Advances in Science, Technology & Innovation
IEREK Interdisciplinary Series for Sustainable Development

Attila Çiner · Stefan Grab · Etienne Jaillard · Domenico Doronzo · André Michard · Marina Rabineau · Helder I. Chaminé *Editors*

Recent Research on Geomorphology, Sedimentology, Marine Geosciences and Geochemistry

Proceedings of the 2nd Springer Conference of the Arabian Journal of Geosciences (CAJG-2), Tunisia 2019

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Preface

This proceedings volume is based on 84 papers accepted and presented during the 2nd Springer Conference of the Arabian Journal of Geosciences (CAJG-2), Tunisia 2019. Major subjects treated in the volume include geomorphology, sedimentology and geochemistry. The volume presents an updated unique view in conjugating field studies and modeling to better quantify the process-product binomial unusual in geosciences. Earth systems requires a comprehensive understanding on processes and dynamics of geology, morphotectonics, sedimentology, stratigraphy and geochemistry. In the geomorphology section, 24 papers deal with topics related to fault slip and incision rates, soil science, landslides and debris flows, coastal processes, and geoarcheology and geoheritage. Under the Sedimentology section, 34 papers including stratigraphy, and environmental, tectonic and diagenetic processes, together with evolutionary, biostratigraphic and paleoenvironmental significance of paleontology are presented. Additionally, this section also contains papers on marine geosciences, from molecular proxies related to climate to geophysical surveys. Last but not least, the third section on geochemistry is composed of 26 papers that are focused on sedimentary geochemistry and mineralogical characterization, magmatic and metamorphic processes and products, and the origin and exploration of mineral deposits. This volume resumes the current situation related to the abovementioned topics mainly in the Mediterranean realm. Although more than half of the contributions come from North African countries, especially from Tunisia, other Mediterranean countries such as Turkey and Italy also actively participated in the development of this volume, testifying the geological importance of this area and surroundings. The volume is of interest to all researchers, practitioners and students in the fields of geomorphology, sedimentology, geochemistry, as well as those engaged in environmental geosciences, soil science, stratigraphy and paleontology, geoarcheology and geoheritage, marine geosciences, petrology, metallogenesis and mineral deposits.

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Facies Analysis, Sequence Stratigraphy and Hydrocarbon Habitat Prospectivity of the Pindiga Formation and Fika Shale, Gongola Sub-basin, Northern Benue Trough, Nigeria

Isah Goro, Muhammad Abubakar, Nuhu Waziri, Bukar Shettima, and Babangida Jibrin

Abstract

Outcrop-based sequence stratigraphic studies have been conducted on the Pindiga Formation and Fika Shale of the Gongola sub-basin, Northern Benue Trough, Nigeria. This has implications for hydrocarbon play identification in the basin especially at the intermediate temporal position where the poorly studied, recently delineated Sandy members occur. The approximately 600-m-thick interval was subjected to detailed facies, depositional environment, and depositional trend analyses as well as major bounding surfaces marking out based on 17 measured stratigraphic sections. Sequence stratigraphy analysis led to the delineation of one depositional sequence (DS), shared with the underlying formations and two complete second-order sequences using Depositional Sequence III model. Dark grey-to-black shales of the late transgressive systems tract (TST) to early highstand systems tract (HST) in the three depositional sequences constitute potential source rocks. Lowstand systems tract (LST) sandstones deposited in fluvial and tidal channels as well as bayhead delta make up potential reservoir rocks within DS2. The TST and HST of DS1 and DS2 contain potential reservoir rocks including tidal bar, estuary mouth and shoreface to nearshore sandstones. Potential intra-formational seals comprise the late TST and early HST mudstones of DS1, the early HST mudstones of DS2, and a regional top seal is provided by DS3, which consists entirely of the Fika Shale. These depositional sequences consist of varied lithologies, and their relative temporal and spatial distribution promises high potential for further exploration in the basin.

Keywords

Gongola sub-basin • Benue trough • Sequence stratigraphy • Pindiga formation • Fika Shale

1 Introduction

The mainstay of Nigerian economy is oil and gas all of which is derived from the Niger Delta basin. In order to increase the treasure base of the country, major exploration efforts are concentrated in the frontier inland basins of Nigeria with more emphasis on the Benue Trough. The drilling of only three wells led to the discovery of hydrocarbon in the Gongola sub-basin of the Northern Benue Trough. The wells include Kolmani-1-Well with reported discovery of sub-commercial oil; Nasara-1-Well and Kuzari-1-Well were reported to be dry. Controversy, however, arose after the publications of Abubakar et al. (2008) who reported the presence of migrated oil between depths of 4710–4770 ft in the Nasara-1-Well based on geochemical techniques.

It became obvious that gaps still exist in detailed understanding of the possible petroleum habitat especially at the intermediate temporal stratigraphic position where the recently delineated, understudied Sandy members (Zaborski et al. 1997) of the Pindiga Formation occur. The juxtaposition of the Sandy members between limestones and shales of Kanawa member, below and Fika Shales above makes them high-quality targets for hydrocarbon accumulation. In order

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to effectively explore for hydrocarbon in the Gongola sub-basin, adequate understanding of the genetic evolution of the sedimentary packages of Pindiga Formation and Fika Shale using sequence stratigraphic technique is critical due to its predictive nature.

The present work provided detailed outcrop facies, facies associations, facies successions, sequence stratigraphic framework and hydrocarbon play potentials of the approximately 600-m-thick Pindiga Formation and Fika Shale.

2 Materials and Methods

Sedimentological and stratigraphic information on the outcropping sedimentary rocks in the study area were recorded through the construction of graphic logs. Seventeen sedimentological graphic logs were constructed from fairly well-exposed parts of the study area. Lithofacies were identified and analysed using the lithology, colour, texture, sedimentary structures, and geometry as well as vertical and lateral relationship of beds, bounding surfaces and trace fossil content.

The composite logs were prepared from isolated exposures that occur laterally adjacent to each other to provide more complete scenarios of their temporal relationship. The identified lithofacies were coded K, S and Fk for the Kanawa, Sandy members and Fika Shale, respectively. A two-stage approach was used for the interpretation: (1) deduction of environment of deposition and (2) identification of systems tracts and erection of sequence stratigraphic framework for the sediments using Depositional Sequence III Model (after Christie-Blick 1991).

3 Results

3.1 Facies Analysis and Environment of Deposition

A detailed outcrop facies analysis led to the identification of 21 lithofacies, 13 facies associations (Table 1) and 6 facies successions (Table 2). Lithofacies of the Kanawa Member include dark grey-black fissile mudstone (K1) and limestone (K2) facies.

The Sandy members consist of the following facies: grey mudstone (S1), ripple laminated mudstone (S2), laminated siltstone (S3), heterolithic sandstone (S4), cross-laminated sandstone (S5), planar-bedded sandstone (S6), horizontal to low angle stratified sandstone (S7), swaley cross-stratified sandstone (S8), hummocky cross-stratified sandstone (S9), herringbone cross-bedded sandstone (S10), planar cross-bedded sandstone (S11), trough cross-bedded sandstone (S12), conglomerate (S13), shell bed (S14). The fissile grey mudstone (Fk1), lime-mudstone (Fk2), graded-bedded sandstone (Fk3), heterolithic siltstone to sandstone (Fk4) and planar-bedded sandstone (Fk5) facies were recognized from the Fika Shale.

Six facies successions representing broad environments of depositions were interpreted from the juxtaposition of the 13 facies associations (Table 2).

Table 1 Facies and facies associations of the Pindiga Formation and Fika Shale

Facies association	Code	Lithofacies present
Kanawa member		
Outer ramp	FA1	K1, K2
Mid-ramp	FA2	K1, K2
Sandy members		
Wave/storm-dominated prodelta to delta front	FA3	S1, S2, S4, S6, S9, S14
Wave/storm-dominated shoreface to nearshore	FA4	S1, S7, S8, S9, S11, S12
Offshore to offshore transition	FA5	S1, S9
Tide influenced fluvial channel	FA6	S4, S10, S11, S12, S13
Tidal bar	FA7	S2, S3, S4, S11, S12, S13
Bayhead delta	FA8	S1, S4, S6, S10, S12,S13
Tidal channel	FA9	S4, S12, S13
Central bay	FA10	S1, S5
Estuary mouth	FA11	S1, S2, S4, S7, S8, S9, S12, S13
Fika Shale		
Prodelta facies association	FA12	Fk1, Fk2, Fk3
Delta front facies association	FA13	Fk1, Fk3, Fk4, Fk5

Table 2 Facies successions of the Pindiga Formation and the Fika Shale

S/N	Facies succession	Facies associations present
Kanawa member		
1	Carbonate platform	FA1, FA2
Sandy members		
2	Wave/storm-dominated prodelta to delta	FA3
3	Wave/storm-dominated offshore to nearshore	FA4, FA5
4	Wave-dominated estuary	FA6, FA7
5	Tide-dominated estuary	FA8, FA9, FA10, FA11
Fika Shale		
6	Prodelta to delta front	FA12, FA13

4 Discussion

A detailed facies analysis and delineation of major bounding surfaces that mark changes in lithofacies associations and their stacking patterns allowed the definition of three erosionally bounded packages within the Pindiga Formation and Fika Shale. These packages approximately correspond to three depositional sequences (DS, Fig. 1). The lower package is DS1 and is only partially developed within the study interval. Its lower sequence boundary is believed to occur in underlying Yolde or Bima Formations. The basal boundary of the Pindiga Formation is interpreted as a transgressive surface, and the carbonates of Kanawa Member constitute a TST due to the identification of maximum flooding zone within it. The overlying wave/storm-dominated offshore to nearshore and its adjacent wave/storm prodelta to delta front facies successions serve as the HST of the DS1. Whereas

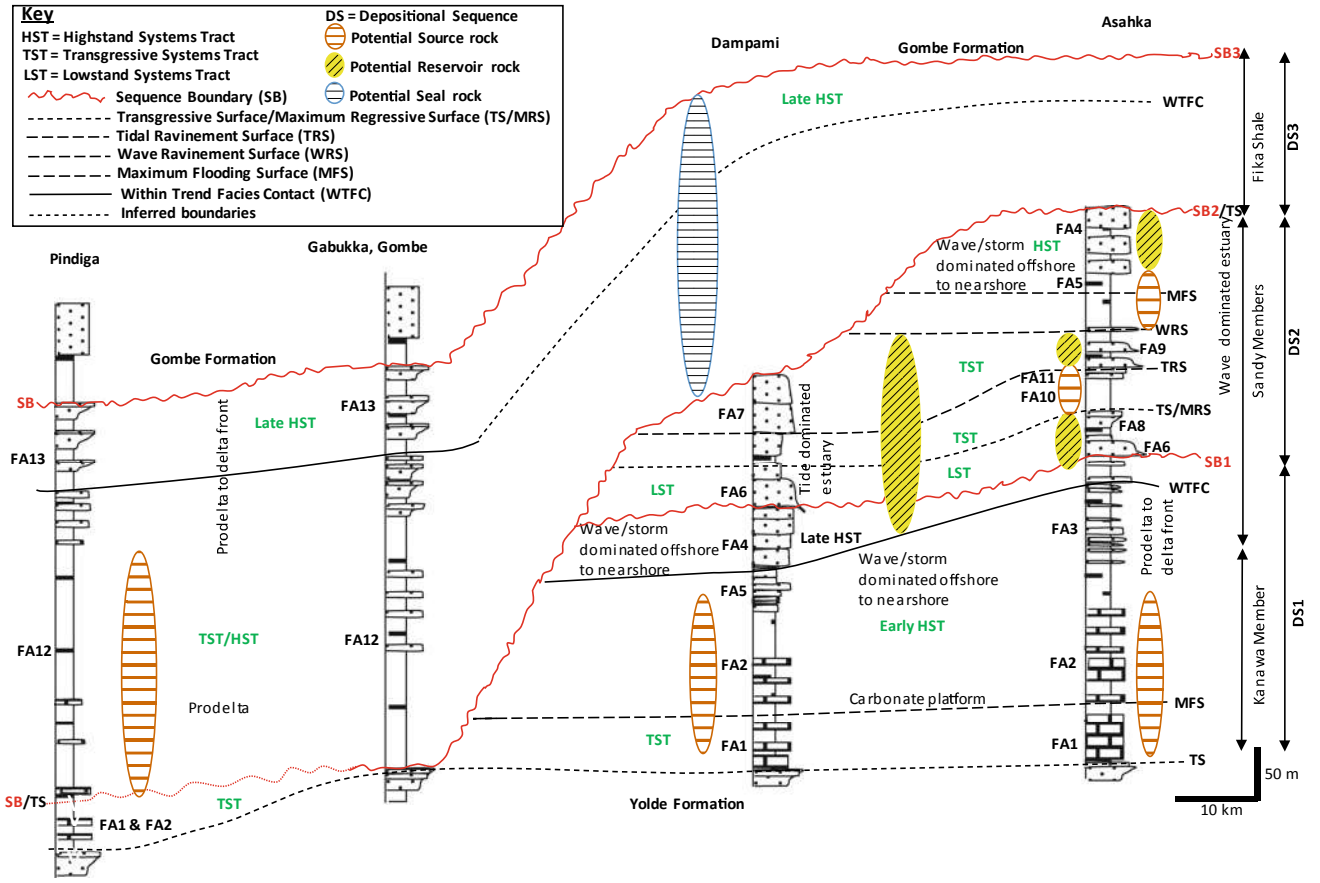

Fig. 1 Composite log illustrating the sequence stratigraphic framework of the Pindiga Formation and Fika Shale, Gongola sub-basin, Northern Benue Trough, Nigeria

the disconformity surface that temporally separates the Sandy members into two (SB1, Fig. 1) represents the upper sequence boundary of this sequence.

The DS2 is the most complete sequence in the Pindiga Formation because it contains most of the expected sequence stratigraphic surfaces and systems tracts that can be related to one complete sea level fall and rise (Fig. 1). It contains both wave- and tide-dominated estuary facies successions and is bounded at the top by angular unconformity recognized by the presence of thick paleosol unit. This gives evidence for the Santonian compressional event in the Gongola sub-basin. The DS3 is formed by the Fika Shale. The absence of LST and major facies shift across the lower sequence boundary indicates tectonic control accompanied by abrupt deepening.

Potential source rocks include hemipelagic shales of the late TST to early HST of DS1 and DS3. The former coincides with the worldwide anoxic event, which deposited organic matter-rich shales. The identified potential reservoir rocks are concentrated within DS2 and the upper part of DS1. These lithofacies associations comprise of the shoreface to nearshore sandstones of late HST of DS1 and DS2. Others include fluvial and tidal channels as well as bayhead delta sandstones of the LST and tidal bar and estuary mouth sandstones of the TST in DS2. A regional top seal is provided by the laterally extensive, approximately 200-m-thick Fika Shale constituting the DS3. Less extensive, intra-formational seal rocks may be provided by the central estuary, prodelta and offshore to offshore transition shales within DS2 and DS1.

5 Conclusions

1. Outcrop lithofacies and sequence stratigraphic analyses of the Pindiga Formation and Fika Shale reveal new insights in to the regional stratigraphy and juxtaposition of source, reservoir and seal lithofacies within the Gongola sub-basin of the Northern Benue Trough, Nigeria.
2. The interval represents one partial and two complete depositional sequences.
3. The lower depositional sequence comprises a TST and HST with potentials for source and reservoir rocks, respectively.
4. The middle depositional sequence contains LST overlain by TST and HST with great potentials for reservoir rocks provided by fluvial and tidal channels, tidal bar and shoreface to nearshore sandstones of the Sandy members.
5. Potential regional seal rock is provided by the laterally extensive, approximately 200-m-thick upper depositional sequence represented by TST and HST mudstones of the Fika Shale.

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