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SEDIMENTATION IN THE DEEP-SEA AREAS ADJACENT TO THE CANARY AND CAPE VERDE ISLANDS

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ABSTRACT

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Bottom sediments between the eastern Canary Islands and Morocco, as revealed in piston cores, are principally of continental-shelf derivation with little material from the islands. The sediment is in general *Globigerina* ooze with silt-size quartz and much clay. Clay minerals are iron-rich chlorite, illite and locally abundant smectite. Glauconite, both authigenic within foraminifera tests, and detrital, is common. Carbonates are mainly from marine organisms but dolomite is entirely detrital. Sedimentation rates as determined by ^{14}C dating are about 2–3 cm/1,000 years.

In the inner Cape Verde deep-sea area terrigenous material is scarce. Sediments are composed of autochthonous marine organisms, mostly foraminifera, and/or material derived from the shallow-marine areas around the islands where biogenic carbonate is formed and reworked locally with volcanics. Layers of the latter material can be traced within the basin; their ^{14}C ages correspond to low sea-level stages in the Atlantic within the past 35,000 years according to Milliman and Emery (1968).

The mineralogy of the Inner Cape Verde Basin sediments studied is different from the Canary Islands samples. Quartz, as well as dolomite, is uncommon. Glauconite was found only within foraminifera chambers. The clay minerals comprise rare chlorite, almost no illite, and some smectite. Normally, the clay fraction consists of allophanic material. Amorphous silica is rather abundant and probably originated from radiolarians and sponge spicules. Carbonates (calcite, high-Mg calcite and aragonite) are biogenic. Volcanic sand mixed with the shallow-water carbonates is composed of abundant basaltic glass with magnetite inclusions, clinopyroxene and scarce olivine and feldspar. This particular sediment distribution within the Inner Cape Verde Basin reflects a combination of open marine conditions and a chain of volcanic islands forming a barrier against terrigenous sedimentation from the African continent. ^{14}C ages indicate average sedimentation rates between 2 and 3 cm/1,000 years.

In the Canaries the principal constituents are terrigenous. In both areas, but particularly in the Cape Verdes, sedimentation is discontinuous, because the steady accumulation of the normal marine material is interrupted by a sudden influx of reworked shallow-marine sand.

Contrary to general opinion, little volcanic material is present in the sediments investigated of both the Canary and the Cape Verde islands.

INTRODUCTION

The general opinion is prevalent that surrounding oceanic volcanic islands there are sediments called "volcanic mud". Our studies show that at least in some cases the sediment is dominantly composed of non-volcanic material. This paper considers sediments of the deep-sea environment surrounding the Canary and Cape Verde islands, both of which are of volcanic origin. Due to technical reasons, the samples from the Canaries were taken only from the area between the eastern islands of the Archipelago and Morocco on the African continent. The Cape Verde samples represent the area bordered in the north, east and south by the Cape Verde Islands. Although sampling was done by grab sampler and piston-corer, most of the data reported here are from the latter. Cores range in length from 0.8 m to 4.65 m and the water depths of the stations vary from less than 200 m to almost 4000 m. The stations are shown in Fig.1 and 2.

ANALYTICAL PROCEDURE

The grab samples were split and the cores cut into samples of about 5 cm length. All samples were washed free of salt. The mineralogy of the carbonates and clay minerals was determined by X-ray diffraction using CuKα – radiation (Philips PW 1310 and Müller Mikro 111, respectively). Carbonates were diffracted in unoriented powder samples, while for the identification of clay minerals oriented preparation was done by sedimentation on glass slides. Total carbonate content was measured by the CO_2-pressure method of Müller and Gastner (1971). Chemical composition of the total samples was determined and trends were established in cores. Ground samples were dissolved in HCl and the elements Ca, Mg, Sr, Fe, Mn, Zn, Cu were determined using a Perkin-Elmer 303 model atomic-absorption spectrophotometer. Si and Ti were analysed by X-ray fluorescence with a Philips PW 1310 spectrometer. Grain-size parameters were determined on selected samples only to establish the prevailing sediment characteristics. Four samples from the Canary Islands and nine samples from the Cape Verdes were selected for age determinations using the ^{14}C method; four of these radiocarbon ages are shown in Fig.3 and 4.

RESULTS

Canary Islands

Sample locations and short description of sediment types

Samples from the Canaries were obtained between the easternmost islands Lanzarote and Fuerteventura, and the offshore area of Morocco. The samples can be placed in two categories, depending upon the depth of water:

(*1*) Two stations are located in rather shallow water of about 200 m depth, one on a seamount-like bank, Banco de Concepción (about 250 m) and one on the shelf of Morocco (169 m).

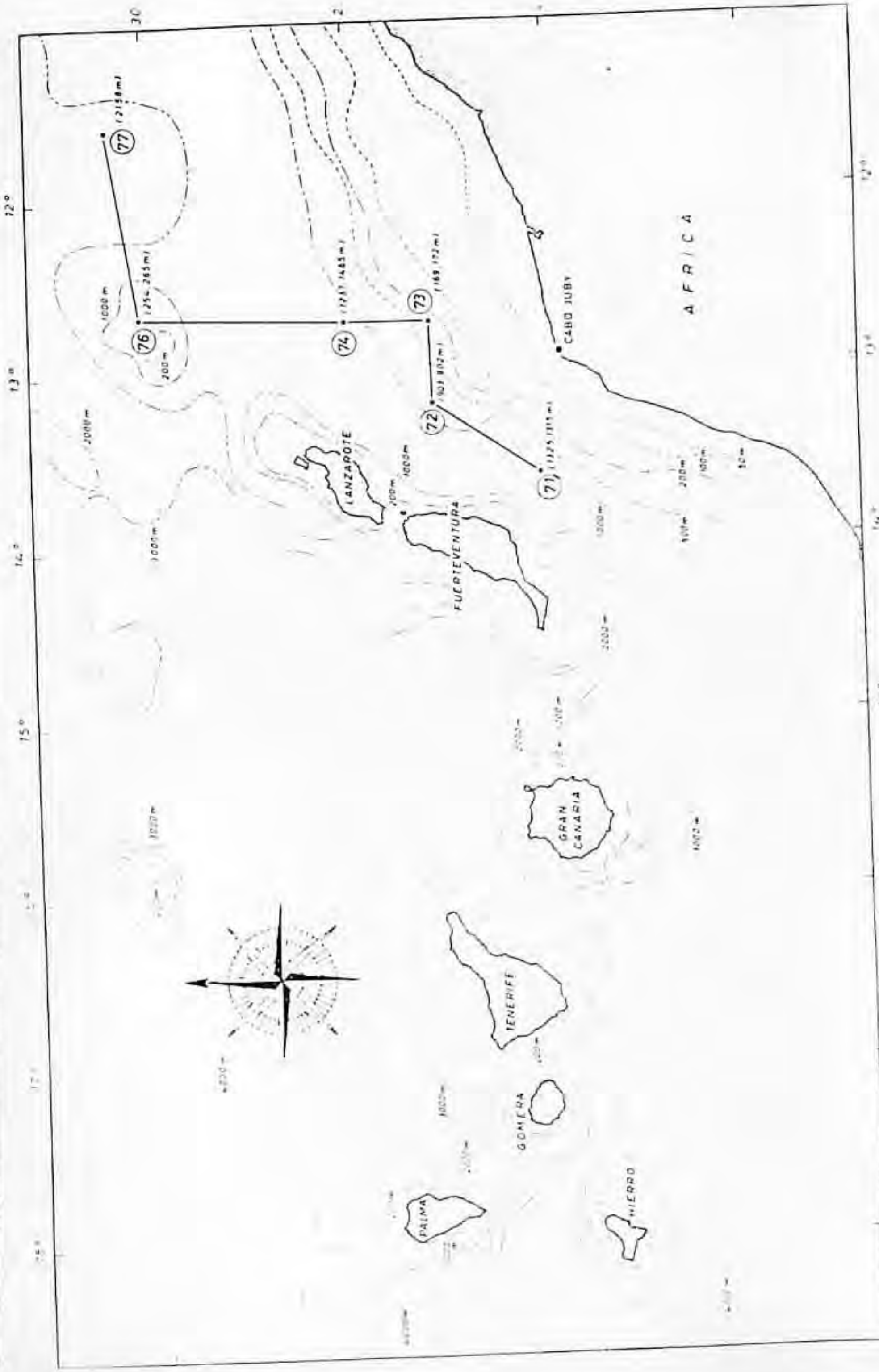


Fig.1. Sample locations in the Canary Islands area. (Atlantic Expedition, 1967, F.S. "Meteor".)

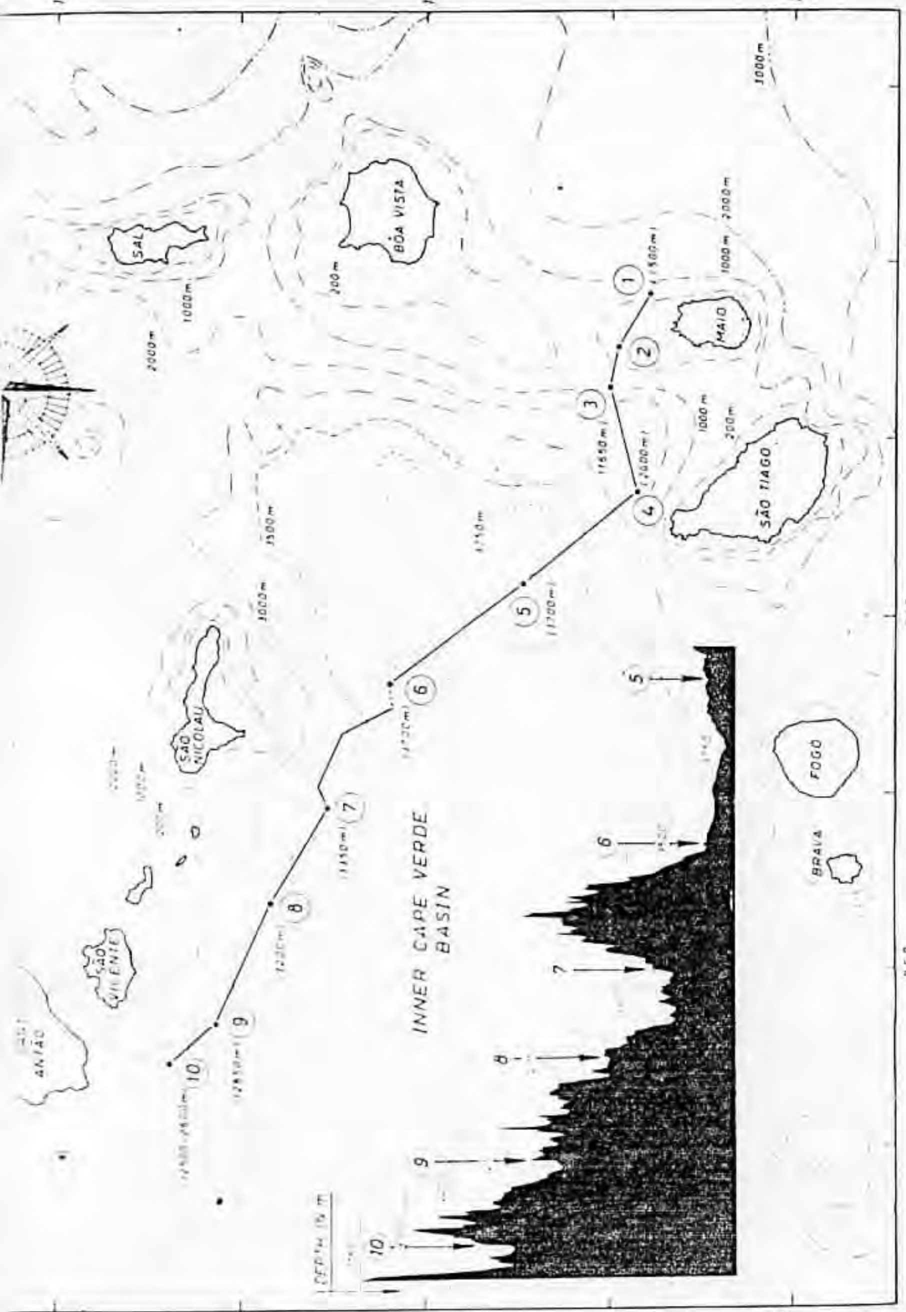


Fig.2. Sample locations in the Cape Verde Islands area. Left side: water depths according to echo-soundings. (Atlantic Expedition, 1969, W.F.S. "Planet".)

Sediments at both stations are mainly coarse-grained sands and gravel of different composition: the gravel fraction of Banco de Concepción sediments is mainly mollusks, bryozoans and echinoderms, whereas the sand fraction consists of foraminifera of both the *Globigerina* type and benthonic species. Carbonate content is higher than 95%.

The Morocco shelf sediment has a similar gravel and sand fraction but contains more terrigenous material due to the proximity of the African continent; average carbonate content is 80%.

(*2*) Three stations are located in deeper water (903, 1,325 and 2,158 m) almost midway between the islands and Africa. The sediment is a grey-green *Globigerina* ooze with a brown oxidation zone within the uppermost 40 cm of the cores.

The ooze is composed of silty clay or clayey silt containing abundant quartz and even fragments of quartz sandstone. Volcanic components, on the other hand, are scarce. Clinopyroxene, olivine and magnetite are present in trace amounts only.

Carbonate mineralogy

The carbonates present in the samples from the Canary Islands are aragonite, calcite, high-magnesian calcite and dolomite. Aragonite is derived primarily from mollusks: pteropods, pelecypods and larger gastropods. High-magnesian calcite is mostly from echinoderms and red algae. Calcite is from *Globigerina* and other foraminifera but could also be detrital in origin as is the dolomite.

Within the cores a definite zonation of carbonates occurs. In the longest core, aragonite is not present at depths of about 3 m below the sediment–water interface. This distribution could most probably be explained by primary lack of (mollusk) aragonite in the lower part of the core. The aragonite content is paralleled by high-magnesian calcite, but high-magnesian calcite is restricted to a smaller vertical zone of the cores (Fig.3). Shallow-water material, i.e., skeletal remains of echinoderms, mollusks etc. transported into deep water, might be responsible for the particular distribution of carbonate minerals. Aragonite dissolution in deeper water (Friedman, 1965) cannot be excluded, but seems less probable.

Clay minerals

Illite, chlorite of the iron-rich variety, smectite and kaolinite are present. Further investigations are being carried out to determine the vertical distribution of clay minerals.

Other minerals

Detrital quartz is abundant within the sediments from deep water. Glauconite occurs in two forms: (*1*) pale-green to brownish, authigenic within tests of foraminifera; and (*2*) single rounded grains of a darker green colour obviously detrital in origin.

Chemical parameters

Chemical composition of the samples is clearly related to both carbonate content and carbonate mineralogy. Generally, low carbonate content of the samples corresponds to high contents of Fe, Mn, Cu and Ti. On the other hand, Mg may be related either to high clay-mineral content – that is, low carbonate content – or to an abundance of high-magnesian calcite and/or dolomite. Strontium is related to aragonite which is abundant in the shells of the shallow-water samples. Titanium runs parallel to Si and is an indicator of continental-detrital material.

One example of the relationship between mineralogy and chemical composition of the sediments is given in Fig.3.

Sedimentation rates in the Canary Islands area

Four samples from three cores were analysed with the ^{14}C method to estimate sedimentation rates. Two determinations from one core are shown in diagram (Fig.3).

Grain-size parameters as well as mineralogy suggest a discontinuous sedimentation. Thus the results indicating an "average" rate should be regarded with caution. Much sediment has been reworked from shallow-water environments and deposited in a very short time interval whereas the normal marine production requires a much longer period to accumulate a comparable amount of sediment. The "average" of four samples is about 2–3 cm/1,000 years.

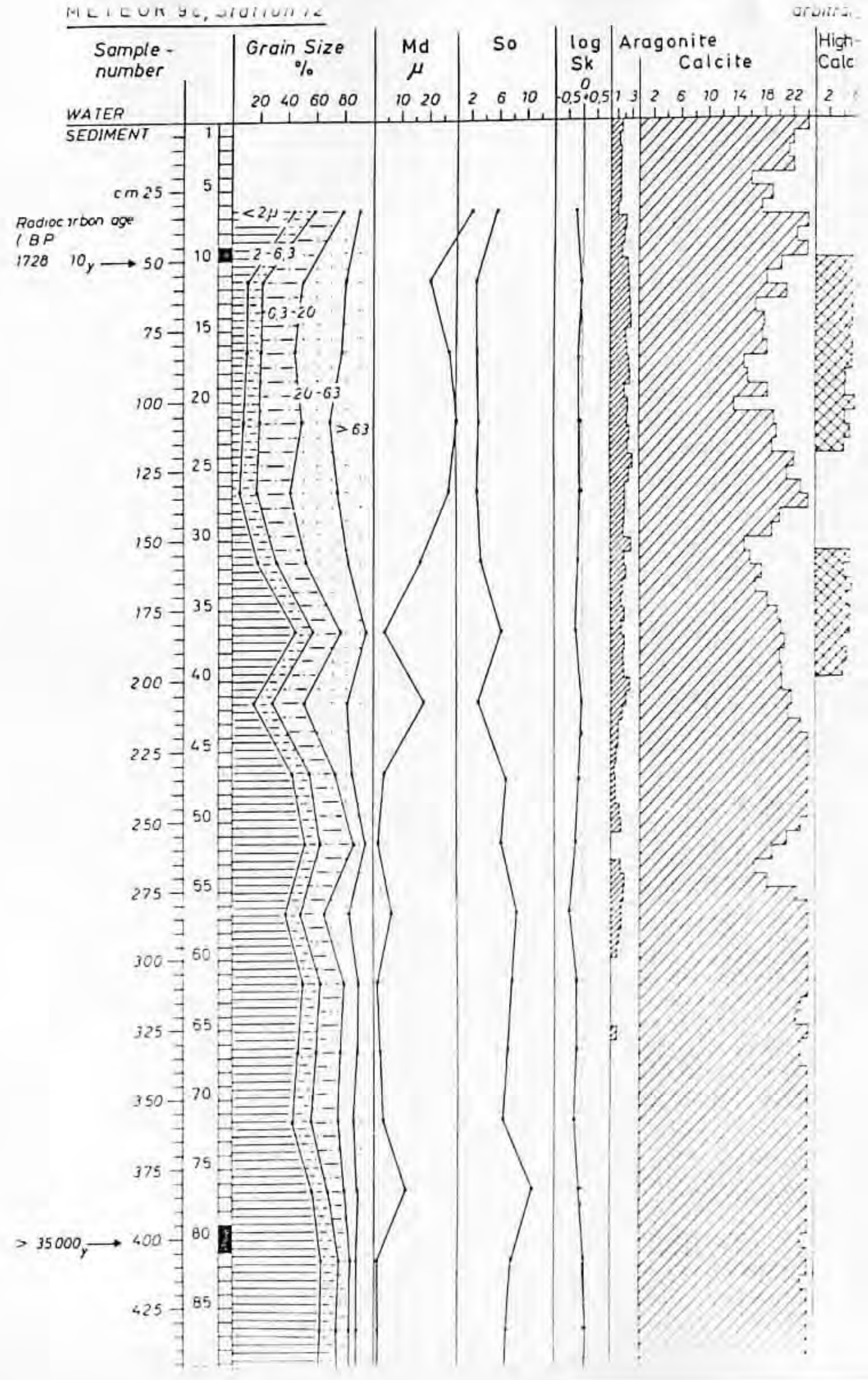
Cape Verde Islands

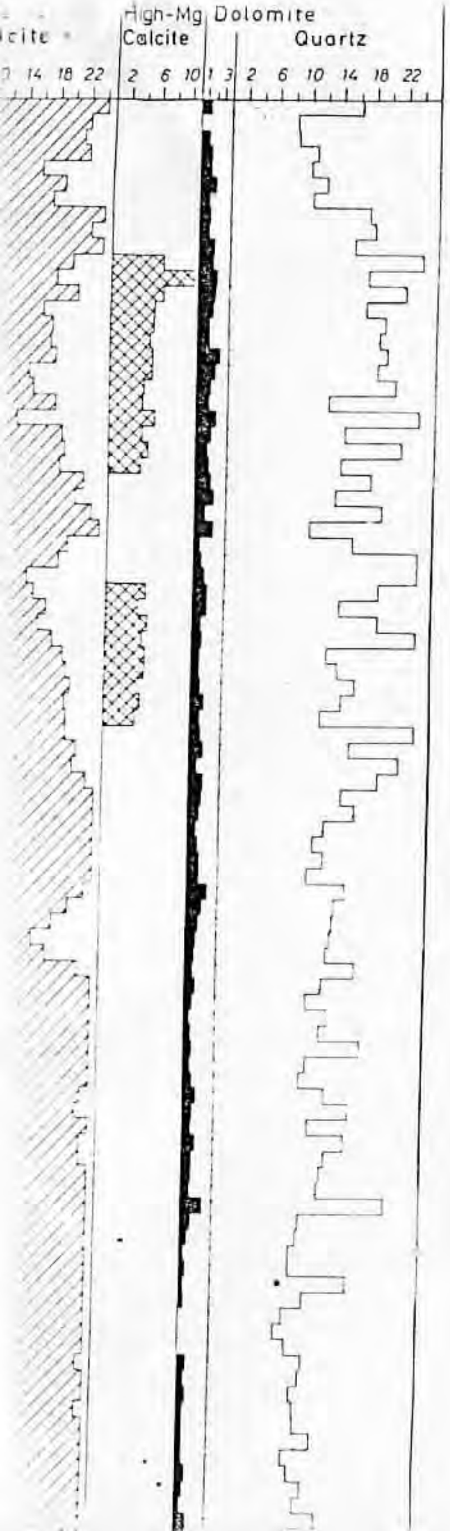
Sample locations and short description of sediment types

Ten stations within the Cape Verde Island area, here referred to as "Inner Cape Verde Basin" (Fig.2), were sampled, five by grab sampler and five by piston corer. Only the results of the piston cores are reported here. The basin is a rather flat-floored deep-sea area of 3,500–4,000 m depth surrounded by steep slopes of the flanks of the volcanic islands. It is open westward towards the ocean and is inaccessible to sedimentation from the continent except for wind deposits. Hence the Inner Cape Verde Basin is an almost ideal model-area to study co-sedimentation of both the open marine and volcanic island material.

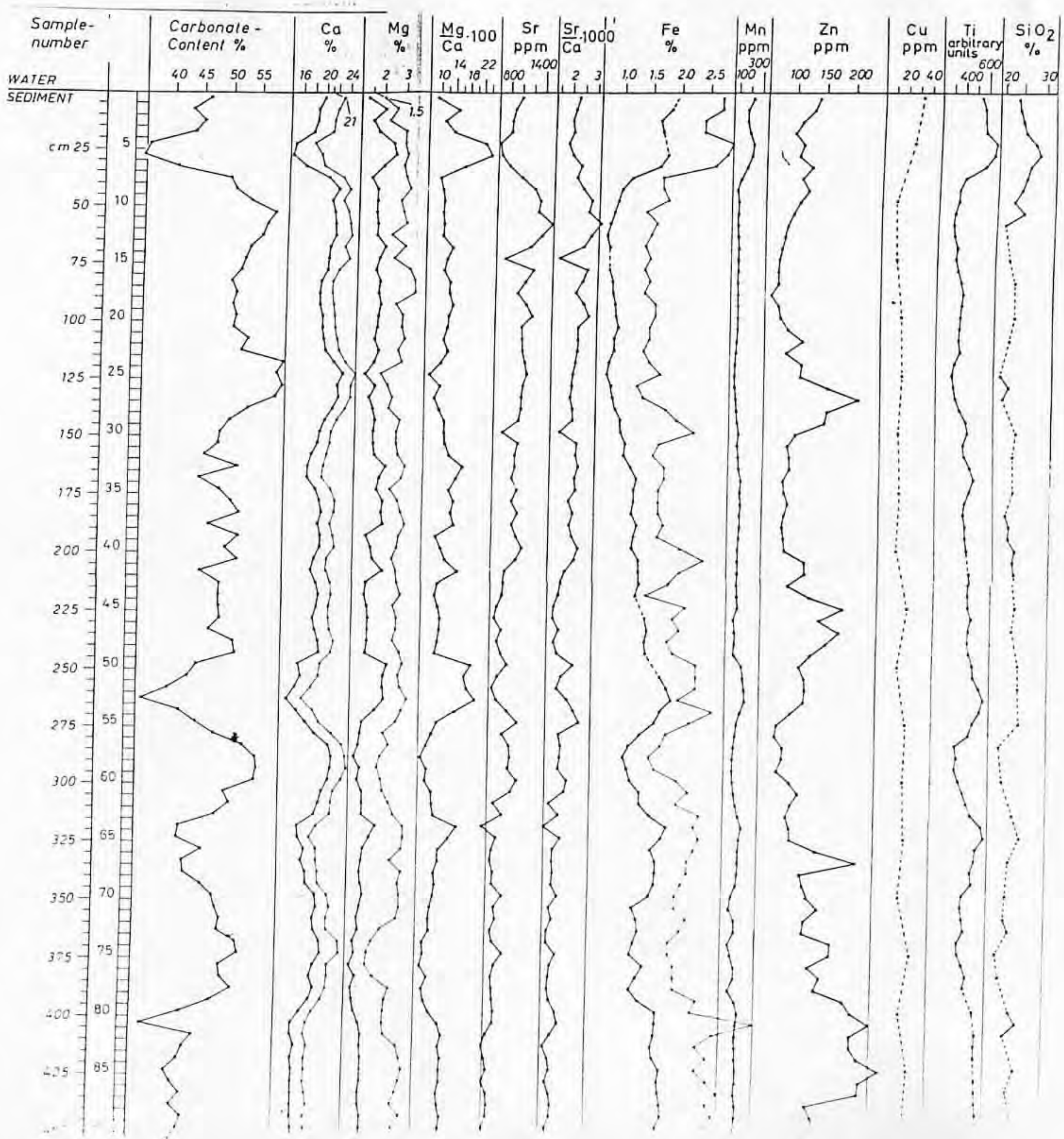
The five stations are aligned on a section of about 200 km and mutually separated by about 40 km (Fig.2). Some material collected from shallow-water areas between Maio and Boavista is almost entirely shallow-marine coarse carbonate sand and some gravel. The sediment from the piston cores is mostly "*Globigerina*-rich" (following the term introduced by Nayudu and Enbysk, 1964) but in all cores at least one layer of shallow-water carbonate sand containing volcanic detritus (basaltic glass, clinopyroxene, magnetite, etc.)

Fig.3. Grain-size parameters, mineralogy and chemical composition of a sediment core from the Canary Islands area. Water depth is 903 m. Note double curves for the Ca, Mg and Fe concentrations: the right curves are data from HF-HClO$_4$-treatment. (Meteor 9c, station 72. For location, see Fig.1.)

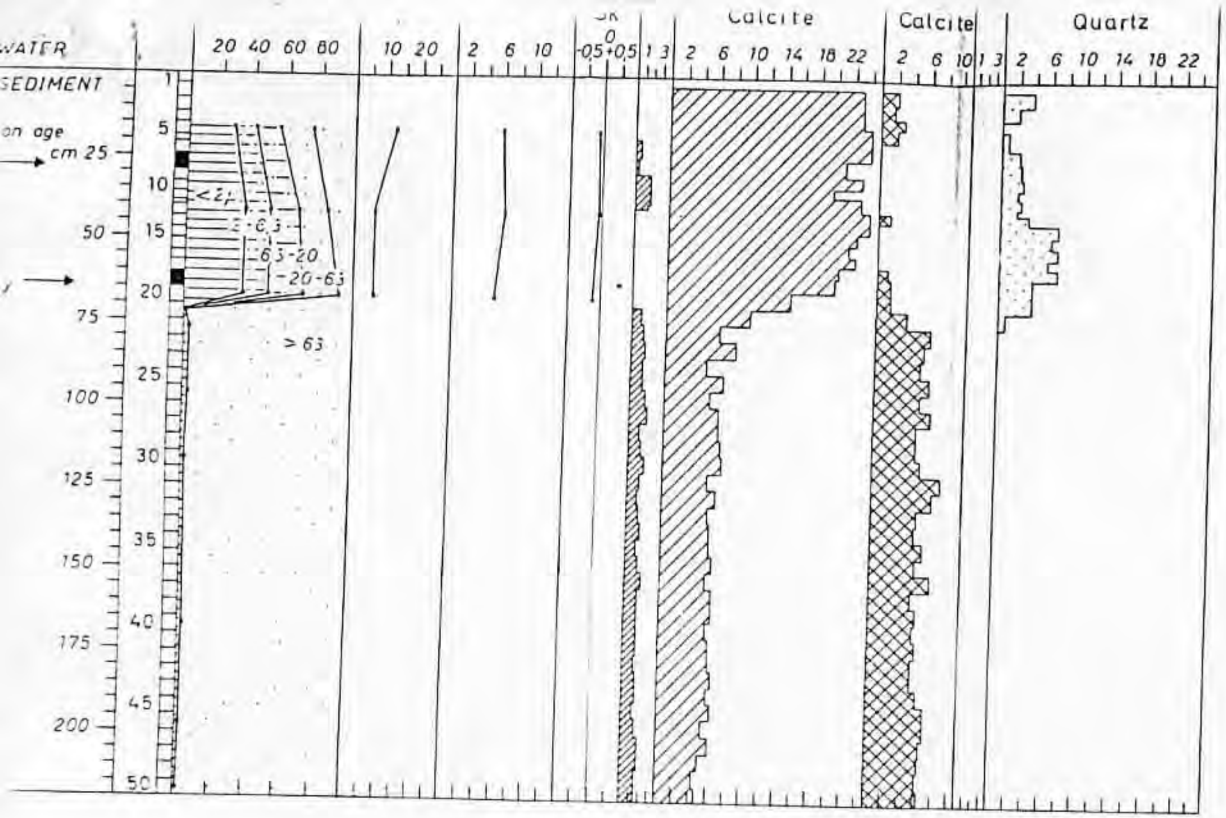


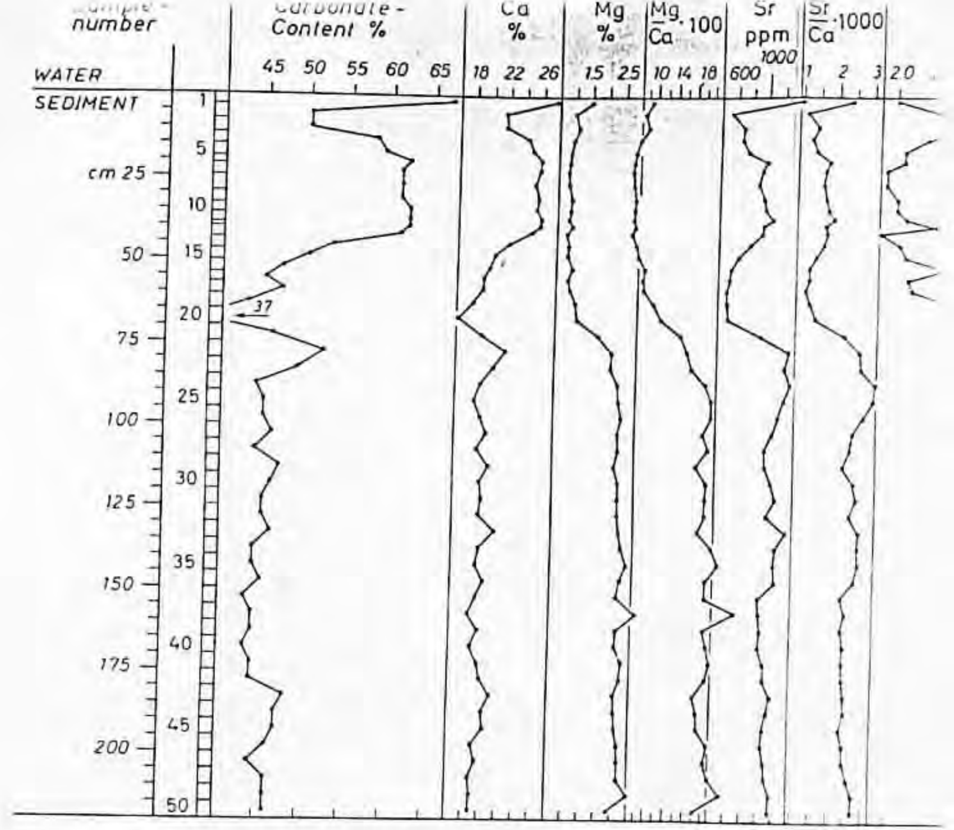


High-Mg
Calcite
Dolomite
Quartz

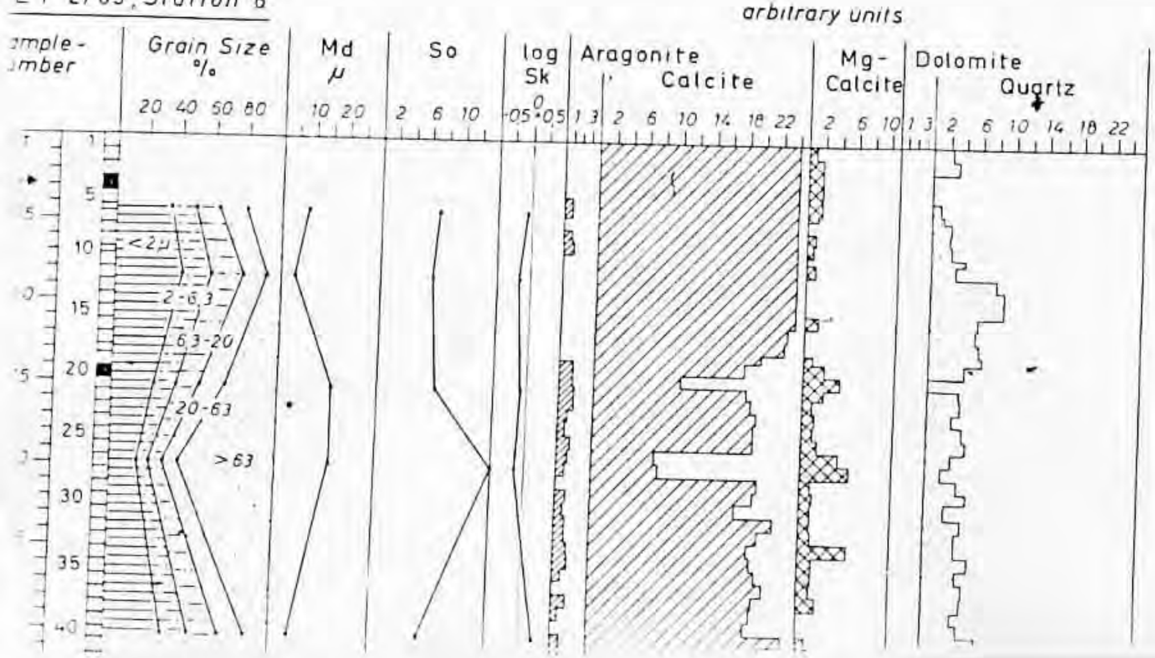


Sample-number
Carbonate-Content %
Ca %
Mg %
Mg/Ca·100
Sr ppm
Sr/Ca·1000
Fe %
Mn ppm
Zn ppm
Cu ppm
Ti arbitrary units
SiO2 %
WATER
SEDIMENT
cm

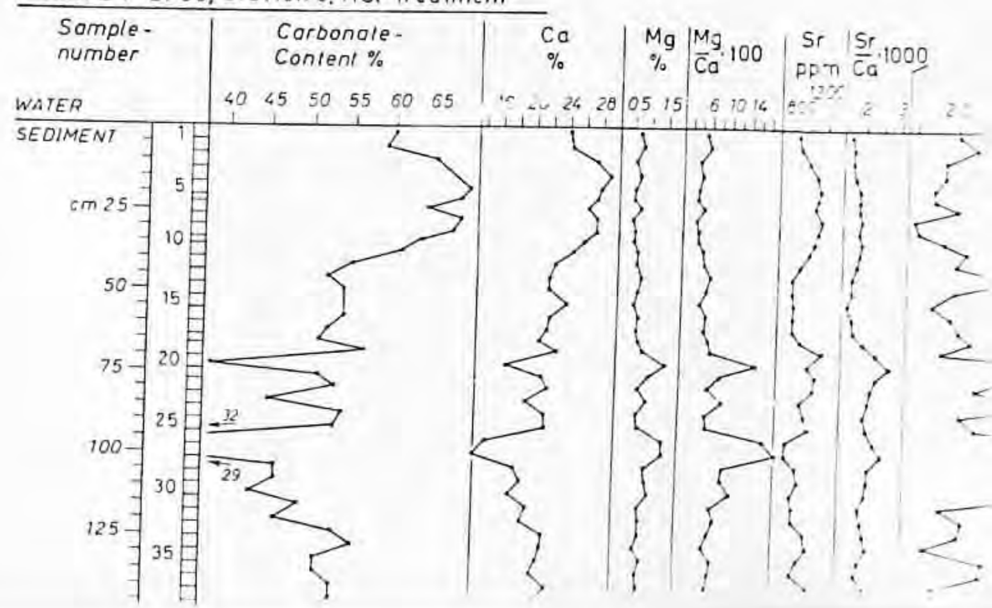


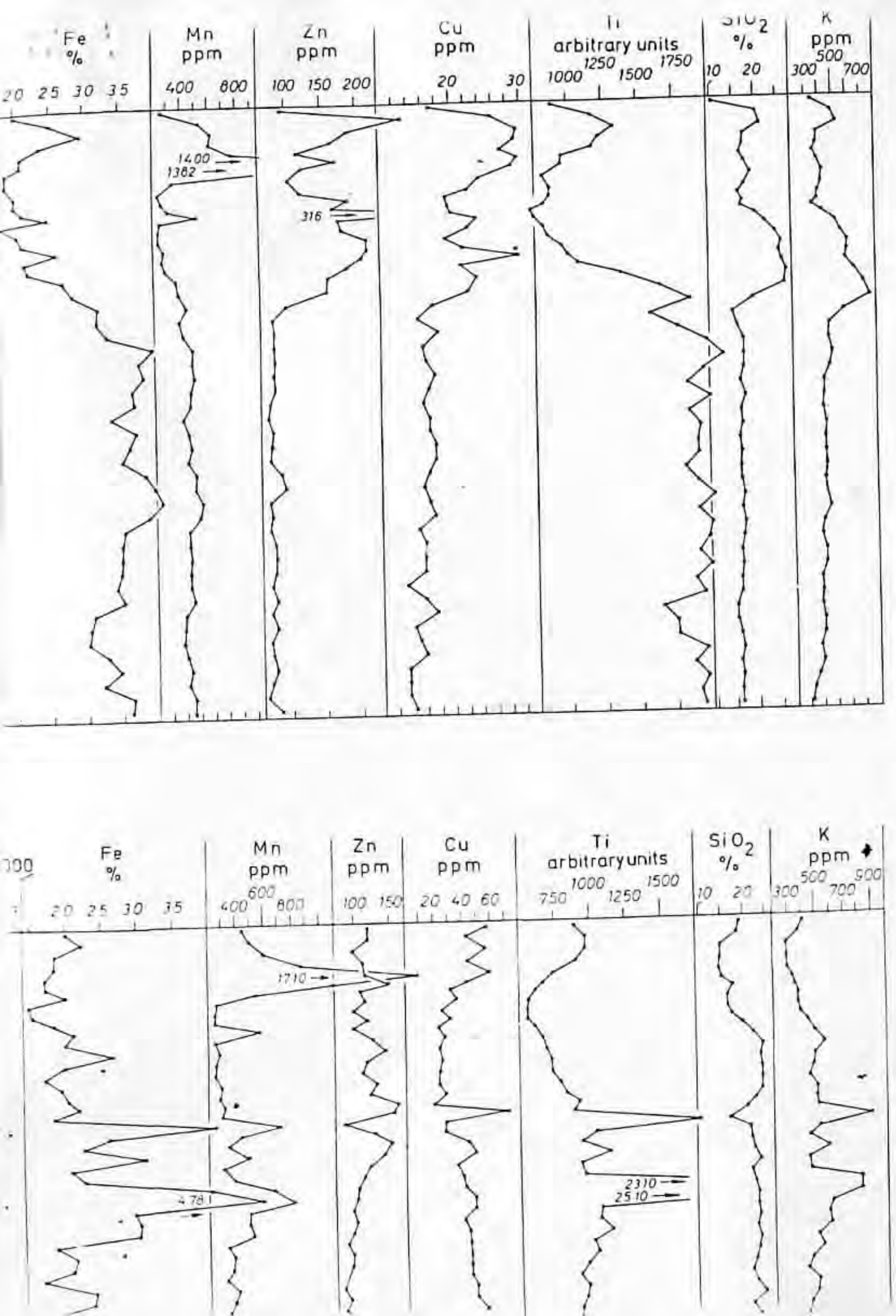


ET 2/69, Station 6



PLANET 2/69, Station 6, HCl-treatment





was found. The carbonate sand is composed of foraminifera, red algae, mollusks and echinoderms. The common sediment type is a silty sand to clayey silt. In contrast to the Canary Islands, the sediment tends towards coarser grain size with a small clay fraction, hence "*Globigerina*-rich" is used instead of "*Globigerina* ooze".

Carbonate mineralogy

Aragonite, calcite and high-magnesian calcite occur, but dolomite is rare in the sediments of the Inner Cape Verde Basin. The origin of the carbonates seems entirely biogenic with subtropic organisms comparable to those of the Canary Islands samples. Skeletons of red algae, responsible for the content of high-magnesian calcite, are abundant in the sands of shallow-marine origin.

Clay minerals

Semiquantitative information on clay-minerals content indicates little clay present in the Inner Cape Verde Basin. Using the same technique as for the Canary samples, almost no clay minerals could be detected. After careful removal of carbonate by acetic-acid treatment, however, small peaks of chlorite were found. The smectite found in some of the samples seems to be not well crystallized. Most of the diagrams suggest that allophane material is present. Further investigations are being carried out.

Other material

The glauconite in the Cape Verde samples seems restricted to the authigenic type occurring only in the tests of foraminifera and/or other organisms. No detrital glauconite has been found so far. Quartz is scarce or absent. A characteristic X-ray diffraction pattern in the $< 2\,\mu$ fractions of the samples suggests the presence of a certain amount of amorphous silica. Comparative analyses of siliceous sponge spicules and diatomaceous earth show them to have similar X-ray patterns. Because of the presence of sponge spicules, radiolaria and diatom tests in the Cape Verde samples, the origin of the amorphous silica (= opal) cannot be referred to any one source exclusively.

Chemical parameters

Specific data for the Cape Verde Islands will be published elsewhere. In the Cape Verde samples, Ti, Si and Fe are clearly related to volcanic detritus, whereas in the Canaries these elements increase with the increase of continental detritus.

Fig.4 represents one typical example of a core from the Inner Cape Verde Basin showing the relationship between mineralogy and chemical composition of the sediments.

Fig.4. Grain-size parameters, mineralogy and chemical composition of two neighbouring stations from the Inner Cape Verde Basin. Water depth is 3,700 m at both stations. (Planet 2/69, stations 5 and 6. For location, see Fig.2.)

[14]C age determinations were made on nine samples from the Inner Cape Verde Basin, …o of which are shown in the diagram of Fig.4. Grain size and mineralogy suggest that …rmal marine sedimentation is influenced episodically and is enhanced by influx of …worked shallow-water material. The resulting "average" sedimentation is 2–3 cm/1,000 …ar as in the Canaries.

Two different horizons containing shallow-water material from three cores were …alyzed. The upper layer in all three cores has an age of about 10,000 years, whereas the …ver layer gave ages of about 20,000, 23,000 and 27,000 years. Both age groups …rrespond to significantly lower sea-level stages in the Atlantic according to the diagram … Milliman and Emery (1968). Presumably the islands' shelf areas were eroded and the …terial transported to the surrounding deep-sea environment.

Although most of the shallow-water material found within deep-sea sediments is …posed to have been transported by turbidity currents (Kuenen, 1964), the majority of … Cape Verde material has almost none of the properties of classical turbidites:

The coarse-grained lower layers do not contain much silt or mud-sized particles; no …ding was observed within the layers, nor were convolute bedding, fine laminations or … like.

The upper layer is a "normal" deep-sea mud, but it also contains shallow-water …bonate and volcanics.

Only one case of graded bedding was observed, within a layer measuring < 10 cm in …kness of one single core. This may be a proper turbidite, but it does not belong to the …rs mentioned above. Hence, maybe turbidites do also occur within the Inner Cape …de Basin, but most of the shallow-water material lacks evidence of normal turbidites.

The mechanism of the transportation of the shallow-water material into the deep-sea …ronment cannot be stated at present with certainty due to lack of information on the …l conditions of the islands' shelves; sand creep or small-scale rivers may, however, be …ested as being as well possible as turbidity currents. On the other hand, with regard …urbidites, the small-scale area of the Inner Cape Verde Basin may be responsible for …development of special turbidite types lacking "classical" criteria.

The velocity of sediment accumulation would have been much higher than during the …mal marine conditions. Probably the lack of continental components in the Cape Verde …ples and hence slower "normal" marine sedimentation is enhanced by this influx of …low-water material. Resulting "average" sedimentation rates are then about the same … the Canaries, though the mechanisms in the two areas are quite different. Sedimen…n rates of 2–3 cm/1,000 years are high compared to a normal average rate of 1.2 cm …e deep-water equatorial Atlantic (Schott, 1939). In the Canaries much reworked …inental shelf material off Morocco is responsible for the higher rates whereas in the … Verdes the islands' shelf sediments, of volcanic and shallow-water carbonate origin, …eased the sedimentation rates.

DISCUSSION OF RESULTS: SEDIMENTATION IN THE MARINE ENVIRONMENT ADJACENT TO VOLCANIC ISLANDS

In the deep marine environment around volcanic islands five factors contribute to the formation of sediments:

(*1*) normal, open marine sedimentation: planktonic organisms, (*2*) detrital sedimentation from the adjacent continent(s); (*3*) erosion of the volcanic rocks of the islands; (*4*) transportation of shallow-marine sediments from the shelf areas of the islands; (*5*) volcanism, direct influence of pyroclastic products: windblown ash.

The first two clearly occur at the Canary stations with an additional contribution of material from the continental shelf due to the proximity of the islands to the African coast and the broad shelf in this area (Fig.1).

On the other hand, the last three seem to dominate – together with factor 1 – in the Cape Verde area without an obvious contribution from the continent. Mineralogy seems characteristic of the sample location: sediments from the deep-sea area between the eastern Canary Islands and Africa contain much quartz, illite, chlorite and smectite along with dolomite and detrital glauconite, the latter most probably from Cretaceous marls along the coast of Morocco. The high aragonite content indicates either the strong influence of open-marine sedimentation (pteropods) or reworked shallow-marine material (other mollusks). The content of aragonite and high-magnesian calcite seems to coincide, reflecting a shallow-marine source of echinoderms and red algae. In some of the Canary cores, aragonite and dolomite are roughly inversely proportional indicating the detrital origin of dolomite and the "autochthonous" formation of aragonite by the planktonic pteropods. Dolomite content runs parallel to that of quartz (Fig.3).

The absence or scarcity of almost all detrital material (quartz, dolomite, clay minerals and detrital glauconite) in the Cape Verde samples can be explained by the geographic situation, the islands form a horseshoe-shaped arc which shields the Inner Cape Verde Basin from the continent. A certain amount of smectite in this area must be regarded as formed autochthonously by alteration of volcanic glass.

The influence of active volcanism in both the Canary and Cape Verde surroundings is not evident.

It is difficult at present to establish relationships between active volcanism on the Cape Verde Islands and the layers of volcanic material within the deep-sea sediments, due to lack of age data from prehistoric activity. Some precise data exist on the recent volcanic activity of the island of Fogo, summarized from the observations and reports of sea-faring Portuguese people from the 15th to the 18th century (Friedländer, 1913; Machado, 1965). For the Canary Islands, no layers of volcanic material were found within the deep-sea cores. If present during sedimentation, they might have been destroyed and mixed up with the non-volcanic components by winnowing.

The absence of abundant volcanics in the sediments reported here may reflect little volcanic activity during the past 30,000 years.

Further investigations are needed, however, but it seems that the term "volcanic mud", generally applied to the deep-marine sediments surrounding volcanic islands may have been too heavily over-emphasized. This is at least valid for sediments from the past 30,000 years of the two island areas investigated and further work is necessary to judge whether these statements can be applied generally.

The results summarized here will be published in greater detail in "*Meteor*"-*Forschungsergebnisse.*

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