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PETROLEUM SYSTEM ELEMENTS ANALYSIS OF SEDIMENT OUTCROPS IN THE EDDA AREA OF THE AFIKPO SUB-BASIN

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ABSTRACT

This study analyzed the petroleum system elements of sediment outcrops deposited within the Edda area in the Afikpo Sub-basin. The area comprises the Nkporo Group and the Coal measures Group (Mamu, Ajali, and Nsukka Formations) in the Southern Nigeria sedimentary basin. The deposits are characterized by a range of lithological units, including shales, sandstones, siltstones, heterolithic units, and coal seams. This work aims to integrate lithostratigraphic, structural, and sedimentological parameters to understand the petroleum prospectivity and unlocks hydrocarbon opportunities within the Afikpo Sub-basin. The methods used in this study includes detailed field/outcrop descriptions, sedimentological and structural analyses. Over ten outcrops were studied and sampled for this study. The field investigations identified thick, organic-rich strata belonging to the Nkporo and coal measure Groups as potential source rocks. The medium- to coarse-grained, well-sorted Afikpo, Owutu and Ajali sandstones, with high porosity and bioturbation, are viable reservoir rocks. At the same time, the interbeds shales and indurated/iron rich siltstones were identified aseffective seals. Hydrocarbon traps identified in the area include: fault, anticlinal folds, and ferruginized indurated siltstones interbedded within the larger sandstone deposits. The depositional environment ranges from deltaic/tidal to shallow marine. The sedimentary sequences present in the study indicate suitable conditions for hydrocarbon generation, migration, and preservation. The vertical stacking of lithostratigraphic units observed in the study area indicates favourable conditions for efficient hydrocarbon production planning and development.

KEYWORDS: Nkporo, Coal measures, Source rock, Reservoir, Traps, Stratigraphic sequence.

INTRODUCTION

The study area is located in the southern part of Afikpo town in Edda community within the latitude of N5°48'-N5°55' and longitude of E007°44'-E007°50" (Figure 1). The Edda area of the Afikpo Sub-basin is composed locally of the Nkporo Group, comprising Asaga Amangwu shale, Amaiyi/Ekeje Shale, and Owutu sandstone; Coal measure Group (Mamu Formation) exposed at Ebunwana just before Iyere bridge (Figure 4.1) and Nguzu hill (Figure 4.7); Ajali Formation exposed at the Ezi Edda village (Figure 4.9) and Nsukka Formation outcropping at the hill before Ogwuma village (Figure 4.5), top of Nguzu hill and Ugwuifere.

The lithological composition of the study area is predominantly black to dark grey shale, interbedded with coal, heterolithic units, fluvio-deltaic sands, siltstones, and clays. In the past, researchers classified the sedimentary depression in the study area as the Afikpo syncline or Afikpo Sub-basin (Murat, 1972; Agagu and Adighije, 1983 Benkhelil, 1987; Nwajide *et al*. 1996; Reijers *et al.,* 1997; Okoro & Igwe, 2018; Okoro *et al*., 2020; Dim, 2021). However, Odigi and Amajor (2009) in a pivotal structural study analyzed microfault arrays and regional tectonic data to argue that the area had sufficient tectonic independence from the Anambra Basin to be formally elevated from a "syncline" or "Sub-basin" to a full, independent "Afikpo Basin" status.

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In Geology of Nigeria's Sedimentary Basins by Nwajide (2013), he argues against classifying the Afikpo Basin as a distinct entity, proposing instead that it is a direct extension of the Anambra Basin based on shared Santonian tectonic origins and continuous stratigraphy. He maintains that because they lack substantial structural separation, the two areas share identical geological histories and stratigraphic successions, such as the Campanian–Maastrichtian Nkporo Group. This work aligns with those that classify the area as the southernmost part of the four of the Sub-basins in Anambra basin comprising of Lafia, Ankpa, Onitcha and Afikpo Sub-basins due to the lack of major structural elements support designating it as an independent basin.

Previous studies in the study area were focused on origin and basin type, source of sedimentary fill, sedimentological description, lithostratigraphic composition, age determination, and depositional environments (Reyment, 1965; Genik, 1993; Nwajide & Reijers, 2005; Nwajide, 2013; Ibe & Iduma, 2018; Dim *et al*., 2019; Okoro *et al*., 2012; Okoro & Igwe, 2020). No work has been done on the petroleum system element analyses of the Edda area in Afikpo Sub-basin hence the need for this stud

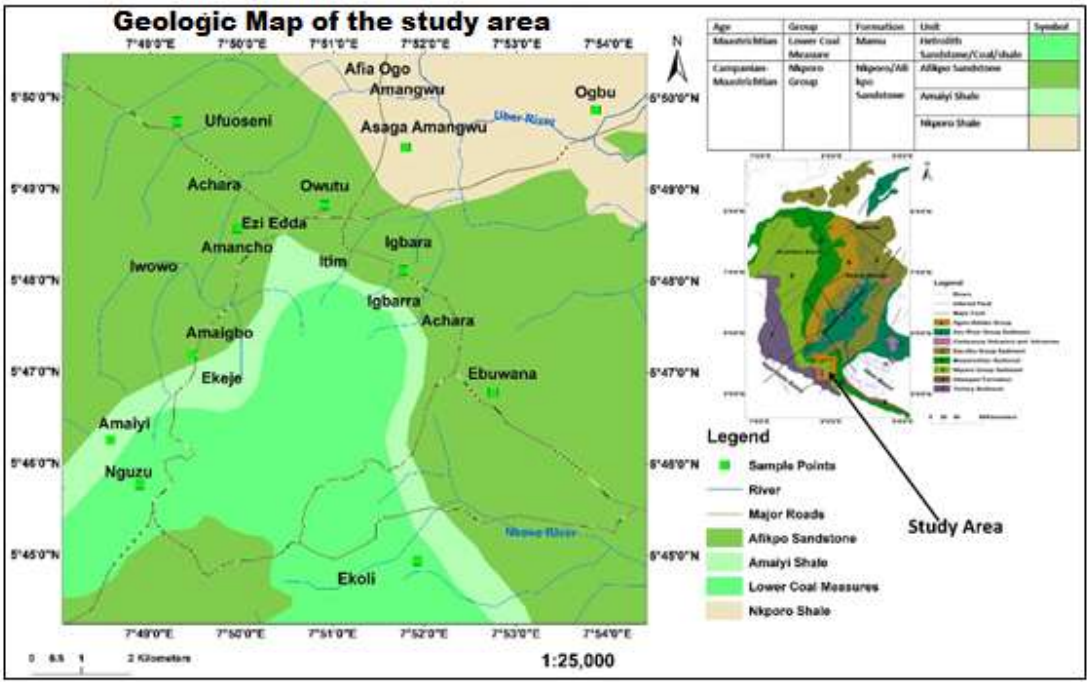

Fig. 1: Geologic map of Edda area, Afikpo Sub-basin, Southeastern Nigeria

Petroleum system element analysis is a holistic study of the critical elements necessary for the formation, migration, accumulation, and preservation of hydrocarbons in a basin. It requires a detailed study of source rock, reservoir rock, seal/cap rock, traps, migration pathways, and time. All the elements must be present and work collaboratively for hydrocarbons to accumulate. Field mapping in the study area shows that these elements are present. The aim of this work is to systematically examine the lithostratigraphy, depositional patterns, and structural elements present in the Nkporo and Coal Measure Groups (Mamu Formation, Ajali Formation, and Nsukka Formation) in the Edda area of the Afikpo Sub-basin in order to enhance the chances of discovering more hydrocarbon prospects in Southeastern Nigeria.

GEOLOGIC FRAMEWORK

The Afikpo Sub-basin is located in the Southeastern part of the Southern Benue Trough, Nigeria. It forms the narrower, eastern structural extension of the Anambra Basin and originated during the Santonian tectonic eperiogeny in the Late Cretaceous. The Sub-basin resulted from a thermal sag and downfaulting of the former Anambra platform and Ikpe platform around west and east of Abakaliki Anticlinorium, respectively (Akpa *et al*., 2024; Nwajide, 2013), and subsequent upliftment of the Abakaliki depo-center (Abakaliki Anticlinorium) of the Trough (Dim *et al*., 2017). The Afikpo Sub-basin is bounded to the north by Abakaliki Anticlinorium, it opens southward and is continuous with the Niger Delta Basin with which it shares a broadly similar post Santonian sedimentary fill reaching up to about 12, 000 m in thickness (Hoque & Nwajide 1985; Onyekuru *et al.,* 2023).

As part of Southern sedimentary Basin, the formation of Afikpo Sub-basin was linked to the Y-shaped, RRR triple-junction ridge system that initiated the rifting and separation of the African and South American plates in the Late Jurassic (Burke *et al*., 1971; Benkhelil, 1982). Hoque and Nwajide (1985) recognized four (4) tectonic stages in the evolution of Benue Aulacogen.

(1) The rifting stage in the Benue –Abakaliki Trough was characterized by crustal extension and rifting associated with the South Atlantic Ocean. This resulted in thinning and subsidence of the crust, leading to the creation of accommodation space for initial continental sedimentation (Awe Sandstone) and subsequent marine deposits (Asu-River Shale). The volcanic activity during the rifting stage deposited the Abakaliki pyroclastic rocks in the basin (Burke *et al*., 1971).

(2) The trough stage in the Benue Aulacogen is the period when the basin has fully formed towards the late Cretaceous. During this period, the basin experiences significant subsidence, massive sedimentation, transgression, and regression, resulting in the deposition of a series of Formations, including Odukpani, Eze-Aku, and Awgu (Benkhelil, 1989).

(3) The deformation stage in the basin is the period associated with compressional tectonic episodes of the Santonian stage. Compressional tectonics reversed prior extensional tectonics in the basin, creating a series of folds and converting some normal faults to reverse faults. It also resulted in the uplift and erosion of late cretaceous sediments and subsequent deposition in the neighbouring basins (Obiora & Umeji, 2004; Ofoegbu, 1984; and Nwachukwu, 1972)

(4) The platform stage occurred after the Santonian epirogeny that uplifted and eroded older sediments, resulting in platforms like Ikpe, Anambra, and Calabar Flanks. It was a period of minimal tectonic activity, associated with continental and shallow-marine sedimentation across southern Nigeria in the late Cretaceous (Ofoegbu 1984 and Benkhelil 1986).

The lithostratigraphic units of the study area comprise the Nkporo Group, the basal unit, and the Coal measures (Mamu, Ajali, and Nsukka Formations). In the study area, the Nkporo Group consists of three lithologic units: the Asaga Amangwu Shale, Owutu Sandstone, and Amaiyi-Ekeje Shale (Okoro & Igwe, 2018). The Formation was deposited during the first marine incursion in the Anambra Basin. It comprises dark- to light grey, laminated, and very fissile shale, mudstone, siltstone, and sandstone with variable grain sizes. The Nkporo shale is highly fossiliferous. It is also highly bioturbated with *Skolithos isp*., *Ophiomorpha isp*., and *Thalassinoides isp*. being the dominant ichnofacies (Adeoye *et al.,* 2024).

The Nkporo Group is overlain by the Coal measures. The Coal Measure Group is made up of the Mamu, Ajali, and Nsukka Formations. The Mamu Formation in the basin is characterized by heterolithic sedimentation, comprising interbedded mudstones, siltstones, shales, sandstones, and coal seams. This formation is reportedly deposited in a diverse range of environments, from paludial to pro-deltaic, with channels and marine influence (Nwajide & Reijers, 1996). The Ajali Formation is underlain by the Mamu Formation. It consists of milky, friable, coarse- to medium-grained sandstone, with moderate to low sorting and bioturbation. The sandstone is highly cross-bedded with planar, trough, herringbone, and flaser stratification (Okoro & Igwe, 2018). The Ajali Formation also contains bands of carbonaceous shale sometimes with beautiful colouration. It is believed to have been deposited during the late Maastrichtian transgression. (Reyment, 1965; Agagu *et al*., 1985; Adeoye *et al*., 2024). The Nsukka Formation, also referred to as the upper Coal measures, overlies the Ajali Formation. The lithologic composition of this Formation is predominantly shales, siltstones, sands, and thin coal seams. The layering is cyclic, with lithology rhythmically deposited throughout the Formation. The sandstones are interbedded with clays that occasionally occur in commercial quantities. Limestones have also been reported in the Nsukka Formation (Obi *et al*., 2001).

MATERIALS AND METHOD

The main material used in this study is the sediments samples collected from outcrops across the study area. Equipment such as geological compass, topographic/base map, field notebook; GPS, geologic hammer, hand lens (magnifying glass), measuring tape, sample bags and masking tape were also used in collecting and studying the samples. While set of standard sieves, an automatic sieve shaker, a sensitive weighing balance and a mechanical sample splitter were used for sieve analysis. And Sedlog software was used for plotting lithologs.

The sediments were studied through detailed field mapping, lithological description, facies analysis, sieve analysis, and 2-D facies Models. Many outcrop exposures occur as road cuts along the Ebunwana-Ekoli Road, the Owotu-Nguzu Road, the Ezi Edda sand mines, and at the peak of Nguzu Hill. More than ten outcrops were studied and sampled. The outcrops were systemically examined based on lithology, colour, grain size distribution, sorting, bioturbation, syn/post depositional sedimentary structures and tectonic structures. Outcrop locations were referenced using a global positioning system (GPS). Each bed occurring in the outcrops was clearly delineated, and its thickness was measured. Sand samples were collected for sieve analysis.

The strike and dip, as well as the azimuth of cross-bedding, fractures, and other structural elements, were represented in the geologic map. Lithofacies, structural, and stacking patterns of the sedimentary packages were used as critical elements of the petroleum system in the study area.

RESULTS AND DISCUSSIONS

Lithostratigraphic description of major outcrops in the Edda area

Ebunwana Sand Mine Exposure

This outcrop is a big exposure with a variety of different lithofacies such as sandstones, siltstones, shale, heterolithic units, coal, and clay. It is located 300m before the Iyere bridge, behind the Assemblies of God Church. The basal unit is composed of light grey mudstone/clay with evidence of ferruginization and is interbedded with siltstone lenses (Figure 4.3). The midsection is made of heterolithic sections characteristic of the lower Coal Measures (Mamu Formation). Below the Heterolithic unit is a highly bioturbated calcareous shale unit with concretion. While above the unit is an indurated surface indicating a stratigraphic surface. The upper part of the section consists of thick beds of highly bioturbated sandstone with ophiomorpha ichnofacies. The grain sizes range from medium to coarse grained, with a pebbly bed at the top. Based on the outcrop description, facies model, and sieve analysis (see Figures 4.1 and 4.2), the depositional environment is interpreted as a deltaic system prograding in a shallow-marine setting.

Fig 4: Composite images of Mamu Formation outcrop

A -The basal unit of the outcrop consists of light-grey to brownish mudstone. B- Heterolithic unit capped by a hardground made of ferruginised and indurated sandstone. C-intercalation of siltstone and shale above the unit B. D &E- The stratigraphic surface above the heterolithic units with fractures, scoured surfaces, and low-grade coal above it. F- The topmost part of the outcrop consists of thick sandstone interbedded with thin beds of clay, as indicated by the arrow. The sandstone is a coarsening-upward sequence in Ebunwana town showing mudstone, heterolithic units, and sandstones

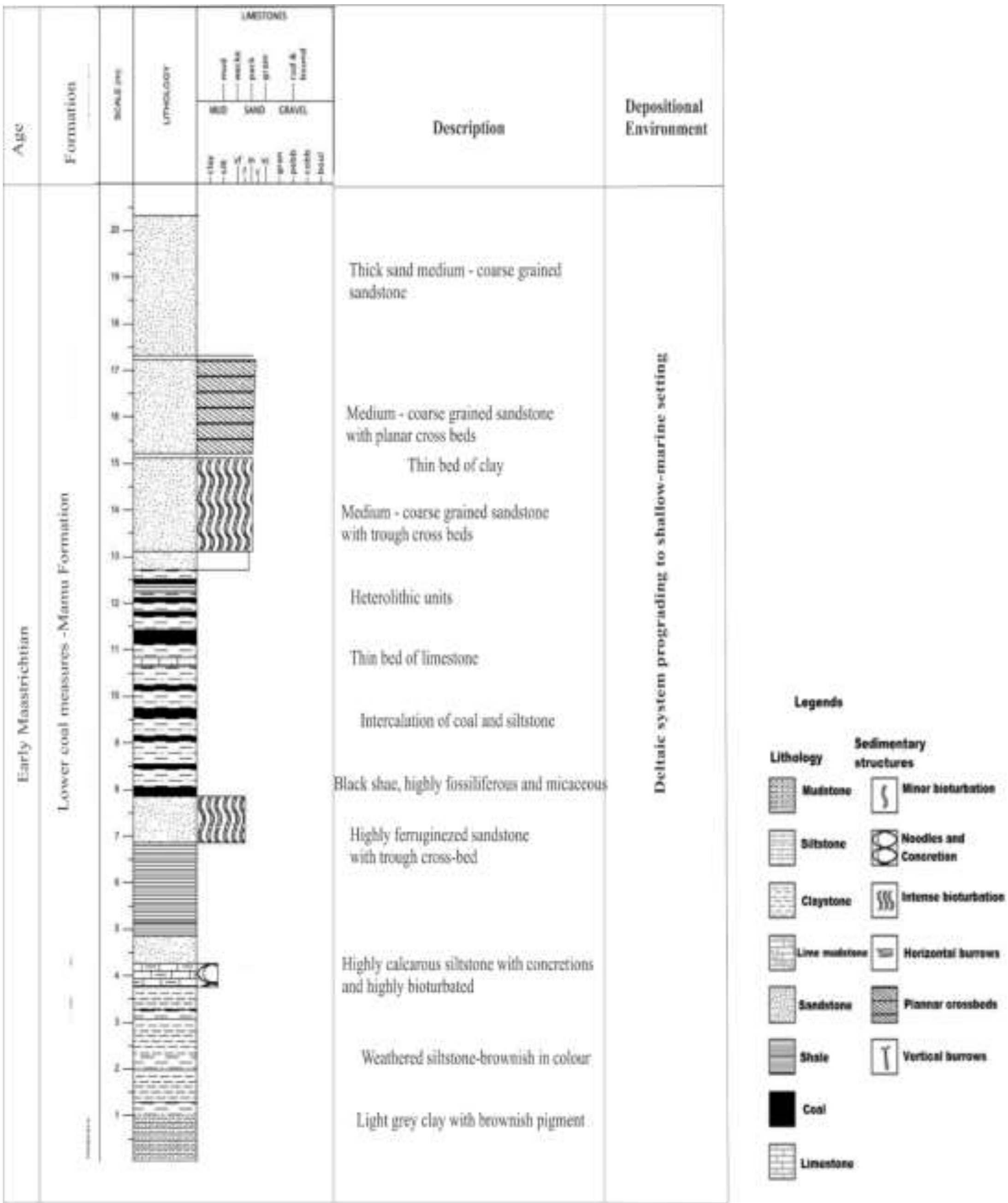

Fig. 4: Facies model of lower Coal Measure (Mamu Formation) outcrop exposed behind the local Assemblies of God church, Ebunwana Edda. The unit has diverse lithology including, shale, sandstone, coal, clay, heterolithic units etc

Road cut before the Iyere Bridge

The outcrop is similar to the Ebunwana sand mine; it consists of interbeds of sandstone, shale, coal, and siltstone. The shale at the basal part is very dark in colour with an interbed of lignite while the associated siltstone is light grey. The mid-section of the outcrop consists of a heterolithic unit with an erosional surface capping the unit and a highly consolidated, highly bioturbated and highly fractured sandstone, milky to light brown in colour (Figures 4.3 and 4.4). The grain size ranges from medium-coarse to pebbly. Above the sandstone is an indurated silty shale, low-grade coal, and siltstone beds. The top of the outcrop is made up of very thick sandstone units interbedded with siltstone (Figures 4.3 and 4.4)

The depositional environment is similar to that of the outcrop section at Ebunwana, which ranges from a delta plain to a shallow-marine environment.

Fig 4.3: Sections of lower coal measure units exposed at the road cut before Iyere bridge fly-over in Edda town.

A- Low-grade silty coal at the base of the outcrop. B-Light grey shale, probably of a swamp or vegetated delta plain, prograding into the heterolithic unit C- Heterolithic unit deposited within the tidal flats/ delta front with a sandwich of hardground (indurated sandstone) interpreted to be a sequence boundary. D- Bioturbated sandstone medium in grainsize, containing joints and fractures, and other features suggesting a distributary channel as the environment of deposition. E- Thick sandstone unit with thin beds of clay, medium – coarse in grain size.

Fig. 4.4: Litholog of the upper part of the lower coal measure unit exposed at the road cut before Iyere Bridge fly-over in Edda town

Ogwuma Hill Outcrop

The exposure after the Iyere bridge towards Ogwuma village was open to source sand for the bridge's construction. The hill is composed predominantly of sandstone interbedded with highly indurated, ferruginized, fine-grained sandstone. The sandstone units are bioturbated, milky white in color, and tend to attain about five meters in thickness before a very hard sandstone is sandwiched in between. The middle of the hill consists of an interbedding of indurated siltstone and sandstone. This heterolithic unit also contains indurated, highly ferruginized sandstone. Towards the top of the outcrop is a thick-bedded sandstone interbedded by a beautiful pink clay, followed by very dark shale, siltstone, and sandstone (Figures 4.5 and 4.6)

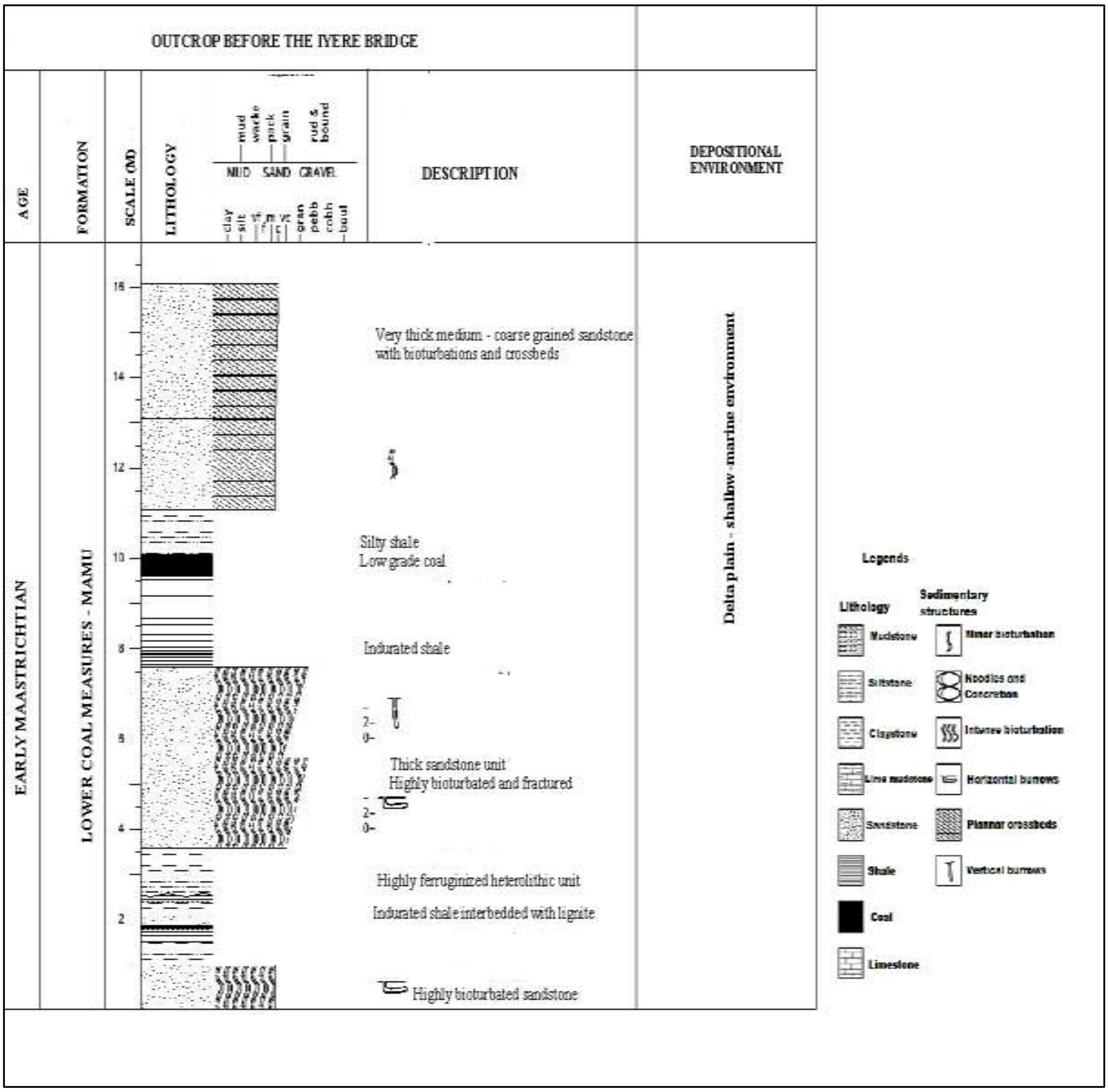

Fig. 4.5: Enigmatic outcrop of Pink Sandstone, yellow siltstone, and black shale at Ogwuma Hill. Below this unit is highly consolidated and ferruginized sandstone, with heterolithic units containing interbedded indurated sandstone lenses. The depositional environment of this section is interpreted as a fluvial-dominated delta.

Nguzu Hill Road Cut

The lithofacies units of Nguzu Hill consist of sandstone, siltstone, clay, and shale. The basal unit of the hill consists of sandstone interbedded by siltstone and clay. The unit is highly bioturbated and overlain by a very thick, consolidated, medium-grained sandstone that is light brown in color (Figures 4.7 and 4.8).

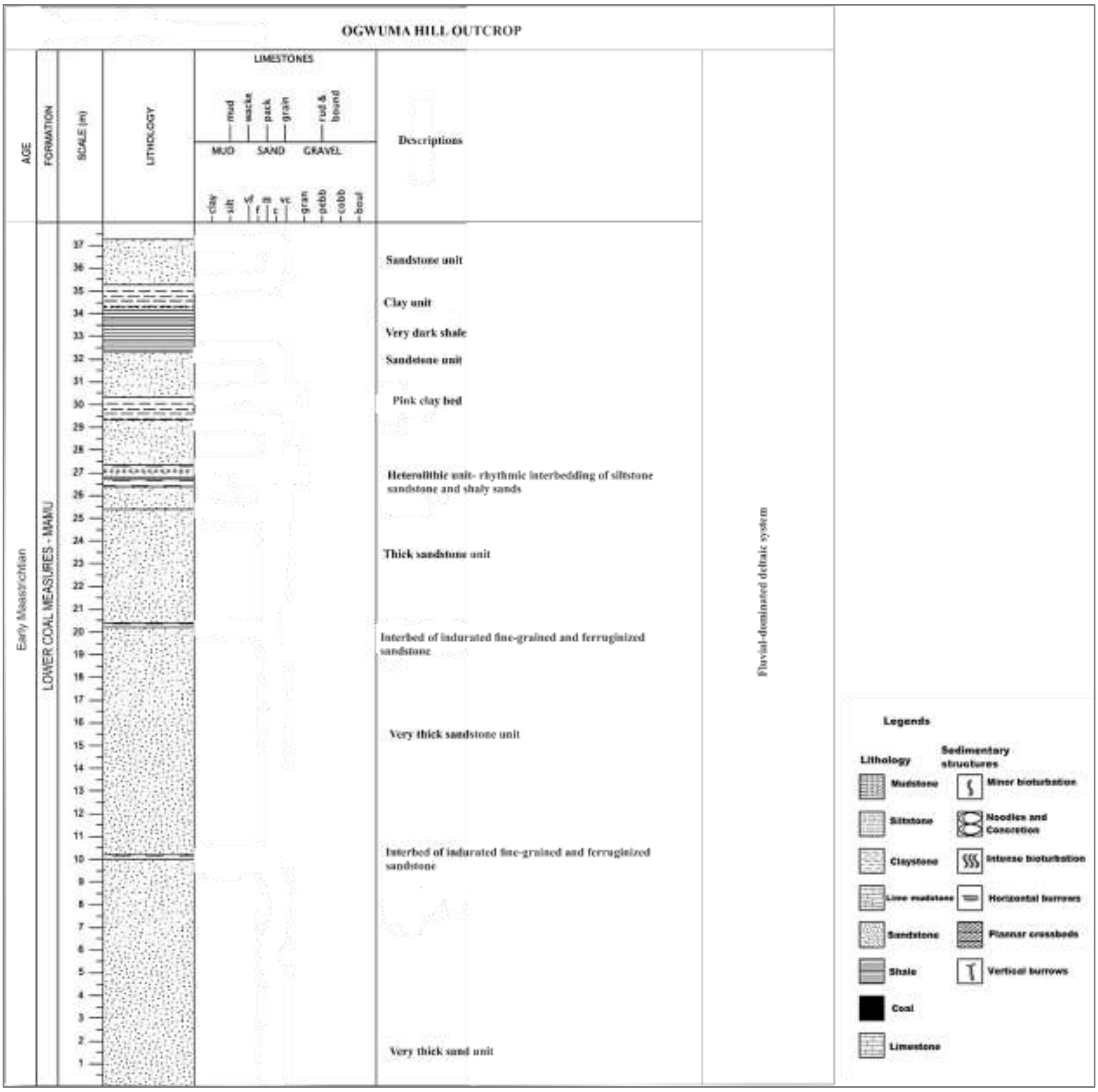

Fig 4.6: Log motif of thick sandstone, siltstone, and black shale at Ogwuma Hill.

Fig. 4.7 Composite lithologic units exposed at Nguzu Hill, the shales are highly organic, carbonaceous with sulphur effervescence. It contains concretions with calcareous and pyritic inclusions.

A-Highly bioturbated consolidated sandstone at the foot of Nguzu Hill. B-cross-bedded Milky white sandstone with burrows. C-silty shale with embedded clast. D- Dark grey shale, laminated and fissile with some noodles/Concretion. E- Laminated and fissile shale, light grey in colour, with a thin bed of limestone as indicated by the red arrow, these lithofacies occurred rhythmically for the majority of the escarpment. F-Blocky shale, Light grey in colour. G-consolidated sandstone at the upper part of the escarpment. H- Siltstone interlayered with sandstone and shale at the peak of the escarpment.

The sandstone facies are also overlain by a silty shale that pinched out into a clay bed. Above the clay is a very thick sandstone facies of about six meters. This sandstone-siltstone intercalation is overlain by a series of thick dark grey shales over 30m thick. The shales are interbedded with thin lenses of calcareous lime/mudstones (Figure 4.7E), calcareous siltstone and indurated sandstone. The top of the hill consists of interbeds of sandstone, siltstone, clay, and mudstone as indicated in the log (Figure 4.8). The depositional environment is interpreted to be delta front to marine shelf based on the lithofacies association in Figure 4.8

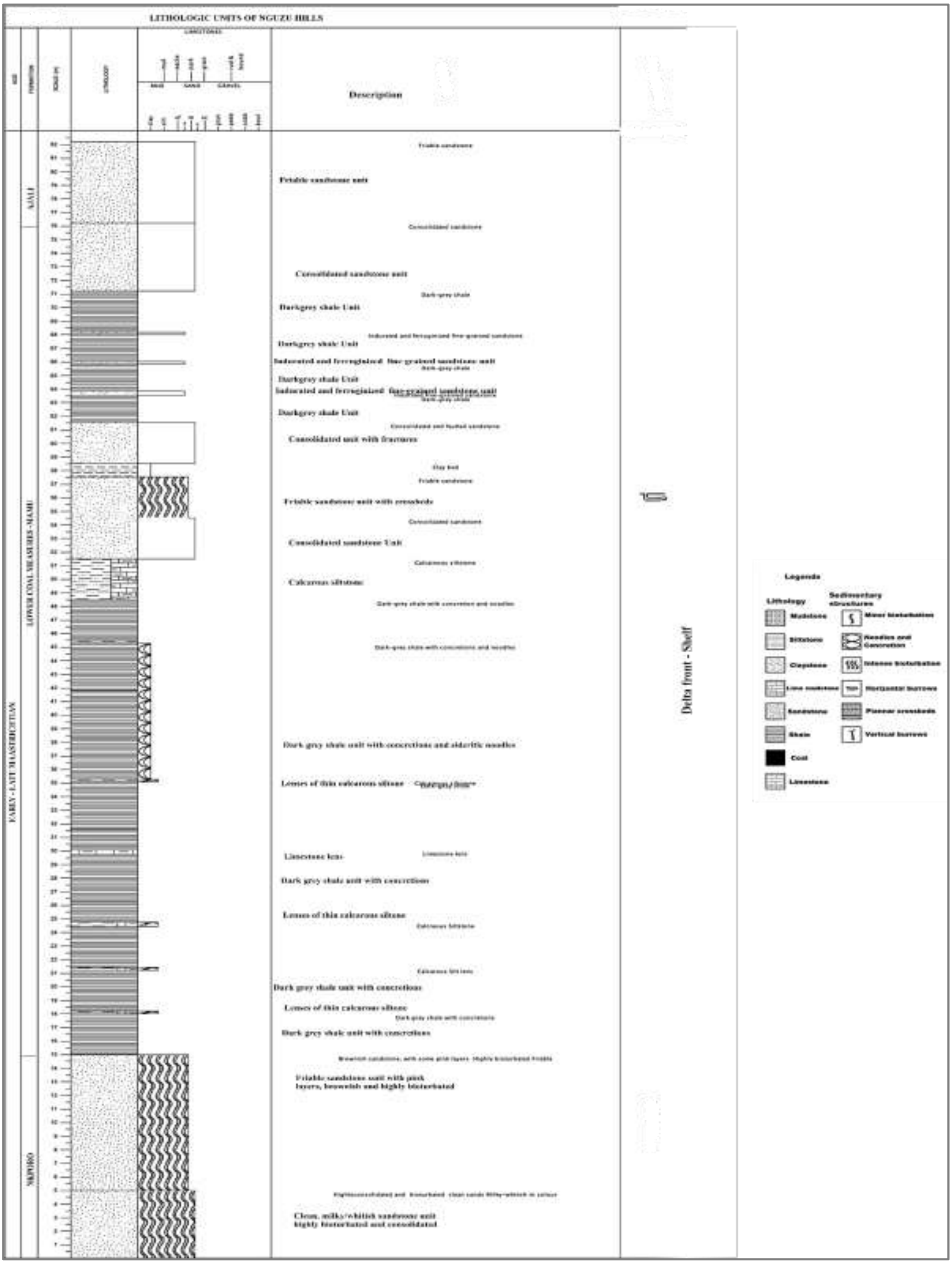

Fig 4.8: 2-dimensional facies model of Nguzu Hill showing a complete sequence from the basal sandstone unit through thick dark-grey shales to the upper sandstone unit extending to Ekoli Edda

Ezi-Edda sand mine pit

This area is made up of hills with friable, beautiful sandstone outcrops. The sandstones are variable in grain size, ranging from fine to very coarse. They are generally well sorted. The sandstone is friable due to the poor cementing quality of the clay; it is generally a quartz arenite with a low amount of feldspar and rarely micas. It is milky to brownish in colour. The sandstones are highly bioturbated in some places, with vertical and horizontal burrows of Ophiomorpha and Skolithos. Underlying it is a very fine-grained, white sandstone, well-suited for plastering and decorating structures. The sedimentary structures in sandstone outcrop at Ezi Edda include: planar and trough cross-beds, clay drapes, lenticular bedding, flaser beds, and laminations (Figure 4.7). The outcrops occur in a vast expanse of land where it is quarried for construction purposes.

The location was deposited in the tidal environment due to the presence of cross-bedding, clay drapes and bioturbation.

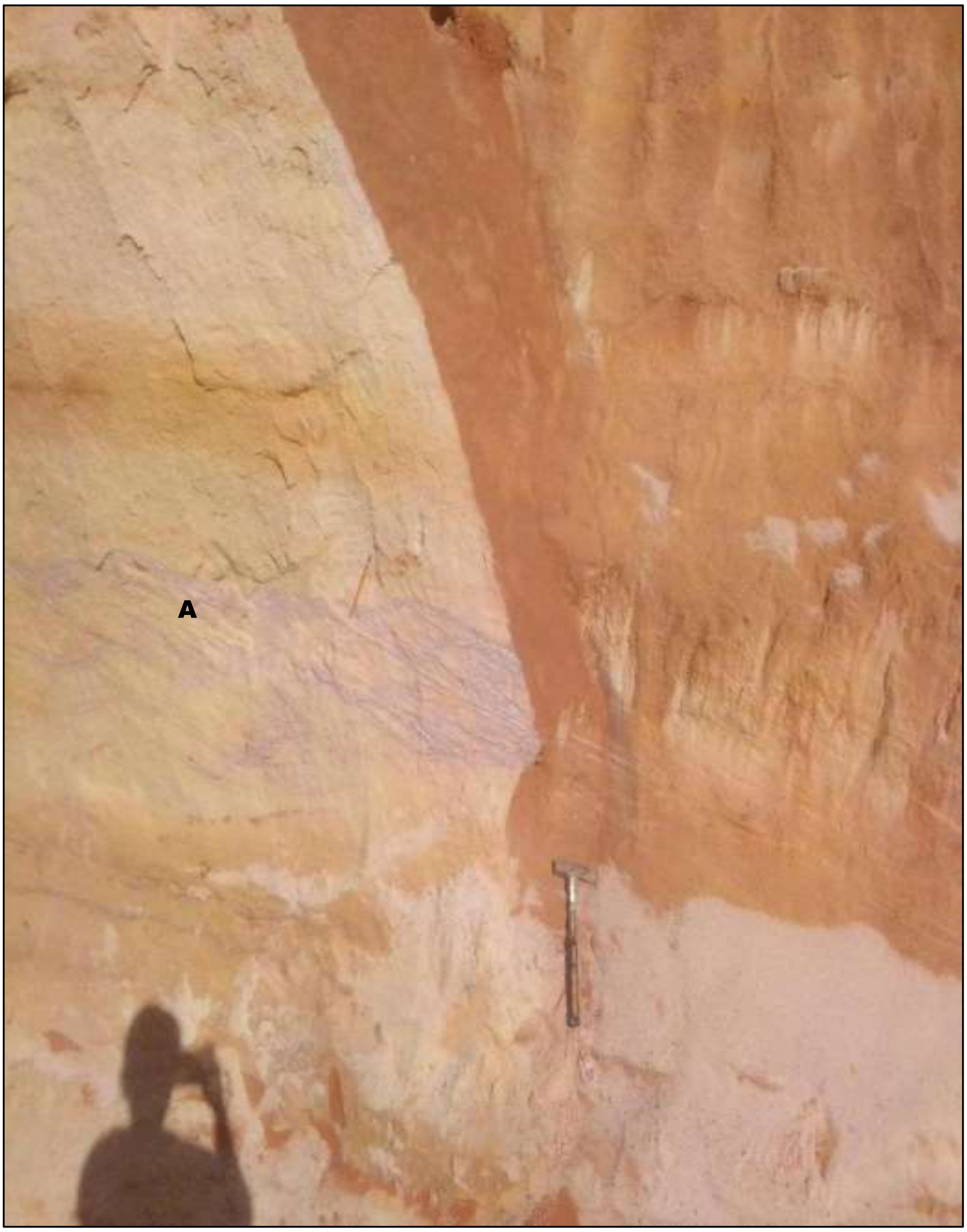

Fig 4.9 A: Ajali Sandstone exposed at Ezi-Edda village. Stratigraphic terminations are evident on the unit. The brownish colouration is a result of weathering of laterite above the unit

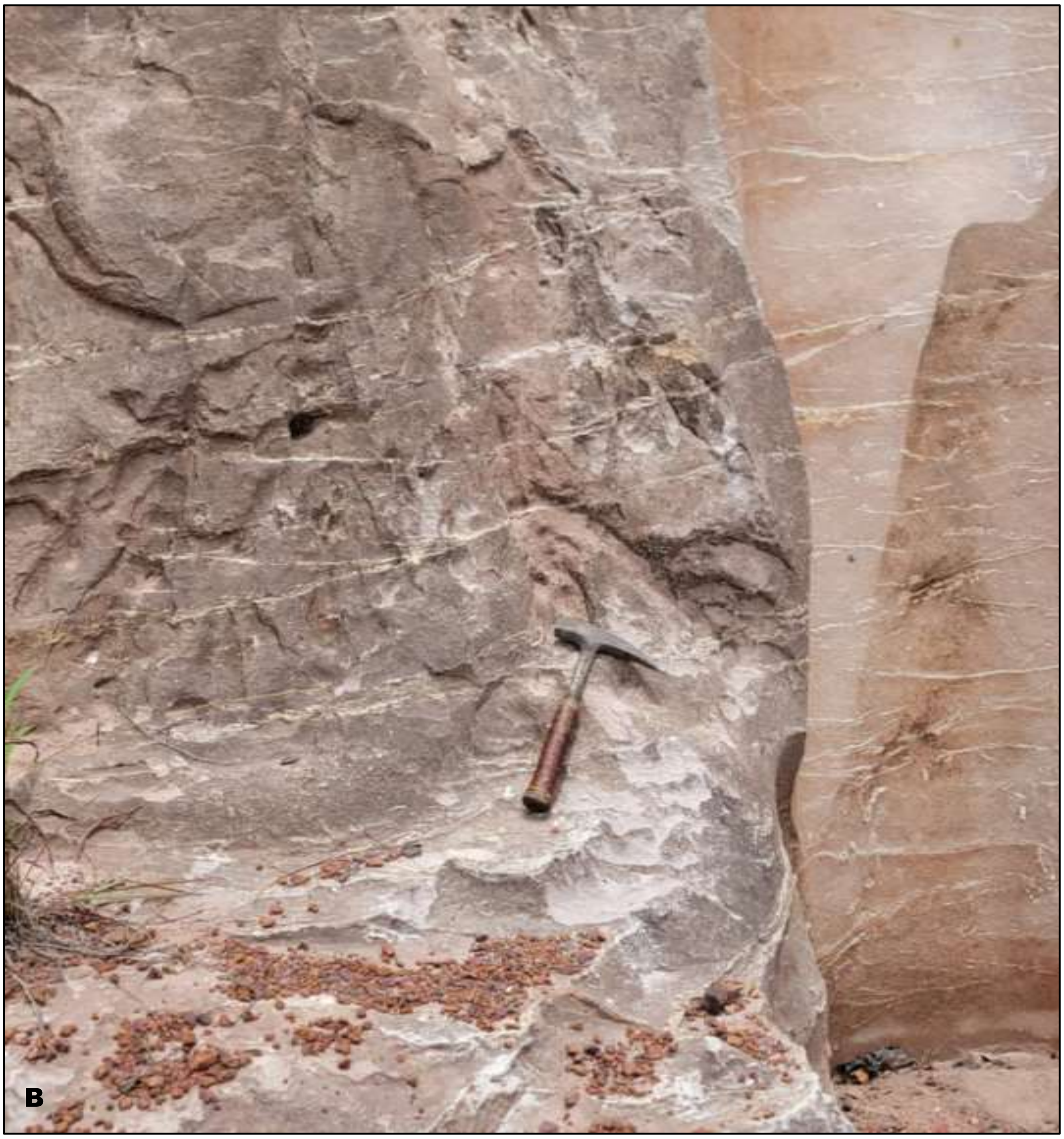

Fig 4.9 B: Sandstone Unit belonging to Ajali Formation exposed at Ezi-Edda sand mining pit off Owutu – Ekoli road. The outcrops consist of cross-beds, clay drapes, lenticular bedding, and various types of burrows (see also Figure 4.13b).

Lithostratigraphic Units

Amaiyi Section

The Amaiyi Section is part of the Nkporo Group in the study area. It consists of dark-grey shale with siltstone/sandstone intercalation at the Amaiyi and Ekeje areas. The shale samples from this unit are laminated, fissile and in some places blocky. It contains some anoxic environmental mineral indicators such as pyrite and glauconite. The shale unit at Amayi contains very big nodules and concretions within them (Figure 4.10 a&b)

Fig: 4.10a: Dark gray shale exposed at Amaiyi Ekeje Road. This Unit is a good potential source rock for the Edda area
Fig. 4.10b: Septarian noodle/concretion as exposed at Amaiyi before Nguzu hill

Owutu sandstone.

This unit outcrops at Owutu, Amigbo, and Amoso areas. It is also part of the Nkporo Group. The lithology is composed of highly consolidated sandstone. It contains many joints and, in some outcrops, healed fractures. The outcrop at Amigbo Primary School contains an erosional surface with many potholes. The sandstone is bioturbated, medium- to fine-grained, with clay as the cementing material; it is brownish in color and contains numerous fractures. (Figure 4.11a,b, and c). The unit also contains both planar and Trough crossbeds. Sometimes structures such as concretions occur within the sandstones, and it is believed that the potholes were formed by the dissolution of these concretions.

The sandstone is moderately to well sorted and displays an upward coarsening sequence.

Fig 4.11a: Consolidated sandstone unit exposed at Amigbo primary School. The sandstone is bioturbated, as shown in the picture

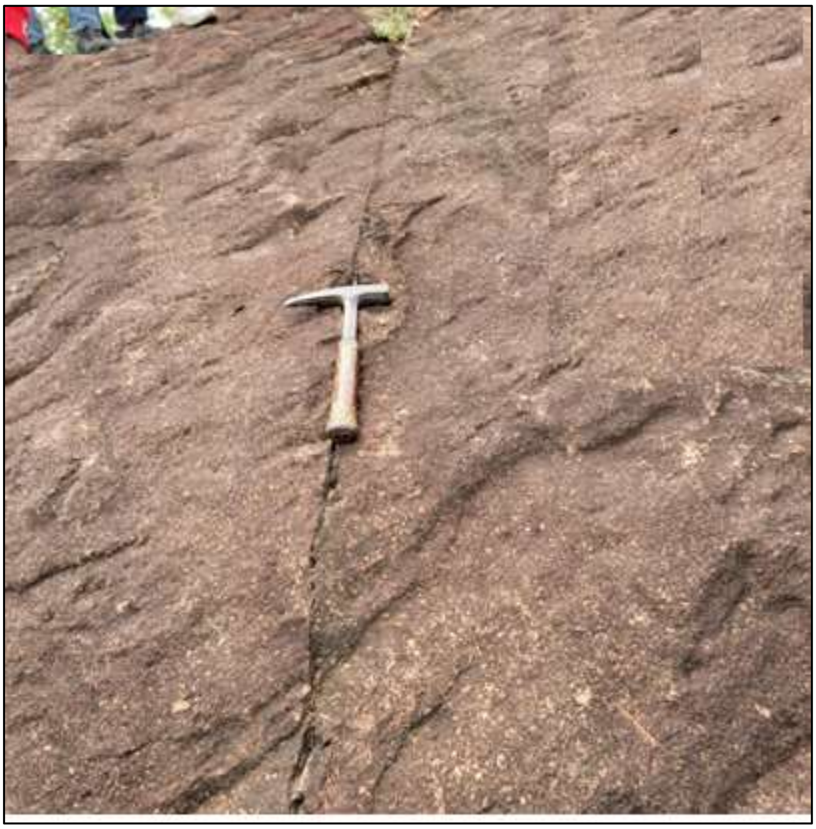

Fig 4.11b: Owutu Sanstone exposed at Amigbo Primary school, the sandstone unit contains cross-beds as indicated in the picture

Fig 4.11c: Owutu sandstone exposed along Owutu- Ekoli Road at Amaigbo Village. This sandstone is highly and interconnected fractured and the fracture could be a migration pathway for hydrocarbons

PETROLEUM SYSTEM ANALYSIS OF THE SEDIMENTARY DEPOSIT OF EDDA AREA.

The Petroleum system analysis of the sedimentary deposits exposed in the study area involved a critical examination of the source rock, reservoir, trapping system, and seal/cap rock. The outcrops described in the previous section suggest that the presence of these key elements in the study area makes them suitable for petroleum accumulation and production.

The Source Rock

Shales with potential source rock properties are ubiquitous in the study area. They are exposed at Nguzu Hill, Amaiyi, Ekeje, Asaga Amangwu, and Ebunwana, close to the Iyere bridge, as coal and black shales (Figures 4.5, 4.7, 4.10, and 4.12). The shales are very thick and contain high organic content (Ibe & Iduma, 2018; Okogbe *et al.*, 2005). The Nkporo shale outcrops at Amaiyi, Ekeje, and Asaga Amangwu as thick black-to-dark grey shale with concretions, forming about 70% of the rock in the hill. The shales at these locations may serve as a source rock for hydrocarbon generation. In fact, the presence of this rock has attracted multinational oil/gas companies to Edda area, and they have drilled up to four exploratory wells in the area. The organic geochemical analysis of Nkporo Shale by previous authors indicates that the Total Organic Carbon (TOC) content ranges from 1.2% - 4.5% (Obiora & Umeji, 2004; Akande *et al.*, 2005; Uzoegbu & Onuoha, 2011; Eniola, 2002). This value is reportedly similar to the values of Akata/Agbada Formations that are the main source rocks in the Niger Delta petroleum province (see Ekweozor and Daukoru, 1994).

Source rocks are also found in the Mamu Formation, as exposed at the Ebunwana/Iyere bridge axis, with shale and coal outcrops. Coal and dark shale are considered good source rocks. Dim *et al.* (2018) reported that Coal beds constitute the best source rock in the Anambra Basin.

The dark gray shale prevalent at the base of Nguzu Hill and Asaga Amangwu contains abundant precipitated sulphur, which indicates ocean anoxia which is suitable to hydrocarbon preservation. The hydrocarbon generated from this shale could be stored in the surrounding sandstone units.

Fig 4.12: Nkporo shale at Ekeje is believed to be the source rock for the Edda petroleum province

Reservoir Potential
The study area contains very thick sandstone units that are suitable as reservoir rock. These sandstone outcrops are located in the villages of Ebunwana, Ekoli, Amigbo, Owutu, and Ezi Edda. Most of the sandstone units in the study area are friable due to poor cementation; they are generally quartz arenites with low feldspar content and rarely contain micas. It is milk-to-brownish in color. The sandstone is generally moderately well-sorted and, in some places, highly bioturbated, with vertical and horizontal burrows of Ophiomorpha and Skolithos. The bioturbation enhances porosity (Dim *et al.,* 2019; Onyekuru *et al.,* 2023). In some locations like Nguzu, Ndi-olughu, and Ugwuma, the sandstone is interbedded with highly ferruginised/ indurated sandstone lenses, resulting in some sort of compactment within the reservoir. The sandstone will be a very good reservoir because it contains little or no clay. This sandstone is mature and well-sorted, suggesting that it could be a good reservoir rock.

The sedimentary structures of Owutu sandstone include planar and trough cross-beds, lenticular bedding, hummocky stratification, and flaser beds (Figure 4.16a and b).

Fig. 4.13a: Sandstone unit exposed at Ogbu, the outcrop shows lenticular bedding and channel lag deposits above

Fig 4.13b: Ajali Formation sandstone unit exposed at Ezi Edda sand mine pit. It is fine – medium-grained, well-sorted, and poorly cemented.

The grain-size sieve analysis indicates a mean size of 0.704, interpreted as moderate-to-coarse-grained sandstone. Moreover, the sorting value of 1.167 indicates that the sandstone in the study area is a moderately sorted sediment (see Table 1 below). This result also indicates moderate to high porosity and the environment of deposition to be a shoreline -marginal marine environment with moderate energy (Folk & Ward, 1958; Okoro *et al.,* 2020)

Table 1: The summary of sieve analysis results from various sandstone units in the area across the study area

SAMPLE	MEAN SIZE	SORTING	KURTOSIS	SKEWNESS
CNN1	0.67 coarse	0.70 moderately sorted	0.30 Platykurtic	0.10 positive skewed
CNN 2	0.20 Fine	1.00 moderately sorted	3.50 very leptokurtic	3.0 very positive skewed
CNN 3	0.60 coarse	0.84 moderately sorted	2.0 Very Leptokurtic	0.27 positive skewed
CNN 4	0.45 medium	1.55 poorly sorted	0.76 Platykurtic	0.19 positive skew
CNN 5	0.6 coarse	0.84 moderately sorted	2.19 very leptokurtic	2.20 very positive skewed
CNN 6	1.10 Very coarse	1.43 poorly sorted	1.92 Leptokurtic	0.61 very positive skewed
CNN 7	1.01 Very coarse	1.11 poorly sorted	1.9 Leptokurtic	0.613 very positive skewed
CNN 8	1.15 Very coarse	1.13 Poorly sorted	2.19 very leptokurtic	0.88 very positive skewed
CNN 9	1.18 Very coarse	1.72 poorly sorted	1.44 very leptokurtic	0.85 very positive skewed
CNN 10	0.483 medium	1.25 poorly sorted	0.80 Platykurtic	0.412 positive skew

Average Values:
Mean Size: 0.704
Sorting: 1.167
Kurtosis: 1.741
Skewness: 0.990

Evidence of Hydrocarbon Traps

Both structural and stratigraphic trapping mechanisms are present in the studied area. For instance, the Owutu Sandstone is bounded above by the dark gray Ekeje Shale and below by the Asaga Amangwu Shale, thereby creating a vertical migration-trapping mechanism. Though no major faults have been reported in the area, there is a presence of highly fractured sandstone unit at Amigbo Primary school indicating the presence of unidentified fault (see Fig 4.11c). Also, there are large-scale, very thick sand units, as seen in Ogwuma Hill, interlaid by indurated siltstone with iron oxides. The ferruginized siltstones are so hard and impermeable that they can seal the reservoir and prevent fluid transmission. Anticlinal structures were identified on the sedimentary facies along Owutu Nguzu Hill just before Amaiyi Village (Figure 4.16). A faulted sandstone with a polished and indurated surface (Figure 4.14 below) was discovered above the Nguzu hill. These faults and folds could provide significant structural traps for hydrocarbons (Figures 4.15 and 4.16). There need for more geophysical study on the basin to understand the sub-surface structure as surface features points to the presence of more structural and stratigraphic traps in the area (see Fig. 4.15)

Fig 4.14: Strike-slip fault at Nguzu hill, this could provide a migration pathway and seal.

Fig 4.15. Edda landscape-it could provide clues to subsurface structures like a large-scale fold in the basin

Fig. 4.16 Anticlinal fold along Owutu-Ekoli Road providing evidence of structural trap

The implication of key petroleum elements on the hydrocarbon potential of Edda area.

This study has identified the presence of source rocks, reservoirs, traps and migration paths in the outcrops described above. It has shown that the studied area has significant potential to host a substantial hydrocarbon prospect, hence the need for increased petroleum exploration efforts. The presence of these petroleum elements on the surface prompted the colonial government to explore for oil in the Afikpo area before Nigeria's independence. About three exploration wells were drilled in the studied area, namely, Nguzu well, Ezi Edda well, and the Asaga Amangwu Well. The sediment thickness in the Edda area estimated with aeromagnetic data is reported to be above 1000 meters, which is suitable for hydrocarbon accumulation (Okogbue, 2006; Ibe & Uche, 2018). The exposed outcrops (overburden) at the Nguzu area are over 300m thick.

The presence of gypsum and pyrite precipitation in the shales and heterolithic units is evidence of hydrocarbon maturation. Data on the thermal gradient in the study area are not available, but results from other parts of the Anambra Basin show that it ranges between 480 °C -780 °C, and these values are similar to those in the Niger Delta (Okogbue, 2006).

CONCLUSIONS

This preliminary study of the petroleum system elements in the Edda area of the Afikpo Sub-basin has shown that the area has a huge potential for hydrocarbon prospect. The lateral and temporal distribution of the sedimentary sequences strongly supports hydrocarbon accumulation. The basal Afikpo sandstone unit is suitable for a good reservoir, and it is properly sealed by the overlying Asaga Amangwu shale, which serves as the source rock and seal. Other reservoir units are the Owutu, Ebunwana and Ezi Edda sandstone facies. The major source rock facies are the Asaga Amangwu, Amaiyi/Ekeje, Nguzu shales, and Ebunwana coal seams and shale. These lithologic units are arranged in a vertical stacking pattern with multiple reservoir compartments, as shown in Table 2 below. The compartmentalization of the petroleum system in the study area will make production planning easier because the sedimentary sequence in the study area could be accessed by a single wellbore.

Table 2: Stratigraphic sequence/Lithofacies units of the Edda Area in Afikpo Sub-basin

AGE	FORMATION/SUBUNITS		FORMATION/SUBUNITS	PETROLEUM SYSTEM	FORMATION
UPPER MAASTRICHTIAN	NSUKKA		NGUZU CLAY	Source Rock/seal/Reservoir	NSUKKA
MIDDLE MAASTRICHTIAN	AJALI		EZI EDDA SANDSTONE	Reservoir Rocks	AJALI
			NGUZU SHALE	Source Rock/seal	MAMU
LOWER MAASTRICHTIAN	MAMU		EBUNWANA SANDSTONE	Reservoir	
			EBUNWANA COAL SEAM/SHALE	Source Rock/seal	
	AMAIYI EDDA SHALE	NKPORO FM	AMAIYI/EKEJE SHALE		NKPORO FM
UPPER CAMPANIAN	OWUTU SANDSTONE		OWUTU SANDSTONE	Reservoir	
	ASAGA AMANGWU SHALE		ASAGA AMANGWU SHALE	Source Rock/seal	
	AFIKPO SANDSTONE		AFIKPO SANDSTONE	Reservoir	
OKORO & IGWE 2018			THIS STUDY		ODIGI 2007(abridged)

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- **Data availability:** All the data used for the research are included in the manuscript. More data will be made available on request
- Compliance with Ethical Standards: Ethical clearance not required for this work

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