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Stratigraphy of Chad and Iullemmeden basins (West Africa)

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ABSTRACT

The origin of the Mesozoic-Cenozoic intracratonic basins in West Africa is related to the geodynamic processes of plate tectonics and seafloor spreading. The differentiation of the Chad and Iullemmeden basins and the marine transgressions into these basins during the Mesozoic and Cenozoic were controlled by rifting and subsidence and by seafloor spreading along the continental margin of West Africa. Although the Chad and Iullemmeden basins formed at different times the depositional environments in both basins were similar. Sedimentation in the warm, fluctuating epeiric seas that occupied both basins from the Cenomanian to the Paleocene produced similar shallow-water fossiliferous marly limestones and marginal gypsiferous shales which interfinger with coastal fine-grained sandstones, siltstones and mudstones along the margins of the basins.

ZUSAMMENFASSUNG

Die Entstehung der westafrikanischen mesozoisch-känozoischen, intrakratonischen Becken ist mit den geodynamischen Prozessen der «Plattentektonik» und dem «Auseinanderfliessen des Ozeanbodens» verknüpft. Die Differenzierung der Becken von Chad und Iullemmeden sowie die Meertransgression in die genannten Senken während des Mesozoikums wurde von der Rift-Entstehung und der Verbreitung der ozeanischen Kruste längs des westafrikanischen Plattenrandes kontrolliert. Obzwar die Becken von Chad und Iullemmeden von verschiedenem Alter sind, waren die Ablagerungsbedingungen in warmen epirogenetischen Meeren, die zwischen Cenoman und Paleozän beide Becken erfüllt haben, ähnlich. Längs der Beckengrenzen kommen fossilreiche Mergelkalksteine und ufernahe gipsführende Schiefer, fingerartig durchwachsen von feinkörnigen Sandsteinen, Peliten und Tonsteinen, vor.

Introduction

The origin of most African Phanerozoic sedimentary basins is related to the dynamic process of plate divergence. Notable exceptions, however, are the deformed basinal sequences of the Paleozoic foldbelts of Mauritania and Morocco which resulted from Hercynian convergent plate motion and the collision of Africa and North America, and the Tindouf and Ougarta basins which are Paleozoic successor basins (DILLON & SOUGY 1974). The Atlas foldbelt was caused by the convergence of African and Iberian plates during the Alpine orogeny.

The African continent also provides many examples of rift systems and associated sedimentary basins, for example, the Late Carboniferous-Early Jurassic Karroo basins of southern and eastern Africa (HAUGHTON 1963; KENT 1974), the Triassic-

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Liassic Moroccan grabens (Van Houten 1977), the Early Cretaceous rift systems extending southward from the Saharan platform of Algeria and Libya through central West Africa to the Gulf of Guinea (Burke & Dewey 1974; Louis 1970; Radier 1959), and the Neogene East African Rift System.

The geologic history of the East African Rift System, the Red Sea, and the Atlantic continental margin of West Africa provides a model for the evolution of continental rifts into young and extended ocean basins. Geophysical investigations and petroleum exploration drilling in the basins along the Atlantic continental margin of Africa have enabled understanding of the structural and stratigraphic evolution of the Atlantic-type divergent continental margins (Thompson 1976; Lehner & de Ruiter 1977). Another class of sedimentary basins which are indirectly related to continental plate divergence in West Africa are the broad intracratonic epeirogenic basins. Among these are the Chad and Iullemmeden basins (Fig. 1).

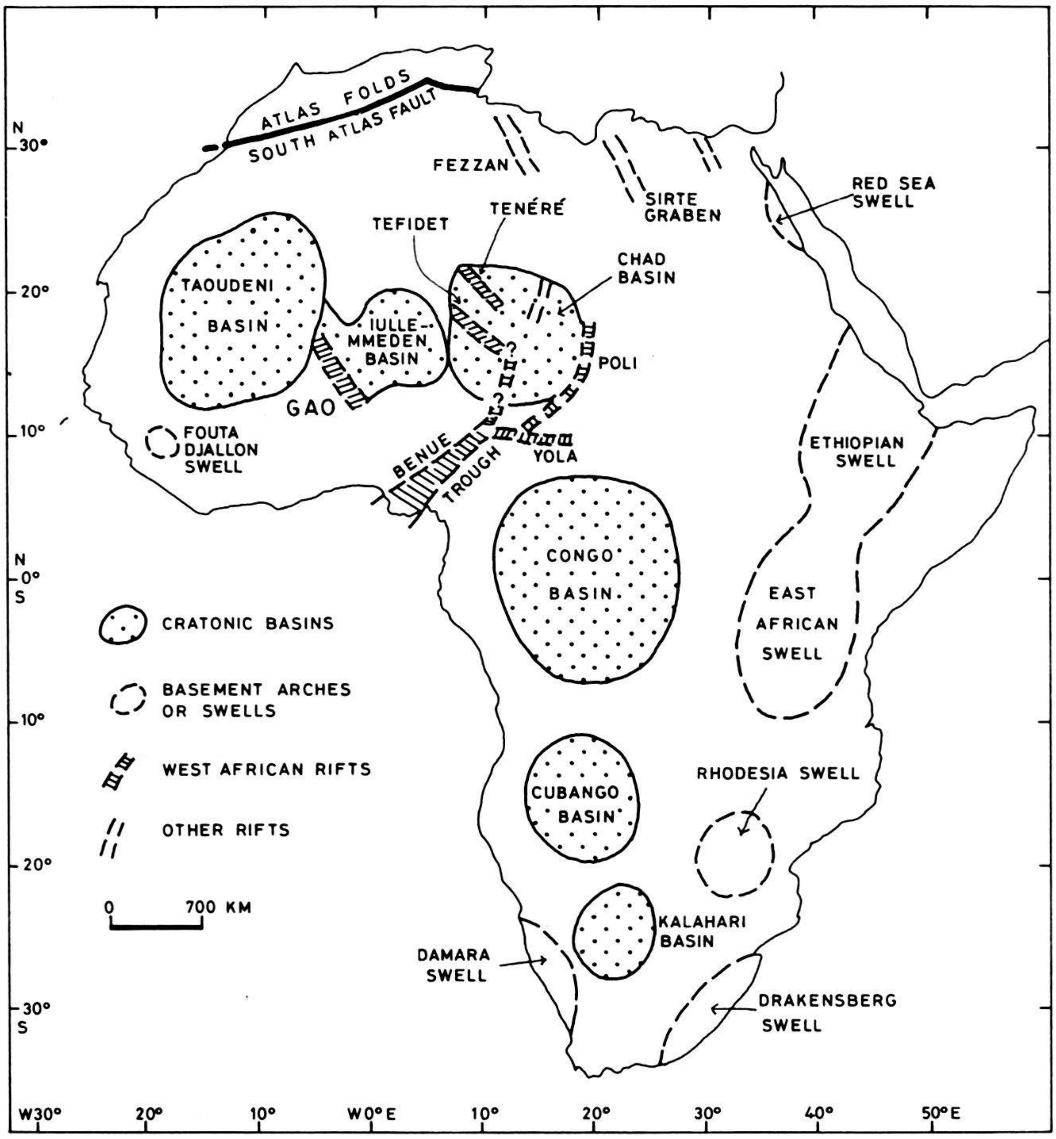

Fig. 1. Schematic diagram showing African intracratonic basins and swells (after Burke & Wilson 1972).

Apart from the excellent monographs of FAURE (1966) and LOUIS (1970) on the Chad basin, and those of GREIGERT (1966), GREIGERT & POUGNET (1967), and RADIER (1959) on the Iullemmeden basin, no regional stratigraphic synthesis is available that gives a comprehensive and coherent stratigraphic picture for both basins. NAIRN (1978) gave a brief account of the stratigraphy of the central Sahara in his review of the geology of northern Africa but his account was incomplete, formation names were mis-spelt and the stratigraphic thicknesses were incorrect. PETTERS (1978*a*, 1979*a*) furnished a stratigraphic framework for the Iullemmeden basin in which a facies model was proposed and the depositional environments and paleogeography were interpreted. Recent stratigraphic observations by the writer on the southeastern part of the Iullemmeden basin enable comparisons between the Iullemmeden basin and the Chad basin. Although they are different in age the Chad and Iullemmeden basins show similarities in their stratigraphic relationships and depositional environments. These similarities are explainable by their common tectonic and paleogeographic setting. The Chad and Iullemmeden basins are broad epeirogenic downwarps in the interior of West Africa and were occupied by an epeiric sea several times from the Cenomanian to the Paleocene. Both basins differ markedly from the coastal West African basins in their structure and sedimentary fill.

Megatectonic setting and origin

The interior basins of West Africa occupy broad, shallow, flat-bottomed basement downwarps that form a curvilinear system of basins which lie parallel to the continental margin between latitudes 25° N and 30° S (Fig. 1). The Taoudeni, Congo, Cubango and Kalahari basins are located on Archaean cratonic nuclei, whereas the Chad and Iullemmeden basins lie within the belt of Pan-African reactivated basement (about 500 m.y.). The basement arches which surround the West African interior basins north of latitude 10° N are the Nubo-Arabian swell to the east, the Tibesti, Ahaggar and Reguibat uplifts to the north, the Kayes and Eastern Senegal massifs to the west, and the Upper and Lower Guinea Arches to the south (Fig. 2). The Congo, Cubango and Kalahari basins are separated from the coast by narrow basement upwarps and are flanked on the east by uplifted Precambrian basement.

Theories of the origin of African interior basins have stressed the role of rifting (CLOOS 1939; FURON 1963; BURKE & DEWEY 1974). Rifts have been recognized in the Chad basin by LOUIS (1970) and on the western flank of the Iullemmeden by RADIER (1959). The Chad basin lies along the trans-Africa lineament which was defined by NAGY et al. (1976) as a zone of weakness that runs transversely from the Niger delta to the Nile delta, and is also occupied by the Benue trough in Nigeria, the Chad basin in Niger and Chad Republics, the Kufra basin in Libya and the Qattara depression in Egypt.

Recent theories of cratonic subsidence and basin formation have emphasized the role of changes in mantle thermal regime, and subsidence due to flexure of the lithosphere in response to sediment and water load (BOTT 1976). FAURE (1973) and SLOSS & SPLEED (1974) ascribed cratonic subsidence to seafloor spreading, plate tectonics and mantle thermal perturbations. The migration of cratonic subsidence and marine sedimentation from the Late Cenomanian in the Chad basin to the Paleocene in the Iullemmeden basin was attributed by FAURE (1973) to horizontal relative translation between the lithosphere and the asthenosphere. According to FAURE crustal uplift occurs as continental lithosphere rides over bumps in the asthenosphere while subsidence occurs after the continent moves over the lithospheric bump. FAURE observed that the migration of cratonic subsidence from the Chad basin to the Iullemmeden was at the rate of 1 to 2 cm/year. The rate and direction of migration was comparable with seafloor spreading and the motion of the African plate. A kindred hypothesis is that of SLOSS & SPEED (1974). These authors suggested that the causes of widespread cratonic vertical movements which operated synchronously in different continents (SLOSS 1972) including Africa (PETTERS 1979*b*) are manifestations of global tectonics. Invoking the idea of solid-melt transformations in the asthenosphere, SLOSS & SPEED (1974) argued that the upper surface of the continental lithosphere will be elevated when the astheno-

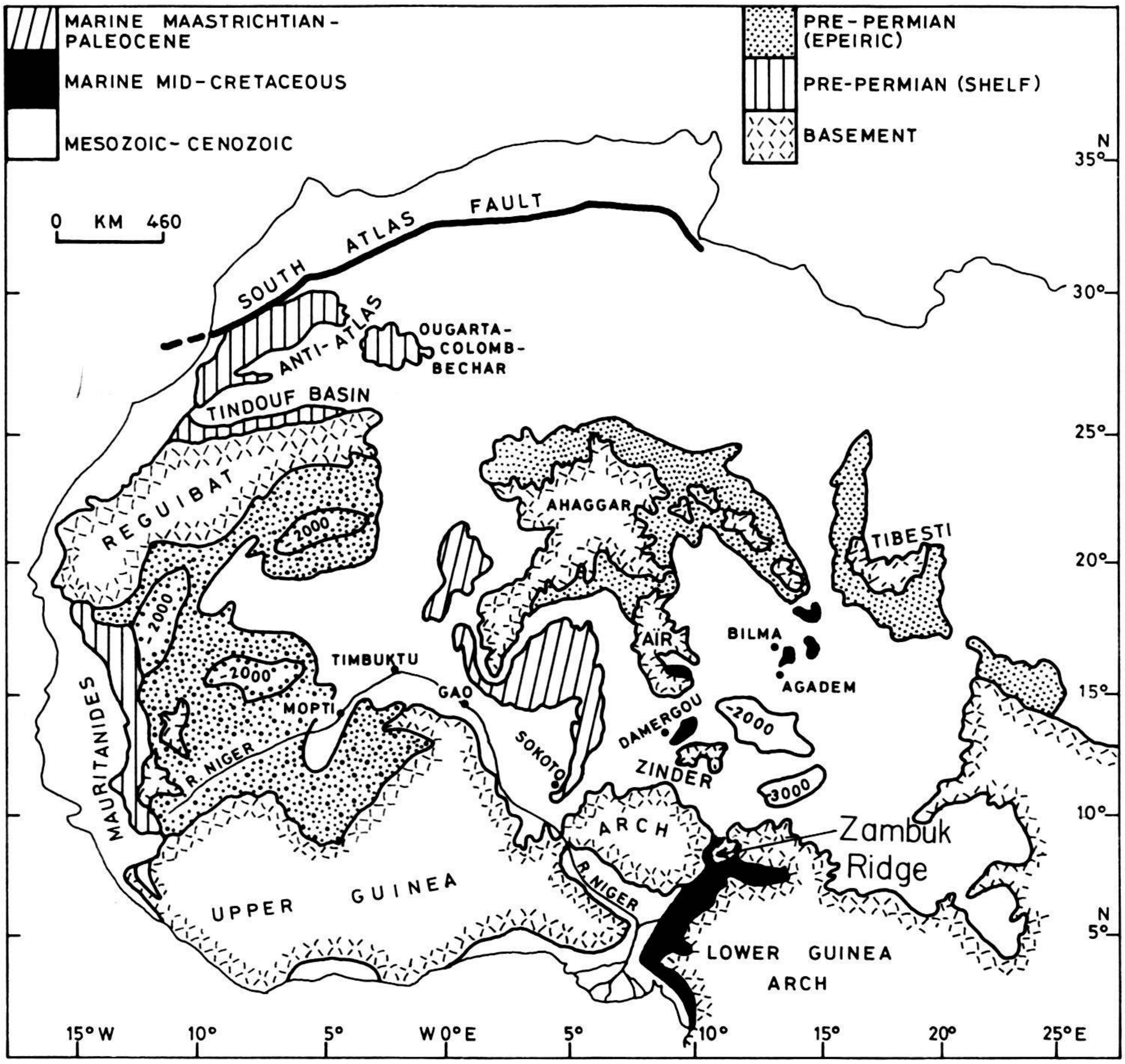

Fig. 2. Geological sketch map of West Africa between latitudes 10°N and 25°N.

sphere thickens as a result of partial melting. With the expulsion of the melt, the asthenosphere deflates and the craton subsides. SLOSS & SPEED (1974, Fig. 9) showed that during periods of cratonic uplift there are slow seafloor spreading rates, whereas periods of cratonic submergence are characterized by high spreading rates.

The uplift and subsidence history of the African plate appears to be related to the history of seafloor spreading in the Atlantic Ocean in a manner that seems consistent with the FAURE (1973) and the SLOSS & SPEED (1974) models. The apparent segregation of basement arches and basins in Africa (Fig. 1) is more than accidental. Basement uplift is strongest in eastern Africa where Neogene continental fragmentation is in progress, whereas the cratonic basins of western Africa line up parallel to the coastal zone of Early Mesozoic uplift and continental separation. Strong subsidence of western African intracratonic basins during the mid-Cretaceous phase of active seafloor spreading in the Atlantic is evident in the widespread Cenomanian-Turonian marine transgression in the Chad, Iullemmeden and Congo basins (FURON 1963; FRANKS & NAIRN 1973). BOND (1978) demonstrated that the African continent has been undergoing stronger uplift than the other continents since the Miocene. BURKE & WILSON (1972) argued that the rise of swells in Africa (Fig. 1) may be due to convection plumes in the mantle which by lifting parts of the continent have resisted and halted eastward motion from the Mid-Atlantic Ridge and have held Africa stationary for the past 25 m.y. (since Miocene). Renewed subsidence in the Chad basin during the Quaternary shows that once formed, intracratonic basins can be reactivated by sediment loading if the surrounding basement areas are uplifted and eroded (BURKE 1976).

Stratigraphy of the Chad basin

The Chad basin is a broad structural depression in central West Africa. Gravity surveys by LOUIS (1970) located buried rifts at Tefidet and Ténéré, and a possible northeastward extension of the Benue trough (Fig. 1). Subsequent reflection seismic surveys and oil exploration drilling in the Chad basin (BIRO 1976; BIGNELL 1977) have penetrated thick sedimentary sections in two prominent structural trends which seem to be continuations of the buried rifts.

One trend runs south of the Ténéré rift and continues through Seguedine, Bilma and Zoo Baba (Fig. 3). At Seguedine basement was penetrated at 3148 m (BIRO 1976), while at Tiffa about 70 km southeast of Seguedine, a well bottomed in the Lower Cretaceous at 2787 m. Basement is exposed near Dibella; this basement arch separates the Ténéré trend (Fig. 1) from a second trend which is the southern continuation of the Tefidet rift. In the Tefidet trend a well at Fachi bottomed in the Lower Cretaceous at 3740 m; at Madama another well bottomed in the Upper Cretaceous at 3810 m, while at Kumia, near Lake Chad a well bottomed in the Cretaceous at 4272 m (BIRO 1976). There is a basement uplift at Termit which seems to be the western flank of the Tefidet rift trend. A basement high which is mostly buried runs northeast-southwest between Potiskum and Gombe (Fig. 1, 3). This is the Zambuk basement ridge (CARTER et al. 1963) which separates the Chad basin from the upper Benue trough. The Zambuk ridge was a structural high during the Cretaceous as evident from the thinning of Cretaceous strata over the ridge (CARTER et al. 1963).

Geologic exposures in the Chad basin are scarce being concealed beneath Quaternary sands. In his detailed stratigraphic description of the Chad basin FAURE (1966) proposed separate formations for the various outcrop areas (subbasins) at Damergou, Tefidet, Termit, Dibella, Agadem, Bilma and Seguedine. In the present article the lithologic summaries are presented chronostratigraphically.

Lower Cretaceous

A variable sequence of red sandstones and mudstones belonging to the "Continental Intercalaire" Group rests on Precambrian basement in the Chad basin. The

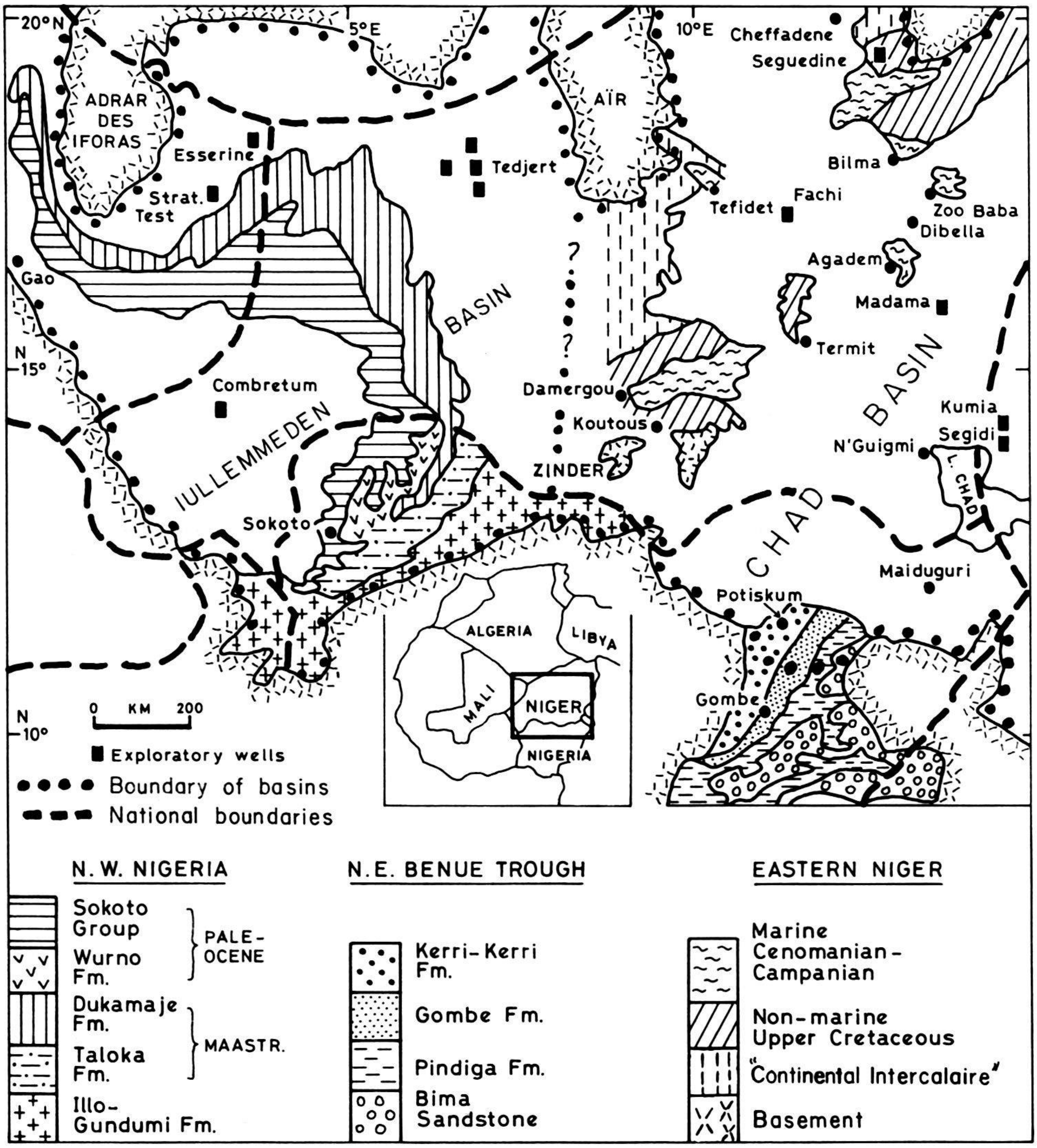

Fig. 3. Geologic sketch map of Chad and Iullemmeden basins (partly after FAURE 1966).

maximum thickness of these continental redbeds occurs at Damergou where about 1000 m of a more complete Permo-Jurassic and Lower Cretaceous sequence is exposed (Fig. 3). The basal unit at Damergou, outcropping south of Aïr, is the L'Irhazer Formation which comprises red lacustrine mudstones with marly sandstones and limestones of Permo-Jurassic age, and contains dinosaurs, the fish *Ceratodus* and Wealden invertebrates (FAURE 1966; GREIGERT & POUGNET 1967). The L'Irhazer Formation grades upward into coarse, variegated, cross-bedded sandstones with shale intercalations. This sequence is of Lower Cretaceous age and is known as the Tegama Group at Damergou, the Tefidet Group at Tefidet, the Dibella Formation at Dibella-Agadem, the Achegour Formation at Achegour-Bilma and the Tiffa Formation at Cheffadene and Seguedine (FAURE 1966). The Lower Cretaceous is represented in the northeastern Benue trough and the Nigerian part of the Chad basin by the coarse, thick to massive-bedded, cross-stratified and feldspathic Bima Sandstone.

Lower Cenomanian

Coarse clastic sedimentation ended in the Chad basin during the Cenomanian. Most of the Lower Cenomanian is represented by a conformable series of fine-grained sandstones, siltstones and greenish paper shales variously known as the Farak, Alanlara and Ezerza Formations (Fig. 4). These are passage beds which contain oyster beds, gastropods and *Ceratodus* and attain a maximum thickness of 200 m. The Yolde Formation in the northeastern Benue trough and the Gongila

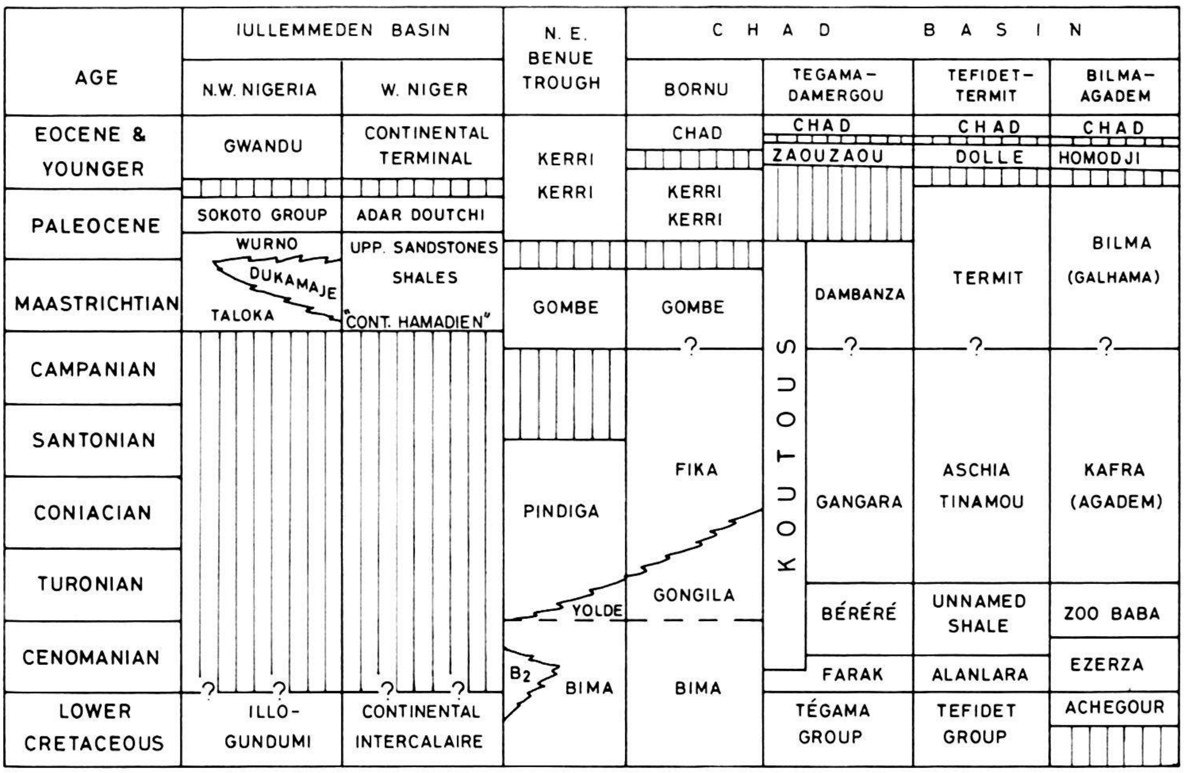

Fig. 4. Stratigraphic correlation chart for the Chad and Iullemmeden basins (formations in bracket refer to Agadem area).

Formation in the Nigerian part of the Chad basin are their partial equivalents which comprise a variable sequence of thinly bedded sandstone and alternating sandy mudstone and oyster beds. On the evidence of fish remains such as *Onchosaurus pharao* (Dames), *Schizorhiza stromeri* Weiler, *Enchodus lamberti* cf. Arambourg, and *Ceratodus* sp., a Cenomanian-Turonian age was assigned to the Yolde Formation by Carter et al. (1963).

Cenomanian-Turonian

The Late Cenomanian was strongly transgressive in northwestern Africa so that in Libya, Algeria, Morocco, Niger and Chad Late Cenomanian fossiliferous marls, limestones and shales disconformably overlie the "Continental Intercalaire" Group. The Late Cenomanian transgression is marked by the occurrence of the Tethyan-North African ammonite *Neolobites vibrayeanus* (d'Orbigny) in the Chad basin at Bilma, Damergou and Tefidet (Faure 1966). This transgression is believed to have reached its acme in the Early Turonian because of the widespread pseudotissotiid and vascoceratid ammonites with such genera like *Nigericeras* occurring in Nigeria (Barber 1957; Reyment 1955), Niger (Faure 1966; Furon 1963) and Tunisia and Algeria (Collignon 1957, 1965).

Lithologically, the Cenomanian-Turonian sequence in the Chad basin consists of glauconitic, pyritic and gypsiferous grey-green shales with highly fossiliferous

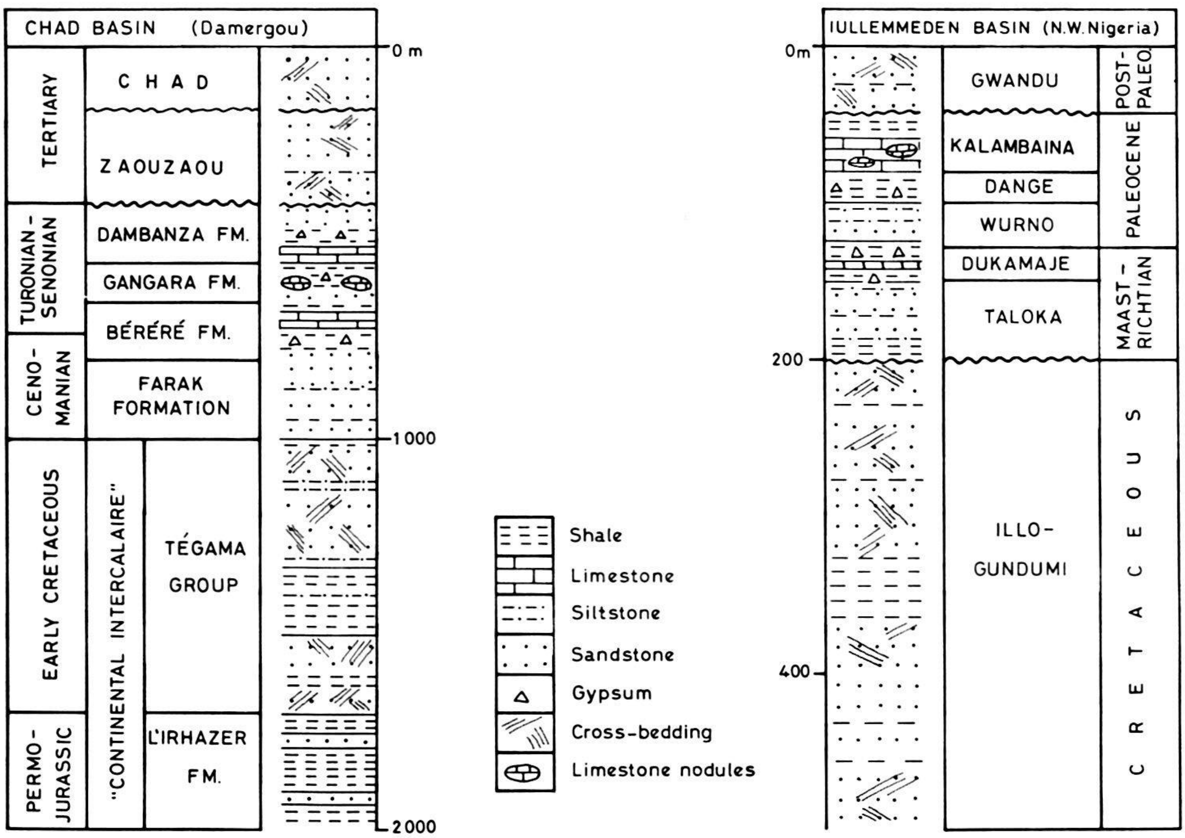

Fig. 5. Composite stratigraphic columns for Chad and Iullemmeden basins.

limestone intercalations. The Late Cenomanian-Turonian sequence in the Chad basin is up to 150 m thick and is known as the Bérére and Zoo Baba Formations. The Upper Turonian in the Chad basin is mildly regressive as evident in the unfossiliferous, fine-grained sandstones and siltstones at the base of the Gangara and Agadem Formations (Fig. 5).

In the Benue trough in Nigeria, south of the Chad basin, the mid-Cretaceous transgression started in the Middle Albian (REYMENT 1955) and peaked in the Late Turonian-Coniacian as evident in the occurrence of fully marine, rich and diverse planktonic and benthonic foraminiferal assemblages of Late Turonian-Coniacian age (PETTERS 1978*b*, *c*). The cross section in Figure 6*A* shows the pinch-out of marine Upper Cretaceous units towards the Zambuk basement high. This stratigraphic interpretation is based on the fact that boreholes located near Maiduguri and Potiskum penetrated thick paralic Upper Cretaceous shales with fish remains (BARBER & JONES 1960; RAEBURN & JONES 1934), and a microfauna comprising arenaceous foraminifera and ostracodes. Also at Gombe, south of the Zambuk ridge, a borehole penetrated about 800 m of gypsiferous shales which also yielded arenaceous foraminifera and ostracodes. Some of these paralic arenaceous foraminifera were recently described from nearby exposures by PETTERS (1979*c*). The existence of these thick paralic lithologies on both sides of the Zambuk basement ridge suggests that the southern shorelines of the Cenomanian-Turonian transgression probably lay to the northeast and southwest of the Zambuk ridge. The recent discovery of marine Cenomanian near the Niger-Libya-Chad border in the northern part of Chad basin (H. Faure, written communication, 1979) further extends the northern limits of the Cenomanian transgression.

Coniacian-Campanian

Variously known as the Gangara, Aschia Tinamou, Kafra and Agadem Formations, the Coniacian-Campanian sequence in the Chad basin comprises a basal, regressive sandstones and siltstones with marine pelecypods. This passes into a middle dark-green, gypsiferous, pyritic, paper shale with thin fossiliferous limestones bands. The upper unit consists of gypsiferous and glauconitic shale and fine-grained sandstones and siltstones with abundant pelecypod impressions. The Agadem and Aschia Tinamou Formations are up to 100 m thick. The Coniacian ammonite *Tissotia* occurs in the Aschia Tinamou Formation while in the Agadem Formation Santonian-Campanian pelecypods are common (FAURE 1966).

Maastrichtian-Paleocene

Continental clayey sandstones and siltstones variously known as the Dambanza, Termit, Bilma and Galhama Formations conformably overlie the Coniacian-Campanian deposits (Fig. 4). These sandstones are cross-bedded and contain kaolinitic clays and pisolitic and oolitic ironstones and bauxite and are up to 150 m thick. The Gombe Sandstone of Maastrichtian age, and the Kerri-Kerri Formation of Paleocene age (ADEGOKE et al. 1978) were deposited in the southern part of the Chad basin and in the northeastern Benue trough.

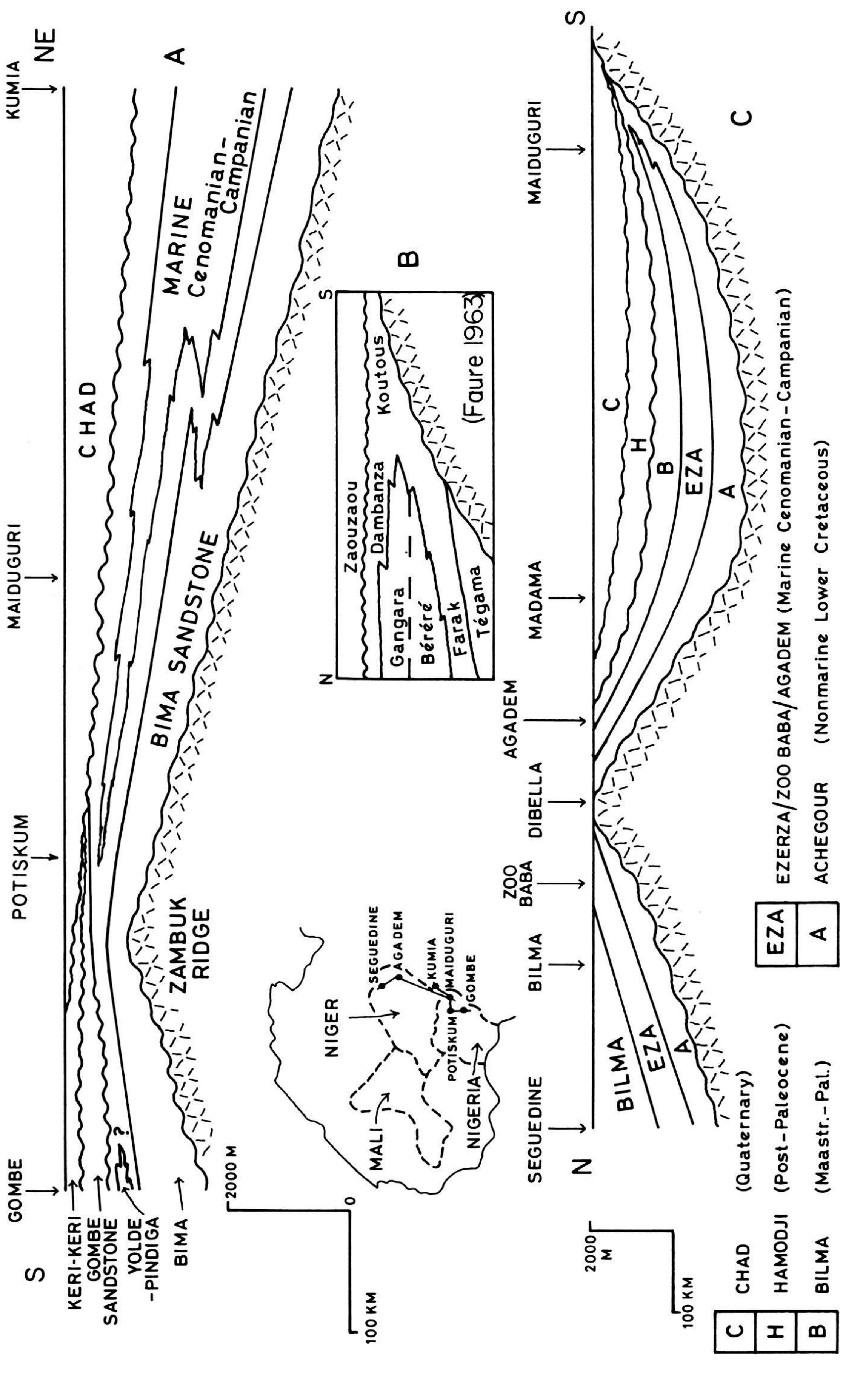

Fig. 6. Schematic stratigraphic sections across the Chad basin.

Post-Paleocene

Coarse, clayey, fluviatile sandstones and lacustrine clays, up to 400 m thick rest disconformably on the Maastrichtian-Paleocene. This sequence is referred to as the "Continental Terminal" Group throughout West Africa. In the Chad basin the "Continental Terminal" Group is variously known as the Homodji, Dolle and Zaouzaou Formations. These formations are separated from the overlying Chad Formation by a pronounced erosional surface. The Chad Formation is over 600 m thick in the Nigerian part of the Chad basin (BARBER & JONES 1960) and comprises thick pluvial lacustrine clays with diatomite, Pleistocene mammals and coarse fluviatile sands.

Stratigraphy of the Iullemmeden basin

The Iullemmeden basin occupies a broad depression between the Ahaggar mountains and the Upper Guinea basement arch, and extends from northwestern Nigeria into western Niger Republic and eastern Mali. South of Adrar des Iforas the basin forms a narrow panhandle being located in the Gao graben (Fig. 1). Apart from the Gao graben no other rifts are known in the Iullemmeden basin. A well drilled northeast of Gao, outside the rift, reached basement at about 2000 m having penetrated Cretaceous and Paleozoic marine strata (HAZZARD et al. 1971). These are the deposits of the Devonian-Carboniferous and Cenomanian transgressions which preceded the differentiation of the Iullemmeden basin. The Maastrichtian-

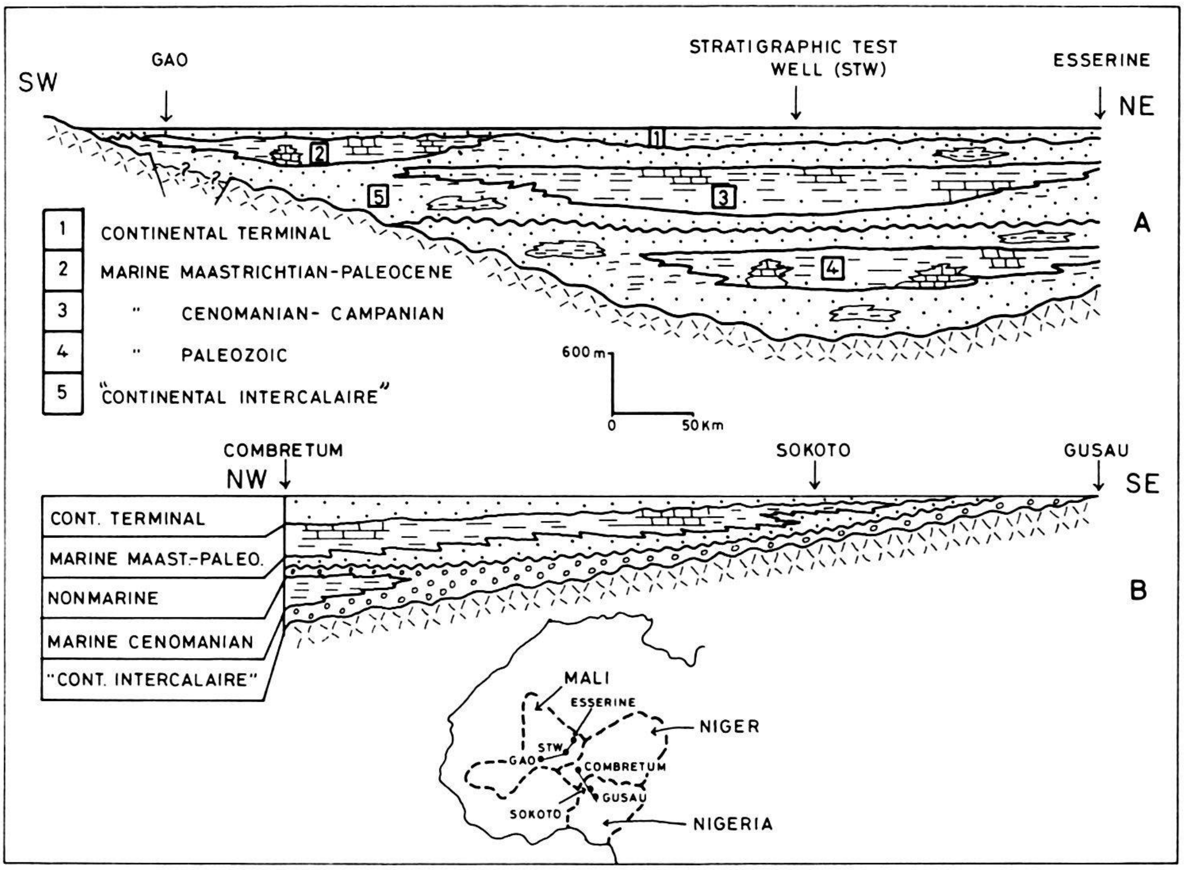

Fig. 7. Schematic stratigraphic sections across the Iullemmeden basins.

Paleocene sequence onlaps the southeastern and western parts of the Iullemmeden basin (Fig. 7*B*) suggesting maximum subsidence of the basin during that time.

The southeastern part of the Iullemmeden basin is located in northwestern Nigeria (Fig. 3) which is stratigraphically representative of the exposed basin margin. There is close agreement between the stratigraphic succession in northwestern Nigeria and the successions in neighbouring Niger Republic described by GREIGERT (1966), GREIGERT & POUGNET (1967) and RADIER (1959). Stratigraphic descriptions presented below are based largely on personal observations on parts of the basin in Niger and Nigeria.

Lower Cretaceous

The "Continental Intercalaire" Group is the basal sandstone sequence in the Iullemmeden basin. In eastern Mali, western Niger and northwestern Nigeria the sandstones and clays of the "Continental Intercalaire" Group rest directly on crystalline basement and have yielded fossil wood and vertebrate and invertebrate fossils of Lower Cretaceous age (FURON 1963; GREIGERT & POUGNET 1967) and of Late Jurassic-Early Cretaceous age in northwestern Nigeria (KOGBE & LEMOIGNE 1976). In the Sokoto State of northwestern Nigeria the "Continental Intercalaire" Group is known as the Gundumi Formation in the northeastern part and as the Illo Formation in the southwestern part (JONES 1948). Both formations are lateral equivalents and are up to 300 m thick. The Illo-Gundumi sequence comprises a lower, white conglomeratic, arkosic, cross-bedded sandstone with interbedded concretionary and highly aluminous clays, and an upper coarse to medium, cross-bedded sandstone.

Cenomanian–Turonian

Marine Cenomanian–Turonian deposits are not widely distributed in the Iullemmeden basin. They are exposed north of Tahoua where a Cenomanian fauna comprising *Exogyra columba minor* LAMARCK, *Strombus incertus* D'ORBIGNY and *Ostrea biauriculata* var. *hippopodium* FURON are known (FURON 1963). The Lower Turonian fauna comprises *Exogyra olisiponensis* SHARPE, *Paravascoceras cauvini* CHUDEAU and *Paracanthoceras chevalieri* FURON (FURON 1963). The Upper Turonian is sandy and regressive. Cenomanian–Turonian marine beds are known in boreholes in the Gao trough (RADIER 1959) and between the Gao trough and the Adrar des Iforas (HAZZARD et al. 1971; KRASHENINNIKOV & TROFIMOV 1969).

Maastrichtian

A Late Cretaceous transgressive sandstone sequence disconformably overlies the "Continental Intercalaire" Group in the Iullemmeden basin. In Niger the Senonian continental facies which rests on the "Continental Intercalaire" Group is known as the "Continental Hamadien" (FURON 1963). The equivalent in northwestern Nigeria is the Taloka Formation (Fig. 4, 8*A*) which comprises a lower brown, laminated and carbonaceous mudstone with lignite beds, and an upper sequence of alternating thin, parallel-bedded, tabular, laterally persistent, clayey, fine-grained sandstone, siltstones and massive, tabular mudstones. The lower mudstones and siltstones are cross-laminated. In exposures northeast of Sokoto (Fig. 3) pelecypod casts and impressions, worm fecal castings and *Thalassinoides* (Fig. 9*A*, *B*; Fig. 10*C*) occur in the middle siltstone beds. *Ophiomorpha* (Fig. 10*A*, *B*) and reptilian fragments are common in a sandstone ledge at the top of the Taloka Formation (Fig. 8*A*).

The Taloka Formation is about 50 m thick and becomes very clayey at the top where it grades into 10 m of gypsiferous, fissile, bluish-grey shale and marl, the Dukamaje Formation. The Dukamaje Formation consists of a thin basal bone bed; a lower shale with thin gypsum beds, septaria and fragments of turtles, crocodiles, fishes and mesosaurus; a middle fossiliferous marl with the ammonite *Libycoceras;*

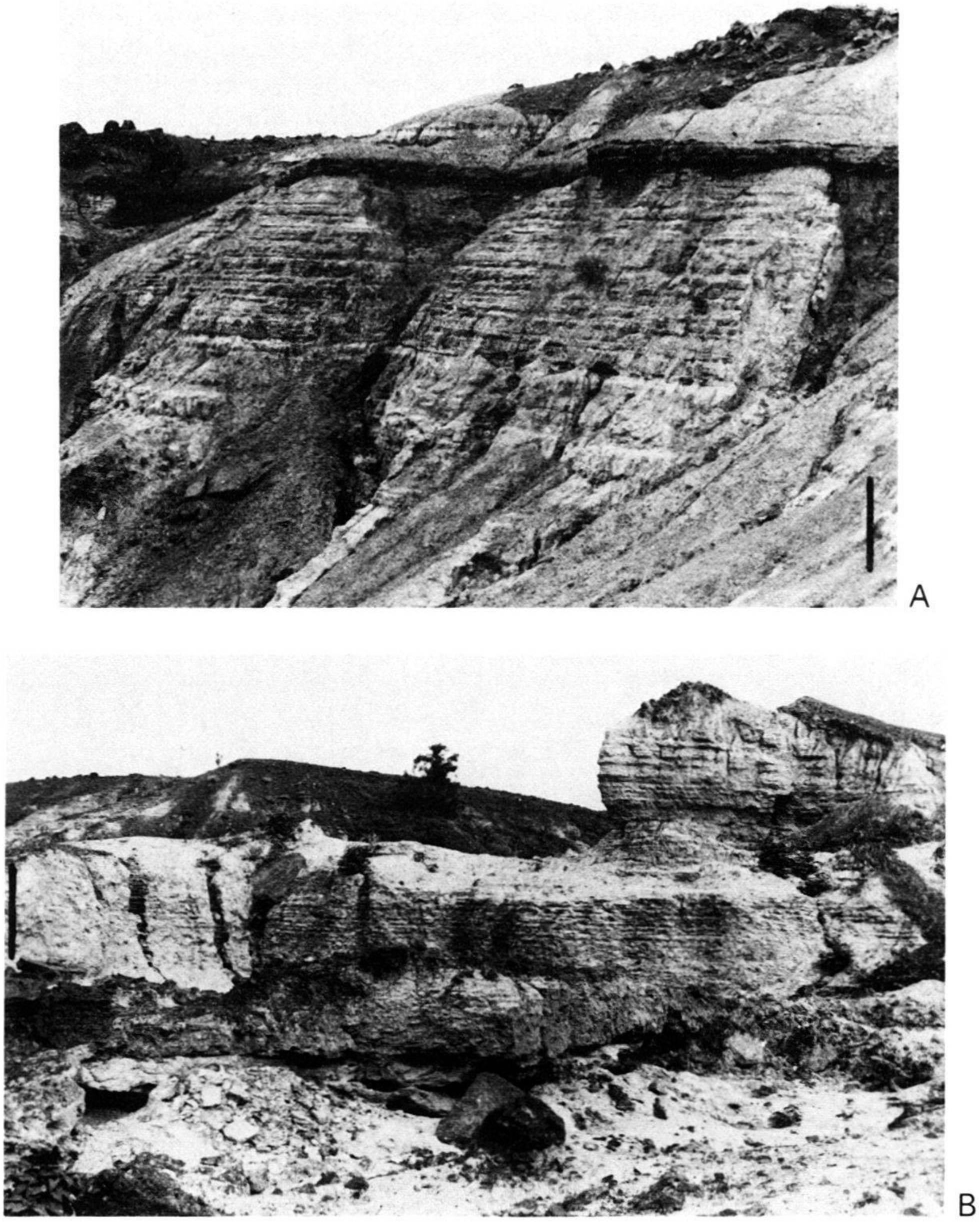

Fig. 8. *A* = Type section of the Taloka Formation (upper part) at Taloka village northeast of Sokoto, bar scale is 3 m. *B* = Wurno Formation at type locality near Wurno village northeast of Sokoto, bar scale is 4 m.

and an upper gypsiferous shale (PETTERS 1979*a*). The foraminiferal microfaunas of the Dukamaje Formation support Middle to Late Maastrichtian age (PETTERS 1978*a*, *d*). Marine Maastrichtian beds in the Iullemmeden basin occur both in outcrop and in the subsurface in Mali and Niger (FURON 1963; GREIGERT 1966; KRASHENINNIKOV & TROFIMOV 1969; RADIER 1959). Marine Maastrichtian beds pinch-out to the northwest of Sokoto in the southeastern part of the Iullemmeden basin. There is an exposure of marginal marine Maastrichtian beds 450 km south of the Sokoto area in the middle Niger valley in southern Nigeria (ADELEYE 1972), but these beds have yielded only arenaceous foraminifera of marsh and transitional origin and belong to a contemporaneous embayment from the Gulf of Guinea which existed in southern Nigeria.

Paleocene

A mild regression occurred at the end of the Maastrichtian in the Iullemmeden basin. The Wurno Formation (Fig. 8*B*) is the regressive clastic unit in northwestern Nigeria. The Wurno Formation comprises parallel-bedded, tabular mudstones, muddy siltstones and fine-grained sandstones. The siltstones contain horizontally

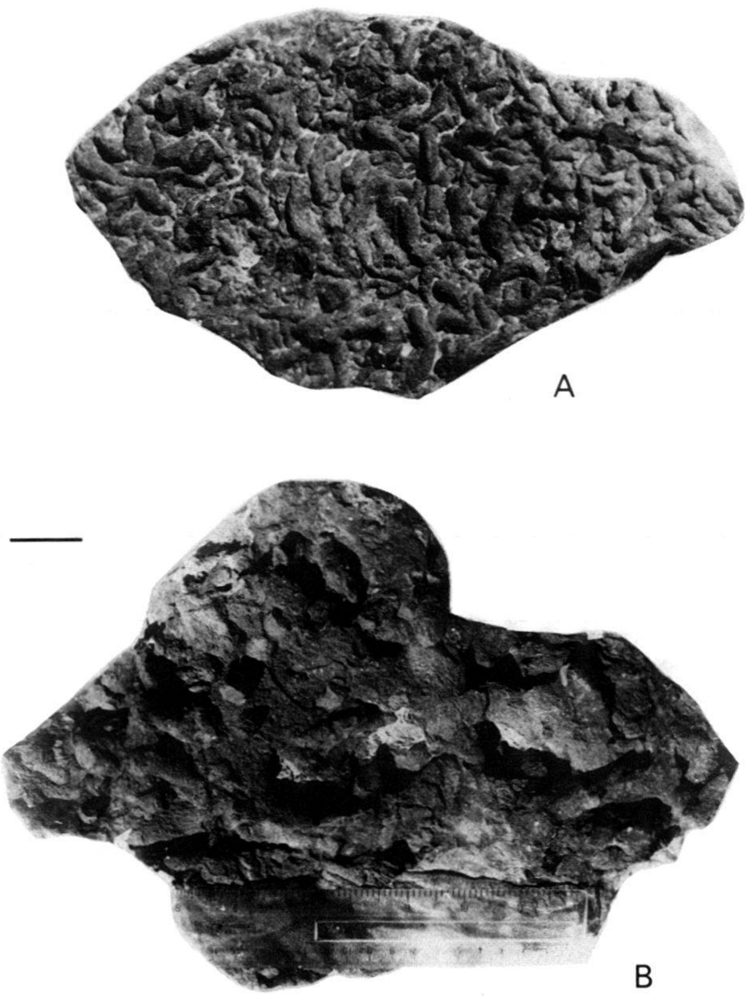

Fig. 9. *A* = Worm fecal castings in the middle part of the Taloka Formation at Taloka village, bar scale is 15 mm. *B* = *Thalassinoides* from the middle part of the Taloka Formation at Taloka village.

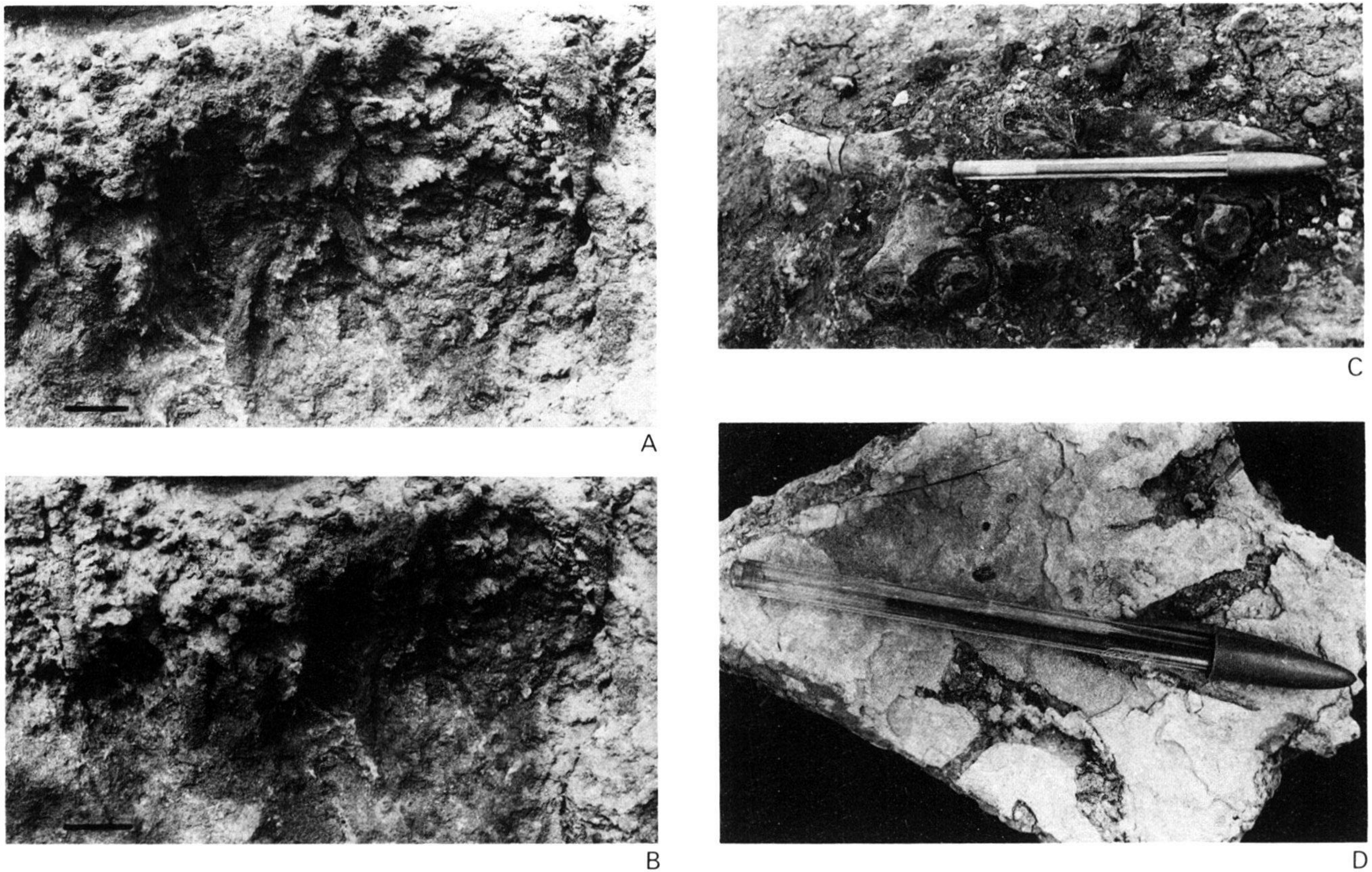

Fig. 10. *A*, *B* = *Ophiomorpha* from sandstone ledge at the top of the Taloka Formation at Taloka village, bar scale is 5 cm. *C* = *Thalassinoides* from sandstones ledge at the top of the Taloka Formation at Taloka village. *D* = Horizontal branching burrows in middle siltstone of the Wurno Formation at Wurno village.

branching burrows (Fig. 10*D*) and arenaceous foraminifera in the middle part. The Wurno Formation is so similar lithologically to the Taloka Formation that both formations are indistinguishable beyond the wedge-out belt of the intervening Dukamaje Formation (PETTERS 1979*a*). From a thickness of about 20 m northeast of Sokoto, the Wurno Formation thins very rapidly basinward and is indistinguishable just downdip from Sokoto town. The Wurno Formation was correlated with the Lower Paleocene (PETTERS 1978*d*). In the region surrounding the Adrar des Iforas an intervening sandstone is exposed between the underlying Maastrichtian marine beds and the overlying Paleocene marine beds (FURON 1963, Fig. 15). This sandstone is equivalent to the Wurno Formation.

The Wurno Formation grades into the overlying transgressive Sokoto Group in northwestern Nigeria which is equivalent to the Paleocene Adar Doutchi Formation in Niger (GREIGERT & POUGNET 1967). A similar unit comprising mudstones and a highly fossiliferous marly limestone was reported from the subsurface of Mali by KRASHENINNIKOV & TROFIMOV (1969). In northwestern Nigeria the Sokoto Group is divided into: a) a lower Dange Formation which is a 10-m gypsiferous, greenish-grey paper shale with abundant Paleocene vertebrates and arenaceous foraminifera, b) a middle Kalambaina Formation - a 10-m fossiliferous marly limestone with shallow, warm-water Tethyan Late Paleocene benthonic foraminifera, and c) an upper 2-m greenish-grey paper shale at the top of the Kalambaina Formation with an impoverished arenaceous foraminiferal assemblage. The latter unit was referred to as the Gamba Formation by KOGBE (1973); however, this stratigraphic term should be abandoned since the Gamba Formation in Gabon has priority (DE KLASZ & MICHOLET 1972; PETTERS 1979*d*).

Post-Paleocene

The continental deposits of the Gwandu Formation (northwestern Nigeria) or "Continental Terminal" Group (in francophone West Africa) disconformably overlie the Upper Paleocene marine beds in southeastern Iullemmeden basin. These Tertiary variegated lacustrine clays and cross-bedded sandstones and siltstones outcrop as mesas in the Iullemmeden basin, and attain up to 300 m thickness in the center of the basin.

Paleoenvironments

Four major lithofacies are recurrent in the Chad and Iullemmeden basins, namely:

1. continental mudstones and sandstones;
2. transitional mudstones, siltstones and fine-grained sandstones;
3. transitional gypsiferous shales;
4. highly fossiliferous marine marly limestones.

In his stratigraphic model for the Chad basin FAURE (1966, Fig. 93, 94) showed a facies relationship in which the fossiliferous marine shales and limestones of the Cenomanian–Turonian Zoo Baba Formation interfinger with the littoral gypsiferous shales and siltstones of the Ezerza and Kafra Formations. The latter formations grade into continental sandstones. FAURE (1963) depicted a similar facies relationship north of Zinder (Fig. 2) where the littoral and marine Farak, Béréré and Gangara Formations interfinger southward with the continental Koutous Formation (Fig. 6*B*).

PETTERS (1979*a*) depicted a similar intertounging stratigraphic relationship in the Maastrichtian-Paleocene sequence along the margins of the Iullemmeden basin (Fig. 7*B*). The marginal shales and marine marl of the Maastrichtian Dukamaje Formation interfinger with the littoral sandstones and siltstones of the Taloka and Wurno Formations. Foraminiferal paleoecologic analysis (PETTERS 1978*a*) shows that the Paleocene Kalambaina marly limestone is the marine equivalent of the littoral Dange shale and the upper Kalambaina shale (formerly Gamba Formation).

In addition to similarities of stratigraphic relationships, the littoral and marine deposits of the Chad and Iullemmeden basins, though different in age, share common sedimentological characteristics (Fig. 5). For example there is close lithologic similarity between the thin, parallel-bedded, fine-grained sandstones and siltstones at the base of the Coniacian-Campanian Agadem Formation in the Chad basin (FAURE 1966, Pl. 111, Fig. 1-4) and the Taloka and Wurno Formations in the Iullemmeden basin (Fig. 8*A*, *B*). The gypsiferous Cenomanian-Senonian paper shales in the Chad basin are comparable with those of the Dukamaje and Dange Formations in the Iullemmeden basin. The highly fossiliferous Dukamaje marl and Kalambaina marly limestone have analogues in the Cenomanian-Senonian fossiliferous limestones of the Chad basin. The marginal marine and marine shales of the Chad basin and the Iullemmeden basin contain mainly montmorillonite and attapulgite (FAURE 1966; RADIER 1959).

The above lithofacies similarities between the Chad and Iullemmeden basins underscore similarities of depositional environments. Epeiric sedimentation in both basins was of the shallow mixed epiclastic and carbonate type. The evaporites and vertebrate faunas of both basins suggest warm tropical climates. Fishes like *Ceratodus* and *Enchodus* which are common in the "Continental Intercalaire" Group and in the Cenomanian-Turonian of Niger (FAURE 1966; FURON 1963) and also in the Yolde Formation of the northeastern Benue trough (CARTER et al. 1963) suggest tropical paleoclimates (SCHAEFFER 1970). The presence of tropical fishes such as *Abula* and *Ginglymostoma* in the Maastrichtian of southeastern Iullemmeden basin (WHITE 1934) and crocodiles and turtles in the Maastrichtian-Paleocene of this basin suggest warm paleoclimates for the region. The alternation of wet climatic phases with dry phases is also suggested by the presence of lignite seams in the Taloka and Wurno Formations in southeastern Iullemmeden basin, and furthermore by the occurrence of hyposaline arenaceous foraminifera in the same area (PETTERS 1979*d*, *e*).

In the quiet tectonic setting with slow basement downwarp, only fine detrital sediments were supplied to the basins. The tabular bedding of the littoral sandstones and siltstones, and the strong lateral persistence of beds suggest deposition by several small streams that entered the sea, instead of a few large rivers which would have built large deltaic lobes. However, since the interior of West Africa was flooded several times by the Tethys Sea, it is likely that several inland drainage systems with many deltas existed in the region during most of its subsidence history. Perhaps the inland delta on the course of the river Niger between Mopti and Timbuktu (Fig. 2) is a remnant of such an ancient deltaic system. The river Niger, whose basin now dominates the drainage system of West Africa, may have emptied into the Saharan seas in the past. FURON (1963) discussed the Quaternary paleogeography of the middle Niger river and showed that the river Niger built deltas into a Quaternary lake which existed in the Mopti–Timbuktu region.

The Taloka and Wurno Formations are well exposed northeast of Sokoto for over 200 km and furnish a basis for interpreting littoral clastic sedimentation in the Saharan epeiric sea. The laminated, nonfossiliferous, carbonaceous mudstones with thin siltstone intercalations and lignite beds in the lower parts of the Taloka and Wurno Formations suggest paludal supratidal flats. The thin cross-laminated siltstone intercalations are probably intertidal deposits. The upper alternating sequence of thinly-bedded to massive, clayey, bioturbated sandstones and siltstones with mottled mudstone intercalations are also intertidal deposits, while the middle siltstone bed in the Taloka Formation with crowded pelecypods and *Thalassinoides* are probably beach deposits (Fig. 11).

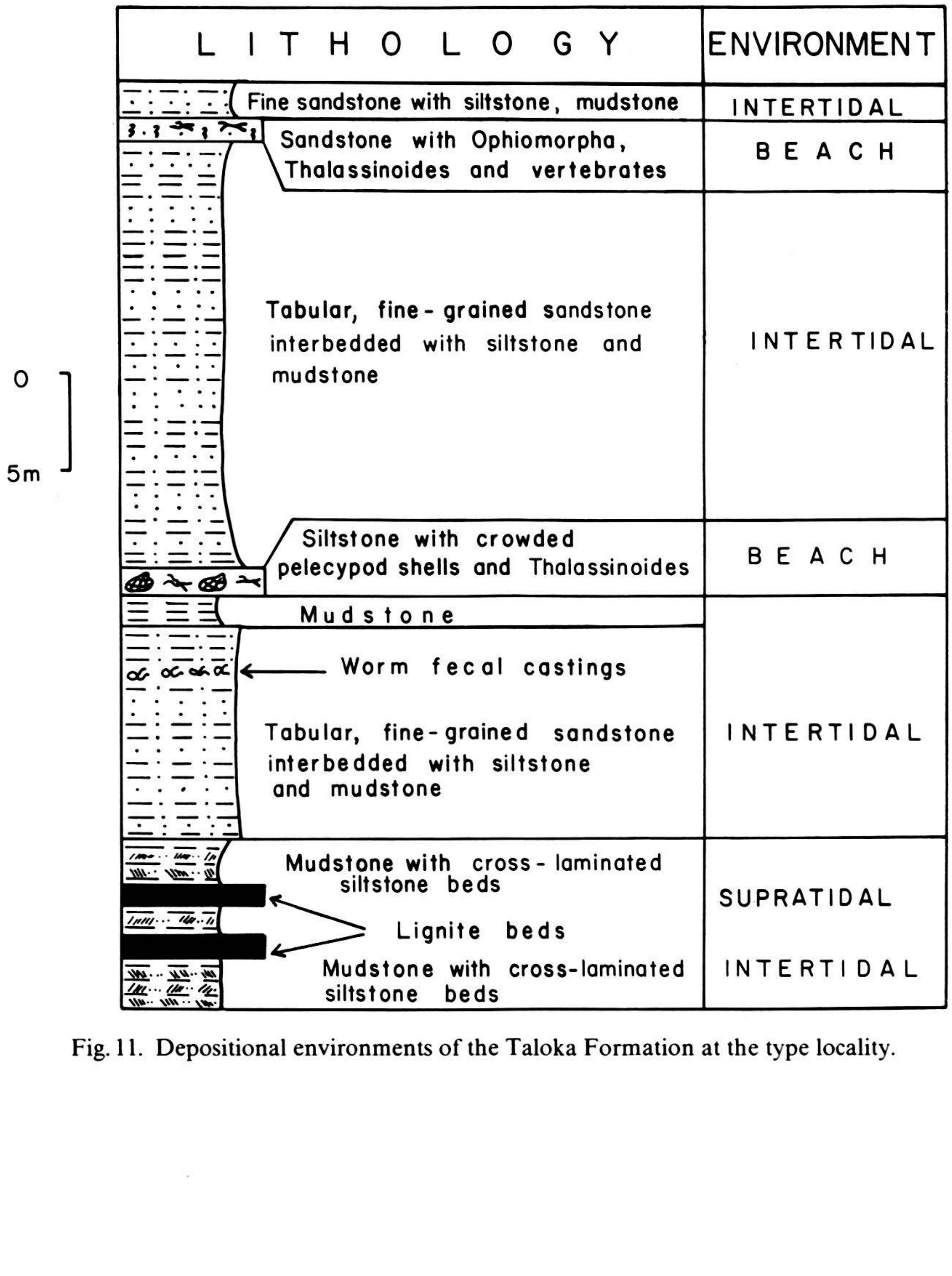

Fig. 11. Depositional environments of the Taloka Formation at the type locality.

The littoral deposits of the Saharan epeiric sea suggest weak tidal influence. Sedimentary indicators of strong tidal activity according to KLEIN'S (1977) model are conspicuously absent from the Taloka and Wurno Formations. These include flaser and lenticular bedding, cross-bedding, tidal channels, winnowed sand bodies and "fining-upward" facies. The uniform horizontal lamination and bedding and the predominance of silts and clays are features which the Saharan littoral deposits have in common with ancient deposits of shorelines of weak tidal activity described by WALKER & HARMS (1975). Recent analogues of the Saharan tidal flats are probably the smooth, featureless tidal flats of the Colorado river delta in the northwestern Gulf of California (THOMPSON 1975), where tidal channels and barrier features are rare because of the large supply of silt and clay into a low energy gulf.

Conclusions

Mesozoic break-up of Gondwana between western Africa and eastern South America affected the tectonic differentiation of the cratons in West Africa. Subsidence of the Chad and Iullemmeden basins during the Late Mesozoic and Early Cenozoic, and marine transgressions therein, occurred during episodes of craton submergence which was probably related to the motion of the African plate.

Several times in the Phanerozoic, an interior sea existed in central West Africa which was an embayment of the Tethys sea from the north. The Gulf of Guinea also transgressed up the Benue trough in Nigeria. The deposits of the Late Cretaceous-Early Tertiary Saharan epeiric seas in the Chad and Iullemmeden basins are generally thin and regionally persistent. They comprise shallow-water fossiliferous limestones which grade into littoral gypsiferous shales and clayey fine-grained sandstones and siltstones along the basin margin. From the low-lying basement terrain fine-grained detrital sediments were supplied to the low-energy Saharan seas especially during wet climatic phases.

The above stratigraphic framework has bearing on the economic potential of the Chad and Iullemmeden basins. Recent oil strikes in the southeastern part of the Chad basin, near Lake Chad (BIGNELL 1977) indicate favourable petroleum prospects in the thicker sedimentary fill (up to 4000 m) of the Chad basin. The Cretaceous marine and littoral shales of the Chad basin are potential source rocks, while the basal sandstones of the "Continental Intercalaire" Group which is a major oil-bearing formation in Libya (KENT 1969) are promising reservoir rocks. Hydrocarbon occurrences in the interfingering littoral sandstones is a possibility. The petroleum prospects of the Iullemmeden basin are not as promising. So far, only dry holes have been drilled in this basin (BIRO 1976; HAZZARD et al. 1971). This is not surprising in view of the thin sedimentary cover in this basin (about 2000 m), and the probably immature state of the widespread Maastrichtian-Paleocene marine shales which have not been deeply buried.

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REFERENCES

ADEGOKE, O.S., JAN DU CHENE, R.E., AGAMANU, A.E., & AJAYI, P.O. (1978): *Palynology and age of the Kerri-Kerri Formation, Nigeria.* - Rev. españ. Micropaleont. *10*/2, 267-283.

ADELEYE, D.R. (1972): *A fauna from the ironstone of middle Niger valley, Nigeria.* - Niger. J. Mining Geol. *8*, 45-48.

BARBER, W. (1957): *Lower Turonian ammonites from north-eastern Nigeria.* - Bull. geol. Surv. Nigeria *26*.

BARBER, W., & JONES, D.G. (1960): *The geology and hydrology of Maiduguri, Bornu Province.* - Rec. geol. Surv. Nigeria *1958*, 5-20.

BIGNELL, R. (1977): *Petroleum developments in central and southern Africa in 1976.* - Bull. amer. Assoc. Petroleum Geol. *61*, 1746-1794.

BIRO, P. (1976): *Petroleum developments in central and southern Africa in 1975.* - Bull. amer. Assoc. Petroleum Geol. *60*, 1813-1864.

BOND, G. (1978): *Evidence for Late Tertiary uplift of Africa relative to North America, South America, Australia, and Europe.* - J. Geol. *86*, 47-65.

BOTT, M.H.P. (1976): *Mechanisms of basin subsidence - An Introductory review.* - Tectonophysics *36*, 1-4.

BURKE, K. (1976): *The Chad basin: An inactive intra-continental basin.* - Tectonophysics *36*, 197-206.

BURKE, K., & DEWEY, J.F. (1974): *Two plates in Africa during the Cretaceous.* - Nature *249*, 313-315.

BURKE, K., & WILSON, J.T. (1972): *Is the African plate stationary?* - Nature *239*, 387-390.

CARTER, J.D., BARBER, W., TAIT, E.A., & JONES, G.P. (1963): *The geology of parts of Adamawa, Bauchi, and Bornu Provinces in northeastern Nigeria.* - Bull. geol. Surv. Nigeria *30*.

COLLIGNON, M. (1957): *Céphalopodes neocrétacées du Tinrhert (Fezzan).* - Ann. Paléont. *43*, 115-136.

— (1965): *Nouvelles ammonites néocrétacées sahariennes.* - Ann. Paléont. *51*, 165-202.

CLOOS, H. (1939): *Hebung-Spaltung-Vulcanismus.* - Geol. Rdsch. *30*, 405-527.

DE KLASZ, I., & MICHOLET, J. (1972): *Elements nouveaux concernant la biostratigraphie du bassin gabonais* (p. 109-143). - IV^e Colloq. Afr. Micropaleont. Act. Congr.

DILLON, W.P., & SOUGY, J.M.A. (1974): *Geology of West Africa and Canary and Cape Verde Islands.* In: NAIRN, A., & STEHLI, F. (Ed.): *The ocean basins and margins* (vol.2, p.315-390): *The North Atlantic.* - Plenum Press.

FAURE, H. (1963): *Carte géologique de reconnaissance du Niger oriental, scale 1:1000000.* - Mém. Bur. Rech. géol. min.

— (1966): *Reconnaissance géologique de formations sédimentaires post-Paléozoïques du Niger oriental.* - Mém. Bur. Rech. géol. min. *46*.

— (1973): *Vertical movements and horizontal translation of the lithosphere.* In: RUNCORN, S.K., & TARLING, O. (Ed.): *Implications of continental drift to the earth sciences* (vol.2, p.731-733). - Academic Press.

FRANKS, S., & NAIRN, A.E.M. (1973): *The equatorial marginal basins of West Africa.* In: NAIRN, A., & STEHLI, F. (Ed.): *The ocean basins and margins* (vol. 1, p.301-350): *The South Atlantic.* - Plenum Press.

FURON, R. (1963): *Geology of Africa.* - Oliver & Boyd.

GREIGERT, J. (1966): *Description des formations Crétacés et Tertiaires du basin de Iullemmeden.* - Mém. Bur. Rech. géol. min. *36*.

GREIGERT, J., & POUGNET, R. (1967): *Essai de description des formations géologiques de la Republique du Niger.* - Mém. Bur. Rech. géol. min. *48*.

HAZZARD, J.C., MORRIS, A.E.L., & WISSLER, S.G. (1971): *Petroleum developments in central and southern Africa in 1970.* - Bull amer. Assoc. Petroleum Geol. *55*, 1559-1602.

HAUGHTON, S.H. (1963): *Stratigraphic history of Africa south of the Sahara.* - Haffner.

JONES, B. (1948): *The sedimentary rocks of Sokoto Province.* - Bull. Geol. Surv. Nigeria *18*.

KENT, P.E. (1969): *The geological framework of petroleum exploration in Europe and North Africa and the implications of continental drift hypothesis.* In: *The exploration for petroleum in Europe and North Africa* (p.3-17). - Inst. Petroleum.

— (1974): *Continental margin of East Africa - a region of vertical movements.* In: BURK, C., & DRAKE, C. (Ed.): *The geology of continental margins* (p.313-320). - Springer, Heidelberg.

KLEIN, G. DE V. (1977): *Tidal circulation model for deposition of clastic sediment in epeiric and mioclinal shelf seas.* - Sediment. Geol. *18*, 1-12.

KOGBE, C.A. (1973): *Geology of the Upper Cretaceous and Tertiary sediments of the Nigerian sector of the Iullemmeden basin (West Africa).* - Geol. Rdsch. *62*, 197-211.

KOGBE, C.A., & LEMOIGNE, Y. (1976): *Bois de structure gymnospermienne provenant de la formation D'Illo (Continental Intercalaire) au nord ouest du Nigeria.* - 7th Afr. Micropaleont. Colloq. Abstr.

KRASHENINNIKOV, V.A., & TROFIMOV, D.M. (1969): *Sravitel'nyy analiz benthosnykh foraminifer datsko-paleotsenovykh otlozhneniy Mali, oblasti tetisa i severo-zapodny Evropy.* - Vopr. Micropaleont. SSSR *12*, 108-144.

LEHNER, P., & DE RUITER, P.A.C. (1977): *Structural history of Atlantic margin of Africa.* - Bull amer. Assoc. Petroleum Geol. *61*, 961-981.

LOUIS, P. (1970): *Contribution géophysique à la connaissance géologique du basin du Lac Tchad.* - Mém. Office Rech. Sci. Tech. Outre-Mer *42*.

NAGY, R.M., GHUMA, M.A., & ROGERS, J.J.W. (1976): *A crustal suture and lineament in North Africa.* - Tectonophysics *31*, 67-72.

NAIRN, A.E.M. (1978): *Northern and eastern Africa.* In: MOULLADE, R., & NAIRN, A. (Ed.): *The Phanerozoic geology of the world* (vol. 2, p. 329-370): *The Mesozoic.* - Elsevier.

PETTERS, S.W. (1978*a*): *Foraminiferal paleoecology of the southeastern part of the Maastrichtian-Paleocene Saharan epeiric sea.* - J. foram. Res. *8*, 303-313.

— (1978*b*): *Mid-Cretaceous paleoenvironments and biostratigraphy of the Benue trough, Nigeria.* - Bull. geol. Soc. Amer. *189*, 151-154.

— (1978*c*): *Stratigraphic evolution of the Benue trough and its implications for the Upper Cretaceous paleogeography of West Africa.* - J. Geol. *86*, 311-322.

— (1978*d*): *Maastrichtian-Paleocene foraminifera from NW Nigeria and their paleogeography.* - Acta palaeont. pol. *23*, 131-152.

— (1979*a*): *Stratigraphical history of the south-central Saharan region.* - Bull. geol. Soc. Amer. *90*, 753-760.

— (1979*b*): *West African cratonic stratigraphic sequences.* - Geology *7*/11, 528-531.

— (1979*c*): *Paralic arenaceous foraminifera from the Upper Cretaceous of the Benue trough, Nigeria.* - Acta palaeont. pol. *24*/4, 451-471.

— (1979*d*): *Maastrichtian-Paleocene cyclothems and paleoclimate in SE Iullemmeden Basin, West Africa.* - Newsl. Stratigr. *8*/3, 180-190.

— (1979*e*): *Maastrichtian arenaceous foraminifera from north-western Nigeria.* - Palaeontology *22*/4, 945-962.

RADIER, H. (1959): *Contribution à l'étude géologique du Soudan oriental (A.O.F.). Le basin crétacé et tertiaire de Gao le détroit Soudanais.* - Bull. Serv. géol. Prosp. Min. *26*, 315-556.

RAEBURN, C., & JONES, B. (1934): *The Chad basin: Geology and water supply.* - Bull. Geol. Surv. Nigeria *15*, 20-23.

REYMENT, R.A. (1955): *The Cretaceous Ammonoidea of southern Nigeria and the southern Cameroons.* - Bull. Geol. Surv. Nigeria *25*.

SCHAEFFER, B. (1970): *Mesozoic fishes and climate.* In: YOCHELSON, B. (Ed.): *Proceedings of the North American Paleontological Convention* (p. 376-388). - Allen Press.

SLOSS, L.L. (1972): *Synchrony of Phanerozoic sedimentary-tectonic events of the North American craton and the Russian platform.* - 24th Int. Geol. Congr. Montreal, Sect. *6*, 24-32.

SLOSS, L.L., & SPEED, R.C. (1974): *Relationship of cratonic and continental-margin tectonic episodes.* In: DICKINSON, E. (Ed.): *Tectonics and sedimentation.* - Spec. Publ. Soc. econ. Paleont. Mineral. *22*, 98-119.

THOMPSON, R.W. (1975): *Tidal-flat sediments of the Colorado River delta, northwestern Gulf of California.* In: GINSBURG, R. (Ed.): *Tidal deposits* (p. 57-65). - Springer, Heidelberg.

THOMPSON, T.L. (1976): *Plate tectonics in oil and gas exploration of continental margins.* - Bull amer. Assoc. Petroleum Geol. *60*, 1463-1501.

VAN HOUTEN, F.B. (1977): *Triassic-Liassic deposits of Morocco and eastern North America: Comparison.* - Bull. amer. Assoc. Petroleum Geol. *61*, 79-99.

WALKER, R.G., & HARMS, J.C. (1975): *Shorelines of weak tidal activity: Upper Devonian Catskill Formation, Central Pennsylvania.* In: GINSBURG, R. (Ed.): *Tidal Deposits* (p. 103-108). - Springer, Heidelberg.

WHITE, E.I. (1934): *Fossil fishes of Sokoto province.* - Bull. Geol. Surv. Nigeria *14*.