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Lithology, colour and mineralogy of pelagic sediments from the Romanche Fracture Zone (RFZ) in the Equatorial Atlantic

E. O. ODADA

Department of Geology, University of Nairobi, P. O. Box 30197, Nairobi, Kenya

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Abstract - Sediment cores from the Romanche Fracture Zone (RFZ) in the equatorial Atlantic have been described visually and microscopically as well as analysed by X-ray diffraction techniques in order to study the main controls on their lithology, colour and mineralogy. The sediments display graditional changes in colour, mineralogy and lithology. Water depth and biogenic dissolution appear to play an important role in controlling the lithology and mineralogy of the sediments. Distance from continental and volcanic sources of sediment appear to play secondary roles. Changes of colour downcore largely reflect variation in the Mn and Fe oxides content of the sediments.

INTRODUCTION

The equatorial Atlantic is one of the most extensively faulted parts of the ocean floor. Here, a set of closely spaced fracture zones offset the mid-Atlantic ridge (MAR) (Fig. 1). The longest, widest and deepest of them, the RFZ offsets the axis of the MAR by approximately 950 km and is characterised by east-west lineations of the basement morphology (Gorini, 1977). The deepest parts of the floor of the Romanche Trench are more than 7 km, whilst the highest parts of the ridges flanking the trench are less than 1 km below sea level (Fig. 2).

The various factors controlling the lithology, colour and mineralogy of sediments in and around the RFZ area are virtually unknown. Knowledge of sedimentation and sedimentary processes has been especially limited, and until now, has been confined to superficial descriptions of scattered piston cores (Petterson, 1955; Heezen *et al.*, 1964; Cifelli, 1970; Bonte *et al.*, 1982).

Petterson (1955) described two sediment cores from the Romanche Trench which contain a top layer of red clay with fragments of volcanic nature. Below this layer, he found a layer consisting of brown grey clay overlying stratified dark grey hemipelagic sediments. At the base, there was a light grey sediment which contains some lime. He considered the bottom layer to be globigerina ooze, and suggested that the bank covered with the material had first been raised to a level in which hemipelagic sediments were deposited and later sunk to its present great depth.

Bonte *et al.* (1982) described several sediment cores raised from the Romanche Trench. One of the cores contains, at the base, well preserved micro and nannofossils of early Pliocene ages. These are overlain by alternating sequences of broken eroded flora and fauna of mixed early-late Pleistocene ages, followed in turn by well preserved latest Pleistocene/recent assemblages. Bonte *et al.* (1982) suggested that the varied sedimentary assemblages were probably slumped due to the rugged topography of the Romanche Trench (Fig. 2).

This paper examines the various factors controlling the lithology, colour and mineralogy of the sediments in and around the RFZ area. In particular, the paper examines the influence of such factors as water depth, proximity to sources of terrigenous or volcanogenic sediments, biological productivity of surface waters, bottom current activity, bottom topography and inputs of authigenic minerals on the lithology, colour and mineralogy of the sediments.

Sediment samples used in this work were collected in 1983 aboard an English research vessel R. V. Shackleton. The samples were obtained using gravity corer with a 2 m barrel containing a plastic liner. As soon as the corer was brought on deck, the liner was removed and capped at both ends and then stored in a freezer until the end of the cruise. Sampling was done with the help of an echo sounder, a satellite navigation system and a gyro compass. Additional piston cores were collected from the Romanche Trench in 1979 aboard a French research vessel R. V. Jean Charcot (Bonte *et al.*, 1982). A bathymetic chart showing sample locations is presented in Fig. 2.

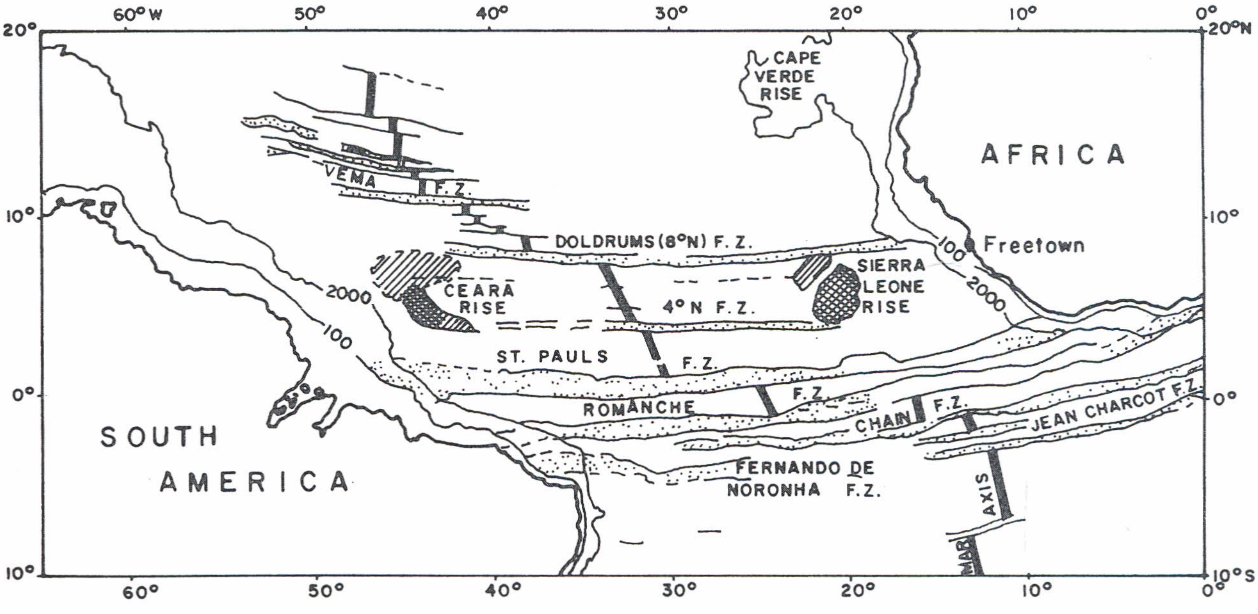


Fig. 1. The equatorial Atlantic with a simplified outline of the axial segments of the Mid-Atlantic Ridge and of the major fracture zones (Kumar and Embley, 1977).

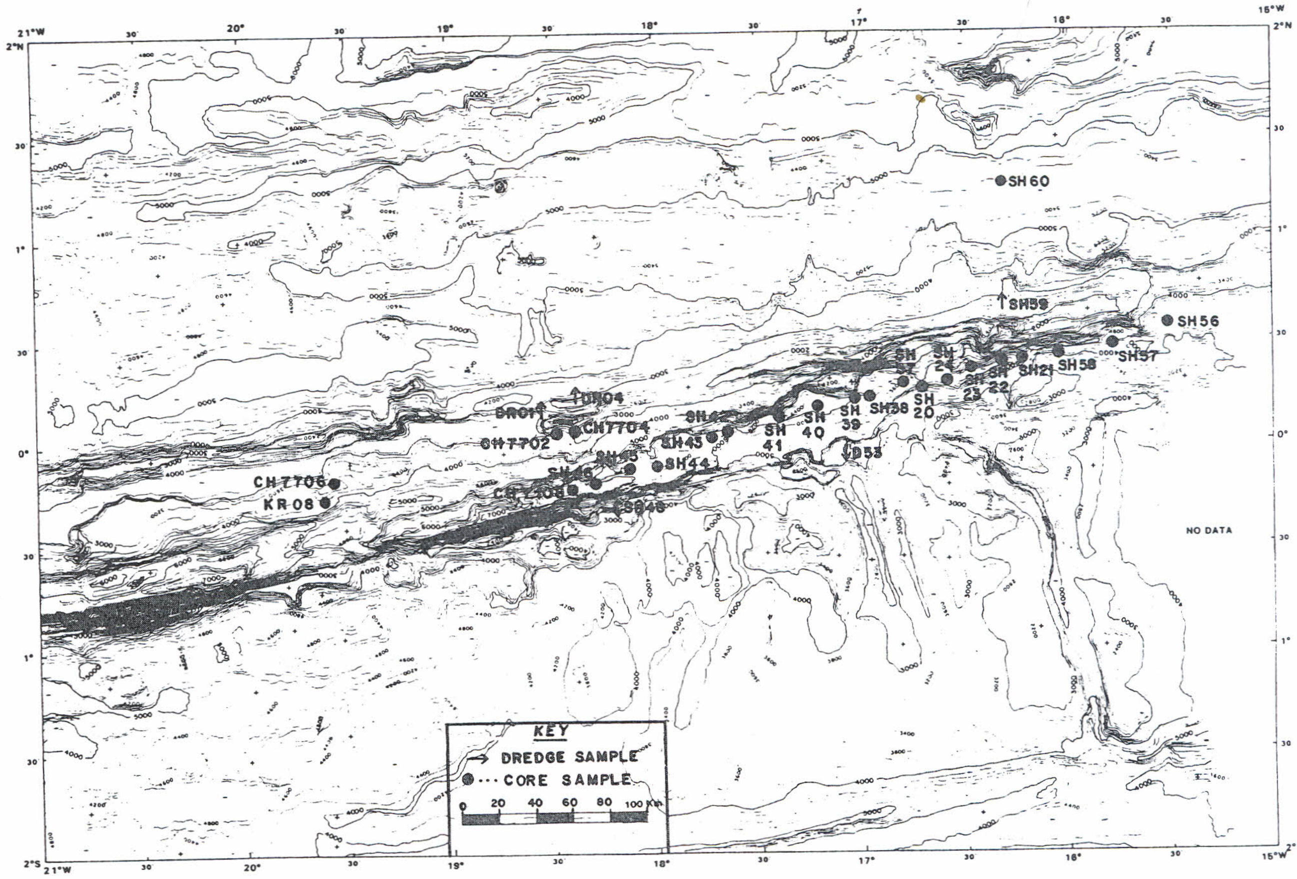


Fig. 2. Bathymetric map of the RFZ-MAR intersection showing sample locations.

SAMPLE PREPARATION

In the laboratory, the sediment cores were split into two halves using specially designed core cutter. Half of the core was preserved as a reference. The other half was visually described and colour coded using the Munsell soil colour code (Munsell, 1971). The nomenclature used, in this work, follows that established for deep-sea sediments by the Deep-sea Drilling Project (Weser, 1973).

METHODS

The main lithological components of the sediments were determined by visual and microscopic examination of smear slides. Smear slides of the sediments were prepared by smearing sediment onto a glass microscope slide, and sealing with a cover slip and Canada Balsam. The slides were then air-dried before examination by a microscope. The colour of the sediments were described using the Munsell Soil Charts (Munsell, 1971).

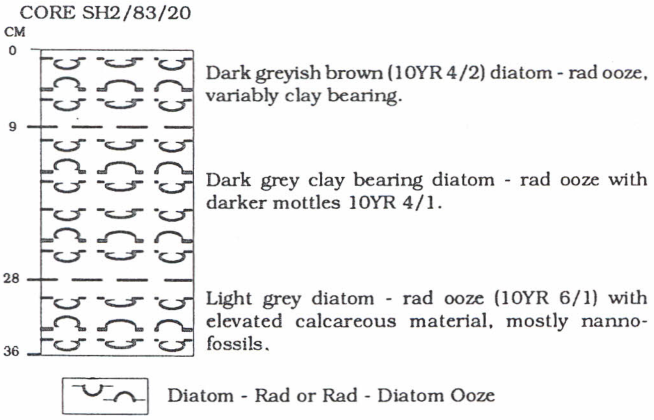
The mineral constituents of the sediments were determined by X-ray diffraction using Copper K alpha radiation method (Hathaway, 1956). Sediment samples were glycolated and heated to 550 °C and then analysed by X-ray diffraction. Peaks were identified using mineral identification charts as shown in Figs 8-10.

RESULTS

Figures 3-7 illustrate lithological descriptions of the sediment cores examined in this work. In general, the sediments consist essentially of siliceous-nannofossil, nannofossil-foraminifer and foraminifer-nannofossil oozes, variably clay-bearing and various terrigenous clays with significant amount of authigenic constituents.

As can be seen in Figs 3-7, the sediments exhibit a wide range of colours. Calcareous oozes display pale greyish brown to dark greyish brown colour ranging from 10YR4/1 to 10YR8/4 in the Munsell Colour Charts, whereas clay sediments and detrital constituents display various shades of grey, varying from very dark (10YR3/1) to almost black (10YR2/1) colours.

The graditional changes of colours with depth are probably due to $CaCO_3$ removal from the sediments by solution of calcareous tests below the CCD (which is approximately 5500 m water depth in the RFZ area). Down core colour changes are probably due to variations in minor



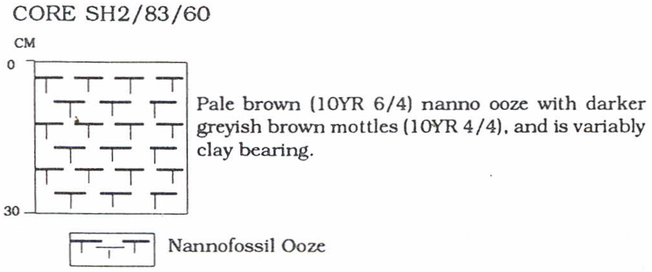
Dark greyish brown (10YR 4/2) diatom - rad ooze, variably clay bearing.

Dark grey clay bearing diatom - rad ooze with darker mottles 10YR 4/1.

Light grey diatom - rad ooze (10YR 6/1) with elevated calcareous material, mostly nannofossils.

Diatom - Rad or Rad - Diatom Ooze

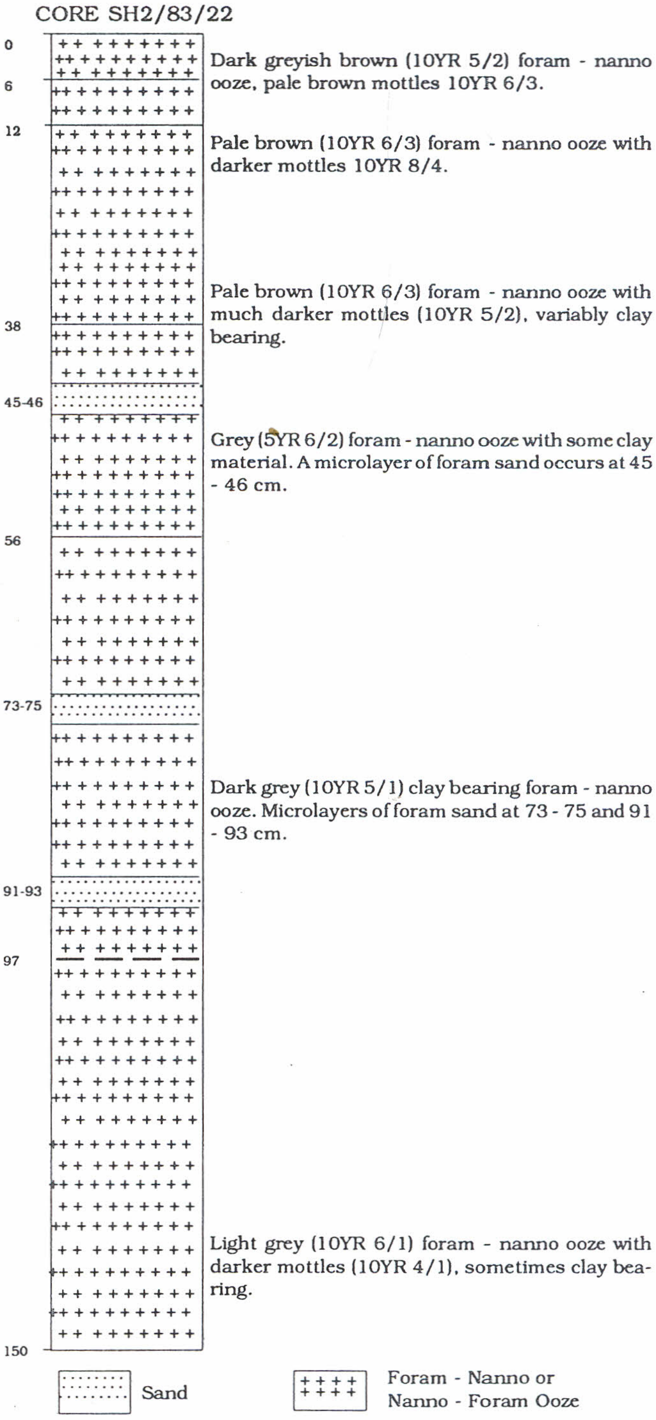
Fig. 3a. Clay Bearing Diatom - Radiolarian Ooze with some Calcareous Material.



Pale brown (10YR 6/4) nanno ooze with darker greyish brown mottles (10YR 4/4), and is variably clay bearing.

Nannofossil Ooze

Fig. 3b. Calcareous (Nannofossil) Ooze with Variable Amount of Clay Material.



Dark greyish brown (10YR 5/2) foram - nanno ooze, pale brown mottles 10YR 6/3.

Pale brown (10YR 6/3) foram - nanno ooze with darker mottles 10YR 8/4.

Pale brown (10YR 6/3) foram - nanno ooze with much darker mottles (10YR 5/2), variably clay bearing.

Grey (5YR 6/2) foram - nanno ooze with some clay material. A microlayer of foram sand occurs at 45 - 46 cm.

Dark grey (10YR 5/1) clay bearing foram - nanno ooze. Microlayers of foram sand at 73 - 75 and 91 - 93 cm.

Light grey (10YR 6/1) foram - nanno ooze with darker mottles (10YR 4/1), sometimes clay bearing.

Sand

Foram - Nanno or Nanno - Foram Ooze

Fig. 4. Clay Bearing Foraminifer - Nannofossil Ooze.

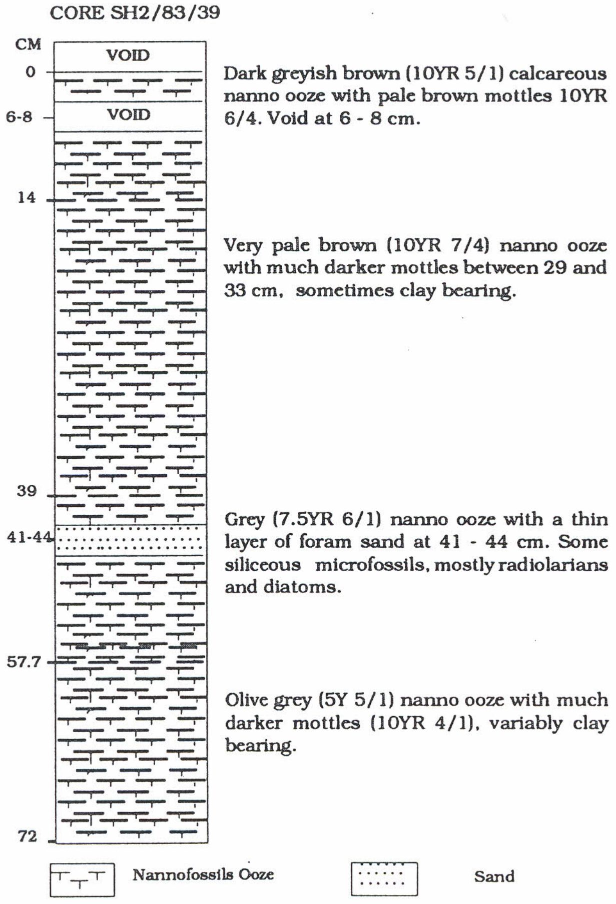


Fig. 5. Calcareous (Nannofossil) ooze with some Siliceous Microfossils mostly Radiolarians and Diatoms.

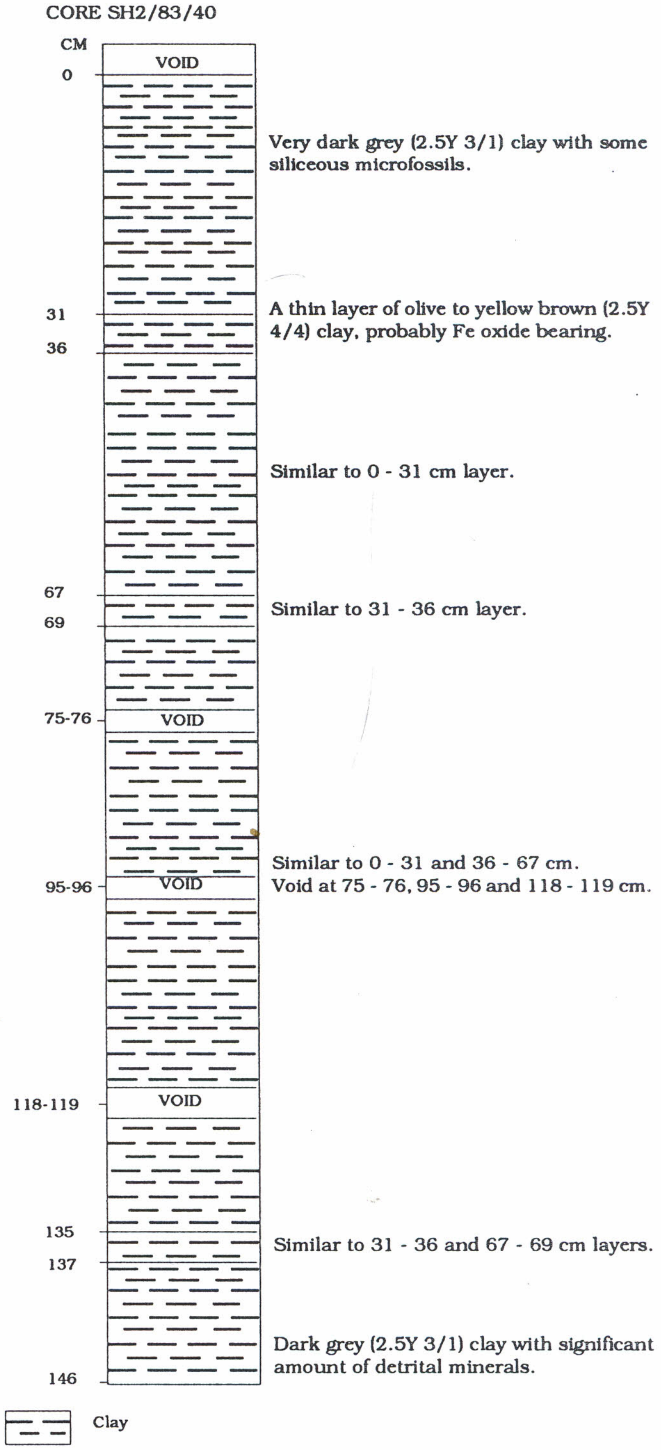


Fig. 6. Fe - Oxide Rich Clay with some Siliceous Microfossils and Detrital Minerals.

constituents such as Fe and Mn oxides.

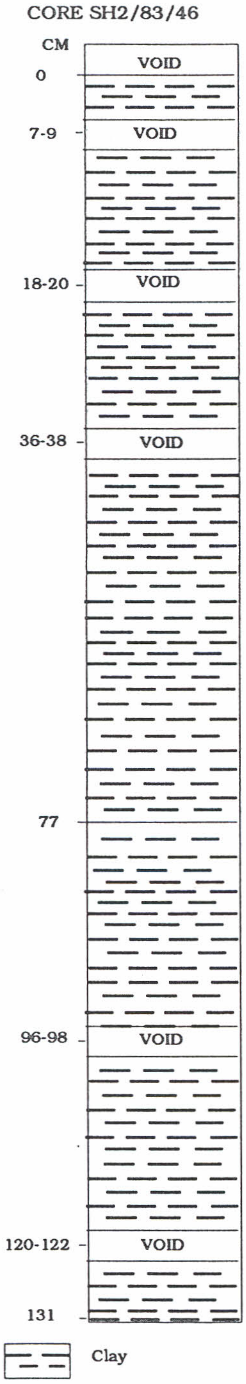
The X-ray diffraction traces of the glycolated and heated samples from three different cores are shown in Figs 8-10. Calcareous samples were first leached with weak acetic acid in order to remove $CaCO_3$ and NaCl which could mask clay minerals. As a result, calcite peaks are not developed in the XRD traces. It is, therefore, not possible to assess calcite content of the sediment samples analysed. But the clays and detrital constituents are essentially composed of kaolinite and serpentine with some chlorite, illite, smectite, quartz, felspar, talc and amphibole.

Of all the minerals identified by XRD, kaolinite, quartz, illite and smectite appear in every sediment sample analysed. This suggests that there is a uniform mixing of terrigenous and authigenic sediments throughout the study area. The former is probably transported by wind from desert areas of the bordering continents (cf. Riley and Chester, 1971; Chester *et al.*, 1972).

From visual core descriptions and smear slide observations, the sediments can be divided into four main components: biogenic, terrigenous, volcanogenic and authigenic (Odada, 1986, 1990).

Biogenic components can be divided into two main groups: siliceous and calcareous microfossils. The siliceous microfossils comprise radiolarians with some diatoms and only few sponge spicules. The calcareous microfossils comprise foraminifers and nannofossils, mostly coccoliths. Biogenic components dominate the sediments and are mostly found above the CCD in topographically more elevated areas.

Terrigenous components of the sediments are composed primarily of various clays. Their presence is indicated by the occurrence of kaolinite, chlorite, quartz and illite in the sediments. They are probably supplied by fall out of atmo-



Dark brown (10YR 4/2) siliceous clay with pale brown mottles 10YR 4/4. Void at 7 - 9, 18 - 20 and 36 - 38 cm. Sharp contact at 77 cm, which divides the core into two lithologically different sections.

Very dark to black (10YR 2/1) siliceous clay with greyish brown mottles 10YR 6/1. Void at 96 - 98 and 120 - 122 cm.

Fig. 7. Siliceous (Radiolarian) Clay with over 50 % Clay Material and 40 % Siliceous Microfossils.

spheric particles and river runoff, and are thoroughly mixed by ocean currents. This is suggested by their uniform distribution throughout the study area. The X-ray diffraction analysis shows the presence of kaolinite, quartz and illite in every sediment sample studied (Figs 8-10).

The presence of volcanogenic detritus in the sediment is suggested by the occurrence of serpentine, feldspar and volcaniclastic particles. Their distribution is probably largely controlled by local weathering of the basement, although fine volcaniclastic particles such as volcanic ashes may have been transported through the atmosphere by wind and/or within the water column by currents.

Authigenic components of hydrogenous and/or diagenetic origin can be divided into two categories: Fe-Mn micronodules and amorphous Fe oxides. The presence of Fe-Mn oxides is indicated by dark coatings on clay material and foram tests (Odada, 1986). The presence of amorphous iron oxides is inferred from the appearance in smear slides of reddish-brown speckles usually dispersed in dark brown clay patches and coatings. Similar red-brown semiopaque oxides have been previously observed by Meylan *et al.* (1982) in S. W. Pacific sediments, thought to be disseminated grains and globules of amorphous iron oxides.

DISCUSSION

Deep-sea sediments are usually classified by their relative proportions of biogenic, continental, volcanogenic and authigenic constituents. The RFZ sediments contain all these components. The proportion of any one component in the sediments is controlled in varying degree by water depth, proximity to sources of terrigenous or volcanogenic sediments, biological productivity of surface waters, bottom current activity, bottom topography and by inputs of authigenic minerals.

On the basis of the observed lithological and mineralogical characteristics of the sediments, water depth and biogenic dissolution appear to play a most important role in controlling the sediment-type in the study area. Sediment cores found between 2000 and 5000 m water depth primarily contain calcereous oozes, whereas those found between 5000 and 7500 m depth contain various clays and detrital minerals (Figs 3-7). This reflects the influence of the CCD (which is approximately 5500 m water depth in the RFZ area) on sediment-type.

This is consistent with the findings of Maxwell *et al.* (1970) for sediments from the mid-Atlantic ridge. These workers noted that biogenic dissolution during deposition plays an important role in determining the lithology of the sediments they studied and their net rate of accumulation. On the basis of these observations they suggested that the red clays they studied probably represent the insoluble residue of calcareous oozes.

The mineralogy of the sediments clearly show that there has been an influx of terrigenous sediments to the RFZ area. This is indicated by the presence of kaolinite, quartz and illite in the sediments (Figs 8-10). The introduction of material from rivers such as the Amazon, Congo and Niger has been suggested as the main source of terrigenous sediments in the equartorial Atlantic (Goldberg and Griffin, 1964; Emery and Uchupi,

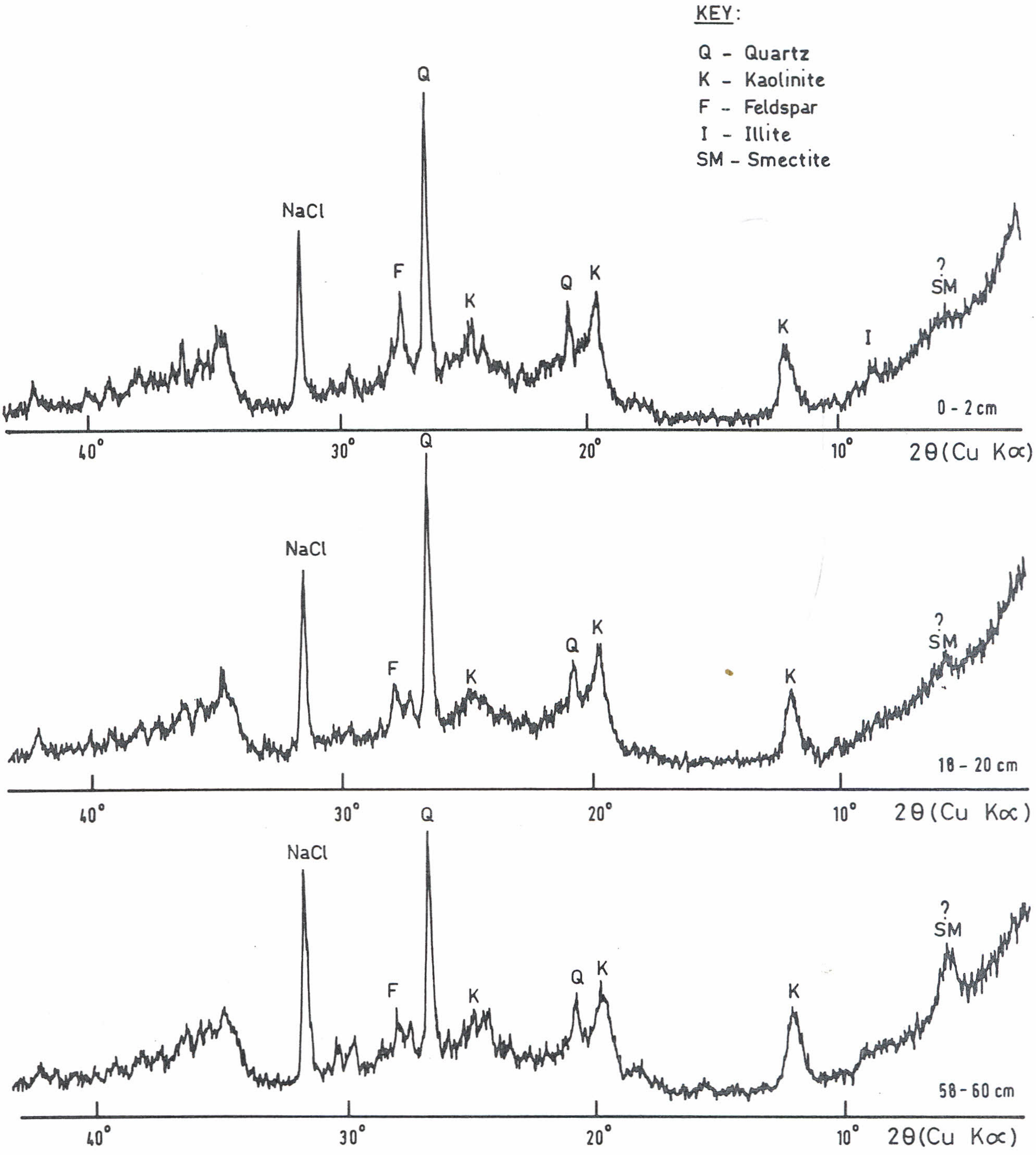


Fig. 8. X-ray diffractograms of sediment from Core SH2/83/46.

1984).The mechanism by which the sediments are transported from the continental slope to the deep-sea is, however, less clear. The Antarctic bottom water is believed to play an important role in redistributing this material (Emery and Uchupi, 1984). Extensive areas of the western Atlantic are subject to erosion by movement of the Antarctic bottom water.

The uniform distribution of kaolinite and illite in the study area indicates, however, that wind may be the primary transport mechanism for much of the terrigenous sediments. This is consistent with the findings of Riley and Chester (1971) and Chester *et al.* (1972) for North Atlantic terrigenous sediments, thought to have been transported by trade winds from the bordering north African desert areas.

A combination of wind, river and bottom current transport mechanism might be invoked to explain the influx of terrigenous sediments into the study area. The first two would be responsible for transporting material to the seabed and once on the seabed, dispersal might occur due to the action of bottom currents.

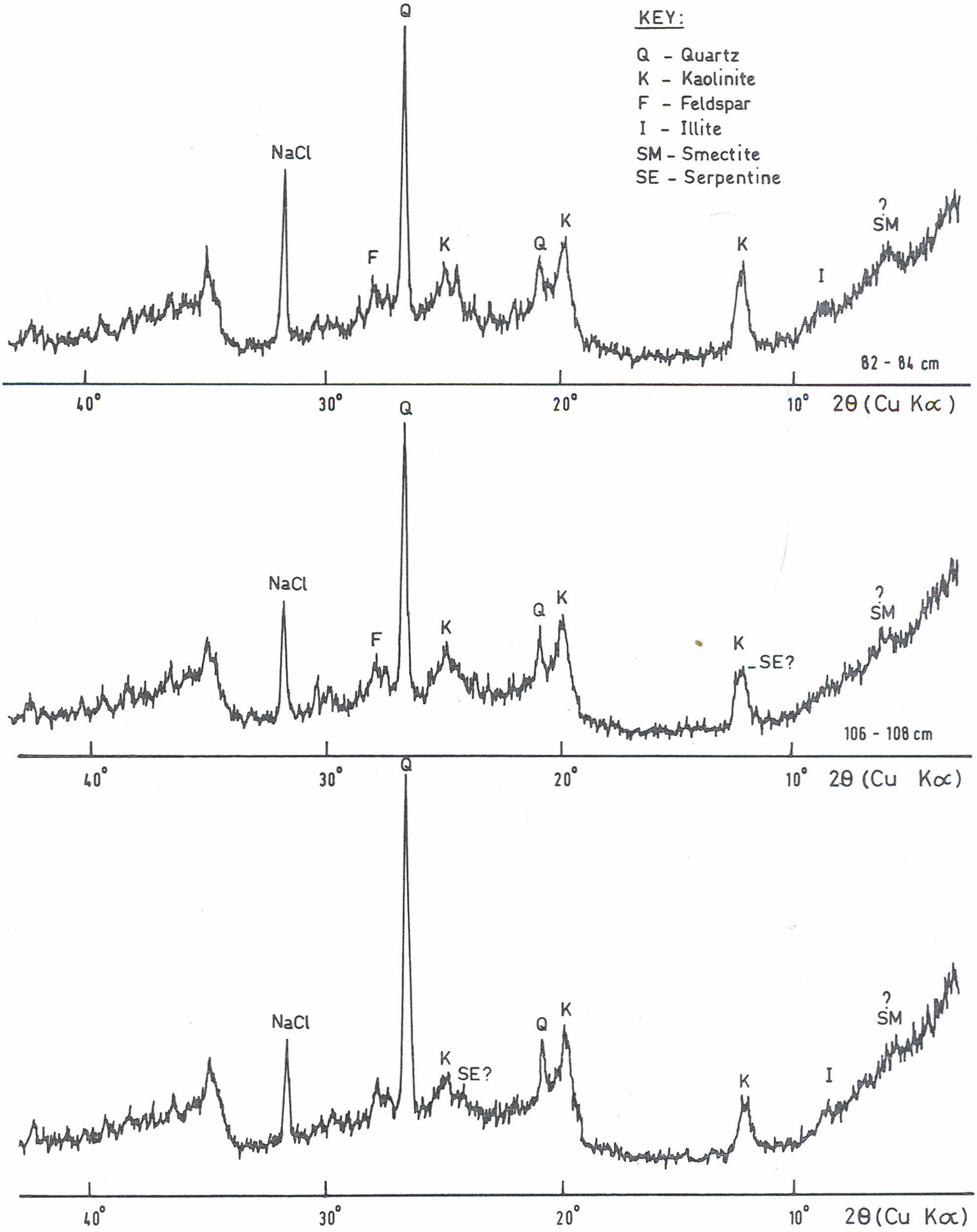


Fig. 8 (cont.). X-ray diffractograms of sediment from Core SH2/83/46.

The influence of submarine weathering of igneous material on the sediment is suggested by the occurrence of serpentine, felspar and volcaniclastic particles in core CH7108 (Fig. 10). The nature and distribution of igneous rocks in the RFZ have been described by Bonatti *et al.* (1977, 1979) and more recently by Bonte *et al.* (1982), who reported that the thick section of oceanic crusts exposed in the RFZ essentially consists of ultramafic, gabbroic and basaltic rocks plus their alteration products, with peridotites and other ultrabasic rocks being the dominant rock type.

The highest flux of carbonate debris to the sea

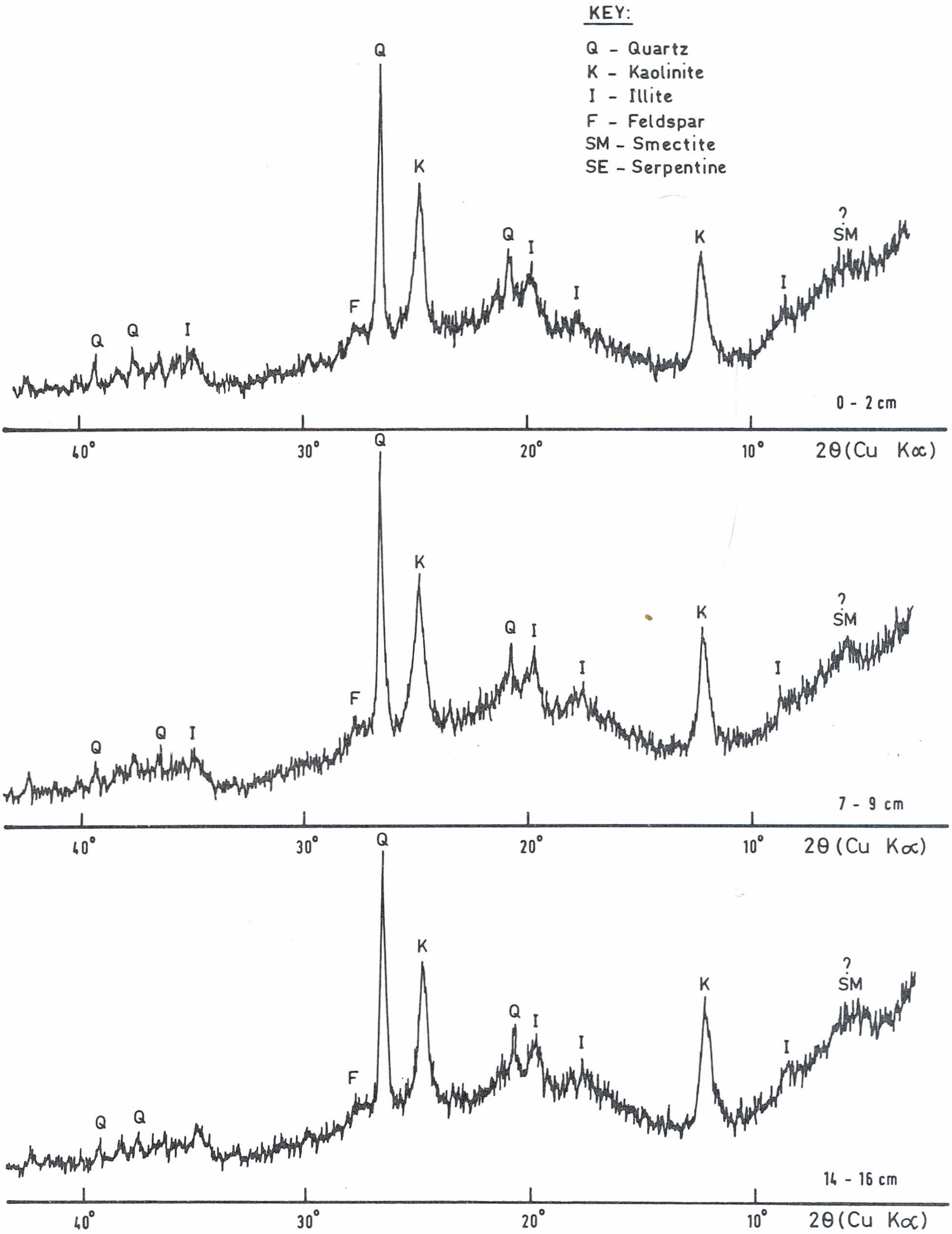


Fig. 9. X-ray diffractograms of sediment from Core SH2/83/60.

floor would be expected under areas of highest biological productivity. This is indeed the case in the present study, where several types of organic debris have been recognised in smear slides of sediments found on topographically more elevated areas. Foraminifers and nannofossils were the most prevalent comprising 25 - 75 % of almost every sample above the carbonate compensation depth. Siliceous microfossils, mostly radiolarians, diatoms and sponge spicules were also detected in

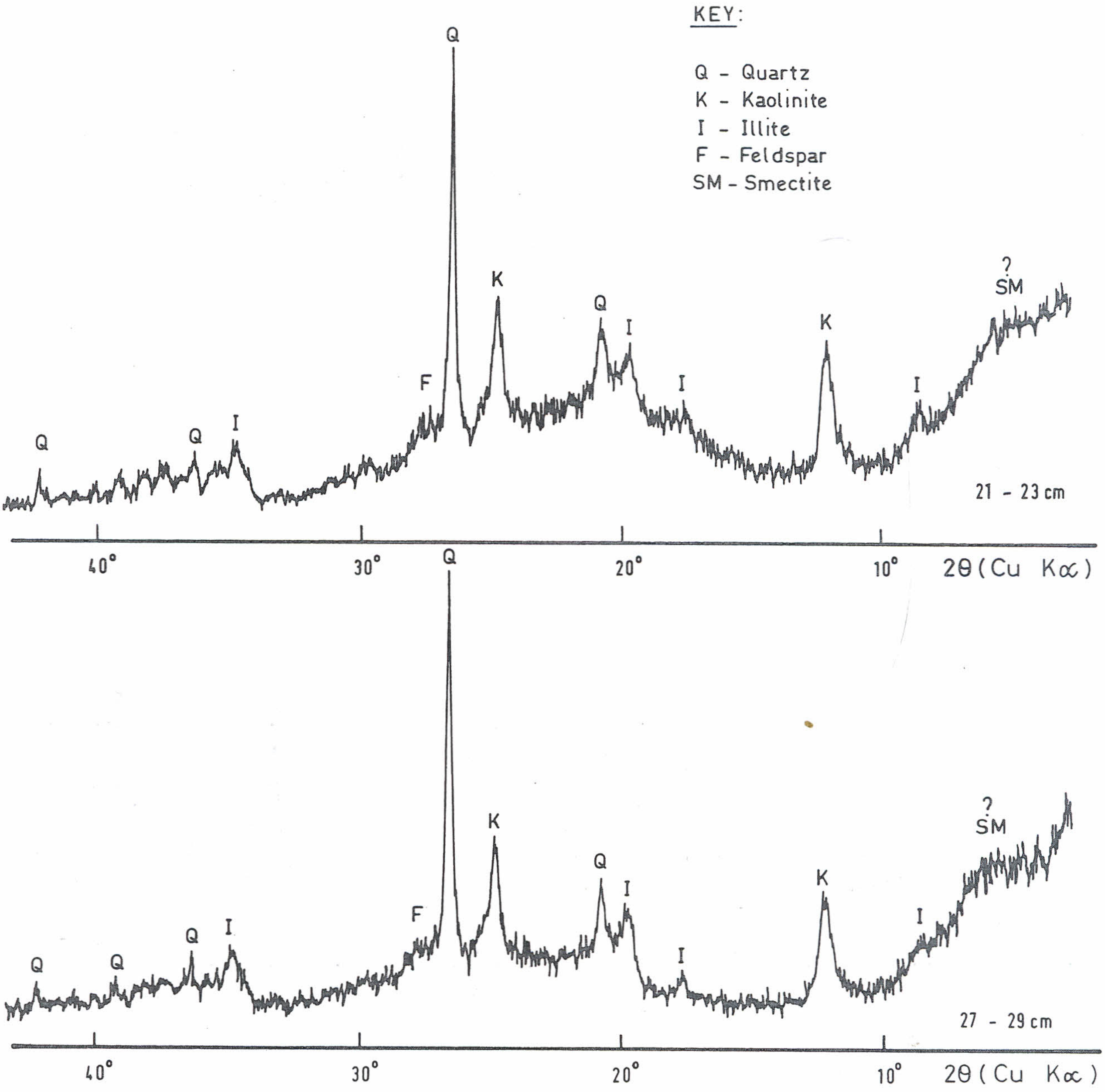


Fig. 9. X-ray diffractograms of sediment from Core SH2/83/60.

significant quantities in the sediments.

Contours of primary productivity of the equatorial Atlantic are shown in Fig. 11. Estimation of the annual production of organic carbon (primary productivity) has been carried out for most parts of the Atlantic, including the high-latitude region of highest productivity. Koblentz-Mishke *et al.* (1970) computed an average production of organic carbon of 69.4 g c/m^2/yr for the entire Atlantic. Emery and Uchupi (1984) also estimated the primary productivity from the plankton maps of Koblentz-Mishke and her associates for the Atlantic Ocean between latitude 60 °N and 60 °S that yielded an average of 65.8 g c/m^2/yr, including the equatorial region of high productivity. In the case of equatorial region, high productivity may be due to new supplies of dissolved nutrients (N, P, Si and trace metals) in near surface water well lit by sunlight (Emery and Uchupi, 1984).

The strong Antarctic bottom current flow through the RFZ is believed to be responsible for sweeping off some portion of the RFZ sediments into sediment-ponds of uneven distribution (Bonte *et al.*, 1982). Current-smoothed bottom was noted on echograms of the valley floor and the rate of 2 - 20 cm/10^3 yrs (Odada, 1986) is quite variable even over small areas. Further, several of the cores from the RFZ floor and deep terraces contain sections that appear to be calcareous turbidites (Figs 3-7). These cores contain coarser foraminifer-rich layers within ungraded, structureless sediments composed primarily of calcareous clays. Similar sediments have been described in the RFZ by

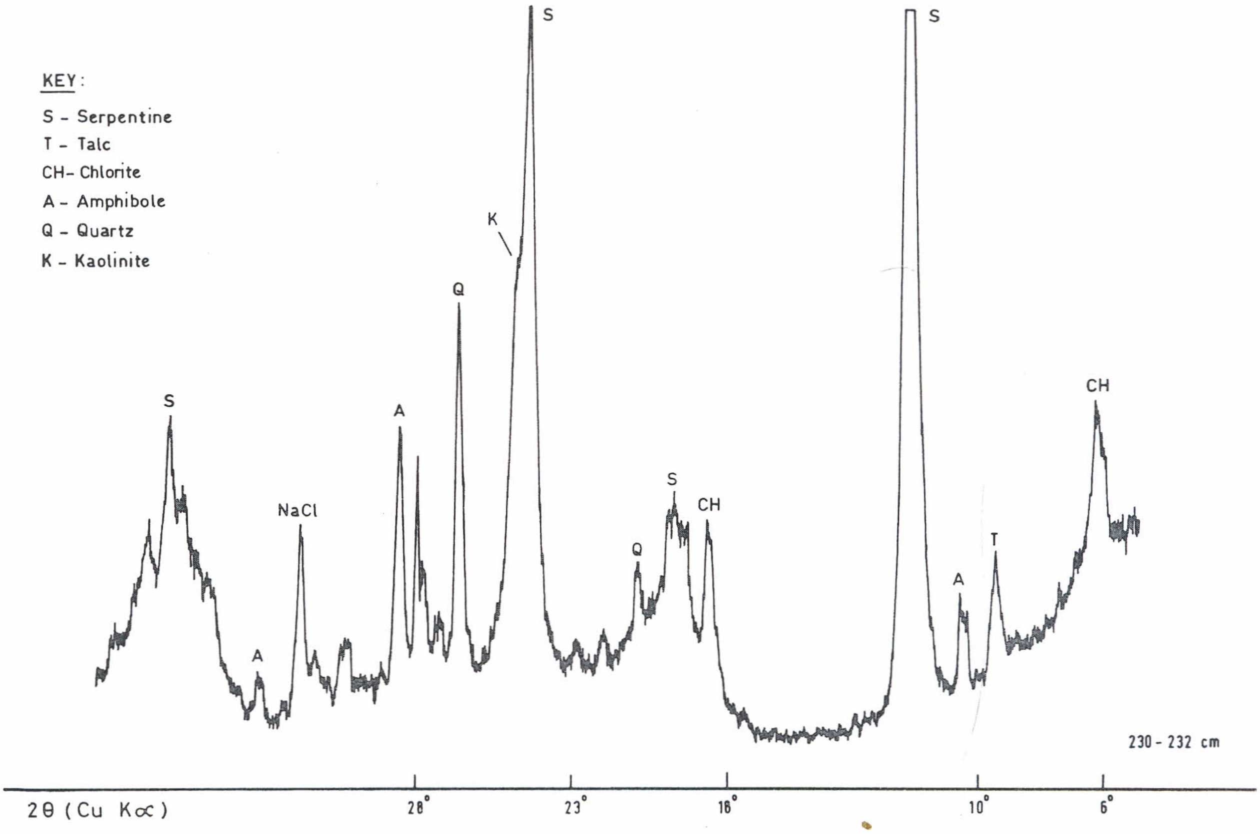


Fig. 10. X-ray diffractograms of sediment from Core CH7108.

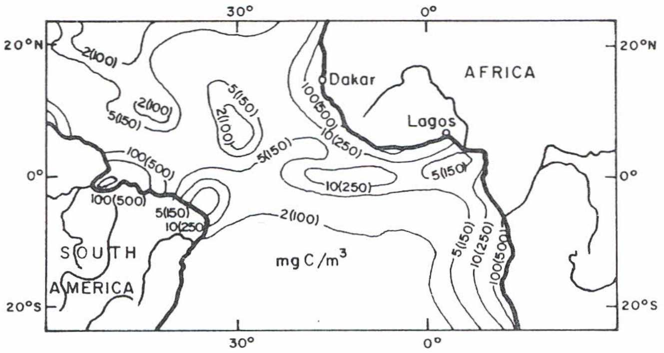


Fig. 11. Contours showing Primary Productivity for the Equatorial Atlantic. Data from World Ocean Atlas by S. G. Goschov (1978). Measurements in mg Carbon in m³ surface water and in m² Photic layer.

Petterson (1955), Heezen et *al.* (1964), Cifelli (1970) and Bonte *et al.* (1982), who consider the coarser foraminifer-rich layers to be slumped carbonate material transported from shallower water under the influence of turbidity current activity.

The effect of bottom topography on the sediments of the RFZ area is clearly seen in their distribution (Figs 3-7). The sediments on the topographically more elevated areas are derived primarily from carbonate debris, whereas the sediments on the valley floor and lower terraces that receive eroded material are dominantly composed of admixtures of clay and detrital material. Local occurrences of carbonate below the CCD have also been observed in some cores from the RFZ floor and deeper terraces. Slumping and/or turbidity current processes may explain these anomalous occurrences. Bonte *et al.* (1982) reported similar occurrences of calcareous sediments in cores recovered on the RFZ floor, thought to have been slumped due to the rugged topography of the Romanche Trench (Fig. 2).

Authigenic inputs are indicated by the presence of goethite and manganese micronodules in the sediments. In addition, thin layers of yellow or rust coloured sediments have been noted in the sediment cores (Odada, 1986). Authigenic components of the sediments have also been recognized microscopically on smear slides. They appear as reddish-brown speckles and yellow flakes in a clay matrix. Similar materials have been previously reported in sediments by Meylan *et al.* (1982) who consider the material to be X-ray amorphous iron hydroxides which exist either discreetly or as coatings on clay mineral particles and/or on foraminiferal tests.

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