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A PALAEOMAGNETIC AND ROCKMAGNETIC STUDY OF SEDIMENT CORES FROM THE ZAIRE SUBMARINE FAN

by

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CONTENTS

1. INTRODUCTION

This study is part of a research project on the Angola Basin carried out by the Netherlands Institute for Sea Research. The palaeomagnetic work was carried out at the Paleomagnetic Laboratory of the University of Utrecht. During cruises in 1978 and 1980, 38 not oriented piston cores were collected. This paper presents the palaeomagnetic results for 10 cores from the Zaire (Congo) submarine fan (Fig. 1). An extensive wedge-shaped body of sediment which has accumulated from the Zaire river. The river is intersected by an east-west running submarine canyon and a large system of fan valleys. The fan sediments consist of reworked shelf sediments and a much smaller quantity of pelagic sediments (JANSEN *et al.*, 1984). According to HEEZEN (1964) the Zaire material contains large amounts of (high coercivity) haematite and haematite-coated quartz whereas in typical pelagic sediments low coercivity minerals—predominantly (titano)magnetite—are dominant (LØVLIE, 1971; KOBAYASHI & NOMURA, 1974).

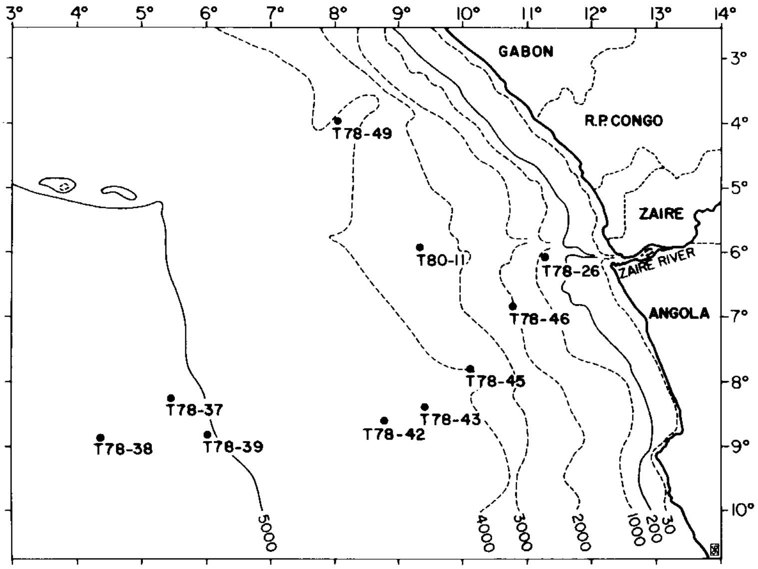

Fig. 1. Location map with core sites and depth contours (m).

In several cores the Late Quarternary climatic zones Z, Y, X, V, W, as defined by Erickson *et al.* (1968), could be identified by correlating

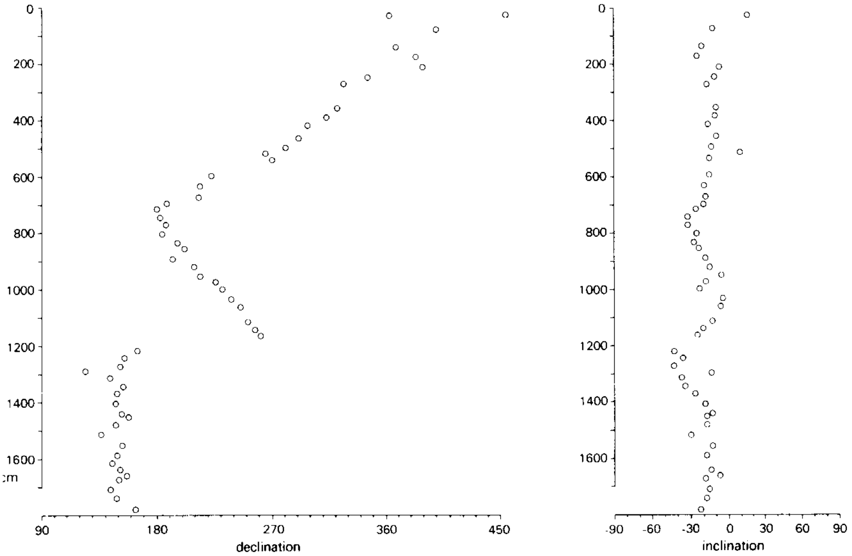

Fig. 2. Declination and inclation of characteristic NRM directions for core T80-11 (as he core is unoriented, declination values are given with respect tot the splitface of the core; connections between pipes occur at 6 m and 12 m).

calciumcarbonate peaks with warm intervals (Jansen *et al.*, 1984).

The palaeomagnetic study has two main aims: (1) to determine the directions of natural remanent magnetization as a function of depth in order to identify possible polarity reversals, (2) to determine the stratigraphical variation of rockmagnetic parameters, which may reflect the variation of concentration, composition and grain-size of the magnetic mineral fraction.

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2. METHODS

Since the unoriented piston cores come from near equatorial lattitudes possible polarity reversals in the NRM shoud show most clearly in the declinations. Therefore, great care was taken to halve segments of the core liners along a straight line. Since in many cores a declination shift occurs at the junction of connected pipes (Fig. 2), obviously the efforts made on board of the ship to control the relative orientation of the core

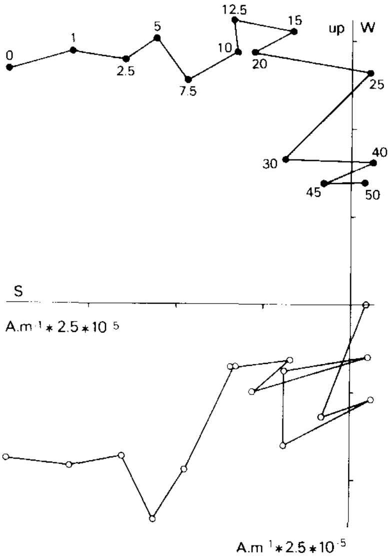

Fig. 3. Alternating field demagnetization diagram of orthogonal projections of the NRM vector of a sample from the weakly magnetized part of core T78-38; projections on vertical plane (O) and horizontal plane (x); alternating field strength in mT.

liners have been only partly successful. Cylindrical samples of 7.9 cm^3 were taken every 10 to 15 cm from core halves by pushing transparant plastic cups with orientation marks into the sediment. These cups were closed with a lid and, like the whole cores, kept at 4°C until the sample was measured.

The NRMs were measured with a two-axis Sct superconducting magnetometer. Characteristic directions were determined from orthogonal projections (ZIJDERVELD, 1967; Figs 3 and 4). For all samples the magnetic susceptibility was measured with an a.c. susceptibility bridge. The acquisition branch of the remanent hysteresis curve was determined form most samples and for 50% of these samples the complete remanent hysteresis curve was measured. For this purpose a specimen was placed in a uniform magnetic field between the poles of an electromagnet, and its remanence was measured using a fluxgate magnetometer. The complete remanent hysteresis curve was obtained by repeating this procedure for stepwise increasing field strength. Although most of the samples could be saturated in fields well below 2 Tesla it should be noticed that the parameter which in this paper is called Saturation Isothermal Remanent Magnetization (SIRM) is actually the intensity of the remanent magnetization acquired in the maximum obtainable field strength of 2 T.

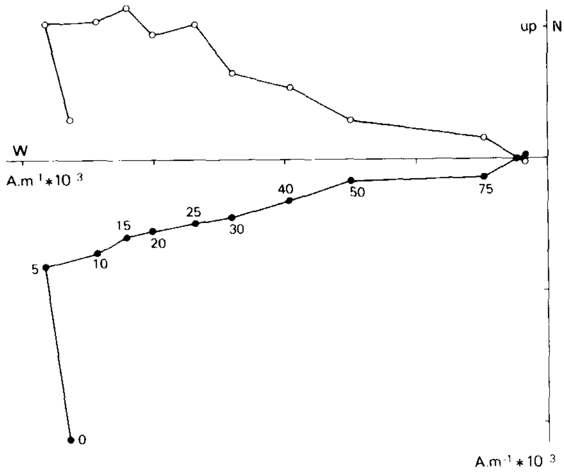

Fig. 4. Alternating field demagnetization diagram of orthogonal projections of the NRM vector of a sample from the relatively strongly magnetized part of core T78-38; projections on vertical plane (○) and horizontal plane (×); alternating field strength in mT.

3. RESULTS

3.1. NATURAL REMANENT MAGNETIZATION

3.1.1. INTENSITIES

In the majority of the cores the NRM intensities are lower than normally found in deep-sea sediments (HARRISON, 1966). Core T78-42 and (with much turbidite) core T78-37 consist entirely of sediments with low NRM intensities ($<5\cdot10^{-4}$ A·m^{-1}; (Fig. 8), except for a zone of 50 to 150 cm ($5\cdot10^{-3}$ to $5\cdot10^{-2}$ A·m^{-1}) at the core top. Cores T78-43, -45 (Fig. 5), -46 and -49 (Fig. 6) are also weakly magnetized. The high intensity of the top of these cores roughly coincides with the sediments of the Z zone which have a relatively high $CaCO_3$ content. Similar $CaCO_3$ peaks in deeper parts of the cores in question are not accompanied by high NRM intensities.

Furthermore, the steep decrease in NRM intensity is—at least in cores T78-45 and -46 for which clay mineralogy has been studied in detail (VAN DER GAAST & JANSEN, 1984)—not accompanied by any perceptible change in the overall composition of the detritic mineral fraction. A similar jump from high NRM intensities ($>5\cdot10^{-3}$ A·m^{-1}) to low intensities ($2\cdot10^{-4}$ A·m^{-1}) in core T78-38 is not related to any change in clay mineralogy or $CaCO_3$ content, but coin-

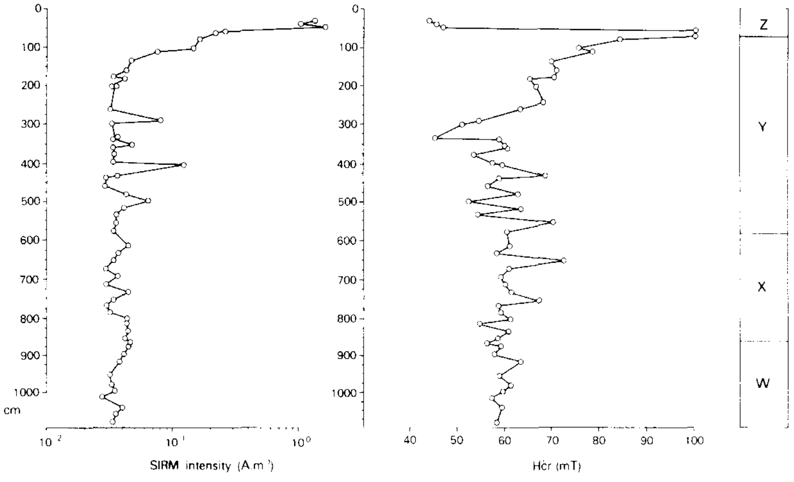

Fig. 5. Saturation Isothermal Remanent Magnetization (SIRM) intensity and remanent acquisition coercive force (H'cr) for core T78-45; Late Quaternary temperature zones (ERICKSON *et al.*, 1968) indicated.

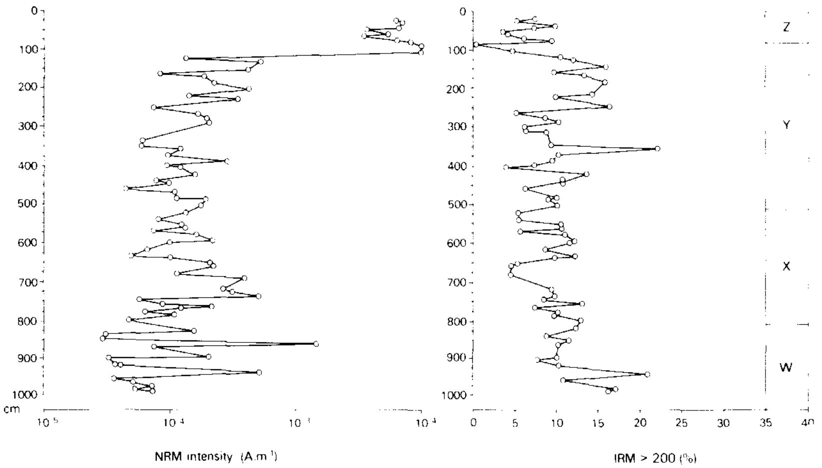

Fig. 6. Natural Remanent Magnetization (NRM) intensity and the percentage of total intensity of the isothermal saturation remanence acquired at field intensities higher than 200 mT for core T78-49. Late Quaternary temperature zones (ERICKSON *et al.*, 1968) indicated.

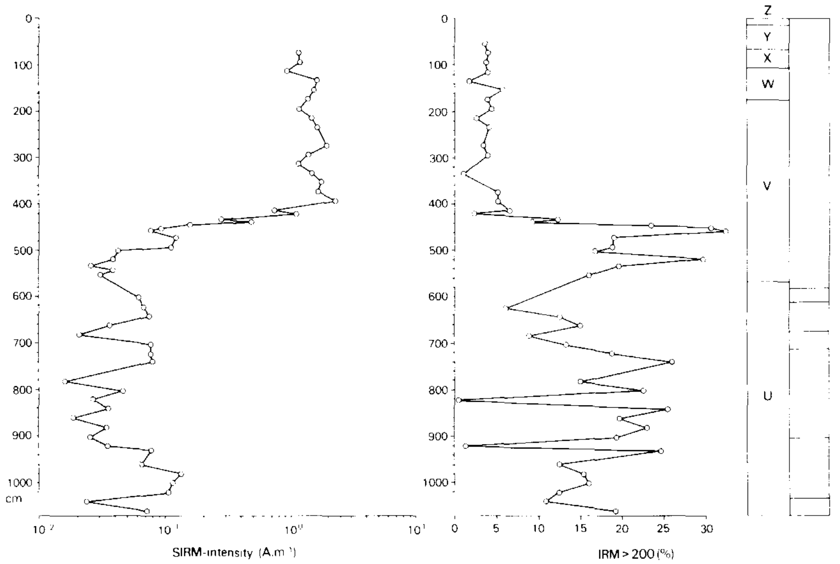

Fig. 7. Saturation Isothermal Remanent Magnetization (SIRM) and the percentage of total intensity of the isothermal saturation remanence acquired at field intensities higher than 200 mT for core T78-38. Late Quaternary temperature zones (ERICKSON *et al.*, 1968) and the presence of turbidites (hatched) indicated.

cides with a change in sedimentation rate (Jansen *et al.*, 1984). In core T78-38 the switch from high to low intensities occurs in the V zone at 4.2 m below the top (Fig. 7).

Although not related to clay mineralogy, the change towards weak intensities in cores T78-38, -45 and -46 coincides with a level below which a significant concentration of pyrite is observed (van der Gaast & Jansen, 1984); in core T78-38 and -46 this phenomenon is accompanied by a colour change from mainly yellow-brown (top) to grey (below). The upper 410 cm of core -38 consist of slowly deposited pelagic sediments. The lower part of this core has a higher sedimentation rate (Jansen *et al.*, 1984) and consists of hemipelagic sediments interrupted by turbidite sections between 1032 and 905 cm, between 714 and 674 cm and between 612 and 589 cm (Fig. 7). The hemipelagic sediments have NRM intensities which do not significantly differ from the NRM intensities of the turbidites. This is in contrast to cores T78-42 (Fig. 8) and -43 which contain both hemipelagic sediments and turbidites. In these cores the turbidites tend to have higher NRM intensities ($>10^{-3}$ $A{\cdot}m^{-1}$) than the hemipelagic intervals ($\leqslant 2{\cdot}10^{-4}$ $A{\cdot}m^{-1}$).

Cores with predominantly high NRM intensities are T80-11 and T78-26, the latter with NRM intensities much larger than those found for the other cores.

The NRM intensity of core T78-11 (Fig. 9) from the levee of the main channel of the Zaire fan—consisting almost completely of

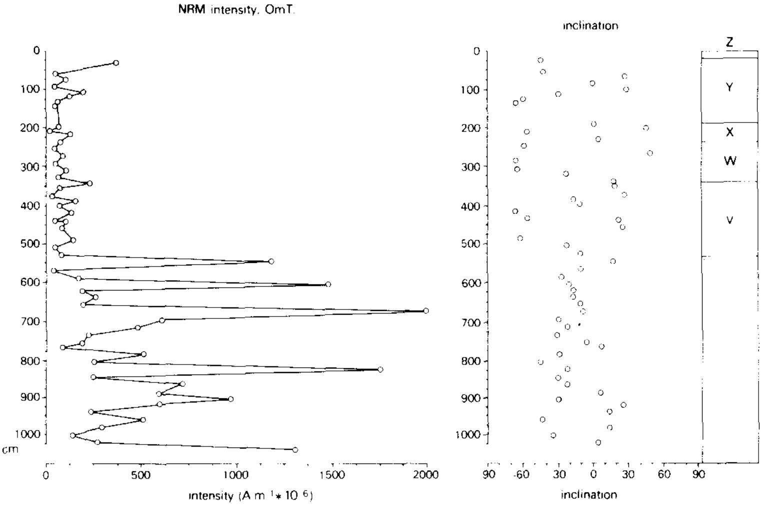

Fig. 8. Inclinations as deduced from alternating field demagnetization diagrams and Natural Remanent Magnetization (NRM) intensities for core T78-42. Late Quaternary temperature zones (Erickson *et al.*, 1968) and turbidites (hatched) indicated.

turbidites—shows a rather pronounced pattern of alternating high ($>10^{-2}$ A·m^{-1}) and low ($>10^{-2}$ A·m^{-1}) intensity zones. A comparable bimodal intensity variation, although of smaller amplitude, is present in the turbidite sections of cores T78-42 (Fig. 8) and -43. Neither visual inspection of cores T78-42, -43 and T80-11 nor X-ray photographs provided a sedimentological clue to an explanation of this intensity variation. While in these cores the turbidites mainly consist of rather fine-grained laminated silts, the lower 5 m of core T78-39 contains many turbidites of which the basal parts consist of coarse silt and sand. It is quite clear from visual examination of this core that NRM intensity peaks coincide with the coarse-grained base of the turbidites. From the base upwards the NRM intensity steeply decreases where the grain-size becomes smaller. This coincidence may well be caused by a concentration of magnetic heavy minerals in the coarsest part of a settling turbidite. Although no detailed information on grain-size variations is available for the turbidite sections in cores T78-43, -42 and -11, it is suggested that a similar relation between high intensity and large grain-size also applies to the turbidites in these cores.

Although 30 to 40% of the NRM of the weakly magnetized sediments consists of a soft viscous component (Fig. 3), the percentage of viscous remanence tends to be smaller for the strongly magnetized sediments (10 to 15% in T80-11; 25% in the upper 420 cm of T 78-38; 5% in T78-26; Fig. 4). In almost all cases the viscous component could be eliminated by alternating magnetic fields of 15 mT.

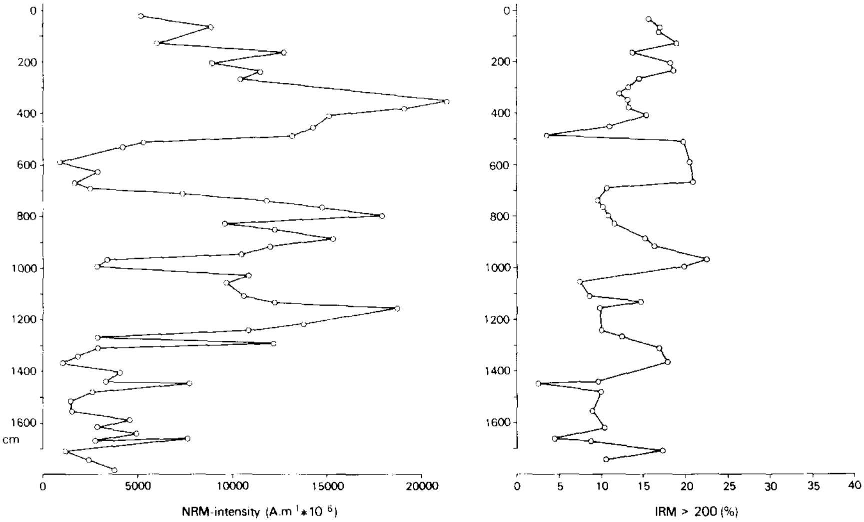

Fig. 9. Natural Remanent Magnetization (NRM) intensity and the percentage of total intensity of the isothermal saturation remanence acquired at field intensities higher than 200 mT (IRM>200) for core T80-11.

TABLE 1

Inclinations (mean and range) and declinations (range) for each core as derived from alternating field demagnetization diagrams.

Core	*Inclination*	*Declination*	*Remarks*
T78-26	- 18.8° ± 6°	30°	
T78-37	- 8.4° ± 28.8°	240°	corer rotated
T78-38	- 15.8° ± 9.2°	30°	upper 450 cm
T78-38	- 8.8° ± 24.4°	200°	lower 620 cm
T78-39	- 15° ± 18.2°	100°	
T78-42	- 15.6° ± 28°	360°	corer rotated
T78-45	- 9.2° ± 32.8°	270°	
T78-46	- 12.4° ± 12°	50°	
T78-49	- 0.8° ± 15.8°	-	segments unoriented
T80-11	- 14.8° ± 15.8°	270°	corer rotated

3.1.2. CHARACTERISTIC DIRECTIONS

All samples were demagnetized stepwise in alternating magnetic fields up to 0.1 T.

The Median Destructive Field (MDF) for the weakly magnetized sediments is 15 to 20 mT whereas alternating magnetic fields of 40 to 60 mT were required to remove 90% of the NRM of these sediments. For the strongly magnetized sediments of the upper 4.3 m of core

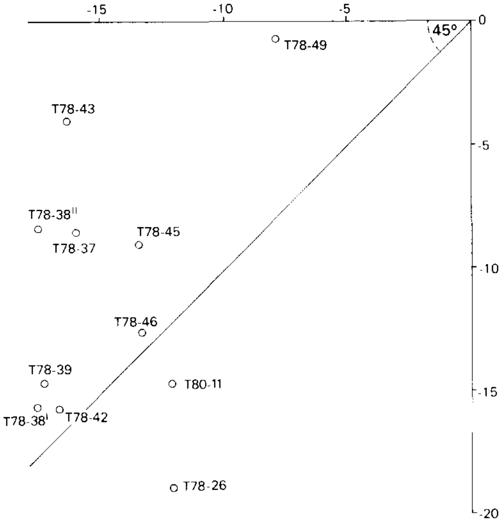

Fig. 10. Core mean values for the inclination of Natural Remanent Magnetization (NRM) directions deduced from alternating field demagnetization diagrams (vertical axis), plotted against geocentric axial dipole field inclinations at the core site (horizontal axis).

T78-38, the MDF and the 90% destructive fields are 30 mT and 70 mT respectively. For core T80-11 with a high intensity these values are 40 mT and 75 mT respectively. Characteristic directions were determined from orthogonal projections (Figs 3 and 4).

Due to (1) loss of orientation at pipe connections, (2) orientation errors when core segments are split, and (3) possible rotation of the corer during the penetration of the bottom, the declination record of the sedimentary cores tends to contain more errors than the inclination record. Therefore, instead of calculating the mean direction and 95% confidence levels with Fisher statistics, only the arithmetic mean of the inclinations and the standard deviation were calculated (Table 1). All studied cores have negative mean inclinations. As the cores come from the southern hemisphere this indicates normal polarity. Obviously none of the cores reaches the youngest polarity reversal, the Brunhes-Matuyama reversal of 700 000 yBP.

No relation was found between the axial dipole field inclinations and the mean inclinations (Fig. 10) which is not surprising because of the large scatter of characteristic directions (Table 1) particularly within the weakly magnetized sediments. This scatter also prevents conclusions about secular variation, except in the cores T80-11 and T78-26 with high NRM intensity and high sedimentation rate, where the inclination shows a few swings possibly recording secular variation (Figs 2 and 11). Core T80-11 consisting of turbidites likely contains many hiatuses and may therefore not give a continuous secular variation

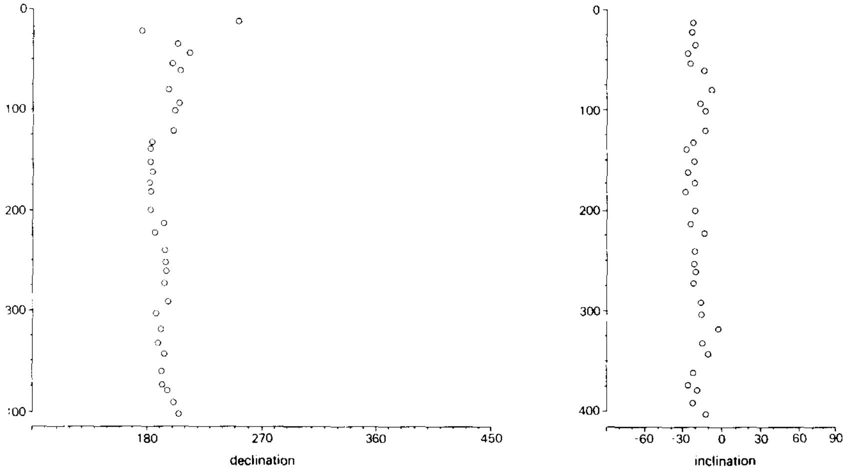

Fig. 11. Declination and inclination of characteristic Natural Remanent Magnetization (NRM) directions of core T78-26 (as the core is unoriented, declination values are given with respect to the splitface of the core.)

record. Core T78-26 is a clay core covering the Holocene of which the inclination varies with an amplitude of 15 to 20 around the mean inclination (Fig. 11).

3.2. ROCKMAGNETIC PARAMETERS

3.2.1. HYSTERESIS RESULTS

A hysteresis curve may give qualitative information about the relative amounts of high coercivity (haematite) and low coercivity magnetic minerals (mainly magnetite and titanomagnetites) in a sample. However, the SIRM per gramme of magnetite is—depending on grain size—10 (25 to 30 μm) to 50 (<5 μm) times the SIRM per gramme of haematite. Therefore this in practice applies only to samples in which the ratio of haematite to magnetite is large. For values of this ratio <1 the remanent hysteresis parameters will be determined almost entirely by magnetite. The following hysteresis parameters were determined for the majority of samples from each core:

(1) Saturation Isothermal Remanent Magnetization (SIRM). The SIRM is the maximum magnetic remanence which samples can acquire if exposed to a direct magnetic field of sufficient strength. The SIRM depends on the composition and grain size of the magnetic fraction and on the amount of magnetic material present.

(2) The remanent acquisition coercive force (H'cr). This is the magnetic field strength needed to give a non-magnetized sample half its SIRM. For magnetite of grain size >5 μm H'cr is smaller than 63 mT, H'cr being smallest for large grains and decreasing to 20 mT for grains of 100 μm. For haematite H'cr is generally larger than 100 mT and may even be larger than 300 mT for grains <10 μm (Hartstra, 1982).

(3) Since magnetite with even small grain sizes is saturated well below 200 mT, the magnetization acquired in fields larger than 200 mT can be considered to be carried by haematite only. The percentage of SIRM which is acquired in direct fields larger than 200 mT, was determined for each sample. This parameter will be indicated as IRM$>$200.

(4) Hcr is the direct field required to reduce the SIRM to zero. For ⅓ of the samples Hcr was determined.

In the studied cores the SIRM as a function of its stratigraphic position correlated quite well with the NRM intensity and with magnetic susceptibility (Table 2). While the value of the SIRM depends on the amount of magnetic material and its composition and on grain size, the other hysteresis parameters, H'cr and Hcr and IRM$<$200, depend

TABLE 2

Range of intensity of Natural Remanent Magnetization (NRM) before and after alternating field demagnetization at 15 mT, susceptibility (x), remanent acquisition coercive force (H'cr), remanent coercive force (Hcr), the percentage of total intensity of the isothermal saturation remanence acquired at field intensities higher than 200 mT (IRM > 200) and Saturation Isothermal Remanent Magnetization (SIRM) for each core or for the high and low NRM intensity parts of a core separately.

Core	*Depth (cm)*	*NRM (10^{-4} A·m^{-1})*	*NRM (10 A)*	*X (10^{-5} SI units)*	*H'cr (mT)*	*Hcr (mT)*	*IRM < 200 (%)*	*SIRM (10^{-1} A·m^{-1})*
T78-26	0- 414	250 -400	200 -370	15 -20	49-55	43-48	8-15	180-220
T78-37	0- 988	0.6- 3	0.3- 2	0.4- 3	58-70	50-60	8-15	2.8-6
T78-38	0- 449	40 -100	30 - 65	3 -12	42-48	37-44	3- 5	40-170
	449-1068	1- 2.5	0.5- 1.5	1- 2.2	55-72	48-60	12-20	3- 10
T78-39	0-1086	2 - 40	1.5- 30	3 -18	50-62	40-50	3-12	10-150
T78-42	0-1059	0.5- 4	0.3- 3	2.5- 6	55-65	45-50	10-15	3- 12
T78-43	0- 48	12	7	4.5	59	47	12	39.9
	48-1084	0.8- 2.5	0.4- 1.8	2.5- 5	55-65	45-50	6-15	3- 10
T78-45	0- 47	0.5- 3.5	0.3- 2	2.5- 4.5	55-65	40-45	10-35	15-120
	47-1081	0.5- 3.5	0.3- 2	2.5- 4.5	55-65	40-55	10-20	3- 7
T78-46	0- 162	40 -120	30 - 80	5 -10	50-55	43-53	10-15	40-170
	163-1102	0.5- 2.5	0.3- 0.9	2.7- 4.5	50-58	40-50	10-15	2- 3
T48-49	0- 108	36 -100	24 - 70	5.5-10	38-50	38-45	4- 7	90-130
	108-1028	0.4- 4	0.2- 2.5	2 - 4	40-50	39-35	6-13	3- 5
T80-11	0-1798	20 -200	18 -170	6 -10	60-75	50-60	10-15	40-200

only on the composition and grain size distribution of the magnetic mineral fraction and not on its concentration. Although H'cr and Hcr each depend on grain size, the ratio H'cr/Hcr is a function of composition only (DANKERS, 1981). Mean values of H'cr and Hcr with their standard deviations plotted for each core (Fig. 12) show that most cores fall neither in the magnetite region nor in the haematite region and therefore probably contain a mixture of both minerals. This is also indicated by the mean IRM < 200 values (Table 2) which are generally larger than 10%. Most "magnetite-like" are core T78-49 and the upper part of core T78-38. The H'cr and Hcr values are best explained by supposing a fine-grained (titano-)magnetite to be dominant, although core T78-49, according to its IRM < 200 values (Table 2), probably also contains significant quantities of haematite. Since core

T78-38 was taken at the border of the fan, this core is less influenced by the Zaire material than any of the other cores (JANSEN *et al.*, 1984). Therefore, the suggestion that the magnetic fraction of the pelagic upper 4.2 m of core T78-38 has a lower haematite content than the magnetic fraction of the fan cores (Fig. 12), is in accordance with the idea that the Zaire supply is the cause that the fan is relatively more enriched with haematite than more normal deep-sea sediments.

The H'cr variation in the cores tends to correlate well with the IRM < 200 variation, although IRM < 200 generally varies in a more pronounced way than H'cr. Large increases and decreases of SIRM are quite generally accompanied by a decrease and increase respective-

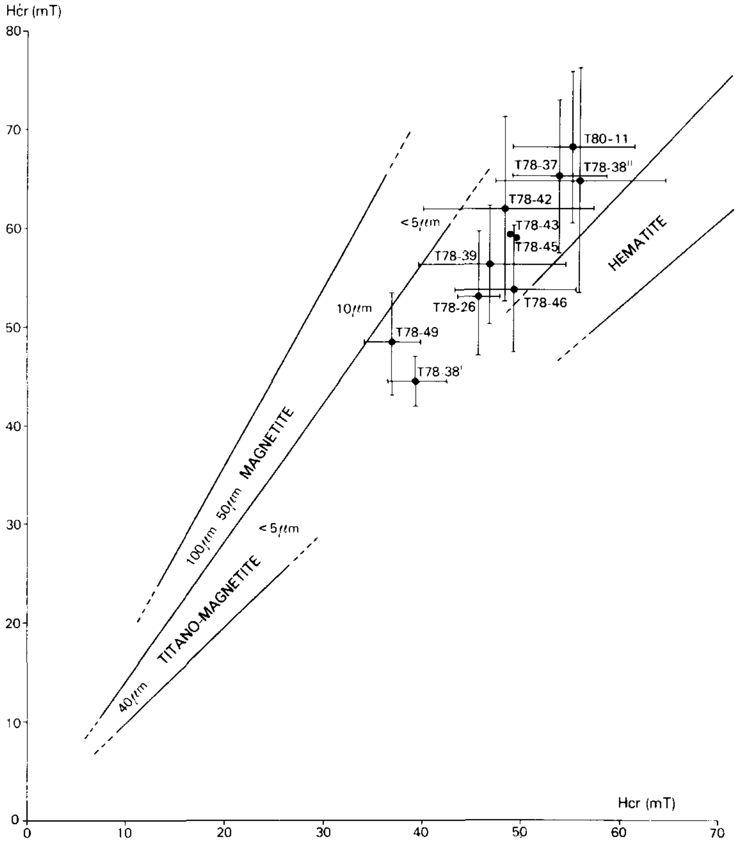

Fig. 12. Mean remanent acquisition coercive force (H'cr) plotted against mean remanent coercive force (Hcr); crosses indicate standard deviations (T78-38I: upper 4.2 m of core T78-38; T78-38II: lower part of T78-38). Boundaries between magnetite, titanomagnetite and haematite region and grain size values (μm) are derived from DANKERS (1981).

ly of IRM<200 and H'cr. The jumps from high NRM and SIRM values in the top of cores T78-38 (Fig. 7), -46 and -49 (Fig. 6) towards low intensities at greater depth are accompanied by a pronounced increase of IRM<200 and Hcr. Likewise the bimodal NRM and SIRM intensity pattern in the turbidite core T80-11 and in the turbidite sections of cores T78-42 and -43 is accompanied in cores -43 and -11 by a corresponding variation in IRM<200 and H'cr, large coercivities coinciding with low intensities (Fig. 9). The coincidence of high SIRM intensities with low coercivities may well be caused by a relatively large magnetite to haematite ratio for the magnetic fraction of the high intensity sediments.

3.2.2. MAGNETIC SUSCEPTIBILITY

The magnetic low field susceptibility (X) was determined for all samples (Table 2). The susceptibility tends to correlate with NRM intensity and SIRM intensity, although in the weakly magnetized sediments the correlation between susceptibility and NRM intensity is somewhat less than the correlation between NRM and SIRM.

The susceptibility of a sample is the sum of its diamagnetic, paramagnetic and ferromagnetic susceptibilities. The "ferromagnetic" susceptibility tends to dominate the total susceptibility, except in sediments with a very low content of magnetic minerals, and depends on the amount, grain size and composition of the magnetic mineral fraction. Since the susceptibility and SIRM are both proportional to the amount of magnetic minerals in a sample—provided the paramagnetic contribution to X is negligible—the ratio X to SIRM will not depend on the amount of magnetic mineral. Therefore, it is assumed that this ratio (LANSER, 1980; HARTSTRA, 1982) gives an indication of magnetic grain size, if the magnetic mineral fractions of the samples to be compared have indentical compositions. For magnetite the X to SIRM ratio varies from $7 \cdot 10^{-4}$ A^{-1} m for 250 μm to $2 \cdot 10^{-5}$ A^{-1} m for <5 μm (HARTSTRA, 1982) whereas for haematite the ratio X to SIRM is $<5 \cdot 10^{-6}$ A^{-1} m (THOMPSON *et al.*, 1980). For samples containing a mixture of magnetite and haematite the X to SIRM ratio will depend mainly on the grain size of the magnetite. Large X to SIRM ratios (>1) may occur if the susceptibility is dominated by paramagnetic susceptibility or by superparamagnetism. HARTSTRA (1982) published experimental curves for magnetite representing the relationship between grain size and the X to SIRM ratio. Following this relationship for magnetic grain sizes, present results imply that in cores T78-45, -46, -49, -38 -42 and -43 the magnetic grain size is generally larger than 100 μm, except in the high intensity top zone which yields extrapolated grain sizes of 5 to 20 μm.

As a magnetic grain size of 100 μm for the fine-grained hemipelagic sediments in these cores is quite unlikely, it is assumed that the large X to SIRM ratios for the weakly magnetized sediments are caused by relatively large contributions to total susceptibility of paramagnetic minerals or superparamagnetic fractions.

4. DISCUSSION

A majority of the cores of the Zaire fan (T78-37, -42, -43, -45, -46, -49) consists of sediments with a weak and partly unstable magnetization (VRM 30 to 50%). Although directions are scattered (Fig. 8), with little improvement when stepwise alternating field demagnetization is applied, the mean characteristic inclinations have low negative values, as one would expect for sediments from near equatorial southern latitudes, not more than a few hundred thousands years old. In the cores with prevailing high NRM intensities (T78-26, T80-11) the remanence directions show much less dispersion (Figs 2, 11 and 13). The inclination record of T78-26 is possibly a registration of secular variation during the Holocene.

The declination can be regarded as an indicator of possible rotations

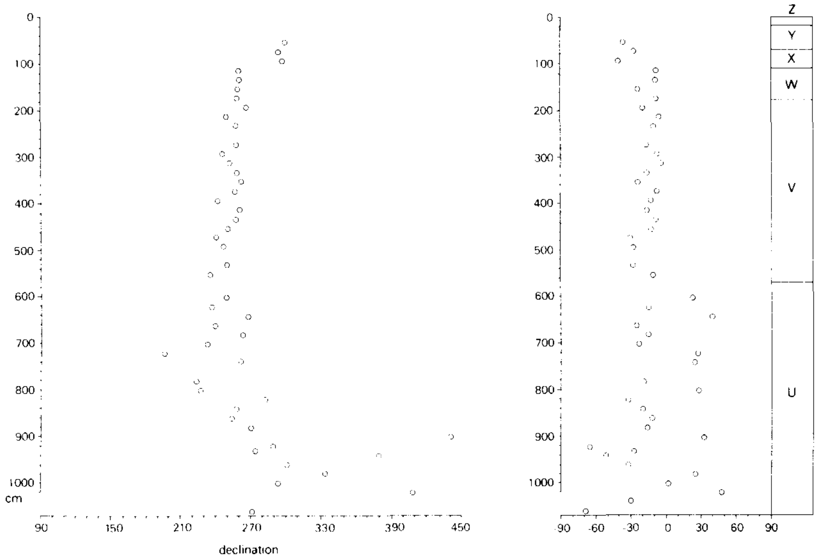

Fig. 13. Declination and inclination of characteristic Natural Remanent Magnetization (NRM) directions for core T78-38. Late Quaternary temperature zones (ERICKSON *et al.*, 1968) indicated (as the core is unoriented, declination values are given with respect to the splitface of the core).

of the corer during penetration of the bottom. Piston corer behaviour has been studied directly by McCoy (1980) with help of a compass and a camera mounted on the core head. He showed that often dramatic rotations of the corer occur during the coring process, and that abrupt rotations following initial penetration are normal. In T80-11 (Fig. 2) the declination first changes almost linearly over 200° from the top to 8.0 m and then from 8.0 m downwards changes in the opposite sense (Fig. 2). Apparently the corer inverted its sense of rotation during penetration. A gradual declination change of at least 180°, indicating large core rotations has also been found for cores T78-42 and -37.

Attempts to a detailed sedimentological interpretation of magneto-mineralogical results (H'cr, Hcr, IRM <200, SIRM) only make sense when the magnetic mineral fraction of the sediments has not been subjected too much to post-depositional changes. From the present results it appears that at least in the weakly magnetized sediments (cores T78-37, -42, -43, -45, -46, -49 and the lower 6.2 m of -38) the magnetic minerals have probably been largerly transformed into non-magnetic pyrite.

The upper, pelagic part of core T78-38 has likely been less influenced by the detritic sediment from the Zaire river than any of the other cores (Jansen *et al.*, 1984). It then seems reasonable to suppose that, comparing sediments of the same age, the sedimentation rate of magnetic material in the other cores has been at least that of the upper 4.2 m of core T78-38. In fact one expects the deposition rate of magnetic material in $g \cdot 10^{-3} \cdot y^{-1}$ surface unit to be larger in the fan region, since in the fan region the detritic output of the Zaire river has most probably also contributed to the magnetic mineral fraction of the sediments. From available age determinations and SIRM results for the pelagic and high intensity upper 4.2 m of core T78-38 an oceanic sedimentation rate M in $A \cdot m^{-1} \cdot 10^{-3} \cdot y^{-1}$ can be calculated, M defined as the mean SIRM intensity per sample divided by the mean duration of time which a sample of the core represents. If M is the contribution per 1000 y of the slow "oceanic" sedimentation to the SIRM of the fan sediments, the "oceanic" contribution to the mean SIRM of a sample from a pelagic fan core with length L and sedimentation rate S is given by: $M \cdot L \cdot S^{-1}$. The value of M for the upper 4.2 m (zones Z, Y, X, W and part of V) of core T78-38 is 1600 $A \cdot m^{-1} \cdot 10^{-3} \cdot y^{-1}$. This oceanic contribution to the SIRM per sample (Fig. 14) is indicated as a function of sedimentation rate together with the mean SIRM intensities which have actually been observed for hemipelagic fan sediments. The mean SIRM intensities for the high intensity of the upper 50 to 150 cm of cores T78-45, -49 and -46 (Table 2) are much larger than the calculated minimum value. This may be due to extra supply of magnetic material from the continent. The weakly magnetized parts of the fan cores, however, have much lower mean SIRM intensities than can be explained even by an oceanic contribution only. As possible explanation for this apparent deficiency of magnetic material it was assumed that a major part of the original magnetic material was chemically transformed into non-magnetic minerals (see above).

A sudden change in the original composition of the heavy mineral fraction would probably be accompanied by a more general change in mineralogy, but the jump in magnetic intensitiy in the cores for which detailed (clay)mineralogical information is available (T78-45, -46) does not coincide with a conspicuous change in clay mineralogy (VAN DER GAAST & JANSEN, 1984). This is an argument in favour of the postdepositional origin of the low NRM and SIRM intensities. In these cores pyrite occurs in appreciable quantities below the level where NRM and SIRM intensities incline steeply (Fig. 15). In core T78-46 this occurrence of pyrite is accompanied by a colour change

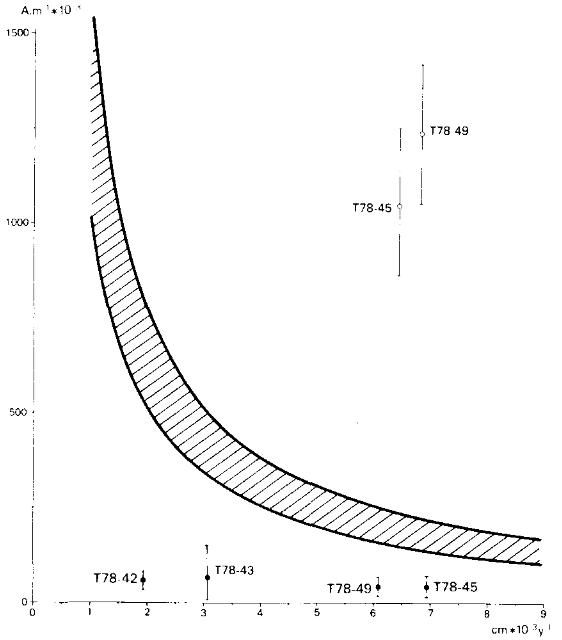

Fig. 14. Mean Saturation Isothermal Remanent Magnetization (SIRM) intensities plotted against mean sedimentation rate. Mean values for the weakly magnetized cores (O) and for the strongly magnetized top of some cores are given separately; the calculated contribution of "oceanic" sedimentation to SIRM intensity is indicated (hatched).

from yellow-brown to grey. Although detritic ironoxides are generally supposed to be relatively stable in environments favouring pyritisation (Berner, 1970; Graham, 1974), there are several reasons to believe that—given the right pE and pH conditions—ironoxides in marine sediments may actually be pyritised. In the first place, the possibility of such a pyritisation in anoxic sediments is suggested by the pE-pH equilibrium diagram of the Fe-S-H^2O system as recalculated by Henshaw & Merrill (1980). In the second place the actual occurrence of pyritised detritic ironoxides in marine cores has been observed by oremicroscop in the magnetic fraction of sediments from the Japan Sea (Kobayashi & Nomura, 1972). Furthermore, a relation between the onset of ironsulphide formation and a steep decline of NRM intensity in the upper part of cores—probably caused by pyritisation of magnetite—has recently been found for hemipelagic sediments from the Gulf of California and from the Oregon continental margin (Karlin & Levi, 1983). Pyritisation is therefore considered as the most likely cause of the low intensities. Since in cores T78-39, -42, -43, -45, -46 and -49 the zone of high intensity more or less coincides with the Z zone. Either the Z zone represents a period during which bottom circumstances did not favour pyritisation of detrital ironoxides or the magnetic mineral fraction of the Z zone sediments has not yet had enough time to pyritise.

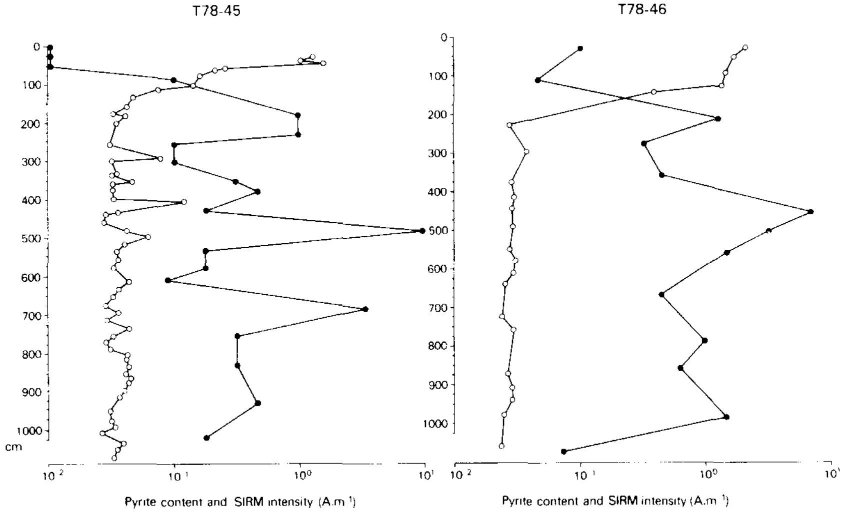

Fig. 15. Saturation Isothermal Remanent Magnetization (SIRM) intensity (○) and pyrite content (●) according to röntgendiffraction studies by van der Gaast & Jansen, (1984) in core T78-45 and -46.

In core T78-38 (Fig. 7) the magnetic intensity (and coercivity) jump at 4.20 m, although not coinciding with a change in clay mineralogy, probably corresponds with a change in the sedimentation rate of the non-carbonate fraction. According to JANSEN *et al.* (1984) the sedimentation rate of the non-magnetic fraction in this core changes between 4.5 m and 3 m from 1.4 $g \cdot cm^{-2} \cdot 10^{-3} \cdot y^{-1}$ before 400 000 yBP to 0.37 after 300 000 yBP. Results from smear-slides show that the sediments below 4.10 m contain appreciable amounts of silt-sized grains suggesting that the change from high to low sedimentation rate occurs at about this level. Both phenomena may be related. The change of SIRM intensity (by a factor of 30) and of coercivity indicates that the sediments below 4.5 m have much lower (titano)magnetite content than above 4.0 m. Either the original (titano)magnetite content of the depositing sediment did steeply increase after 360 000 yBP, or the magnetic boundary has a postdepositional (chemical) origin, as has been proposed for the intensity contrast in cores T78-45, -46, and -49 (page 000). As the sediments in the weakly magnetized part of core T78-38 contain significant amounts of pyrite, a mineral which is lacking in the high intensity upper 4 m of this core the last explanation seems most plausible. In that case the change in magnetic proporties between 4.5 and 4.0 m in this core reflects an ancient geochemical transition from reducing bottom conditions related to a high sedimentation rate to oxidizing bottom conditions during the deposition of the pelagic upper 4 m.

The jump from high to low intensities in cores T78-39, -43, -45, -46 and -49 is accompanied by a steep increase of IRM$>$200 and H'cr (Figs 5 and 6), suggesting that pyritisation has caused an increase in coercivity. As the value of the coercivity of magnetite and haematite increased with decreasing of grain size, the coercivity increase could be explained by a decrease of magnetic grain size caused by pyritisation. The coercivity contrast between the high and low intensity part of core T78-38 is related to a change in sedimentation rate and may partly reflect an original difference in the magnetomineralogy of these core parts.

In the Zaire fan sedimentation rates calculated on a carbonate free basis are systematically higher for the cold Y and W periods than for the warm Z, X and V periods (JANSEN *et al.*, 1984). This variation in the supply of the detrital material from the continent may have caused a variation in the original magnetomineralogy of the sediments. I calculated the mean values of H'cr and IRM$<$200 for the warm and cold periods in each core of sufficient length to cover several such periods (cores T78-42, -43, -45 and -49). In spite of the conclusion that the major part of the original magnetic minerals has changed in pyrite,

TABLE 3

Mean values and ranges of the percentages of total intensity of the isothermal saturation remanence acquired at field intensities higher than 200 mT (IRM > 200), calculated for the zones Z, Y, X, W and V in cores from the Zaire fan (turbidites in the V-zone of T78-42 and T78-43 excluded).

Zone	*IRM > 200*					
	T78-42	*T78-43*	*T78-45*	*T78-46*	*T78-49*	*Mean*
Z (warm)		12.1	10 ± 0.6	11.1 ± 1.5	5.8 ± 2.7	9.3 ± 1.7
Y (cold)	16.9 ± 6.6	20.8 ± 8.5	16.2 ± 6.6	12.8 ± 4.5	9.9 ± 2.7	15.95 ± 6.1
X (warm)	15.6 ± 9.9	9 ± 4.7	12.3 ± 4		9.4 ± 2.4	11.6 ± 5.3
W (cold)	14.7 ± 5	13.5 ± 3.2	13.7 ± 3.6		12.4 ± 4.3	13.6 ± 4
V (warm)	12.4 ± 1.7	11.3 ± 5.3				11.9 ± 3.5

the mean values of these parameters show a rather consistent relation to climatic variation, cold periods having systematically higher mean IRM < 200 and H'cr values (Table 3) than warm periods. The observed relation is in agreement with the view that high IRM < 200 and H'cr values indicate a relatively large contribution of continental haematite to the magnetic fraction of the sediments, suggesting that the magnetomineralogical relict which has escaped pyritisation may still partly reflect variations in the original mineralogy of the sediments.

5. SUMMARY

The characteristic directions of the Natural Remanent Magnetization (NRM) and some rockmagnetic parameters have been determined as a function of stratigraphic position in 10 cores from the Zaire submarine fan.

Most of the sediments have a weak and partly unstable NRM. The top 50 to 150 cm of many cores show a higher NRM intensity. The prevailing low NRM intensities are likely to be a consequence of pyritisation of a major part of the magnetic mineral fraction. Low negative values for the mean characteristic inclination are in accordance with near equatorial sediments of not more than a few hundred thousand years. A correlation of relatively high mean values for the remanent hysteresis parameters H'cr and IRM > 200 with cold climatic periods suggests that the magnetic relict which has escaped pyritisation may still reflect original variations in magnetomineralogy.

6. RÉSUMÉ

UNE ÉTUDE PALAÉOMAGNÉTIQUE ET DE MINÉRALOGIE MAGNÉTIQUE DES SÉDIMENTS CAROTTÉS DU DELTA PROFOND DU ZAIRE

Les directions caractéristiques de la magnétisation rémanente naturelle (NRM) et de quelques paramètres de minéralogie magnétique ont été déterminés en fonction de la stratigraphie dans 10 carottes du delta sous-marin du Zaïre.

Beaucoup de sédiments ont une faible et en partie instable NRM. Les 50 à 150 cm du toit de plusieurs carottes montre une NRM plus élevée. Les basses NRM dominantes sont attribuées à une consequence de la pyritisation de la plus grande partie de la fraction minérale magnétique. Les basses valeurs négatives de l'inclination caractéristique moyenne sont celles connues pour des sédiments proches de l'équateur et âgés de pas plus que quelques centaines de milliers d'années. Une corrélation des valeurs moyennes relativements les plus élevées correspondant aux paramètres rémanents d'hysteresis H'cr et IRM > 200 avec les périodes climatiques froides suggère que les reliques magnétiques qui ont échappé à la pyritisation peuvent encore refléter les variations originelles du magnétisme des minéraux.

7. REFERENCES

Berner, R.A., 1971. Principles of chemical sedimentology. McGraw-Hill, New York: 1-240.

Dankers, P., 1981. Relationship between median destructive field and remanent coercive forces for dispersed natural magnetite, titanomagnetite and haematite.—Geophys. J. R. Astr. Soc. **64:** 447-461.

Erickson, D.B. & G. Wollin, 1968. Pleistocene climates and chronology in deep-sea sediments.—Bull. geol. Soc. Am. **72:** 193-286.

Gaast, van der, S.J. & J.H.F. Jansen, 1984. Mineralogy, opal and manganese of Middle and Late Quaternary sediments of the Zaire (Congo) deep-sea fan: origin and climatic variation.—Neth. J. Sea Res. **17** (2-4): 313-341.

Graham, S., 1974. Remanent magnetization of modern tidal flat sediments from San Francisco bay, California.—Geology **2** (5): 223-226.

Hartstra, R.L., 1982. Grainsize dependence of initial susceptibility and saturation magnetization related parameters of four natural magnetites in the PSD-MD range.—Geophys. J. R. Astr. Soc. **71:** 447-495.

Heezen, *et al.*, 1964. Congo submarine canyon.—Bull. Am. Ass. Petrol. Geol. **48** (7): 1126-1149.

Henshaw, P.C. & R.T. Merrill, 1980. Magnetic and chemical changes in marine sediments.—Rev. Geophys. Space Phys. **18:** 483-504.

Jansen, J.H.F., T.C.E. van Weering, R. Gieles, & J. van Iperen, 1984. Middle and Late Quaternary oceanography and climatology of the Zaire-Congo fan and the adjacent eastern Angola Basin.—Neth. J. Sea Res. **17** (2-4): 201-249.

Karlin, R. & S. Levi, 1983. Diagenesis of magnetic minerals in recent hemipelagic sediments.—Nature, Lond. **303:** 327-330.

KOBAYASHI, K. & M. NOMURA, 1972. Iron-sulphides in the sediment cores from the sea of Japan and their geophysical implications.—Earth planet. Sci. Lett. **16:** 200-208.

——, 1974. Ferromagnetic minerals in the sediment cores collected from the Pacific basin.—J. geophys. Res. **40:** 501-512.

LANSER, J.P., 1974. Palaeomagnetism of some Late Quaternary sediments. Thesis, Univ. of Amsterdam: 1-145.

LØVLIE, R., 1971. Magnetic properties and mineralogy of four deep-sea cores.—Earth planet. Sci. Lett. **15:** 157-168.

McCOY, F., 1980. Photographic analysis of coring.—Mar. Geol. **38:** 263-282.

THOMPSON, R. *et al.*, 1980. Environmental applications of magnetic measurements.—Science, N.Y. **207:** 481-486.

ZIJDERVELD, J.D.A., 1967. A.C. demagnetization of rocks: analysis of results. In: D.W. COLLINSON, K.M. CREER & S.K. RUNCORN. Methods in palaeomagnetism. Elsevier, Amsterdam: 254-286.