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South Atlantic organic-rich sediments: facies, processes and environments of deposition

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SUMMARY: Organic-rich sediments (black shales) occur in parts of the South Atlantic ocean within Jurassic, Cretaceous and Neogene sections. These black shales are represented by various lithologies, including mudstones, marlstones, limestones, sandstones, pebbly mudstones and diatomites. They range from thin to very thick bedded, laminated, fissile or structureless, and show varying degrees and types of bioturbation. Texturally and compositionally they are equally varied. Organic carbon may be of principally marine or terrigenous source and forms from 1% to over 20% of the sediment. In many cases, the black shales are interbedded with organic-poor lithologies in cycles with irregular periodicities that average 20,000 to 140,000 years. The range of depositional processes of these black shales includes sliding, debris flows, high- and low-concentration turbidity currents, pelagic/hemipelagic sedimentation, and winnowing by shelf bottom currents. They occur in various palaeogeographical settings from nearshore shelf to ocean basin, and have been differently influenced by variations in bottom water oxygenation, organic matter supply and rates of sedimentation.

Introduction

Sediments containing more than about 2% organic carbon are common at certain stratigraphic intervals in the South Atlantic. Such sediments are often loosely described as 'black shales' and occur commonly throughout the world, although black-shale sections usually comprise interbedded dark- and light-coloured intervals that show variations in both organic-carbon and carbonate content. The lithologies are most often mudstones and shales, but may include coarser terrigenous sediments, limestones and dolomites. The term 'black shale' is used interchangeably with organic-rich sediments in this paper.

Previous work on South Atlantic organic-rich sediments includes overview of the Mesozoic occurrences (Arthur & Natland 1979), documentation of the present day upwelling system off Namibia (Calvert & Price 1971), and more detailed studies of sediment facies (Stow & Dean 1984), inorganic geochemistry (Dean *et al.* 1984; Calvert & Price 1983), and organic geochemistry (Meyers *et al.* 1984). Arthur *et al.* (1984) have recently synthesized much of the current thinking concerning models for the deposition of fine-grained organic-rich sediments in the deep sea. Studies of North Atlantic, Pacific, Mediterranean and onshore examples of black shales have been equal or more numerous (see reviews by Demaison & Moore 1980; Weissert 1981; Arthur *et al.* 1984).

Against this background of interest in and knowledge of black shales worldwide, this paper

focuses more specifically on the detailed sedimentology of selected examples of South Atlantic black shales with a view to its bearing on their processes and environments of deposition. We first present a brief updated overview of South Atlantic black shale occurrences set in the context of regional development.

Stratigraphy and occurrence

Mesozoic black shales

The oldest black shales recovered during DSDP drilling in the South Atlantic are the Callovian-Oxfordian dark-coloured mudstones at Sites 330 and 511 on the Falkland Plateau (Fig. 1) with up to 8.5%, mainly marine and part terrestrial, organic carbon (type II of Tissot *et al.* 1974). This black shale sequence extends throughout the early and mid Cretaceous period, whereas that at Site 361 in the Cape Basin is mainly Aptian in age, with up to 6% organic carbon of dominantly terrestrial origin (type III of Tissot *et al.* 1974). In the Angola Basin and on the Walvis/Rio Grande Ridge (Fig. 1) the main interval of black shale accumulation was during the mid to late Cretaceous (Albian to Santonian). Organic carbon contents are up to 23% and, particularly in the Cenomanian-Turonian sediments, are mainly of amorphous marine material (types I and II of Tissot *et al.* 1974). At many of the sites, marked hiatuses are present through at least part of this upper black shale section.

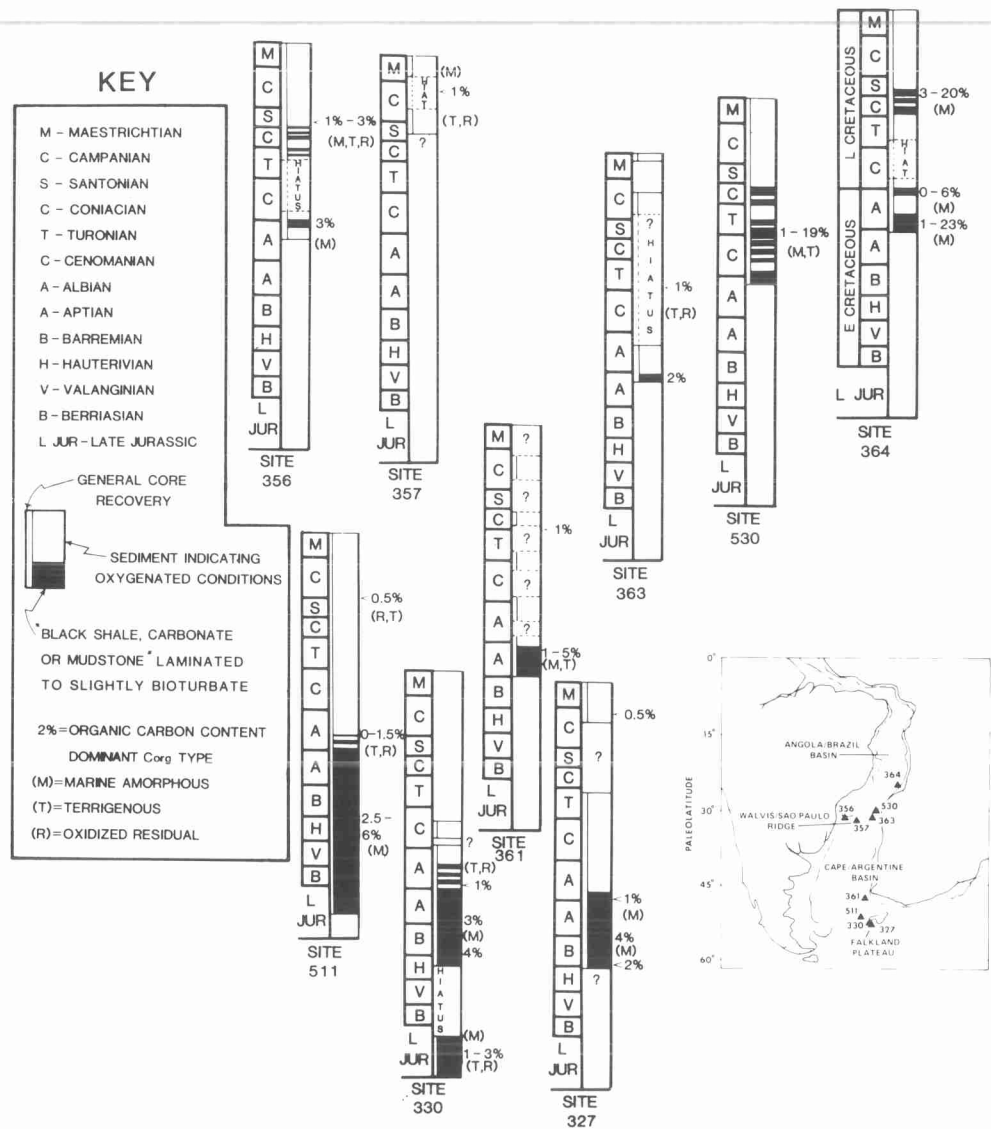


FIG. 1. Summary stratigraphic columns for the Mesozoic sections of DSDP holes in the South Atlantic that have recovered organic-carbon-rich sediments. Inset map shows DSDP Site locations on a mid-Cretaceous palaeoreconstruction. From Arthur, Dean & Stow (1984).

Cenozoic black shales

The Palaeogene sediments recovered at DSDP sites throughout the South Atlantic do not show any appreciable enrichment in organic carbon. However, the development of the Benguela Current upwelling system off south-western Africa during the Neogene led to the accumulation of organic-rich sediments over a broad belt in the southeast Atlantic (Sites 362, 364, 365, 530 and 532) (Fig. 2). Organic-carbon contents reach up

to 8% in the early Pliocene to late Pleistocene sediments and are dominantly of marine origin. The direct influence of the upwelling system extends to depths of at least 1330 m and decreases generally offshore. However, the late Miocene to Recent section at Site 530, in 4650 m water depth, comprises similar organic-rich sediments that have been redeposited downslope from the Walvis Ridge (see later).

The organic-rich sediments appear to be limited to this eastern belt. The cluster of DSDP

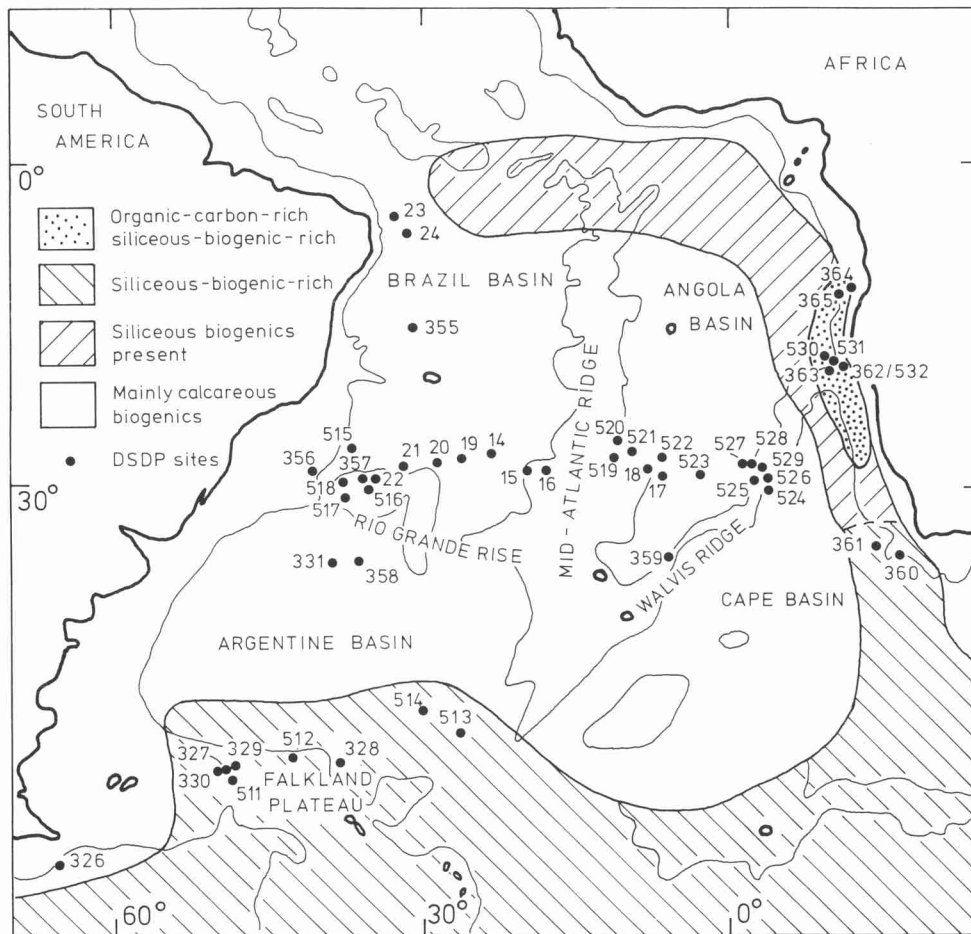


FIG. 2. South Atlantic ocean showing location of all DSDP sites drilled to date, and generalized areas of Pleistocene and/or Recent sediments rich in organic carbon and siliceous biogenic material.

sites (14–22, 355–359, 515–529) (Fig. 2) across the central South Atlantic are nearly all dominated by calcareous oozes, with muds and some siliceous biogenics at the deepest sites. There is a high latitude belt of siliceous biogenic-rich sediment of late Miocene to Recent age, recovered at Sites 327–330 and 511–514 (Fig. 2). This is commonly darker coloured than the calcareous oozes, rarely laminated, but does not seem to be rich in organic carbon.

Sedimentary characteristics

Falkland Plateau

The Callovian–Oxfordian to Aptian–Albian sections recovered on the Falkland Plateau at Sites

327, 330 and 511 contain a dominant black shale facies throughout the 130 to 220 m cored interval. These dark-coloured, organic-rich mudstones and calcareous mudstones are interbedded with only rare lighter-coloured calcareous mudstones, zeolitic mudstones and limestones (Fig. 3), although these interbedded lithologies become more common through the Aptian and Albian sections (Barker, Dalziel *et al.* 1977; Thompson 1976; Ludwig, Krasheninnikov *et al.* 1983), in which an irregular cyclicity of carbon and carbonate content on the order of 100,000 years has been noted (Parker *et al.* 1983).

Organic geochemical results indicate an average content of about 3.5% organic carbon (maximum 8.5%), decreasing upwards through a transition zone in the Aptian–Albian section, in which the average is about 0.3% and the maximum about 3.5%. The carbon is dominantly

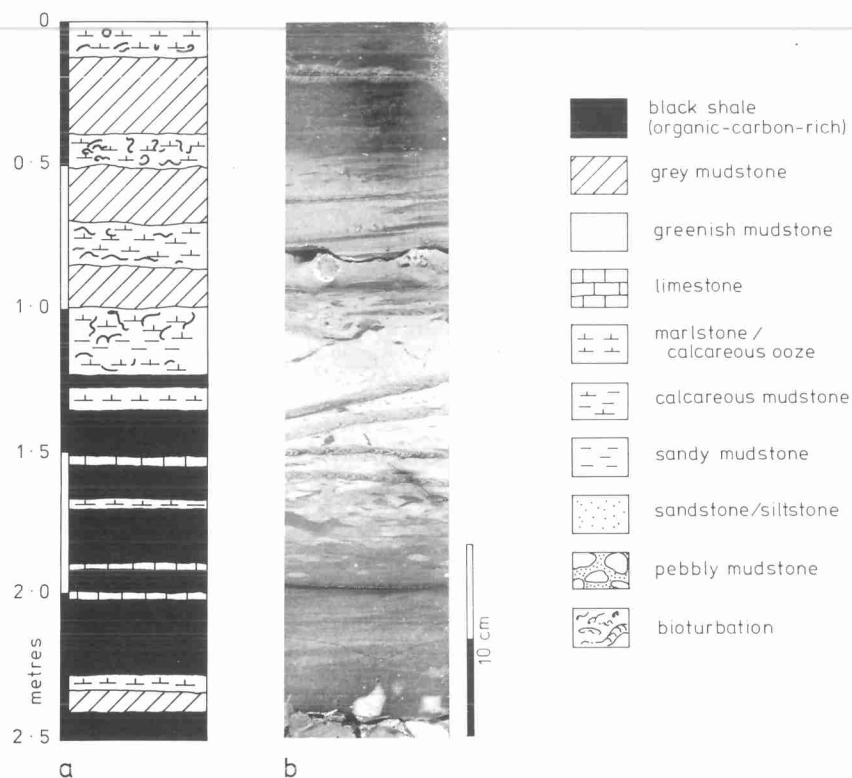


FIG. 3. Sedimentary characteristics of Jurassic-Cretaceous black shale sections from Falkland Plateau Sites 327, 330 and 511. (a) typical vertical sequence showing interbedded black shales, grey mudstones, marlstones and limestones; (b) photograph from DSDP Site 511-56-5.

of marine origin, with some increase in terrestrial material in the lowermost (Callovian-Oxfordian) sediments and towards the top (Aptian-Albian), in which residual (oxidized) marine kerogen is also present (Comer & Littlejohn 1976; Deroo *et al.* 1983; von der Dick *et al.* 1983; Parker *et al.* 1983).

The black shales show a range of sedimentary structures from essentially structureless through faintly laminated and well-laminated to highly fissile. They show some degree of bioturbation in parts, with burrows being more evident in black shales associated with the interbedded lithologies (Parker *et al.* 1983). There is little evidence of re-sedimentation, apart from the sharp bases to some black shale beds and isolated examples of (?) slump folds and inclined laminae. Sedimentation rates are extremely low throughout (0.1 to 1 cm/1000 years) and favour dominantly pelagic-hemipelagic sedimentation.

Inorganic geochemical analyses of the organic-rich sediments at Site 511 (Varentsov 1983) reveal concentrations of trace metals (Zn, Cu, Cr, Rb and Ba) associated with the late Jurassic section,

and relatively lower concentrations of V, Zn, Cu and Cr in the early Cretaceous black shales. In this latter section, diagenetic concentrations of Zn, Ni, La and perhaps Mo are associated with the carbonate phase.

Cape Basin

The Aptian section at Site 361 in the southern Cape Basin comprises thin to thick sandstones, pebbly sandstones and contorted slump units, interbedded with grey, green and black mudstones and minor marlstones and limestones (Natland 1978) (Fig. 4). The organic-rich sediments make up an average of 10–20% of the total section (maximum about 50% in parts) and occur in over 100 distinct beds, each from 1 cm–40 cm in thickness. Organic-carbon contents are from 1.5–6% in the black shales and <0.5% in the interbedded lithologies; land-derived organic-carbon is dominant with various admixtures of marine-derived material.

Two types of sequence are common: (a) an alternation of thick sandstones, mostly rich in

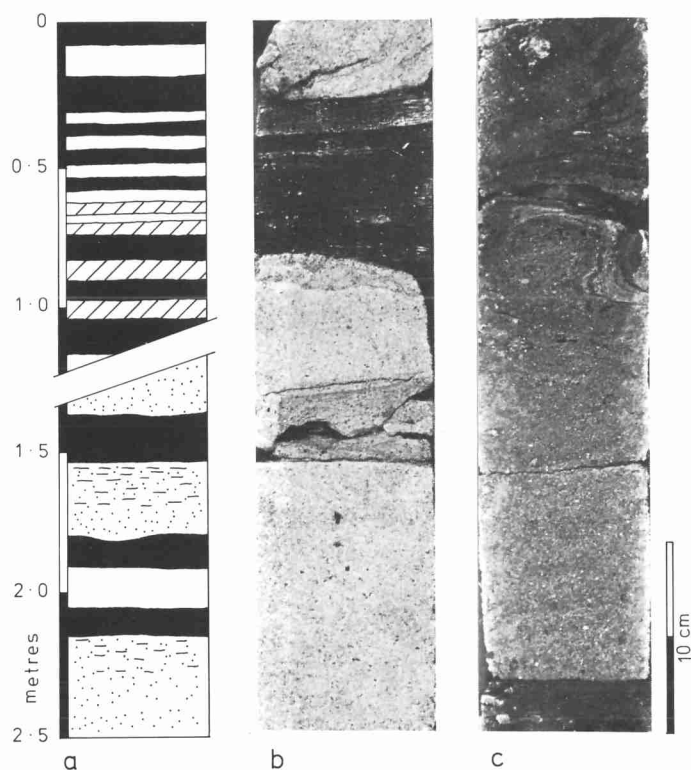


FIG. 4. Sedimentary characteristics of mid Cretaceous black shale sections from Cape Basin Site 361. (a) two typical vertical sequences showing interbedded green, grey and black mudstones (upper), and mudstones with organic-rich sandstones and muddy sandstones (lower); (b) photograph from DSDP Site 361-35-2; (c) photograph from DSDP Site 361-36-2. For legend see Fig. 3.

terrestrial organic debris, and thin laminated dark grey or black mudstones containing both terrestrial and marine organic matter; and (b) an alternation of green and dark grey or black mudstones, with rare interbedded limestone and marlstone intervals.

The first sequence is clearly turbiditic in origin, the couplets showing positive grading over a sharp scoured base and internal lamination and cross-lamination. At least the upper parts of the black mudstones overlying the sandstones may be of pelagic origin, whereas the lower parts are more probably turbiditic. The sediments of the second sequence are more typical of fine-grained facies associated with coarse turbiditic intervals and may be part turbidite, part hemipelagite-palagite in origin. Structures within the black shales include horizontal- and micro-cross-lamination and micro-bioturbation.

The average sedimentation rate for the Aptian black shale section was between 5 and 10 cm/1000 years, yielding a periodicity for the occurrence of black shale horizons of 20,000 to 60,000

years. However, with such clear evidence of significant contribution from turbidites, giving very high instantaneous rates of sedimentation, these figures provide only an order of magnitude.

Angola Basin

The late Albian to early Santonian section at Site 530A in the southeastern Angola Basin comprises red, green, grey and black mudstones and calcareous mudstones with thin siltstones and rare limestones (Stow & Dean 1984) (Fig. 5). The organic-rich sediments make up just less than 10% of the complete 170 m thick section, and up to 50-60% in parts of the late Cenomanian-Turonian interval. They occur in some 260 separate beds ranging from less than 1 cm to over 60 cm in thickness, with organic-carbon contents from about 1% to 19%, mainly marine sapropelic but with small variable admixtures of terrigenous material.

Two types of sequence are most common: (a) an alternation of dark grey or black organic-rich

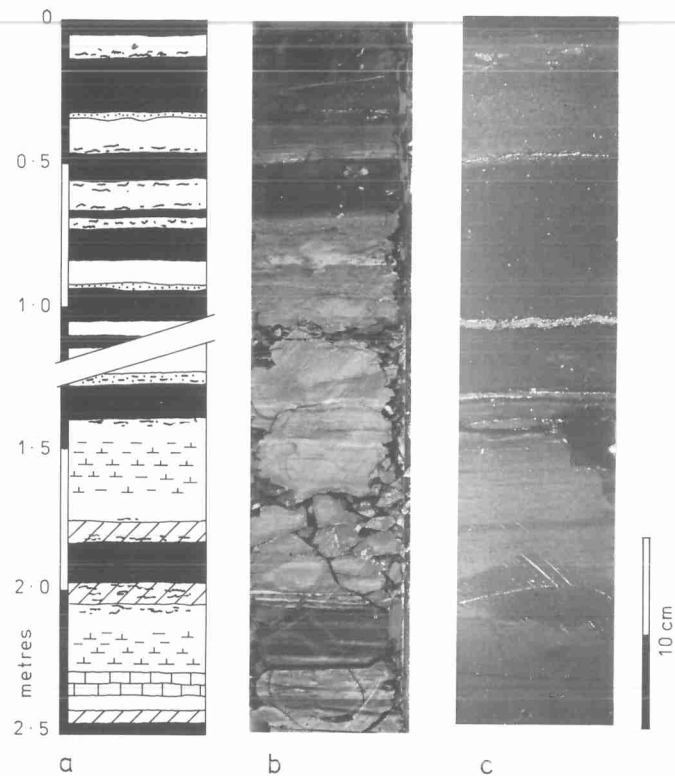


FIG. 5. Sedimentary characteristics of mid-Cretaceous black shale sections from Angola Basin DSDP Sites 364, 365 and 530. (a) two typical vertical sequences showing interbedded green and black mudstones (upper), and green, grey and black mudstones, marlstones and limestones (lower); (b) photograph from DSDP Site 530A-87-4; (c) photograph from DSDP Site 530A-98-3. For legend see Fig 3.

mudstone and green organic-poor mudstone; and (b) a rather thicker sequence from pale-coloured limestones, through pale greenish marlstone and grey (\pm calcareous) mudstone to black organic-rich mudstone, and back through grey to green mudstone.

Silt laminae and thin beds may occur at any part of either sequence; they commonly show micro-structures such as scoured bases, positive grading and micro-climbing-ripples that suggest a probable turbiditic origin, and tend to be pyritiferous when associated with the black shale beds. Bioturbation is most evident in the limestones, marlstones and green mudstones, and tends to diminish in both intensity and in burrow size towards the black shales. Black shale beds may be finely laminated, structureless or with microbioturbation in parts.

The average sedimentation rate for the Albian to Santonian interval is of the order of 1 cm/1000 years; certain minor hiatuses may be present in the Turonian. The periodicity of occurrence of black shale beds is very variable, from about

10,000 to 350,000 years (most commonly between 20,000 and 80,000 years). It has been estimated (Stow & Dean 1984) that some 5–20% of the section is of basinal turbiditic aspect, the remainder being hemipelagic and pelagic in origin, but that these depositional processes have varied for the most part independently of the black shale cycles.

Results of inorganic geochemical analyses through the Cretaceous section (Dean & Parduñ 1984; Dean *et al.* 1984) reveal significant enrichment of a wide range of trace metals, notably Cd, Co, Cr, Cu, Mo, Ni, Pb, V and Zn, in the black shales relative to the interbedded organic-poor lithologies. These elements show markedly different concentration gradients within the section, suggesting differential mobility has occurred during diagenesis. Concentrations of Cd, Zn, V, Cu and Mo are highest in parts of the section where black shales are most abundant, which suggests that they have not migrated far. However, Pb, Ni, Co and Cr, together with the major elements Ba and Mn appear to be more mobile,

and may have migrated up to tens of metres from their original organic-rich source (Dean *et al.* 1984).

At Site 364 further north on the Angola continental slope, the period during which black shales accumulated intermittently was somewhat more prolonged, from late Aptian through to early Santonian, although for much of the Albian only limestones and marly limestones were deposited and there was an important hiatus in sedimentation through much of the Cenomanian and early Turonian. Both the Aptian and, more particularly, the younger sections are very similar to that drilled at Site 530A. The sediments are generally richer in carbonate, including dolomite, limestone and marly limestones, and the black shale beds are less numerous but equally varied in their thickness, carbon content (dominantly marine) and in their periodicity of occurrence. Bioturbation is common throughout the limestone, marlstone and mudstone facies and micro-bioturbation is present in many of the black shale beds. Many of these also show fine horizontal lamination. Sedimentation rates were very low and hemipelagic-pelagic processes apparently dominated.

Other DSDP sites in the Angola Basin did not penetrate mid-Cretaceous sections, although Site 365 on the continental slope off Angola recovered a thick displaced unit of Albian-Turonian sediments within a Tertiary sequence. These organic-rich Cretaceous sediments are generally similar to those at Site 364, but not so rich in organic carbon, and probably represent a large slide block that caved from a now partly buried canyon wall during the Miocene (Bolli *et al.* 1978).

Namibian shelf and Walvis ridge

The Recent sediments on the Namibian continental shelf were sampled with short gravity corers and described by Senin (1968), Avilov & Gershanovich (1970) and Calvert & Price (1971). Organic-rich diatom ooze, containing fish debris and phosphorite, occurs in a 600 km long coastal belt up to 70 km wide off Walvis Bay in water depths less than 140 m. There are smaller areas of terrigenous gravelly sands and muddy sands within this belt. Much of the middle and outer shelf is covered by calcareous oozes and muds, rich in foraminifera and mollusc debris.

The siliceous oozes contain up to a maximum of 22% organic carbon and have accumulated at rates between 30 and 120 cm/1000 years. The calcareous shelf facies contain rather less organic carbon, from 1–15%, and have accumulated more slowly, with sedimentation rates on the order of

5 cm/1000 years on the outer shelf. The organic carbon in both cases is entirely marine planktonic in origin. Pelagic sedimentation and a certain amount of redistribution and winnowing across the shelf have been the main processes operating.

Inorganic geochemical analyses of the Namibian Shelf sediments have shown relative enrichment in trace metals (Cu, Mo, Ni, Pb, Zn and U) of the diatomaceous oozes compared with the outer shelf calcareous muds. The distribution of these elements closely mirrors that of organic carbon, apart from uranium which also appears to reflect phosphorite concentration (Calvert & Price 1970, 1983; Calvert & Morris 1977).

DSDP Sites 532 and 362 were drilled at more or less the same location on the eastern end of the Walvis Ridge in a water depth of 1330 m some 600 km NW of Walvis Bay. There are 300 m of late Miocene to Recent oozes, muddy oozes and biogenic muds, which were particularly well recovered by hydraulic piston coring at Site 532 (Hay *et al.* 1984). These sediments occur as a regular alternation of lighter coloured beds, richer in CaCO₃, and darker coloured beds, richer in terrigenous clays and organic carbon (Fig. 6). The dark coloured beds make up 30–60% of the section, occurring as over 100 separate beds from 10–100 cm in thickness and with an average content of 3–8% organic carbon. This carbon is entirely of marine planktonic origin. The periodicity of the light-dark cycles ranges from 10,000 to 80,000 years (average 41,000 years), whereas the organic-carbon-rich to organic-carbon-poor cycles are not entirely coincident with the colour changes, averaging 24,000 years over the last 2.5 million years (Gardner *et al.* 1984). The average sedimentation rate was on the order of 4–6 cm/1000 years.

The sedimentary characteristics of the organic-rich beds at Site 532 are significantly different from those of the Mesozoic black shales described above, and much more similar to those of the present day organic-rich sediments on the Namibian shelf. They are dark olive greens and greys, biogenic rich with a dominance of diatoms in the more organic-rich intervals, and completely devoid of primary sedimentary structures. Bioturbation is intense throughout and has resulted in relatively thick intermixed zones between the light and dark layers. There is little evidence for anything other than pelagic-hemipelagic depositional processes, although sedimentation rates are almost an order of magnitude higher than those of many open-ocean pelagic sediments.

Geochemically there is only very slight enrichment of trace metals in the darker beds relative to the lighter beds, particularly of Cr, Cu, Ni, V and Zn (Dean & Parduhn 1984).

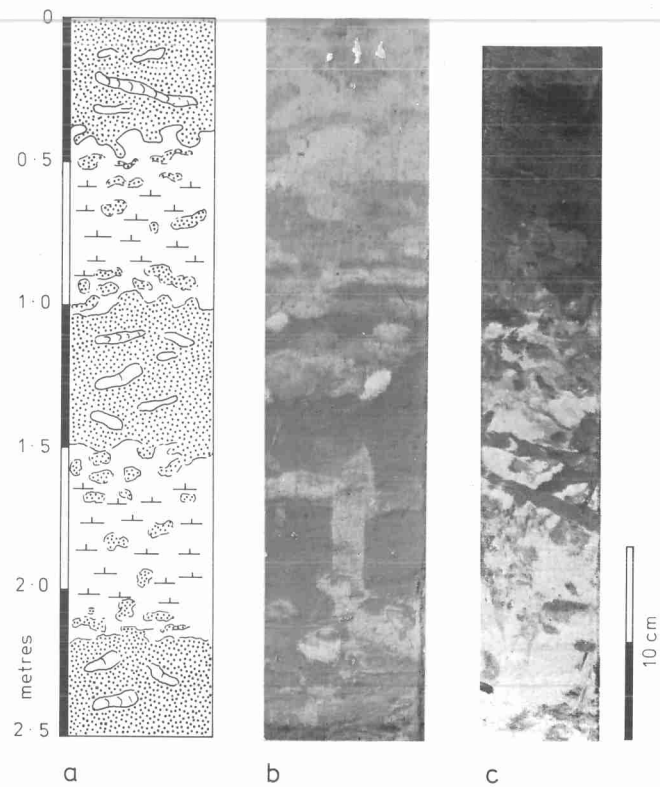


FIG. 6. Sedimentary characteristics of Pliocene-Recent organic-rich biogenic oozes and muddy oozes from Walvis Ridge Sites 362, 363, 531 and 532. (a) typical vertical sequence showing interbedded and bioturbated dark greenish grey siliceous oozes (organic-rich) and light greyish-white calcareous oozes and muds; (b) photograph from DSDP Site 532-42-2; (c) photograph from DSDP Site 532-5-3. For legend see Fig. 3.

At the present day the Benguela Current upwelling system off Namibia results in high primary productivity in the surface waters and the accumulation of diatomaceous, organic-rich sediments on the Namibian shelf. The records of diatom abundance and organic-carbon content in the sediments at Site 532 suggest that upwelling began in the late Miocene (about 5 my ago), and increased to a maximum in the late Pliocene to early Pleistocene. On the Walvis Ridge, upwelling activity then declined to the present day, most likely due to a southward migration of the system (Hay *et al.* 1982, 1984). It is interesting to note that the rise and decline of upwelling intensity at Site 532 did not apparently disturb the cyclicities of carbonate and organic-carbon that remain relatively constant throughout (Dean & Parduhn 1984).

Immediately adjacent to the Walvis Ridge at the foot of its northern flank (4.6 km water depth), Site 530B penetrated 270 m of late Miocene to Recent calcareous and siliceous oozes,

muds and pebbly muds (Hay *et al.* 1984). The lithologies are very similar to those on the crest of the Ridge described above (Sites 532, 363), with organic-rich sediments making up 20–40% of the section, occurring in over 100 beds from 5 cm to > 10 m thick (Fig. 7). The total organic carbon content of these beds ranges from 1–6% and is of dominantly marine origin. The darker beds are rich in diatoms and/or terrigenous clays and are interbedded with nannofossil foraminifera oozes and muds.

However, the dark organic-rich beds nearly all show very clear structures indicative of resedimentation, including sharp scoured bases, minor parallel lamination near the base, marked positive grading, and bioturbation increasing towards the gradational upper boundary. Some of the thicker beds contain reworked clasts of semi-lithified muds and oozes in either a dark organic-rich or light carbonate-rich matrix. The whole sequence has been interpreted as part of a small, ridge-flank, deep-sea fan system, con-

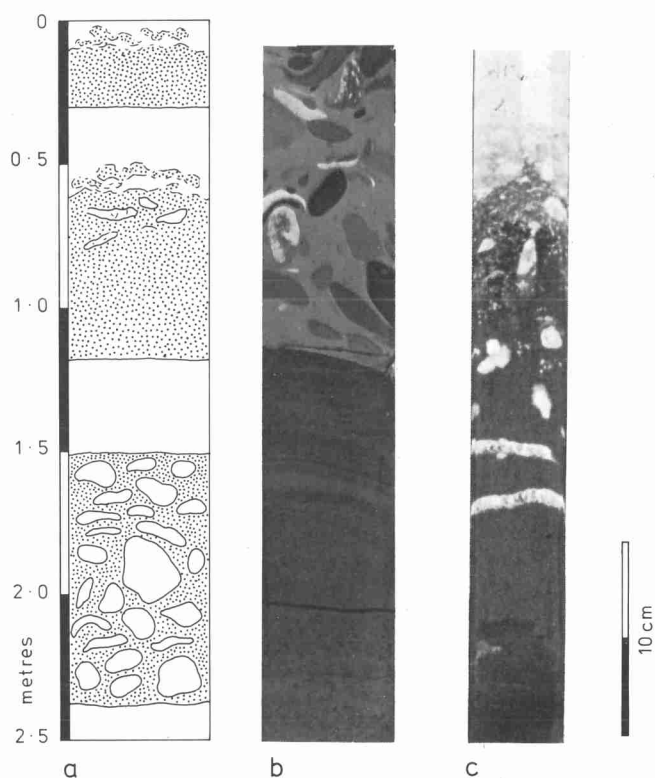


FIG. 7. Sedimentary characteristics of Pliocene-Recent organic-rich resedimented biogenic oozes and muddy oozes from Angola Basin Sites 530A and 530B (a) typical vertical sequence showing interbedded dark greenish-grey siliceous ooze turbidites (organic-rich), light greyish-white calcareous oozes and muds, and pebbly mud debrites (organic-rich); (b) photograph from DSDP Site 530B-8-2; (c) photograph from DSDP Site 530B-5-3. For legend see Fig. 3.

structured by resedimentation of mainly organic-rich sediments from the adjacent Walvis Ridge into the mainly carbonate-rich pelagic-hemipelagic facies of the Angola Basin (Stow 1984a, b).

Discussion

Processes of deposition

It is clear from this brief survey of the sedimentary characteristics of organic-rich sediments in the South Atlantic ocean, that black shales may be deposited or affected by one of a number of different processes:

- (a) resedimentation by large-scale sliding (e.g. Angola Basin Sites 365 and 530B);
- (b) resedimentation by large-scale debris flows (e.g. Angola Basin Site 530B);

- (c) high-concentration sandy and muddy turbidity currents (e.g. Cape Basin Site 361 and Angola Basin Site 530B, respectively);
- (d) low-concentration turbidity currents (e.g. Angola Basin and Cape Basin Sites);
- (e) normal pelagic (biogenic) and hemipelagic (part terrigenous silt) sedimentation (e.g. parts of all areas and Sites discussed); and
- (f) winnowing and reworking by shelf bottom currents (e.g. Namibian Shelf).

These different processes result in black shales having a wide range of structural, textural and compositional characteristics. The coarser grained sandstone turbidites and mud-clast debrites, commonly structureless or indistinctly stratified, are clearly recognizable. The finer grained silty and muddy black shales show more subtle micro-structural and micro-fabric differences (Fig. 8). A sub-horizontal lensoid fissility appears to be characteristic of many hemipelagic

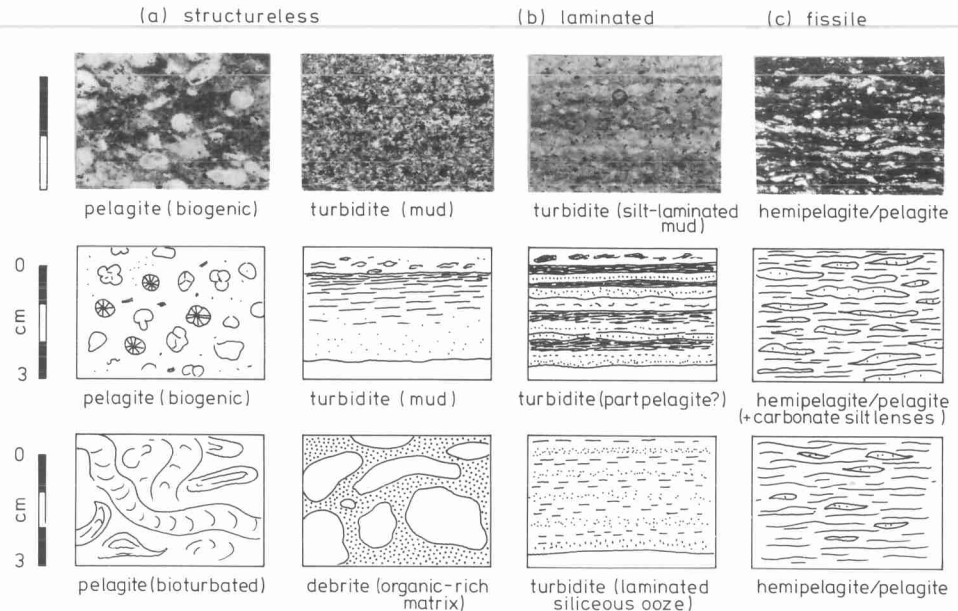


FIG. 8. Characteristic microstructure and fabric of various organic-rich sediments from the South Atlantic. Upper row = photographs of thin sections; lower two rows = sketches from polished core slabs. (a) structureless sediment with more or less random fabric may result from pelagic, hemipelagic, turbiditic or debris flow processes; (b) laminated sediment resulting from part turbiditic and part pelagic processes; (c) fissile sediment probably resulting from hemipelagic/pelagic processes. For legend see Fig. 3.

and pelagic black shales. The lenses of lighter-coloured terrigenous, biogenic or diagenetic material are on a millimetre to micrometre scale and form from 10–60% of the rock. They are draped with darker-coloured, finer-grained, organic-rich material. A more regular horizontal lamination or thin bedding characterizes turbiditic black shales. The laminae may be from less than 1 mm to 1 cm in thickness and show grading, sharp contacts, internal lamination, etc. They tend to be composed of lighter-coloured, terrigenous silty material separated by thin to thick layers of darker, muddy, more organic-rich material that is largely structureless. A more structureless aspect with more or less random internal fabric can occur in some biogenic pelagic black shales (either siliceous or calcareous), in some hemipelagic black shales that have been homogenized by extensive bioturbation, as well as in the thick-bedded, massive, organic-rich turbidites and debrites.

The composition of and type and amount of organic carbon in black shales are equally variable and partly related to the depositional process but also, of course, to the original source of sediment and organic matter. The turbiditic and other resedimented black shales tend to have

a more marked terrigenous signature, in terms of both mineral and organic composition. However, this does not apply to, for example, the resedimented siliceous organic-rich sediments in the Angola Basin at the foot of the Walvis Ridge flank, which are thoroughly marine. Open ocean pelagic black shales are the most fully marine, whereas continental margin and shelf hemipelagites are commonly mixed with some terrigenous material.

Environments of deposition

The paleogeographical settings in which the black shales of the South Atlantic accumulated are equally as varied as their processes of deposition. They include:

- nearshore and shelf environments (e.g. Namibian Shelf);
- outer shelf and oceanic plateau or ridge (e.g. the Falklands Plateau and Walvis Ridge sites);
- continental slope and rise or submarine fan settings (e.g. the Cape Basin and Angola Basin margin sites); and
- deep ocean basin environments (e.g. Angola Basin Site 530).

What is clearly more important for the preservation of organic matter in sediments, than either depositional process or geographical setting are the following three main variables (Demaison & Moore 1980; Arthur *et al.* 1984; Stow & Dean 1984):

- the degree of bottom-water oxygenation within an oxygen minimum zone, throughout the water column or throughout the bottom waters within a basin;
- the volume of supply of marine and terrigenous organic matter from primary productivity at the surface, from fluvial discharge and from downslope resedimentation processes; and
- the rate of sedimentation and hence the rate of burial/dilution of organic matter.

That these factors were variable in both time and space during the accumulation of black shales is well illustrated by the range of interbedded organic-rich and organic-poor lithologies that occur at different ages in the South Atlantic. The percentage of organic carbon preserved and the percentage of the total section that is black shale both increase with the degree of anoxicity and the volume of organic matter supply. The rate of sedimentation is a balancing variable.

The Jurassic-lower Cretaceous black shales of the Falkland Plateau sites were, most probably,

principally the result of low bottom-water oxygenation in the narrow, restricted, southern Atlantic ocean of that period. Similarly, the middle Cretaceous black shales of the Cape and Angola Basins were influenced by restricted basin circulation, a warm equable climate and a high sea-level, that all contributed to the ancient South Atlantic ocean being poised at relatively low oxygen levels. Only small changes in the flux of organic matter, ocean circulation, climate, or other variables would then have been sufficient to cause anoxia or near-anoxia in the bottom waters and sediments. Variable periodicity of such changes led to the cyclic interbedding of black shales with organic-poor sediments. At site 361 in the Cape Basin, terrigenous input of organic matter and high sedimentation rates were also a factor in the formation of black shales. This complex interplay of variables is illustrated in Fig. 9.

The oceanographic and climatic conditions under which the Miocene–Recent organic-rich sediments accumulated on the shelf and margin off Namibia are markedly different from those of the Cretaceous. The principal factors for organic-carbon preservation on the Namibian shelf are high organic-matter influx from primary productivity in surface waters over an upwelling system, together with the consequent high rates of

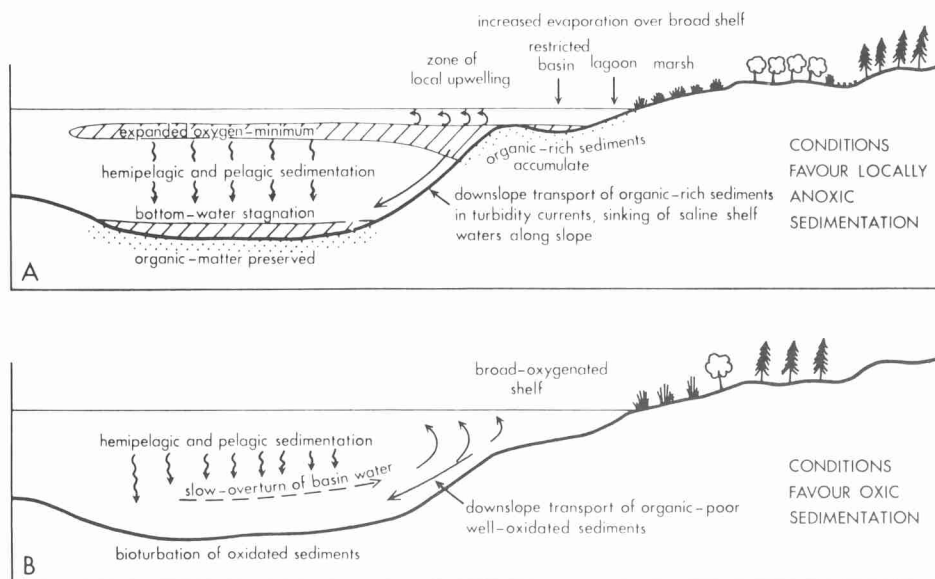


FIG. 9. Schematic model for accumulation and preservation of interbedded organic-carbon-rich (upper) and organic-carbon-poor sediments (lower). Note multiple interacting variables, each of which may have been relatively more or less important for any particular black shale section. After Stow & Dean (1984).

sedimentation. Only in the central part of this system are the bottom waters over the shelf also anoxic. The high preservation of organic-carbon in the fully-oxygenated Angola Basin (Site 530B) is due primarily to high organic-matter influx and high rates of sedimentation caused by downslope resedimentation processes.

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