Petroleum and Coal

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Recognizing Key Petroleum System Elements within the Coal-Bearing Sequence of the Mamu Formation in the Anambra Basin, Southeastern Nigeria

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Received November 2, 2024; Accepted February 6, 2025

Abstract

Newly exposed section at the Onyeama Hill axis along Enugu-Onitsha Express road of southeastern Nigeria, has revealed some key structural and stratigraphic features within the Maastrichtian coal-bearing sequence of Mamu Formation in the Anambra Basin. These geologic features have only been seen through limited drilled wells and 2D seismic sections, which are rarely available on public domain. However, recent open cast mining activities within this axis has opened up section revealing classic geologic features such as series of fault structures with well-displayed hanging and footwalls, which has not been reported in this section of the formation. Such structural elements were only reported within the outcropping section of the underlying Enugu Formation (Campano-Maastrichtian sequence) of the same basin. Also, evident within this section were amalgamated stratigraphic channel fills. The faults could serve as possible entrapment structures and offer migration path for hydrocarbon if present. In addition, the sand fill channels could serve as reservoirs with the presence of underlying coal bed as source rock material, an indication of the existence of key petroleum elements within the Manu Formation, of the Anambra Basin.

Keywords: *Outcrop; Fault; Channel-fill; Mamu Formation; Anambra Basin.*

1. Introduction

Recent exploration campaigns across the inland sedimentary basins of Nigeria by national and international oil companies, have spurred some research interests in some frontier basins in Nigeria, one of which is the Anambra Basin. Although there have been some literature within the Basin, some formations in the Anambra such as the coal-bearing Mamu Formation characterized, Maastrichtian sequence are yet to be fully studied [1-4]. As there are recent outcropping features which were not recorded captured in previous work that are now being exposed through extensive open cast mining in some axis of the basin. This has given rise to the present research work whose aim is to recognise and provide outcrop evidence of geologic features such as geologic features such as series of fault structures with well-displayed hanging and footwalls, and sand fill channels. These geologic features have only been seen through limited drilled wells and 2D seismic line sections, which are rarely available on public domain [5-7]. Hence, the present study focuses on recognizing and characterizing these structural and stratigraphic features within the framework of petroleum system and its implication for hydrocarbon exploration within the basin.

2. Geologic framework

The Anambra Basin is a curved, southward-dipping synclinal structure that emerged following the inversion and folding of the Southern Benue Trough during the Santonian Tectonic event [8-12]. The Benue Trough, a northeast-southwest trending rift basin associated with wrench tectonics, originated from the opening of the Equatorial Atlantic Ocean. Both the Benue

Trough (Albian to Santonian) and the subsequent Anambra Basin developed above the passive margin of the Equatorial Atlantic. The Anambra Basin formed along the western and southern flanks of the uplifted Abakaliki Anticlinorium, which was part of the Southern Benue Trough. This basin became a major depositional center, accumulating over 3000 meters of sediment in its central regions [13-14]. The basin extends southward and southwestward, disappearing beneath the Paleogene to Recent Niger Delta Basin, which represents the ongoing deltaic buildup on Nigeria's Atlantic passive margin. During the Oligocene-Miocene period, the entire Anambra Basin region experienced uplift, resulting in the formation of a 500-kilometer-long cuesta [15-16]. This study area is located on the east facing scarp slope of the Enugu-Udi Cuesta.

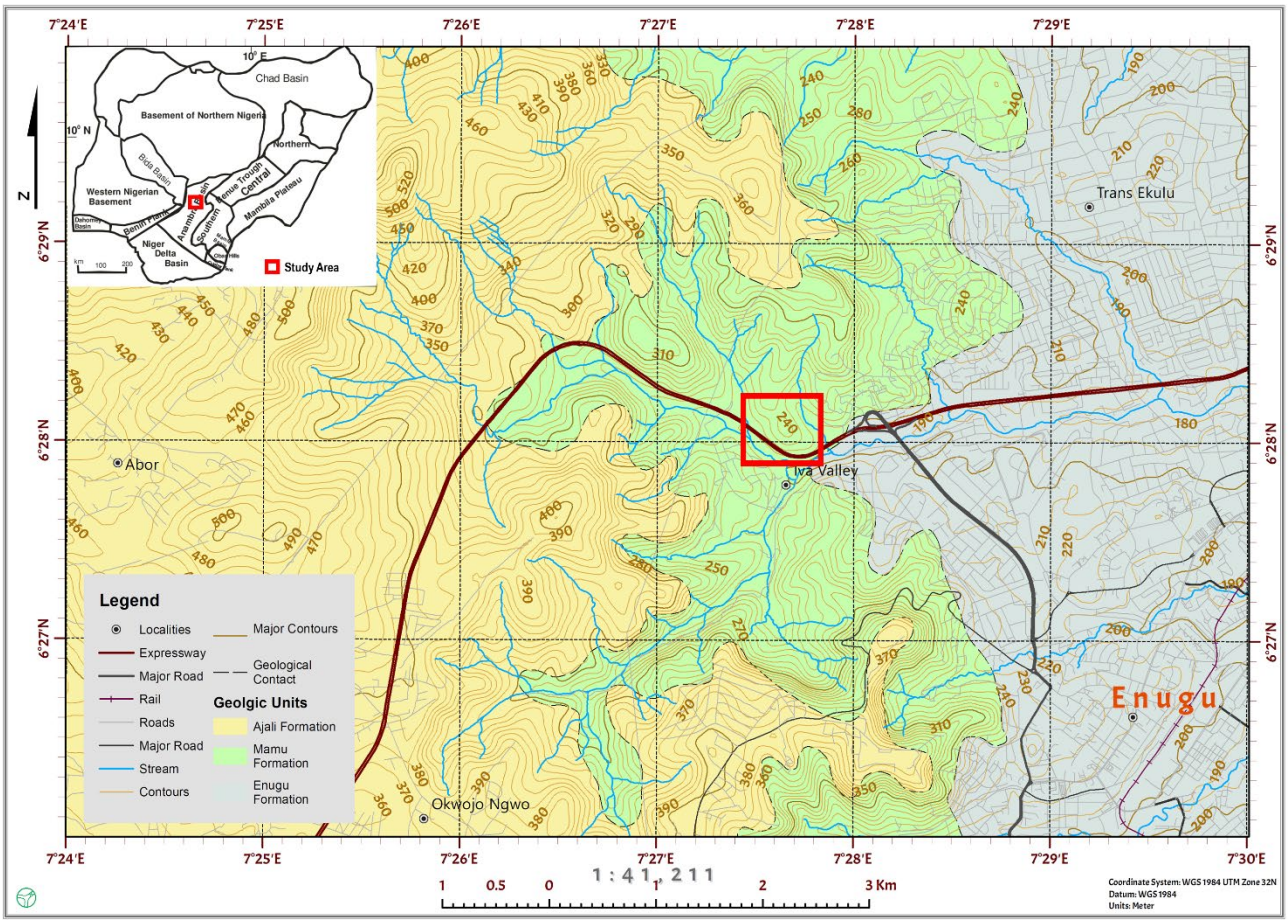

Fig. 1. Geologic Map of the study area (Inset red box) and its environs with geographic (accessibility and locations) and physiographic (topography and drainage) features.

The Anambra Basin contains up to 3 kilometers of Campanian to Maastrichtian clastic sediments, deposited in alternating regressive and transgressive cycles. The basin's stratigraphic fill within the study area, begins with the Nkporo Group comprising three formations; the Nkporo Formation (which consists of dark grey shales with thin sandstone and limestone layers), the Enugu Formation (which consists of black carbonaceous shales interbedded with thin sandstone and siltstone layers), and the Owelli Formation (with massive medium to coarse-grained sandstones with pebble bands) [17-18]. Above this lies the Mamu Formation, which is major outcropping unit in the area of study. It is composed of sandstones, sandy shales, sand-silt-shale heteroliths, and coal seams [15,19-20]. There are several of these coal seams at different stratigraphic levels with thicknesses up to 5 metres. The Ajali Formation, which overlies the Mamu Formation, is characterized by friable, white, cross-bedded sandstones with thin white mudstone beds. It features large-scale cross-bedding [10,21]. It represents the continental sequence in the Anambra Basin's regressive delta complex, alongside the paralic Mamu

Formation and marine Nkporo Group. The uppermost unit is the Nsukka Formation, consisting of alternating sandstones, shales, and coal seams similar to the Mamu Formation. It signifies a return to paralic conditions from late Maastrichtian to early Danian times [22-23].

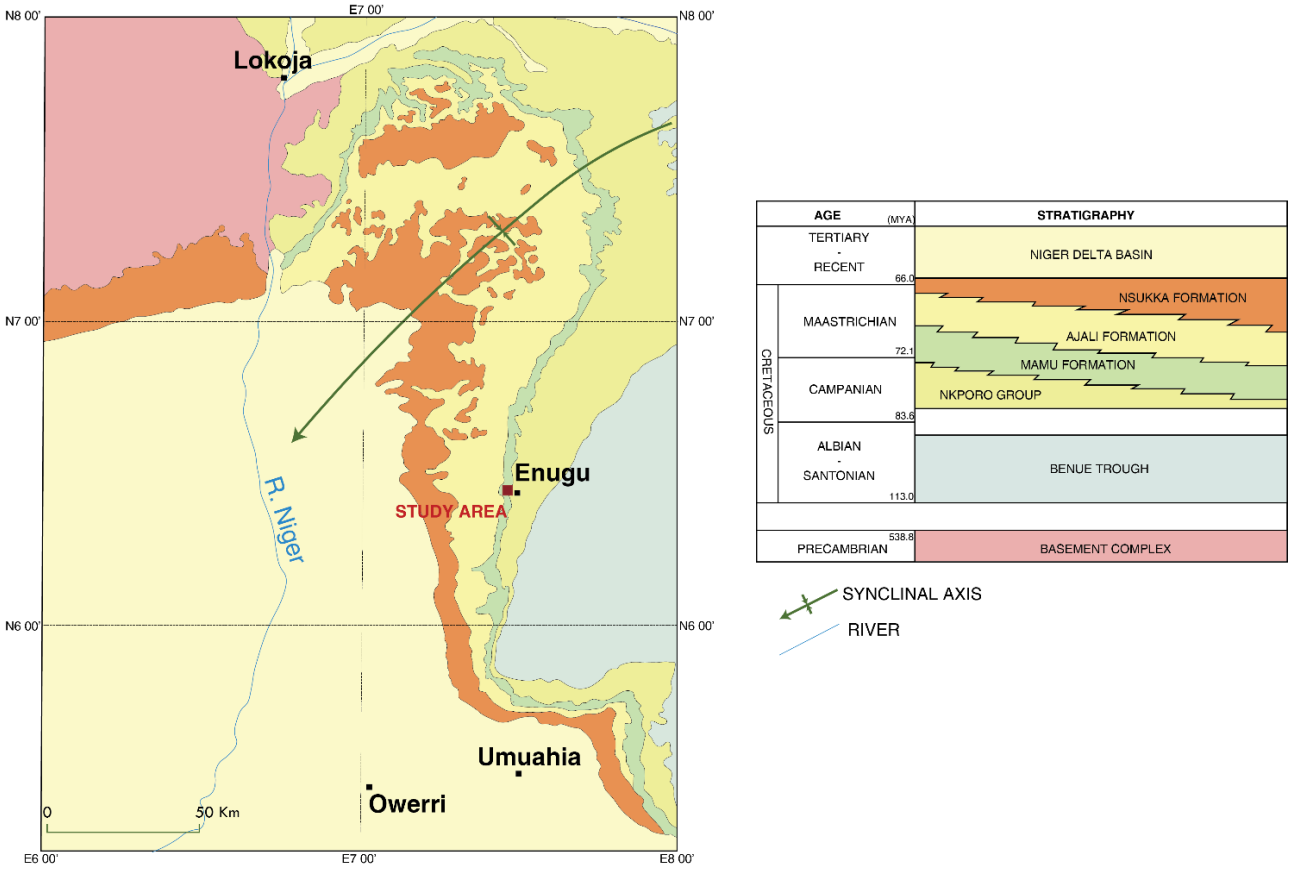

Fig. 2. Geological map of and stratigraphic summary of the Anambra Basin.

3. Methodology

The exposed section through mining activity at the Onyeama Hill section was visited and studied (Figs. 3 and 4). GPS coordinates, latitudes, and longitudes of the exposed section were obtained and the outcrop location plotted on a geologic base map. Detailed outcrop logging and rock unit descriptions were carried out. Structural and stratigraphic features were identified and analysed on the field. These geologic features and rock units were further interpreted and characterised based on petroleum system analysis (Fig. 5).

4. Results and discussion

4.1. Stratigraphic channel fill element

One of the striking stratigraphic features seen in the right-hand side section of this outcrop is a channel fill deposit. These are usually produced either by the accretion of sediment transported by water flowing through the channel or by the infilling of an abandoned channel. It also consists of sandy point bars deposited in the convex part of the meander [24–25]. Another channel with parallel to sub-parallel sand deposits overlies this sand-filled channel, which is about 3 m thick and 14 m wide. A relatively thick coal seam of about 1.5 m and heterolithic units with thin bands of siltstone units and shale units of about 0.3 m underlie this channel fill deposit. These channel fills are associated with hetrolithic channel fills with a truncating surface (mainly clay or shale bands) that makes the unset of another channel fill, characterised by the Mamu Formation [5-7].

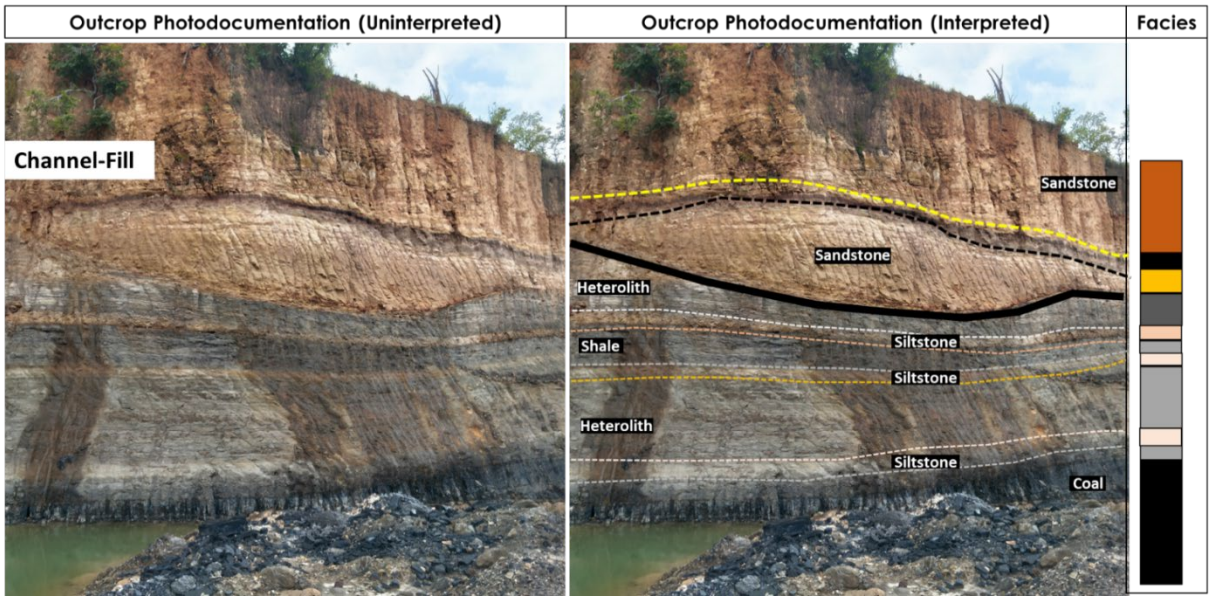

Fig. 3. Uninterpreted and interpreted outcrop photo-documentation of sand channel-fill at coal mining section on the Onyema Hill axis off Onitsha-Enugu Road, Southeast, Nigeria.

4.2. Structural styles element

On the left-hand side of the outcrop section is a well-developed normal fault system characterised by three fault blocks within the upper section of the exposure and what seem to be a partially reverse thrust fault system at the lower section (Figs. 4 and 5). In the case of normal faulting, the fault blocks constitute both footwalls (upthrown fault blocks) with slight thickening on the downthrown block, which is the hanging wall (downthrown fault blocks). For the reverse faulting, the hanging wall (upthrown fault blocks) has been juxtaposed against the footwalls (downthrown blocks) (Figs. 4 and 5).

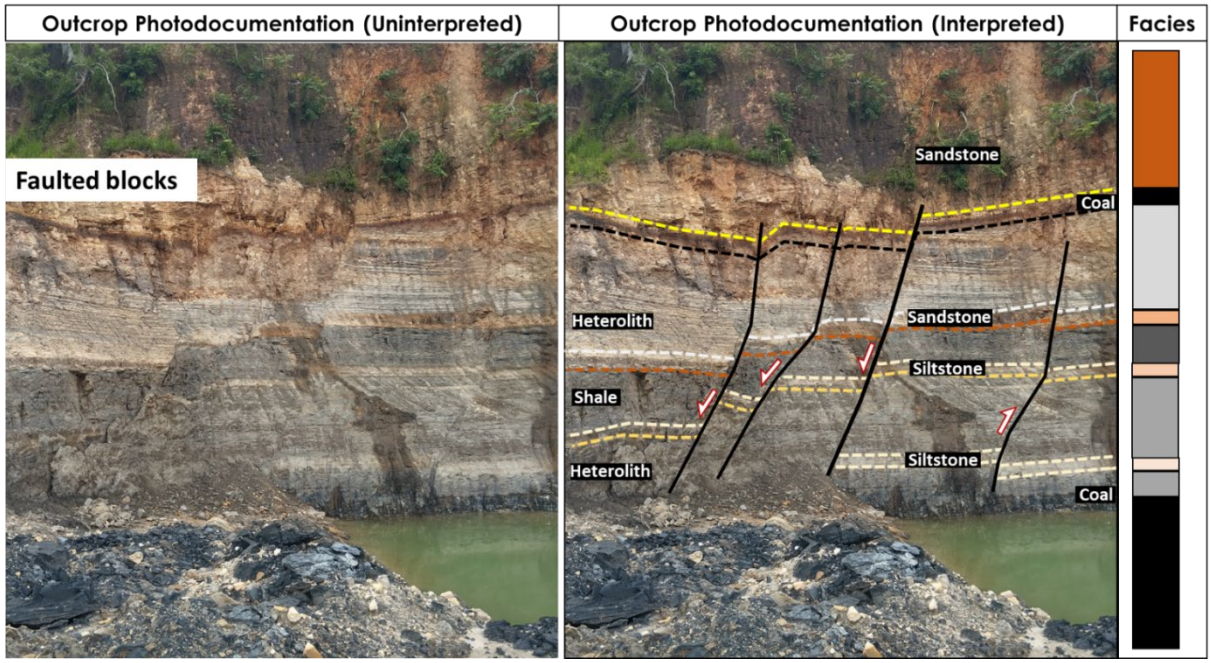

Fig. 4. Uninterpreted and interpreted outcrop photo-documentation of the faulted blocks showing both normal and reverse faulting at at coal mining section on the Onyema Hill axis off Onitsha-Enugu Road, Southeast, Nigeria.

4.3. Petroleum system analysis and implications for hydrocarbon exploration

The key petroleum system elements evident in this section are:

i) The source rock units, which include coal and shale, are characterised by a soluble organic matter/total organic carbon content range of 34.2 to 40.7 and a vitrinite reflectance (Ro) value of 0.40-0.50. The source maturity status has been classified as immature to mature [26–27]. The occurrence of these coal units is such that they are partly continuous and discontinuous seams seen within three intervals in this section (Fig. 5).

ii) The reservoir rock units are those of sand fill channels and heterothic intervals (with dominant sand package), which are seen across the section (Fig. 5). These sandstone units have been reported to contain hydrocarbons in some sections of the basin [7, 4,20].

iii) The entrapment structures are the series of juxtaposed fault blocks (hanging walls and footwalls) seen within the sections. These fault blocks are capable of trapping hydrocarbon in the basin when present and could provide a migratory pathway for generated hydrocarbon fluid in some cases, as seen in the nearby Niger Delta Basin. In addition, these fault blocks, when juxtaposed against the walls of the downthrown section, could act as a sealing fault block, thereby providing an entrapment for fluid accumulation, especially when reservoir rocks flank a non-reservoir rock package [14,20].

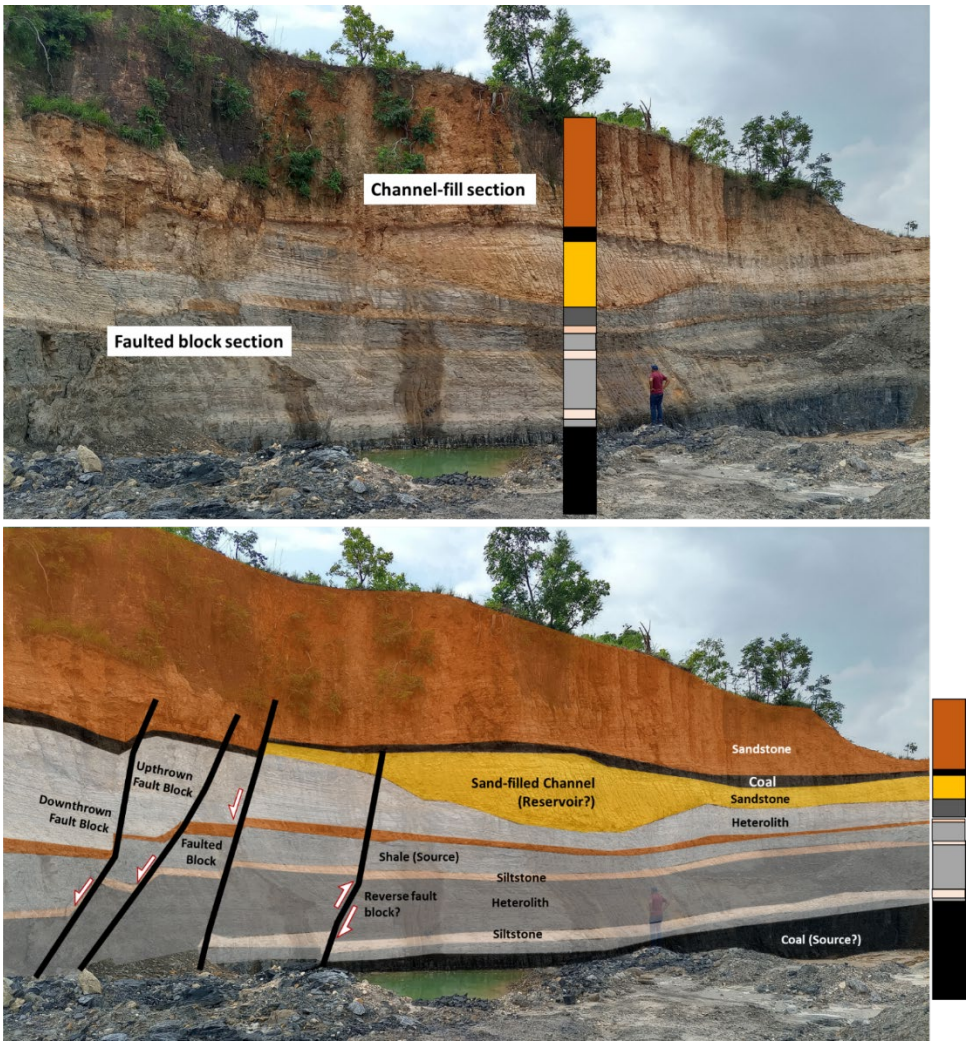

Fig. 5. Uninterpreted and Interpreted section showing the juxtaposed faulted blocks (entrapment structures) and the channel-filled package (reservoir) and associated source rocks (coal and shale) (Note: Geologist approx. 2m).

5. Conclusion

The outcropping rock units of the Mamu Formation have provided evidence of stratigraphic and structural features, which are key elements of the petroleum system. These stratigraphic features include channel fill reservoirs and laterally extensive shale coal seams, which constitute reservoir and source rock packages. The presence of faulted blocks evident within this indicates available traps and a possible migration pathway for hydrocarbon if present. Generally, this section of outcrop provides good support for the existence of key petroleum elements within the Manu Formation and provides an in-depth understanding and exploratory guide to the Anambra Basin subsurface.

Acknowledgement

The authors are grateful to the Petroleum Technology Development Fund (PTDF) Chair, of the University of Nigeria, Nsukka for the opportunity provided through her routine fieldwork exercise that gave rise to this research work.

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