

The palaeoenvironment of deposition of Late Maastrichtian to Paleocene black shales in the eastern Dahomey Basin, Nigeria

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Abstract

Extensive black shale facies of Late Maastrichtian to Paleocene age are associated with the equally widely distributed tar sand sequence in the Nigerian sector of the Dahomey Basin. The shales are commonly finely laminated and are rich in organic carbon. They contain an abundance of pyrite and have yielded a rich faunal assemblage indicating shallow water conditions. The co-occurrence of abundant benthos, pyrite and enhanced organic carbon contents in the shales suggests an overall euxinic depositional palaeoenvironment that was episodically oxygenated.

Introduction

Since the discovery of extensive tar sands with estimated reserves of over 30 billion barrels of oil in the Nigerian sector of the Dahomey Basin (Adegoke et al. 1980, 1981) studies on the associated black shales seem to have gathered momentum.

Black shales are argillaceous rocks rich in organic matter. They are characteristically composed of fine grained materials forming laminae that are arranged parallel to the bedding (Hallam, 1980). According to Curtis (1980) black shales are fissile fine grained rocks with “abnormally” high carbon, low carbonate and high pyrite contents. The fissility is commonly associated with lamination and has been attributed to an abundance of straight-chain aliphatic hydrocarbons within the organic-rich laminae (Blatt et al., 1980).

In recent years much attention has been focused on black shale sequences because of their importance as potential source rock for liquid hydrocarbons. Particularly, studies focusing on the origin and depositional environment of black shales have generated considerable debate and various deposi-

tional models have been proposed (Legget, 1980; Jenkyns, 1978, 1980; Hallam, 1978; Hallam & Bradshaw, 1979).

Detailed field data on the occurrence and extent of the black shales within the eastern Dahomey Basin became available after a comprehensive drilling programme was carried out by the Geological Consultancy Unit, University of Ife in Ondo State. This programme was restricted to the tar sand outcrop belt (Fig. 1) since it aimed in particular at appraising the extent and quality of the tar sand deposits. The reserve estimates (Adegoke et al. 1980), the clay mineral distribution (Enu et al., 1981) and the maturity (Nwachukwu & Adebayo, unpubl. ms.) of the black shales have been re-examined. In all these relatively independent studies little attention was paid to the physical characteristics of the shales to assess their depositional environment. This paper therefore attempts to interpret the depositional environment of the black shales on the basis of sedimentological and faunal characteristics.

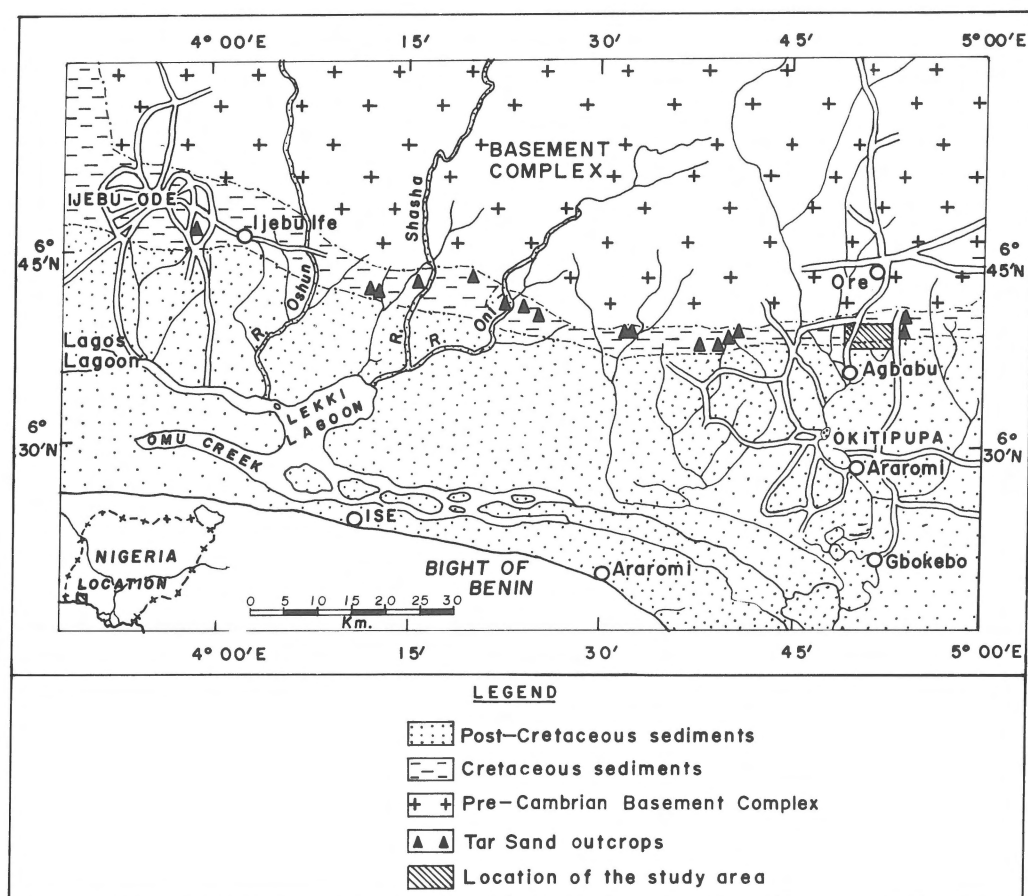


Fig. 1. Geological sketch map of southwestern Nigeria showing the tar sand outcrop belt and the location of the study area.

Stratigraphic summary

The stratigraphy of the eastern margin of the Dahomey Basin was initially described by Slansky, (1962) and Adegoke (1969), and recently re-examined on the basis of additional data by Billman (1976) and Omatsola & Adegoke (1981).

Three formations of Upper Cretaceous-Paleocene age are distinguished within the basin: viz. the Ise, Afowo and Araromi Formations. The oldest Ise Formation comprises a sequence of continental sands and grits. It overlies a block-faulted Precambrian basement complex. The overlying Afowo Formation is composed of sands with interbedded shales while the youngest Araromi Formation consists essentially of shales with thin interbedded limestone beds and lignitic bands.

A typical stratigraphic section showing the black shale and tar bearing sands is shown in Fig. 2. The basal horizon consists of loose conglomerate and clean quartz sand with admixtures of kaolinitic clay. This is overlain by two levels of oil-bearing, fine grained sands with an average thickness of 15 metres each. The two levels, designated as Horizon X and Y (Adegoke et al., 1980), are separated by a fairly thick organic-rich black shale. The uppermost sediments consist of a variable sequence including sand, shale, (thin) limestone, sandy siltstone and a lateritic top soil. The beds dip gently southwards at about 10° – 12° .

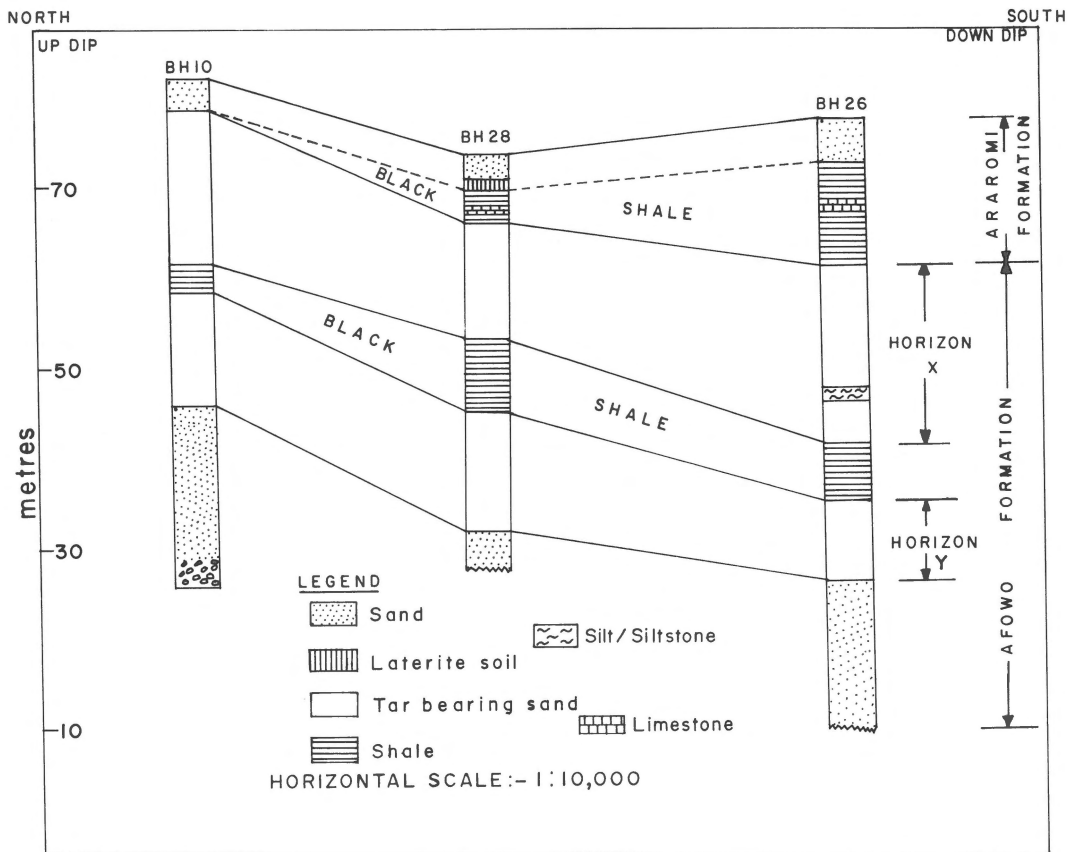


Fig. 2. Schematic north-south cross section of the studied stratigraphic sequence.

The black shales

The black shale facies within the Nigerian sector of the eastern Dahomey Basin belongs to the Afowo and Araromi Formations and occurs between and above the two tar-bearing sands (Fig. 2). The black shales, here referred to as the "Agbabu black shales", are dark grey to black and they are commonly finely laminated. The thickness ranges from 6 metres to 15 metres and averages 8 metres. Lateral facies changes are common in the black shales. The most noticeable changes concern the colour and the texture. The shales range from a grey, silty variety in the west to dark grey to black shales in the east of the area (Adegoke et al., 1980).

Sedimentary structures

Structurally, the black shales are characterised by a fine parallel lamination that imparts a fairly well defined fissility to the rock. The laminae are organic-rich and bituminous. The lighter coloured variety of the shale, which contains less organic material, is commonly bioturbated.

Mineralogy

The "Agbabu black shales" essentially comprise only silt and clay particles. Fine quartz silt constitutes about 5% of the shales. The quartz grains are chiefly subangular to subrounded. Feldspars are absent and muscovite flakes constitute the pre-

dominating micaceous mineral in the shales. Pyrite is abundant and occurs as spheroidal framboids of about 1 cm in diameter. In addition, pyrite occurs as a coating on fossils and as rims on concretions. Some of the shales are calcareous; they may contain up to about 25% CaCO₃. This high carbonate content is attributable to the presence of shell fragments of, among others, bivalves, gastropods and ammonites.

Clay Mineralogy

Clay particles account for over 80% of the shales. The clay mineral distribution pattern within the tar sand sequence shows that kaolinite is dominant, followed by randomly mixed layer clays. (Enu et al., 1981). There is a progressive decrease in kaolinite content from over 95% updip (e.g. BH 10), through 50–70% in the central part to 35%–50% and less downdip (Enu et al., 1981). Conversely, the mixed layer clay content in the shales increases from about 20% to 85% in a downdip direction. Overall the shales contain little smectite. Only a few boreholes drilled downdip (e.g. BH 26) yielded smectite percentages of 5 to 12%. Chlorite and illite are present in small amounts; they do not exceed 5%. The observed increase in mixed layer clays downdip, at the expense of kaolinite and smectite, may be due to mineralogical alteration resulting from burial diagenesis (Dunoyer de Segonzac, 1970).

Organic carbon

Organic carbon content was determined of typical black shale samples retrieved from core material. The results obtained show that the black shales contain significant amounts of organic material. The black shales interbedded between the tar sands yielded the highest total organic carbon values, ranging from 3.0% to 4.9 wt%. The shales above the tar sands possess an average total organic carbon content of 2.4 wt% (Adedayo, 1985; Nwachukwu & Adedayo, unpubl. ms). The high to fairly high total organic carbon values of the black shales

are incontestable evidence of organic enrichment in the “Agbabu black shales”.

Fauna and age

The black shales contain a rich assemblage of foraminifera, ostracods, pollen and spores (cf. Adegoke et al., 1980; Jan du Chene, 1977). The interbedded shales yielded a faunal assemblage including *Heterohelix striata*, *H. navaroensis*, *Cibicides harperi* and *Afrobolivina afra*, which is indicative of a Late Maastrichtian age. The shales above the tar sands contain in their lower portion a microfauna with *Subbotina triloculinoides* and *Bulimina Kugleri* and have therefore a transitional age of Late Maastrichtian to Paleocene. The upper part of this shale section contains essentially Paleocene forms, such as *Lenticulina midwayensis* and *Dentalina colei* (Adegoke et al., 1980). Thus a total age range of Late Maastrichtian to Paleocene can be assigned to the black shale facies.

Depositional environment

The black shales in the Agbabu area of the eastern Dahomey Basin are interpreted to have been deposited in an overall epicontinental, shallow marine environment that is characterized by usually anoxic, but episodically oxygenated, low energy bottom conditions. This interpretation is further discussed below. In southwestern Nigeria, including the location of the eastern, Nigerian sector of the Dahomey Basin, the Late Maastrichtian-Paleocene is known to have witnessed an important transgressive phase in an epicontinental setting (Adegoke, 1977). Jenkyns (1980) in particular described a mechanism by which a transgression may promote the deposition of organic-rich sediments. According to him, Cretaceous transgressions induced the production of sufficient organic material to render them potential sources of oxygen-depleted waters in epeiric and marginal seas. The regional geological setting of the “Agbabu black shales” thus conforms numerous other black shale occurrences, where deposition is often also inter-

puted to be related to global marine transgressions (Legget, 1980; Hallam, 1981; Hallam & Bradshaw, 1979; and Jenkyns, 1980).

Black colours in clayey sediments are in most cases attributed to enrichment in organic matter. The conservation of substantial amounts of organic, i.c. bituminous matter in such sediments can only occur under conditions of oxygen depletion and stagnant bottom waters. Thus, the grey to black colour and associated relatively high organic carbon content of the "Agbabu black shales" suggests similar environmental circumstances. During the late Cretaceous sediments accumulated in the Dahomey Basin within block-faulted grabens which formed as a result of major Santonian tectonic activity (Omatsola & Adegoke, 1981). Apparently, these grabens were sites with oxygen-depleted and stagnant bottom water conditions which enhanced the preservation of organic matter in the sediments.

Pyrite in shales in general is an indication that sediments accumulated in an environment where anoxic conditions extended to the sediment surface (Morris, 1980). The abundance of this mineral in the "Agbabu black shales" is thus also an indication for poorly aerated bottom waters.

An environment that supports extensive pyrite precipitation is inimical to the establishment of benthic fauna. (Legget, 1980). However, the faunal assemblage retrieved from the "Agbabu black shales" includes epifaunal suspension feeder-type benthic macrofossils such as the molluscs *Sphenodiscus* and *Inoceramus*. The presence of this benthos attests to a shallow water depositional environment but negates the argument in favour of total euxinic bottom conditions. It is evident that the benthic environment in which the "Agbabu black shales" were deposited was not persistently oxygen-deficient. There was at least some episodic oxygenation of bottom waters to allow temporary existence of the benthos. This interpretation is in agreement with previous views given for similar deposits in the Vaucontian basin in S. France (Guerin & Moullade, 1979; and for the Middle Triassic of Monte San Giorgio in Switzerland (Gall, 1979).

Since sand grains are virtually lacking, it is ap-

parent that the shales were deposited in an environment where bottom currents must have been so insignificant, that they allowed settling of the fines only. The presence of distinct laminations as well as concretions in the shales supports this interpretation of a low energy environment of deposition.

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