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Structural, Stratigraphic and Combination Traps on Outcropping Lithostratigraphic Units of the Anambra Basin, Southeast Nigeria

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Abstract

Although several works utilizing subsurface seismic data acquired within the inland Anambra Basin and the neighbouring onshore and offshore section of the Niger Delta Basin have revealed the presence of structural and some stratigraphic hydrocarbon entrapment mechanisms, none have been able to document the existence of these traps on outcrops. This is probably due to poor exposures and lack of access to vicinities where these structural and stratigraphic features are visible on outcrops. This work captures a selection of outcrops in the Anambra inland basin across southeastern Nigeria that are associated with possible hydrocarbon traps. Key structural traps observed include; hanging wall closures, footwall closures, horst and collapsed-crest structure. The stratigraphic traps comprise channel fills and pinch-out structures. In addition, some strati-structural/combination traps were seen in some outcrop sections with faulted sand lenses. These traps are essential elements of the petroleum systems, which could accommodate hydrocarbons within the Anambra Basin, and associated inland basins of Nigeria. Hence, could act as a guide during hydrocarbon prospectivity studies.

Keywords: *Outcrop; Structural trap; Stratigraphic trap; Combination trap; Anambra Basin.*

1. Introduction

Several hydrocarbon exploration campaigns in sedimentary basins of Nigeria have targeted basins with good petroleum system potentials. Studies have shown that one of the key elements of the petroleum system that must be present is the entrapment mechanism. This entrapment mechanism comprises trapping styles that could be structural, stratigraphic or a combination of both. In the Niger Delta Basin, structural traps such as anticlinal dip closures, footwall and hanging wall closures, faulted rollover anticlines, collapsed-crest structures, horst block and sub-detachment structures, have been interpreted using seismic data [1-3]. Stratigraphic traps formed through crestal accumulations below mature erosion surfaces, canyon-fill accumulations above unconformity surfaces, and facies change traps, have also been documented in the Niger Delta Basin [4]. Interpreted seismic section from Bornu Sub-basin in the Northern Benue Trough has shown the existence of some structural styles and hydrocarbon traps such as updip entrapment intrusive rocks, anticlinal traps, graben structure entrapment, unconformity and mounded structural traps, onlap structural traps, growth fault and basement traps [5-6]. Within the Anambra Basin, some structural styles such as hanging walls, footwalls, horst block and collapsed crest structures providing good entrapment mechanisms for hydrocarbon accumulation, have been interpreted on seismic section [7].

However, all these documented entrapment mechanisms were seen only on seismic through subsurface exploration studies with little or no outcrop examples. Recently, work has shown that these trapping configurations can also be seen on outcrops [8]. Therefore, the focus of this work is to highlight some of the entrapment mechanisms observed through detailed outcrop studies in the southeastern section of the Anambra Basin of Nigeria (Fig. 1).

Emphasis will be on establishing the types of entrapment mechanisms and discussing their implications for hydrocarbon exploration.

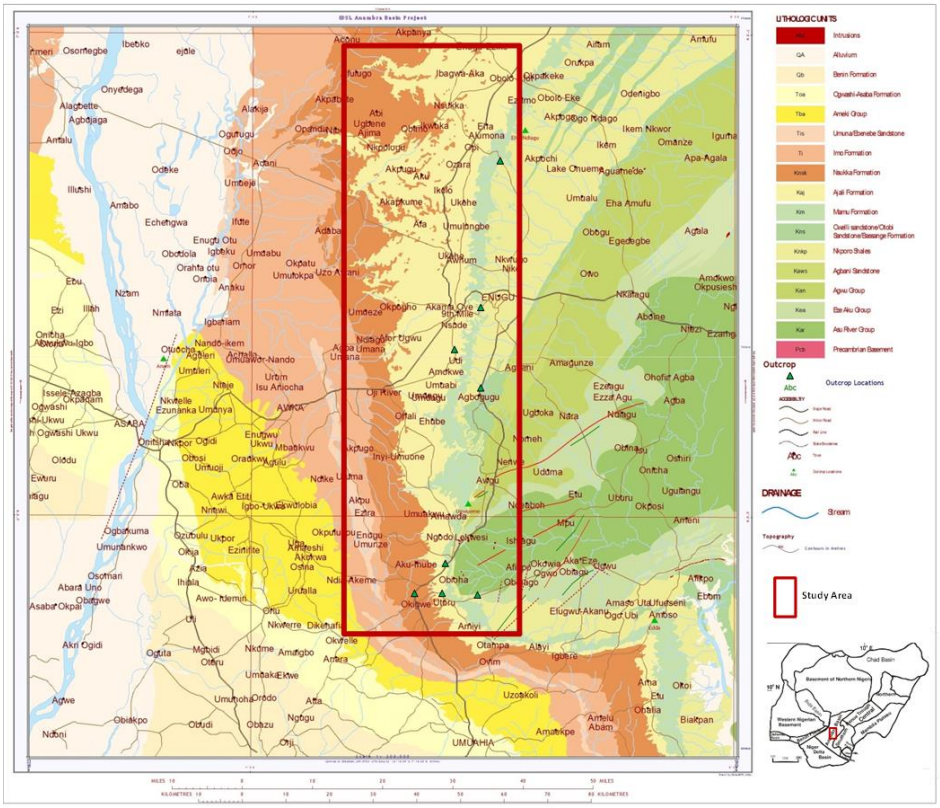

Fig. 1. Geologic Map of Southeastern Nigeria showing the four lithostratigraphic units that makes up the Anambra Basin (Nkporo Group, Mamu Formation, Ajali Formation and Nsukka Formation) on the red rectangle and the spatial distribution of outcrop locations in that were studied [8-9]. Note: Inset map of Nigeria with outlines of geology showing the Anambra Basin

2. Brief geologic framework of Anambra

The tectonostratigraphic evolution of the Anambra Basin is well documented in several works [10-15]. The basin was formed as a result of the Santonian compressional uplift of the Abakaliki-Benue Trough, with its resultant sediment folding, that displaced the depositional centre from the Abakaliki Basin to the Anambra Basin and finally, in the Cenozoic, to the neighbouring Niger Delta [16]. The basin fill comprises of four lithostratigraphic units (Fig. 1; [17-19]). These units are the Campanian Enugu Formation of Nkporo Group (with carbonaceous shales and sandstone, the Maastrichtian Mamu Formation (with alternating sandstones, sandy shales and mudstones, with interbedded sub-bituminous coal seams), the Ajali Formation (mainly sands with interbeds of clay laminae) and the Nsukka Formation (with dark shales and sandstones and thin coal seams). These units are said to have been deposited during a regressive cycle (relative sea-level fall) within fluvio-tidal, deltaic, shelfal and marine settings [7]. For the purpose of this study, the effort was made to ensure that exposed sections of each of these lithostratigraphic units were studied.

3. Methodology

Representative outcrops with good structural and stratigraphic configuration across the lithostratigraphic units in the Anambra Basin were visited and studied (Fig. 1). Detailed outcrop studies, the examination of stratigraphic and structural features were used for trap classifications (Fig. 1-10). Based on the classified entrapment type, their implications in hydrocarbon exploration studies were discussed.

4. Results and discussion

4.1. Structural traps

Key structural traps were observed within the lithostratigraphic units of Enugu Formation and Nsukka Formation (Figs. 1-6). The Enugu Formation exposed at road cut sections of i) Neke Isi-Uzo area along Ugwuogo-Nike – Ikem Road, ii) Amagu along Enugu-Port Harcourt express road, iii) Near Enugu Flyover along Enugu-Onitsha express road, and iv) Ozala Four-Corner Junction along Enugu-Port Harcourt express road, and Nsukka Formation exposed at a quarry section in Ikpankwu area of Okigwe, off Enugu-Port Harcourt express road reveals several structural styles, which serve as good trap for hydrocarbon accumulation. These structural styles are:

a) Anticlinal Structures: These are characterized by several faulted blocks with synthetic (faults dipping in the same direction as the regional stratigraphic dip) and antithetic (faults dipping against the direction of regional stratigraphic dip) faults (Fig. 1). The anticlinal structures could form traps by means of simple or faulted closures with associated synthetic and/or antithetic faults that are present. Outcrop studies show that the combination of this synthetic and antithetic faulting system gave rise to down warping (when these two faults dipping towards each other) of a crestal region, forming a collapsed-crest/graben. In addition, evidence of uplifted sediment packages was seen (where these two faults dip away from each other producing a back-to-back structure), resulting in the formation of horst block structures. Doust and Omatsola [1] documented that almost half the hydrocarbon-bearing reservoirs in the neighbouring Niger Delta Basin are trapped within the anticlinal structures.

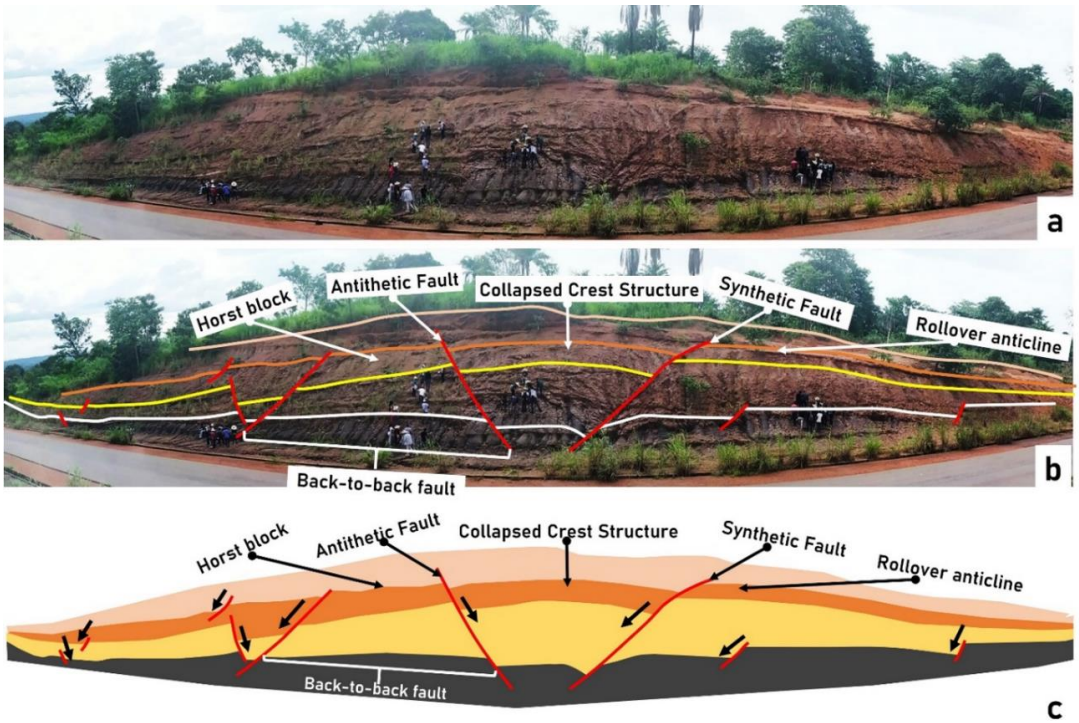

Fig. 2. **a)** Outcropping Enugu Formation of Anambra Basin, off-Opi Abakpa-Nike Bypass, along Ugwuogo-Nike – Ikem Road Enugu State, southeastern Nigeria

b) Interpreted structural styles (collapsed-crest, rollover anticlines and horst blocks) and associated synthetic and antithetic faulting in outcropping Enugu Formation of Anambra Basin

c) Schematic showing the trapping elements in the outcrop of Enugu Formation, off-Opi Abakpa-Nike Bypass, along Ugwuogo-Nike – Ikem Road Enugu State, southeastern Nigeria

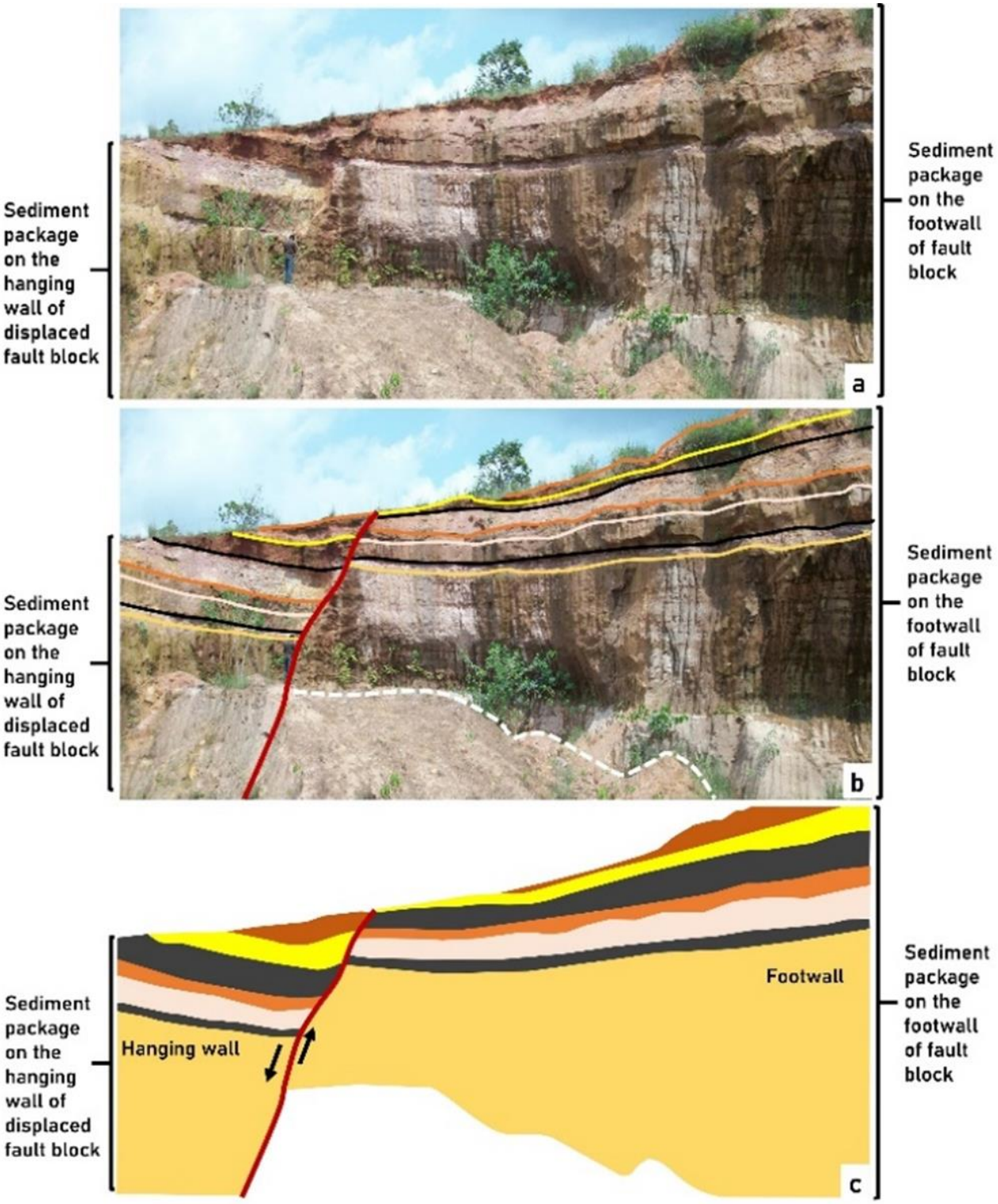

Fig. 3. **a)** Outcropping Nsukka Formation of Anambra Basin exposed at Ikpankwo quarry, off Enugu–Port Harcourt express expressway, SE Nigeria

b) Interpreted normal fault system showing hanging and footwall elements at Ikpankwo quarry, off Enugu–Port Harcourt express expressway (note, the arrow indicates displaced/juxtaposed fault blocks). **c)** Schematic showing the trapping elements in the outcrop of Enugu Formation, off Enugu–Port Harcourt express expressway, SE Nigeria (Note scale: Geologist = 1.8 m)

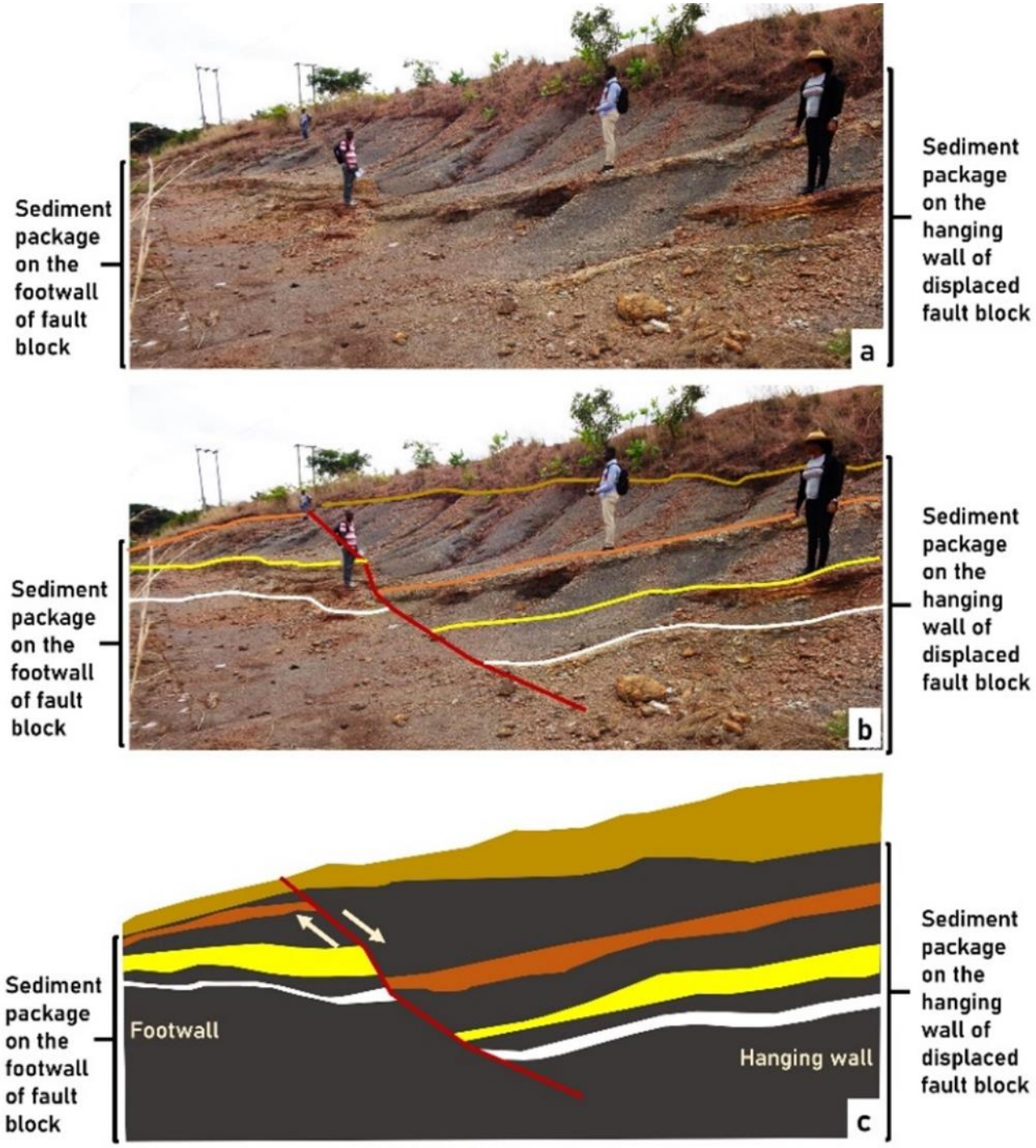

Fig. 4. **a)** Outcropping Enugu Formation of Anambra Basin exposed at at Amagu along Enugu–Port Harcourt expressway, SE Nigeria

b) Interpreted outcrop section showing normal fault system on thick shale with siltstone interbeds, geologists, positioned on the handing wall and footwall (outcrop at Amagu along Enugu–Port Harcourt expressway, SE Nigeria)

c) Schematic of normal fault showing the down-thrown (hanging wall) and up-thrown (footwall) block exposed at Amagu along Enugu–Port Harcourt expressway, SE Nigeria (Note scale: Geologist = 1.8 m)

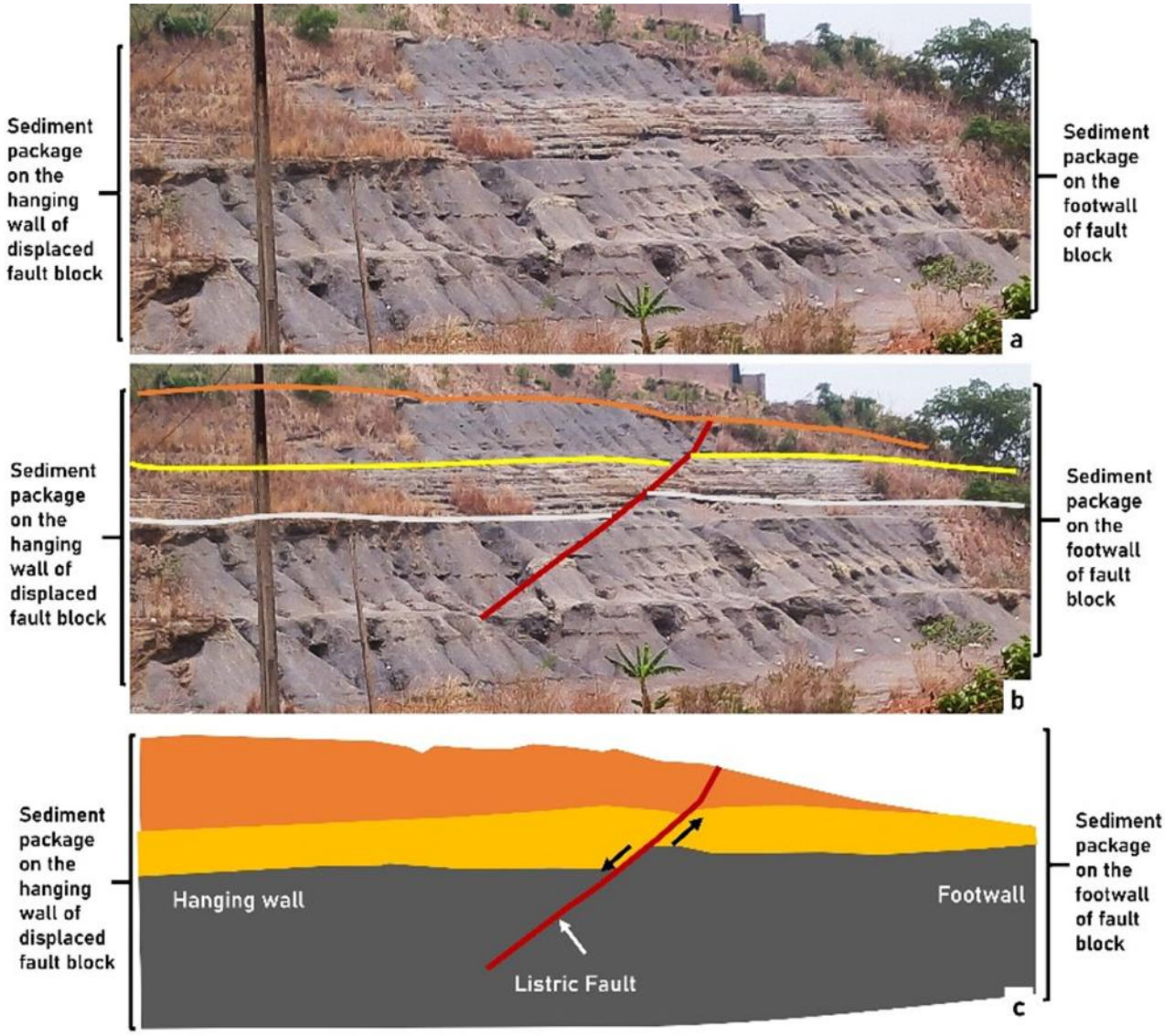

Fig. 5. **a)** Outcropping Enugu Formation of Anambra Basin exposed at near Onitsha road flyover in Enugu, SE Nigeria

b) Interpreted outcrop showing a heterolithic interval with well-developed growth fault in the Enugu Formation exposed near Onitsha road flyover in Enugu, SE Nigeria (note rollover structures on both hanging walls and the footwall)

c) A schematic of the structural elements (upthrown and down-thrown blocks) of the faulted section in the Enugu Formation exposed near Onitsha road flyover in Enugu, SE Nigeria

b) Footwalls: These are un-displaced or upthrown fault blocks (in the case of normal faulting) in a structurally distorted setting that are associated with listric faulting (growth faults with sediment packages thickening on the downthrown block) (Fig. 3-6). 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. This is typical of such traps in Anambra and Niger Delta Basins as revealed from seismic [1, 7].

c) Hanging wall: These are displaced or downthrown fault blocks (in the case of normal faulting) in a structurally distorted setting that are also associated with listric faulting (growth faults). These fault blocks are usually associated with rollover anticlines and are

juxtaposed against the footwalls (Fig. 3-6). Juxtaposed strata within these hanging wall blocks provide entrapment for fluids. This is usually the case when potential reservoir units (sandstone) are flanked by non-reservoir units (shale) as could be seen in Figure 6.

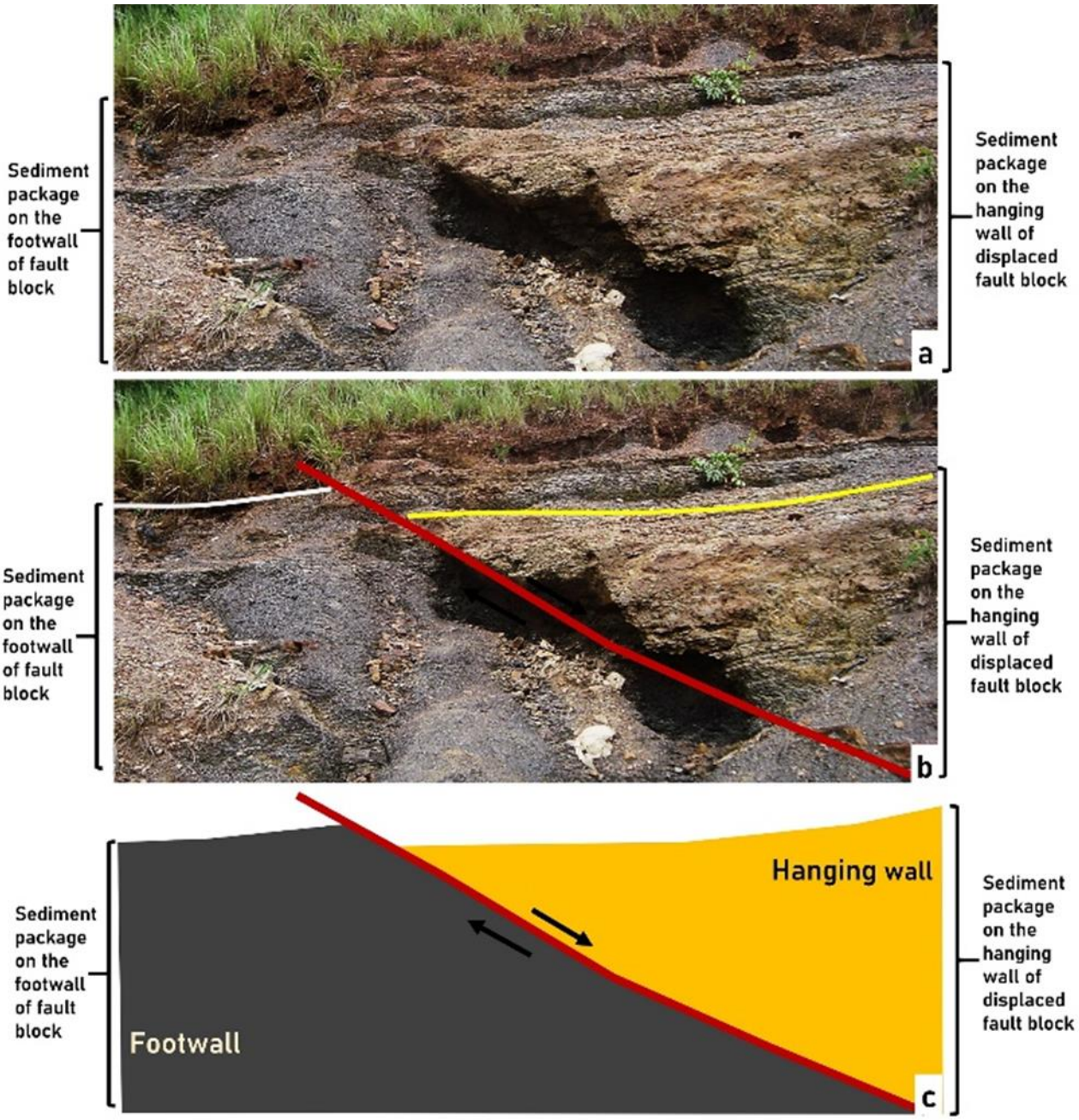

Fig. 6. **a)** Outcropping Enugu Formation of Anambra Basin exposed at Ozara/Four-Corner Junction along Enugu-PortHarcourt Express Road, SE Nigeria

b) Interpreted faulted blocks showing juxtaposed siltstone/sandstone block on shale block, at a road-cut exposure around Four Corner, Ozalla Junction, along Enugu—along Enugu–Port Harcourt expressway, SE Nigeria

c) Schematic showing the justaposed reservoir siltstone/sandstone rock against non-reservoir shale rock at Four Corner, Ozalla Junction, along Enugu–Port Harcourt expressway, SE Nigeria

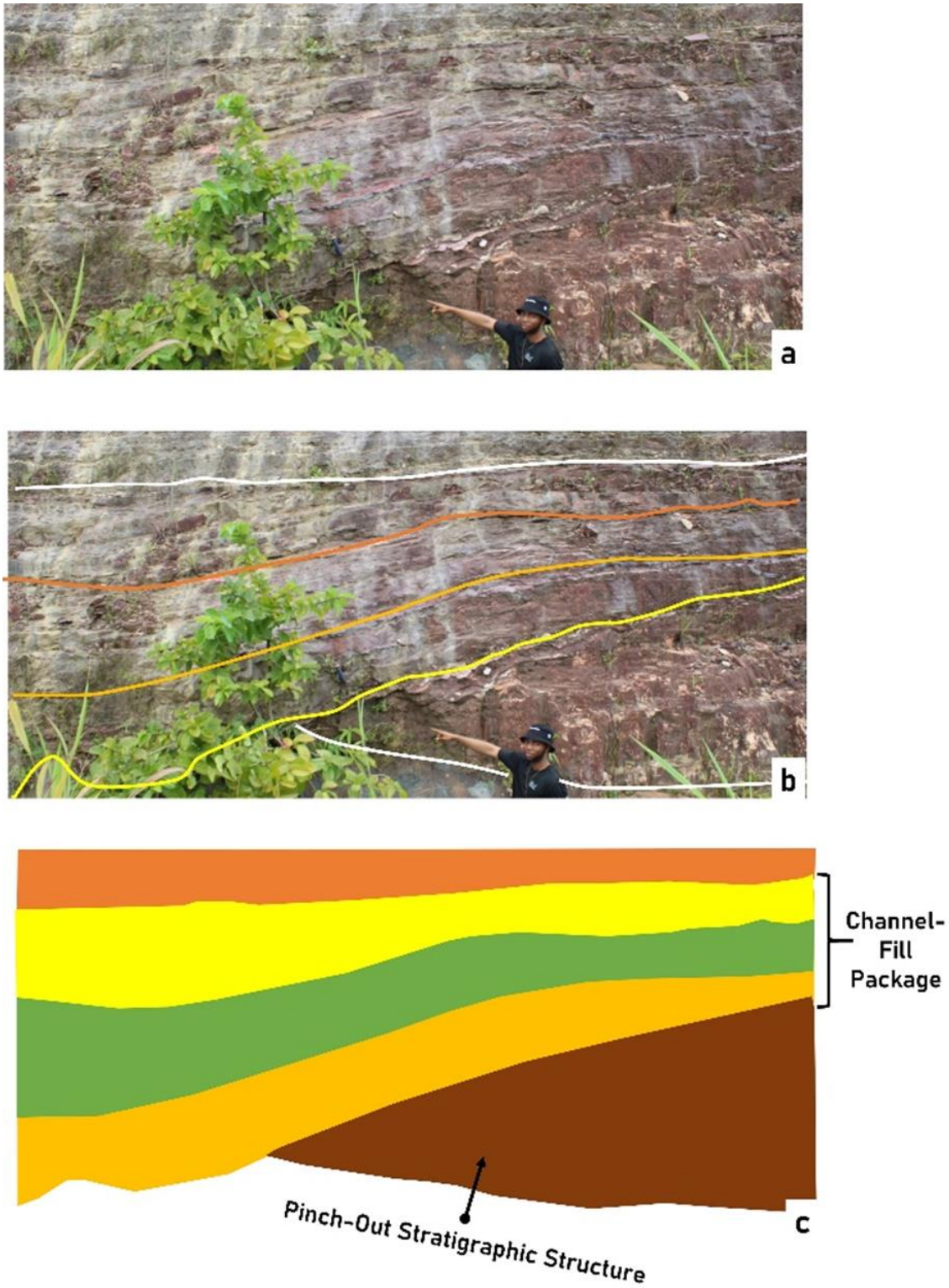

Fig. 7. **a)** Outcropping Mamu Formation of Anambra Basin exposed long Opi–Nike by-pass, SE Nigeria (at the western section of the outcrop)

b) Interpreted truncating pinch out structure on wave ripple-laminated sandstone unit of Mamu Formation exposed long Opi–Nike by-pass, SE Nigeria. c) Schematic showing the truncating pinch-out structure (stratigraphic trap) exposed long Opi–Nike by-pass, SE Nigeria

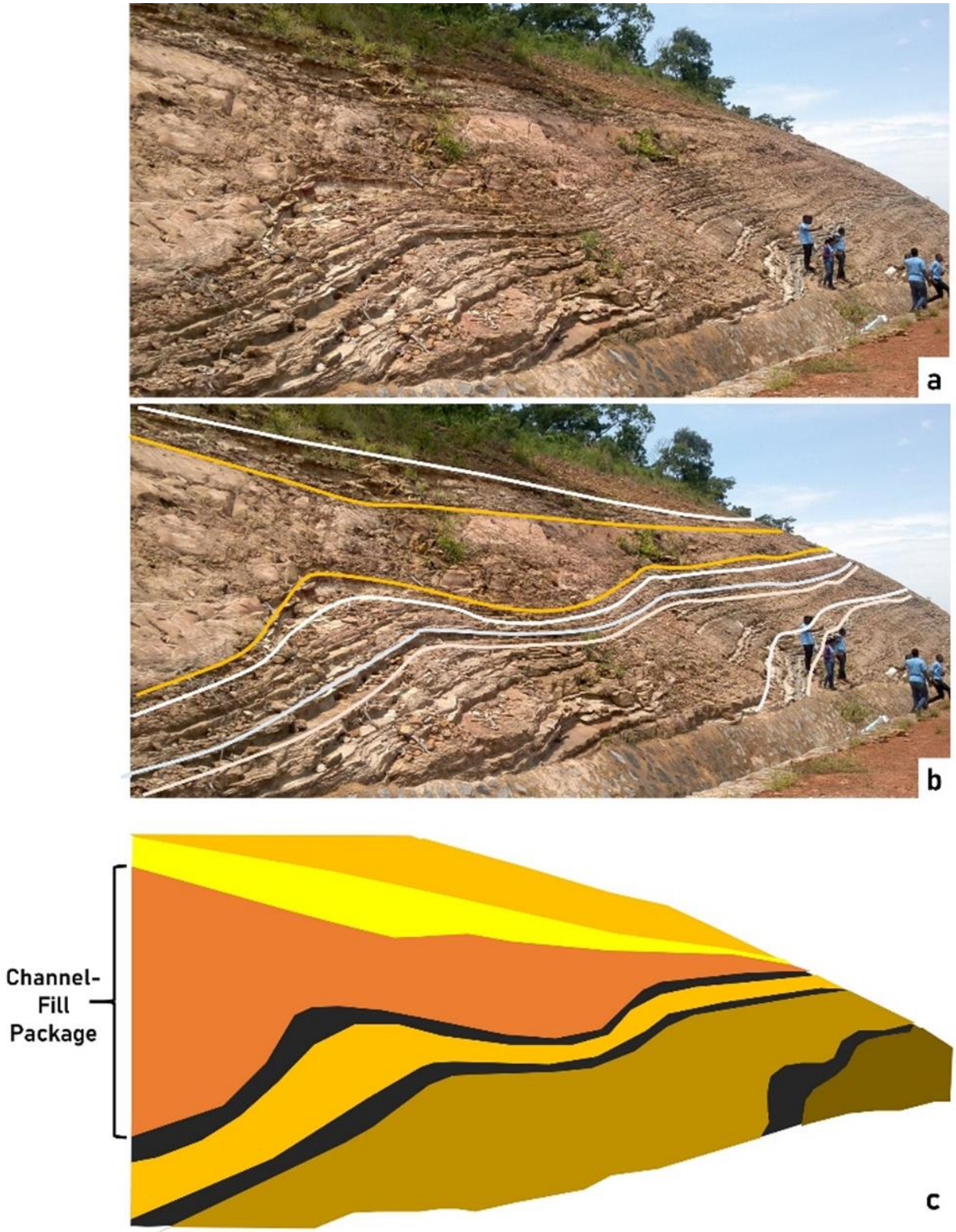

Fig. 8. **a)** Outcropping Mamu Formation of Anambra Basin exposed long Opi–Nike by-pass, SE Nigeria (at the eastern section of the outcrop)

b) Interpreted outcrop section of Mamu Formation showing stratigraphic trap exposed long Opi–Nike by-pass, SE Nigeria. **c)** Schematic of showing channel fill and pinch-out structure exposed at a road-cut long Opi–Nike by-pass, SE Nigeria

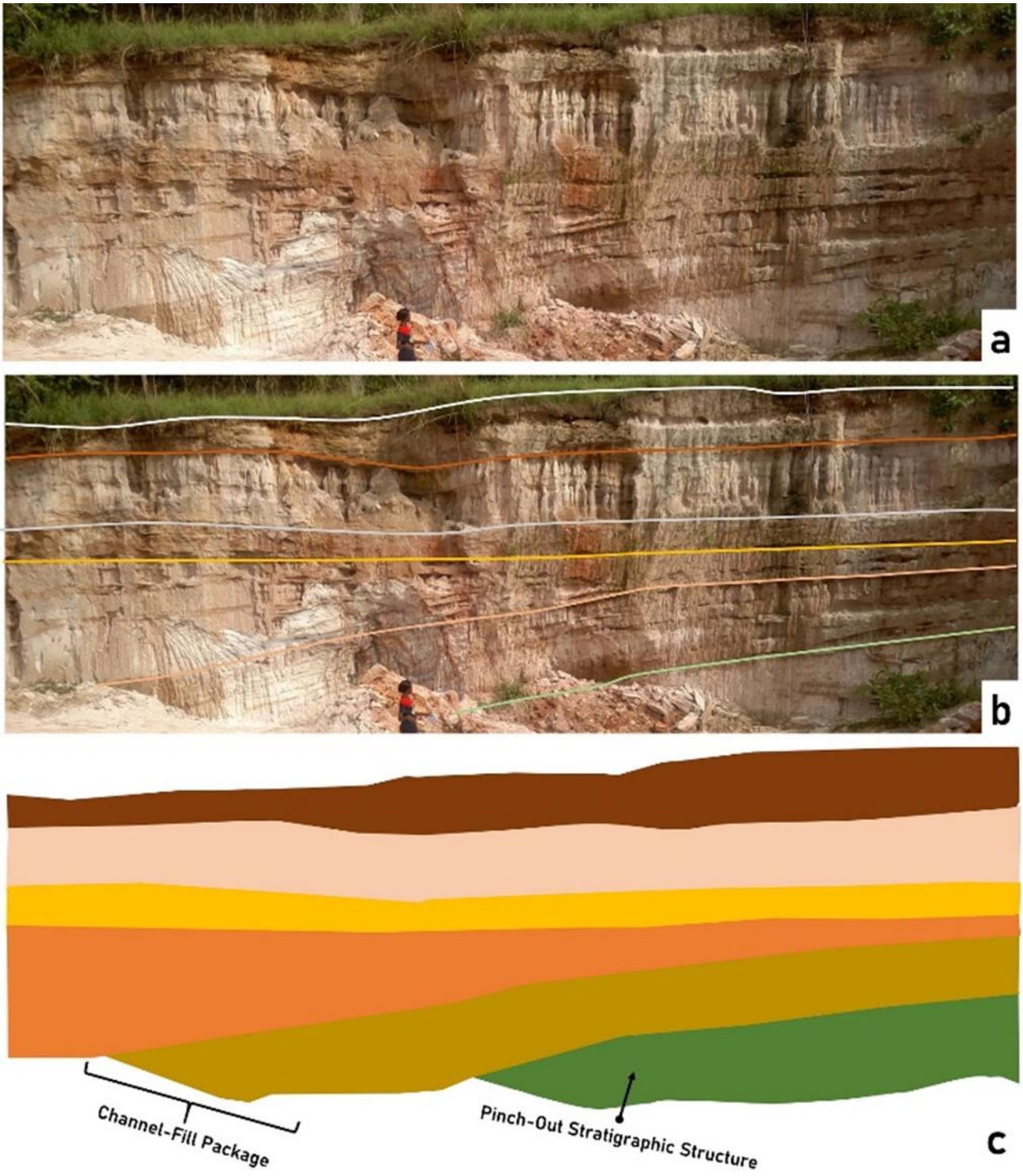

Fig. 9. **a)** Outcropping Ajali Formation of Anambra Basin exposed Ihube quarry section along Enugu–Port Harcourt expressway, SE Nigeria.

b) Channel-fill of thick sandstone units with clay bands at Ihube quarry section along Enugu–Port Harcourt expressway, SE Nigeria. **c)** Schematics of stratigraphic trap showing channel fills with pinch-out structures at Ihube quarry section along Enugu–Port Harcourt expressway, SE Nigeria (Note: Geologic hammer 0.3m)

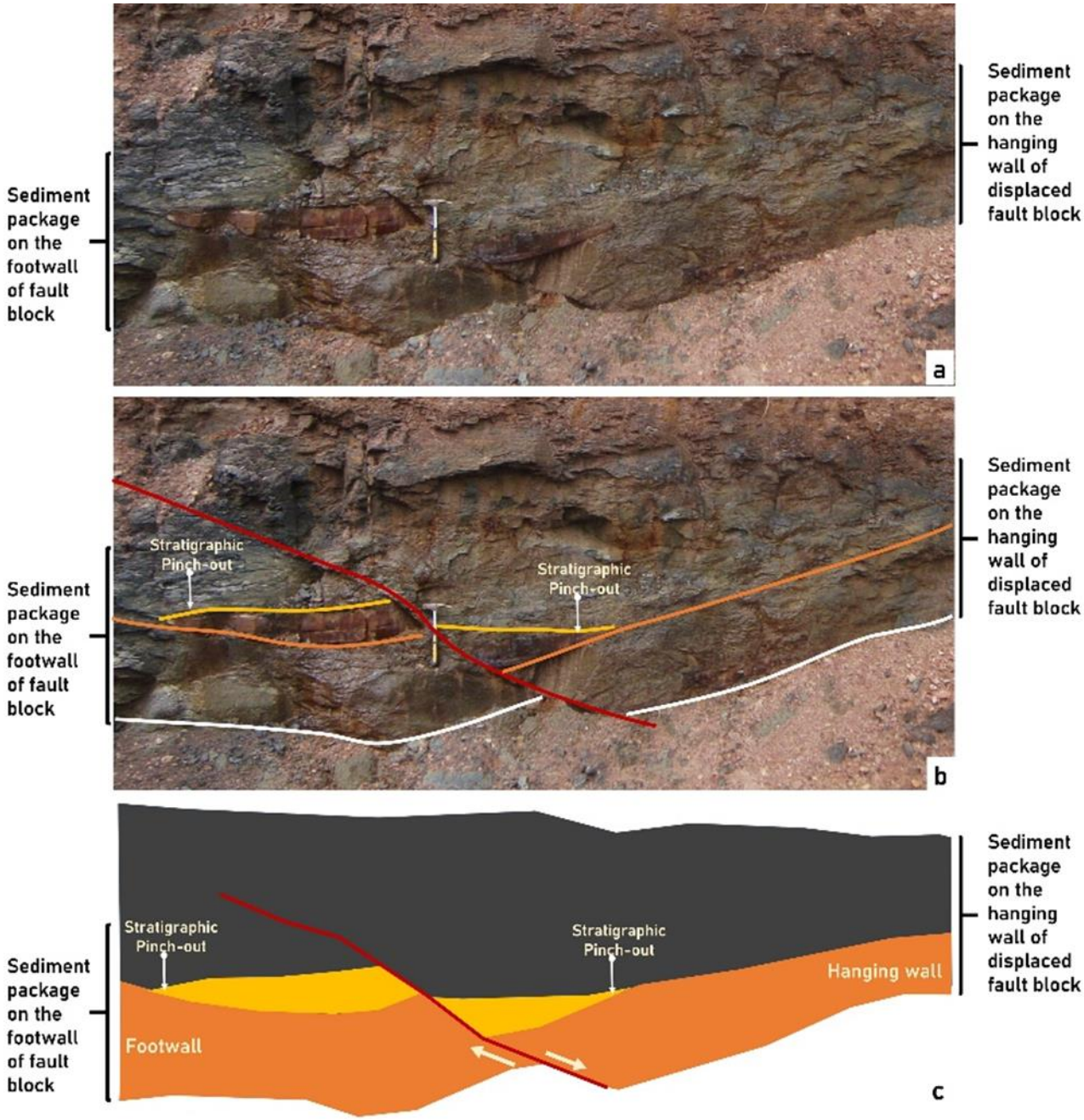

Fig. 10. **a)** Outcropping Enugu Formation of Anambra Basin exposed at at Four Corner, Ozalla Junction, along Enugu—along Enugu–Port Harcourt expressway, SE Nigeria

b) Strati-structural trap of normal faulting of thin siltstone/sandstone lens in Enugu Formation exposed at a road-cut exposure at Four Corner, Ozalla Junction, along Enugu—along Enugu–Port Harcourt expressway, SE Nigeria

c) Schematic of combination trap showing faulted siltstone/sandstone lens in Enugu Formation exposed at a road-cut exposure at Four Corner, Ozalla Junction, along Enugu—along Enugu–Port Harcourt expressway, SE Nigeria (Note: Geologic hammer 0.3m)

4.2. Stratigraphic traps

Some stratigraphic traps were seen within the lithostratigraphic units of Enugu Formation, Mamu Formation and Ajali Formation (Figs. 7-10). The Enugu Formation exposed at road-cut

section in Ozara/Four Corner Junction along Enugu – Port-Harcourt Express Road, Mamu Formation exposed at road cut section at Opi along Opi – Abakpa-Nike Bypass Road and Quarry section at Ihube-Okigwe axis along Enugu-Port Harcourt express road reveals rare stratigraphic configuration that could allow serving as a trap for fluid accumulation. These stratigraphic configurations are;

a) **Channel/Truncation against channel-fill Structures:** Thick heterolithic package interpreted as channel fills characterized the Mamu Formation (Fig. 7 and 8). These channel fills are associated with truncating surface (mainly clay or shale bands) that makes the unset of another channel fill, hence providing a truncation trap (Fig. 9). Much of the oil reserves in the nearby Niger Delta Basin are trapped in sands and gravels within channel fills below truncations of clay laminea that are extensive.

b) **Wedge/Pinch-Out Structures:** Wedge-like and pinch-out structures were observed at the lower section of Enugu Formation exposed at Ozara section and Mamu Formation exposed (Fig. 7 and 10). These stratigraphic features are developed on the flanks of channel fills due to thinning out of sediment package. Documented studies have also shown that these features could act as an entrapment mechanism for fluid accumulation.

Strati-structural/Combination Trap: A faulted sand lens was observed at the basal section of Enugu Formation exposure at Ozara/Four Corner Junction, creating two juxtaposed wedge-like/pinch-out structures that provide a good example of both Stratigraphic and structural trap (strati-structural/combination trap) (Fig. 10). This combination trap could allow for fluid migration and accumulation, thereby offering a suitable trap mechanism.

4.3. Entrapment mechanism and implications for hydrocarbon exploration studies

Traps are geologic structures, or stratigraphic features that are could allow for hydrocarbon accumulation. Structural traps are those formed as result of sediment deformation such folding and faulting whereas stratigraphic traps result from changes in rock type (facies changes), pinch-outs, unconformities and truncations, or other sedimentary features such as channels [4]. A mixture of both stratigraphic and structural trapping styles offers a strati-structural or a combination trap. Outcropping lithostratigraphic units of the Anambra Basin have revealed many stratigraphic and structural features that could allow for hydrocarbon accumulation. Anticlinal closures, footwalls and hanging walls closures, horst blocks and graben with associated rollover structures seen on the exposed section are classic examples structural entrapments known to harbour hydrocarbon. The channel fills and pinch-out features are good stratigraphic traps know to have accumulated hydrocarbon in the Niger Delta Basin. With the increasing search for hydrocarbon in the inland basin of Nigeria, these entrapment mechanisms that are the essential part of a working petroleum system provides good insight to subsurface and should be targeted during exploration studies. Furthermore, this points to the existence of such trapping styles in other inland basins of Nigeria that may require detailed outcrop study to unravel.

5. Conclusion

The presence of key structural traps such as hanging walls, footwalls, horst blocks and collapsed-crest structure and stratigraphic traps such as channel fills and pitch-out structures observed on the outcropping section of representative lithostratigraphic units of the Anambra Basin, points the existence of working hydrocarbon system. In addition, this outcrop evidence has unravelled key structures that could guide during exploration campaigns.

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