Journal of African Earth Sciences 118 (2016) 284–300

Contents lists available at ScienceDirect

Journal of African Earth Sciences

journal homepage: www.elsevier.com/locate/jafrearsci

Trace fossil assemblages in the tide-dominated estuarine system: Ameki Group, south-eastern Nigeria

O.C. Ekwenye [a, *, 1], G. Nichols [b], C.O. Okogbue [a], A.W. Mode [a]

[a] Department of Geology, University of Nigeria, Nsukka, Nigeria
[b] Nautilus Limited, Ashfields Farm, Hermitage, Berkshire, United Kingdom

ARTICLE INFO

Article history:
Received 12 November 2015
Received in revised form
30 January 2016
Accepted 1 February 2016
Available online 6 February 2016

Keywords:
Trace fossils
Ichnofacies
Estuarine
Palaeoecology
Eocene
Ameki Group

ABSTRACT

A systematic ichnological analysis with sedimentological study of the Eocene Ameki Group in south-eastern Nigeria, was conducted to infer depositional and biogenic processes operating during basin fill, identify discontinuities using substrate controlled ichnofacies, and identify the paleoecological conditions that affected the diversity of the trace fossils. The Ameki Group represents a tide-dominated estuarine system characterised by a range of trace fossils assemblages. Eighteen individual ichnogenera and nineteen ichnospecies observed in the study area, were grouped into six recurring ichnofacies namely *Scoyenia, Psilonichnus, Skolithos, Cruziana, Glossifungites* and *Teredolites. Skolithos and Cruziana* ichnofacies are predominant in the estuarine deposits indicating that the sedimentary successions of the Eocene are dominantly of moderate to high energy marginal marine environments. The estuarine deposits (*senus stricto*) were controlled by low to fluctuating salinity levels, high sedimentation rate and fluctuating hydrodynamic energy. These resulted in the occurrence of low diversity of *Scoyenia* and *Teredolites* ichnofacies and low to moderate ichnodiversity of mixed *Skolithos* and depauperate *Cruziana* ichnofacies. Low levels of dissolved oxygen in quiescent water-embayment (open estuarine) resulted in low diversity of impoverished *Cruziana* ichnofacies. *Glossifungites* ichnofacies marked an amalgamated sequence boundary/marine flooding and an initial flooding surface at the base of the tidally influenced fluvial deposits.

1. Introduction

Trace fossil analysis is an important tool used in determining depositional settings and identifying the characteristics of a sedimentary environment such as the depositional energy, sedimentation rates, substrate cohesiveness, salinity and other chemical parameters (Bromley, 1990; Pemberton et al., 1992; Taylor et al., 2003; McIlroy, 2004; Gingras et al., 2011). Ichnology is also important in recognising and delineating key strata surfaces in stratigraphic sequence (MacEachern et al., 1992; Taylor and Gawthorpe, 1993; Goldring, 1995; Taylor et al., 2003; Pemberton et al., 2004). It records the behaviour of the organisms as a response to subtle changes in environmental parameters such as substrate consistency, salinity, energy conditions and oxygenation (Buatois et al., 2002). Ichnofacies analysis uses the ethological grouping of trace-fossils, based on the temporal and spatial recurring suites that are commonly associated with depositional conditions (Pemberton et al., 1992; Gingras et al., 2011).

Numerous works have been carried out on the palaeoecological and paleoenvironmental interpretations of trace fossils in the Benue Trough and the Anambra Basin (Barnerjee, 1982; Akpan and Nyong, 1987; Arua, 1989, 1991; Anyanwu and Arua, 1990; Mode, 1993, 1997, 1998; Mode and Odumodu, 2014; Odumodu, 2014). But most published works on the ichnology of the strata of the Ameki Group are limited to the Nanka Formation (Nwajide and Hoque, 1979; Nwajide, 1980, 2006; Odumodu and Mode, 2014); however, the trace fossils assemblages were limited to *Skolithos* ichnofacies (Nwajide and Hoque, 1979; Nwajide, 1980), *Cruziana* and *Glossifungites* ichnofacies (Odumodu and Mode, 2014) for the sedimentary rocks of the Nanka Formation.

This research aims at integrating sedimentology and ichnology in order to: infer depositional and biogenic processes operating during basin fill; identify discontinuities using substrate controlled

* Corresponding author.
E-mail addresses: ogechi.ekwenye@unn.edu.ng, sedogechy@yahoo.com (O.C. Ekwenye).
[1] Research work carried out at: Department of Earth Sciences, Royal Holloway University of London, United Kingdom.

http://dx.doi.org/10.1016/j.jafrearsci.2016.02.001
1464-343X/

ichnofacies; identify physiological stressful conditions that affected the diversity of trace fossils; unravel the ichnofacies assemblages found within the Eocene tide-dominated estuarine rocks and provide ichnologically controlled facies model for the Eocene strata.

2. Study area and stratigraphic setting

The Ameki Group is a lateral equivalent of the Agbada Formation in the subsurface Niger Delta (Table 1) and is commonly referred to as the outcropping Niger Delta (Short and Stäuble, 1967). It consists of the Nsugbe Formation (formerly called Nsugbe Sandstone), Nanka Formation (formerly referred to as Nanka Sandstone), and Ibeku Formation (formerly known as Ameki Formation) (Nwajide, 1980; Ekwenye, 2014) which are lateral equivalents (Fig. 1). The Ameki Group consists of alternating sandy shale, clayey sandstone, fossiliferous shale (consisting of molluscs, foraminifera and corals) and fine-grained argillaceous sandstone with thin limestone bands (Reyment, 1965; Arua, 1986). The age of the group is Middle Eocene (Lutetian) (Berggren, 1960; Reyment, 1965; Adegoke, 1969), but Oloto (1984) assigned Middle Eocene to Oligocene age to the formation based on dinoflagellate cysts and miospore assemblages. Kogbe (1976) considered the Ameki Group to be of Lutetian to Lower Bartonian age. Various paleoenvironmental interpretations have been suggested for the Ameki Group. Reyment (1965) suggested a partly non-marine to estuarine and a partly marine environment for the group. Estuarine, barrier ridge–lagoon complex and open marine are further suggested based on lithofacies interpretation and faunal content (Adegoke, 1969; Arua, 1986; Mode, 2002; Odumodu and Mode, 2014). Ekwenye, 2014 suggest a macrotidal estuarine system for the Ameki Group.

3. Methodology

Systematic sedimentological and ichnological field descriptions were obtained from twenty-nine outcrop locations in the study area (Fig. 2). The outcrops are randomly distributed in the Onitsha, Awka, Bende, Amaeke and Umuahia regions in the south-eastern Nigeria. Detailed field work which involved sedimentological logging of outcrops was carried out to unravel the rock types, textural features, sedimentary structures, nature of bedding and structural features. Thickness of beds, dips and strikes were measured and the lateral extent of the outcrops were established. For the heterolithic deposits, thickness variation of sand, silt or clay couplets were recorded. The Munsell colour chart was used to accurately describe the rock colours. Photopanorama mapping was carried out for the laterally extensive outcrops. The field observations were used to interpret the lithofacies units and genetically related facies were grouped to form facies assemblages which are used to interpret the depositional environments. Detailed description and interpretation of environments of deposition is documented in the works of Ekwenye, 2014. This paper focuses only on the application of ichnology in the tidally dominated estuarine deposit.

The trace-fossil size, ethological diversity, trace-fossil distribution and degree of bioturbation were recorded. The taxonomic affinity of the trace fossils is recognised by observing the burrow boundary or wall structure, the burrow fill and the branching characteristics. Observations from the field are used to describe the trace fossils and to consider the ichnofacies assemblages present. Information from the trace fossil studies was then synthesized for the interpretation of depositional environments.

4. Environment of deposition

The Ameki Group have been interpreted as tide dominated estuarine system based on detailed outcrop studies and facies analysis (Ekwenye, 2014). So, the integration of ichnology to this sedimentological interpretation enhances the understanding of the environmental conditions and distribution of the trace fossils within the estuarine deposits (Table 2). Seven facies associations which include FA 1 (fluvial channel), FA 2 (tidally influenced fluvial channel channel), FA 3 (tidal channel), FA 4 (tidal flat), FA 5 (supratidal), FA 6 (tidal sand bar) and FA 7 (estuarine embayment or open estuarine) were delineated and discussed in details in Ekwenye (2014).

Facies association 1 (FA 1) is interpreted as fluvial channel deposit based on the scoured and erosive base filled by cobbles and pebbles referred to as channel lag deposit occurred at the basal part of the Ameki Group (Ekwenye, 2014). The sandstone unit fines upward, exhibiting trough-, planar cross-beds, horizontal bedding and climbing ripples. This outcrop is exposed at Nsugbe, Ukwu-Nnadi quarry, Nsugbe (SUG 1) and at Awka (Fig. 3). No burrows were observed in this section, probably due to relatively high-energy and rapid fluctuations in rates of sedimentation and erosion (Buatois and Mángano, 2004). Interbedded siltstone and mudstone which is adjacent to ferruginised channelized sandstone was observed at Awka. The siltstone units are characterised by monospecific low occurrence of *Skolithos* in the upper units. The degree of bioturbation is very low (bioturbation index 0–1).

Facies association 2 (FA 2) is interpreted to as tidally influenced fluvial channel. It is characterised by sandy heterolithic and muddy heterolithic units as observed at Ugwu-Nnadi (SUG 2) Nsugbe, where deposits of FA 2 succeed that of facies association 1. The sandy heterolithic facies is moderately to well burrowed with a moderate diversity of mixed *Skolithos* and *Cruziana* ichnofacies which includes *Thalassinoides, Planolites, Rhizocorallium, Palaeophycus, Taenidium satanassi, Laminites, Skolithos, Arenicolites, Ophiomorpha* (Fig. 3) as well as sporadic small scale burrow mottling and robust articulated bivalves resting trace (Fig. 4). The degree of bioturbation is relatively moderate (bioturbation index 2–4). The presence of both *Skolithos* and *Cruziana* ichnofacies indicates normal marine water deposition (Pemberton et al., 1992; Gingras et al., 2002).

Facies association 3 (FA 3) is interpreted as tidal channel consists of unidirectional large scale trough-cross stratified sandstone, thick mud lenses and mud clasts (Fig. 3). FA 3 is commonly associated with tidal flat deposits (FA 4). The dominant trace-fossil assemblages are mixed *Skolithos-Cruziana* ichnofossils of low diveristy. The sandstone unit is moderately burrowed, with the presence of

Table 1
Correlation of subsurface and outcrop formations of the Niger Delta (redrawn after Short and Stäuble, 1967; Avbovbo, 1978; Ekwenye et al., 2015).

Subsurface			Outcrop		
Youngest known age	Formation	Oldest known age	Youngest known age	Formation	Oldest known age
Recent	Benin	Oligocene	Recent	Benin Formation	Miocene
Recent	Agbada	Eocene	Miocene	Ogwashi Formation	Eocene
			Eocene	Ameki Group	Eocene
Recent	Akata	Paleocene	Lower Eocene	Imo Formation	Paleocene