065	1.051
2	45	6	358	19	26.8	9.3	2.9	351/-6	48/81	1.014	1.075	1.060	1.046
3	75	7	360	27	15.5	8.7	1.8	10/5	114/86	1.011	1.047	1.037	1.049
4	60	7	6	42	13.9	9.3	1.5	2/1	207/89	1.015	1.080	1.064	1.048
5	38	6	358	3	37.4	9.6	3.9	358/3	93/87	1.013	1.082	1.067	1.053
6	0	5	329	0	115.5	9.9	9.2	345/-3	38/86	1.014	1.100	1.085	1.069

N: Experiment number, H: Ambient field inclination, n: number of samples, D, I: NRM mean declination, inclination, Int: Intensity:( $\mu\text{G/g}$ ), k: Bulk susceptibility ( $\mu\text{G/Oe}$ ),  $Q'_n = \text{Int}/k$ ,  $(D/I)_1$  and  $(D/I)_3$ : Mean declination/inclination of AMS maximum (1) and minimum (3) axis,  $P_1, P_2, P_3, E$ : Mean values of AMS parameters

be accounted for by postulating that  $f$ , the fraction of magnetic grains aligned parallel to the magnetic field direction, decreases with increasing  $I_H$ . This will not necessarily affect the tangent relationship between  $I_{\text{DRM}}$  and  $I_H$ .

Magnetic fabric

Magnitudes and directions of the principal axis of magnetic susceptibility ellipsoids ( $k_{\text{max}}$ ,

$k_{\text{int}}, k_{\text{min}}$ ) were determined on an induction bridge. All ellipsoids are oblate ( $E > 1$ ), cf. Table 1, with vertically distributed  $k_{\text{min}}$  axis, cf. Figure 2. These results are in general agreement with results of still-water deposited magnetite-bearing sand/silt (Hamilton and Rees, 1970), in which the fabric is dominated by gravity controlled settling of magnetite grains. Similar considerations are applicable for tabular hematite grains in which minimum susceptibilities are perpendicular to the horizontally oriented basal planes.

Coinciding azimuthal distributions of the almost flat-lying  $k_{\text{max}}$  axis with the meridian of the ambient field, cf. Figure 2 and Table 1, are not observed in silt/sand magnetite deposits. These results is suggested to reflect the fundamentally different properties of hematite and magnetite with respect to the relationship between magnetic moment and susceptibility.

Variations of the magnetic fabric parameters  $P_1$  ( $k_{\text{max}}/k_{\text{int}}$ ),  $P_2$  ( $k_{\text{max}}/k_{\text{min}}$ ) and  $P_3$  ( $k_{\text{int}}/k_{\text{min}}$ ) with  $I_H$  are shown in Figure 4. The lineation,  $P_1$ , appear to be independent of  $I_H$ , indicating that  $k_{\text{max}}$  and  $k_{\text{int}}$  either are unaffected by  $I_H$  or that both change in the same relative proportions.

The anisotropy factor,  $P_2$ , and foliation,  $P_3$ , both exhibit the same concave decay trend with increasing  $I_H$ . Above  $60^\circ$  there is a pronounced drop to some 50% of the initial values. The decrease in  $P_2$  and  $P_3$  can be related to increasing contributions to  $k_{\text{min}}$  with increasing  $I_H$ . This indicates that the orientation of the magnetic fabric, are controlled by the ambient magnetic field.

Discussion and conclusion

The present redeposition procedure resulted in laminated sediments. It is suggested that successive, discontinuous sedimentation may introduce disturbances in the fine-grained top of the previous deposited layer, resulting in a randomization of aligned magnetic grains. Hematite will be more affected than magnetite grains due to the much weaker magnetic force acting on the former and which may cause at least partial realignment after a depositional orientation has been disturbed. Intuitively, the effect of this randomizing process will be more dominant for inclined tabular grains. It is tentatively con-

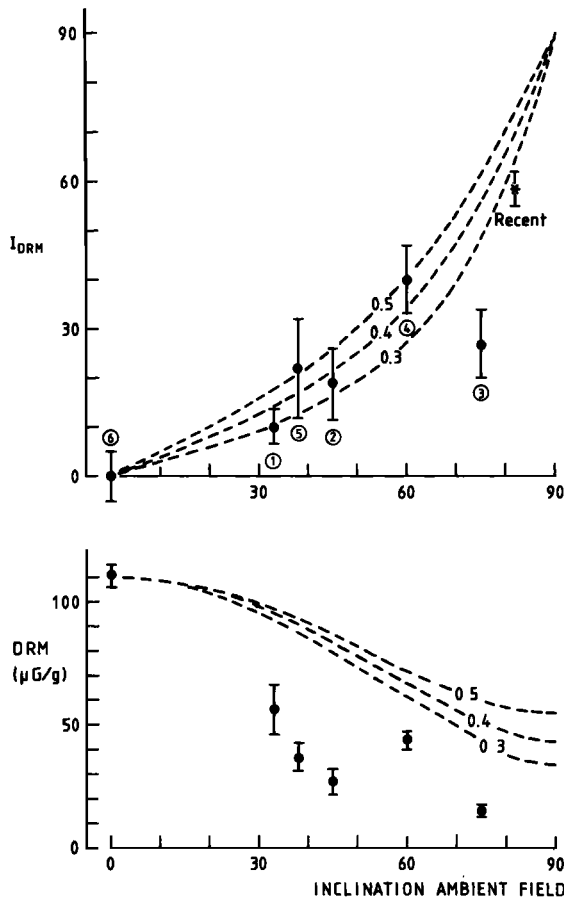


Fig. 3. Plots of inclination (top) and intensity (bottom) of DRM versus inclination of ambient field. Error bar: 1 $\sigma$  standard deviation of the mean.

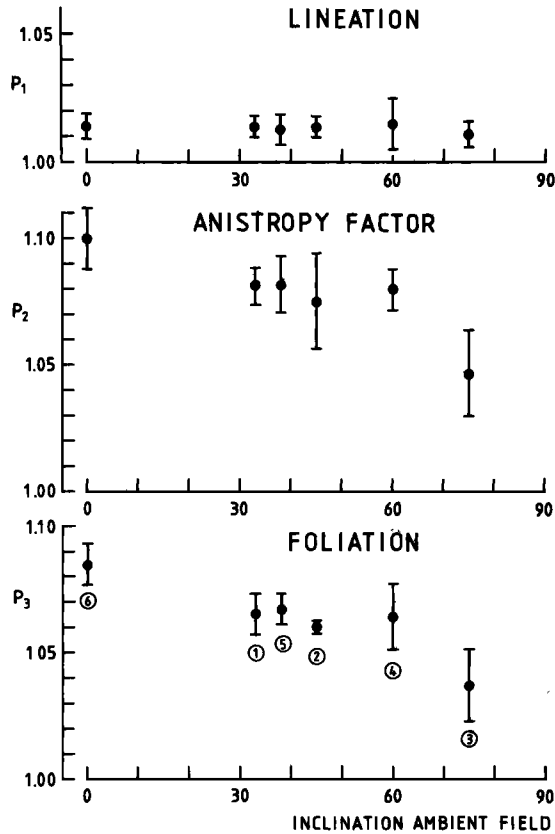


Fig. 4. Anisotropy parameters  $P_1$ ,  $P_2$  and  $P_3$  versus inclination of ambient field. Error bar: 1 $\sigma$  standard deviation of the mean.

cluded that this process may account for the observed dependence of  $J$  upon  $I_H$ , cf. Figure 3.

Coinciding  $k_{max}$  and remanence directions, cf. Figure 2, is concluded to reflect intrinsic properties of hematite grains. Basal plane alignment of susceptibility and magnetic moment is theoretically not possible in single domain grains of hematite, which, on the contrary should show an orthogonal relationship (Stacey, 1963). The observed parallelism is concluded to depend on

domain configuration in multidomain hematite grains, implying that AMS may be a potential method for studying domain states in hematite.

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