



Geochemistry and paleoecology of shales from the Cenomanian-Turonian Afowo formation Dahomey Basin, Nigeria: Implication for provenance and paleoenvironments

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Abstract

Cenomanian – Turonian (CT) Afowo shales selected from offshore X, and coastline Orimedu-1 and Ise-2 exploratory wells in the Dahomey Basin, southwestern Nigeria, were analyzed for foraminifera, major oxide and trace elements to evaluate their provenance and paleoenvironments.

The hydrocarbon rich calcareous CT shale is about 100m thick in the coastline area and 300m thick in offshore area with abundant of marine planktonic and benthonic foraminifera. Benthonic species were significantly present in the coastline wells suggesting a shallow marine condition probably a neritic to inner shelf environments while abundant deep water *Rotaliporid* sp. and shallow water fauna *heterohelix* sp. in X well suggest inner shelf to bathyal (ca. >350m) depositional environments.

SiO₂ and Al₂O₃ are the most abundant oxides of CT shale with average value of 46.4% and 12.7% in X, 57.1% and 15.65% in Orimedu-1 and 55.3% and 13.1% in Ise-2 respectively suggesting high influx of terrigenous and argillaceous sediments at the coastal area. Average Al₂O₃/TiO₂ of 19.2 in X, 17.8 in Orimedu-1 and 19.3 in Ise-2 indicates that the sediments were sourced from intermediate igneous rock. Favorable oxic conditions for chemical weathering is more pronounce in the manganese concentration of 658–937 ppm in Orimedu-1 and 829–838 ppm in Ise-2 than 364–604 ppm in the shales from X well. Their degree of weathering estimated from chemical index of alteration (CIA) averaging 97 in the coastline wells is higher than 61 in X well, thus

indicating high degree of oxidation in the depositional environments. Vanadium to nickel ratio ranging from 2.88 to 5.0 in X well suggest mixed marine and terrigenous source under dysoxic to oxic conditions for the shales while 0.48–1.2 values in Orimedu-1 further indicates a prevailing oxidizing condition at the time of deposition.

Dysoxic-oxic and moderate deep-water conditions were more favorable in the offshore area and probably a significant paleo-factor for organic matter preservation of CT shales in the basin.

Introduction

The Cenomanian-Turonian (CT) Afowo Formation has been characterized as a prospective petroleum source rock in the Eastern part of Dahomey Basin, southwestern Nigeria (Fig. 1) (Adeoye et al., 2013). Petroleum potentials of Dahomey Basin are an interesting subject for about a decade because of its onshore tar sand deposit and recent offshore discoveries which affirm the presence of a working petroleum system. The basin fill consists of about 6000m thick Cretaceous siliciclastic sedimentary formations (Omatsola and Adegoke, 1981; Brownfield and Charpentier, 2006) and Paleogene to Neogene carbonate sequences. Carbonate rocks are unevenly distributed across the basin and are currently being explored for cement production. The Cenomanian to Turonian Afowo shale is still the best known and well documented potential hydrocarbon source rock in the basin (Adeoye et al., 2013). Marine Campanian Araromi and Paleocene-Eocene Oshosun shales are not rich in organic matter and immature for hydrocarbon generation (Adekeye et al., 2006; Nton et al., 2006, 2009).

However, the paleoenvironmental conditions that controlled the Late Cretaceous organic matter productivity and preservation are still not well known particularly from the perspective of foraminiferal paleoecology and inorganic geochemistry studies.

Foraminiferal occurrences and distributions along with enrichment of paleoredox proxies such as vanadium, nickel, molybdenum, copper and uranium can be used to confirm the existence of worldwide Cenomanian-Turonian oceanic anoxic events favorable for the development of organic rich black shales. Major oxides and trace elements geochemistry are useful tools in exploration to evaluate paleoenvironments, provenance, diagenetic history, paleoredox, and paleo-climatic conditions of sedimentary rocks (Vine and Tourtelot, 1970). They are most useful in fine-grained and impermeable rocks like shales, claystones, mudrocks etc. which retain most of the mineral constituents of their parent rocks and the depositional environments. The relative abundance of trace elements and oxides in sediments are controlled by sedimentation rate, terrigenous influx, biogenic influx, hydrothermal input, diagenesis and ultimately, weathering (Leventhal, 1998; Schieber and Zimmerle, 1998). Trace elements commonly have low concentration in oxic to suboxic conditions while reducing conditions their favor authigenic enrichment (Piper and Calvert, 2009; Neumeister et al., 2016). The properties and responses to different environmental conditions make trace elements and major oxides significant in provenance and depositional environmental studies. Therefore, major oxides, trace elements and foraminiferal analyses were carried out on the Cenomanian to Turonian Afowo shales from X, Orimedu-1 and Ise-2 exploratory wells (Fig. 1) and integrated to evaluate their provenance and paleoenvironments across the offshore and coastal part of Dahomey Basin, southwestern Nigeria.

The present-day position of the Dahomey Basin was a closed platform during the existence of Pangea which later broke up into Laurasia and Gondwanaland in the Triassic. Gondwanaland, an ancient supercontinent further broke up in the Jurassic into the continents of Africa, South America, Australia, Antarctica, the Indian subcontinent and the Arabian Peninsula (U. S. Geological Survey World Energy Assessment Team, 2000). Plate tectonic activities were continuous and controlled by the Romanche, Charcot and Chain fracture zones

representing period of initial fracturing of the basement in the Late Jurassic-Barremian which led to the development of rift valley and marginal depressions in the Gulf of Guinea. Fractured basement created accommodation space for a first set of sediment accumulation comprising of non-marine, fluvio-deltaic conglomerates, sandstones, mudstones, evaporites and deep-water deposits of Ise Formation. (Fig. 2) (Dumestre, 1985; Adediran and Adegoke, 1987; Haack et al., 2000; De Matos, 2000; Arthur et al., 2003; Macgregor et al., 2003; Burke et al., 2003).

The Gulf of Guinea continued to open in the Aptian - Early Albian with extensional fracturing and block faulting that formed a series of horsts and graben and accommodated a thick sedimentary succession. There was a progressive development of deeper troughs and half grabens in the South Atlantic segments as the rifts emerge. This phase in Dahomey Basin marked the first marine transgression resulting in the deposition of an alternating sequence of black shales and sandstones belonging to the Ise Formation (Omatsola and Adegoke, 1981). Ise Formation is commonly seen at the flank of the basin in the onshore area yet to be penetrated in the deep offshore. Seismic data indicate that its deposition occurred in series of grabens and half grabens in the basin. The end of the syn-transform stage was delineated by a major unconformity separating Ise Fm. from the marine post-transform rocks of the uppermost Albian and Cenomanian (Dumestre, 1985; Kjemperud et al., 1992; Chierici, 1996; Macgregor et al., 2003; Burke et al., 2003; Brownfield and Charpentier, 2006). This major unconformity is also readily recognized in the Brazilian marginal basins, which supports the interpretation that the two continents were in close vicinity during the Early Cretaceous and that their geologic histories were similar then.

Sea level rose gradually in the Cenomanian leading to regional marine transgression of the entire rift basin. This period corresponds to global flooding of the Atlantic Ocean which led to deposition of predominantly thick Cenomanian – Turonian marine Afowo Fm. shales in the Dahomey Basin and the contiguous Lokpanta shale in the Lower Benue Trough (Adeoye et al., 2013). Northeastern part of Benue Trough was influenced by the connection of this major transgression from the South Atlantic and the Tethys Sea across the Sahara. The presence of dark-grey shales with dominance of well-preserved planktonic foraminifera suggests restricted water circulation and a low oxygen content suitable for organic matter preservation in Afowo Formation. The Turonian Lokpanta oil shale of Eze- Aku formation, Abakaliki Basin, Nigeria contains similar characteristics of abundant planktonic assemblage indicating the extensiveness of the source rock facies of Afowo Formation in the Turonian beyond Dahomey Basin. The water depth was shallower in the Upper Benue Trough favoring benthonic foraminiferal species as recorded in the transitional Turonian Yolde Formation (Ekweozor and Unomah, 1990; Ehinola et al., 2003; Adeoye et al., 2013).

Marine transgression and regression events in Afowo Formation were succeeded by shallow marine facies of Campanian-Maastrichtian Araromi Formation consisting of shales and carbonate rocks (Omatsola and Adegoke, 1981). In the Late Maastrichtian, there was another major transgression sustained until the Paleocene and subsequently succeeded by shallow marine to lagoonal environment accompanied by the deposition of fossiliferous carbonates of the Ewekoro Formation (Adegoke et al., 1971b; Omatsola and Adegoke, 1981; Okosun, 1996). The Oshosun Formation above Ewekoro Formation (Fig. 2) also represents shallow marine facies essentially consisting of grey shales, glauconites and phosphorites (Adegoke, 1969). In the Late Eocene, sea level dropped and regressed leading to deposition of continental Ilaro Formation (Ako et al., 1980) a lateral equivalent of Benin Formation in the Niger Delta. Similar tectonic evolution and sedimentation events were also documented in Ivory Coast, Tano, Saltpond, Central, and the Keta Basins (Adegoke, 1969; Ako et al., 1980; Omatsola and Adegoke, 1981; Brownfield and Charpentier, 2006). Previous studies on sedimentology, geochemistry, and paleontology of Late Cretaceous to Cenozoic successions in the eastern Dahomey Basin, Southwestern Nigeria are reported in Adediran and Adegoke (1987), Nwachukwu et al. (1992), Okosun (1996, 2000), Burke et al. (2003), Adekeye et al. (2005), and Akande et al. (2010 & 2012).

Section snippets

Materials and methods

Eleven Cenomanian-Turonian Afowo shales from offshore X well and coastal wells Orimedu-1 and Ise-2 were sampled for major oxides, trace elements and foraminiferal studies. A foraminiferal paleoecologic study was carried out on the eighty (80) shale samples from the three wells to estimate prevailing 1 paleowater depths and depositional environments. They were treated with 10% hydrogen peroxide solution to loosen the clay, washed in water, and sieved with 0.063 μ m mesh to retain the...

X well

Shales, sandstones, claystones and carbonates constitute the rocks encountered in the offshore X well that penetrated a total depth (TD) of 2585m (Fig. 3) below the sea level of ca. 914m located 40km offshore, south of the city of Lagos, Nigeria. The basal part of the well consists of sandy shales and sandstones while middle and top parts consists essentially of shales interbedded with thin carbonate beds. Sandstones are well sorted and medium to coarse grained. Shale being the most abundant...

Provenance of Cenomanian-Turonian shales

The application of major oxide analysis in provenance, terrigenous influx, and clay mineral assessments of a sedimentary rock is significant because major oxides are essentially products of weathering of preexisting rocks. Silica is mostly derived from terrigenous detrital quartz with rare biogenic source. Silica often associates with argillaceous sediments such as clay minerals (Pettijohn, 1975). SiO₂ across the basin correlates positively with Al₂O₃, TiO₂ and P₂O₅ ($r=0.28, 0.17$ and $0.80...$

Conclusions

Provenance and paleoenvironmental studies of the petroleum prospective Cenomanian- Turonian Afowo shale from the Eastern part of Dahomey Basin has been studied using major oxides, trace element and foraminiferal data. CT shales generally have substantial amount of quartz across the basin but more significantly in the coastline area where considerable input of terrigenous detrital quartz is suggested based on average values of SiO₂ and Al₂O₃. The Al₂O₃/TiO₂ ratio implies that implying that the...

Declaration of competing interest

The authors have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper....

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Research data for this article

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