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FACIES EVOLUTION AND CARBONATE DISSOLUTION CYCLES IN SEDIMENTS FROM BASINS AND CONTINENTAL MARGINS OF THE EASTERN SOUTH ATLANTIC SINCE EARLY CRETACEOUS +

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INTRODUCTION

—The evolution of the sedimentary facies in the southeast Atlantic Ocean since the Cretaceous is strongly correlated to the structural history of this ocean. Since the first observations of Wegener (1929) about the continental drift, numerous authors (Bullard et al., 1965 ; Almeida and Black, 1967 ; Hurley et al., 1967 ; Hurley, 1968 ; Reyment and Tait, 1972 ; Krommelbein and Wenger, 1966 ; Maack, 1969) have confirmed the hypothesis of the separation of both continents, Africa and South America.—An excellent review of the major works and theories dealing with the birth and the opening of the

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Wegener, A., 1929 : Die Entstehung der Kontinente und Ozeane. Braunschweig, West Germany, F. Vieweg and Sohn (Eds.), 144 p.

Bullard, E., Everett, J.E., and Smith, A.G., 1965 : The fit of the continents around the Atlantic, in Symposium on continental drift : Roy. Soc. London Philos. Trans., v. 258, p. 41-51.

Almeida, F.F.M. and Black, R., 1968 : Geological comparison of Northeastern South America and Western Africa. Ann. Acad. Bras. Cienc., v. 60, p. 317-319.

Hurley, P.M., De Almeida, F.F.M., Melcher, G.C., Cordani, U.G., Rand, J.R., Kawashita, K., Vandoros, P., Pinson, W.H., and Fairbairn, H.W., 1967 : test of continental drift by comparison of radiometric ages. Science, v. 157, p. 495-500.

Hurley, P.M., 1968 : The confirmation of continental drift. American Scient., v. 218, p. 52-64.

Reyment, R.A., and Tait, E.A., 1972 : Biostratigraphical dating of the early history of the South Atlantic Ocean. Phil. Trans. R. Soc. London, v. 264, p. 55-95.

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South Atlantic Ocean was recently done by Nairn et al. (1973) and by Mascle (1975). Following the last author, and Falvey (1974), we may assume that the rupture between both continents took place in late Jurassic time, resulting from an extension of the continental crust above a deep thermic anomaly. A graben-like structure was formed, which received abundant terrigenous sediments. In early Cretaceous (Neocomian) the site of the future aseismic ridges (Walvis Ridge-Rio Grande Rise) was characterized by an important volcanic activity, which perhaps corresponds to the first manifestations of the active opening of the South Atlantic. From the study of the magmatic phenomena (see Mascle, 1975) and from the datation of magnetic anomalies (Ladd et al., 1973 ; Larson and Ladd, 1973), it seems obvious that the opening of the South Atlantic began in the early Cretaceous. The biostratigraphical study and the facies distribution of the coastal basins(Reyment, 1969 ; Stoneley,1966) show that the opening begun in the south (Neocomian ?) and reached the equatorial zone only later (middle Albian ?). Le Pichon (1968) suggests that the South Atlantic Ocean

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Krommelbein, K., and Wenger, R., 1966 : Sur quelques analogies remarquables dans les microfaunes crétacées du Gabon et du Brésil oriental (Bahia et Sergipe) : IUGS Symposium on "sedimentary basins of the African Coast", D. Reyre (Ed.), p. 193-196.

Maack, R., 1969 : Kontinentaldrift und Geologie des Südatlantischen Ozean. W. Degruyter and Co. (eds.), Berlin, 164 p.

Nairn, A.E.M., Douglas, R.G., and Moulade, M., 1973 : Causes and consequences of drift in the South Atlantic ; in D.H. Tarling and K.S. Runcorn (eds.), Implications of continental drift to the earth sciences, v. 1, p. 523-534, Acad. Press, London.

Mascle, J., 1975 : Géologie sous-marine du golfe de Guinée, Thèse Sciences, Université Paris VI, 380 p.

Falvey, D.A., 1974 : The development of continental margins in plate tectonic theory. Aust. Pet. Expl. Assoc. Journ., v. 14 (in press).

Ladd, J.W., Dickson, G.A., Pittman, III, W.C., 1973 : The age of the South Atlantic in Nairn and Stehli (eds.), the Ocean basins and margins, v. 1 : the South Atlantic, p. 555-571.

Larson, R.L., and Ladd, J.W., 1973 : Evidence for the opening of the South Atlantic in the Early Cretaceous. Nature, v. 246, p. 137-140.

Stoneley, R., 1966 : The Niger delta region in the light of the continental drift. Geol. Mag., v. 103, p. 385-397.

Le Pichon, X, 1968 : Sea floor spreading and continental drift : Journ. Geophys. Res., v. 73, p. 3661-3697.

expansion may be divided in three different phases : 1) Albo-Aptian to Paleocene ; 2) Paleocene to Miocene ; 3) Miocene. According to Ewing et al. (19_6), the Miocene was marked by a general uplift of the Walvis Ridge and of the Rio Grande Rise : uplift perhaps related to a decrease of the rate of expansion in the mid Atlantic Ridge (Le Pichon, 1968) and to a tectonic rejuvenation of the Ridge. This hypothesis would be in agreement with the Oligocene-Miocene discordance or with the lack of Oligocene, encountered in many places around the South Atlantic Ocean and reflecting apparently a general uplift of the continental margin during the Oligocene (Mascle, 1975). Nevertheless, we may note that previous results of the Deep Sea Drilling Project (Maxwell et al., 1970) have shown a constant expansion rate of the South Atlantic since the late Cretaceous (80 m.a.).

Concerning the communication between the North and South Atlantic, the first water exchanges took place in the late Cretaceous, first (Turonian) through the Sahara and then (Santonian) through the equatorial zone (Reyment, 1969 ; Mascle, 1975). Furthermore, the Romanche fracture zone had allowed the passage of deep water masses from the Brazil to the Angola basins since the Santonian.

Finally, although the major aspects of the birth and of the opening of the South Atlantic have been drawn, it was necessary to drill through the oceanic sedimentary cover and to try to reach the oceanic basement, to confirm the previous hypothesis. Therefore, several legs of the Glomar Challenger were planed by the Deep Sea Drilling Program in the South Atlantic. During leg 40, which began in Cape Town on December 1974 and terminated in Abidjan on February 1975, we drilled six sites (site 360 to site 365) : sites situated on the continental margin of South African and Angola, in the Cape basin and on the Walvis Ridge (fig. 1). Our objectives were to determine the evolution of the Cape and Angola basins continental margins from early Cretaceous to the present time, and to evaluate the role of the Walvis Ridge in the early history of these basins.

. SITUATION OF DRILLED SITES

Leg 40 took advantage of erosional unconformities and each site was coupled with a complementary site. Thus, in the southern Cape basin (fig. 2) site 360 penetrated Pliocene to Eocene sediments, while site 361 (1 314 m penetration) cored Eocene to lowermost Aptian sediments, at a location where most of the Tertiary has been stripped away by an apparently Pleistocene erosional event. Profiler records demonstrate that the sequence cored at site 361 can be traced directly to site 360, so that an effectively continuous section of over 2 000 meters thickness was cored at the two sites, with an overlap of about 100 meters. A similar overlap in time was achieved at sites 362 and 363 on the Walvis Ridge (fig. 3). Site 362 recovered a virtually complete Pleistocene to Eocene section, while site 363 presented a shortened section from middle Miocene to lower Aptian. Volcanic basement was not reached. Sites 364 (fig. 4) was an attempt to penetrate the entire Quaternary, Tertiary and Cretaceous continental margin section of the Angola basin down to the salt. Sediments with high salinity of Aptian age were reached, but the bit destroyed itself apparently only 20 meters from the salt. A second attempt to reach the salt was done (site 365,

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Ewing, M., Le Pichon, X., and Ewing, J., 1966 : Crustal structure of the mid-ocean ridges : 4 - Sediments distribution in the south Atlantic Ocean and the Cenozoic history of the Mid-Atlantic Ridge.Journ.of Geoph. Res.,v.71,p.1611-1635.

Maxwell, A.E., et al., 1970 : Initial Reports of the Deep Sea Drilling Project, vol.3, Washington (U.S. Government Printing Office), 806 p.

fig. 4), a few kilometers away from the first, at the edge of a canyon, but the hole was abandoned short of the objective because of the end-of-cruise schedule. Drillsites have been selected on Conrad and Vema seismic profiles for the Cape basin and on Jean Charcot profiles for the Walvis Ridges and the Angola basin.

. LOWER CRETACEOUS STAGNANT BASINS WITH INTENSIVE CARBONATE DISSOLUTION

The most unusual and revealing lithologies cored on leg 40 were upper Barremian to lower Aptian sapropelic black shales interbedded with siltstones and massive silty sandstones in the Cape basin (site 361, fig. 2) and upper Aptian to lower Albian sapropelic shales with marly dolomitic limestones on the Angola continental margin (site 364, fig. 4). The sapropelic sediments are rich in pyrite, organic matter and plant debris, to 10 centimeters in length were recovered. These sediments indicate that totally stagnant euxinic conditions persisted through much of the lower Cretaceous in both the Cape and Angola basins. The absence of communication of the narrow south Atlantic ocean (similar to the present gulf of Aden) with the north Atlantic (see introduction), and the restricted communication with the open ocean (note the presence in the Cape basin of lower Aptian pelagic foraminifera very similar to those found in Madagascar and the near East ; Bolli et al., 1975) because of the presence of the Agulhas and Falkland plateau off the southern tip of Africa (Barker et al., 1974), may easily explain these euxinic conditions. Euxinic conditions prevailed in Angola basin long after (upper Albian - Santonian) the Cape basin recovered oxygenated conditions. The presence of upper Albian black sapropel layers on the Walvis Ridge (site 363), shows that the Walvis Ridge has acted as a barrier between the Cape and Angola basins since the lower Cretaceous and indicates that a dense, stagnant water mass, at least two kilometer-deep, filled the Angola basin at that time. The disparition of sapropelic deposits in Santonian time is most likely related to the expansion, at that time, of the Guinea gulf and to the establishment of the North Atlantic-Angola basin communication (see introduction). At the end of the Cretaceous, the sedimentation is characterized by the deposition of marly nanno chalk, chalk and limestones on the Angola basin continental margin and of pelagic clay in the Cape basin. The sedimentation rate decreased drastically, from 60 - 70 m/m.y. in Aptian-Albian times, to 1,5 - 6 m/m.y. at the Cretaceous-Tertiary boundary,in both basins, reflecting an important evolution in environmental conditions : climate becoming less humid, vegetation less luxuriant and the terrigenous input less abundant ; distance from the continental terrigenous sources increasing more and more ; open ocean conditions favouring more and more the like of calcareous planktonic microorganisms : early Tertiary sediments being thus highly calcareous (60 - 80 %) except, naturally, near or below the CCD. One may note that most of the late Cretaceous sediments of the Cape and Angola basins were very poor in calcareous microfossils or barren. This may be explained, not only by the great terrigenous dilution (i. e. turbiditic sedimentation), but also by the acidity of the depositional environment : acidity related to the high supply of organic matter in the restricted, stagnant basins. No sedimentary hiatus was encountered in both basins in Cretaceous times, except an eventual Cenomanian hiatus on the Angola continental margin.

. TERTIARY OXYGENATED BASINS AND THEIR CARBONATE DISSOLUTION CYCLES

With the exception of the part of the basins situated at a water depth greater than that of the CCD (ex. site 361, fig. 2), the sedimentation in

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Bolli, H.M., Ryan, W.B.F., et al., 1975 : Leg 40, preliminary results, Geotimes (in press).

both basins is highly dominated, from Paleocene to Eocene times, by marly chalk or chalk. A differentiation in the sedimentary facies distribution, between Angola and Cape basins continental margins, appears in Oligocene : Angola margin is characterized by the presence of pelagic clay and siliceous mud, while the Cape margin is essentially constituted of chalk or calcareous ooze (site 360, fig. 2). Since the Pliocene siliceous sediments occurred also on the eastern part of the Walvis Ridge, related probably to upwelling phenomena, similar to those actually known north of the Cape basin (Walvis bay). After reaching 60 m/m.y. in Eocene time, the sedimentation rate has been extremely uniform (16-21 m/m.y.) on the upper continental rise of South Africa (site 360) since the Oligocene (where a small hiatus may be present). The sedimentation rate on the Angola continental margin seems to be also constant (10 - 12 m/m.y.) since the upper Cretaceous, except for the interval middle Eocene-lower Miocene, where a major hiatus may exist. In the Cape basin, carbonate content increases from 30 % in Eocene, to 60/80 % in post-Eocene times. In the deeper part of the basin (site 361) the carbonate content is approximately constant ($\underset{-}{\sim}$ 10 %) for the whole tertiary sequence, except for a few Paleocene-Eocene levels (turbidite ?), where it abruptly reaches 40 - 60 %.

Concerning the carbonate dissolution cycles, we assume that they are reflected in the degree of fragmentation of planktonic foraminifera : planktonic foraminifera observed in the coarse fraction of the sediment. The degree of carbonate dissolution found in fossil sediment is then compared to the carbonate dissolution facies distribution encountered in surface sediments of the western South Atlantic Ocean (Melguen and Thiede, 1974 a). Cape and Angola basins continental margins seem to have been affected at the same time by a very similar degree of carbonate dissolution, reflecting major CCD fluctuations in the South Atlantic Ocean, both north and south of the Walvis Ridge. The major dissolution phases occur at the Eocene and Oligocene times, with both sites situated well below the foraminiferal lysocline. A third, but less intensive dissolution cycle, occurs from middle to upper Miocene. At the end of the Miocene both sites were apparently situated above the foraminiferal lysocline. However, because of lack of coring at site 364, the comparison of both sites for the middle Miocene is quite impossible. It seems that at the end of the Miocene they were both situated above the foraminiferal lysocline. Major changes in the $CaCo_3$ equilibrium of the ocean water have occurred in both Cape and Angola basins in Eocene, Oligocene, Middle-Upper Miocene. These changes were most likely correlated with worldwide fluctuations of the CCD, itself related to the major pulsations of the Antarctic Bottom Water since the Eocene (see Watkins and Kennett, 1971 ; Kennett et al., 1972). According to the great similarity of the Tertiary carbonate dissolution cycles between Angola and Cape basins, we assume that during the Tertiary Angola basin had received approximately the same amount of Antarctic Bottom Water as the Cape basin. According to the important lowering of the CCD in the south Atlantic at the Eocene-Oligocene boundary ($\sim$ 3 200 m in the South Atlantic, see Berger and Von Rad, 1972) and during the Miocene ($\leqslant$ 3 700 m ; see Melguen

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Watkins, W.D., and Kennett, J.P., 1971 : Antarctic Bottom Water : major change in velocity during the late Cenozoïc between Australia and Antarctica. Science, v. 173, p. 813-818.

Kennett, J.P., Burns, R.E., et al., 1972 : Australian Antarctic continental drift, Paleocirculation changes and Oligocene deep-sea erosion, Science, v. 239,91, p. 51-55.

Berger, W.H., and Von Rad, U., 1972 : Cretaceous and Cenozoic sediments from the Atlantic Ocean. in : Initial Reports of the Deep Sea Drilling Project, vol. XIV (D.E. Hayes and A.C. Pimm, et al.), U.S. Government Printing Office, Washington, p. 787-954.

and Thiede, 1975), it seems reasonable to think that the Antarctic Bottom Water could have easily reached the Angola basin, not only through the Romanche fracture zone. but also through the channels cut in the Walvis Ridge : Ridge which did not act as a barrier between both basins during the Tertiary. If we consider the very surprising (with respect to the very deep, 5 200 m, actual CCD in the Angola basin) high degree of carbonate dissolution at shallow water depth (∿ 2 500 m) on the Angola continental margin, not only through the Tertiary, but also during the Pleistocene, it seems obvious that the CCD fluctuations are correlated, not only to the Antarctic Bottom Water pulsations, but also to regional environment conditions, such as high fertility, intensive benthonic life (see Berger, 1974). A major differentiation between Angola and Cape basins continental margins exist since the end of the Miocene : the Angola margin being characterized by siliceous and/or non- carbonate sediments, while the sediments of the Cape margin consists essentially of calcareous oozes. It is obvious that the Cape basin continental margin (site 360) has been situated well above the foraminiferal lysocline since the Miocene and that the Antarctic Bottom Water has not flowed through the Walvis Ridge since that time.

SEDIMENTARY FACIES EVOLUTION ON THE WALVIS RIDGE SINCE APTIAN TIME. PRESENCE OF OLIGOCENE "BRAARUDOSPHAERA CHALK"

Sites 362 and 363 (fig. 3) drilled on the Walvis Ridge, recovered a lower Aptian to Pleistocene sedimentary sequence. The deepest core of site 363, located just below the summit of a peak on the Walvis Ridge and containing calcarenites, extremely rare calcareous algae remains and a small amount of phosphorite, may suggest a nearby source of shallow water (neritic conditions ?) material in lower Aptian time. All younger cores have bathyal microfossils' assemblages and reflect a deep marine environment. There is no sedimentological evidence for a re-emergence of any portion of the ridge at any later time, nor any evidence of ash falls or volcanoclastic breccias that would suggest any nearby emergent active volcanoes since lower Aptian. The Cretaceous sedimentation on the Walvis Ridge (fig. 3) is characterized by the dominance of limestone, marly limestone, chalk marly chalk and marls, with relatively abundant fine terrigenous material and black sapropel layers in Albian times. Black layers are correlated with the Albian euxinic conditions of the Angola basin. Evidence for current action (slumping, microfaulting, winnowing, laminations) are frequent. Terrigenous, sapropelitic and calcareous deposits reflect a strongly cyclic sedimentation, with sedimentation rates, carbonate content fluctuating from 30 to 90 %, very high (> 65 m/m.y.) in Aptian-Albian times, drop drastically to 1,5 m/m.y. at the Cretaceous/Tertiary boundary. A sedimentary hiatus (erosional in origin, judging from current and erosional structures) seems to be present between the uppermost Albian and the Coniacian.

Chalks and calcareous oozes form the entire post-Campanian sedimentary column (sites 363, 362, fig. 3). The terrigenous input is very small and, therefore, the carbonate content very high (60 - 100 %) all along the Tertiary. The carbonate content falls to 40 % in Plio-Pleistocene times because of the deposition of abundant siliceous microfossils. The Cenozoïc sedimentation rates vary from 10 m/m.y. for the middle Eocene to early Oligocene, to 16 - 18 m.y. during Oligocene and to 40 m/m.y. for the Miocene. The sequence of sediment drilled at site 362 is

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Melguen, M., and Thiede, J., 1975 : Influence des courants profonds au large du Brésil sur la distribution des faciès sédimentaires récents (ce volume).

Berger, W.H., 1974 : Deep-Sea sedimentation, in Burke and Drake (Eds.), "The Geology of continental margins" (Springer-Verlag, Stuttgart), p. 213-241.

remarkably complete. No gaps are present. The Cenozoic sediments of the Walvis Ridge do not reflect major fluctuations of the CCD, except perhaps in the middle-upper Miocene. The very shallow water depth (1 325 m) of the site could easily explain that fact. One very interesting point has to be mentioned : the good preservation of planktonic foraminifera at Eocene time, period during which both Cape and Angola basins were strongly affected by carbonate dissolution processes. The key of this apparent disconformity (with respect to the surrounding basins, is the occurrence, on the Walvis Ridge,at the Eocene time, of a calcareous turbiditic sedimentation, in the vicinity of the ridge crest.

One of the most interesting discovery of leg 40 on the Walvis Ridge is the presence of Oligocene "Braarudosphaera chalk" (sites 362 and 363). Normaly, great concentration of Braarudosphaera bigelowi and thus "Braarudosphaera chalk", are restricted to coastal waters of low salinity and restricted ocean circulation, such as Gulf of Maine and Gulf of Panama. Only lower content are recorded in sediment of open oceans of normal salinity conditions. Fossil forms of Braarudosphaera bigelowi are most abundant in Cenozoic coastal marine deposits, such as, for example, Cenozoic deposits of the Paris Basin. Conversely, mid-ocean cores of lower Cenozoic sediments obtained by DSDP typically contain no Braarudosphaera chalk. The only anomaly in the fossil record regarding a neritic dominance of"Braarudosphaera" is the report of a thin zone of Braarudosphaerids in Oligocene strata from the South Atlantic. The first finding was made on Leg 3 (cf. Saito and Percival, 1970) in Oligocene strata from the Mid-Atlantic Ocean Ridge and from the Rio Grande Rise. The "Braarudosphaera chalk" appears as being a remarkable time stratigraphic marker, recognized at drillsites some 2 800 km apart. The last discoveries of Braarudosphaera-rich sediments were made during leg 36 (Barker et al., 1974) and leg 39 (Perch-Nielsen et al., 1974). On the Sao Paulo Plateau (site 355, leg 39) abundant"Braarudosphaera"were found in Danian sediments and assumed to be correlated to restricted ocean conditions, rather than to shelf depths, while they are associated with foraminifera indicating depth greater than shelf depth. On the Falkland Plateau (site 330, leg 36), abundant"Braarudosphaera"were found in Albian-Aptian sediments and considered as indicating the continued presence of a nearby continental margin. As the Oligocene "Braarudosphaera chalk" in the South Atlantic is widely distributed and associated with bathyal microfauna, we may assume that it reflects neither ocean shelf conditions nor restricted environment, but rather some prolonged ecological effect such as a reduction of the salinity of the South Atlantic near surface water favoring prolonged blooms of low salinity phytoplankton. However, the presence and distribution of the Oligocene "Braarudosphaera chalk" in the South Atlantic Ocean is still a very interesting open question !

CONCLUSION

Six weeks after our South Atlantic expedition on board the Glomar Challenger (leg 40) it is still too soon to draw conclusions about our preliminary observations. More than three thousand meters of sedimentary sections have to be studied in details before we may be able to reasonably reconstruct, step after step, and since the birth of the South Atlantic, the paleoenvironmental history of its eastern part.

Barker, P.F., Dalziel, I.W.D., et al., 1974 : Leg 36. Preliminary shipboard results.

Perch-Nielsen, K., Supko, P., et al., 1975 : Leg 39 Deep Sea Drilling Project, Shipboard preliminary results.

Saito, T., and Percival, S.F., 1970 : Mid-Atlantic Ridge sequence paleontology. in Maxwell, A.E. et al., 1970, Initial Reports of the Deep-Sea Drilling Project, vol. III, Washington (U.S. Government Printing Office), p. 444-445.

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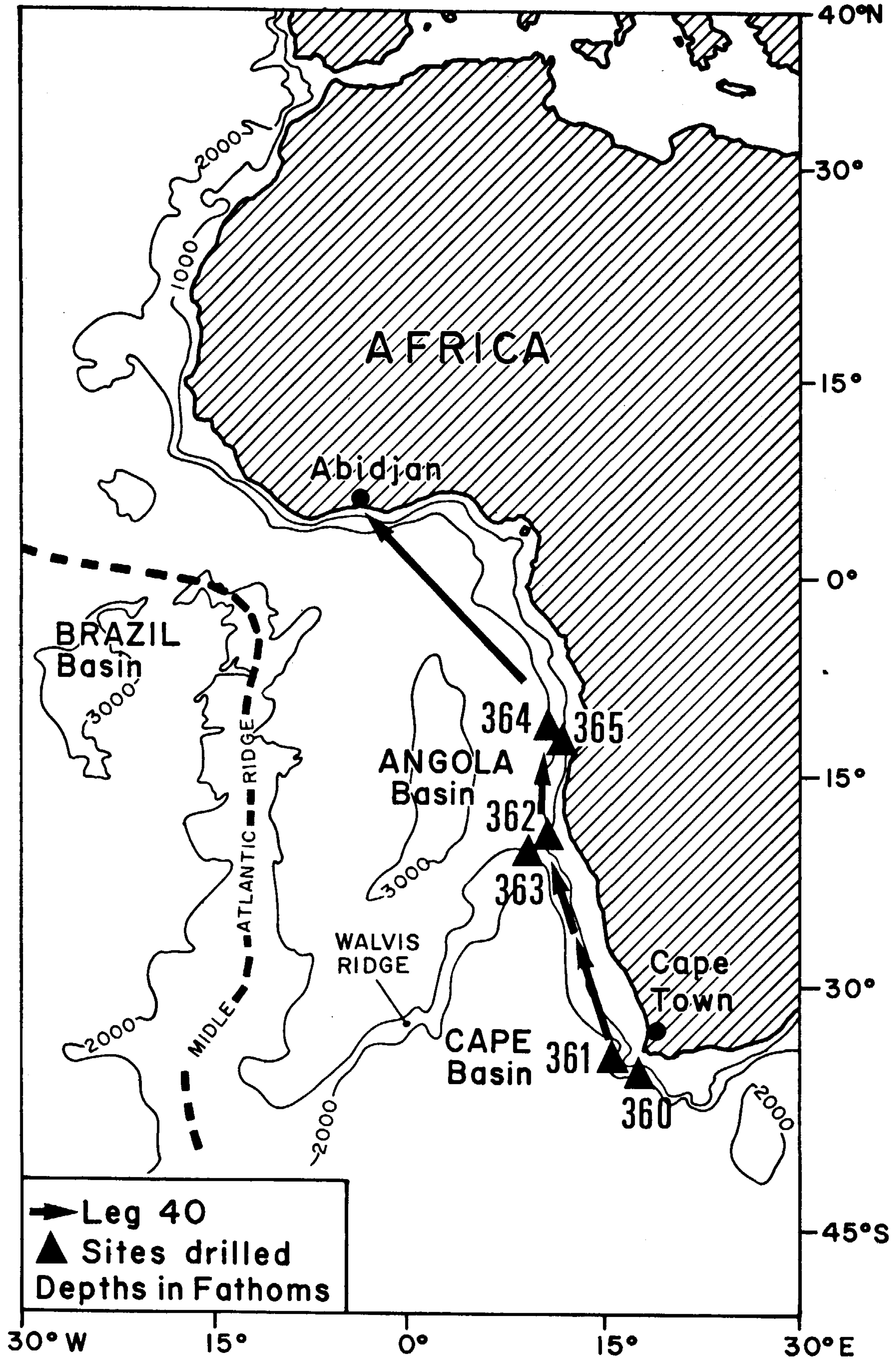
AFRICA
Abidjan
BRAZIL Basin
ANGOLA Basin
CAPE Basin
Cape Town
WALVIS RIDGE
MIDLE ATLANTIC RIDGE
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362
363
361
360
1000
2000
3000
Leg 40
Sites drilled
Depths in Fathoms
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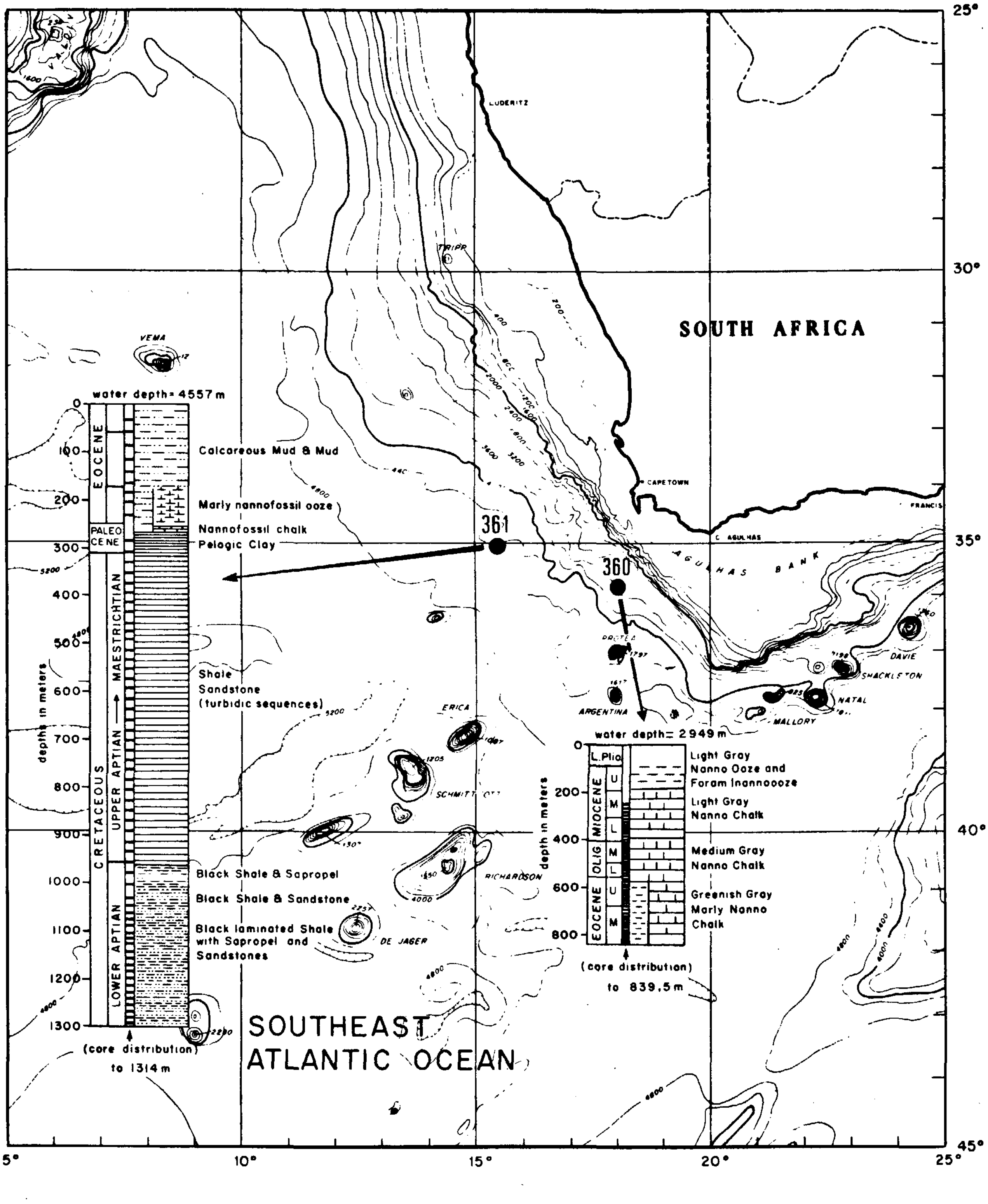
Fig.1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VEMA
CAPETOWN
FRANCIS
C. AGULHAS
AGULHAS BANK
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360
PROTEA
ARGENTINA
DAVIE
SHACKLETON
NATAL
MALLORY
ERICA
SCHMITT OTT
RICHARDSON
DE JAGER
SOUTHEAST ATLANTIC OCEAN
water depth= 4557 m
depth in meters
0
100
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300
400
500
600
700
800
900
1000
1100
1200
1300
EOCENE
PALEOCENE
CRETACEOUS
UPPER APTIAN → MAESTRICHTIAN
LOWER APTIAN
Calcareous Mud & Mud
Marly nannofossil ooze
Nannofossil chalk
Pelagic Clay
Shale
Sandstone
(turbidic sequences)
Black Shale & Sapropel
Black Shale & Sandstone
Black laminated Shale with Sapropel and Sandstones
(core distribution)
to 1314 m
water depth= 2949 m
depth in meters
0
200
400
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800
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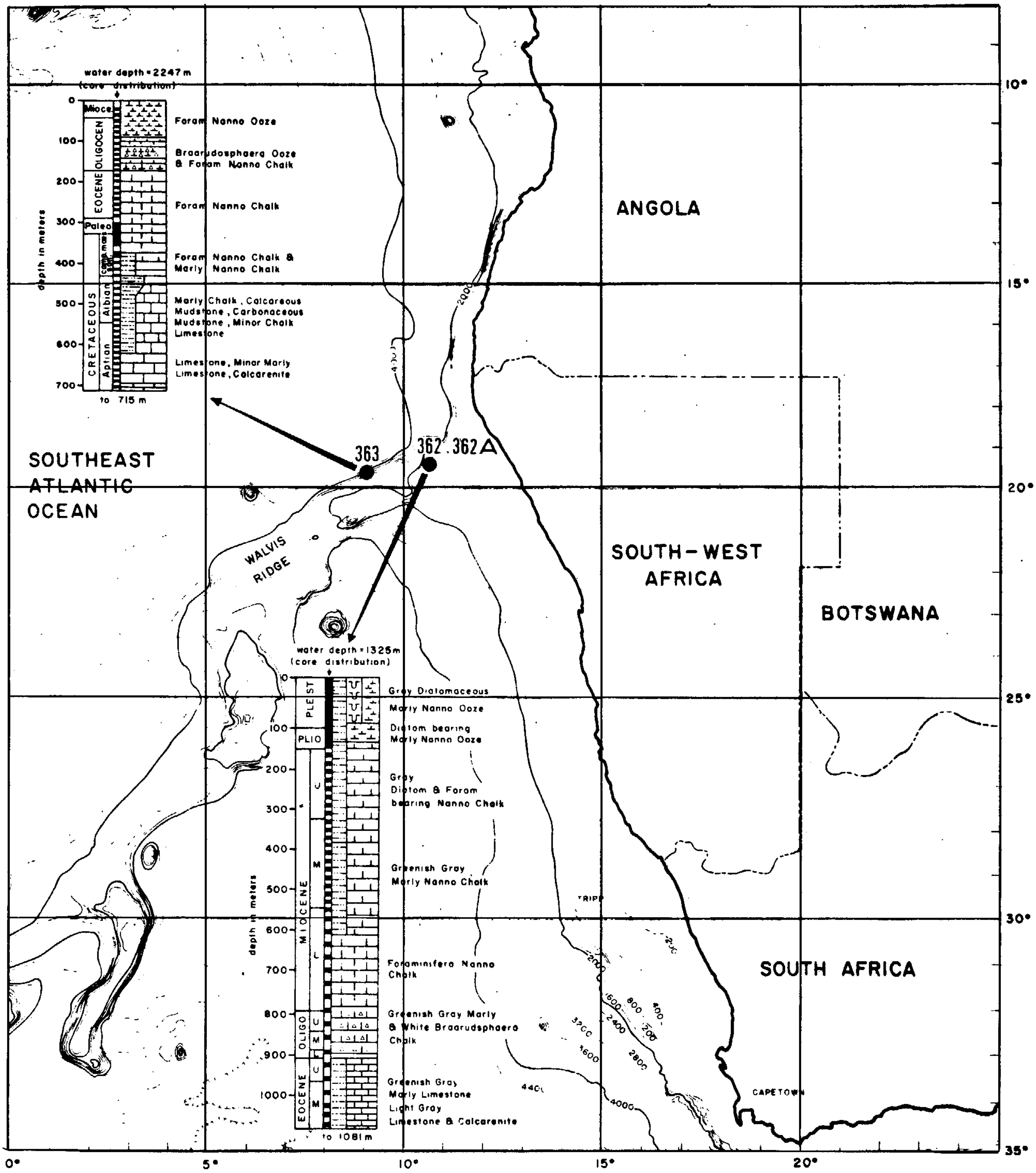
Light Gray Nanno Chalk
Medium Gray Nanno Chalk
Greenish Gray Marly Nanno Chalk
(core distribution)
to 839,5 m

Fig. 2


water depth = 2247 m
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to 715 m
Foram Nanno Ooze
Braarudosphaera Ooze & Foram Nanno Chalk
Foram Nanno Chalk
Foram Nanno Chalk & Marly Nanno Chalk
Marly Chalk, Calcareous Mudstone, Carbonaceous Mudstone, Minor Chalk Limestone
Limestone, Minor Marly Limestone, Calcarenite
363
362 . 362A
ANGOLA
SOUTHEAST ATLANTIC OCEAN
WALVIS RIDGE
SOUTH-WEST AFRICA
BOTSWANA
SOUTH AFRICA
CAPETOWN
water depth = 1325m
(core distribution)
PLEST
PLIO
MIOCENE
OLIGO
EOCENE
U
M
L
depth in meters
0
100
200
300
400
500
600
700
800
900
1000
to 1081m
Gray Diatomaceous Marly Nanno Ooze
Diatom bearing Marly Nanno Ooze
Gray Diatom & Foram bearing Nanno Chalk
Greenish Gray Marly Nanno Chalk
Foraminifera Nanno Chalk
Greenish Gray Marly & White Braarudsphaera Chalk
Greenish Gray Marly Limestone Light Gray Limestone & Calcarenite
2000
4000
3200
2400
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400
200
2800
4400
10°
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25°
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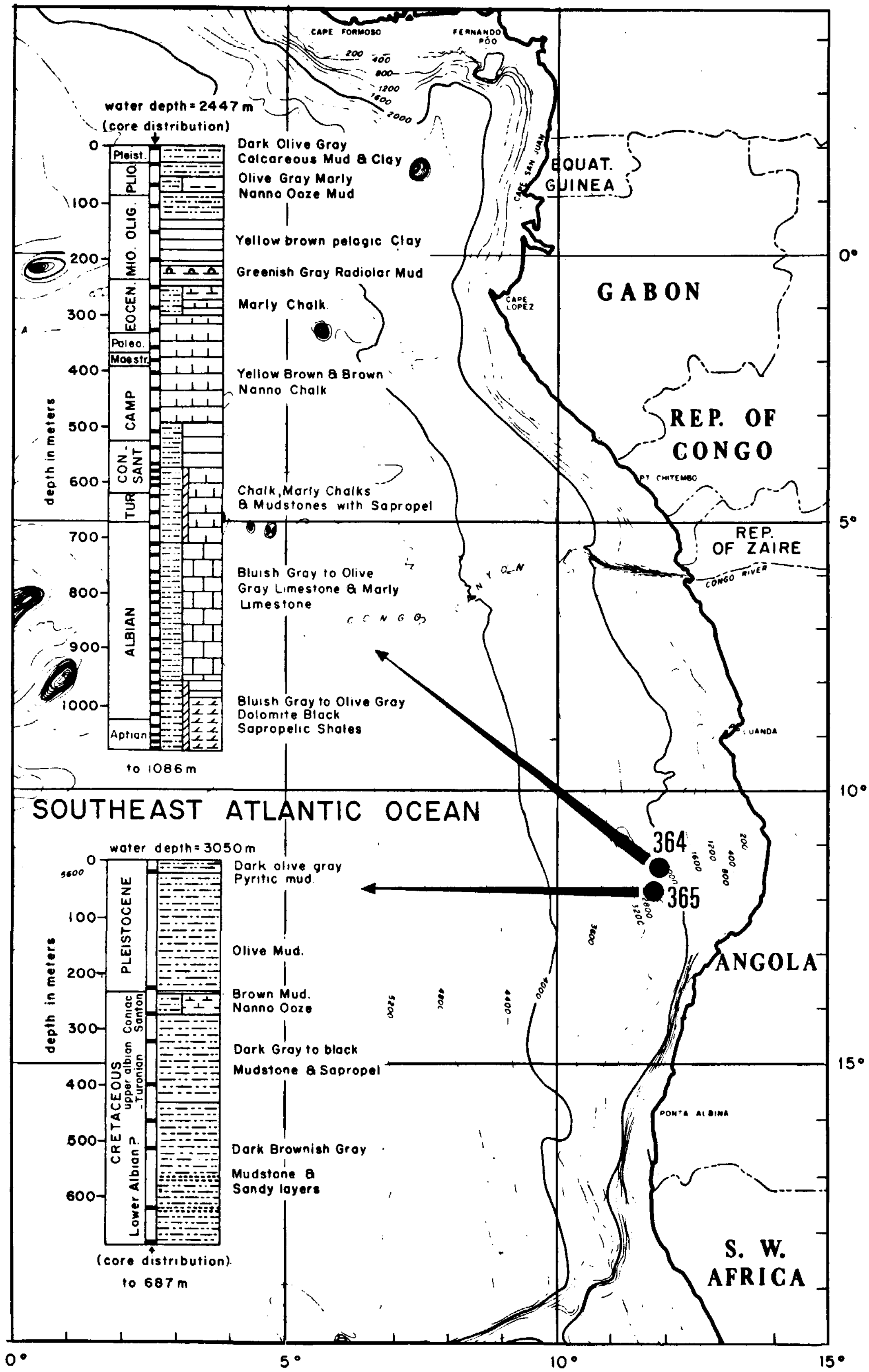
Fig.3


CAPE FORMOSO
FERNANDO POO
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EQUAT. GUINEA
CAPE SAN JUAN
GABON
CAPE LOPEZ
REP. OF CONGO
PT. CHITEMBO
REP. OF ZAIRE
CONGO RIVER
CONGO
LUANDA
ANGOLA
PONTA ALBINA
S. W. AFRICA
SOUTHEAST ATLANTIC OCEAN
364
365
water depth = 2447 m
(core distribution)
Pleist.
PLIO.
OLIG.
MIO.
EOCEN.
Paleo.
Maestr.
CAMP
CON. SANT
TUR
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Aptian
depth in meters
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200
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900
1000
to 1086 m
Dark Olive Gray Calcareous Mud & Clay
Olive Gray Marly Nanno Ooze Mud
Yellow brown pelagic Clay
Greenish Gray Radiolar Mud
Marly Chalk
Yellow Brown & Brown Nanno Chalk
Chalk, Marly Chalks & Mudstones with Sapropel
Bluish Gray to Olive Gray Limestone & Marly Limestone
Bluish Gray to Olive Gray Dolomite Black Sapropelic Shales
water depth = 3050 m
5600
PLEISTOCENE
CRETACEOUS
Coniac Santon
upper albian Turonian
Lower Albian ?
Dark olive gray Pyritic mud
Olive Mud.
Brown Mud. Nanno Ooze
Dark Gray to black Mudstone & Sapropel
Dark Brownish Gray Mudstone & Sandy layers
(core distribution)
to 687 m
3600
4000
4400
4800
5200
0°
5°
10°
15°

Fig. 4