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Biostratigraphical Dating of the Early History of the South Atlantic Ocean

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BIOSTRATIGRAPHICAL DATING OF THE EARLY HISTORY OF THE SOUTH ATLANTIC OCEAN

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[Plates 3 to 5 and pull-out map]

CONTENTS

The southern Atlantic has always been a favoured testing ground for the hypothesis of continental drift. Apart from the remarkable agreement in the geographical shape of the coast of western Africa and eastern South America, considerable attention has been paid to the origin of the Mid-Atlantic ridge and these factors have provided a basis for testing the concept of drift.

Detailed studies of the geology of NE Brazil and Gabon indicate that both areas had been basins of non-marine sedimentation almost continuously from the Upper Palaeozoic through to the Neocomian. During the Neocomian it would appear that both areas were parts of a large freshwater lake which may have been situated in a zone of subsidence produced by an initial phase in the separation of the two land masses. This structure may have been similar to the Great Rift Valley system of today in East Africa. It would seem that the rift continued to widen during the Neocomian and made connexion with the open ocean during the Aptian, thus developing into a 'protoatlantic' similar in configuration to the present day Red Sea. During the latter part of the Aptian, salt deposits began to accumulate in the narrower parts of the elongated bays. The deposits in Gabon, Angola and Brazil are large and of economic importance. About this time South America seems to have begun a relative clockwise rotational motion, which in its later stages may have resulted in a fracturing and tearing movement of the crystalline basement rocks in the area bounded by the Ivory Coast and Maranhão.

The point in time at which northern and southern arms of the protoatlantic became united may be ascertained by means of a biostratigraphical analysis, based mainly on the evidence provided by the ammonites of the critical sequences.

The crucial area lies in a zone formed by the states of Rio Grande do Norte, Pernambuco, Alagoas, Sergipe and Bahia in Brazil, and the Ivory Coast down to Angola and Gabon in West Africa. The analysis of the Albian to Turonian invertebrate associations, in particular the dispersion of the genus *Elobiceras* and the vascoceratid, pseudotissotiid, mammitid and benueitan faunas shows that the final break between South America and Africa may be dated as upper Lower Turonian. Furthermore, the geographical dispersion of Turonian invertebrates shows that the rifting apart was accompanied by a periodic pattern of regressions and transgressions possibly brought about by oscillatory movements of the continental block.

Resumo

O Atlântico Sul é um campo experimental favorável à hipótese da Deriva Continental. Além da nítida concordância na forma de costa da África oeste e o leste da América do Sul, merece a origem da Cordilhera Meso-Atlântica considerável atenção, São êstes os fatôres que constituiram os fundamentos para investigações do conceito de deriva continental.

Estudos detalhados da geologia do Nordeste do Brasil e Gabão indicam que as duas áreas constituiram bacias de sedimentação não-marinha quase contínua desde o Paleozóico Superior até o Neocomiano. Durante êste andar do Cretáceo parece que as duas áreas foram partes de um grande lago de água dôce que, ao que tudo indica, localizava-se num 'rift valley' produzido na fase inicial da separação das duas massas continentais. Esta estrutura deve ter sido semelhante ao sistema atual 'Great Rift Valley' do leste da África. O afundamento continuou alargando-se durante o Neocomiano até entrar em contato com o mar aberto no Aptiano, desenvolvendo-se assim num 'pré-atlântico', a configuração do qual assemelhava-se a do atual Mar Vermelho. No Aptiano Superior iniciou-se o acúmulo de depósitos de sal nas partes mais estreitas das bacias alongadas. Os depósitos no Gabão, Angola e Brasil são grandes e de importância econômica potencial. Aproximadamente nesta época a América do Sul parece ter iniciado um relativo movimento rotatório no sentido horário, que nos seus últimos estágios pode ter causado fraturamento e abrasão das rochas do embasamento cristalino, na área da Costa do Marfim e Maranhão.

O momento no qual os braços norte e sul do 'pré-atlântico' se uniram pode ser determinado através de uma análise bioestratigráfica, baseada principalmente nas evidências fornecidas pelos amonitas encontrados nas sequências críticas.

A área em questão está situada, no oeste da África, na zona compreendida entre a Costa do Marfim, Gabão e Angola, e no Brasil, nos estados de Rio Grande do Norte, Pernambuco, Alagoas, Sergipe e Bahia. A análise das associações de invertebrados do Albiano ao Turoniano, particularmente a dispersão do gênero *Elobiceras* e as faunas de vascoceratideos, pseudotissotiideos, mammitideos e benueitideos, mostra que a quebra final entre a América do Sul e a África pode ser datada na parte superior do Turoniano Inferior. Ainda, a dispersão geográfica de invertebrados turonianos mostra que a separação foi acompanhada por um sistema periódico de regressões e transgressões evidentemente causadas por movimentos oscilatórios dos blocos continentais.

1. Introduction

(a) *History of research*

There can be little doubt that the marked similarity of the configuration of the opposing coastlines of Africa and South America planted the original germ of the concept of continental drift. Many criteria have been used in attempts to substantiate the theory that, in the past, the Americas were joined to Africa and Europe and the literature on this is voluminous and varied. However, at first the majority of scientists opposed the concept of drifting continents with views ranging from scepticism to outright rejection (see Mayr 1952; Teichert 1952).

The study of the phenomenon of palaeomagnetism in the early 1950's brought about a major revolution in the attitudes of many scientists to the problem of continental drift, but many still believed that the evidence could be interpreted in ways other than by drifting continents. During the last decade tremendous advances have been made in the knowledge of the structure and nature of the ocean floors. The recognition and interpretation of the magnetic anomalies over the midoceanic ridges (e.g. see Heirtzler *et al.* 1968; Pitman & Heirtzler 1966; Vine 1966; Cox, Doell & Dalrymple 1968) have added weight to the concept of ocean floor spreading (see Wilson 1963) and provided one possible explanation of a mechanism for continental drift. Wilson (1965) introduced the concept of transform faults, and the subsequent theory of 'plate tectonics' has been expanded and developed by many workers.

At the present time it is probably true to say that the majority of earth scientists would accept that the present geographical distribution of the continents has arisen, either from the configuration proposed by Bullard, Everett & Smith (1965), or from one very similar to it. It is improbable that this or any other reconstruction of the continents can be proved conclusively, but a degree of probability may be obtained by detailed studies of selected areas along opposing, present-day coastlines which, if the reconstruction is correct, would formerly have been joined together.

(*b*) *Scope and limits of the present research*

Most of the purely geological factors that have been studied in order to substantiate the former conjunction of West Africa and South America have involved features which were present or had developed prior to any rupture having taken place. A. du Toit (1937, 1954) constructed pre-Cretaceous stratigraphical boundaries across the two continents and others have worked along similar lines. More recently a comparison has been made of the Cabo granite in Brazil with the 'Younger Granites' of Nigeria (Almeida & Black 1966). Allard & Hurst (1969) compared the Propria geosyncline along the Rio São Francisco with a similar structure in Gabon. Reyment (1969*a*) has drawn attention to the fact that the crystalline rocks of the Recife–Natal area of Brazil fit snugly between the Benin Flank and Oban Massif of Nigeria. Krömmelbein & Wenger (1966) have found remarkable similarities between the pre-Cretaceous non-marine ostracod faunas of Brazil and West Africa.

The fact that the earliest marine rocks along either coastline are Cretaceous in age is well documented. However, although the biostratigraphy of the Cretaceous rocks in the West African sedimentary basins is well known (Reyment 1965), far less is known of the corresponding basins on the Brazilian coastline. In view of the apparent close agreement in the former location of the Albian–Turonian basins of the Sergipe–Alagoas region of Brazil and the Gabon basin in Africa, and the basins of Potiguar and Eastern Nigeria (Reyment 1969*a*) the authors decided to concentrate their efforts in these areas. The main objects were to determine the extent and precise palaeontological dates of the various Cretaceous marine transgressions and regressions and compare these with events in West Africa and to make a comparison between the fauna and their environments in the two continents, and hence deduce the nature of the original basin and the precise palaeontological date of the initial rupture.

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2. General geological framework

(a) *Africa*

Several, recently published general works on the geology of Africa are available (Haughton 1963; Reyre 1966; Furon 1968); we have therefore refrained from detailed reviews of the

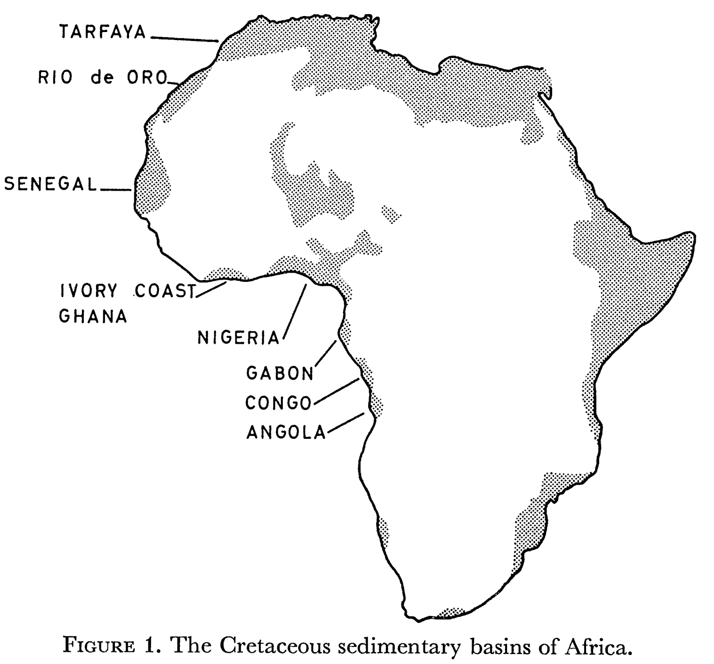

Figure 1. The Cretaceous sedimentary basins of Africa.

sequences in the West African sedimentary basins and confined our comments to the presentation of relevant new data. Published information on the geology of South America is rarely in the English language and is difficult of access; we have, therefore, given more detailed information in this section.

(i) *Congo–Angolan Basin*

Although there are in fact two major areas of Cretaceous sediments in the long, coastal band stretching from the northern tip of South-West Africa to the Congos, there does not seem to be any good reason for regarding the individual sequences as different depositional entities. We shall therefore treat the so-called Mossamedes, Cuanza, Congo and Cabinda basins as one unit. It is also possible to include the Gabonese basin with this group (Hourcq 1966), as all have many features in common which separate them from the Nigerian coastal sedimentary basin. Owing to the importance of Gabon in our present analysis, we have not chosen to do this but have preferred to give the Gabonese basin more detailed treatment.

The coastal Cretaceous deposits of Angola ('Gulf of Luanda (Cuanza)' and 'Gulf of Mossamedes') and the Congo s.l. rest directly on the crystalline basement and begin with a continental, lacustrine series. The next major cycle of sedimentation consists of an evaporitic sequence, which in Gabon and Congo s.l., is mainly composed of salt beds, but which in Angola (Cuanza) has a more complex lithology (Hourcq 1966, p. 166). Finally, there is an uppermost sequence of sediments which ranges in age from Upper Aptian to Recent with breaks in the sequence. The thickness of the sediments of the third phase of sedimentation is great and the beds lie in an 'open basin', by virtue of their being spilled out on the ocean floor.

The Albian of the Congo basins is still a matter for conjecture and, although sediments are referred to this stage, no characteristic fossils have ever been recorded in the literature. The Albian of the Angolan basins is, on the other hand, classical, particularly the associations near Benguela, where there are numerous species of mortoniceratids, including *Elobiceras*. The most recent publication on Angolan ammonites is by Howarth (1965), who observed that the earliest occurring species of the Upper Albian belong to *Neokentroceras* and *Hysteroceras*, which he concluded dates this part of the series as low Upper Albian. *Douvilleiceras* has long been known from the Salinas area which proves the presence of Lower Albian (cf. Howarth 1965).

The preliminary analysis of the Sergipian material indicates that many of the *Elobiceras* are identical with species well known from West Africa, in particular, Angola and Elobey Island. This has not been adequately realized in the past with the result that the literature contains numerous synonyms of West African species.

The Cenomanian of Angola is less fossiliferous than the Albian. It is also less well understood. The occurrence of *Stoliczkaia* in beds of Cenomanian age supports the observations of others, particularly palaeontologists working in Texas (e.g. Perkins 1960, pp. 36, 37, 41). The current zonal scheme in which uppermost Albian is marked by the zone of *S. dispar* therefore seems to be in need of revision for, as things stand, this zone lies partly in the uppermost Albian (as is the case in England and Nigeria) and partly in the lower Cenomanian (as is the case in Texas, Brazil and Angola).

The Turonian is poorly known. There are no vascoceratids and the only records of Lower to Middle Turonian ammonites are doubtful. More information is, however, available for the Upper Turonian which is particularly interesting, as the identification of this substage is something of a problem in the South Atlantic. Basse (1963) described a collection of Upper Turonian to Lower Coniacian ammonities from Cabo Ledo in the Cuanza area which resembles one found by Reyment in Eastern Nigeria six years ago (unpublished).

Reference to the genus *Deshayesites* quoted in the literature referred to above deserves comment (see p. 83). There can be little doubt that this is the result of an incorrect determination or determinations, for *Deshayesites* is restricted to the Lower Aptian, as is also its species *D. consobrinoides* (Sinzow) (cf. Casey 1964). There is a possibility that the species in question belongs to *Neodeshayesites* Casey, a genus founded for certain Upper Aptian deshayesitids from western South America.

Consideration of the Neocomian ammonite associations allows a test of the former proximity of the southern tip of South Africa to South America during the Lower Cretaceous. If our hypothesis be true, and the opening of the South Atlantic rift started in this area during early

Aptian, then one may reasonably expect a measure of agreement in the fossil associations of the Neocomian. A collection of Upper Valanginian molluscs from the Uitenhage Formation (South Africa), made by Reyment in July 1970, was studied with this end in view. The closest affinities of this well-known fauna turn out to lie with the molluscs of the Mulichino and Agrio formations of western Argentina and Chile. The majority of the species appear to be different, although related, but several were found to occur in both regions, for example, *Olcostephanus uitenhagensis* Kitchin, *Eriphyla agrioensis* Weaver, *Megacucullaea kraussi* (Tate) and *Gervillia anceps* Deshayes?

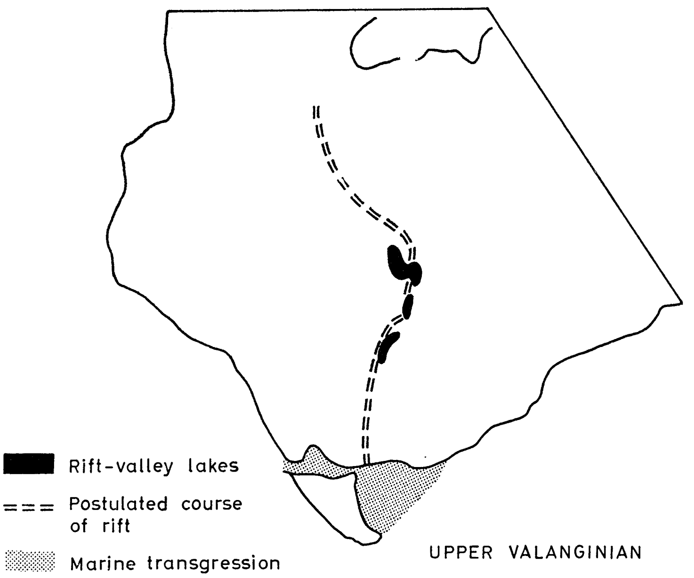

FIGURE 2. Reconstruction of the Amero–African Continent during the Neocomian. Large freshwater lakes formed at several sites along the line of the rift. A marine transgression crossed the southern tip of the landmass.

(plate 4). Hallam (1967, p. 219) has summarized earlier views on the similarity of the trigoniids of both areas. In summary, the evidence indicates that there was a marine faunal connexion during the Valanginian (figure 2). See also Weaver (1931).

(ii) *Gabonese Sedimentary Basin*

The basal non-marine beds of the Gabonese coastal Cretaceous (Cocobeach Formation) are placed in the Neocomian (table 1) (de Klasz 1965). They consist of brown and black shales with a marl band in which fish, considered to be of Purbeckian age, are found. The middle sequence of the Cocobeach Formation is made up of grey and black shales in which thin sandstone intercalations occur. On palynological evidence, the Upper Cocobeach Formation is placed by French workers in the Lower Aptian (de Klasz 1965); it consists of shales, sandstones and conglomeratic beds. Krömmelbein & Wenger (1966) and Krömmelbein (1966) have pointed out the great similarity between the Neocomian non-marine ostracod fauna of Gabon and that of northeastern Brazil (Bahia and Sergipe). Thus, of the 40 odd species of ostracods known from the Cocobeach Formation and 90 species from northeastern Brazil, 33 occur in the Bahia–Sergipe area and Gabon. This lacustrine ostracod assemblage is unknown in Europe and North America.

The freshwater sediments of the Cocobeach Formation are followed by salt deposits. The salt beds are overlain by marls in which an ammonite, possibly *Neodeshayesites* (see above), occurs. The top of the Albian–Aptian is placed by French workers in a sequence consisting of shales, sandstones and sandy shales. The Albian is taken to begin with reddish sandy shales, followed by the calcareous Madiéla Formation, from which *Douvilleiceras* has been reported. Higher up in the formation, Middle Albian (with *Oxytropidoceras*) and Upper Albian (with *Elobiceras* spp. and *Mortoniceras* spp.) occur. A Cenomanian age has been assigned to the overlying limestones,

Table 1. Succession in the Gabonese Coastal Basin
(Based on de Klasz 1965)

age		formation names			
		west		east	
Post Miocene		Akosso			
Miocene	Upper	Alewana	N'Tchengué		
			M'Béga		
	Lower		Mandorové		
Oligocene					
Eocene	Upper	Mandji	N'Gola		
	Middle		Aniba		
	Lower				
Paleocene	Upper		Ozouri	Namino	
	Middle		Ikando		
	Lower	Port Gentil	Oguendjo	N'Goumbi	
Maastrichtian			Ewongué	Komandji	
Senonian	Campanian	Pointe Clairette	Upper		
	Santonian		Lower		
	Coniacian		Basal	Milango	
Turonian		Azilé		Sibang	
Cenomanian		Cap Lopez	Upper	Série Rouge	
			Lower		
Albian		Madiéla		Madiéla	
Aptian	Upper	Série salifère			
	Lower	Cocobeach s.l.		Cocobeach	Upper
Neocomian and older					Middle
					Lower
				N'Dombo	
				M'Vone	
				Agoula	

shales and sandstones from the content of foraminifera. The Lower Turonian calcareous Sibang and argillaceous Azilé Formations contain typical fossils. Outcrops of the former formation near Libreville have yielded *Bauchioceras nigeriense* (Woods), *Wrightoceras wallsi* Reyment, *Exogyra olisiponensis* Sharpe, *Lima gramamensis* Maury, etc. Freneix (1959) thought that the Sibang Formation ranged from Upper Turonian to basal Coniacian, but she was misled by erroneous ammonite determinations and the doubtful report of a *Heterotissotia*. The ammonites are, however, clearly Lower Turonian, as could be ascertained from material collected by Reyment in 1969 from the Libreville quarries. The presence of Upper Turonian in Gabon is, therefore, still uncertain. The Komandji Formation is of Coniacian, Santonian and probably younger age, although really characteristic fossils have only been recorded for the Coniacian and Santonian. Species of *Peroniceras*, *Gauthiericeras*, texanitids and barroisiceratids have been found, but these are worldwide in distribution.

(iii) *Nigerian Coastal Basin*

The biostratigraphy of this sedimentary basin has the longest history of study of the West African basins and for this reason, as well as for the richness of the assemblages, particularly the ammonites, it has become the principal standard of reference for Cretaceous biostratigraphy in West Africa.

Non-marine deposits outcrop in and around Mamfe Division (Cameroun) and in north-eastern Nigeria. These underlie the oldest known marine deposits, although the relationship is not always clear owing to deficient field evidence. The palaeontology of the non-marine deposits has been sadly neglected and it is still not possible to provide a reasonable coverage of this undoubtedly important part of the succession. The marine Cretaceous sequence was initiated by a transgression during the Middle Albian; outcrops of these basal rocks occur in the lower part of the Benue valley. The assemblage of ammonites contains species of *Oxytropidoceras* s.l. and *Dipoloceras*. The oxytropidoceratid subgenera *Adkinsites* and *Manuaniceras* are represented in the association but, it is important to note, not *Venezoliceras*. Comparison with our Brazilian oxytropidoceratid collection disclosed that none of the species appears to be conspecific with those of Nigeria. (Young (1966) records the Brazilian *O. buarquianum* (White) from Texas and considers that it occurs in Peru.) Upper Albian is more widely developed, and a considerable area of Eastern Nigeria and southern Benue Province is underlain by shale (Asu River Formation and unnamed formations) in which species of *Hysteroceras*, *Mortoniceras*, *Dipoloceras* and *Elobiceras* are to be found, locally in abundance. Species of particular biostratigraphic importance for correlations in the South Atlantic are listed in table 2.

The top of the Nigerian Albian is marked by a distinctive association containing *Stoliczkaia* (a different species from the Brazilian (Sergipe) Cenomanian *Stoliczkaia*), and species of *Mortoniceras* (*Durnovarites*) as well as *M.* (*Angolaites*) *gregoryi* (Spath). This latter species is related to *M.* (*Angolaites*) *sergipense* (White), but it shows more pronounced differences in the lateral tuberculation than would be expected for infraspecific variation in ammonites.

The Albian sedimentation took place during a phase of gradual regression so that the oldest deposits are found farthest inland and the youngest much nearer the coast.

Undoubted Cenomanian has only been recorded from Calabar Province, close to the present coast, in the beds of the Odukpani Formation. There has been some discussion (unpublished) of this question in Nigeria, as, on palynological evidence, it has been suggested that the upper part of the Asu Formation is Cenomanian. The ammonite biostratigraphy contradicts this contention and, as no Cenomanian fossil fauna has been found outside the area specified above, we are left with the inescapable conclusion that by Cenomanian time the sea had reached its lowest ebb in the Nigerian Cretaceous basin. The Odukpani Formation, consisting lithologically of sandstones and conglomerates, rests on rocks of the basement complex (see, for example, Reyment 1965, p. 34). Thereafter, there is a thin bed of bluish shale which could be Albian since a thick limestone containing Cenomanian ammonites occurs next in the sequence. The

Table 2. Chart of ammonite species that occur in the Atlantic coastal basins of South America and Africa

age and species	Brazil	Gabon	Angola	Cameroun	Nigeria	Trinidad	Peru/Columbia	Morocco	Sahara	Argentine	S. Africa
Coniacian											
Eulophoceras natalense Hyatt	×	.	.	.	.	.	.	.	.	.	.
Solgerites armata (Solger)	×	.	.	×	×	.	×	.	.	.	.
S. brancoi (Solger)	×	×	.	×	×	.	×	.	.	.	.
Upper Lower Turonian											
Benuites benueensis Reyment	×	.	.	?	×	×	×	×	.	.	.
B. spinosus Reyment	×	.	.	×	×	×	×	×	.	.	.
B. reymenti Collignon	.	.	.	.	.	×	×	×	.	.	.
Neoptychites telingaeformis Solger	×	×	.	×	×	×	.	.	.	.	.
N. crassus Solger	?	.	.	×	×	×	×	.	.	.	.
Hoplitoides ingens (von Koenen)	×	.	.	×	×	×	×	.	.	.	.
H. wohltmanni (von Koenen)	?	.	.	×	×	×	×	.	.	.	.
Glebosoceras glebosum Reyment	×	.	.	.	×	.	×	×	.	.	.
Kamerunoceras jacobsoni Reyment	×	.	.	.	×	?	.	×	.	.	.
K. eschi (Solger)	×	.	.	×	×	×	.	×	.	.	.
Watinoceras guentherti Reyment	.	.	.	×	.	.	.	×	.	.	.
W. hesslandi Reyment	.	.	.	×	.	.	.	×	.	.	.
Mammites chouberti Collignon	?	.	.	.	.	.	.	×	.	.	.
M. dixeyi Reyment	×	.	.	.	×	.	.	.	.	.	.
Lower Lower Turonian											
Wrightoceras wallsi Reyment	×	×	.	.	×	.	.	.	.	.	.
Bauchioceras nigeriense Reyment	×	×	.	.	×	.	.	.	×	.	.
B. planum (Barber)	×	.	.	.	×	.	.	.	.	.	.
Gombeoceras gongilense (Woods)	×	.	.	.	×	.	.	.	.	.	.
Pachyvascoceras hartti (Hyatt)	×	.	.	.	×	.	.	.	.	.	.
P. globosum Reyment	×	.	.	.	×	.	.	.	.	.	.
Vascoceras bulbosum Reyment	×	.	.	.	×	.	.	.	.	.	.
Cenomanian											
Metoiceras aff. *ornatum* Moreman	×	.	.	.	×	.	.	.	.	.	.
Sharpeiceras sp.nov.	×	.	×	.	×	.	.	.	.	.	.
Acanthoceras quadratum Crick	×	.	.	.	×	.	.	.	.	.	×
Upper Albian											
Angolaites gregoryi Spath	×	.	×	.	×	.	.	.	.	.	.
Elobiceras lobitoense Spath	×	.	×	.	×	.	.	.	.	.	.
E. angustum Spath	×	.	×	.	.	.	.	.	.	.	.
E. intermedium Spath	×	.	×	.	×	.	.	.	.	.	.
E. subelobiense Spath	×	.	×	.	×	.	.	.	.	.	.
Middle Albian											
Oxytropidoceras buarquianum (White)	×	.	.	.	?	.	.	.	.	.	.
Lower Albian											
Douvilleiceras offarcinatum (White)	×	.	?	.	.	.	.	.	.	.	.
D. orbigny Hyatt	×	.	×	.	.	.	.	.	.	.	.
Neocomian											
Olcostephanus uitenhagensis Kitchen	.	.	.	.	.	.	.	.	.	×	×

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

remainder of the sequence consists of shales with occasional limestone bands in which Cenomanian ammonites occur. The shales have yielded species of *Turrilites*. The ammonites found in the limestones are species of *Acanthoceras*, *Acompsoceras*, *Forbesiceras*, *Turrilites* and *Euhystrichoceras*. *Acanthoceras quadratum* Crick, originally recorded from South Africa, has been noted from Calabar and was found by us in the lower Cotinguiba Formation in Sergipe, Brazil.

The role of the Cenomanian in the Atlantic is important. In all cases known to us the deposits of Cenomanian age in the South Atlantic coastal basins accumulated in a regressive sea. The Upper Cenomanian of north-western Africa, the so-called Saharan Upper Cretaceous, is strongly transgressive and it is now well documented that an epicontinental sea began to spread across northwestern Africa in late Cenomanian time. This sea stretched from North Africa around the western side of the Ahaggar, to a shallow inland basin to what is now Niger Republic and Chad Republic. The late Cenomanian transgression is marked by the occurrence of *Neolobites vibreyanus* (d'Orbigny), a species, and genus, unknown from the southern Atlantic Cretaceous, although *Neolobites* has been recorded from Peru (Benavides-Càceres 1956). By the end of the Cenomanian the epicontinental sea had reached the Damergou area of Niger Republic (see p. 86). A transgression then began in the Nigerian coastal sedimentary basin. The biostratigraphical evidence indicates that the northern and southern seas united for a short period in the lower part of the Lower Turonian. Experimental studies (Reyment 1971 *a*) show that it is possible to simulate the progress of the trans-Saharan shallow sea in relation to other marine coastal transgressions in the southern Atlantic region. Thanks to the work of Faure (1966), more certainty may now be attached to our interpretation of the sequence of events. It seems as though the Lower Turonian sea withdrew rapidly northwards and less rapidly southwards. Faure has recorded and figured Coniacian fossils of 'Camerounian type' from eastern Niger, and Coniacian and possibly Upper Turonian, as well as Santonian sediments, occur in northeastern Nigeria (cf. Reyment 1965, p. 44). The geology of the deposits of northeastern Nigeria have been described in detail by Carter, Barber & Tait (1963).

The Lower Turonian ammonites occupy a key position in our interpretation of the palaeobiography of the South Atlantic Ocean. The rich Lower Turonian vascoceratid and pseudotissotiid associations of northeastern Nigeria have been described by Barber (1957). The surprising thing is that so very few of these species occur in the nearby vascoceratid fauna of Niger. In fact, specific identity has really only been established for *Bauchioceras nigeriense* (Woods) and *Epengonoceras nigeriense* (Furon). The same worker (Barber 1958) has, however, described and figured several species of pelecypods and gastropods from northeastern Nigeria, eight of which are known from Niger Republic, and many from the Turonian of Cameroun (tables 3, 4).

The upper part of the Lower Turonian has not been recorded from northeastern Nigeria, Niger Republic and the central Sahara (Collignon 1966), and this fact tempts one to speculate about the possibility of a retreat of the sea during this time. Upper Lower Turonian fossils have only been found as far north as the Makurdi area of southern Benue Province, where the association is typical and highly important in the biostratigraphy of the southern Atlantic. It is characterized by species of *Mammites*, *Hoplitoides*, *Benueites*, *Kamerunoceras*, *Neoptychites* and *Watinoceras*.

The lower Turonian of southeastern Nigeria is complete, consisting largely of limestones, marls and shales with less important occurrences of sandstones in the sequences. However, in the Duala embayment (Cameroun) of the Nigerian sedimentary basin, the Mungo River Formation begins with an unfossiliferous sandstone (Mundeck Sandstone) of possible freshwater

TABLE 3. IMPORTANT PELECYPODS IN THE SOUTH ATLANTIC REGION

M = Maastrichtian, Ca = Campanian, Sa = Santonian, Co = Coniacian, T = Turonian, C = Cenomanian, A = Albian, N = Neocomian, U = Upper, M = Middle, L = Lower

species	S. Brazil	N. Brazil	Gabon	Angola	Cameroun	Nigeria	Congo–Cabinda	Ivory Coast–Ghana	Niger Republic	Argentine	S. Africa
Modiolus aff. *subsimplex* (d'Orbigny)	.	Ca	.	.	.	.	Ca–M	.	.	.	.
Veniella drui (Munier Chalmas)	Ca	.	Co–ML	.	Co–ML	Co–MU	Co–ML	.	Co	.	.
Pseudocucullaea lens Solger	Co	.	Co–ML	.	Co–Sa	Co–ML	Co–ML	Ca	Co	.	.
Legumen ellipticum Conrad	.	Ca	M	.	Co–Sa	.	Ca–ML	.	.	.	.
Trigonarca furoni	Co	.	.	.	Co–Sa	.	Sa	.	.	.	.
Modiolus sp.nov.	Co	.	.	.	.	.	Co	.	.	.	.
Trigonarca camerunensis Reidel	Co	.	Co–Ca	Co–Ca	Co–Ca	Co–ML	Co–Ca	.	Co	.	.
Plicatula flattersi Coquand	TL	.	.	.	Co–Ca	Co	TL–Co	.	.	.	.
Lopha lombardi	TL	.	.	.	Co–Ca	.	Sa–Ca	.	.	.	.
Aphrodina angustosinuosa (Riedel)	TLL	.	TL–Sa	Co–Sa	Co–Sa	.	T–Ca	.	.	.	.
Lima grammensis Maury	.	Ca	TL–Co	.	.	.	Co–Sa	.	.	.	.
Fragum perobliquum (von Koenen)	TLL	.	TL–Co	.	TUL–Co	TUL	TL–Co	.	.	.	.
Atrina laticostata Stoliczka	TLL	.	.	.	TUL–Co	TLL	.	.	.	.	.
Plagiostoma perplana von Koenen	TLL–Co	.	.	.	TL–Co	TUL	TL	.	.	.	.
Exogyra olisiponensis Sharpe	.	.	TL	TL	TUL	TLL	.	.	TLL	.	.
Trigonarca cf. *diceras* (Seguenza)	TLL	.	.	C?	.	.	.	.	.	.	.
Liopistha incurvata Riedel	TLL	.	.	.	TUL	.	.	.	.	.	.
Modiolus typicus (Forbes)	TLL	.	.	.	.	TUL	.	.	.	.	.
Inoceramus labiatus	TLL	.	.	.	.	TLL	.	.	.	.	.
Brachydontes? praetexta (White)	AU	.	.	.	.	.	C–Co	.	.	.	.
Neitha gibbosa (Pulteney)	AU	.	.	AU	.	AU	.	.	.	.	.
Megacucullaea kraussi (Tate)	.	.	.	.	.	.	.	.	.	NM	NM
Eriphyla agrioensis Weaver	.	.	.	.	.	.	.	.	.	NM	NM
Gervillia anceps Deshayes	.	.	.	.	.	.	.	.	.	NM	NM

origin, the age of which is unknown. This is overlain by sandy beds with intercalations, some thick, of limestones, marls and shales, the oldest ammonites of which indicate an age of upper Lower Turonian. The assemblage contains species of *Neoptychites*, *Hoplitoides*, *Kamerunoceras*, *Benueites* and *Choffaticeras*. None of the typical vascoceratid elements of northeastern Nigeria occur.

The reason why lowermost Lower Turonian fossils have not been found in the Mungo River Formation is worth conjecture. Although the structure of the Mungo Valley is not nearly as well known as its palaeontology and stratigraphy, there seems to be some evidence

TABLE 4. IMPORTANT GASTROPODS IN THE SOUTH ATLANTIC REGION

Ca = Campanian, Sa = Santonian, Co = Coniacian, T = Turonian, C = Cenomanian, A = Albian, U = Upper, M = Middle, L = Lower

	S. Brazil	Gabon	Angola	Cameroun	Nigeria	Congo –Cabinda
Turritella nodosa Romer	TLL	.	.	TUL–CaU	Co	.
Turritella harborti Riedel	AU–TL	.	.	TUL–CaU	.	.
Piestochilus aff. *bleicheri* (Thomas & Peron)	TLL	Co–Sa	T	.	.	T–Co
Tylostoma globosum Sharpe?	TLL	.	AU–TL	.	.	AU–TL
Tylostoma cossoni Thomas & Peron	AU	.	AU–TL	.	.	AU–TL

for the rift origin of the valley. The fact that the first marine invasion took place in upper Lower Turonian time (zone of *Benueites benueensis*) suggests that the rifting, if such indeed did take place, occurred then (Reyment 1969*a*). Important species for correlations in West Africa have been noted by Reyment (1965, p. 46), where also a detailed review of the stratigraphy is presented.

The deposits of the Dahomeyan embayment of the Nigerian sedimentary basin have yielded a few Maastrichtian fossils at the base of the marine succession and thus are comparable with the succession in Western Nigeria. The lithology of the Dahomeyan rocks is the same as that of the Nkporo Shale of Nigeria, of which they are a lateral continuation. According to a verbal communication received from the Service de Mines of Dahomey, recent offshore drilling has, however, indicated the possibility of the occurrence of older Cretaceous sediments near Porto Novo.

(iv) *Ivorian–Ghanaian Basin*

The marine sedimentary sequence of the sedimentary basin of the Ivory Coast and Ghana begins with argillaceous sandstones in which two fragments of ammonites, referred to *Elobiceras* and *Dipoloceras*, have been recovered from drilling cores (Collignon 1966). These sediments overlie non-marine shales and conglomerates. This discovery, in relation to the recent information on the offshore deposits of Dahomey (see above), and the report of an *Elobiceras* in a drilling core offshore from Maranhão, Brazil, shows that in the late Albian there was a short-lived, epicontinental transgression from the south (figure 3).

The evidence for Cenomanian and Turonian is less well founded. Firstly, no ammonites have been found in the Anwiafutu Limestone of Ghana (the fossils of which were described by Cox in 1952), nor in the supposedly lateral equivalents (shales, sandy shales) of the Ivorian part of the basin. The age determination must therefore be treated with caution. The younger Cretaceous is best known from the Nauli Limestone of Ghana, where a fauna of Campanian age occurs

(Cox 1952). Many of the fossils of this assemblage are the same as those of the more southerly basins – for example, species of *Trigonarca*, *Pseudocucullaea* and *Venericardia*.

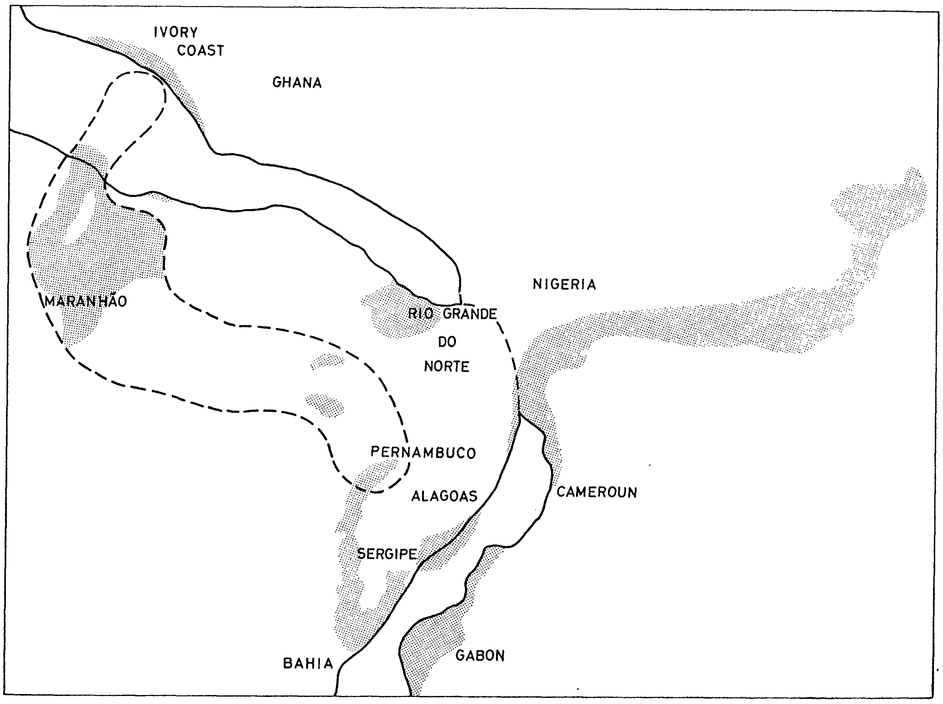

FIGURE 3. Sketch denoting the distribution of Cretaceous outcrops in central West Africa and northeastern Brazil (based on Beurlen (1970) and Reyment (1965)). The dotted boundary based on Beurlen (1961), marks the inferred extent of a possible epicontinental sea for which only indirect evidence exists. The tie-up of the Nigerian–Camerounian Lower Turonian deposits with those of Pernambuco (Beurlen 1970) is worthy of note (Reyment 1969*a*). The orientation of the continents is that of Bullard *et al.* (1965).

(v) *Senegalese Basin*

Information on the pre-Campanian deposits of this basin comes entirely from off-shore drilling. On micropalaeontological evidence (foraminifers and ostracods), a Valanginian to Aptian age has been assigned to a sequence of shales, oolitic and granular limestones, sandy limestones and occasional thin beds of anhydrite. Certain algae and foraminifera in the basal part of the succession may indicate a late Jurassic age. This dating agrees well with the report of late Jurassic from the Demerara Plateau (Fox, Heezen & Johnson 1970).

A sequence of shales with rare sandstone intercalations, limestones and marls, sandy limestones, dolomites and shales with traces of plant fragments and gypsum has been placed in the Lower Albian on slender evidence. Overlying shales, sandstones and sandy shales have been referred to Upper Albian–Cenomanian on foraminiferal evidence. Turonian has been identified, also on the micropalaeontology, in beds similar to the foregoing. The Senonian has yielded molluscs and *Texanites* s.l. in an alternating sequence of shales and sandstones with rare limestone and dolomitic intercalations. Maastrichtian overlies these deposits, and is known moderately well from outcrops. The Senegalese sedimentary basin is of great extent and it stretches from Mauritania to Guinea.

(vi) *Rio de Oro Basin*

Biostratigraphical evidence concerning the south of this basin is slight. Salt deposits of supposed Triassic age are reported at the base of the sedimentary sequence (Furon 1968, p. 139). There is a thick sequence of reputedly marine Jurassic sediments overlain by an apparently complete Cretaceous succession. The sediments of the Cretaceous consist of continental beds in the Lower Cretaceous, thereafter anhydrite, followed by poorly fossiliferous limestones. The information available has been obtained from a drilling programme.

In contrast to the foregoing, the Tarfaya area in the north of the basin is quite well known and of exceptional importance in our analysis. Drilling indicates the possible presence of Triassic lying directly on the crystalline Basement. The Cretaceous sequence is considered to overlie Jurassic.

The Lower Cretaceous consists of sandstones and marls which are overlain by Upper Cretaceous marls, shales and limestones. The beds of Albian age contain European and North American species of *Dipoloceras*, *Hysteroceras* and *Mortoniceras* (but no *Elobiceras*) and *Hypengonoceras*. The oxytropidoceratids are represented by the subgenera *Venezoliceras* and *Tarfayites*.

The Cenomanian contains turrilitids, acanthoceratids, such as *Eucalycoceras*, *Calycoceras*, *Protacanthoceras* and *Acanthoceras*, as well as the North American *Tarranteoceras*.

The lower part of the Tarfayan Lower Turonian is marked by *Metoicoceras*, *Mammites*, *Neoptychites*, *Pseudaspidoceras*, *Kamerunoceras*, *Selwynoceras*, but none of the vascoceratids so typical of Portugal, Spain and North Africa on the one hand, nor those of the southern Atlantic on the other.

Collignon (1966) drew attention to the missing vascoceratids and expressed the opinion that the lowermost Turonian as represented in Nigeria and northwestern Africa was lacking in Morocco. Higher up in the Turonian, the position is reversed, and a great number of forms common to Nigeria have been recorded, such as species of *Watinoceras*, *Benueites*, *Glebosoceras*, etc. (see table 2).

The Coniacian contains *Peroniceras*, the eastern South American species *Prionocycloceras guyabanum* (Steinmann), and *Gauthiericeras*. The Santonian is characterized by *Texanites texanus* Römer and species of *Pseudoschloenbachia*.

Collignon (1967) was able to correlate the Moroccan Albian without much difficulty with the standard European successions and with Malagasy, but noted the slight agreement with the successions in the southern Atlantic. He considered the Cenomanian to be most closely related to that of North Africa and southern India, but found it remarkable that none of the elements of the *Neolobites* association (uppermost Cenomanian), so typical of North Africa and the Sahara, had been found. He (Collignon 1967, p. 3) concluded that 'la faune de Tarfaya appartient à un domaine bien différent de celui du Sahara central et de la Nigéria, ou pullulent les Vascoceratidae et les Tissotiidae... ainsi la faune du bassin côtier de Tarfaya donne l'impression d'être paléontologiquement et paléogéographiquement isolée dans le domaine ouest-africain.'

(b) *South America*

(i) *Trinidad*

In southwestern Trinidad Lower Turonian ammonites occur in conglomerate clasts in the Plaisance member of the San Fernando Formation which is of Eocene age. The formation yielding the limestone in the conglomerate has not been discovered, despite an intensive search.

The ammonites belong to the Turonian genera *Hoplitoides* and *Neoptychites*, as well as several species of the genus *Benueites*, *B. benueensis*, *B. spinosus*, *B. reymenti* Collignon, *B. collignoni* Reyment, and *Mammites* sp. (Reyment 1971*c*, 1972).

(ii) *Brazil – general*

The geology of Brazil is dominated by the pre-Cambrian rocks of the Brazilian Shield, Within this shield area Palaeozoic rocks are present in three great basins termed the Amazon,

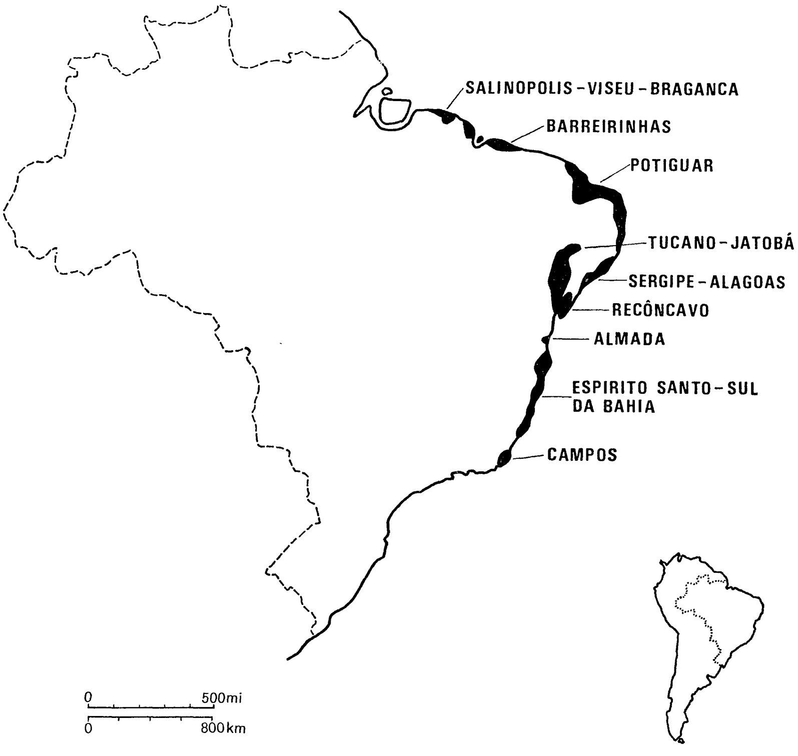

FIGURE 4. Distribution of the coastal Cretaceous sedimentary basins in Brazil (based on Rosa 1967).

Parnaíba-São Francisco and Paraná geosynclines (Oliveira 1956; K. Beurlen 1970). Palaeozoic rocks are also present in both the Tucano and Sergipe–Alagoas coastal basins. In the inland basins the Palaeozoic rocks are mainly of a marine facies with some intercalations of continental rocks. In addition, there is ample evidence of repeated glaciation in Cambrian, Silurian and Carboniferous–Permian times. On the other hand, the Palaeozoic rocks in the basins along the present-day coastline are entirely continental in facies. Apart from some sediments resembling glacial varves in the Boacica Member of the Batinga Formation (table 5, p. 73), in the Sergipe–Alagoas basin there is no sign of glaciation.

During the early Cretaceous there was a general sinking over the whole region which resulted in the deposition of continental sandstones over most of the interior of Brazil and initiated a number of small basins along the present-day coastlines. These coastal basins became more and more saline with the eventual formation of salt deposits. This was followed by a normal marine invasion characterized by a number of transgressive and regressive phases which, together with the associated fauna, resembles the sequence in the Cretaceous basins along the opposing coastline of West Africa.

During the early Tertiary the greater part of Brazil became emergent with approximately its present form, and only a narrow coastal strip remained submerged. In the Eocene the whole region, with the possible exception of the area at the mouth of the Amazon, was elevated above sea level. At the mouth of the Amazon there is a thick sequence of calcareous, richly fossiliferous sandstone known as the Pirabas Formation (Oliveira 1956) which appears to be of Miocene age. Elsewhere the Tertiary deposits from the Amazon round the coastline to Rio de Janeiro are represented by the Barreiras Formation which is considered to be of Pliocene age.

(*c*) *Brazilian coastal sedimentary basins*

(i) *Potiguar Basin* (*Rio Grande do Norte*)

The geology of the Potiguar Basin in NE Brazil is comparatively simple. An account of the stratigraphy, including references to earlier work, was given by Karl Beurlen (1967). A further description of the Cretaceous stratigraphy, incorporating the information obtained from drilling by Petrobrás, was published by Sampãio & Schaller (1968).

From the surface geology the structure appears straightforward, being part of an elliptical basin with a centre to the northeast under the Atlantic. However, evidence obtained from bore-holes and geophysical surveys indicates some subsurface faulting which divides the area into three structural units represented by two shallow monoclinal shelves with a central graben (Sampãio & Schaller 1968, p. 21).

The basal member, the Gangorra Formation, is known only from borehole information. It consists essentially of non-marine dark-coloured shales with rare bands of calcareous and silty material. These sediments are overlain, probably unconformably, by the Açú Formation, which is coarsely arenaceous at the base, becoming finer, with some intercalated beds of shale and marl near the top. Sampãio & Schaller (1968) state that some thin bands of gypsum occur in the uppermost part of the Açú Formation but Oliveira & Leonardos (1943) and Beurlen (1967) claim that these should be placed in the lower part of the overlying Jandeira Formation. The Açú Formation oversteps the Gangorra Formation to lie unconformably on Basement rocks without any sign of marginal faulting.

The Jandeira Formation follows conformably and the junction is marked by a well-defined, minor scarp. The rocks are predominantly limestone with a few shaley and sandy lenses which become more prominent in the eastern part of the basin. The limestones are very varied in their lithology ranging from shell banks of gastropods and pelecypods to chemical precipitates. The fauna is at times prolific although markedly restricted in species. The environment of deposition is typical of a partially, and at times completely, enclosed basin cut off from the open sea by off-shore reefs or bars.

The basin was initiated by the Lower Cretaceous movements which caused a general subsidence accompanied in the very early stages (pre-Açú Formation) by minor faulting.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

(ii) *Pernambuco Coastal Basin*

Structurally the Pernambuco Basin is a narrow eastward extension of the Potiguar Basin, continuing around the coastline to just south of Recife. The Cretaceous rocks are largely obscured by the Tertiary Barreiras Formation and Quaternary sands and gravels.

At the Poty cement factory, São Jose near Paulista, it has been established that the marine sequence begins with Turonian or Cenomanian sediments resting on the Basement. These are overlain by limestones, at times marly or argillaceous which have been dated as Maastrichtian to Paleocene.

(iii) *Barreirinhas Coastal Basin*

No Cretaceous rocks outcrop in this basin, which has an almost complete cover of coastal dunes and sands. Geophysical surveys (Castro 1967) and oil drillings have, however, revealed the existence of a deep Cretaceous basin. The basin occurs to the north of the Palaeozoic Maranhão Basin and it would appear to have been initiated during the Aptian movements.

(iv) *Recôncavo–Jatobá Basin*

This large basin has been described (Fonseca 1966) as a 'half graben' extending northward from the city of Salvador. The sediments are faulted against the crystalline, pre-Cambrian rocks to the east and, in general, rest unconformably on the basement rocks to the west.

Around the margin of the basin there are numerous outcrops of the Estância Formation. The age of this formation is uncertain, being placed in the pre-Cambrian by Allard & Tibana (1966, p. 23) and in the Cambrian/Silurian by Schaller (1969, p. 26). As in the Sergipe–Alagoas Basin the Estância Formation is regarded as part of the floor of the basin and not part of the sedimentary sequence.

On lithological and structural grounds the basin has been divided into a northern part termed the Jatobá Basin, and a southern part known as the Recôncavo Basin. (In some literature a middle, Tucano Basin is defined.) Sedimentation began earlier in the northern part and Fonseca (1966) lists a succession of continental sediments ranging in age from undifferentiated Devonian to Lower Cretaceous. Both Fernandes (1966) and Rosa (1967) consider that the basal sediments are Silurian in age. Fernandes and Rosa, however, place the Lower Batinga Formation of the Sergipe–Alagoas basin in the Devonian and equate it with the lower part of the sequence in the Jatobá Basin. Schaller (1969) places the Batinga Formation in the Carboniferous, although the fossil evidence is scanty.

The entire basin became inundated and the deposition of the Bahia Supergroup took place. The basal group, the Brotas Group, maintains similar lithological characteristics throughout the basin but in the remainder of the section there are marked facies changes from south to north. The basal beds have been dated as Upper Jurassic–Lower Cretaceous by Fonseca (1966). There seems little doubt that during most of the Lower Cretaceous, there were connexions between the Recôncavo Basin and the Sergipe–Alagoas Basin to the north and the Almada Basin to the south as all the units of the Bahia Supergroup have time equivalents in the Sergipe–Alagoas Basin with similar lithology and similar fossils (Fonseca 1966, p. 69).

The first marine invasion of this area was in the Aptian but the transgression does not appear to have been as extensive as it was in the other basins. The Aptian to Albian rocks vary from continental–deltaic–estuarine deposits (Marizal Formation) in the north to truly marine, mainly limestones (Alagoas/Algodões Formations) in the south. Sedimentation ceased in the north in the Albian, but marine conditions persisted in the southern Recôncavo Basin through to the Turonian. Unlike the Sergipe–Alagoas area, salt deposits have not been recorded from these basal marine rocks.

The elucidation of the stratigraphy has been complicated by a fairly extensive cover of the Tertiary Barreiras Formation and the fact that the Lower Cretaceous rocks have been broken into a series of north-easterly trending blocks by an intricate system of normal faults (Fonseca 1966). There was considerable tectonic activity throughout the period of continental deposition, but there is not, as yet, sufficient published information to make any detailed comparison with the tectonic activity in other areas.

(v) *Almada Basin*

The Almada Basin is essentially a southerly continuation of the Recôncavo Basin. The general subsidence in Late Jurassic–Early Cretaceous times seems to have affected this region rather later than the areas farther north as there are no representatives of the basal Brotas Group, the Aliança Formation. The subsequent non-marine, Lower Cretaceous sediments are, however, similar, both lithologically and palaeontologically, to those of the Recôncavo and Sergipe–Alagoas Basins. The Aptian marine transgression flooded this area leaving sediments identical to those of the Alagoas Formation in Recôncavo and similar to those of the Muribeca Formation in Sergipe except that again there are no salt deposits. Marine conditions persisted in the Almada Basin longer than in the other basins, ranging up to the Maastrichtian according to Fonseca (1966, p. 52).

(vi) *Sergipe–Alagoas Basin*

The Sergipe–Alagoas sedimentary basin occupies a narrow coastal strip from approximately Indiaroba at the mouth of the Rio Real in the south to just north of the town of Maragogi in the north. The basin is approximately 400 km long with a maximum width of 60 km in the region of the Rio São Francisco.

Along the western margin the sediments are in general down faulted against metamorphic rocks of the Basement Complex, but in places (e.g. Morro de Chaves) the junction appears to be unconformable. The sediments extend eastwards beyond the present-day coastline for an, as yet, unknown distance – the sequence has been encountered by Petrobrás in a borehole about 10 km offshore.

Sequence and lithology

The sediments may be divided into a lower, non-marine group (table 5) ranging in age from the Carboniferous? to the Aptian, and an upper, marine group (table 6) ranging in age from the Aptian to the Lower Eocene. The two groups are separated by a 'Transition Group' (tables 5, 6). These sediments are extensively covered by a thick sequence of non-marine rocks of Late Tertiary (Pliocene?) age, and widespread Recent alluvium, particularly along the coast and in the valleys of the major rivers.

Non-marine sequence

Batinga Formation. The Batinga Formation is present nearly everywhere at the base of the sequence. A conglomeratic facies, the Mulungu Member, is seen to outcrop near the Basement and close to the major faults and is undoubtedly a basin margin facies.

TABLE 5. NON-MARINE SUCCESSION ON THE SERGIPE–ALAGOAS BASIN
(Based on Schaller 1969)

				Sergipe		Alagoas	
				marine formations			
Lower Cretaceous	Aptian	Transition Group		Muribeca Fm	Oiterinhas Mb	Muribeca Fm	
					Ibura Mb		Ibura Mb
					Carmopolis Mb		Carmopolis Mb
							Tabuleiro dos Martins Mb
							Maceió Mb
	?	Group Baisco São Francisco	Sub-Group Coruripe	Morro do Chaves Fm		Ponta Verde Fm	
						Coqueiro Sêco Fm	Manquaba Mb
							Roteio Mb
							Frances Mb
							Arambipe Mb
						Morro do Chaves Fm	
	?			Peńedo Fm		Penedo Fm	
	Neocomian			Rio Pitanga Fm			
?……	?……			Barra de Itiuba Fm		Barra de Itiuba Fm	
Upper Jurassic			Sub-Group Igreja Nova	Serraria Fm		Serria Fm	
				Bananeiras Fm		Bananeiras Fm	
						Candeeiro Fm	
Permian …?… Carboniferous				Aracaré Fm		Aracaré Fm	
				Batinga Fm	Boacica Mb	Batinga Fm	Boacica Mb
					Mulungu Mb		Atalaia Mb
Cambrian (?)				Estância Fm			
Pre-Cambrian				Basement			

The principal component of the Batinga Formation, the Boacica Member, consists of finely bedded siltstone containing some argillaceous and arenaceous bands. Many horizons show distinct dark and light grey banding similar in appearance to glacial varves. It is considered that, although this alternation may be due to seasonal variation, it is probably not of glacial origin.

Aracaré Formation. The Aracaré Formation, which is poorly exposed, consists of variegated shales with some bands of fine sandstone, siltstone and occasional limestone, and the sequence is characterized by many bands of chert.

Candeeiro Formation. This formation is only known from borehole information. It is regarded by Petrobrás as being of the same age as the Bananeiras Formation.

Bananeiras Formation. This formation is never well exposed. It forms low-lying, flat ground and consists entirely of red and green shales with occasional thin limey shale bands.

Serraria Formation. In contrast to the underlying formations the Serraria Formation is well exposed. It consists of thick-bedded to massive, poorly sorted, white to grey sandstones containing occasional conglomeratic bands. The sandstones almost invariably exhibit false bedding

Table 6. Marine succession in the Sergipe–Alagoas Basin
(Based on Schaller 1969)

			Sergipe		Alagoas	
Recent Pleistocene			Alluvium		Alluvium	
Pliocene			Barreiras Fm		Barreiras Fm	
Miocene						
Oligocene						
U. Eocene L. Eocene		Sergipe Group	Piaçabuçu Fm	Marituba Mb	Piaçabuçu Fm	Marituba Mb
Paleocene						
Upper Cretaceous	Maastrichtian			Calumbi Mb		
	Campanian					
	Santonian					
	Coniacian		Cotinguiba Fm	Sapucari Mb		
	Turonian					
	Cenomanian			Aracuju Mb		
Lower Cretaceous	Albian		Riachuelo Fm	Aquilhada Mb		
				Maruim Mb		
				Taquari Mb		
	U. Aptian			Angico Mb		
	M. Aptian	Transition Group	Muribeca Formation			
	L. Aptian					
			non-marine Formations			

and complicated slump structures. There are also a few bands of reddish shale near the base, and some carbonaceous material.

Barra de Itiuba Formation. This formation consists of a thick series of shales with some intercalations of sandstone and rare horizons of limestone. The shales are poorly exposed but, where seen, are yellowish to grey green with olive and black horizons. The sandstones are well exposed and can be seen to be fine-grained, well bedded, soft, sugary sandstones containing much felspathic material, a little mica and some carbonaceous material. The calcareous bands frequently contain the remains of fish, chiefly broken scales (Schaller 1969). There are a number of horizons of finely bedded, harder sandstones alternating with softer, loose, almost unconsolidated sands. These sandstones exhibit marked false bedding and many slump structures and local unconformities.

Penedo and Rio Pitanga Formations. We consider that these two units may be regarded as facies variations of the same formation. The Penedo facies consists of greyish white to yellow sandstones, with occasional horizons of green shales containing ostracods. The sandstones are well jointed with much false bedding and many slump structures. The Rio Pitanga facies consists of coarse conglomerates with the boulders consisting mainly of metamorphic rocks which only occur near the margin of the basin close to the large faults. At Muribeca it is overlain by the Morro do Chaves Formation. In the field it was not possible to follow the Rio Pitanga outcrops into the Penedo, but that they grade laterally into each other is obvious from aerial photographs.

Morro do Chaves Formation (including the Coqueiro Seco Formation and the Ponta Verde Formation). We consider on the basis of published information (Schaller 1969) that these three units may be different facies variations of the same chronostratigraphical unit. The Ponta Verde and Coqueiro Seco units which are mainly arenaceous only occur in the northern (Alagoas) part of the basin. Near Muribeca the Morro do Chaves Formation consists of limestones which may be chalky, shelly or dolomitic, with intercalations of sandstone, shale and marl. Near Propria the formation was seen to rest unconformably on the Basement without any obvious sign of faulting. Here the rocks consist of conglomerates followed by sandstones with thin interbedded limestones and some shale.

Transition to a normal marine environment

The Muribeca Formation is a hypersaline sequence separating the non-marine and marine beds. In general it rests unconformably on the older beds, but in the region of Maceió it appears to lie conformably on the green shales of the Ponta Verde Formation. In Sergipe the formation is only known from subsurface information. Here the lower members are not present and there is a marked unconformity with the underlying Morro do Chaves Formation. The rocks are mainly bituminous shales with intercalations of brownish limestone and a few horizons of sandstone and siltstone. The formation is characterized by extensive deposits of evaporites which occur in several fairly well-defined zones. In Alagoas the basal members are not seen in outcrop. The Carmopolis member is, however, seen in faulted contact with older rocks. The sequence starts with a coarse conglomerate followed by a coarse arkosic grit containing many bands of fine grained siltstone, calcareous siltstone and impure limestone. There are also many bands of grey shale and bituminous shales. The finer grained bands exhibit complicated sedimentary structures. There are many examples of mud-cracked surfaces with sole marks and flow structures, together with beds showing turbulent flow structures and rolled clay galls. Signs of reworking of the sediments are common. There are also readjustment or accommodation faults with throws of a few millimetres to a few centimetres, together with micro and macro slump structures. Some of the shale bands contain altered, unidentifiable organic material, and there are abundant fossil fish in some bituminous shales. The whole succession indicates deposition in a shallow unstable basin.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Cretaceous marine succession

After the deposition of the Muribeca Formation there was a regression of the sea followed by a short period of erosion. In the Upper Aptian the sea invaded the southern part of the basin as far north as the Rio São Francisco. North of this in most of the State of Alagoas there was no further deposition until late Tertiary (Pliocene?). The marine rocks of Sergipe consist mainly of thick limestones with some sandstone and shale and they exhibit many lateral facies variations.

Riachuelo Formation. Drilling by Petrobrás shows that the Riachuelo Formation rests unconformably on the Muribeca, although this cannot be demonstrated from field evidence. The Angico Member occurs chiefly near the base of the sequence and towards the western margin of the basin. It consists mainly of a very fine-grained friable sandstone which may be either well-bedded or massive. There are a few thin intercalations of limestone in which a number of pelecypod shells have been found. A few reef-like structures are also found in this formation. Near Riachuelo the sequence starts with a conglomeratic sandstone followed by a limestone marked by the occurrence of giant pisoliths and siltstone which in turn is followed by a friable sandstone.

South of Riachuelo there is a bed of shelly limestone containing many broken shells and a peculiar assortment of terriginous material consisting of fragments of granites, schists, gneisses, quartzites and others varying from well rounded to angular. It seems obvious that this accumulation was not far from the shoreline and it is suggested that the terrigenous material was carried by the roots of floating trees. This may be partly supported by the rare occurrence of carbonaceous and coaly material. Where an unfaulted contact can be seen, the Angico Member grades into the Taquari facies. This occurs to the east of the Angico outcrops and represents a slightly deeper water accumulation. It consists typically of an alternating sequence of shales and siltstones. In places (e.g. Fazenda Pati) the siltstone predominates and at others (e.g. Fazenda Matto Grosso) the shale predominates. Occasional thin beds of limestone occur within the sequence. At the top of the sequence, where the Taquari unit is overlain by the Maruim Member, there is a band of yellowish, clayey limestone, 12 to 15 m in thickness, containing some sand.

A considerable thickness (up to 600 m) of limestone of the Maruim Member occurs still farther to the east. Within the sequence, there are a few intercalations of clastic, terrigenous material. The limestones are typically oolitic, very fine grained and vary from fine bedded to massive. In a few places, e.g. Fazenda Matto Grosso, there is a dense white chalky limestone with many algal and pisolitic structures. The limestone is very pure being in places 99.5 to 99.8 % $CaCO_3$ and it is extensively quarried for a variety of purposes. The Aguilhada Member is a dolomitic facies of the Maruim Member.

Upper Aptian fossils have been reported by other workers. K. Beurlen (1970) has recorded *Epicheloniceras*? sp. (see plate 5) and *Diadochoceras*, and Schaller (1969) records *Cheloniceras* (?) sp. *Diadochoceras* (?) sp. and a species of *Deshayesites* (?) (which is problematical; see p. 83). The Albian contains a rich fauna including several species of *Puzosia*, *Douvilleiceras*, *Oxytropidoceras*, *Mortoniceras* and *Elobiceras* (see table 2 and plate 4).

Cotinguiba Formation. This formation is divided into three members on lithological grounds. The Sapucari, which forms the bulk of the formation, is unconformable both at the base and at the top. It consists of a very thick sequence of limestones, the maximum measured thickness being reported by Petrobrás as just over 1000 m. There are occasional thin argillaceous horizons of clay or shale, and locally near the base there are some conglomeratic sandstones.

In places near the base there is a shaley facies containing intercalations of thin mudstones, silts, clay and limestone. This varies in thickness from 0 to 100 m and is usually referred to as the Aracaju Member. Farther up in the sequence there are occasionally massive limestones, e.g. Laranjeiras Quarry (the Laranjeiras Member).

The Cotinguiba Formation rests with slight unconformity on the Riachuelo Formation and begins in the Lower Cenomanian with an association of *Sharpeiceras* sp., *Cymatoceras* sp. and *Metoiceras* aff. *ornatum* (Morrow). The presence of *Stoliczkaia* aff. *africana* (Pervinquière) in this association presents a problem (see p. 84). The Lower Turonian contains a large number of forms (see table 2 and plate 4) but as yet no fossils diagnostic of the Upper Turonian have been reported, although beds of Coniacian age containing *Prionocycloceras* aff. *guyabanum* (Steinmann), *Solgerites armata* (Solger) and *Eulophoceras natalense* Hyatt, follow without any obvious discordance.

Piaçabuçu Formation. The Piaçabuçu Formation is divided into two lithological units, the Calumbi Member which occurs chiefly in the south and the Marituba Member in the north. The Calumbi facies consists of a thick sequence of dark grey shales, up to 1800 m having been measured by Petrobrás. Near the base there are, locally, some very fine grained, yellow sandstones overlain by green, clayey shales. Higher in the sequence there are very rare thin horizons of limestone, silt and clay. The Marituba facies, which is almost entirely arenaceous, was not seen in this investigation.

The Piaçabuçu Formation rests unconformably on the Cotinguiba Formation and has been dated as Campanian to Lower Eocene (Schaller 1969, p. 80).

Post-Cretaceous sediments

Following the deposition of the marine Cretaceous rocks there was a complete withdrawal of the sea followed by a period of erosion. In late Tertiary times there was a widespread and relatively thick (up to 300 m) accumulation of continental rocks of the Barreiras Formation. The basin as such had ceased to exist by this time and the Barreiras transgresses over the borders of the basin on to rocks of the basement. The accumulation consists of variegated, multicoloured, fine to coarse sandstones which are only partially consolidated. Along the coast and the valleys of the major rivers there is an extensive development of alluvium and sands of Recent age.

Structure

The floor of the basin has been divided by faulting into a series of horsts and grabens. There can be no doubt that the major period of movement was pre-Carboniferous giving rise to basins of non-marine sedimentation in the down-faulted areas. During the period of non-marine deposition (Carboniferous to early Aptian) there was either no accumulation over the intervening horsts or what accumulation there was was eroded before the deposition of the Muribeca Formation.

The basin was, however, subjected to a number of later movements. The conglomerates at the base of the Batinga Formation would indicate that during the early Carboniferous the graben was slowly subsiding. Movement stopped during the accumulation of the Upper Batinga, but there was uplift and slight erosion (post-Carboniferous–pre-Permian?) before the deposition of the Aracaré.

The origin of the broken chert beds in the Aracaré is somewhat obscure. Tentatively it is suggested that deposition was in shallow water with the chert forming pene-contemporaneously (the diagenesis of the chert has not yet been investigated). Towards the close of the Aracaré there was further movement along the major fault planes resulting in uplift, erosion and slight warping. This movement was sufficient to break the thinner chert beds but not the thicker ones. The broken chert was then incorporated in the clay bands probably by incompetent flow. This period of movement was pre-Jurassic, probably Permian in age.

Sedimentation recommenced in the Upper Jurassic with the accumulation of the Bananeiras Shales and the sandstones of the Serraria Formation. The basin became unstable towards the close of the Jurassic and the movements continued during the early Neocomian producing the complicated structures in the Barra de Itiuba Formation (see p. 75). These structures resemble those of the Bima Sandstone (Albian–Cenomanian) of Nigeria where the slump structures have been attributed to local earthquake shocks (Jones 1962). The two formations are of different ages but it is suggested that the instability of the basin and the possible seismic activity may have heralded the onset of the fracture which separated the two continents. It should be noted that the separation had already started in the south.

Later in the early Neocomian the basin began to subside more rapidly and the increased movement along the major fault planes gave rise to the conglomerates of the Rio Pitanga Formation.

Throughout the remainder of the Neocomian there was a thick accumulation of limestone in the south particularly around the mouth of the Rio São Francisco. In the north in Alagoas, however, the limestones grade into the arenaceous and shaley beds of the Coqueiro Seco Formation. The shales become predominant towards the top and are bituminous. It seems certain that the upper member of the Morro do Chaves in Sergipe was contemporaneous with the Coqueiro Seco in Alagoas, judging from their stratigraphical positions, although there is no fossil evidence to support this. Thus it would appear that during most of the Neocomian the basin of deposition was a large inland lake, shallow in the north and deeper in the south.

The deposition of non-marine sediment was terminated by slight uplift of the whole basin at the end of the Neocomian. From this time onwards movements within the basin were small, involving only local warping, and the faulting was confined to readjustments with the throw of the faults rarely exceeding a few metres.

The first marine transgression occurred immediately after the erosion of the Morro do Chaves and Coqueiro Seco Formations; it has been dated tentatively as Lower Aptian. This was the most extensive transgression in Brazil and the sea invaded the entire basin. This is interpreted as the initial rupture of the African and South American continents in this locality, with the formation of a feature similar to the present-day Red Sea. However, either the connexion with the open sea was intermittent, or parts of the sea became isolated and landlocked (cf. the Afar, Ethiopia). The lowest member of the Muribeca Formation, the Maceió, consists of sandstones which may be coarse to conglomeratic interbedded with bands of shale and salt. In this newly formed sea there were probably a number of islands of pre-Cambrian as there is no lower Muribeca on the structural highs. The Ibura Member contains thick beds of evaporites which accumulated along the newly initiated coastline.

The deposition of the marine Riachuelo Formation marks the arrival of the 'protoatlantic' ocean in the Sergipe–Gabon area in the late Aptian–Albian. The floor of the basin was uneven and in the shallower portions near the coastline the Angico facies developed while the Taquari developed in the deeper parts. Coral and algal reefs developed on some of the shallower portions.

No reefs have been observed in the areas where the Maruim oolitic limestone developed. At the end of the Albian there was brief but marked regression with slight warping and erosion during which parts of the upper portion of the Maruim Member were dolomitized (the Aguilhada member).

Sedimentation began again in the Lower Cenomanian, but the sea did not transgress so far inland as previously. From this time until about the middle of the Eocene, when the sea finally retreated from the Sergipe area, there was a progressive regression towards the south-east. There were, however, minor fluctuations of the coast line as shown by the occasional over-laps in the sequence, one major transgression in the Paleocene, demonstrated by the presence of the Marituba Member in southern Alagoas, and a hiatus during the Santonian. This sequence of events could be attributed to minor oscillations of the land masses during and immediately after the final rupture of the continents and the progressive widening and deepening of the 'protoatlantic' ocean.

3. Comparison of Gabon and Sergipe–Alagoas Basins

(*a*) *The non-marine sequence*

As may be seen from table 7 both regions have been areas of deposition from at least Permian and probably Carboniferous times. Structurally both are in the form of 'half' grabens with minor horsts within the boundary faults. In the Gabon Basin the lowest sediments, the M'Kohm Formation, are of glacial origin, considered (Michelot, Molenas & Penet 1970) to be moraine infillings of glacial valleys. These glacial deposits rest directly on pre-Cambrian rocks and contain boulders of gneiss and granite and they represent the most northerly extension of the Permo-Carboniferous glaciation of Gondwanaland. In the Sergipe–Alagoas Basin there is no sign of any glacial material in the basal Batinga Formation, unless the dark and light grey, banded siltstones of the Boacica Member could be considered glacial varves. The Batinga Formation is very poor in fossils but has been dated as 'Neocarboniferous' from a few foraminifera (Schaller 1969). The M'Khom Formation has been dated as Carboniferous from a few plant remains (Michelot *et al.* 1970).

These basal beds are followed in Brazil by the Aracaré Formation and in Gabon by the Agoula Formation. The lithology of these two formations is largely different but there are similarities. The Agoula is much more arenaceous and contains a little salt, pisolitic dolomites, glacial material and frequent signs of desiccation which are not present in the Aracaré. However, both formations are characterized by frequent occurrences of chert (see p. 78). The Aracaré has been dated as Permian from Foraminifera and the Agoula as Lower Permian from the microflora (see table 7).

Before the close of deposition, earth movements affected both areas culminating in uplift, followed by a long period of erosion as in neither area are there any sediments of Triassic or Lower Jurassic age.

Sedimentation appears to have started simultaneously in both basins in the Upper Jurassic. Again there are lithological differences. The M'Vone Formation in Gabon is composed mainly of coarse sandstone with some marls which could be compared with the Candeeiro Formation in Brazil. The Candeeiro Formation is, however, of very restricted occurrence and is only known from borehole information (Schaller 1969). In both basins, however, the sediments grade upwards into formations which are lithologically comparable. The N'Dombe Formation in Gabon grades upwards from coarse sandstones through variegated shales to further sandstone, felspathic sandstone and shale. The Serraria is mostly coarsely arenaceous material with a few reddish shale bands containing some carbonaceous material. The fauna of these Brazilian and Gabonese formations is markedly similar and dates them as Upper Jurassic (de Klasz 1965).

The succeeding non-marine rocks in both basins are varied and it is difficult to make lithological comparisons This is not unexpected as within each individual basin there are rapid

Table 7. Correlation between the formations of the Non-Marine Succession in Sergipe–Alagoas and Gabon

	Sergipe–Alagoas	Gabon
L. and M. Aptian	Muribeca	U. Cocobeach
Neocomian	Ponta Verde Coqueiro Sêco Morro do Chaves	M. Cocobeach
	Penedo Rio Pitanga Barra de Itiuba	L. Cocobeach
U. Jurassic	Serraria Bananeiras Candeeiro	N'Dombe M'Vone
Permian	Aracaré	Agoula
Carboniferous ?	Batinga	M'Khom

facies changes and there is still some confusion over chronostratigraphical correlations. However, the Lower Cocobeach in Gabon is similar to the Barra de Itiuba in Brazil. The sandstones are well exposed and in both basins exhibit false bedding with many slump structures and local unconformities, indicating shallow water and instability. There is, in addition, a marked similarity between the fauna of the two basins. Remains of fish are found for the first time in the sequence in Brazil (see p. 74). Similarly, in Gabon remains of *Lepidotus* are found (Michelot *et al.* 1970). There is a pronounced similarity between the non-marine ostracods as has been demonstrated by Krömmelbein (1966). A close relationship between the ostracod assemblages in both basins is maintained throughout the remainder of the non-marine sequence. However, much work remains to be done in comparing other groups of fossils and it would be unwise at this stage to draw any further conclusions.

The non-marine sequence in Gabon is terminated by a discordance beneath the salt-bearing Upper Cocobeach. This is mirrored in Sergipe by a discordance beneath the Muribeca Formation. However, in Alagoas, near Maceió, the marine transition beds appear to lie conformably on the Ponta Verde Formation, but the nature of the junction has been complicated by subsequent faulting.

To conclude, it is considered that the many similarities between the structure, lithology and palaeontology of the Gabonese and Sergipe–Alagoas Basins give a strong indication that until the Neocomian they formed parts of a single landlocked basin of deposition. The differences between them are no more than would be expected between parts of any large basin of deposition. The reconstruction of the Lower Cretaceous locations of South America and Africa,

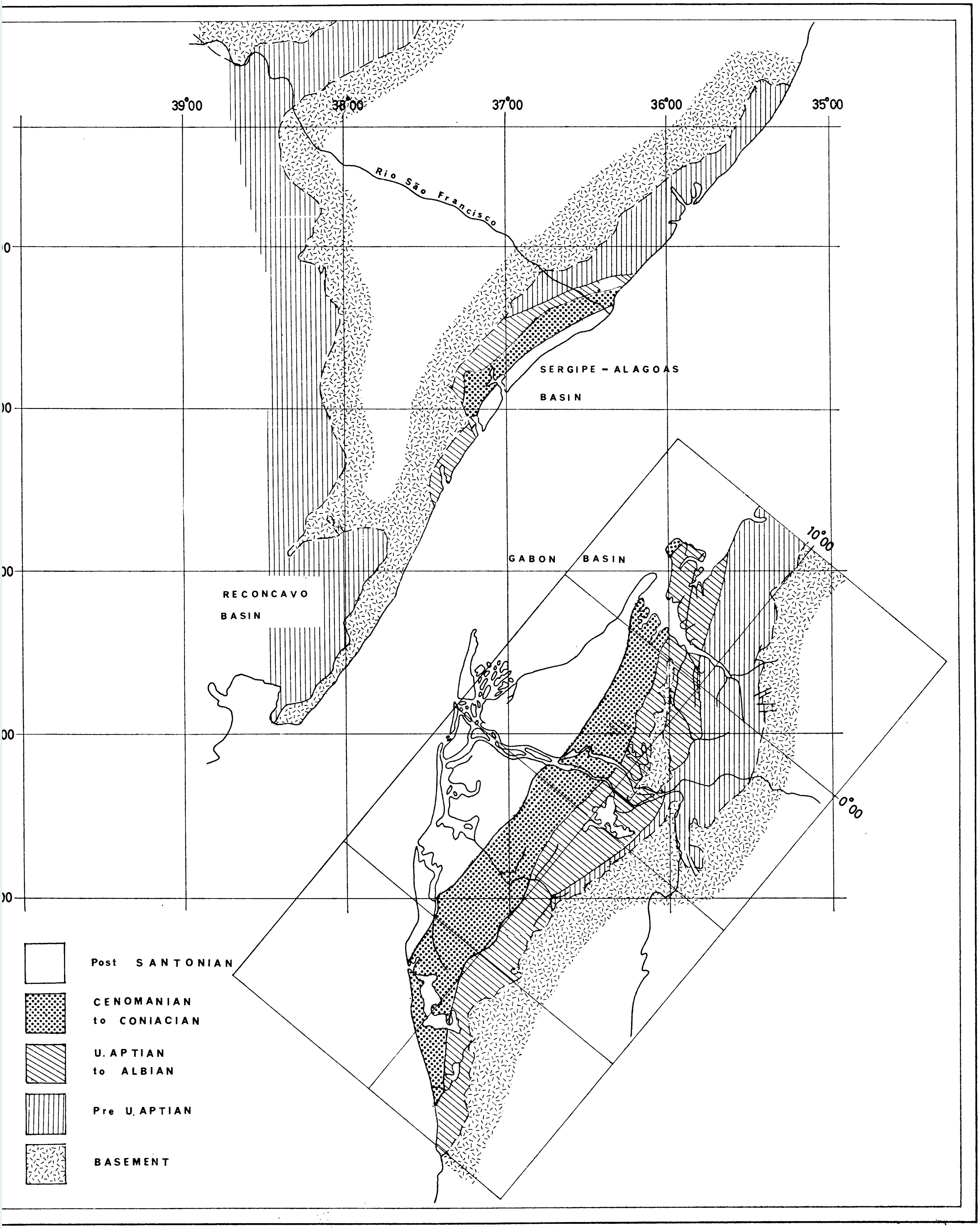

FIGURE 5. Reconstruction of the relative geographical positions of the Sergipe-Alagoas and Gabonese Basins prior to the Aptian (based on Bullard *et al.* 1965). The present-day stratigraphy within each basin is shown with the omission of post-Cretaceous rocks.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

based on Bullard *et al.* (1965) and given in figure 5, indicates that the northern part of the Gabonese basin and Sergipe have lain roughly opposite each other, which would agree with our conclusion.

(*b*) *The marine sequence*

Owing largely to the paucity of exposures in the Gabonese Cretaceous, our knowledge of the ammonite successions of that country leaves much to be desired.

Table 8. Correlation between the formations of the Marine Succession in Sergipe–Alagoas and Gabon

	Sergipe–Alagoas	W. Gabon	E. Gabon
Eocene	Piaçabuçu	Mandji	
Paleocene	Piaçabuçu	Mandji	Namino
Maastrichtian	Piaçabuçu	Port Gentil	N'Goumbi
Campanian	Piaçabuçu	Pointe Clairette	Komandji
Santonian		Pointe Clairette	Komandji
Coniacian	Cotinguiba	Pointe Clairette	Milango
Turonian	Cotinguiba	Azilé	Sibang
Cenomanian	Cotinguiba	Cap Lopez	Série Rouge
Albian	Riachuelo	Madiéla	Madiéla
Aptian	Muribeca	Série Salifère	

As has been pointed out elsewhere, the marine Cretaceous in both basins begins with a transitional sequence characterized by extensive deposits of evaporites which occur in several well-defined zones and are generally accepted as being of Aptian age, although there is no actual fossil evidence for this. De Klasz (1965, p. 284) mentioned the occurrence of globigerinids in the sediments below the salt deposits in Gabon. These sediments are intercalated with freshwater beds indicating that, in this region, the main period of salt accumulation was heralded by at least one, shortlived incursion of the sea. In Brazil the principal salt deposits occur well up in the sequence (Ibura Member, table 5). In the north, in Alagoas, the evaporites are underlain by up to 2000 m of a mixture of marine and non-marine sediments. Near the base (Maceió Member) there are several thin beds of salt. In Sergipe the basal members (Maceió and Tabuleiro dos Martins) do not occur. It would appear that the first marine invasion was of a periodic nature along a narrow cleft, the floor of which had considerable relief leaving a number of emergent islands. Also the sedimentary structures, etc. (p. 75) indicate that the deposition throughout was in a shallow, unstable basin. The evaporites have given rise to a pattern of salt tectonics which has greatly complicated the stratigraphy.

The fossil content of this sequence is poor, consisting of a few non-marine ostracods (Cytheridea), pollen, casts of fish and some unidentifiable plant material. As has been said, this is far from diagnostic, but is generally considered to be of Aptian age.

The transitional sequence was followed by the development of marine conditions and the accumulation of limestones. The earliest part of this transgression has been dated as Upper Aptian (e.g. de Klasz 1965, p. 285) on the evidence of an ammonite, referred to a species of '*Deshayesites*' (see p. 59). '*Deshayesites*' has been recorded from other parts of the Southern Atlantic realm, such as Spanish Guinea (de Klasz 1965, p. 284) and Sergipe, Brazil (Schaller 1969, p. 71) and referred to Upper Aptian. These are most likely to belong to *Dufrenoyia* or *Neodeshayesites*, if they are deshayesitids at all. The Lower Cretaceous marine fossiliferous deposits of Gabon are referred to as the Madiéla Formation, characterized by carbonates, with lagoonal intercalations and gypsum beds mainly in the eastern extremities of the sedimentary basin. The marine sequence in Brazil also begins in Upper Aptian in which Beurlen (1970) has recorded *Epicheloniceras* sp. (plate 5) and *Diadochoceras*, also an Upper Aptian cheloniceratinid. The marine Aptian and Albian of Sergipe are grouped lithostratigraphically under the name Riachuelo Formation.

No upper Aptian fossils were found during our field programme, but we were able to collect and follow the Lower Albian fauna, which is rich in numbers although poor in species. The most characteristic element of this fauna is the ammonite genus *Douvilleiceras*, species of which have also been reported from Angola and Gabon, although not from Nigeria. The forms from Gabon have not been figured and it is difficult to make specific comparisons. However, *Douvilleiceras orbigny* has been recorded from Angola (Howarth 1965) and this species was also found by us in Sergipe. *D. aequinodum*, from Angola (Howarth 1965) appears to differ from *D. offarcinatum* (plate 4) found in Sergipe, and recorded from Gabon (de Klasz 1965). The occurrence of these ammonites proves the presence of the zone of *Douvilleiceras mammillatum* in Sergipe, Angola and Gabon.

De Klasz (1965, p. 285) recorded *Oxytropidoceras*, a genus characteristic of the Middle Albian, and *Hysteroceras* from borehole samples taken near Port Gentil, Gabon. The material has not been figured and it is, therefore, not possible to compare with the Brazilian species of *Oxytropidoceras* of which there are several including *O.* aff. *bravoense* Böse and *O. buarquianum* (White) (plate 4). A species related to *Oxytropidoceras bravoense* Böse occurs, together with several other species, in the oldest marine Cretaceous rocks of the middle Benue Valley of Nigeria (Reyment 1965). None of the South American species, has, however, been found to be conspecific with those of West Africa.

In West Africa the Upper Albian is marked by several species of *Elobiceras* and characteristic mortoniceratids, in particular species of the genera and subgenera *Mortoniceras* (*Mortoniceras*) and *Mortoniceras* (*Angolaites*). In Sergipe *Elobiceras* is common, together with *Mortoniceras* (plate 4, and table 2). The assemblage is typical for the zone of *Mortoniceras inflatum* as interpreted in West Africa.

The classical locality of the Elobey Island, west of Cocobeach in northernmost Gabon, has yielded several elobiceratids, but de Klasz (1965) did not mention having identified *Elobiceras* or other elements of the fauna in subsurface samples from farther south in the Gabonese sedimentary basin. It is of interest to note that limestones are important constituents in the Albian sequences of Sergipe and Gabon, which hinders the erection of a micropalaeontological correlation scheme (de Klasz 1965, p. 285) because of the difficulty of extracting microfossils from this rock.

The zone of *Mortoniceras inflatum* does not mark the top of the Albian, and there is, in the international zonal scheme, a final zone at the top, namely, that of *Stoliczkaia dispar*. As pointed out by Howarth (1965, p. 342), *Stoliczkaia* was first noted in the South Atlantic region from

Angola and that the stratigraphical location of the species concerned is above the beds with *Mortoniceras*. A subsequent find of *Stoliczkaia*, together with Cenomanian ammonites, was made in Angola, and although the field evidence is in some doubt, there is a strong possibility that the specimen is autochthonous and thus of Cenomanian, albeit Lower Cenomanian, age. *Stoliczkaia* occurs in Eastern Nigeria, but here there is no doubt of the late Albian age of the occurrence as it is associated with *Mortoniceras* (*Durnovarites*). A short distance north of Aracaju, near Itaporanga, we collected a *Stoliczkaia* (plate 4) (related to, but not specifically identical with, the Nigerian species) in an association of Cenomanian ammonites: *Sharpeiceras* (plate 4) and *Metoicoceras*, as well as *Cymatoceras* sp. The host rock differs entirely in lithological aspect from the sediments of the Riachuelo Formation and must be placed with the Cotinguiba Formation, which is marked by well-bedded marls (Sapucari member) and massive limestones (Laranjeiras member), in all about 800 m of calcareous sediments. Consequently, considering the fact that the Cotinguiba Formation rests with a slight unconformity on the Riachuelo Formation and the undoubtedly Cenomanian association of the *Stoliczkaia*, the most logical conclusion is that the Cotinguiba Formation begins in the Lower Cenomanian. Another outcrop of the formation yielded a good specimen of the Cenomanian *Acanthoceras* cf. *quadratum* Crick (plate 4) and a few unidentified pelecypods. Our results, therefore, hardly support Schaller's contention (1969, p. 79; but see p. 53 in the same paper) that the uppermost part of the Riachuelo Formation is Cenomanian.

Beds of Cenomanian age in Gabon have been named 'La Série Rouge' and 'La Série du Cap Lopez' (table 1). De Klasz (1965, p. 286) has noted that the regressive phase of the uppermost part of the Madiéla Formation passes into these two formations which consist largely of limestones and shales and from which no ammonities have as yet been recorded.

Perhaps the best represented stage in Brazil, from the point of view of the ammonites, is the Turonian. Beurlen has in many publications (summarized in K. Beurlen 1970) remarked on the similarities of the West African and Sergipian Turonian, and G. Beurlen (1969) has figured several of the more common Turonian to Coniacian forms (see also plate 5). K. Beurlen (1970) refers to the Lower Turonian as being a time of transgression. This contention can hardly be supported in terms of a transgression normal to the shoreline, for Lower Turonian has not been shown to overlap Albian, though there are slight local overlaps of the Cenomanian. We do not believe that Beurlen thought of the Turonian expansion of the sea as a transgression inland in Sergipe but rather in terms of a northern extension, peripherally along Pernambuco, and thus with a greater extent than the Upper Albian sea (Beurlen 1970, p. 254). Our observations in Sergipe suggest that from Cenomanian onwards there was a gradual regression towards the centre of the basin (see p. 79).

The Lower Turonian of Sergipe seems to be complete containing, in the lower part, species of the ammonite genera *Pseudaspidoceras*, *Vascoceras*, *Pachyvascoceras*, *Bauchioceras*, *Wrightoceras*, *Gombeoceras* and *Coilopoceras*, and, in the upper Lower Turonian, species of *Mammites*, *Kamerunoceras*, *Benueites*, *Hoplitoides*, *Neoptychites* and *Glebosoceras* (table 2). In Gabon, on the other hand, macrofossils are mainly confined to the Sibang Limestone, in the eastern part of the basin, and these include one species of *Wrightoceras* and one of *Bauchioceras*, together with *Inoceramus labiatus* (de Klasz 1965), a typically lower Lower Turonian association. The Sibang Formation is essentially a calcareous sequence, but it is reported to contain occasional non-marine, lagoonal intercalations, a reflexion of its near shore origin. In this eastern part of the basin the upper Lower Turonian and Upper Turonian are missing, or at least have not yet been proved to be present.

In the western part of the basin, the Azilé Formation, a lateral equivalent of the Sibang Formation, is of fully marine origin, consisting lithologically of shales which contain microfossils, but no macrofossils. It is considered that the Azilé Formation is Lower Turonian in age.

The Turonian rocks of Gabon are overlain with slight discordance by the Milango and Pointe Clairette Formations which are of Coniacian age. The Milango Formation consists of shales and bituminous shales and contains a characteristic ammonite fauna, including species of *Peroniceras*, *Gauthiericeras* and *Barroisiceras*; it is overlain conformably by the similar shales of the Komandji Formation. Upper Turonian has not been recorded from Gabon or Sergipe. It is possible that the Upper Turonian may be proved to occur above the beds with Lower Turonian fossils and below those with Coniacian species in the Cotinguiba Formation of Sergipe. Two Uppsala students, Peter and Suzana Bengtson, seem to have made such a discovery.

Beurlen (1969) recorded species of *Prionocycloceras*, *Damesites*, *Forresteria*? and *Protexanites* from exposures of the upper part of the Cotinguiba Formation. To this list may be added species of *Solgerites*, *Nowakites*, *Hauericeras*, *Eulophoceras* and *Peroniceras*?. This association is of particular interest in that although there is some relationship to the West African Coniacian assemblages, particularly those of Nigeria, e.g. *Solgerites*, *Forresteria* and *Peroniceras*, there are also marked differences, certainly greater than between earlier Cretaceous assemblages.

4. Faunal analysis

As has been shown, there are many problems concerning the distribution of Cretaceous molluscs in the South Atlantic region. Some of the questions concerning the faunal differences in the northern and southern regions of the South Atlantic were reviewed briefly in Reyment (1971*b*) but it is now necessary to analyse other aspects of this subject.

(*a*) *Distribution of the pelecypods and gastropods*

The upper Cretaceous pelecypod and gastropod faunas of the west coast of Africa are largely uniform (Freneix 1959), at least from the Turonian onwards. This is in itself not particularly noteworthy and it is paralleled in the past by the best-known Cretaceous foraminifer of West Africa, the Campanian–Maastrichtian *Afrobolivina afra* Reyment, which has been found to occur in abundance, from Senegal, through all the coastal sedimentary basins, to Angola (Castelain *et al*. 1962). Species of the foraminifer *Gabonella* have been recorded to range from Central Morocco to Angola (de Klasz, Marie & Meyer 1960), and there are several more examples in the pages of the *Revue de Micropaléontologie*.

Reyment (1969*b*) documented the occurrence of at least 20 species of Recent molluscs which occur along the entire west coast of Africa, and this list could be extended without difficulty.

(*b*) *Distribution of the ammonites*

For some time now, the restriction of the elobiceratids to the southern Atlantic realm and southeastern Africa has attracted attention. (Reports of *Elobiceras* from the European Albian do not stand up to close inspection; they are usually notched derivatives of *Mortoniceras*, and the Texan 'elobiceratids' have been placed in a separate taxonomic category, *Craginites* (cf. Perkins 1960)).

The enigmatic distribution of the vascoceratids and the group of species around *Bauchioceras* s.l. cannot be explained by normal palaeobiogeographical considerations, as was tried by Freund

& Raab (1969, p. 75). The upper Lower Turonian genus, *Benueites*, and associated fauna, display a completely different mode of geographical distribution from that of the ammonite species of the basal Turonian.

The nature of the problem can be well illustrated by a simple quantitative analysis using the so-called *index of biotal dispersity* of Koch (1957) on species lists of the Albian and Turonian for Morocco (Rio de Oro Basin) and Nigeria, Gabon, Brazil. This index is defined as follows: if there are n lists of species, each of which contains $s_1, s_2, \ldots, s_n$ species, the total number of species recorded is S; then

$$T = \sum_{i=1}^{n} s_i,$$

and the index is

$$\text{B.D.} = \frac{100(T-S)}{(n-1)\,S}.$$

Table 9 demonstrates the relationships between the two regions for numbers of known species in the Upper Albian and upper Lower Turonian of the two parts of the Atlantic.

Table 9. Comparisons of species lists for Nigeria–Gabon–Brazil against Morocco

age	area	number of species in each area	total number of different species	B.D.
Upper Albian	Nigeria–Gabon–Brazil	$s_1 = 37$	63	1.6
(*inflatum* zone)	Morocco	$s_2 = 27$		
Upper Lower Turonian	Nigeria–Gabon–Brazil	$s_1 = 22$	26	50.0
(*benueensis* zone)	Morocco	$s_2 = 17$		

The widely different values for the index of biotal dispersity for the two regions are noteworthy and can hardly be ascribable to pure chance. The very low value for the Upper Albian indicates that there was virtually no contact between the two areas during this time. The high value for upper Lower Turonian shows that the seaways must have been open and unhindered by then. From this time onwards to the Coniacian all the evidence points to free connexions between the southern and northern Atlantic oceans and also with the Pacific and not a few of the Coniacian ammonities occur in Columbia, Peru, Brazil and North Africa.

(*c*) *Ostracoda*

The ostracod *Brachycythere sapucariensis* Krömmelbein was first recorded from the Turonian of Sergipe, Brazil, and then subsequently from the Lower Turonian of Gabon. It was later found in the Lower Turonian of eastern Nigeria and most recently in the Turonian of Rio Grande do Norte, Brazil. An extensive survey of the ostracod faunas of Nigeria, Gabon, and northeastern Brazil undertaken by Reyment in 1970 showed that as far as the Maastrichtian and the Paleocene are concerned, the faunas show different species components and the wide occurrence of a particular species in the Upper Cretaceous on both sides of the Atlantic is interesting, bearing in mind the low dispersal potential of benthonic ostracods.

5. The marine connexion across North Africa

In late Cenomanian and early Turonian time a marine connexion existed between the South Atlantic and the Tethys by way of a transcontinental sea across North Africa. This provided a means of faunal communication with the Tethyan area before the Atlantic Ocean had finally opened.

As has already been pointed out, the agreement between northeastern Nigeria and the Niger Republic in the Lower Turonian is slight at the species level but good at the generic level. Thus both areas contain species of *Nigericeras*, *Paravascoceras*, *Paramammites*, *Vascoceras*, *Pachyvascoceras* as well as a few other genera of lesser importance, but only two identical species. Significant also in this connexion is the fact that Nigerian Lower Turonian ammonites have been found in Israel (Freund & Raab 1969), Spain (Wiedmann 1960, 1961), and possibly in Texas and Mexico (Powell 1963).

There is also a relation between the Saharan faunas and some vascoceratids described by Benavides-Càceres (1956) from the Lower Turonian of Peru, although claims to specific identity that have been made recently may be a little venturesome.

The vascoceratids of the Iberian peninsula have long been known, and in fact the group was first recognized in this region. It is interesting to observe that although the majority of the species described and listed by Wiedmann (1960) are North African and West Mediterranean, a few Nigerian and Saharan species also occur. The migration of these ammonites seems to have taken place while the Tethys was connected to the South Atlantic by the transcontinental sea. Barber (1958) figured pelecypods from northeastern Nigeria which are also known from Niger Republic and North African (Schneegans 1943).

6. Summary and conclusions

(*a*) *General*

A comparison of the geological histories of the Sergipe–Alagoas and the Gabonese Basins reveals a number of remarkable similarities which demand a rational explanation. The criteria which have been used to correlate the non-marine sequences, are of course, suspect and can be interpreted in a variety of other ways. However, we consider it reasonable to suggest that the pre-Aptian geology of these two areas is consistent with both being part of one large basin, although this on its own does not constitute a proof.

The biostratigraphy from the Cretaceous onwards is of particular significance and the results of our analysis may be summarized as follows.

(*b*) *The Neocomian*

The first widespread Neocomian transgression in the southern Atlantic covered southern Argentina, southern Chile and the southern tip of South Africa during the Upper Valanginian (figure 2). At the same time as this transgression took place, there were freshwater lakes of considerable size at various sites along a possible rift-like structure, stretching from Angola to Gabon. The ostracod microfauna of Gabon is similar to that of the Recôncavo Basin in northeast Brazil with a great number of species in common. There are many common species of pollen (of 39 morpho-groups of pollen and spores, 34 are common to the Brazilian and Gabon/Congo basins (Freake 1966)). Remains of freshwater fish are found in both areas. There are also striking similarities in the lithology of some of the Gabonese and Bahian Neocomian Formations (Allard & Hurst 1969; Fonseca 1966). As Martin (1968, p. 43) has pointed out, it is difficult to see how 5000 m of non-marine sediments could have been deposited in the subsiding Recôncavo–Tucano graben without marine ingressions, if there had been a Neocomian Atlantic Ocean.

(c) *The Aptian*

Marine Upper Aptian has been documented for the west coast of Africa from Angola to Gabon and, in Brazil, for the Province of Sergipe. In all these places the Aptian is characterized by the occurrence of extensive evaporite deposits of almost identical or closely similar development. This could be coincidental, proving only that several non-marine basins of deposition were subjected to a marine transgression through transitional beds, at the same time in latitudes where one would expect evaporites to accumulate. Belmonte, Hirz & Wenger (1965), and many others, have drawn attention to the fact that much of the salt is found today on the continental shelves of both continents and the conditions of deposition strongly suggest that each of these areas was separated from the open ocean by some form of barrier. It would be difficult although not impossible, to explain the nature and locations of these barriers assuming the present-day configuration of the continents, but if the reconstruction given in figure 5 is accepted then the implication of these barriers becomes minor. The developing Atlantic ocean would then structurally, be a relatively narrow rift or graben containing a number of subsidiary horsts.

(d) *The Albian*

Lower Albian with species of *Douvilleiceras* occurs in Brazil, Gabon and Angola, but not in Nigeria. In Nigeria the oldest marine beds belong to the Middle Albian, the faunal content of

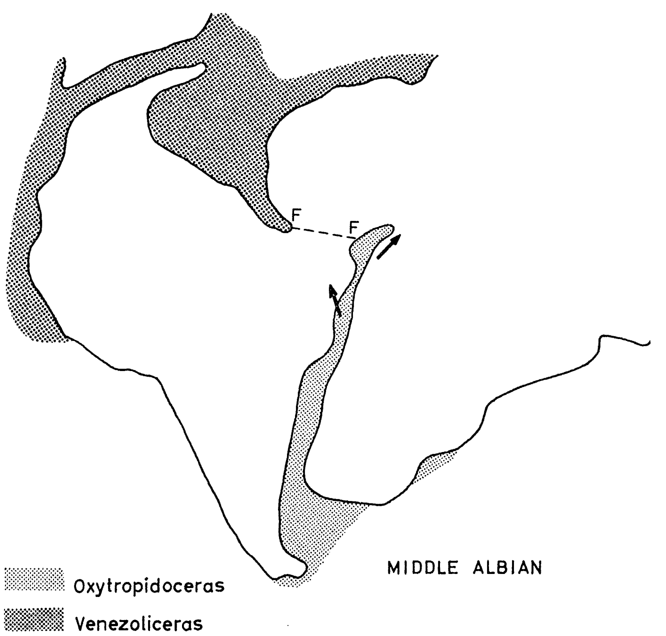

FIGURE 6. The Middle Albian transgressions (arrows) in the southern protoatlantic. Two distinct faunal provinces existed in the northern and southern limbs of the protoatlantic.

which resembles, but is not identical to, that of Sergipe, Brazil. Fossil evidence in the Lower and Middle Albian is too scanty in the southern Atlantic region to permit more than general statements, and it is only in the Upper Albian that ammonities for the first time become sufficiently numerous, and the faunas sufficiently characteristic, to permit more widely based conclusions. Although the generic aspect of all Albian faunas of the northern and southern Atlantic realms and the Caribbean and adjacent Pacific are much the same, allowing for subgeneric differences here and there, the species aspects are different. The South Atlantic appears to have been isolated from the northern ocean, a reflexion of which is the restriction of *Elobiceras* s.str. to this area (figures 6, 7).

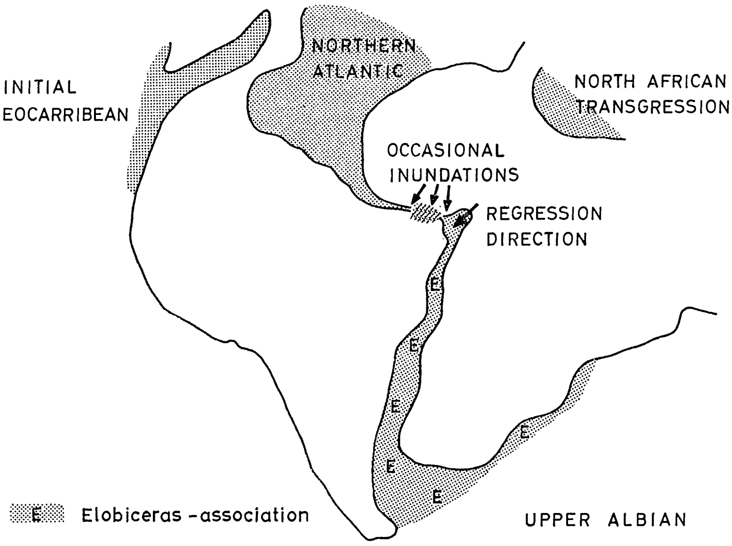

FIGURE 7. Deduced palaeogeographical relationships for the South Atlantic during the later Upper Albian. The right arrow marks the regression that took place in the Gulf of Guinea from late Middle Albian to Cenomanian. The left arrows denote a short-lived epicontinental transgression from the South Atlantic.

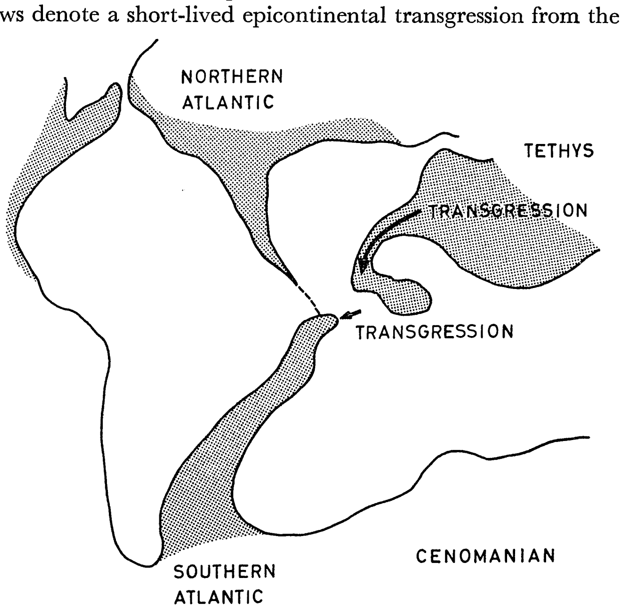

FIGURE 8. Reconstruction of the relative positions of South America and Africa during late Cenomanian time. The northern and southern parts of the South Atlantic constituted different molluscan faunal provinces. A third, Tethyan, molluscan faunal province existed in the shallow North African epeiric sea. The arrows denote sites of rapid advance of the shallow seas on the African continent.

(*e*) *The Cenomanian*

As far as can be ascertained from the fossils of Cenomanian age in the southern Atlantic, the species affinities appear to be local. An interesting anomaly is the lack of the Upper Cenomanian ammonite genus *Neolobites* throughout the entire region (figure 8). Species of this genus occur in North Africa, Spain and the Sahara as far south as Niger Republic, but not

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

northeastern Nigeria. It is significant that *Neolobites* does not occur in the Cenomanian of Tarfaya, Morocco (Collignon 1966).

(*f*) *The Turonian*

We have demonstrated how a shallow epicontinental sea spread across North Africa, beginning in late Cenomanian time and existing into Lower Turonian, after which it once again broke up into northern and southern arms and gradually regressed (figure 9). During the short

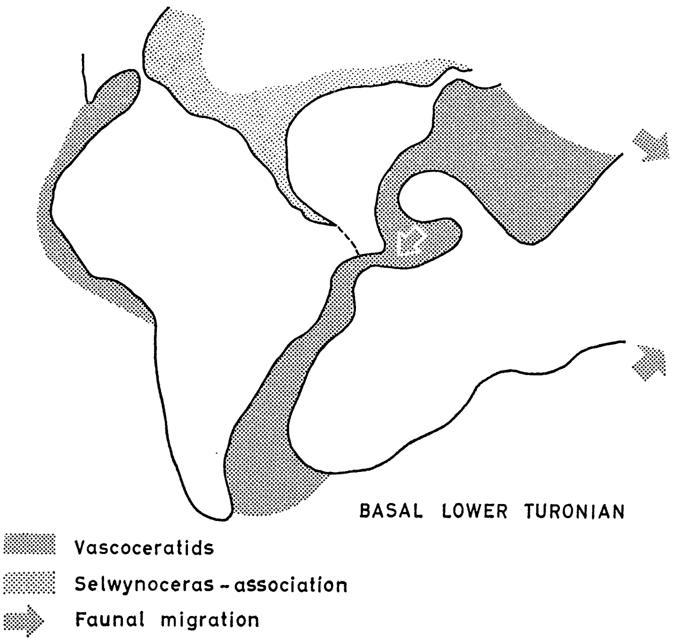

FIGURE 9. Reconstruction of the palaeogeography of the South Atlantic region during the lower part of the Lower Turonian. The existence of a shallow transcontinental sea across northwestern Africa during this part of the Cretaceous permitted an interchange of faunas between the Tethys and the southern limb of the proto-atlantic. The region is marked faunistically by two distinct ammonite associations, the one largely of Tethyan origin, and characterized by vascoceratids; the other displays North American affinities. The arrows in the diagram indicate molluscan migrational ways.

time the Tethys was united with the South Atlantic, vascoceratid and pseudotissotiid ammonites were able to migrate from one region to the other. The palaeobiological evidence suggests that the vascoceratids almost certainly spread from north to south. After the connexion was broken during the later part of the lower Turonian, the now isolated vascoceratids of the South Atlantic arm evolved separately to produce local developments, some of which migrated around the southern tip of South America and spread as far as Peru and Mexico.

The southern Atlantic vascoceratids do not, however, occur in the sedimentary basins of Brazil north of Pernambuco. In fact the Turonian of Rio Grande do Norte shows closer affinities with Mexico and Texas (Beurlen 1961 *a*) than with the region immediately to the south. The southern Atlantic molluscan species do not occur in the Caribbean, the coastal sedimentary basins of West Africa north of Nigeria, nor in Spain nor Portugal. This fact was recognized by K. Beurlen (1961 *a*, 1964, 1969), who promoted the idea of some form of land barrier which he related to the continental drift hypothesis. This seems to us to be a reasonable explanation, but one that is not without certain difficulties. For example, when one recalls that 'Portuguese' vascoceratids have long been known from Mexico (Böse 1918), why does one not find North African and Iberian vascoceratids in the Lower Turonian of the Rio de Oro Basin of Morocco? An explanation for this anomaly, and others in the distribution of molluscs in the coastal sedimentary basins, was suggested by Reyment (1969*a*), who pointed out that the shallow transgressions around Africa and South America can be interpreted by recourse to a hypothesis of tilting of the continental blocks. The geophysical background of this hypothesis still remains to be worked out and one of the principal objections to the idea seems to us to be the difficulty of reconciling the relatively thin sialic crust with the tensile strength required to allow for tipping even on the

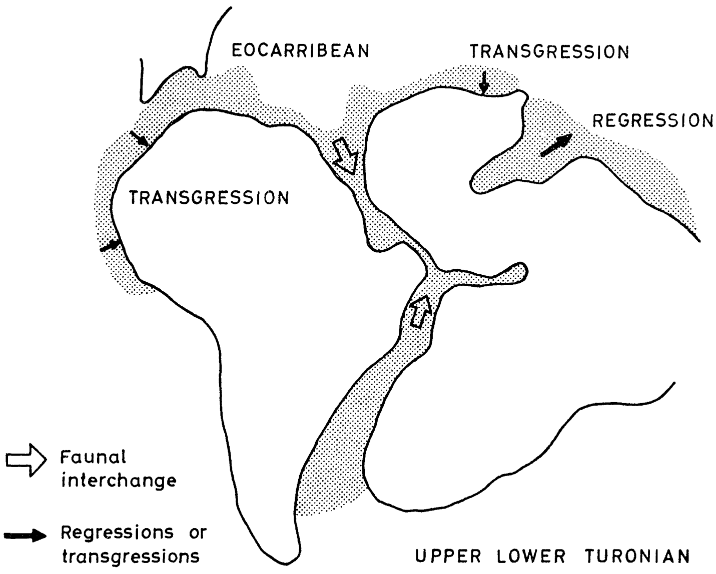

FIGURE 10. Reconstruction of the relationship between South America and Africa at the time of the break between the continents and the opening of the South Atlantic Ocean. The transcontinental Saharan sea has broken up and the remnants of it exist as deep gulfs reaching inland in West Africa and North Africa. The open, broad arrows denote directions of faunal migration. The closed, thin arrows denote sites at which important transgressions and regressions were taking place.

small scale required. Adherents of the concept of plate tectonics now postulate a much greater thickness of sialic crust beneath the continents (more than 200 km has been suggested); this, if true, would add credence to the tilting hypotheses. A plausible mechanism for the regulation of transgressions and regressions based on alterations in the total volume of the ocean basins has been suggested by Menard (1969) and Valentine & Moores (1970). The field observations on the transgressions and regressions seem to indicate that when a transgression was taking place along one part of the coastline, a regression occurred along the opposite coastline. In order to obtain more conclusive evidence for this hypothesis, Reyment (1971*a*, *b*) simulated the transgressional history of the African coastlines during the Cretaceous by use of models.

We have just discussed the basal Turonian and the problems concerning the distribution of the vascoceratids. The next major subdivision of the southern Atlantic Turonian is marked by the occurrence of *Benueites* and its associates. The *Benueites* association has been identified in the Cretaceous of the Mungo River, Cameroun, Nigeria, Brazil, Trinidad, Peru, Columbia and Morocco (Tarfaya) (Reyment 1971*c*). As shown on p. 86, the index of biotal dispersity for the benueitan association, reckoned between the southern Atlantic and Morocco, is about 50 times the value obtained for the Upper Albian (*inflatum* zone) associations. This is an overwhelmingly great difference and must reflect a radical change in the palaeogeographical conditions in the Atlantic Ocean (figure 10).

The most reasonable explanation of these faunal distributional patterns seems to us to lie in the interpretation offered by the theory of continental drift.

7. Reconstruction of the events connected with the origin of the South Atlantic

Some time during the pre-Cretaceous a rift developed in the centre of the Amero-African landmass. The intrusion of the Younger Granites of Nigeria and the Sahara began to take place in the Middle Jurassic (Jacobson, Snelling & Truswell 1963) and this culminated during the Upper Cretaceous in Cameroun and Pernambuco, Brazil (Almeida & Black 1966; see also Petrascheck 1968). Inland lakes developed in subsiding depressions in the rift valley. During the Upper

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Figure 11. Part of the Sergipe–Alagoas basin, Brazil. Rock type and fossil locality map. (Geology based on various Petrobrás maps). The Barreiras Formation (Pliocene) and Recent alluvium, sands and gravels have been omitted.

6	Oolitic Limestone. Marium Mb, Riachuelo Fm.
7	Pisolitic Limestone. Marium Mb, Riachuelo Fm.
8–12, 1/22, 1/30	(Carapeba Quarry) *Elobiceras intermedium* (Spath). *E. lobitoense* Spath; *E. elobiense* (Szajnocha); *E. subelobiense* Spath; *Plicatula modioloides* White.
13–16	Pisolitic Limestone. Angico Mb, Riachuelo Fm.
18, 19	Dolomitic Limestone. Aguilhada Mb, Riachuelo Fm.
20	Green Shales. Calumbi Mb, Piaçabuçu Fm.
22*a*, 23	*Micraster* spp.
24	Limey shales. Aracaju Mb, Cotinguiba Fm.
25	Algal limestone. Taquari Mb, Riachuelo Fm.
26, 27	Coral limestone. Taquari Mb, Riachuelo Fm.
28	*Turritella* sp.
29–36, 1/23	(Laranjeiras Quarry). *Pachyvascoceras hartii* (Hyatt).
2/28	*Coilopoceras discoidum* Barber; *Hoplitoides ingens*. (von Koenen); *Benuites benueensis* Reyment; *B. spinosus* Reyment; *Mammites chouberti* Collignon; *Glebosoceras glebosum* Reyment; *Neoptychites telingaeformis* Solger.
37, 38, 3/22	*Oxytropidoceras* sp.; *O.* aff. *bravoense* Böse; *Puzosia* sp.
39–41, 3/28	*Mortoniceras* (*Angolaites*) *gregoryi* (Spath).
1/19	*Solgerites brancoi* (Solger); *Peroniceras*? sp.
2/19	*Hauericeras* sp.
3/19	*Eulophoceras natalense* Hyatt.
1/20, 2/20	*Prionocyclus* aff. *guyabanum* Steinmann; *Solgerites armata* (Solger); *Tylostoma whitei* von Ihering.
3/20, 3/26	*Pseudaspidoceras* spp.; *P. pedroanum* (White); *Gombeoceras gongilense* (Woods); *Bauchioceras nigeriensis* (Woods); *Kamerunoceras jacobsoni* Reyment; *K.* aff. *eschi* (Solger); *Prionocyclus* sp.; *P. pedroanum* Steinmann; *Glebosoceras glebosum* Reyment; *Vascoceras bulbosum* Reyment; *Mammites dixeyi* Reyment; *Collignoniceras* sp.
2/21, 1/28	*Stolickzaia* aff. *africana* Pervinquière; *Sharpeiceras* sp.; *Cymatoceras* sp.; *Metoiceras* aff. *ornatum* Moreman.
3/21, 1/31	*Bauchioceras nigeriense* (Woods); *Wrightoceras wallsi* Reyment.
2/22, 3/22	*Douvilleiceras* sp.; *Puzosia* spp.; *Panopea brasiliensis* White; *Homomya bisinuso* White.
4/22, 5/22	*Douvilleiceras* sp.; *Puzosia* sp.; *Tylostoma whitei* Ihering.
4/23	*Coilopoceras* sp.; *Hoplitoides* sp.; *Puzosia* sp.
1/27, 2/27	Bedded Limestone. Chert nodules. Sponge spicules. Sapucari Mb, Cotinguiba Fm.
3/27	*Oxytropidoceras* spp; *O. buarquianum* (White); *Acanthoceras* cf. *quadratum* Crick.
4/27	*Puzosia* sp.; *P. garajauana* Maury; *P. brasiliana* Maury; *Melchiorites garajauana* (Maury); *Douvilleiceras* sp.; *Turritella* spp.
5/27	*Douvilleiceras* aff. *orbigny* (Hyatt); *D. offarcinatum* (White); *D.* aff. *mammillatum* (d'Orbigny); *Puzosia* sp.
6/27	*Mortoniceras sergipense* (White); *Puzosia* sp.
7/27	*Douvilleiceras offarcinatum* (White); *Puzosia* sp.
2/30, 3/20	*Neithea gibbosa* (Pulteney); *Pecten* spp.; *Ostrea* sp.

FIGURE 11. For legen

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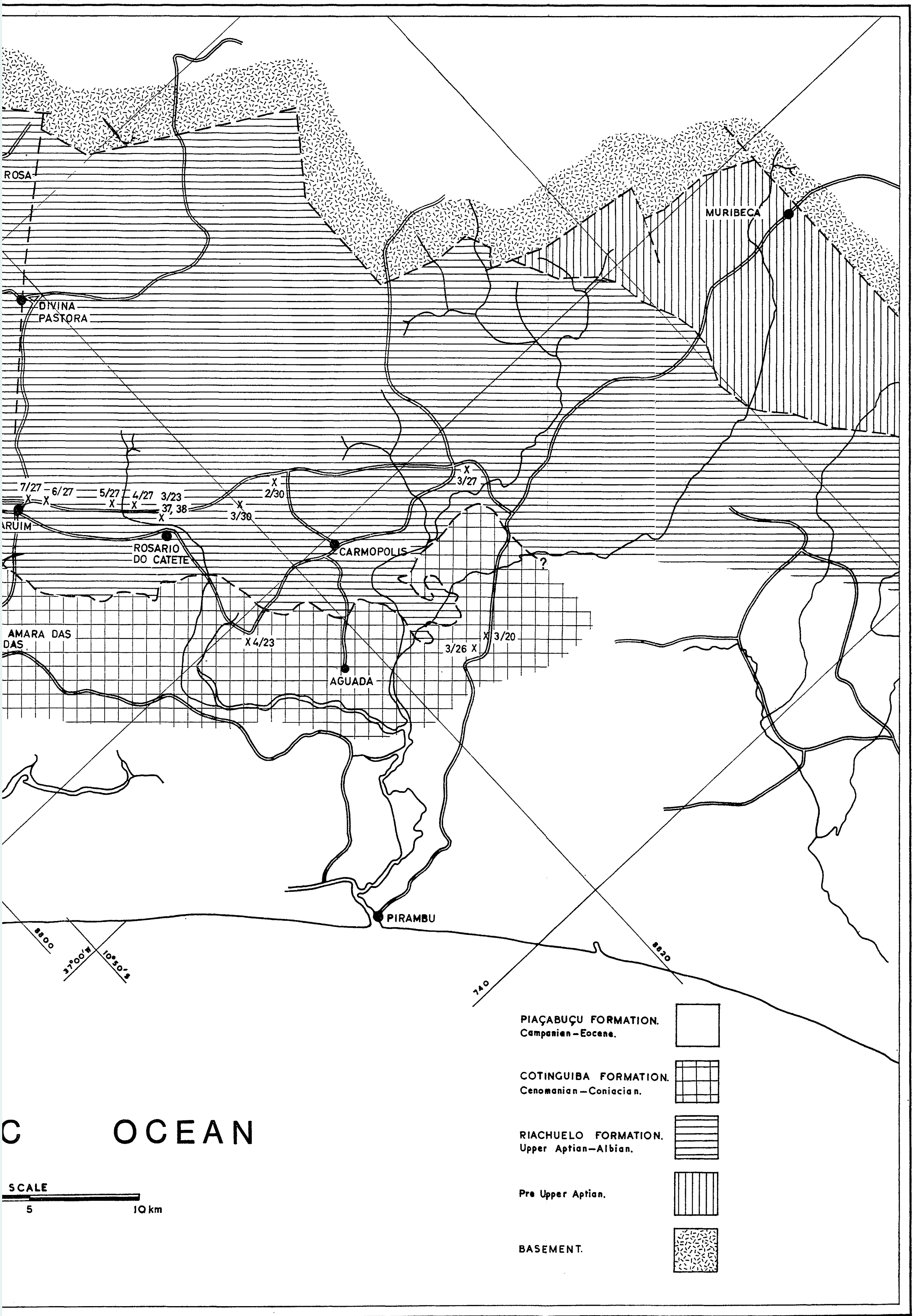

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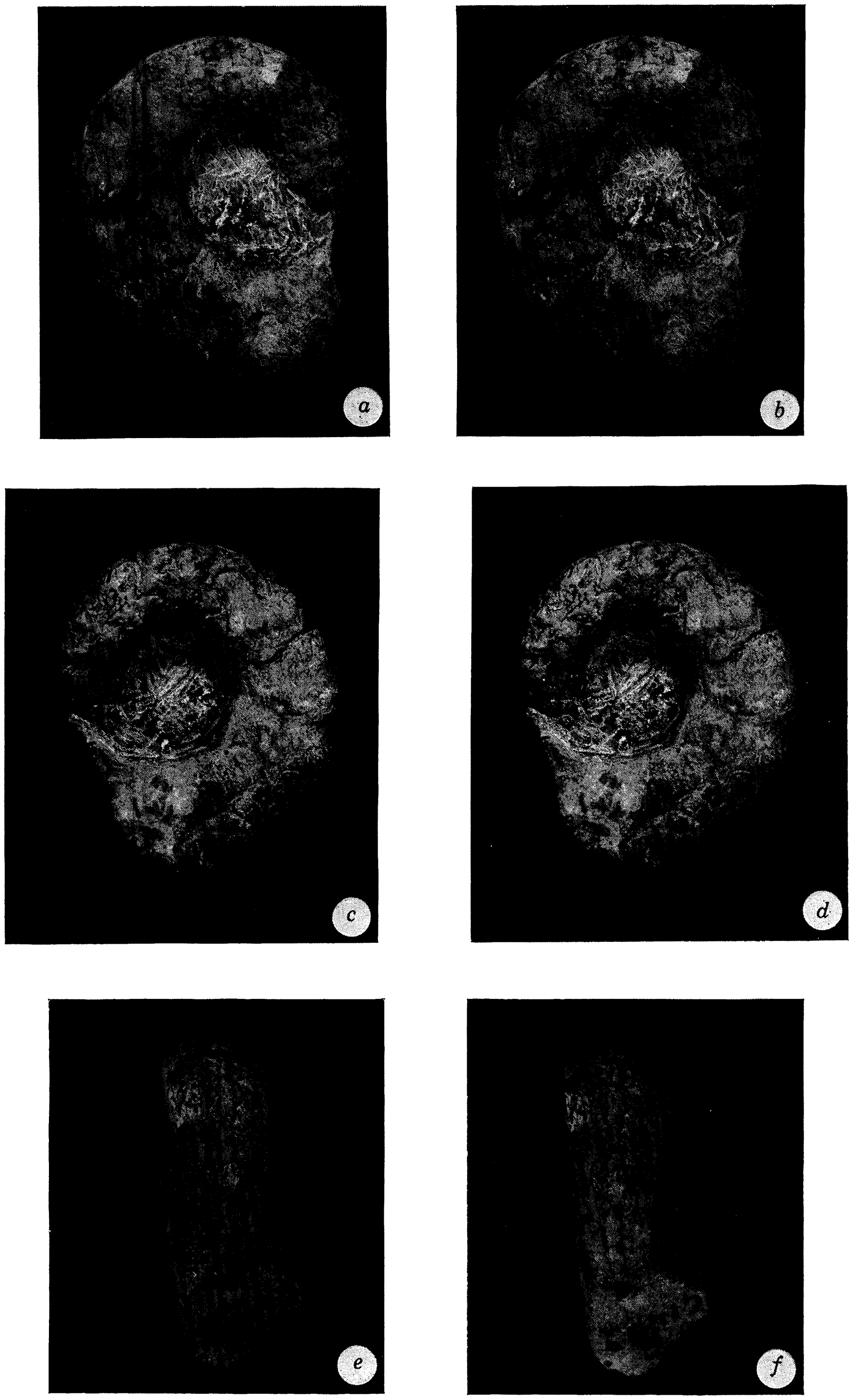

FIGURES 12. *a–f. Pseudaspidoceras pedroanum* (White). Lower Turonian Cotinguiba Formation, Sergipe. Locality 3/26, east of Carmopolis, near Petrobrás locality S4. This species has often been wrongly identified in the literature owing to the poor preservation of the material. We are therefore publishing a set of stereopairs of a good specimen. P.I. SA 43.

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PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Explanation of plate 4

Figure 13. *Megacucullaea kraussi* (Tate). Upper Valanginian. Zwartkops Brick and Tile Quarry, east bank, Zwartkops River, 3 miles north of Amsterdamhoek, Cape Province, South Africa. Many Argentinian and South African specimens display fine longitudinal striations, not shown on these two specimens. Af. 150.

Figures 14 *a*, *b*. *Gervillia anceps* Deshayes. Upper Valanginian. Zwartkops Brick and Tile Quarry, east bank, Zwartkops River, 3 miles North of Amsterdamhoek, Cape Province, South Africa. Af. 151.

Figures 15 *a*, *b*. *Douvilleiceras offarcinatum* (White). Lower Albian. Usina Pedras, on Highway Br 101, Sergipe, NE Brazil. Riachuelo Formation. This species may be locally abundant where it occurs in strandline heaps together with *Melchiorites garajauana* (Maury). C. 1230.

Figure 16. *Oxytropidoceras buarquianum* (White). Middle Albian. Rosario do Catete, Sergipe, NE Brazil. Riachuelo Formation. C. 1424.

Figure 17. *Elobiceras intermedium* Spath. Upper Albian. Carapeba Quarry, Sergipe, NE Brazil. Riachuelo Formation. C 1311.

Figure 18. *Elobiceras subelobiense* Spath. Upper Albian Carapeba Quarry, Sergipe, NE Brazil. Riachuelo Formation. Species of the genus *Elobiceras* are locally common in the Upper Albian of Sergipe. Two specimens of our large collection are shown here. C. 1317.

Figure 19. *Mortoniceras* (*Angolaites*) *gregoryi* (Spath). Upper Albian. Usina Varzina, Sergipe, NE Brazil. Riachuelo Formation. C 1355.

Figures. 20 *a*, *b*. *Stoliczkaia* aff. *africana* Pervinquière. Lower Cenomanian. Near Itaporanga, on Highway Br 101, Sergipe, NE Brazil. The genus *Stoliczkaia* is taken in Northern Europe to denote the top zone of the Albian (*dispar* zone). It occurs, however, in the lowermost Cenomanian of Angola and Mexico and it is found in Brazil with Cenomanian ammonites. It occurs in Eastern Nigeria in uppermost Albian. Cotinguiba Formation. C 1360.

Figure 21. *Shapeiceras* sp. Same locality as for *Stoliczkaia* aff. *africana* Lower Cenomanian. Cotinguiba Formation. C 1358.

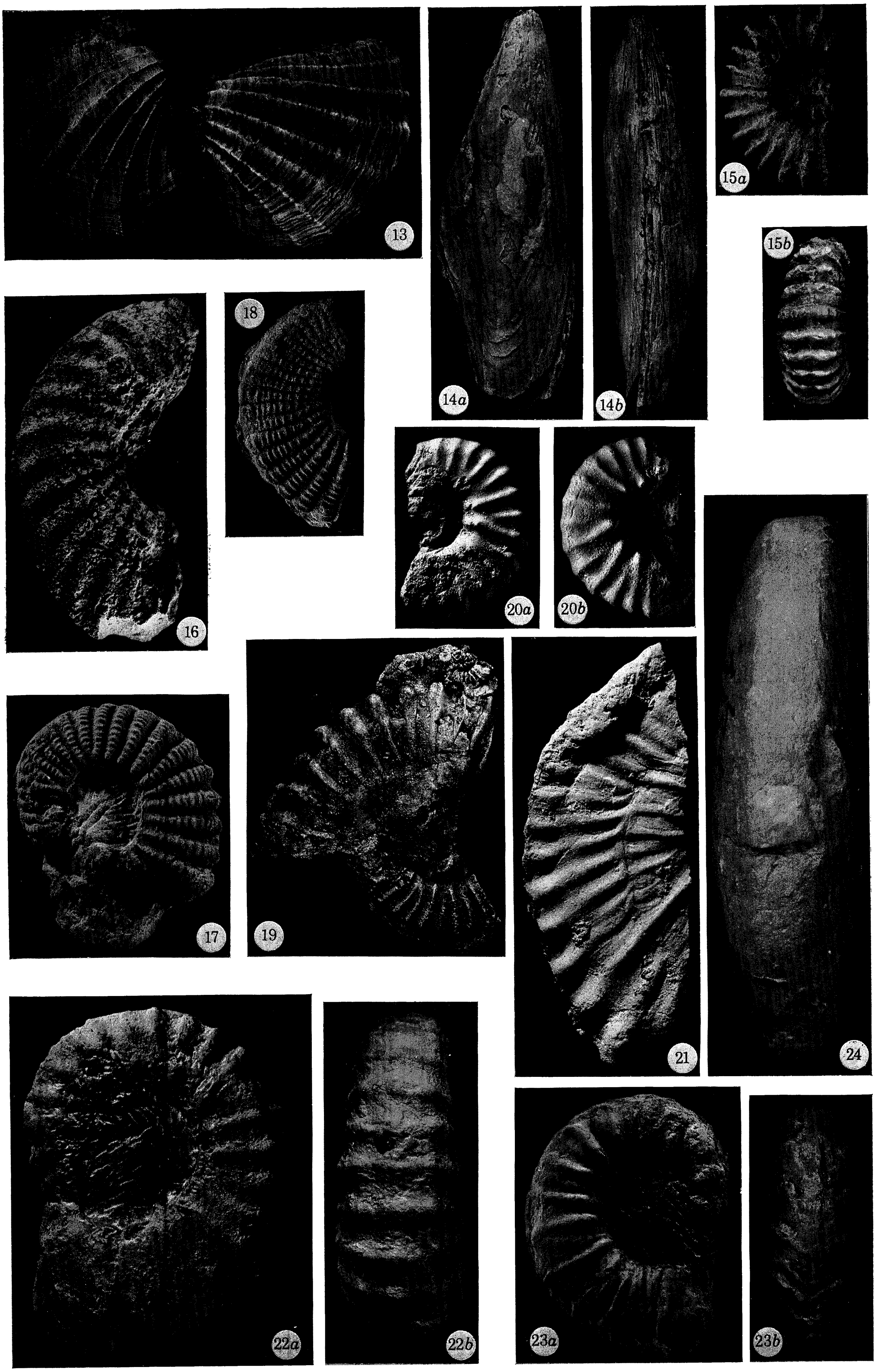
Figures 22 *a*, *b*. *Acanthoceras* cf. *quadratum* Crick. Cenomanian. Near km 77 on Highway Br 101, Sergipe, Brazil. Cotinguiba Formation. C 1470.

Figures 23 *a*, *b*. *Kamerunoceras* cf. *eschi* (Solger). Fazenda east of Carmopolis, Sergipe, NE Brazil. Lower Turonian. C 1438.

Figure 24. *Pseudctissotia* (*Wrightoceras*) *wallsi* (Reyment). Small quarry near São Cristovão, Sergipe, NE Brazil. Specimen showing less inflation of the umbilical half of the flanks than is usual for the species. Lower Turonian C 1420.

All figures are half the size of the specimens except figure 20, which is reproduced at natural size. All figured material has been deposited in the collection of the museum of Paleontologiska Institutet, Uppsala.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES



FIGURES 13 TO 24. For legend see facing page.

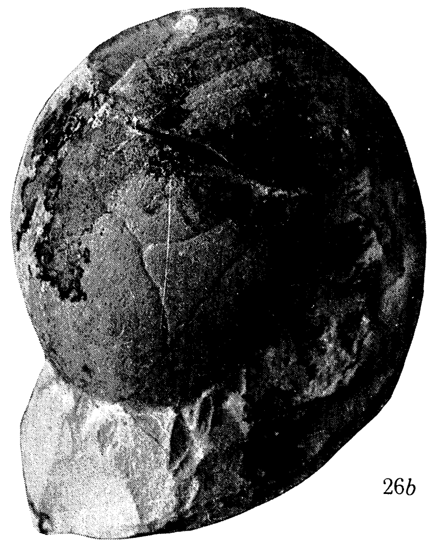
PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES


25*a*


25*b*


25*c*

26*a*

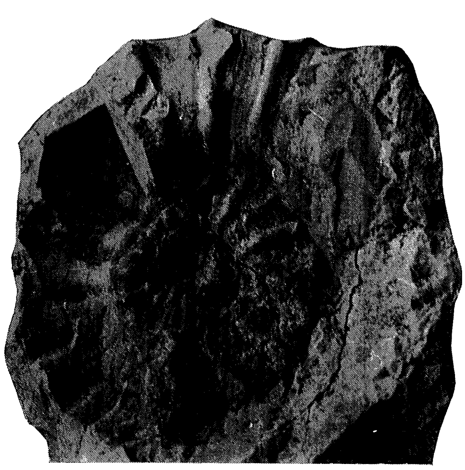

26*b*

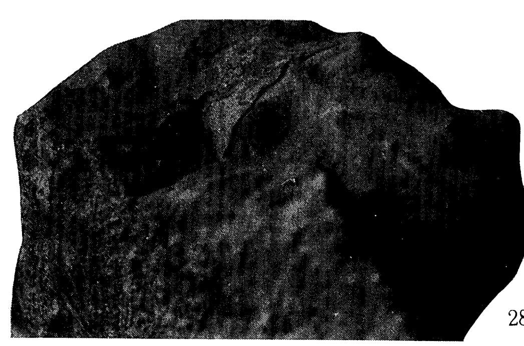

26*c*


27


28*b*


29


28*a*


28*c*

FIGURES 25 TO 29. For legend see facing page.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Valanginian a shortlived marine transgression cut across southern Chile, Argentina and the southern tip of South Africa and the two landmasses began to part. By the Upper Aptian a long, narrow sea, in parts of which considerable deposits of salt accumulated, extended as far as Sergipe and Gabon. By Upper Albian time the sea extended into Nigeria, but had already started to regress from its maximum extent reached during the upper Middle Albian. There seems to have been a short-lived transgression in Brazil over Maranhão to the Ivory Coast, for sediments have yielded a few Upper Albian ammonites offshore from the Ivory Coast and off Maranhão (figure 3). Oscillatory movements of very slight amplitude of the two parts of the landmass seems to have taken place, resulting in a shallow trans-Saharan sea which permitted contact between the South and North Atlantic indirectly by way of the Tethys. The final break between the two landmasses took place in the upper part of the Lower Turonian during the time of the *Benueites* association and the nekroplanktonic ammonite shells were able to drift freely with oceanic currents over the entire Atlantic for the first time in the history of this ocean. Free interchange between the faunas of this ocean and more northerly and westerly waters (cf. *Turonian* in Bürgl 1961) could now take place. This condition has prevailed since the Turonian. After the Coniacian, agreement in faunas gradually becomes less and less as the continents moved farther and farther apart.

Several datings of the final opening have been made, among them K. Beurlen (1970), Sutton (1968) and Wright (1968) but ours appears to be the first to be based on a detailed biostratigraphical analysis.

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Explanation of plate 5

Figure 25. *Vascoceras* cf. *globosum* (Reyment). Lower Turonian. Cotinguiba Formation. Quarry 2.5 km SW of Rita Cacete, Sergipe. Petrobrás LPM-206.

Figures 26 *a–c*. *Pachyvascoceras hartii* (Hyatt). Lower Turonian. Cotinguiba Formation. Same locality as for foregoing specimen. Petrobrás LPM-206.

Figure 27. *Vascoceras* cf. *compressum* Barber. Lower Turonian. Cotinguiba Formation. Same locality as foregoing. Petrobrás LPM-261.

Figures 28 *a–c*. *Kamerunoceras jacobsoni* Reyment. Lower Turonian. Cotinguiba Formation. Laranjeiras. Univ. Fed. Pernamb. 260.

Figure 29. *Cheloniceras* (*Epicheloniceras*) sp. Upper Aptian. Riachuelo Formation. Pocao, Riachuelo. Univ. Fed. Pernamb. 2053.

The specimens shown in figures 25 to 27 were collected and determined by Dr G. Beurlen (Salvador); the specimens depicted as figures 28, 29, were collected and determined by Professor K. Beurlen (Tübingen).

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PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

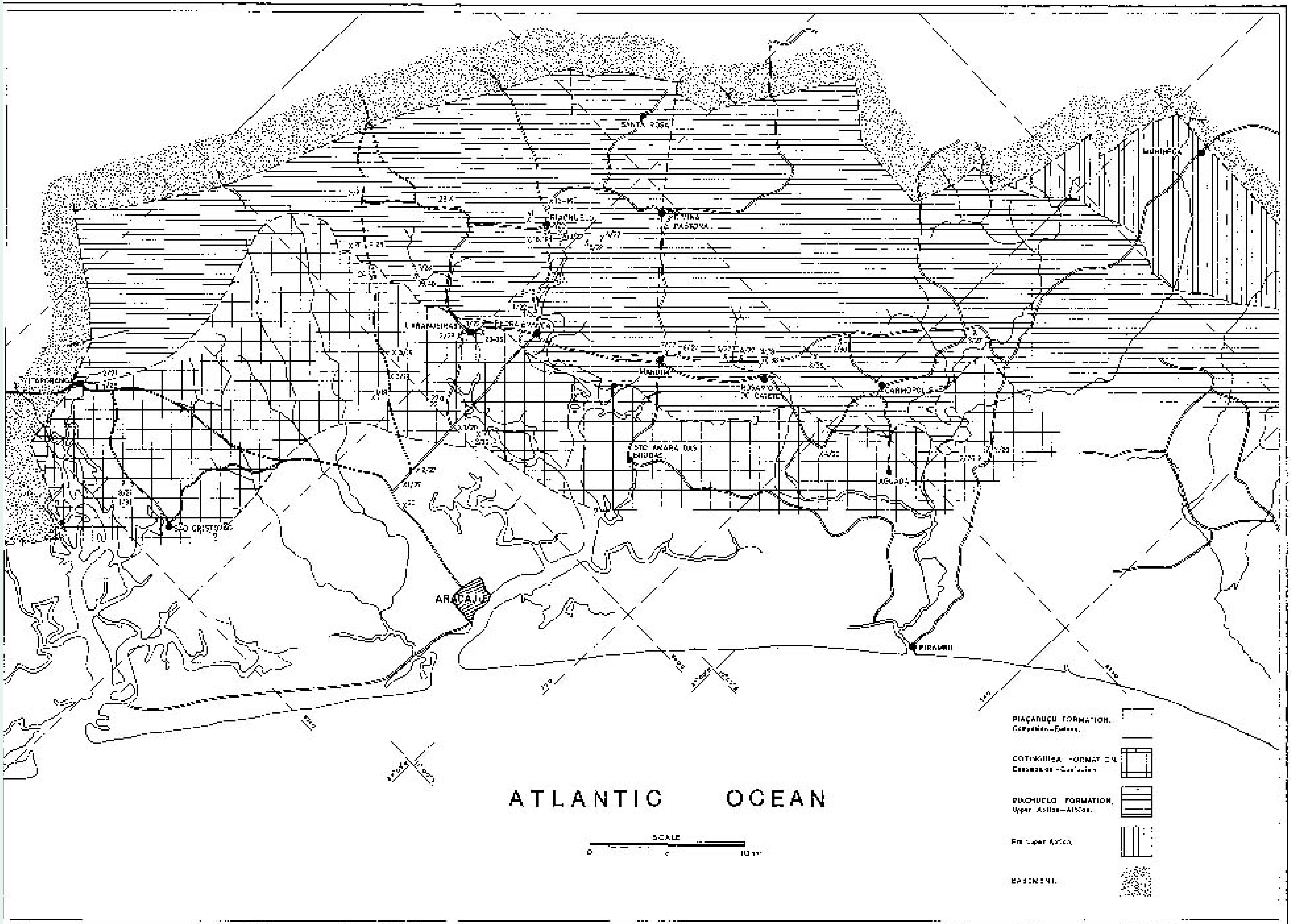
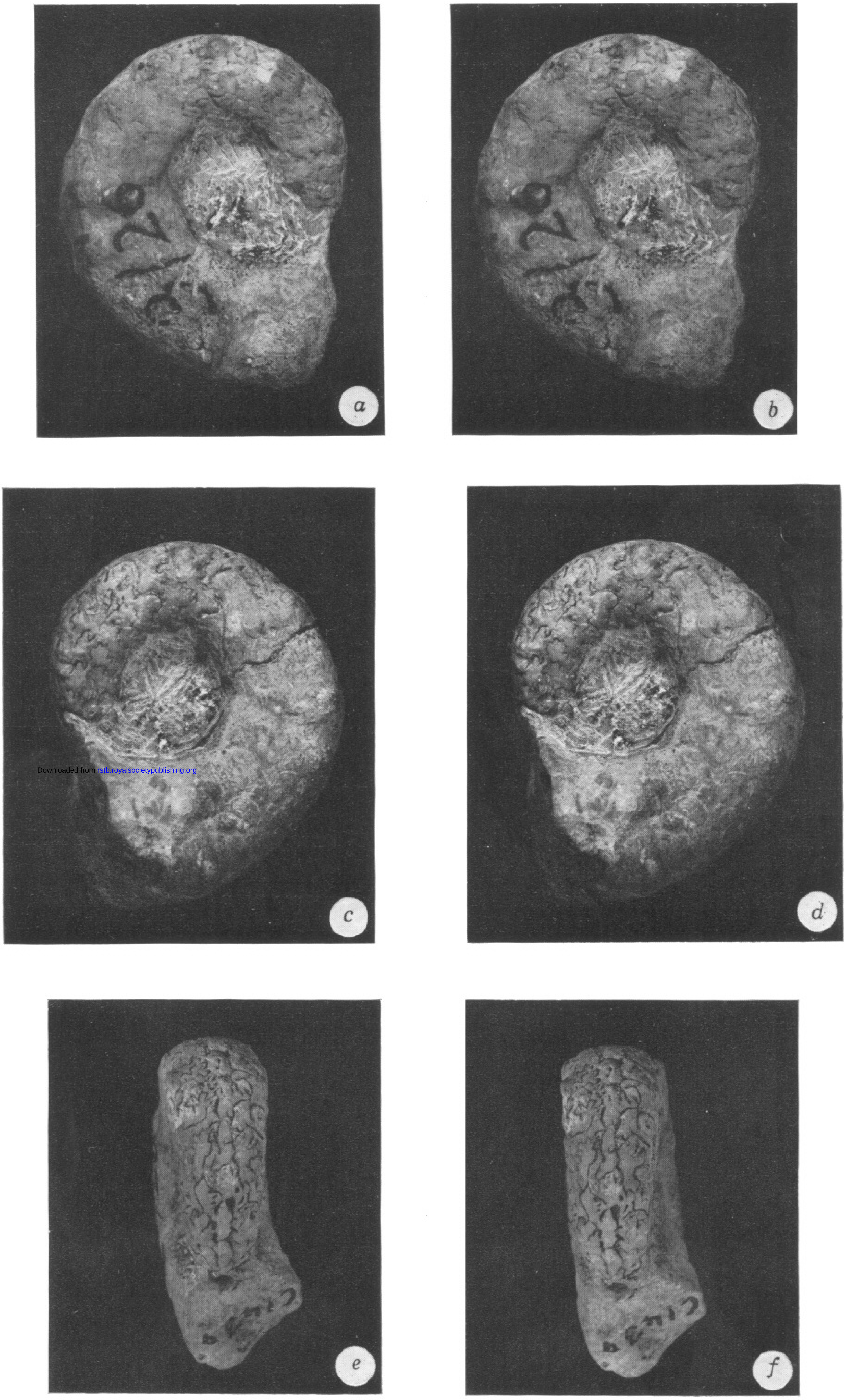


Figure 11. For legend see facing page.



GURES 12. *a–f*. *Pseudaspidoceras pedroanum* (White). Lower Turonian Cotinguiba Formation, Sergipe. Locality 3/26, east of Carmopolis, near Petrobrás locality S4. This species has often been wrongly identified in the literature owing to the poor preservation of the material. We are therefore publishing a set of stereopairs of a good specimen. P.I. SA 43.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

FIGURES 13 TO 24. For legend see facing page.

25*a*

25*b*

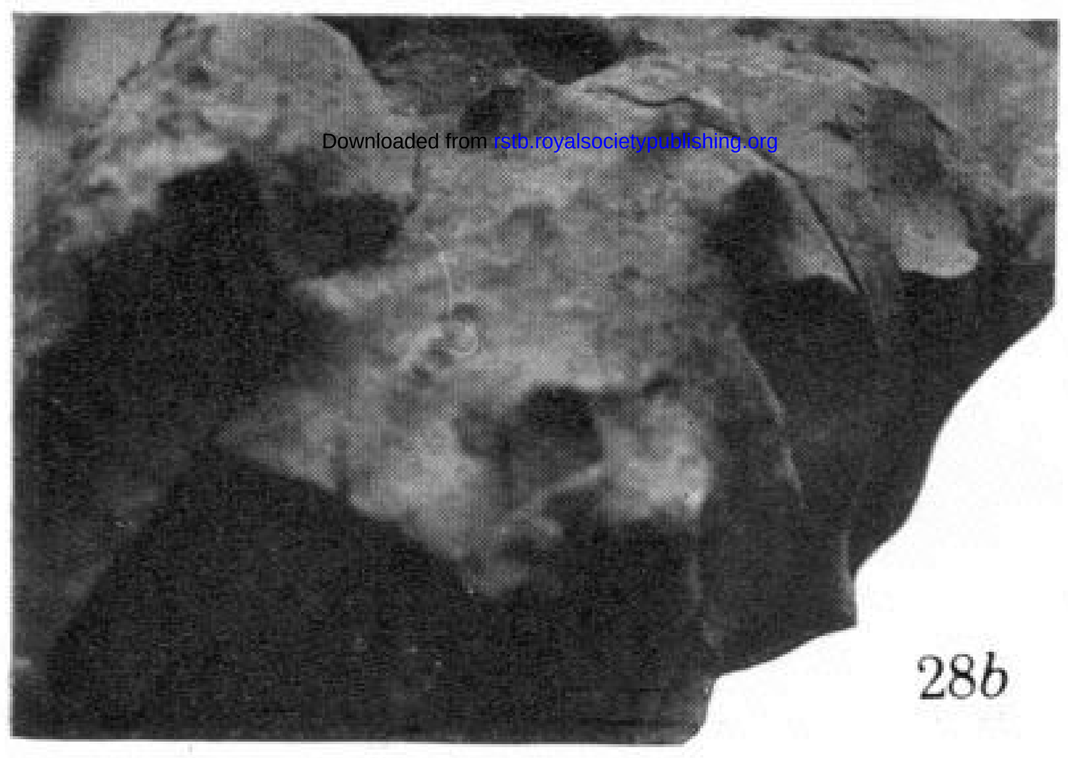
25*c*

26*a*

26*b*

26*c*

27



28*b*

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28*a*

28*c*

FIGURES 25 TO 29. For legend see facing page.