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Particle-size related, mineral magnetic source sediment linkages in the Rhode River catchment, Maryland, USA

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SUMMARY: Characterization of both the source materials and the bottom sediments of an estuary by magnetic characters, on a particle size basis, allows the source of the bottom sediments to be determined and indicates a shift in sediment sources, corresponding to changing land-use patterns. The major source of the sediments in the lower part of cores from the middle of the estuary is eroding shorelines. Soil-derived particulates, from the uplands, dominate the upper part of the cores. This change in source occurred in the early part of the 19th century. The magnetic character of the most recent sediments suggests a progressive depletion, through time, of the upland soils in the finest fractions.

Several published studies use the magnetic properties of sediments to identify the type of source environment from which they were derived (e.g., Oldfield *et al.* 1979; Walling *et al.* 1979). The Rhode River magnetic study was started in 1980 as an extension of the previous work, which had been based largely on fresh water rather than estuarine systems. Two challenges for the emerging methodology were regarded as especially important. The first was to develop and evaluate a comprehensive magnetic approach to catchment studies, through every stage from field survey to detailed source and sediment characterization (Oldfield 1983). The second was to prevent coincidental or invalid sediment source identification, by attempting a detailed magnetic characterization of sources and sediments using where possible mutually independent magnetic parameters measured on a particle size-related basis. The present account focuses on this latter aspect of the work.

Physical setting

The Rhode River is a tidal estuary on the western shore of Chesapeake Bay (Fig. 1) some 10 km south of Annapolis, Maryland. The surface waters of the estuary comprise 485 ha and the total catchment is 3332 ha. The tidal range is low (<1 m) and the estuary is shallow, with no strongly developed deep channels and a maximum water depth of about 4 m at its mouth. The open water is mainly bordered by gentle wooded slopes though here are extensive salt marshes along the southern shoreline and, more locally, actively eroding cliff sections exposed to wave action. In particular, the islands in the estuary are scarred by conspicuous cliffs. Relief overall is low, with no part of the catchment above 180 m. The underlying bedrock comprises a variety of sedimentary types. Very restricted exposures of Marlboro Clay are overlaid by the sandy, glauconitic, Eocene, Nanjemoy formation, the sandy and diatomaceous sediments of the Miocene Calvert formation, and the alluvium of the Talbot formation. The Nanjemoy and Talbot formations are the only important lithologies in the lower parts of the catchment and around the water's edge. Of the actively eroding cliffs, only one is in the Talbot alluvium, the rest are in Nanjemoy sands. Most of the higher ground in the catchment is developed on Calvert sediments or the locally overlying Sunderland terrace deposits. The well drained parts of the catchment are deeply weathered, and soils are mostly eluviated sandy loams. More locally, gleyed soils occur in streamside locations, and the main drainage system is flanked in its lower reaches by an extensive swamp.

The climate is humid through most of the year with a mean annual average precipitation of 1120 mm (Brush *et al.* 1980). There is a tendency to sudden heavy rain-storms in spring and summer, as well as occasional severe hurricanes. No significant transport of material coarser than 3 mm occurs in the catchment, most of which lacks particles larger than this. Only very locally are stream channels incised, and active channel erosion is very limited. Characteristically, at low flow, streams dwindle to a narrow thread of water within a residual sandy-bedded channel between banks of graded and subhorizontally bedded sands, silts and clays laid down during the receding levels of preceding floods. It is apparent from the channel morphology that large volumes of fine sediment are in transit and temporarily stored within the fluvial system.

As part of the Rhode River ecosystem monitoring programme operated by the Smithsonian Institution, several stream gauging stations are maintained, four of which are located on Fig. 1. Three of these are at the outfall of small predominantly single land use catch-

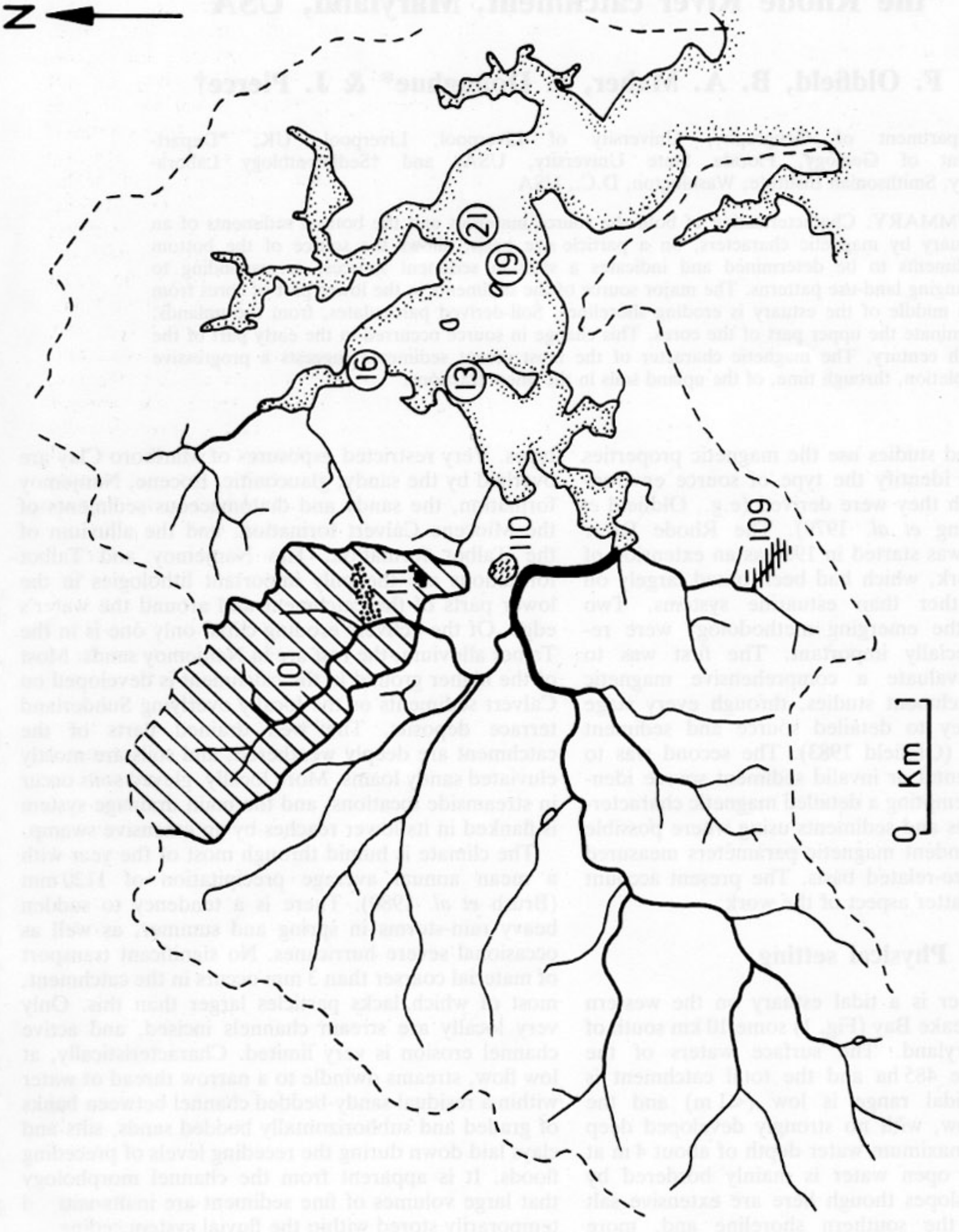

FIG. 1. The Rhode River Catchment. Numbers 101–111 locate the monitored subcatchments from which suspended sediment samples were taken.
101—large mixed land use
111—pasture subcatchment within 101
110—forest
109—corn crop
Numbers 13, 16, 19 and 21 show the location of the four sediment cores used in the present study.

ments—number 109 (cultivated crops—corn and tobacco); 110 (mixed hardwood forest); and 111 (pasture); the fourth, 101, is a large mixed land use catchment which includes 111. Further details of geology and land use, and of the hydrological/sedimentological monitoring programme are given in Correll (1977). The main objective of the monitoring programme is to assess the contribution of non-point pollution sources to the waters of the Bay by making a detailed study of the relationship between land use and water and sediment quality in a small rural watershed.

Sediment sources

There are three potential major sediment sources for the estuary. First, the conspicuous eroding cliffs provide large volumes of predominantly Nanjemoy bedrock and associated deeply weathered subsoil close to the cliffs themselves. This is the local expression of a much more widespread coastal erosion problem round Chesapeake Bay (Slaughter *et al.* 1976). Second, the terrestrial surfaces of the catchment are extensively cultivated. Pierce & Dulong (1977), using data from the suspended sediment sampling programme for the mixed land use catchment 101, calculate a loss of 511 kg/ha/yr for 1975. This implies that erosion rates for the catchment range from 5 to 16 cm/1000 years depending on the total output ascribed to the cultivated parts of the catchment. Third, a significant tidal influx of sediment into the Rhode River from the open waters of Chesapeake Bay is possible. Donoghue (1981) suggests this may contribute up to 17% of the current sediment.

Clearly all these sources, and others less significant at present, have responded to both physiographic and anthropogenic changes over the past few centuries. Notable changes include the isostatic sea-level rise estimated by Donoghue at over 2.7 mm per year for the last millenium; the land use changes that have occurred after the first colonial settlements in the area some 300 years ago; and the recent great increase in power-boating and associated developments along the shores of the 'River'.

Methods

At the beginning of the project, estuarine cores from 1 to 2.5 m in length, including the ones used in the present study, were already available for study (Donoghue 1981), and others were taken subsequently using a simple hand operated piston corer. Samples from several cores had already been used for ^{14}C, ^{210}Pb and ^{137}Cs assay. All cores were scanned for volume susceptibility variations, using successive versions of the Bartington wholecore susceptibility measuring equipment. Examples of whole core traces are shown in Oldfield (1983). These scans confirm that the cores used in the present study are typical of all those taken from non-marginal environments within the Rhode river. Subsequently cores were sliced and subsampled for more detailed measurement.

During the course of the study, samples were taken for mineral magnetic characterization from the following: deep reference soil profiles in Nanjemoy, Calvert and Talbot formation exposures; a variety of field surface flow features in the aftermath of heavy storms; stream channels and the banks of fine contemporary alluvial sediment on either side; areas of water ponding behind the weirs built at each gauging station; the suspended sediment samples taken at each gauging station during flood events in a routine monitoring programme; the suspended sediments of the open estuary; and surface sediments within the Rhode River and beyond its mouth. Particle size separation was done on material from the full range of soils and sediments sampled. Table 1 summarizes the magnetic parameters and instrumentation used in the present study. Standard magnetic characterization for virtually all bulk samples comprised measurement of low field magnetic susceptibility χ, frequency dependent susceptibility $\chi_{fd}\%$ Saturation Isothermal Remanent Magnetization (SIRM), IRM_{-20mT}/SIRM, IRM_{-40MT}/SIRM, IRM_{-100mT}/SIRM and IRM_{-300mT}/SIRM. Full coercivity of SIRM profiles were produced for 24 samples using 12 to 14 reverse fields. Particle size-related measurements were carried out on catchment soils by dispersing material in calgon, then dry sieving down to 4ϕ and separating the finer grades (5ϕ to 10ϕ and less) by the pipette method. Samples of size grades 5ϕ to 9ϕ thus always include additional material of the finer grades. Where weight determinations and magnetic measurements are sufficiently accurate, parameters can be determined for individual grades by means of subtraction and recalculation (Fig. 3).

The sediment cores used in the present account were divided into sand, silt and clay fractions only, and we focus especially on comparisons between sources and sediments, based on the aggregated 'sand' and 'clay' derived results.

Results from catchment surface samples

Fig. 2 plots χ, $\chi_{fd}\%$, SIRM, SIRM/χ and IRM_{-100mT}/SIRM for a selection of representative surface soils and for samples taken from eroding cliffs (cf. Oldfield 1983, Fig. 6.5, and Thompson & Oldfield in press, Ch. 16). $\chi_{fd}\%$ and SIRM are consistently much higher in the soils than in the cliff samples. In the soils SIRM/χ is also much higher and IRM_{-100mT}/SIRM, though variable in both sets, tends to be less scattered and generally rather lower, (i.e., more strongly negative).

Fig. 3 plots the mean values for χ, SIRM/χ and IRM_{-100mT}/SIRM on a particle size related bases for

TABLE 1: *Magnetic parameters and instrumentation*

χ	*Magnetic susceptibility:* the ratio of magnetization induced to intensity of the magnetizing field. This is measured within a small magnetic field, and is reversible (i.e., no remanence is induced). Can be measured on a volume (κ) or mass specific (χ) basis. Often roughly proportional to the concentration of ferrimagnetic minerals within a sample. *Instrumentation:* −20 cm search loop, ferrite probe, core loop (κ) −Single sample susceptibility sensor (χ)
χ_{fd}	*Frequency dependent* (incorrectly termed quadrature in Oldfield, 1983) *susceptibility:* the variation of susceptibility with frequency. This parameter indicates the presence of viscous grains lying at the stable single domain/superparamagnetic boundary, and their delayed response to the magnetizing field. Expressed here as a % of total low frequency susceptibility (χ_{fd}%). *Instrumentation:* Dual frequency susceptibility sensor
ARM	*Anhysteretic remanent magnetization:* if a sample is subjected to a decreasing alternating field (100 mT–OmT) with a small (0.4 mT) steady field superimposed, it acquires an anhysteretic remanence. This parameter can be related to the concentration and the presence of finer grain sizes of ferrimagnetic minerals in a sample. *Instrumentation:* Anhysteretic remanent magnetizer
SIRM	*Saturation isothermal remanent magnetization:* the highest volume of magnetic remanence that can be produced in a sample by application of a very high field (here usually 0.83T). SIRM relates to both mineral type and concentration. *Instrumentation:* Pulse magnetizer, fluxgate magnetometer
SIRM/χ	The ratio of these 2 parameters can be diagnostic of either mineralogy type, (e.g., a low—theoretically zero—ratio indicates the presence of paramagnetic minerals), or, where samples have similar mineral types and concentrations, the dominant magnetic grain size.
$(BO)_{(cr)}$, IRM_{-x}/SIRM, 'S'	*Demagnetization parameters:* obtained by applying one or more reversed magnetic field(s) to a previously saturated sample. The reverse field strength required to return a magnetized sample from its SIRM to zero is termed the coercivity of remanence ($BO_{(cr)}$). The loss of magnetization at other selected backfields can be expressed as a ratio, IRM_{-x}/SIRM (giving a result from +1 to −1); the ratio obtained using IRM_{-100mT}, (a backfield which discriminates between ferrimagnetic and antiferromagnetic mineral types) has been termed the 'S' value. *Instrumentation:* Pulse magnetizer (pm), fluxgate magnetometer (mm)

11 'catchment' samples, ranging from soil aggregates to more sorted material recovered from field surface and stream-side localities immediately after storm events. Although sands comprise almost 70% of the sample weights, they contribute less than 20% to the mean SIRM of the bulk samples. The clay fractions though less than 20% by weight contributes almost 40% to the bulk SIRM of the material. Clays and silts together dominate the bulk magnetic properties of the catchment surface samples. The degree to which the finest grades dominate is certainly underestimated in the present data as a result of incomplete particle dispersal. In the coarsest sands high SIRM and χ are recorded and relatively high SIRM/χ.

IRM_{-100mT}/SIRM values are strongly negative. The medium sands have minimum SIRM, χ and SIRM/χ values, and the IRM_{-100mT}/SIRM values are much less strongly negative. A much 'harder' magnetic mineral assemblage is indicated.

Fig. 4 plots full coercivity of SIRM curves for selected size fraction samples for surface soils, and for bulk samples from reference soil profiles. It illustrates the distinctions already noted between the coarse sands, (e.g., 1 and 3ϕ), medium sands (3 and 4ϕ) and clays (9ϕ).

The magnetic mineralogy of the Rhode River catchment

In attempting to characterize the magnetic mineralogy of the potential sources in the catchment, additional attention has been paid to Nanjemoy bedrock exposures, and to reference soil profiles (Oldfield 1983; Thompson & Oldfield in press Ch. 16) in both Nanjemoy and Talbot formations, as well as to the surface soils developed on all the catchment lithologies.

The magnetic mineral assemblages present in natural soil and sediment samples are almost invariably rather complex (Maher 1984). Moreover it is rarely possible to use magnetic properties alone to establish in fully quantitative terms the relative contribution of different mineral and grain size types. It is however

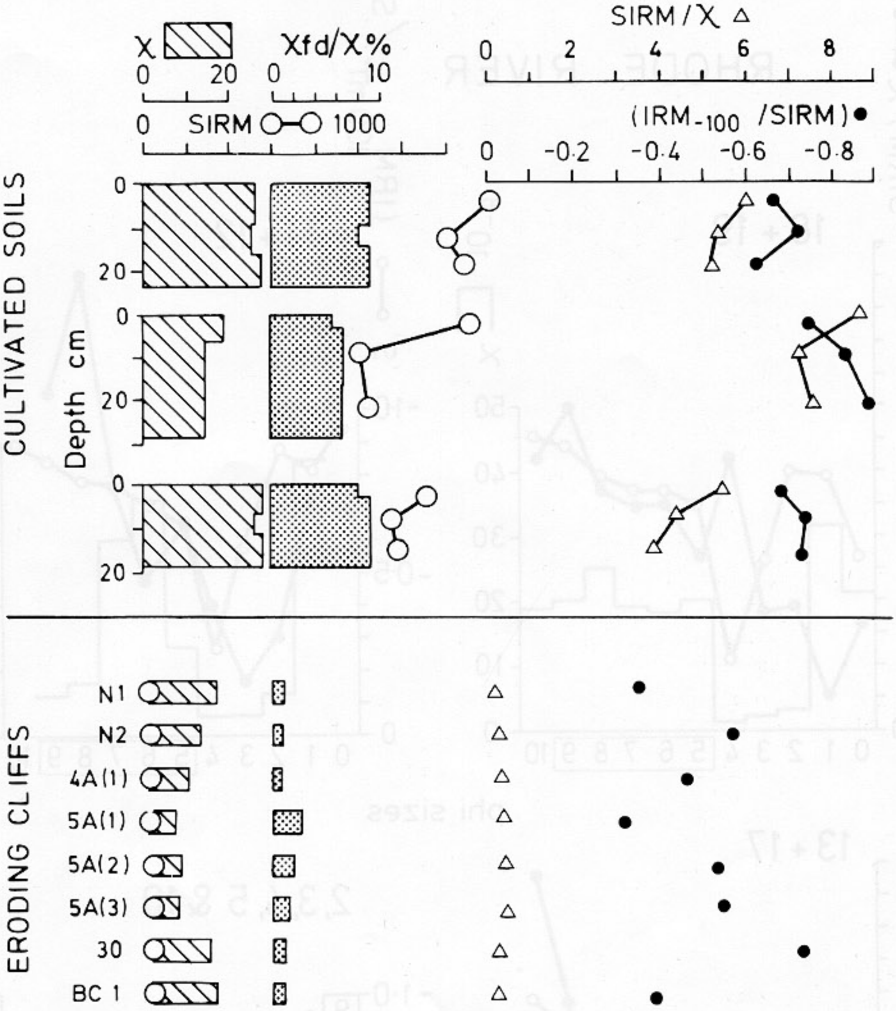

FIG. 2. Magnetic properties of some typical cultivated soils and parent materials from the Rhode River Catchment. The three upper plots are from the top 18–28 cms of three soil profiles (501, 503, 504) typical of the 14 profiles samples. The lower plots refer to samples taken from unweathered and partially weathered parent material exposed in eroding cliff sections along the shoreline. The histograms plot the values for total susceptibility (χ) and frequency dependent susceptibility ($\chi_{\text{fd}}\%$). Open circles plot SIRM, triangles SIRM/χ and closed circles IRM$_{-100}$/SIRM. The soil sample set shows consistently higher values for $\chi_{\text{fd}}\%$, SIRM and SIRM/χ. Mean values for χ are higher and for IRM$_{-100}$/SIRM more strongly negative in the soils, but in both cases the range of values overlaps between sample sets (Oldfield 1983; Thompson & Oldfield, in press). SIRM is plotted as 10^{-6} Am^{2}kg^{-1}; χ as 10^{-8} SI Units and SIRM/χ as kAm^{-1}.

often possible so to characterize the magnetic properties of a soil or sediment sample as to identify what is essentially its distinctive magnetic 'finger print'. Moreover, this can often be interpreted in mineralogical and grain size terms at least qualitatively (Thompson & Oldfield, in press).

The range of magnetic parameters characteristic of potential sediment source types within the Rhode River is shown in Fig. 2. The unweathered parent materials are characterized by low SIRM and $\chi_{\text{fd}}\%$ values and very low SIRM/ratios. Hysteresis loop plots made using a vibrating sample Magnetometer (Thompson & Oldfield, in press), and Mossbauer spectra (Maher 1984) confirm that the parent materials are very rich in paramagnetic forms of iron which contribute to χ but not to χ_{fd} or SIRM. Such remanence carrying oxides as are present are in very low concentrations. They have a low coercivity of

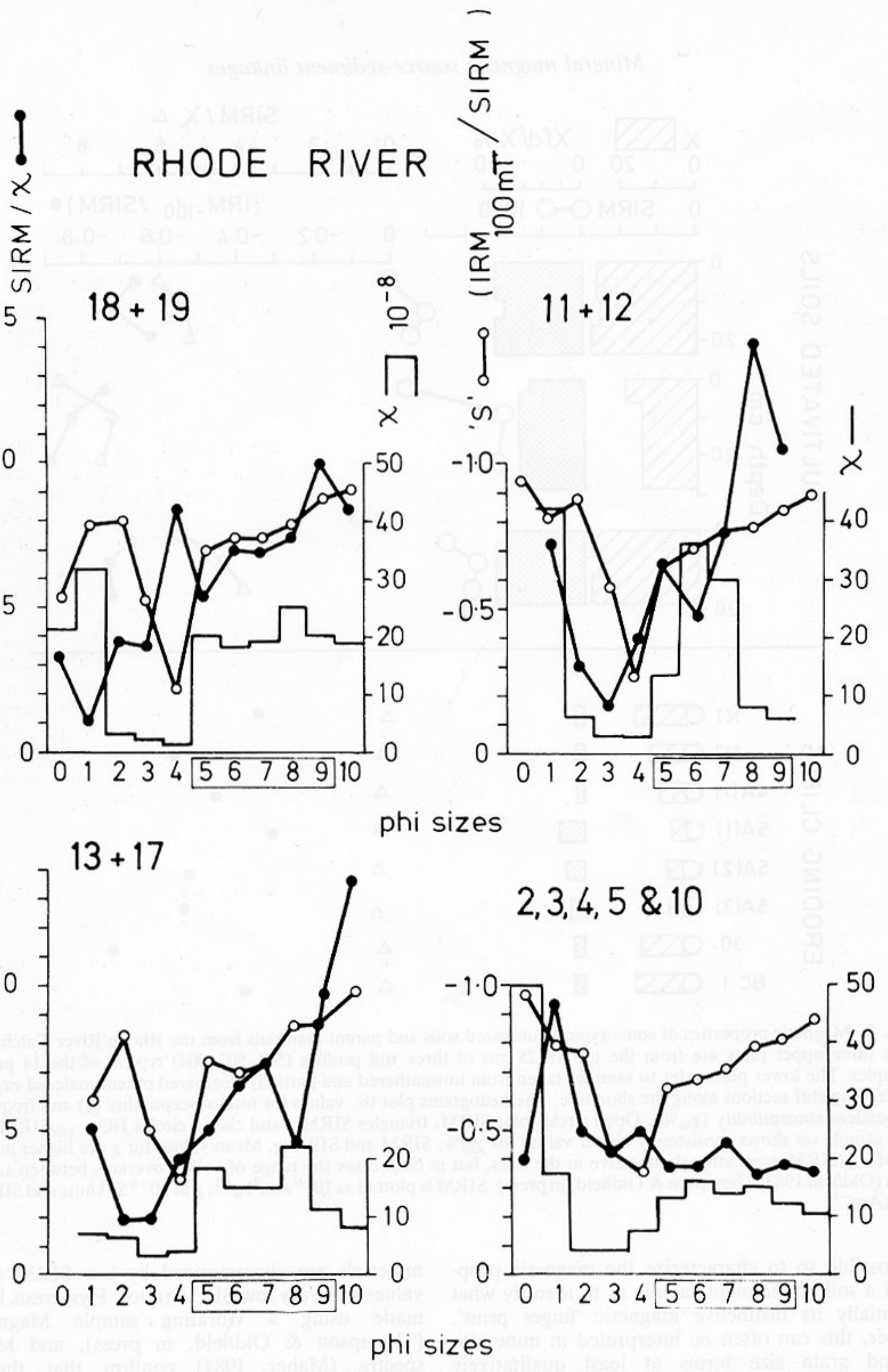

FIG. 3. Magnetic properties of particle size fractions from catchment samples. Samples have been combined to provide enough material for particle size related measurements. Samples 18 and 19 are of tilled soils with well developed aggregate structure. Samples 11, 12, 13 and 17 are of material left behind in the form of flow features on the surface of catchment 109 immediately after a major flood. Samples 11 and 12 are from lobes of relatively coarse, sandy material, samples 13 and 17 are of finer material from areas of surface water ponding. Samples 2, 3, 4, 5 and 10 are from the within-channel sediments of the river draining catchment 101 and they range from clayey silts to silty sands. Magnetic properties χ, SIRM/χ and IRM$_{-100}$/SIRM are plotted against phi sizes. Samples were dispersed in calgon. Phi sizes 0 to 4 were obtained by dry sieving, Samples 5–9 each include material of finer grade (see text).

remanence $(Bo)_{CR}$ and are fully reverse saturated in fields less than 300 mT (see Fig. 4(b)). This suggests that these are predominantly ferrimagnetic. The evidence shows that these magnetic oxides are present in the coarse sand fraction (Fig. 4a).

Samples from the weathered illuviated subsoils, which often include strongly ferruginated 'B' horizons, have intermediate χ, $\chi_{fd}\%$ and SIRM values and include many with a much higher coercivity of remanence (>100 mT) than samples above and below. These samples fail to saturate even in reverse fields well above 500 mT. This behaviour is characteristic of fine grained canted anti-ferromagnetic minerals such as hematite and goethite, both of which are common in deeply weathered soils (Schwertmann & Taylor 1977).

Surface soils have high SIRM, ~, SIRM/χ and $\chi_{fd}\%$. Coercivity of remanence curves are typical of fine grained magnetite. The high $\chi_{fd}\%$ confirms that the grains responsible include a significant number just below the lower volume limits for true stable single domain grains (~0.3 μm diameter) (King *et al.* 1982; Mullins & Tite 1973). The bulk magnetic properties of surface soils are dominated by fine secondary ferrimagnetic grains present in the clay size particles (Le Borgne 1955; Mullins 1977; Longworth *et al.* 1979) though the sand size particles have varied magnetic properties, comparable to the sand fractions deeper in the regolith.

In summary, the following four magnetic components can be identified in the soils and substrates of the Rhode River catchment:

Primary ferrimagnetic component

This is present in the unweathered Nanjemoy sands below the conspicuous zones of ferrugination found at all well drained sites. Very low or zero $\chi_{fd}\%$ values (Fig. 2) coupled with low coercivity of remanence and rapid viscous loss of isothermal remanence suggest that this material is predominantly multidomain.

Secondary antiferromagnetic component

This is especially significant in iron-enriched illuviated subsoil horizons. In extreme cases up to 95 per cent of the SIRM remains unsaturated in a reverse field of $0.3T$ and $(B_0)_{CR}$ exceeds $0.2T$ (Oldfield 1983). This component could be either hematite or goethite.

Secondary ferrimagnetic component

Present in all non-gleyed surface soils, this gives rise to near surface peaks in χ, $\chi_{fd}\%$, SIRM and SIRM/χ. All the mineral magnetic characteristics indicate a stable, single-domain, fine viscous and superparamagnetic assemblage, typical of surface enhancement, whether by fire or 'fermentation' (Mullins 1979). Magnetite and/or maghemite may be represented.

Paramagnetic component

Abundant in all but the eluviated A horizons of freely drained soils, this gives rise to very low SIRM/χ values in the Nanjemoy parent material.

Components 1 and 4 dominate the magnetic characteristics of bulk samples in the extensive unweathered Nanjemoy cliff sections. At higher levels in the regolith, components 2 and 4 dominate, although residual primary ferrimagnetic crystals are still present. In surface soils, component 3 dominates the magnetic characteristics though, especially where soils are mixed by ploughing, all four components are present. Measurements of particle size splits of these mixed soils show that component 3 dominates in the finest clay fractions, component 2 and 4 in the medium to fine sands, and component 1 in the coarser sands, (Figs 3 and 4). Components 1, 2 and 3 may be regarded as conservative components on the timescales of interest in the present account. The paramagnetic component includes readily soluble iron likely to change phase during erosion, transport and subsequent deposition. During removal from the field surfaces and temporary deposition in the channel zone the soluble iron is dissociated from the sand fraction to become associated with finer clay and silt sized particles. For this reason SIRM/χ has not been used here as a key parameter in source characterization.

Results from non-marginal sediment cores

Figure 5 plots the results for core 13, taken from a central location in the estuary. χ, SIRM, SIRM/χ and $\chi_{fd}\%$ are plotted for both the sand and clay fractions in each sample. Above 90 cm the clay fraction dominates the bulk properties and has high χ, SIRM, $\chi_{fd}\%$ and SIRM/χ values. Below this depth the clay and sand contribute more nearly equally to the χ and SIRM, and the SIRM, χ, $\chi_{fd}\%$ and SIRM/χ values are much lower. Only in the clays of the upper samples is $\chi_{fd}\%$ high. In the sands, $\chi_{fd}\%$ values are negligible throughout.

Figure 6 compares plots of SIRM versus IRM_{-100mT}/SIRM for sand and clay fractions from each of the individual catchment surface samples, both for aggregate suspended sediment samples from the weir at the outflow of catchment 101 (mixed land use), and for the clay fractions only from the upper and lower parts of three non-marginal cores 13, 16 and 19 (Fig. 1). In the upper part of each core the parameters are comparable to the contemporary surface clays rich in enhanced secondary ferrimagnetic oxides. In the lower parts of each core the samples are more closely comparable to

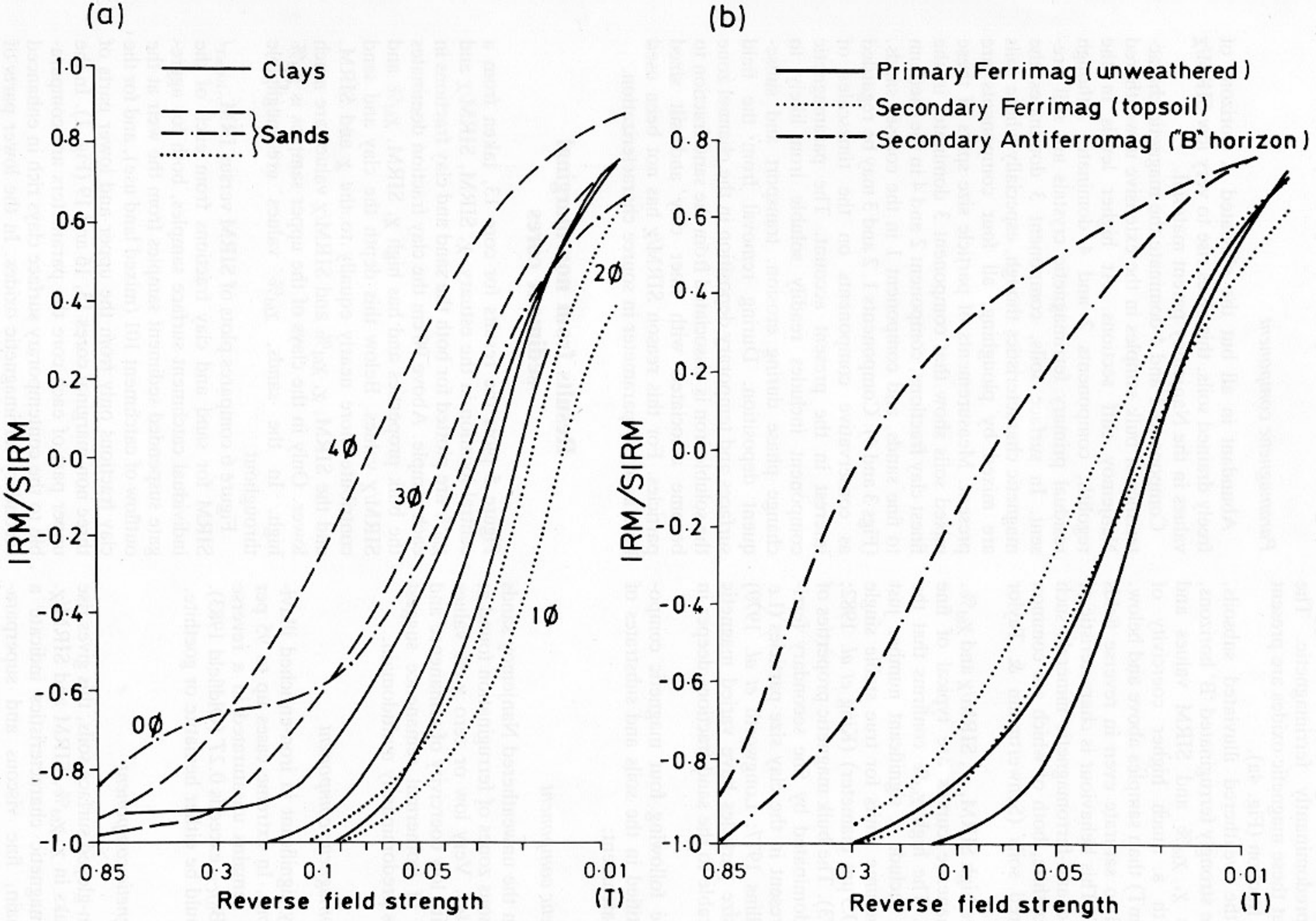

FIG. 4. Coercivity of SIRM curves for selected catchment samples. 4(a) illustrates the relationship between coercivity and particle size. The clay size samples have coercivity curves within a relatively narrow range. The sands include samples (1ϕ and 2ϕ) with low coercivities which are fully reverse saturated in fields below 10 mT. Sand samples 3ϕ and 4ϕ have much higher coercivities and are not reverse saturated even in fields as high as 850 mT. The coarsest sample 0ϕ, has a strongly inflected curve with both 'hard' and 'soft' components. 4(b) illustrates the relationship between soil development and coercivity. The two samples of deep unweathered parent material have low coercivities and are reverse saturated in fields less than 300 mT. The two samples from the iron-rich illuviated 'B' horizon have high coercivities and are not fully reverse saturated even at 800 mT. The surface soil samples have lower coercivities, but the IRM's are not as 'soft' as those of the unweathered parent material.

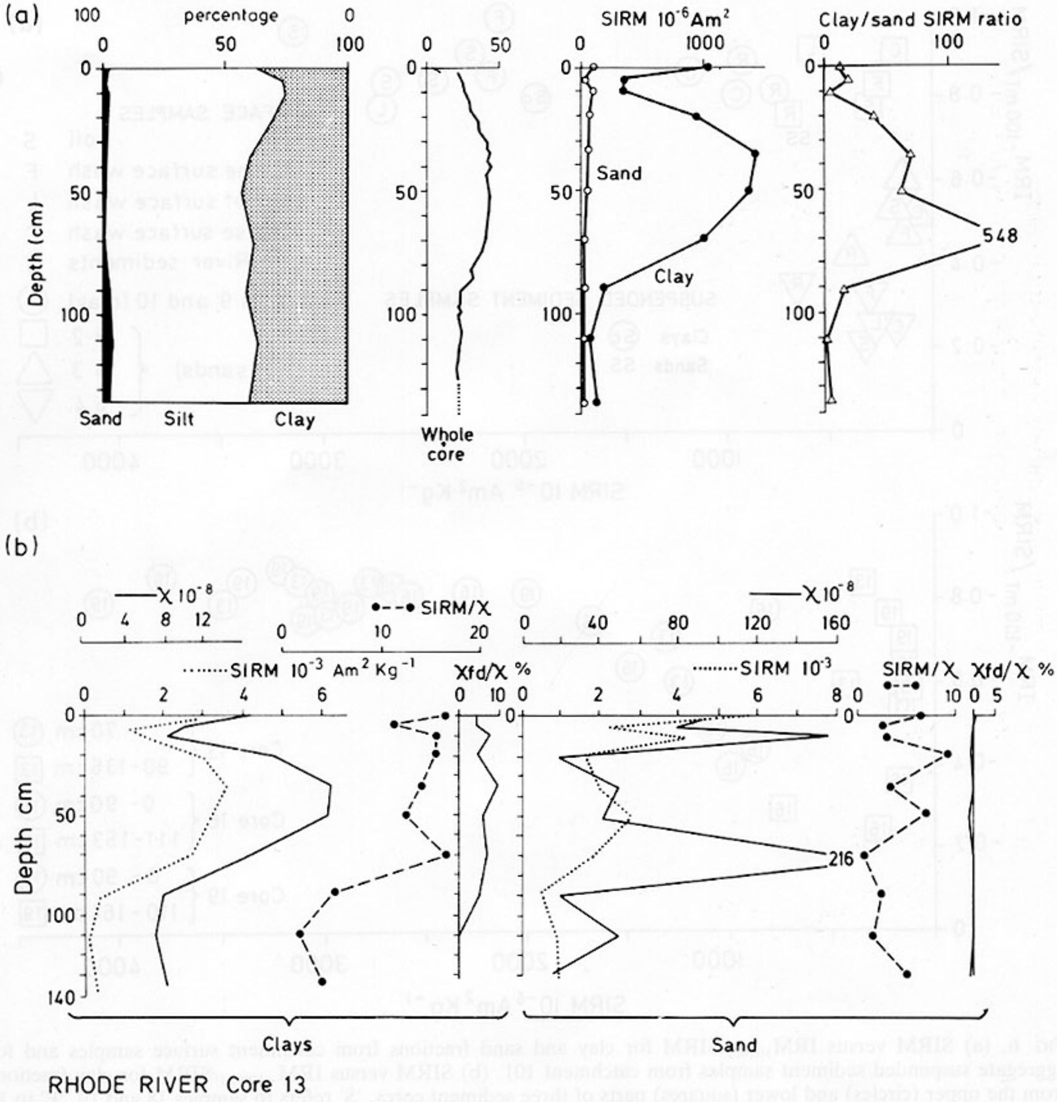

FIG. 5. Particle-size related magnetic measurements from Core 13. 5(a) shows (from left to right) the particle size components of the core, the results of a whole core volume susceptibility scan (in uncalibrated units) using the Bartington susceptibility meter and 70 mm loop sensor, the total SIRM of the sand and clay fractions in 10 subsamples from the core and the ratio between the SIRM contributions of the clays and sands in each sample. 5(b) shows (from left to right), the mass specific SIRM and χ values, the SIRM/χ ratio and the frequency dependent susceptibility percentage for the clays, and the same suite of measurements for the sands in each subsample. Note how the samples above 90 cm are distinguished above all by much higher χ, SIRM, SIRM/χ and χ_{fd}% values (cf. Fig. 2).

the primary magnetic mineral assemblages present in the surface sands as well as in bulk samples deeper in the regolith. Figure 7 shows coercivity curves for paired sand and clay samples from the *upper* part of cores 16, 19 and 21. The clays fall within a narrow envelope of values while the sands lie on either side (Fig. 4).

Source sediment linkages and implications

A previously published account, using bulk sediment properties (Oldfield 1983) suggests that in several

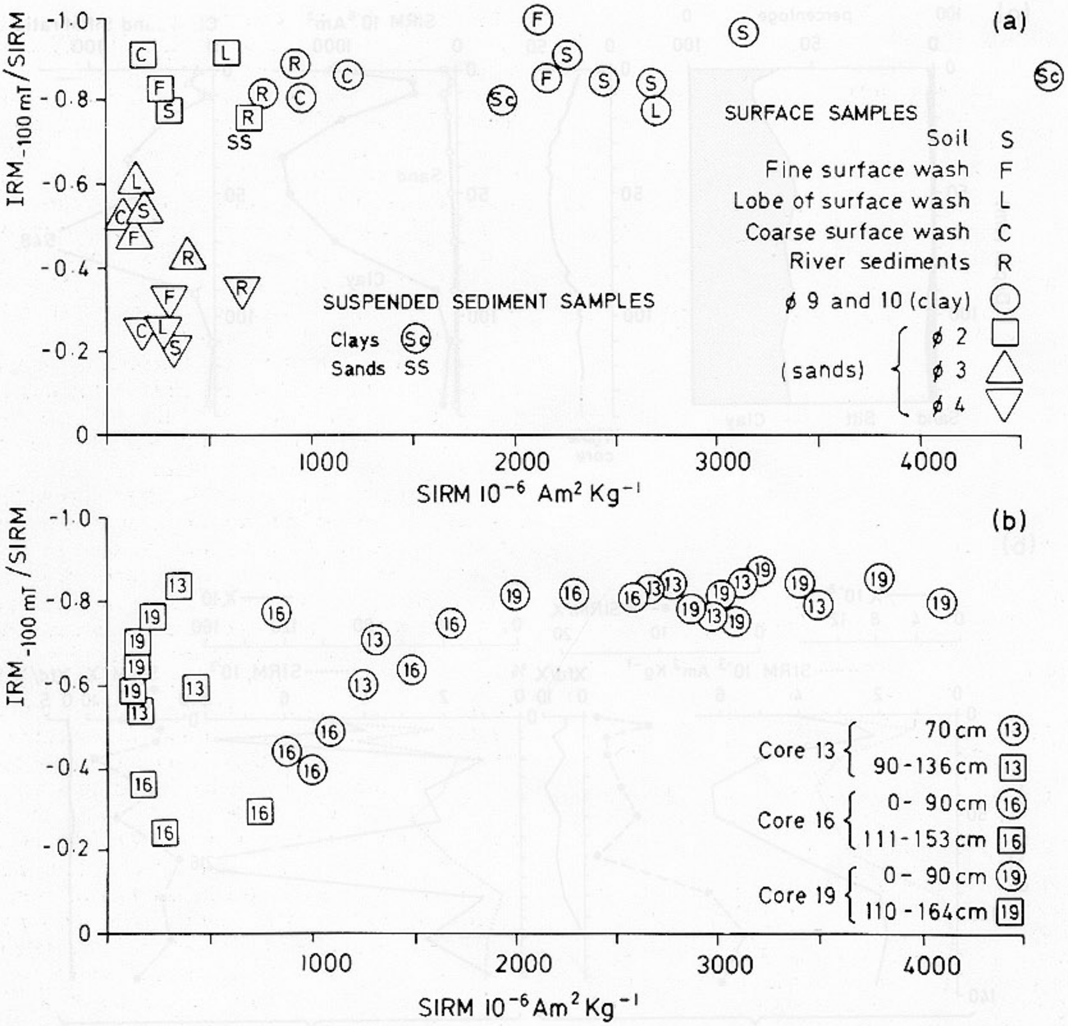

FIG. 6. (a) SIRM versus IRM$_{100mT}$/SIRM for clay and sand fractions from catchment surface samples and for aggregate suspended sediment samples from catchment 101. (b) SIRM versus IRM$_{-100mT}$/SIRM for clay fractions from the upper (circles) and lower (squares) parts of three sediment cores. 'S' refers to samples 18 and 19, 'F' to 13 and 17, 'L' to 11, 'C' to 12 and 'R' to 5 (see Fig. 3).

marginal cores (2B, 4A, 5A) the sediment is dominated throughout the record by material derived largely from unweathered or partially weathered Nanjemoy Cliff exposures. The same approach identifies a shift in sediment type in non-marginal cores from dominance by parent material sources to dominance by surface soil source. The present account presents particle size-related magnetic measurements which strongly reinforce this inferred source shift in the non-marginal cores studies. Below the increase in SIRM common to all non-marginal cores, the magnetic properties of all particle size fractions (Figs 5 and 6) correspond to the properties characteristic of parent material. This is so even within the clay fraction. Within the clay particle size range (<2 μm), magnetic grain size varies from small multidomain through to superparamagnetic. From the relatively low SIRM and zero χ_{fd}% values in these lower clays we can infer the absence of stable single domain and fine viscous grains (~0.05–0.02 μm). The early sediment therefore lacks surface soil input rich in the secondary magnetic minerals characteristic of clay sized soil particles and the clay particle size magnetic assemblage is comparable to the bulk properties of sediment derived from parent material.

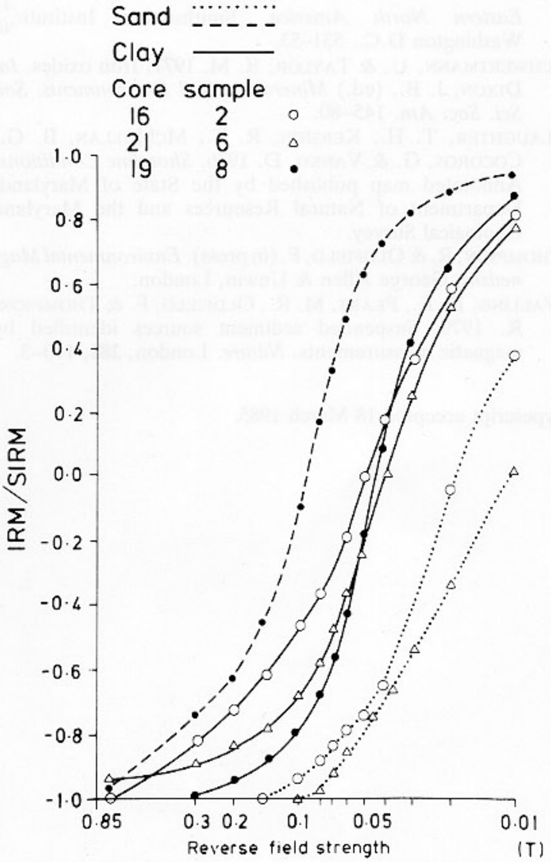

FIG. 7. Coercivity of SIRM curves for sand and clay fractions from samples above the SIRM increase in Cores 16, 19 and 21. Compare the curves with those shown in Fig. 4. The clay samples all fall within a narrow intermediate coercivity range whereas the sands range from very 'soft', e.g., 16(2), 21(6), to 'hard', e.g., 19(2) curves, depending on the source of the sand within the regolith.

The clay fraction in the more recent sediments in each core (Figs 5, 6 & 7) has high SIRM, SIRM/χ and χ_{fd}% values and almost all the samples, with the exception of a few from Core 16 in a narrow tributary estuary, have SIRM versus IRM$_{-100mT}$/SIRM values comparable to the clay fraction of surface soils. The sand component like the sand component of the surface soils has variable SIRM and coercivity values (Figs 4 and 7). However, frequency dependent susceptibility is invariably negligible in the sands (Fig. 5). Thus on a particle size specific basis the magnetic properties of surface soils and of the upper non-marginal estuarine sediments match in every respect.

Preliminary palaeomagnetic measurements and pollen analysis suggest that this shift in sediment type took place in the first half of the 19th century, in response to land use changes which resulted in a much higher proportion of land in tillage.

The results give a pattern of sediment flux within the system over the last 150 years dominated by the export of soil-derived particulates from the land surfaces of the catchment. The high SIRM and χ_{fd}% values associated with this material are found in the clay sized particles, and the magnetic parameters here can be confidently regarded as indicators of the loss of fines from the cultivated soils. The contemporary suspended sediment record confirms that this process is continuing and the magnetic traces from many of the estuarine cores suggest that the material now coming in is itself rather more depleted in the finest fractions than was the sediment deposited during the early stages after the shift to soil sources. The evidence points to selective loss of fines over a long period, leading to their progressive depletion and eventually relative paucity in contemporary soils. This process has serious implications for soil moisture retention, resistance to future erosion and the maintenance of both soil structure and fertility. The mineral magnetic approach thus highlights important qualitative, as well as quantitative aspects of erosion, both for present times and past.

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