

New Lithostratigraphic Data and Depositional Pattern of the Mamfe Sedimentary Basin, Cameroon, West Africa

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ABSTRACT

As part of the West Central African Rift System and the southeastern extension of the Benue Trough that straddles the Nigeria/Cameroon territorial boundary, the Mamfe Basin also holds the history of the opening of the South Atlantic Ocean. It has become so strategic because of its hydrocarbon and solid mineral potentials. However, ever since geologic studies began in this basin, no concerted efforts have ever been made toward harmonizing and standardizing its stratigraphic framework. Consequently, several frameworks exist in literature wherein, no two authors agree on the ranking, number of units or their nomenclature, and none presents designated type sections or type localities of units described. Research activities have however recently intensified with the involvement of international hydrocarbon companies. In order to guarantee its unambiguous intelligibility, an urgent need to review, amend and erect a new standardized and harmonized lithostratigraphic column for the Mamfe Basin is compelling.

Preliminary data from on-going basin-wide studies have confirmed its tripartite depositional pattern which typifies most Cretaceous tropical lacustrine basins comprising: a basal alluvial and fluvial, a middle deep to shallow lacustrine, an upper fluvio-deltaic setting. Sequences studied present different units with unique facies characteristics, lithofacies associations, depositional environment and processes, and lateral extent. Palynological analyses revealed non-marine sediments of Aptian-Cenomanian-Turonian ages. Guided by the international stratigraphic code, a type-section and type-locality were described for each unit and the most appropriate names re-assigned. Each unit was shown to be mappable and exhibits peculiar internal homogeneity.

Accordingly, they have now been reviewed from the rank of members (as in previous literature) to formations, from bottom to top as follows:

- Okoyong Formation, type section: Awatu hill outcrop,
- Manyu River Formation, a composite type-section: Satom bridge and Nfaitok outcrops,
- Akwen Formation, type section: The Akwen and Ndebayang outcrops. A new lithostratigraphic column and depositional pattern have been proposed for the basin.

Keywords: Depositional pattern; Formation; Fluvio-Lacustrine; Lithostratigraphic units; Mamfe basin; New data; Type-section.

INTRODUCTION

The stratigraphic nomenclature commonly used in the literature of Cameroon's sedimentary basins include; formations, members

and to a lesser extent, series but no mention of; group, sub or supergroup. Most of these nomenclatural classifications have however been inappropriately used, by some earlier authors in

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noncompliance with the International Stratigraphic Guide. A typical case which is the focus of this paper is that of the fluvio-lacustrine Mamfe Basin (Figure 1).

Recent basin-wide field mapping of the Mamfe Basin described several new lithologic sequences, most of which were exposed along the recently constructed Trans-African Highways 'Bamenda-Mamfe-Ekok' that traverses this basin. From the new data, it is evident that the basin exhibits the typical tropical lacustrine tripartite depositional pattern which includes:

- A basal alluvial and fluvial.
- A a middle shallow to deep lacustrine.
- An upper fluvio-deltaic depositional unit.

This predictable depositional style is thought to have been initiated by tectonism which in concert with basin filling (water and sediments) created subsidence, both of which must have impacted the basin's geometry. With a sediment thickness of up to about 4000 m ranging from Aptian to probably Turonian age, the Mamfe Basin exposes variably thick and extensive sequences of conglomerates, cross bedded conglomeratic sandstones, sandstones, black organic-rich mudstones, carbonate rocks as well as evaporates [1].

With the rapidly declining hydrocarbon reserves of the coastal basins of Cameroon (Douala/Kribi-Campo and Rio del Rey) and the determination of the government to increase the country's oil production, attention is now focused on the inland basins, one of which is the Mamfe Basin. Recent discoveries of exploitable mineral deposits such as rutile, sapphires and zircons within the heavy mineral suite have attracted recent interest and ongoing investigations especially of the basin's hydrocarbon potentials.

As a prospective petroleum basin in which exploration activities have just begun, it is unfortunate that the sedimentary succession is hitherto represented by several contrasting lithostratigraphic frameworks that are concurrently used both in published, unpublished reports and Ph.D Theses. Examples worth mentioning include. The several frameworks developed for this basin by the authors above conflict and contradict each other in fundamental stratigraphic aspects, amongst which are:

- **Ranks:** The sedimentary rocks of the Mamfe Basin have been sub-divided by different authors into five Series, four formations, one formation, and some of these so-called formations have also been variously sub-divided into: four members' three members and two members with no common stratigraphic basis.
- **Type-section:** No designation of Type-Sections or type localities exists for the units described and named by these authors.
- **Nomenclature:** Multiple names have been assigned to one unit for example, what Abolo, named as the Manyu Member called it Kesham Member meanwhile called the same as Essagem/Munaya Member. The same name used for several units, for example, the Mamfe Formation Mamfe Member.
- **Depositional environment:** Reconstruction of a depositional model and paleo-environments of the various units is still uncertain.
- **Age:** The ages assigned to various units have often been done based on speculations.

Abolo had earlier noted from field observations that the many existing lithostratigraphic frameworks in literature for the basin are not in conformity with stratigraphic norms. As part of the ongoing studies, assigned Aptian-Albian-Cenomanian? Turonian ages to

the fine-grained rocks of the basin based on their palynological content. These stratigraphic irregularities and especially lack of a consensus amongst the authors underline the reason why a review and amendment of the lithostratigraphic framework of the Mamfe Basin is urgently required. This will forestall ambiguity, confusion and misuse of terminologies in order to ease communication in stratigraphic discussions, constrain a plausible geologic history of the basin and ease the exploration of its resources (especially now that both the mineral and hydrocarbon potentials are under active investigations).

The present work therefore, includes new data that will support the reviewing of the existing multiple lithostratigraphic frameworks of the Mamfe Basin and propose an amendment into a new one in accordance with stratigraphic principles and norms. This is achievable by

- A thorough field study, from which new key outcrop sections within the basin were located, described and correlated.
- Promote the three units that make up the basin, now generally thought of as members, up to formations.
- Propose reference sections (Stratotypes/Type-sections) for each unit described.
- Propose appropriate new names for the units described.
- Arrange the units chronologically in a new lithostratigraphic column for the basin.
- Suggest a depositional pattern and the major depositional environments of each lithologic unit (formation) [2-5].

Geology of the basin

The Mamfe Basin (Figure 1) is one of several intercontinental basins of Cameroon. The basin is located in the southwestern region of the country between latitudes 5°30' N and 6°00' N, and longitudes 8°50' E and 9°40' E. It is bounded in the north and south by the Obudu and Oban Massifs respectively. The basin narrows eastward, terminating below the Cameroon Volcanic Line (CVL) but opens into the Benue Trough in the west, across the Cameroon-Nigeria borders where it is known variously as the Mamfe Embayment and Ikom-Mamfe Basin. Like the Garoua Basin in the north (Figure 2), the Mamfe Basin in the south is also genetically associated with the Benue Trough of Nigeria and both form eastern extensions of the latter into Cameroon [6,7].

The Mamfe sedimentary basin has been described as a half graben type but its origin is still doubtful however, it is generally known to be a rift basin that was formed in response to the Gondwana break-up, the subsequent separation of the South American and African plates, the opening of the South Atlantic Ocean and the creation of the Gulf of Guinea. The basin is linked to the West and Central African Rift System (WCARS) and was formed during the Aptian to Cenomanian or Turonian as a result of basement rifting associated with the reactivation of E-W trending mylonite zones within the Pan-African basement (550 ± 100 Ma). In this basin, favorable indicators of the possible presence of hydrocarbons have been noted as well as the exploration of ores like: rutile, sapphire, lignite, lead, and zinc. The Mamfe Basin is oriented in a more or less E-W trending direction with a length of 130 km and a width of 60km and narrows towards the east and widens towards the west where it crosses the Cameroon/Nigerian border and opens into the Benue Trough. Abolo outlined a five phased tectono-stratigraphic evolution of the Mamfe Basin slightly modified here as follows:

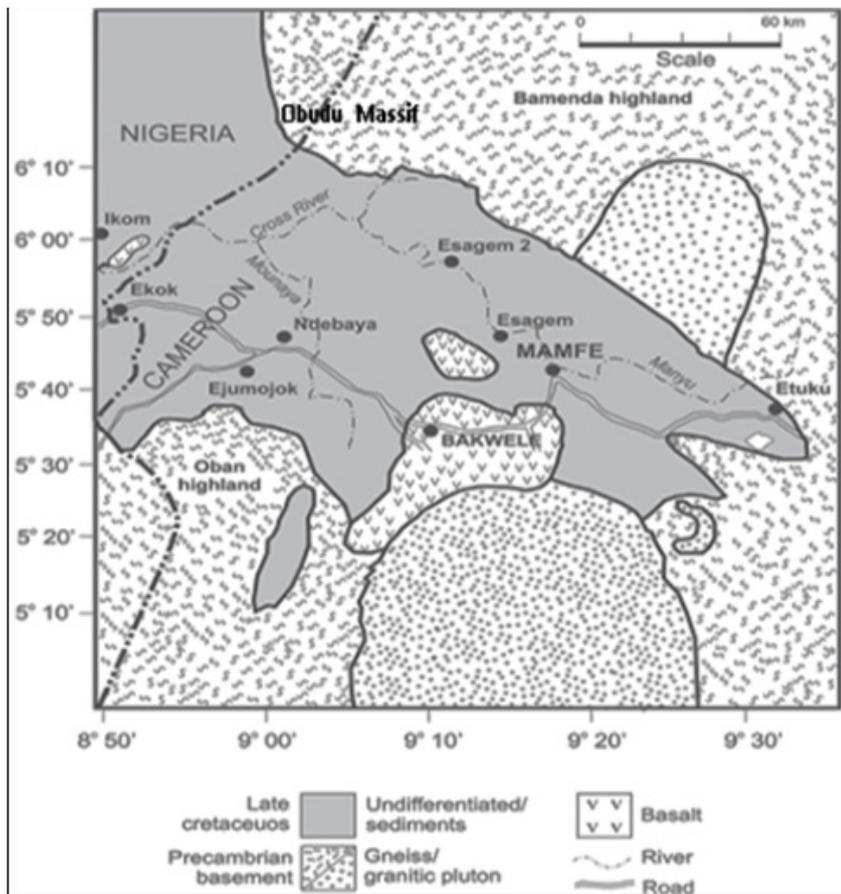


Figure 1: Outline and general geologic Map of Mamfe Basin.

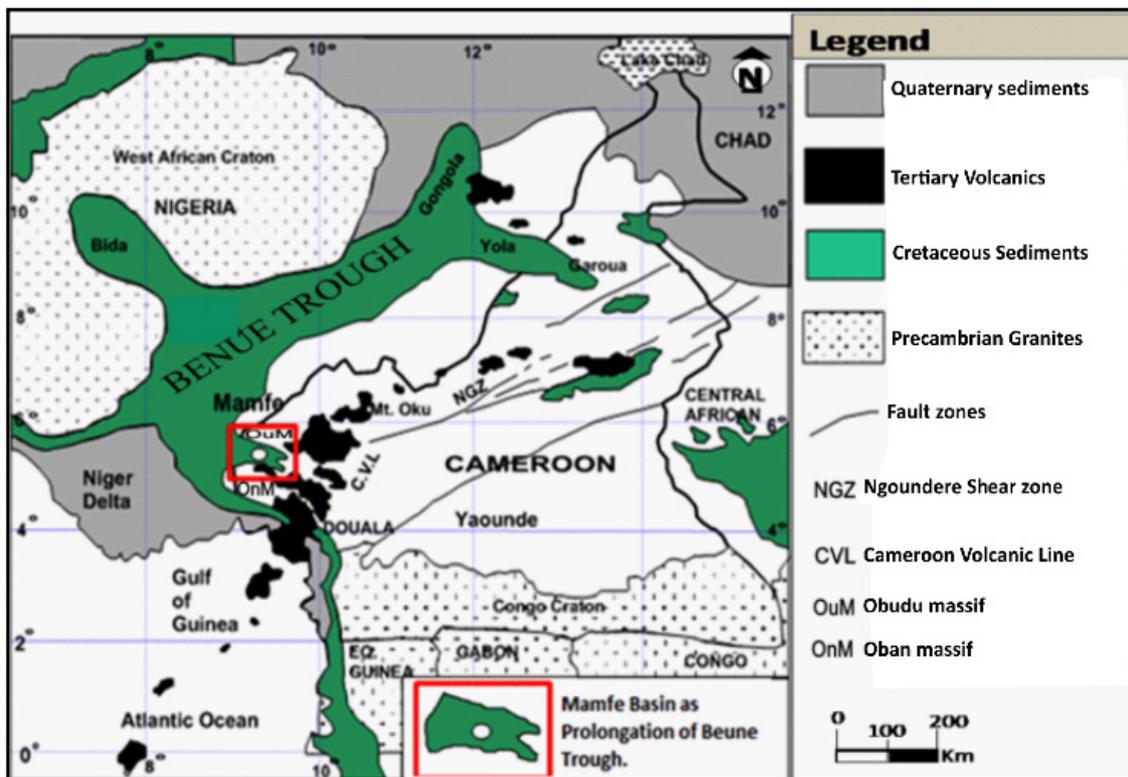


Figure 2: A regional geologic map, showing the location of Mamfe and Garoua Basins as eastern extensions of the Benue Trough of Nigeria into Cameroon and also, the Cameroon Volcanic Line (CVL).

- Eo-rift phase that was characterized by the initial rifting and possible deposition of the first alluvial fan conglomerates during the Berriasian-Barremian.
- Syn-rift and subsidence phase (Barremian-early Albian and late Albian-Cenomanian) during which rifting and alluvial fan conglomerates deposition continued, along with fluvial sandstones and lacustrine shales.
- Post-rift phase-1 that extended to and characterized by folding, faulting and erosion during the Santonian-early Campanian in response to the Abakaliki tectonic event in Nigeria. A subsidence phase during Turonian-Coniacian as postulated is strongly questioned here for lack of evidence.
- Post-rift phase-2 which include all other events that occurred during the latest Cretaceous and beyond; continued erosion, magmatization and possibly uplift.

Sediments of the Mamfe Basin are underlain by gneisses, schists, and granites of Precambrian age basement. These sediments were deformed by the Santonian-Early Campanian deformational event that affected the Benue Trough (Abakaliki Anticlinorium) between 80 and 70 Ma, giving rise to faults and folds oriented parallel to the Benue Trough axis. Several small NW trending anticlines are reported at the eastern end of the Mamfe Basin. On the Munaya River (9° 03'N, 5° 03'E), the Cretaceous sediments dip nearly vertically close to a fault zone. Along the banks of the Cross River the sediments dip 5° to 15° to the southwest. The basement and sedimentary rocks of the basin are intruded by Tertiary effusive basic to intermediate rocks of the CVL such as syenites, diorites, trachytes, rhyolites and basalts noted the foliated augen gneisses that occur in association with N-S tectonized leptynite bands in Bokwa and Kendem Villages in the east of the basin and a mylonitic zone that outcrops at Ekonemann-Awa in the south-west [8-11].

Highlighting the irregularities with existing lithostratigraphic frameworks (a review)

Geophysical data among many others have revealed that the Mamfe Basin is represented by an estimated 3000 m-4000 m thick of predominantly clastic, biogenic to chemically deposited sedimentary sequences. The lithologies include: alluvial fan conglomerates, intra-formational conglomerates, conglomeratic cross-stratified sandstones, organic rich black carbonaceous mudstones and shales, carbonate and evaporitic rocks. Some of these previous authors have published often varying and conflicting lithostratigraphic representations of this sedimentary infill of the Mamfe Basin. The most widely circulated of these are presented here (Figure 3) from which the following stratigraphic irregularities are very outstanding:

- Firstly, remarked that earlier authors, have studied and classified the entire estimated 4000 m of sedimentary deposits of the Mamfe Basin into a single formation named the Mamfe Formation, implying an irregularity.
- Le Fur compared the sediments of this basin with those of the Asu River Group in south-eastern Nigeria, lumped them into this lone formation and divided it into five sub-units termed 'Series'. Arranging them from base to top, these so call Series were labeled C1, C2, C3, C4 and C5. However, the stratigraphic definition of the term "Series" is not clear in this case.
- Instead of the single formation, on the other hand, sub-divided these same sedimentary rocks into four formations and from base to top these were named as Ngeme, Nfaitok, Basso and Cross River Formations and went further to sub-divide Nfaitok Formation into three members from base to top as follows: Manyu, Mamfe and Magba Members respectively. The Basso Formation according to these authors is clearly portrayed as limited in lateral extent and restricted within the Nfaitok Formation and has no reason to be termed a formation.

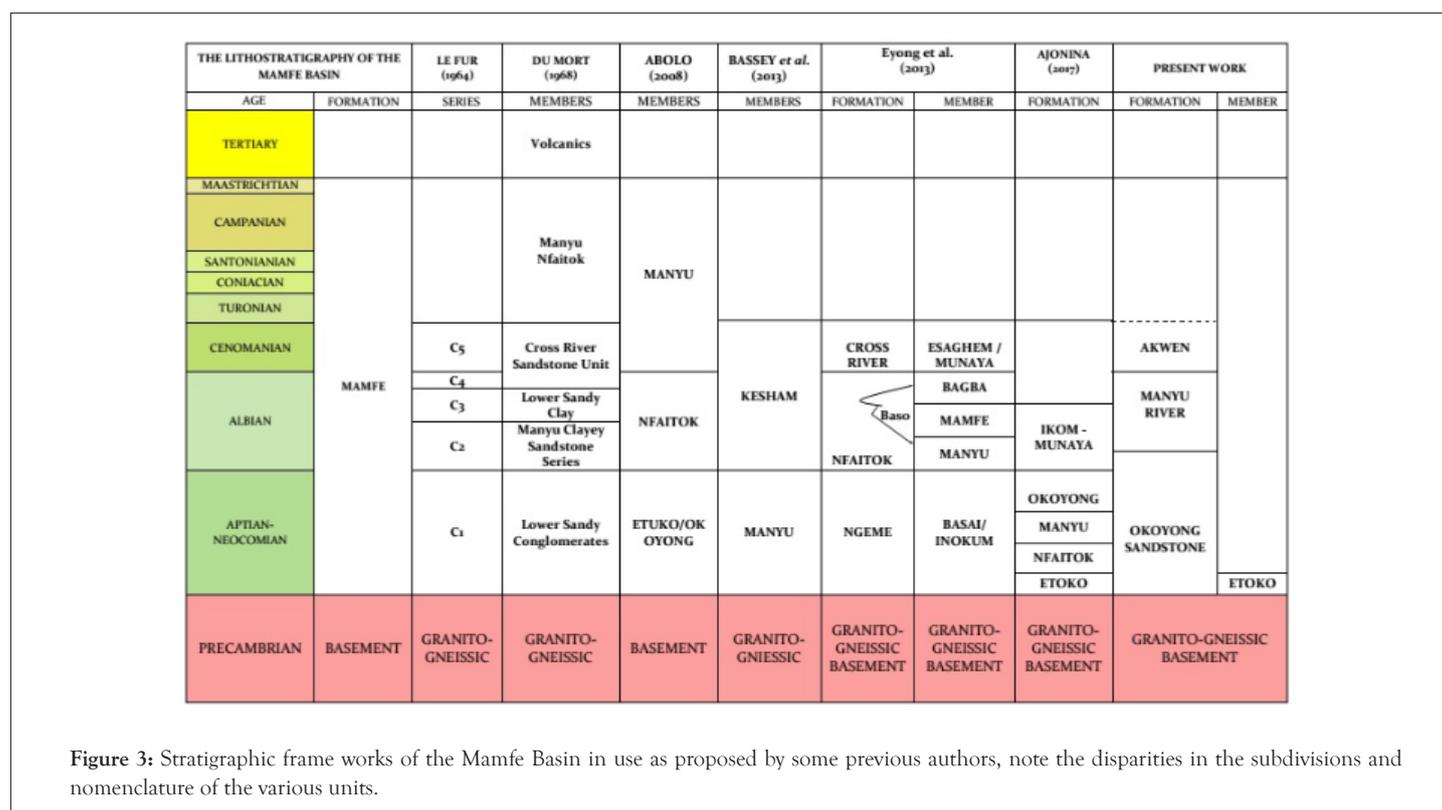


Figure 3: Stratigraphic frame works of the Mamfe Basin in use as proposed by some previous authors, note the disparities in the subdivisions and nomenclature of the various units.

- Abolo recognized from earlier unpublished reports that, the sediments of the Mamfe Basin had been grouped into three unnamed stratigraphic units. These were known simply as the basal, middle and upper units. However, this author went on to support this idea of a single formation which he named the Mamfe Formation. The three sub-units mentioned above were considered as stratigraphic members of the Mamfe Formation and naming them from base to top: Etuku/Okoyong, Nfaitok and Manyu Members. This author considered it inappropriate, the sub-division of the rocks of the Mamfe Basin into too many formations, noting that the sediments are genetically linked and contemporaneous, thus, showing no age difference. However, it should be noted that age is not a component in the stratigraphic definition of a formation.
- Bassey failed to recognize the basal alluvial fan conglomerates that outcrop prominently along road-site cuts within the basin but supported the single Mamfe Formation of the Mamfe Basin. These authors sub-divided the formation only into two members namely: Manyu (bottom) and Kesham (top) Members differing from Abolo.
- The name Manyu for example, has been assigned to three different units of the Mamfe Basin. Assigned the name Manyu Member to one of the sub-divisions of the so called Nfaitok Formation. Assigned the same name Manyu Member to the upper sandstone unit of the Mamfe Basin, while the name Manyu has again been assigned to the lower member (Manyu Member) of the two members according to Bassey.
- Apart from the gross confusion and haphazard manner in assigning names, no type representatives of any of the units have been described.
- None of the frameworks above has been generally accepted. Each author holds onto what he has published and continues to circulate and propagate it and as such, other researchers and explorers get even more confuse.

The lithostratigraphic amendment of the mamfe basin (new)

The few and topical lithostratigraphic irregularities presented above out of the so many, constitute a compelling reason for an urgent review and amendment of the stratigraphic representation of the Mamfe Basin. In addition, frequent questions from students of stratigraphy, other academic researchers and those from the oil industry as to which of these frameworks to adhere to and coupled with the confusion that comes along, underpins the urgency and the need for a harmonious and generally acceptable lithostratigraphic column for this basin. This can only best be done by assembling the current views of some of the previous authors and researchers both from Cameroon and Nigeria, for the benefit of the wider international petroleum geoscience community interested in this basin [12,13].

MATERIALS AND METHODS OF STUDY

A systematic field study and sample collection throughout the basin was carried out within the past few years. Most especially new outcrop sections were located, described and sampled appropriately. This field study benefitted enormously from the newly constructed Trans-African High ways which traverses the basin. New and excellent sedimentary sections which have recently been exposed along this road were described and presented in this work for the first time. All field measurements and data were taken from each outcrop which was given a proper lithologic description, logged and samples collected.

The following laboratory analyses were performed on the sedimentary samples selected to represent the various units described for the basin: digitized lithological logs and petrographic procedures provided the data that was combined with field descriptions for lithofacies analysis. The palynological analysis provided palynostratigraphic data that supported the dating, paleo-environmental analysis and correlations [14].

RESULTS AND DISCUSSION

Outcrop descriptions at designated type-sections (stratotype)

According to the international stratigraphic code (Murphy and Salvador), named stratigraphic units must be defined or characterized at a specified locality where they are well exposed and developed in order that there will be a common, material standard of reference for their identification. The particular sequence of strata chosen as a standard of reference of a layered stratigraphic unit is called a stratotype. It may be an area of exposure and is an essential part of the establishment of a formal stratigraphic unit.

Detail lithologic descriptions, lithofacies and palynological analyses and correlations of most of the sections sampled in the course of the field study can be referred to in Njoh et al. and Njoh and Tembi. Considering the scope of the present work and space, only a few and selected representative sequences (Stratotype) of each of the units (member and formations) have been described below.

The outcrop at awatu hill (stratotype of the okoyong sandstone unit)

The representative (Stratotype) of the Okoyong Sandstone unit is proposed at the Awatu Hill type locality where it is well and best exposed. The lower part of this section is exposed and forms the bed rock over which the River Manyu flows in this locality and peaks at the position of the prominent Crucifix that can be seen from all parts of the town of Mamfe. This hill which is part of a folded ridge and a major topographic feature of this area constitutes the entire outcrop here under consideration. It rises from the river bed below in the form of a 20 m steep slope river bank and continues up to where it peaks at the height of 118 m.

Lithology: Generally, the outcrop is characterized by stacked fining upward sequences, each comprising of well sorted, sub-rounded to rounded, imbricated, clast supported conglomerate beds. Each bed of conglomerates is directly overlain by massive poorly to moderately sorted, matrix supported, conglomeratic medium to coarse grained sandstones. The poorly sorted, trough to angular cross stratified medium to coarse grained conglomeratic sandstone beds that follow are occasionally seen to be overlain by finer grained sandstone beds (Figure 4). This then is most often truncated by another intra-formational conglomerate bed which begins the next sequence above.

Measurements taken at the cross stratified conglomeratic, medium to coarse grained sandstones of this unit exposed at Nsanaragati area and across the west bank of the Cross River extending to Ikom in the west are rather oriented in an ESE direction. The mineralogy is commonly quartz and feldspars. In places, cave-like gaps of variable sizes and partially eroded shale layers occur within these sandstone sequences.

Age: On the basis of the palynomorphs recovered from the intervening shale beds from the section exposed at the Okoyong roadside cut which can be seen to continue to the Awatu Hill outcrop, Njoh assigned an Aptian-Albian age to this unit. This unit was estimated to be overlying or a continuation of the units exposed in the sections near Etoko village.

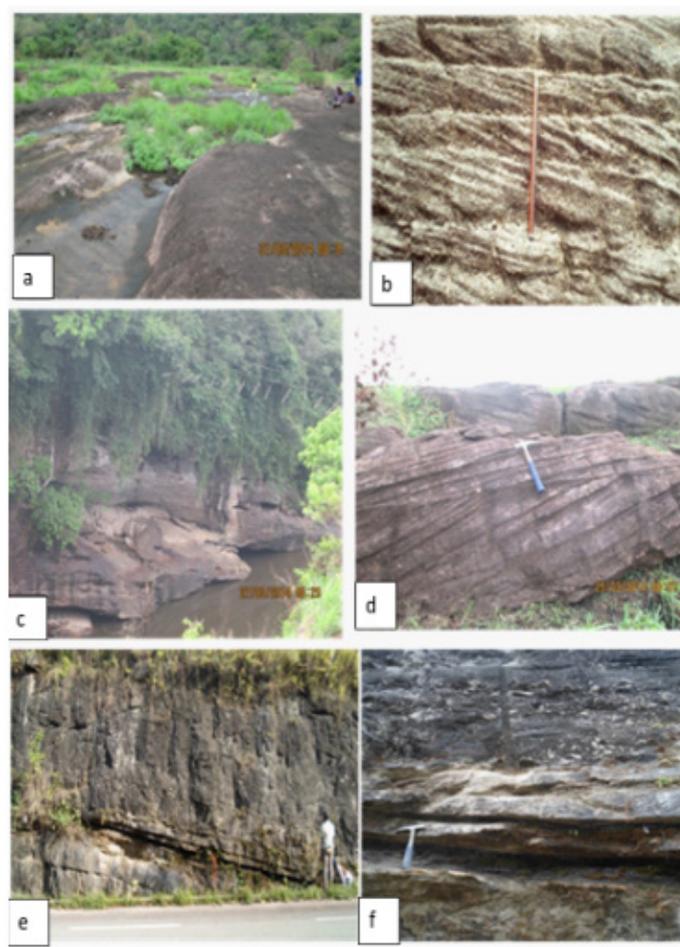


Figure 4: Outcrop section of the Awatu Hill and Okoyong roadside cut. (c and a) sandstone beds exposed along River Manyu and towards the summit, (b and d) common cross stratification, (e and f) sandstone at Okoyong showing intervening shale lenses.

Boundaries/thickness: Unlike stipulated in the international stratigraphic code, the entire thickness of this section cannot for now be ascertained nor can its boundaries lengthwise throughout the basin be clearly described. This is due to the folded nature of the sequences, thick overburden and forest cover. Although the upper and lower boundaries of this unit have been independently spotted or inferred, for example at Akwen village where it is directly overlain unconformably by the Akwen unit and at areas in and around Etoko village where it overlies or continues from the Etoko unit. No exposure within this basin exposes any of the units completely and as of now, no well data are available. Geophysical data set that captured the entire vertical section of the sedimentary pile of this basin distinguished three different characteristic lithologies measuring down to 4000 m. More so, of all the units described in the basin, only the Akwen unit is considerably exposed towards the middle and distal part while the two others have been described in outcrops from the proximal eastern part. However, at the Type-Section, the beds are folded and pass into the sub-surface at River Badi and River Manyu where it is thought to have been over stepped by the unit exposed along the Manyu River. The boundary at Akwen (where the Akwen unit is overlying the Okoyong unit), is an erosional surface while that at Etoko village is most likely to be an angular surface. According to a recent survey by the Nigerian Geological Survey Agency revealed mappable sedimentary units in this basin, while Bassey, the lower unit of the Mamfe Basin is the lateral equivalent of the Awi Formation of the Asu River Group, Calabar Flank in south eastern Nigeria.

Geographic extent: The Okoyong sandstone unit is widespread and several sections are exposed and have been described at localities especially in the western, eastern and northeastern flanks of the basin and is thought to underlie the fine grained, lake bottom sedimentary unit and so does not outcrop in the middle areas of this basin but reappears along the flanks of some anticlinal structures in the distal part of the basin to the west. Ever since it was recognized, many studies have been carried out at several locations in and around Okoyong village near Mamfe town from which the name was derived and need not be changed. This sandstone outcrops within the village and its environs but most recently, it has been mapped and seen to continuously extend to parts of Eyang-Ntui, Awatu, Bijang and beyond in the direction of Akwaya and along the banks of River Momo upstream and most of the areas in the eastern part of the basin (Figure 1). In the western part of the basin, this unit outcrops at Nsanaragati I and its environs, along both banks of the Cross River including the neighboring Ajaso and other Nigerian villages of the Ikom area.

Paleo-environment and depositional model: Paleo-current indicators are very characteristic of the Okoyong Sandstone. Well exposed at the Awatu hill (Figure 4) and elsewhere in the eastern part of the basin, especially at the Okoyong roadside cut where this unit was initially studied and named. The paleo-current indicators (imbrications, preferred parallel alignment of prismatic clasts and cross stratifications) have been measured and shown to be oriented generally in a WSW direction. The unit is made up of repeated stacked sequences, each

fining upward typifying deposition in fluvial channels to floodplains (overbank) environments.

Outcrop sections of the Okoyong Sandstone Formation have been mapped and shown to pre-dominate the exposures in the eastern, west and northern parts of the basin. Paleo-current indicators measured in the distal Ikom area of Nigeria and at Nsanaragati showed a general southeasterly direction. In and around Okoyong and Awatu in the east, these paleo-current indicators showed a general southwesterly direction attesting to the fact that the ancient lake was fed by multiple rivers that entered the lake from both proximal and distal ends of the basin. The generally cross bedded conglomeratic sandstones of the Okoyong Sandstone that were deposited by these rivers most have been the distal continuation of the Etoko units.

Outcrop near etoko village (mile 22-24)

Rocks belonging to the Etoko unit generally occur almost exclusively in the eastern proximal part of this basin where the thickness is said to be inferior to 1000 m. These rocks described below extend laterally westward but soon thin out into the Okoyong Sandstone unit. These rocks occur conspicuously and continuous well over 3 km along the Bamenda-Mamfe Highways to River Masaka (Mile 24) from before and beyond Etoko village. The same rocks were located and described at several other areas in this part of the basin. The outcrop is not uniform in height throughout its length but measures above 20 m at two highest points, about 200 m and 300 m from Etoko village towards River Masaka (Figure 5).

Stratotype: The representative section (stratotype or type-section) of the Etoko unit is here proposed as a composite of two adjoining roadside cuts representing the two lithologic units described below, located along the Bamenda-Mamfe Highways between River Masaka (Mile 24) and (Mile 23) just before Etoko village which has been chosen as its type locality (Figure 5).

Lithology: The lithology of this unit is described in Njoh, the rocks here consist of massive to poorly bedded masses of conglomerates, often very brecciated. They are very poorly sorted (all particle size), very angular to sub-rounded and sometime rounded, clast supported boulders to pebbles mixed with sandy and finer grained size particles (matrix) making up the massive deposit (Figure 5). Above this is a unit of poorly to moderately bedded alternations of thick clasts supported conglomeratic layers and thin layers of matrix supported black, micaceous, sandy-pebbly-mud with the latter commonly limited in lateral extent (inter tonguing) as observed at the outcrops. The boulders and pebbles that dominate the clasts of this typical basal conglomerate unit that dominate this proximal end of the Mamfe Basin are visibly broken particles of granites, gneisses, schists and quartzites from the adjacent basement rocks.

Age: A majority of the samples collected from this unit and treated for palynomorphs yielded practically no palynomorphs (PNP). A few forms of palynomorphs recovered were generally unidentifiable while a few others were very long ranging and did not permit the assignment of any precised age. However, the few non diagnostic palynomorphs recovered (Genera of Classopollis and Cicatricosisporites among others) are common among other lower Cretaceous sediments of this basin and field relationship indicated that this unit is most likely the age equivalent of the Okoyong unit if not older.

Boundaries: The rocks of the Ekoto unit lie directly and unconformably (at a non-conformity) on the highly fractured and folded granitogneissic rocks that constitute the Basement Complex of this region. Basinward, as the Etoko unit thins out, it is unconformably overlain and interfingering by the Okoyong Sandstone unit which extends to the distal western part of the basin as the continuation of the basal unit.

Geographic extent: This unit occurs and is generally limited in extent

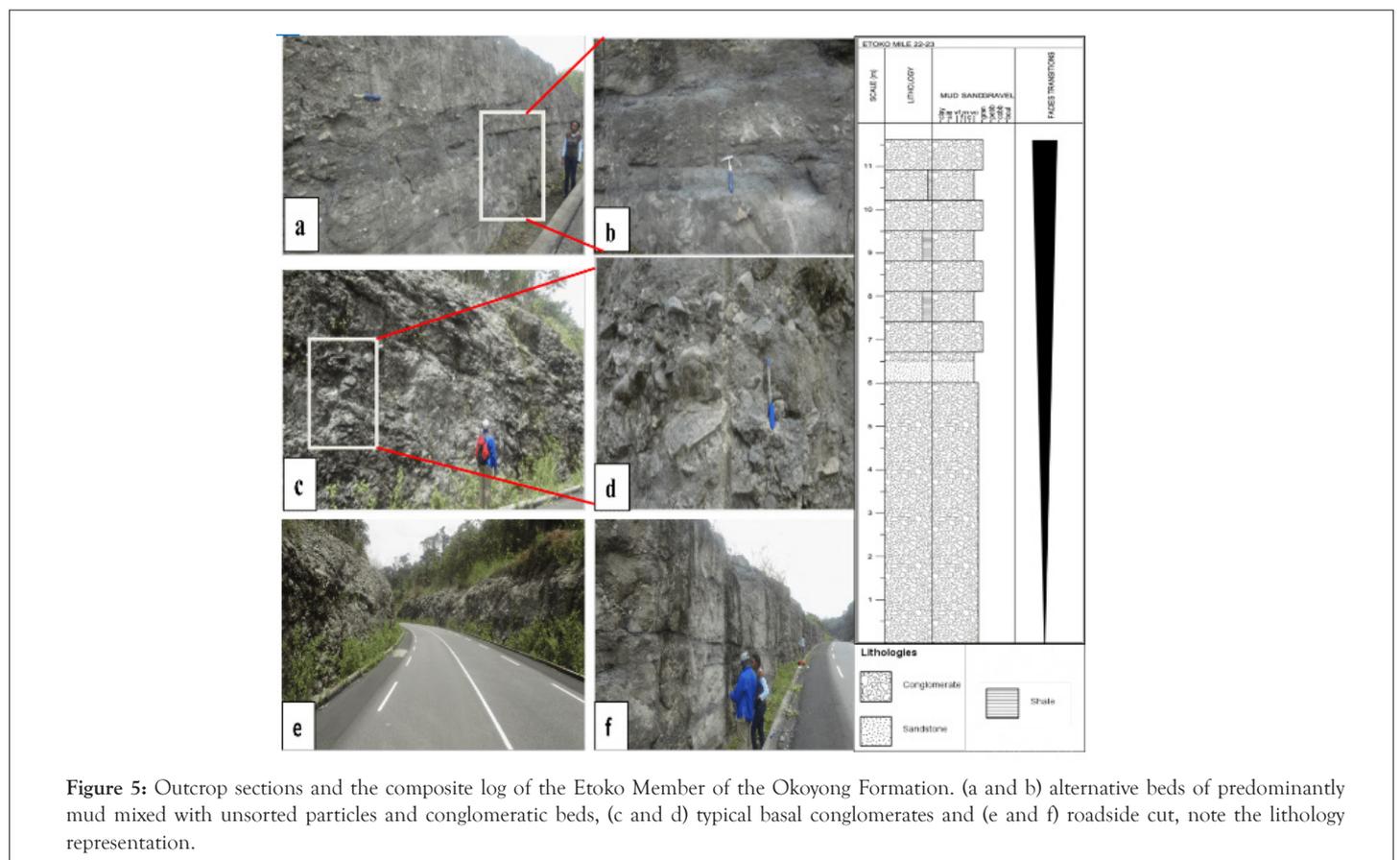


Figure 5: Outcrop sections and the composite log of the Etoko Member of the Okoyong Formation. (a and b) alternative beds of predominantly mud mixed with unsorted particles and conglomeratic beds, (c and d) typical basal conglomerates and (e and f) roadside cut, note the lithology representation.

to the proximal part of the basin is the east. It is well exposed along river banks and channels and at several roadside cut sections, precisely in and around the following localities (Figure 5) from River Masaka along the Bamenda-Mamfe Highway to Etoko village, along the road to Egbemo, Eyang-Ntui, Talangaye and some isolated deposits around Innokum.

Paleo-environment and depositional model: The two outcropping sections described from this proximal end of the Mamfe Basin near Etoko village represent a typical alluvial fan/debris flow facies of the piedmont type, deposited under very high energy conditions. The sediments would have been deposited at the foot of several adjoining hills then coalesced and extended further into the valley, basin-ward beyond which rivers may have emanated and flew into the paleo-lake.

The Etoko Member of the Okoyong Formation has been described as basal conglomerates (in places characterized by breccias) that was produced and deposited as a result of fracturing of the basement complex rocks at the onset of the thermotectonic (heat driven Pan African Orogeny) event that led to the initiation of the basin before and during the Aptian. These conglomerates (and breccias) characterized the syn-rift deposits reported from all the WCARS by Genik and Adediran and Adegoke. Unlike the other units described in here with basin-wide extensions, these conglomerates and breccias that constitute the Etoko Member of the Okoyong Sandstone was clearly deposited and generally limited to the eastern proximal part of and exclusively associated with the Okoyong Sandstone to which it is maintained in this work as a member. This unit lies unconformably (Non-conformity) on the Basement Complex.

The outcrops at satom bridge and nfaitok village (a composite stratotype)

Stratotype: This middle unit of the Mamfe Basin generally known as the Nfaitok unit is here proposed to be represented by two well-known outcrops: the Satom bridge outcrop (Figure 6) which constitutes the lower part of the unit and the Nfaitok outcrop (Figure 7) the upper part. Both outcrop sections outcrop very extensively along the banks and form the bedrocks over which Manyu River is flowing in this part of the basin, are here proposed to define a composite Type-Section for the unit. The River Manyu consequently is preferably designated here as the Type-locality.

Lithology: The Satom Bridge outcrop is located in Mamfe Town, at the bridge over the Manyu River, and stretches along the left river bank facing the downstream side. The Satom bridge section as it is well known exposes a series of particularly fine-grained rocks (Figure 8). Dark to black organic-rich shales, mudstones and coaly beds, that rapidly alternate with medium to thin limestone beds (Figure 8). The section shows very clear beddings that are continuously repetitive or rhythmic (cyclic). These beds are very variable in thickness ranging from a few cm to about 12 cm especially the limestone beds, while the shale and coaly beds range from 5 cm to about 60 cm. All the beds dip at about 180 to the southwest and section is up to 9 m in height measured from the dry-season river water surface. The upper part of this section is exposed especially during the dry season while the lower part continues into the river below.

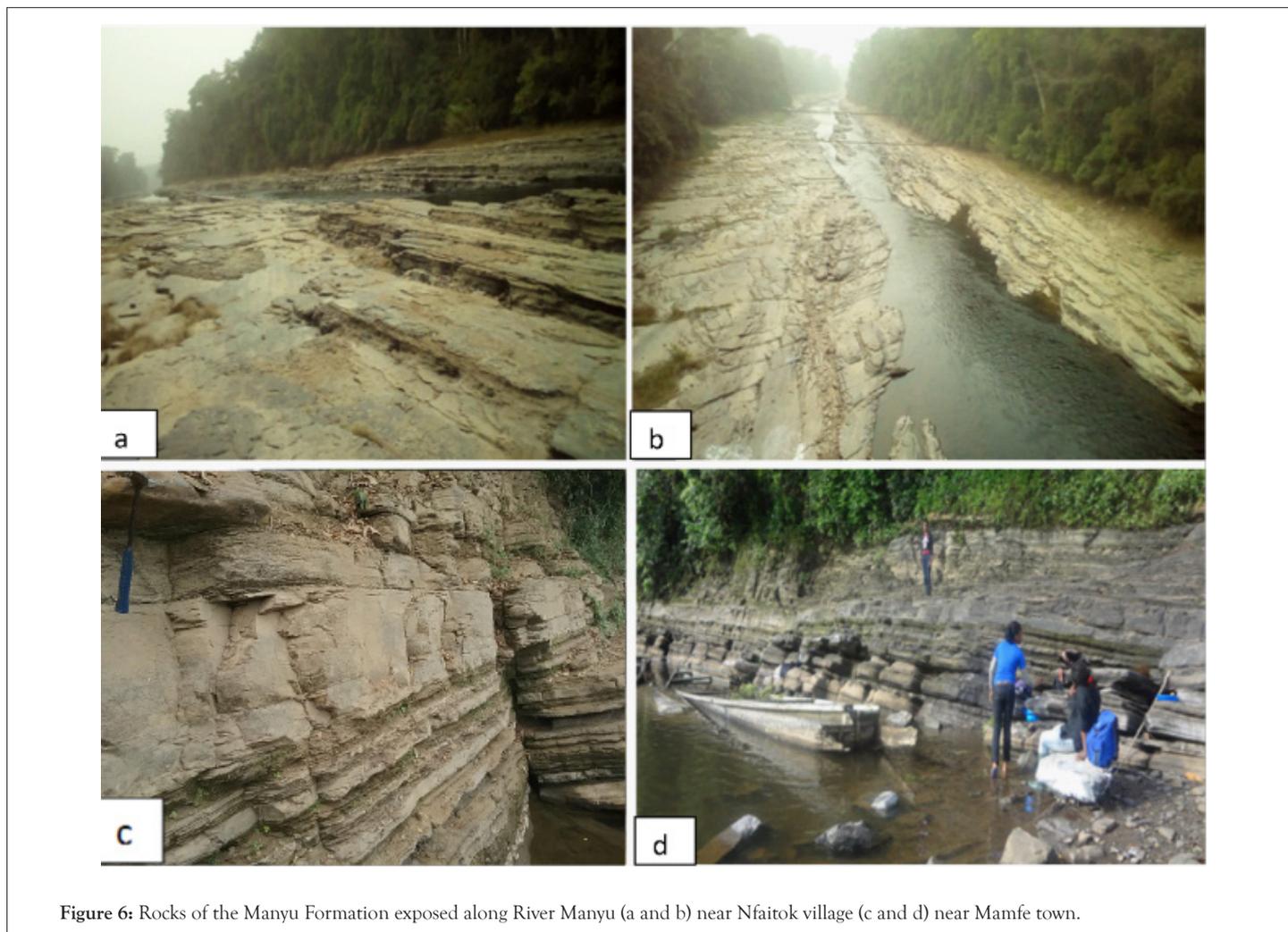


Figure 6: Rocks of the Manyu Formation exposed along River Manyu (a and b) near Nfaitok village (c and d) near Mamfe town.

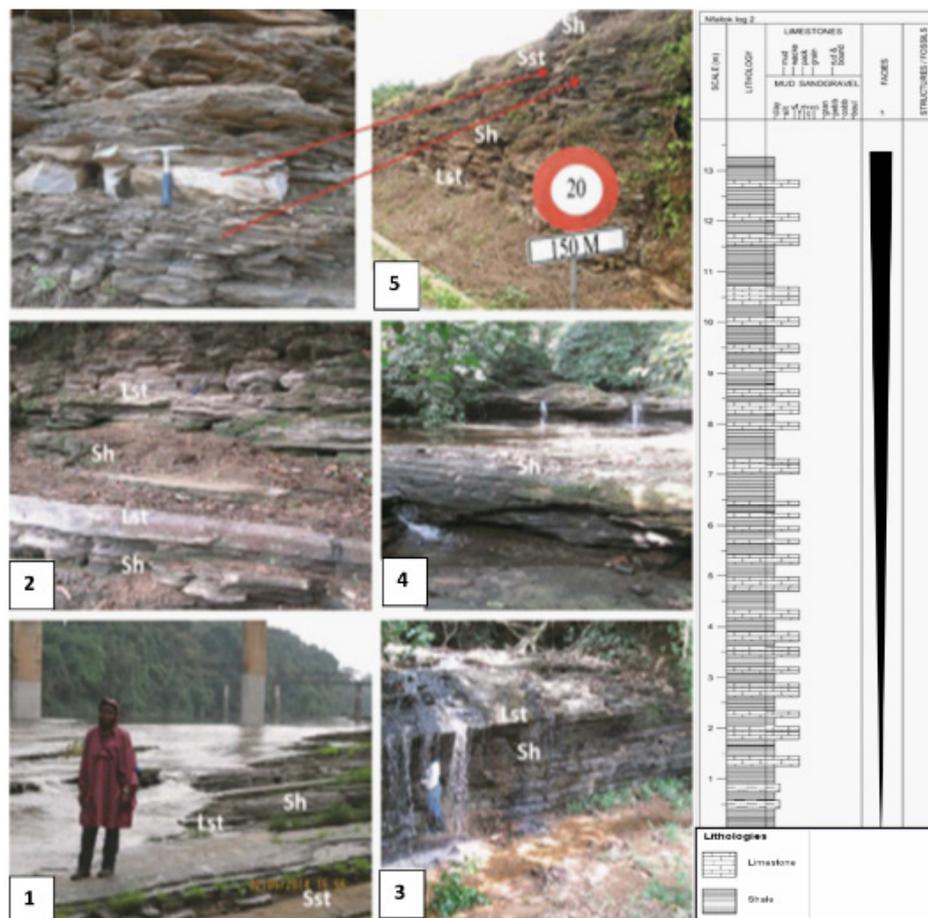


Figure 7: The Nfaitok unit exposed: on the river bed (1), at sections along the river bank (2,3,4), and along the road-side cut (5) up at the Nfaitok village. The representative lithologic log is also shown.

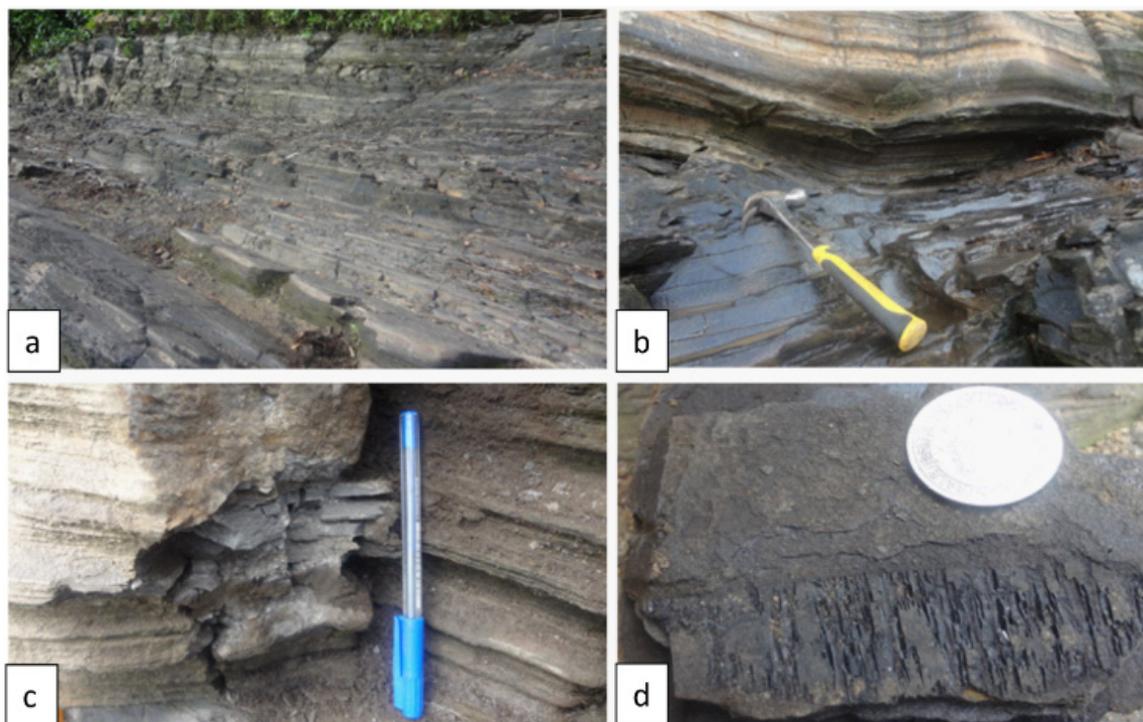


Figure 8: Rhythmic sedimentation (a and b) seen along the banks of River Manyu at the Satom Bridge, including the black organic rich to coally sediments (c and d).

The section exposed at Nfaitok Village (about 40 m high) can be seen all over the village and its surrounding. Extensively exposed vertical sections are observed especially at the main roadside cut, at the bridge crossing (seen along both river banks), and the upstream and downstream parts of the Manyu River at this village where the same rocks are constitute the river bed. The lithology of this unit comprises highly indurated black organic rich shales alternating frequently with limestone and sandstone beds of variable thicknesses. This outcrop shows thicker shale beds that are frequently intercalated by limestone and sandstone and equally expresses a repetitive, cyclic or rhythmic sequences that stack as have been described from the Satom bridge section (Figure 7). The entire rock sequence in this locality, that is; the sections that make up the river bed, river bank and the roadside-cut respectively, measures over 40 m in height and dip at 210 NE.

Age: On the basis of palynomorphs recovered from the sedimentary samples collected from this unit, Njoh and Tembi dated it Late Albian to Cenomanian and probably early Turonian. The sections at Satom bridge and that in Nfaitok village were correlated and noted to be lateral equivalents of each other.

Boundaries/Thickness: The non-availability of subsurface data for this basin makes it impossible to correctly define the thickness of this unit but from outcrop, the base of this unit at the Satom Bridge outcrop suggest and overstep (Angular unconformity) relationship between this unit and the lower Sandstone unit at this proximal part of the basin. An upper boundary separating this unit and the Akwen unit up, is only inferred below the Gendermarie office in Mamfe Town but before the satom Bridge. The outcrop at Nfaitok village is estimated to be up to about 50 m in thickness while the exposure is about 13 m at the Saton Bridge. The unit generally gets thicker basinward.

Geographic extension: The Manyu River Formation is exposed extensively on the bed and along the banks of the Manyu River upstream notably some 3 km southeast of Etoko village in the eastern portion of the Mamfe Basin down to Nfaitok where the sediments

are extensive up and down at the river crossing for over a kilometer especially during the dry season.

The sediments are also very extensively exposed along the same River Manyu downstream near Mamfe town at the Satom Bridge, John Holt beach and beyond westward. Other important outcrops of this unit are seen from the proximal eastern part of the basin at Etoko mile 21, Nchemba, upstream of River Momo, Nfaitok, Nkimichi, Eyang Ntui, Kesham, Nkwo-gem, Ajayuk Ndip, Bakwieb, Besongabang in the middle to distal western parts.

Paleo-environment and depositional model: For the two outcrops at Satom bridge and its equivalent at Nfaitok, Njoh reconstructed a lacustrine depositional environment for these sediments noting that, the black organic-rich strata were deposited in an anoxic bottom lake environment meanwhile the carbonates and sandy strata represent deposition in the more shallow and marginal environments respectively.

The Manyu Formation which overlies the Okoyong sandstone unit is represented generally by two facies associations (Figure 9). The conspicuously cyclic sequences of black organic-rich mud rocks, intercalating with carbonate rocks and evaporates as seen at the Satom section, represent deposition in a quiet but deep anoxic part of the ancient lake. The sequences that are composed of thick black shale beds frequently alternating with sandstone and limestone may be representing the comparatively shallower sub-aqueous parts of the ancient lake with more frequent fluctuations in the lake water level and sediment supply. These sequences are represented by the Nfaitok section and have equally be studied and correlated based on their palynomorphs content with the other outcrops in Etoko mile 21, River Momo and Keshem village Bisongabang and beyond. Sediments of this formation therefore represent lacustrine sediments with no marine fossils which on one hand were deposited in a deep lake environment with low oxygen concentration and on the other, a less deep part of the lake.

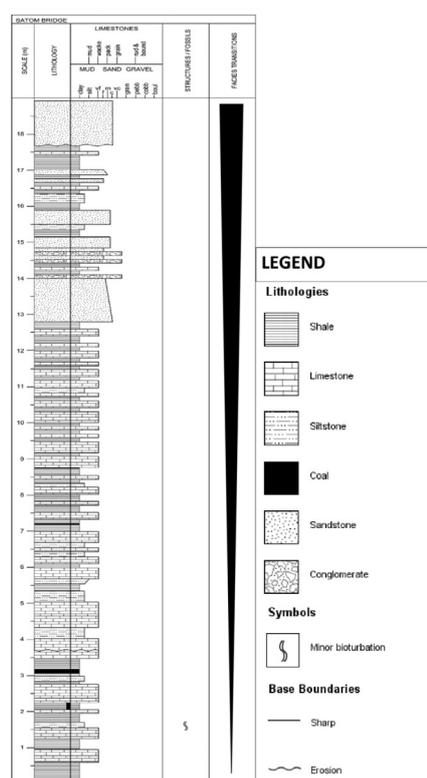


Figure 9: The composite lithologic log representing the Manyu River Formation.

The outcrops at akwen village (composite stratotype)

Stratotype: The newly constructed Trans-African Highways linking Mamfe and Ekok has exposed several sedimentary rock sections at and near Akwen village here designated as type locality. Two sections are described here (Figure 10) the first just before the bridge over River Munaya, measuring over 9 m high extending along the road for over 500 m is inferred as the lower section. It underlies the second section measuring about 12 m about 100 m away and just across the nearby River Munaya. This outcrop extends for over 2.5 kilometers towards and around Ndebaya village. We recommend these two sections to be a composite reference for this unit (Stratotype) as this is where the unit is best exposed and generally representative.

Lithology: The lithologic sections exposed at Akwen village consist of sandstone beds that are commonly intercalated with sandy to silty mudstones (Figure 10). The beds vary greatly in thickness, some are thick up to 3 m while others measure much lesser than 0.5 m. They are often very poorly sorted with grains ranging from very fine, fine, medium to coarse sizes and in places, pebbly but matrix supported. In the pebbly beds, the grains are rounded to sub-rounded and grain supported. They are whitish to grey and yellowish in color and are moderately consolidated. The beds are generally parallel to sub-parallel and undulating with a dip measurement of about 120 in both the NE and SW orientations. The thick sandstone beds clearly exhibit a grading which generally fines upward from a very conglomeratic base that fine through coarse, medium and often terminates with a sandy and silty mudstone bed at the top. Mud lenses of various sizes and shapes occur within the sandstone beds.

The sandy to silty mudstone layers are greenish-grey and dark to purple in colour with only patches that show fissility. These beds measure between sometimes 0.2 m to 2 m in thickness. As seen near Tabor village, dark-grey silty shale beds 15 cm-25 cm thick alternate commonly with variable thicknesses of medium grained sandstones.

Sedimentary structures of several kinds are commonly seen in both lithologic types. While the sandstones show both planar and trough cross stratifications which sometimes are bi-directional (Figure 10) and graded,

the sandy to silty mudstones exhibits various types of deformational structures. Load structures occur at the base of the sandstone beds (Figure 10) and others include ball and pillow and dish structures that are commonly kidney to oblate shape, concave upward and convex downward, and others sub-horizontal, polygonal or near circular. Some of these structures are seemingly imbricated and in between these ball and pillow structures are dark grey mud patches that show some degree of fissility. Other structures include; planar cross stratifications, mudcracks, cobble trains, crude horizontal lamination with deformational structures found at the base of massive sandstone beds with sandy mudstones. These include; load bedding, mud lenses, sand balls, sand pillows and flame structures.

Petrography: Petrographic studies by Bassey, Bassey and Ajonina and Ajonina show that this formation predominated by immature sub-arkosic sandstones with quartz, feldspars and rock fragments in that order of abundance and iron oxides is the main cement.

Age: Palynomorphs obtained from a few samples from the outcrop sections at Akwen yield only scanty and non-determinate specimens and in other sample, practically no palynomorphs. However, field descriptions report this unit as overlying the middle with an erosional and angular surface between them and so can only be equal or younger in age.

Boundary: The rock unit at Akwen is clearly seen to be directly but unconformably overlying the indurated, cross bedded conglomeratic sandstones of the Okoyong rock unit described above. The contact between these two rock units is not only distinct in character but exhibits contrasting dip directions (an angular unconformity). A nearly vertical and major fault is seen on the underlying Okoyong unit whose beds generally dip into the river at an angle over 60°SW confirming an angular contact which at the same time is an erosional surface [15].

Geographic extent: As noted in Bassey outcrops of this formation include those in and around Ndebaya village that is continuous through Akwen village to Eyomojock, Mbakem, Tabor, Ayukegba and Mamfe Town notable at the bank of River Badi. Although the actual boundary is not seen but can easily be perceived as directly overlying the Manyu Formation in an unconformable manner. This formation also outcrops at Eshobi and Mbenyang villages.

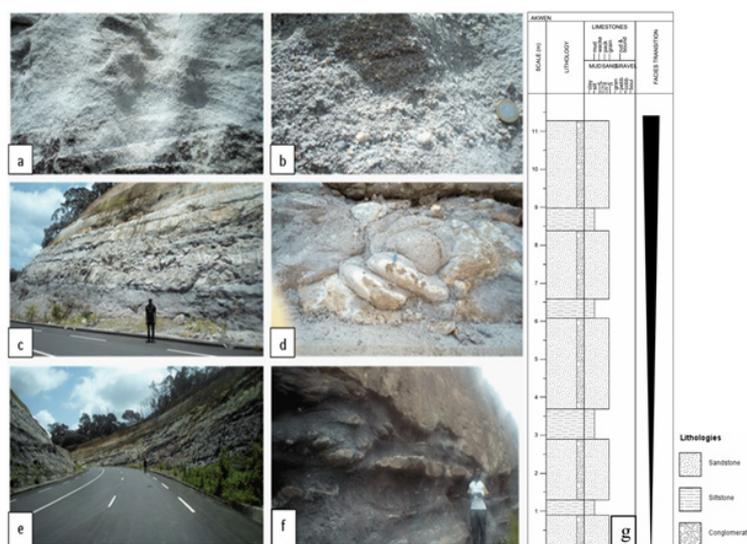


Figure 10: The Akwen Formation as exposed along the Mamfe-Ekok highways near Akwen village, (a) cross stratification in a sandstone bed, (b) conglomeritic sandstone, (c and e) roadside cut section and (d and f) sedimentary structures, (g) composite lithologic section.

Paleo-environment and depositional model: The structures discernible from these outcrops at Akwen village especially the planar cross stratifications, mudcracks, cobble trains, crude horizontal lamination with deformational structures found at the base of massive sandstone beds with sandy mudstones are all indicative of deposition in a fluvial environment but poor sorting may mean deposition under low to moderate energy conditions in probably a meandering or braided river. The load cast, mud lenses, sand balls, sand pillows and flame structures noted here are only indicative of rapid deposition of sandy beds on soft muds.

The Akwen Formation comprises fluvial sedimentary deposits not strongly folded and not indurated but were gently undulating, loose at several intervals and are lying directly ontop of the folded and very indurated units below (Figure 11). This boundary has also been described as an erosional surface (unconformity) indicating that the sediments of the two formations below were folded and eroded. They are thought to have been deposited as the paleo-lake was filling up.

Amendment of the lithostratigraphy of the mamfe basin

It should be noted here that, ever since geologic studies began in the Mamfe Basin till the recent involvement of multinational companies in the search for petroleum, very little effort has been made toward erecting a credible stratigraphic column that could truly represent it's lithologic in-fill. Sometimes it becomes very necessary to revise the categories of the stratigraphic units of a basin especially when they do not serve our present purpose. The multiple existing schemes by different authors, the several stratigraphic pitfalls inherent in each (as already pointed out above) and the inevitable confusion that is created by this scenario, justifies the compelling need for the amendments of the lithostratigraphy of the Mamfe basin. Preliminary lithostratigraphic descriptions, biostratigraphic analysis, correlations and petroleum potential assessment of the sedimentary sequences were undertaken at the beginning of this work as contain in

recent publications. These studies not only highlighted the dire need but provided the elements for the amendment of the basin's stratigraphy [16].

Promotion of stratigraphic ranks, members to formations

Defined as a body of stratified rock considered solely on the basis of its lithologic characters and is mappable on the surface and traceable in the subsurface, a formation must possess an internal homogeneity. On the other hand, a formation is described by the following elements: lithology, petrography, structures, boundaries, fossil (fauna and flora) content, age, environment of deposition, lateral extent, thickness, name and type-section (Stratotype). These elements which fulfill the requirements for the definition, description and naming of lithostratigraphic units in accordance with the standard stratigraphic procedures, have already been addressed above and other references cited in here. The justification for the promotion of the described units from the rank of member to formation is evident from the very elements that describe a formation as elaborated above. More so, each of the units described are internally homogeneous and mappable. The following are therefore proposed to make up the stratigraphic scheme (Figures 12-14) for the Mamfe Basin beginning from the base to top as follows:

- Okoyong Formation (Okoyong Sandstone), Stratotype: Awatu hill outcrop, formerly part of the Etoko/Okoyong Member.
- Etoko Member, of the Okoyong Formation, formerly part of the Etoko/Okoyong Member, Stratotype: a composite of the two outcrop sections at mile 23 and mile 24 respectively along the Bamenda-Mamfe road between Etoko village and River Masaka.
- Manyu River Formation, composite Stratotype: Satom bridge and Nfaitok outcrops, old name, Nfaitok Member Akwen Formation (Akwen Sandstone) (New name), type section: the outcrop at Akwen Village, before and across River Munaya. Formerly; the Manyu Member.

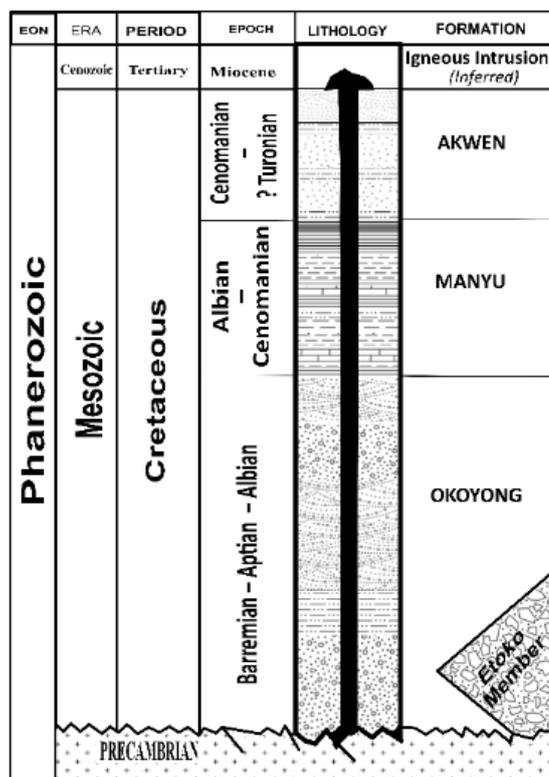


Figure 11: Lithostratigraphic column of the Mamfe Basin.

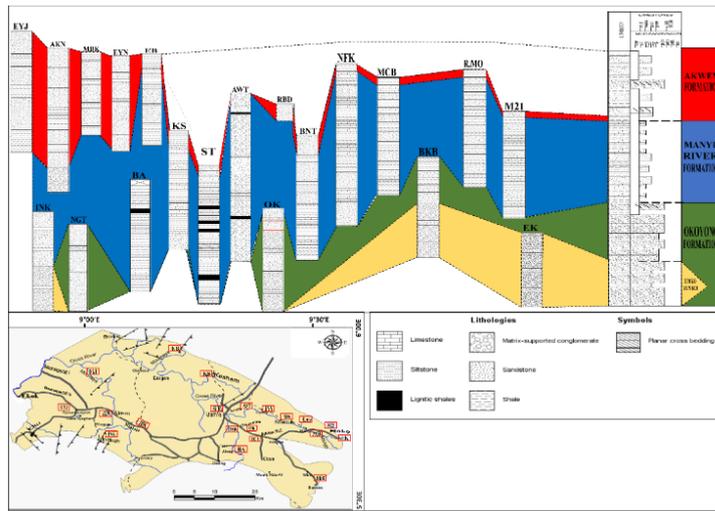


Figure 12: Correlation of the major outcrops.

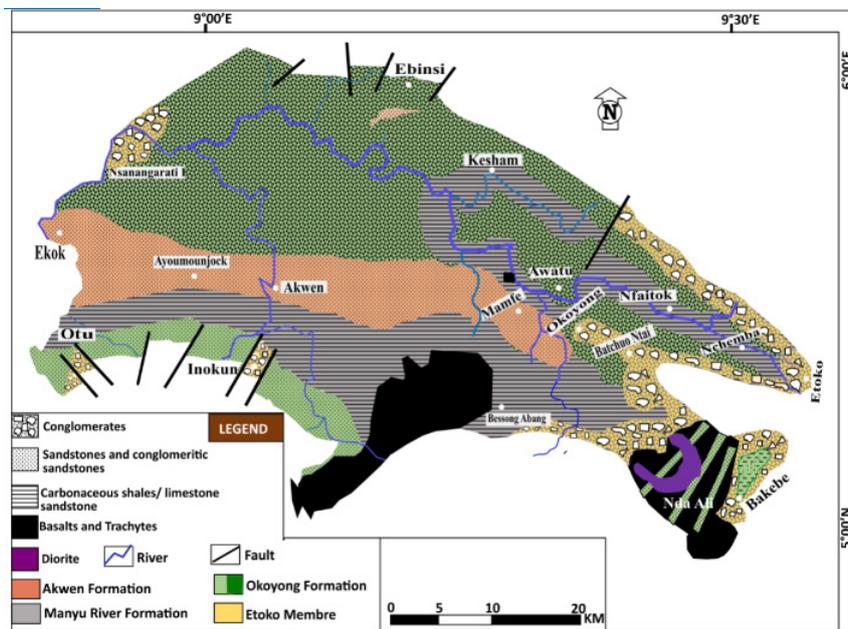


Figure 13: The geologic map of the Mamfe Basin, showing field occurrence of the different lithologic units (Formations).

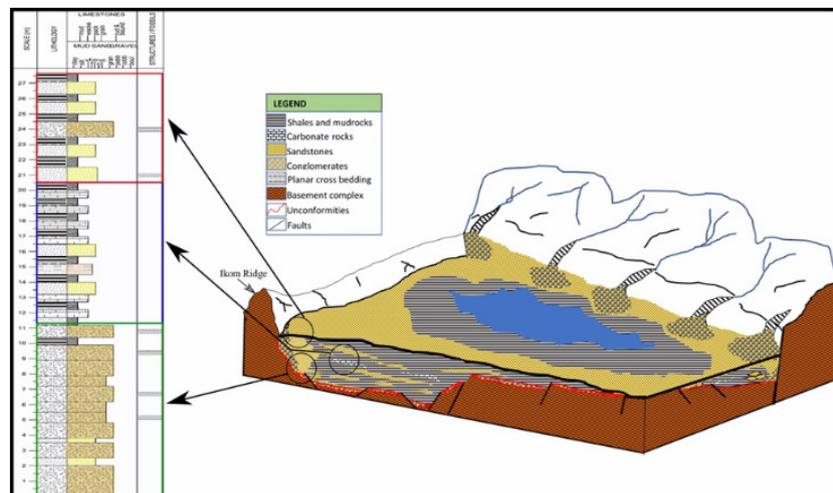


Figure 14: The depositional model of the Mamfe basin.

CONCLUSION

The present work as that of some previous authors have described strictly continental fluvio-lacustrine sedimentary sequences with no indication yet of marine strata in the Mamfe Basin. Recent publications on the stratigraphy of the basin and this present work are unanimous on the sub-division of the sedimentary infill of the Mamfe Basin into three distinct units. The paleo-depositional environments reconstructed for these units recognized a lower fluvial/piedmont, a middle aqueous shallow (deltaic) to deep lacustrine and an upper fluvial environment, for these units. This represents the depositional model of a typical tropical lake environment in which fluvial sediments were deposited by the river system/s, lacustrine fine-grained sediments accumulated under aqueous conditions of the lake water and deltaic sediments characterized the shallow environment together with fluvial sediments that probably closed up the lake.

In the Mamfe Basin, the two fluvial sedimentary units; the Okoyong Sandstone and the Akwen Sandstone respectively described as basal and upper units, are clearly separated by the middle lacustrine unit; the Manyu Formation. The sedimentary facies described above for each of the formations show a general depositional pattern well defined by typical lithofacies produced from distinct modes of sediment transport and sedimentation into separate environments of the deposition within a paleo-lake.

To conclude, field studies of the sedimentary sequences exposed in various localities within the Mamfe Basin have been represented by graphic logs from which lithofacies analyses have been made. The study of the modes and environments of deposition in the basin have revealed two typical fluvial and an aqueous lacustrine and marginal depositional style and with characteristic sedimentary structures. The sediments with a total thickness of about 4000 m have now been packaged into three distinct formations following the international standard stratigraphic guide. Therefore, the present work supports in principle the three units lithostratigraphic layout of the Mamfe Basin by Abolo and disregard the two units proposed by Bassey the five series and four formations of Le Fur, Eyong and Eyong respectively, considering these as simply misleading.

Although considered the three units as stratigraphic members of a single formation and the subdivision of these sediments into many units as inappropriate on the grounds that they are genetically linked and show no discernible age differences. This argument may not hold given that the definition of a formation does not rely on thickness or age although in its description the thickness and age must be included. Rather, the Standard Stratigraphic Code defines a formation as a genetically lithologic homogeneous unit which must reflect deposition under uniform or uniformly alternating conditions. In this instance, a fluvial depositional environment is quite unique in its entire facies character and therefore very different from sedimentary facies in a lacustrine environment as already defined in the Mamfe Basin. In these environments, the origin of sediments, modes of sediment transport and deposition, sediment types, structures and architecture are also quite unique and distinct.

The three units studied in the present work have been shown to possess all elements needed to define and describe a formation. Therefore, we note as follows:

- This work supports the three stratigraphic subdivisions of the sedimentary fill of the Mamfe Basin,
- The three lithologic units have been reviewed and qualified as formations,

- Representative sections (Type-Sections/Stratotypes) have each been suggested and described for each of these formations at their most appropriately named Type localities,
- The previous nomenclature for the units have robustly been modified, namely:
 - The lower unit now known as Okoyong Sandstone or Okoyong Formation with the Etoko Member,
 - The middle unit now called the Manyu River Formation and
 - The Akwen Formation or Akwen Sandstone.

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