




Tectono-sedimentary framework of the Cretaceous intracontinental Babouri-Figuil Basin (Benue Trough, North-Cameroon)

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Received: 2 June 2021 / Accepted: 21 December 2021 / Published online: 29 December 2021
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Abstract

The sedimentary layers of the Babouri-Figuil basin display a variety of dip directions which suggest a tectonic implication in the sifting up of this basin. This study is based on tectono-stratigraphic analysis that seeks to investigate on the relationship between lithostratigraphy and tectonic divergences. Four different depositional phases arise from this constructed lithostratigraphic section, with a fluvial to a fluvio-lacustrine paleoenvironmental characteristic indicating a positive deposition pattern sequence. Constructed lithostratigraphic sections reveal four fining-up sequences which vary from fluvial to fluvio-lacustrine depositional environments. Subsidence (SW-NE) perpendicular to the major fracture direction (N120E) generally SE-NW would be the origin of the abundance of fractures and diachases observed in the basin. It would thus be a small graben with an asymmetric syncline on the south side, formed in an extensive North–South context.

Keywords Sedimentary basin · Syncline · Stratigraphy · Tectonics · Benue Trough · Babouri-Figuil

Introduction

The formation and paleogeographic evolution of the Benue Trough is linked to the opening of the equatorial Atlantic Ocean which led to the separation of the continental blocks of Africa and South America (Fig. 1a, b) following the dislocation of Gondwana (Benkhelil 1982; Chaboureaud et al. 2013; Fernie et al. 2018). This phase is characterized by

brittle tectonics, crustal stretching and regional tilting which established several geological formations, including those of Northern Cameroon and part of Nigeria during the Cretaceous period (Anudu et al. 2020; Owono et al. 2020; Genik 1993). Thus, the structure of the basin would be due to the reworking of the deep faults in the basement. The Northern Cameroon already host small basins, including that of the Babouri-Figuil basin. This basin is located between latitudes 9° to 10° and longitudes 13°30 to 14°20. It is an asymmetrical and tapered basin of 33.5 km long by 1.0 to 7.5 km wide. It is stretched East–West, bordered to the North by Hosséré Houdi and Hosséré Sorawel, to the South by Hosséré Lombel and Hosséré Faourou, and to the NW by Hosséré Peské Bori (Fig. 2). The Babouri-Figuil Basin is drained by the Mayo Louti River (Fig. 2) and drained by its main tributaries (Ngounouno et al. 2001; Balla Ondo et al. 2014; Tchouatcha et al. 2021).

Although there have been a number of contributions on the study of the basin (Ndjeng and Brunet 1998; Fosso Menkem et al. 2011; Balla Ondo et al. 2014), studies of the early depocenters of the Babouri-Figuil Basin have concentrated on either stratigraphic analysis (Tchouatcha et al. 2010, 2021) or on volcanism, and the relationships between the latter and its imprint over sedimentary environments (Michard et al. 1990; Ngounouno et al. 2001; Balla Ondo et al.

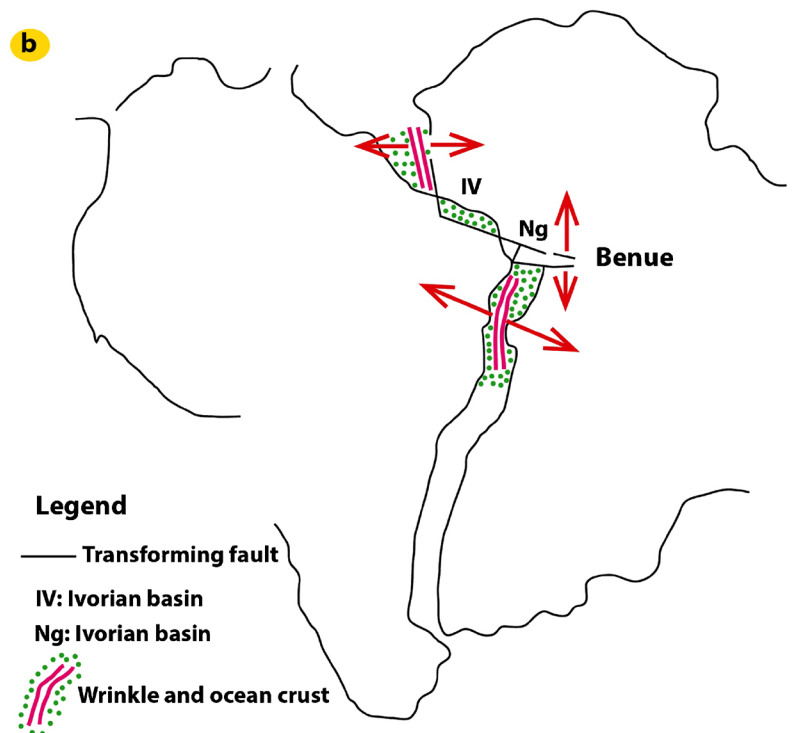
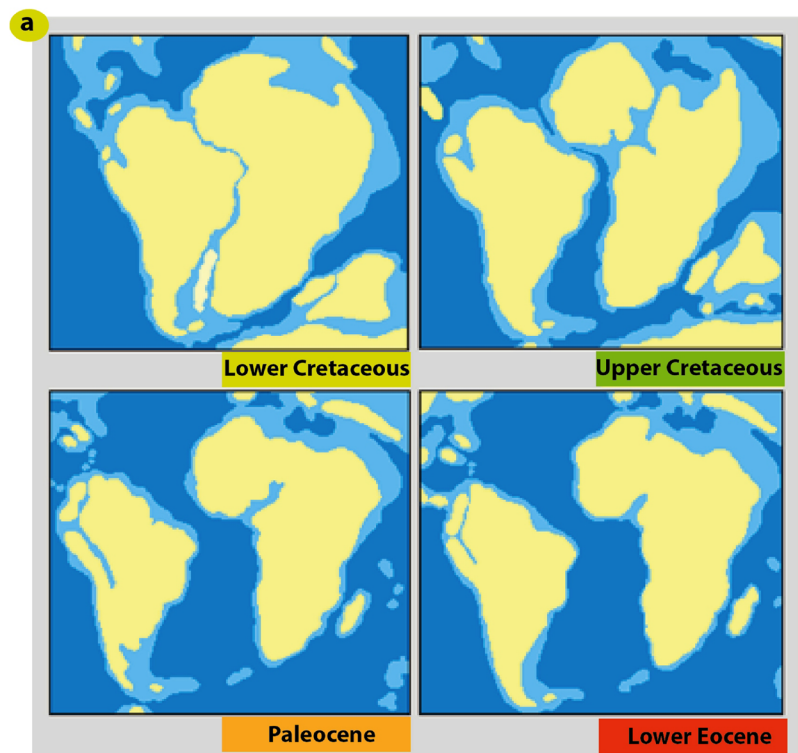
Responsible Editor: François Roure

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Fig. 1 a-Paleogeography of South Atlantique (Cretaceous-Lower Tertiary) (According PALEOMAP Project [C.R. Scotese (2001)], in Mbese (2013)); b-Separation of Africa and South America at Gulf of Guinea to Albian level (Grant 1971)



2021; Tchouatcha et al. 2021). Till date, no known studies have focused on the tectono-stratigraphy of this basin from the field.

The objectives of this study are to carry out a tectono-stratigraphic analysis of the Babouri-Figuil Basin focusing on both the depositional processes and the relationship

between tectonics and stratigraphy in the development of the sedimentary sequences, as well as climatic conditions, to design a depositional model. The study of the parasequences was carried out by means of detailed geological mapping and stratigraphic logs, in order to understand their succession. Also, the reconstruction of the paleoenvironments with

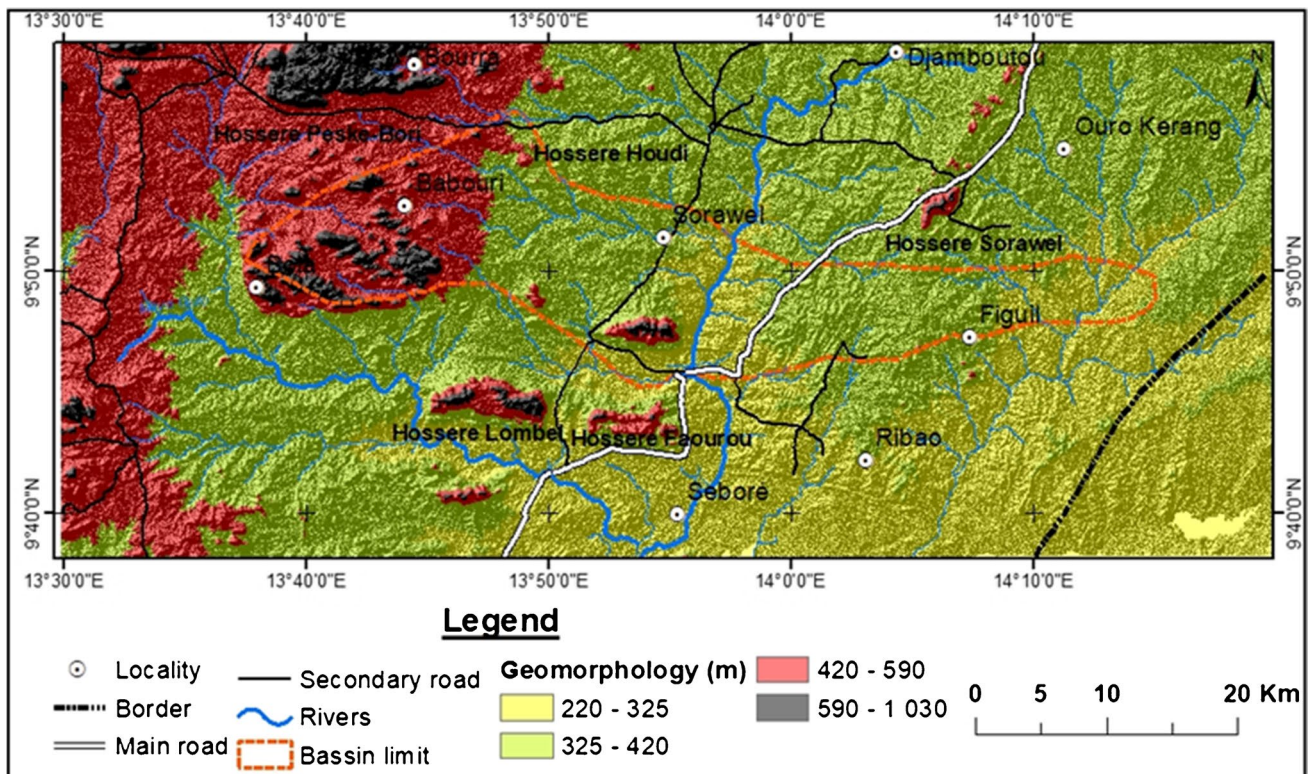


Fig. 2 Location of the Babouri-Figuil Basin; as well as the main hydrographic network of the basin and geomorphology of the locality

the help of field descriptions allowed the identification of the different depositional phases and highlighted the tectonic characteristics of this Basin.

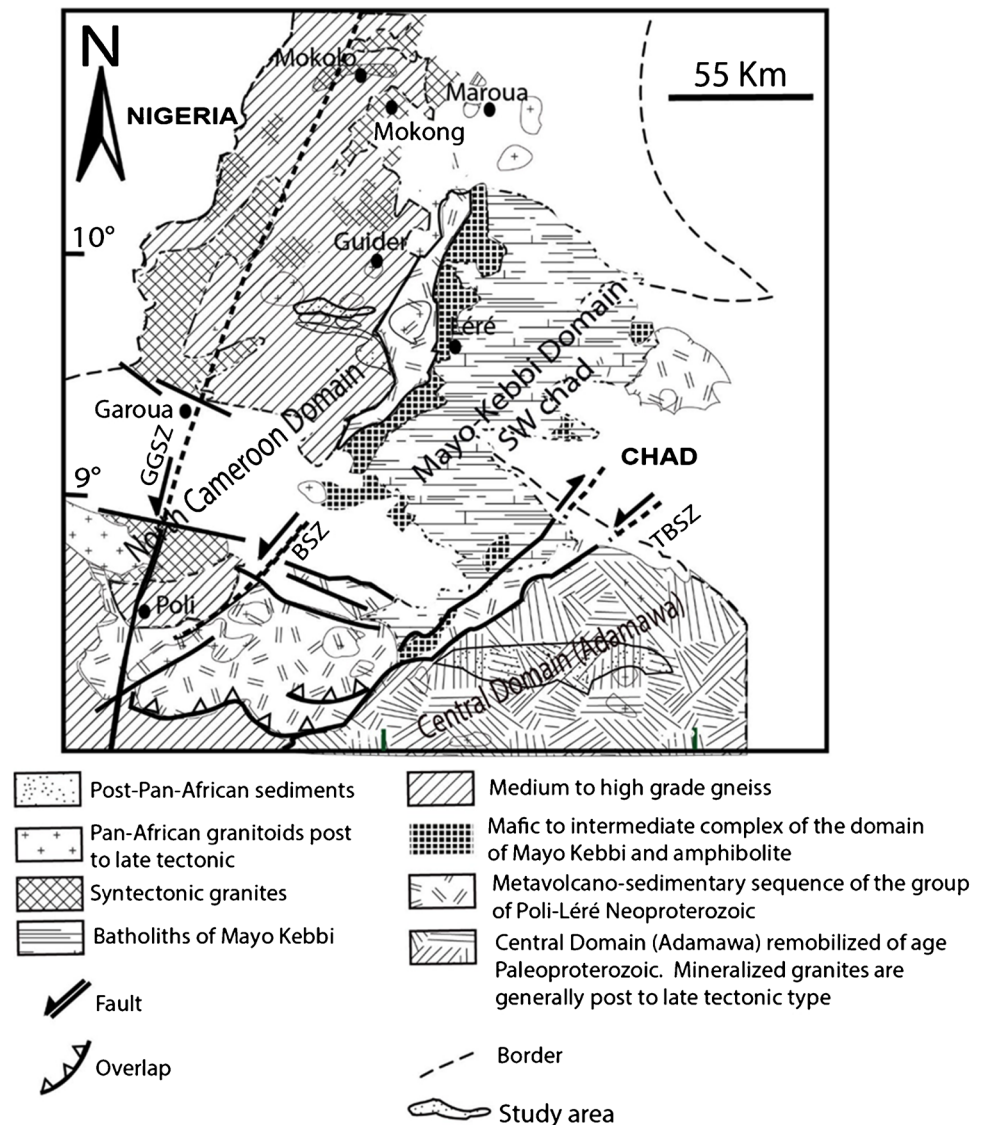
Geological context

The topography of the study area allows us to analyze the area outlined in Fig. 3. The area thus delimited appears as a peneplain slightly inclined toward the South and from which emerge the crystalline and detrital massifs. The latter appear as residual reliefs. Globally located northwest of the Tcholliré-Banyo fault, which extends to northeast Nigeria and southwest Chad, our study area is made up of schists, gneisses and granitoids (Balla Ondo et al. 2014).

From the structural aspect, three phases of deformation are commonly described in the North Cameroon domain (Toteu et al. 2004; Ngami Kamwa et al. 2016; Fuh et al. 2021) and this affects the base of the southern region of Figuil: the first phase of deformation D1 occurs as relics in the gneisses and shales of the Poli Group and its equivalents. It is characterized by foliations variable directions and dip caused by the folding of D2 phase. The axis of the P2 folds, due to their generally low dips, suggests

the existence of an initially sub-horizontal foliation that may result from a tangential shear regime (Ngako 1999; Tchakounté et al. 2017). Phase D2 is more intense and is responsible for the sub-vertical NNE-SSW to NE-SW regional foliation with dips from 0° to 50° south or north (Toteu et al. 2004; Nkoumbou et al. 2014). The migmatization and emplacement of the deformed granitoids are synchronous with this phase. In the Poli zone, syn-migmatitic, dextral and senestral conjugated shears are associated with this second deformation phase. The senestral shear zones are N-S to NE-SW, and locally associated with southward movement (Fig. 3). The dextral shear zones are NE-SW to ESE-WNW. This deformation phase is also marked by prograde metamorphism, ranging from green shale facies to amphibolite facies with migmatites (Toteu et al. 2004; Ngami Kamwa et al. 2016; Fuh et al. 2021). A chronology of tectono-metamorphic and magmatic events is proposed by Hagmoga (2006). The third phase of deformation D3 essentially brittle deformation is materialized by diaclases that have been highlighted in Garoua basin and the sedimentary basins of Babouri-Figuil and Mayo Oulo by Moreau et al. (1987). Their directions correspond to those of the West Central African Rift System (WCARS) from the late Jurassic to the Present (Guiraud and Maurin 1991, 1992).

Fig. 3 Geological outline of North Cameroon and South-West Central Chad (modified from Pennay et al. 2006)



Material and methods

For a detailed and systematic study of our area, the basin was subdivided into three: East, center and west (Balla Ondo et al. 2014). Each outcrop was described from a North–South direction for a better spatio-temporal relation between the different layers. Both the lithological characteristics of the sediments and the sedimentary structures were taken into account. This enabled a correlation between the outcrops leading to the establishment of lithostratigraphic sequence of the Babouri-Figuil sedimentary deposit. Dip directions were measured when necessary. The tectonic setting of the basin was appreciated from the geological sections produced from the different dips, but equally from of fractures and schistosity from field work. These data were processed using stereograms and analyzed in the laboratory for the different directions.

Results

Lithology and spatial distribution of sedimentary facies in the Babouri-Figuil Basin

Extending from east to west over approximately 33.5 km, and in order to contribute to the knowledge of the filling pattern of the Babouri-Figuil trench, five lithological sections were carried out, namely: The Mayo Louti section, the Mayo Figuil section, the Mayo Tafal section, the Sorawel-Lombel section and the Babouri section, which have undergone four volcanic episodes (Balla Ondo et al. 2014). From these sections, three were used for this study. The latter begin at the northern limit of the basin and have yielded convincing results. A detailed description of studied logs has been done by Balla et al. (2014) and Nyangono Abolo et al. (2014). When comparing the three lithological sections (Mayo

Tafal, Sorawel-Lombel, and Babouri) by classical correlation, and in a proposed geological sketch map of the basin's recharge (Fig. 4), it emerges that the syncline consists of coarse, ferruginous and iron-bearing arkosic sandstones with a conglomeratic past, which lie unconformably on the granitic basement at the northern edge of the basin. The mean southward dip varies between 15 and 25°S. Above the coarse sandstones is a fine sandstone layer of shale marl, limestones and even clayey layers with a dip varying between 30 to 35° South.

The sedimentological study of the Babouri-Figuil Basin suggests two probable sources of water supply to the basin. The more or less distant granitic and coarse source that fed its base with the presence of conglomeratic sandstones indicating fluvial-type facies, using strong transport energy, with alternating small fine layers (Balla Ondo et al. 2014). After exhaustion of the latter, the feeding of the basin continued with the second facies, mostly clayey, alternating with fine sandstones and siltstones, and highlighting facies of fluvio-lacustrine type with low transport energy.

Tectonics of the Babouri-Figuil Basin

Brittle tectonic

The Babouri-Figuil Basin presents a brittle tectonic which is materialized by the presence of filled diachases, cracks and faults. These different families of diachases are filled with two types of products. The first which is the largest and most numerous is filled with calcite (Fig. 5a). It presents a sinister detachment with the second family which is filled by fine sandstones (Fig. 5b). Fractures are also abundant in the

basin. They are present on all layers in the basin. They reveal in the Mayo Louti from the base to the top "per ascensum" two intrusions of fine sandstones that cut sub-vertically the shaly marls (Fig. 5c, d). These veins are about 2 m thick and 25 cm wide. They move up to the visible part on a height of about 1.5 m and abruptly about on the slab of a silty layer. These materials can rise in this way, either by the pressure of the over-incumbent sediment load, or by the pressure of accumulated gases or even lithostatic pressure (Reineck and Singh 1980). The cracks which, in some places, present a quadratic system, are sometimes open and sometimes cemented by a secondary matrix (Fig. 5e). Finally, a fault of meridian and visible direction on the outcrop of Mayo Louti presents an oblique rejection. It cups the two synclines of Mayo Tafal and Mayo Oulo, then interrupts toward the West of the syncline of Mangbei.

The discovery of this brittle tectonics made it possible to take measurements of the directions of all these fractures and construct a rose diagram of the directions (Fig. 6). The stereogram of the Babouri-Figuil basin shows a major N120E direction and a N130E secondary direction.

Soft sediment deformation

Tectonic in Babouri-Figuil is syn-sedimentary in the sediments and rocks of the basin. The silty and sandstone layers have temporarily lost their initial internal cohesion after a level of sedimentation. Lignier and Desmet (2002) explain that fine sands are conducive to temporary thixotropy-liquefaction when they undergo a sudden change in pore pressure. Liquefaction of the sands can occur when they are subjected to vibrations, or to a sudden overload (Fig. 7a). It

Fig. 4 Sketch of the geological map on basin recharge

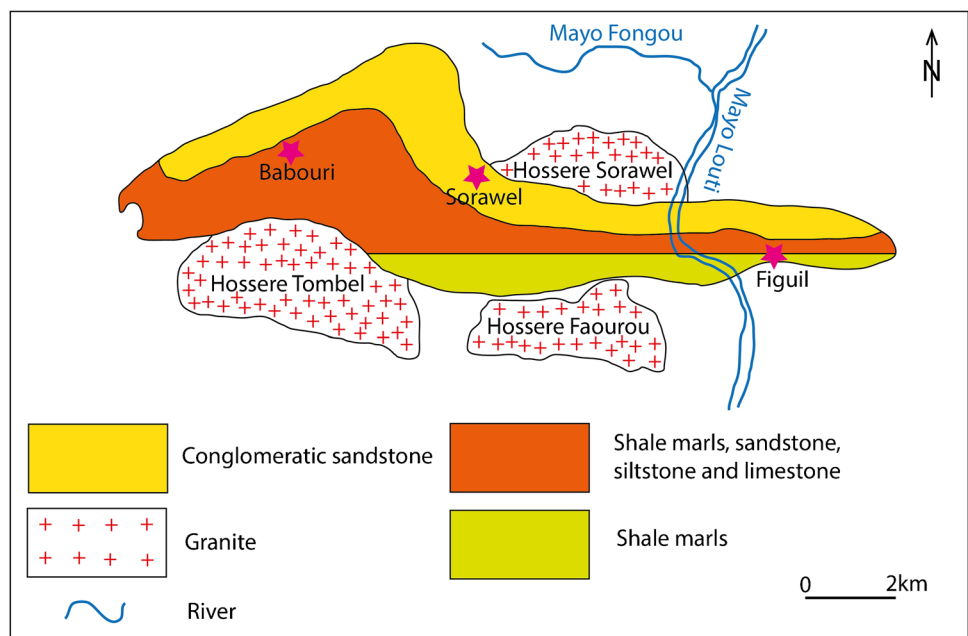


Fig. 5 Brittle tectonic in the Babouri-Figuil basin: **a**-Diaclasses filled with calcite, **b**-Sinistral stripping of calcite and fine sandstone diaclasses, **c**-Injection of a fine sandstone vein with upward rebound of the shaly marl, **d**-Injection of a fine sandstone vein with a double rebound of the shaly marl: bottom right and top left, sign of a double pressure, **e**-Cemented cracks

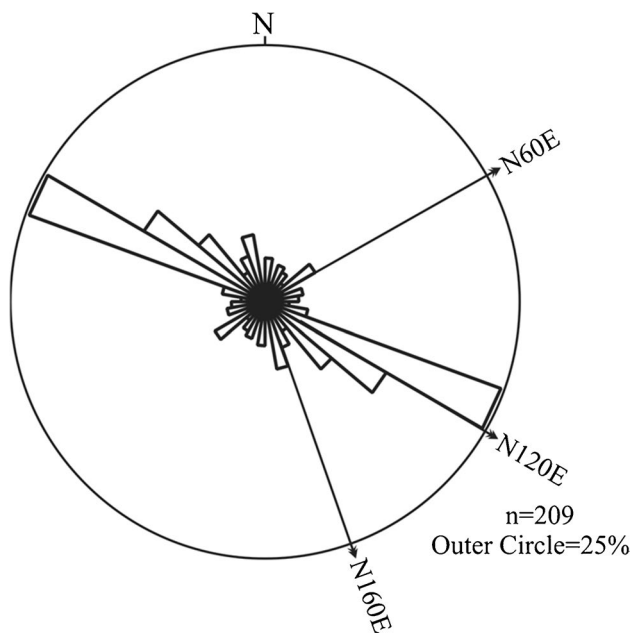
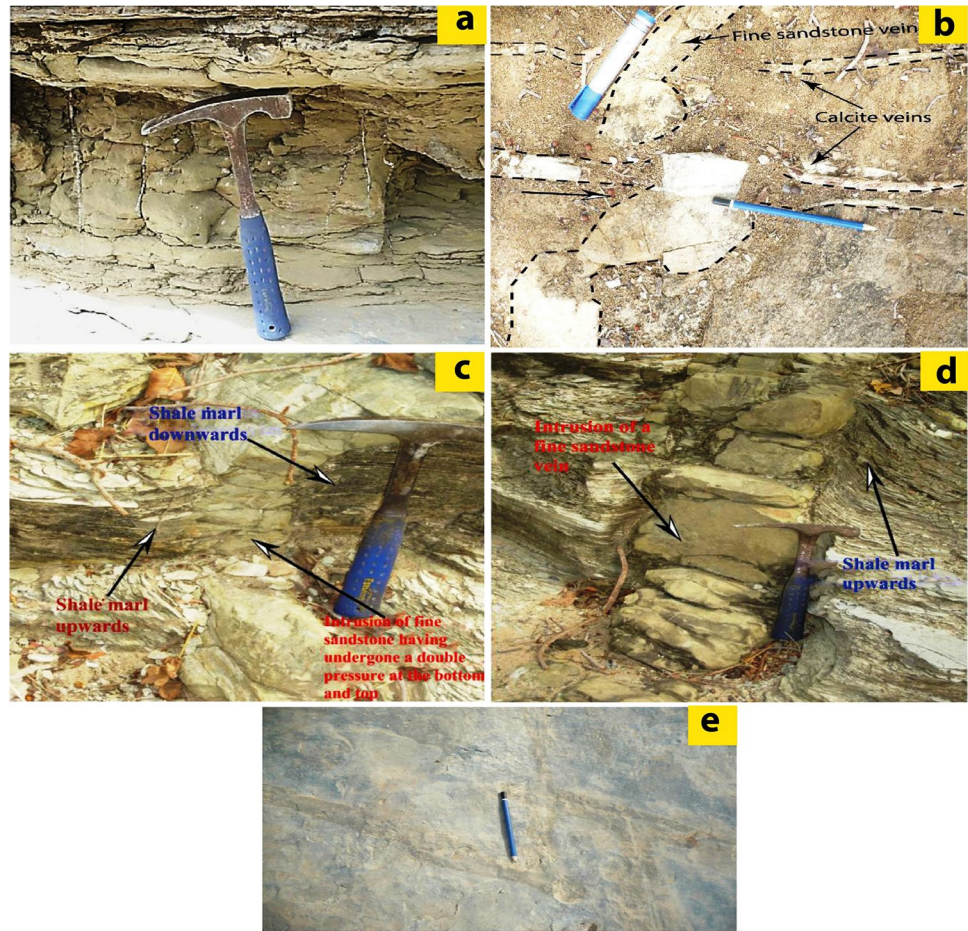


Fig. 6 Rosace of distribution of fracture directions in the Babouri-Figuil basin

can therefore be assumed that the seismic tremors affecting the basin's subsoil caused a break in the equilibrium that led to the installation of sliding structures along the slope.

The tectonic study of the Babouri-Figuil basin also highlights another type of syn-sedimentary fold present on a sandstone slab in the Mayo Tafal formation (Fig. 7b). These are convoluted structures on the surface of sandstone layers. These folds could be linked to the various constraints that the sediments undergo during the setting of the layers, and that erosion allows.

The schistosity in the basin occurs mainly on the layers of shale marls, whose measurements of the plans have been taken. The stereographic projection of the schistosity planes shows a concentration of the poles in the northern quadrant of the stereogram. These poles are closed to the center of the device which translates an average value of the dip angles of the layers on the ground (N118E62°SSE) precisely in the outcrop of the Mayo Tafal, as well as their inclination toward the South. The schistosity poles are arranged in a zone, showing a regional scale fold with axis N119E11ESE, following the compression in the NNE-SSW direction (Fig. 8).

Ultimately, since the Babouri-Figuil sedimentary basin is generally a sedimentary slick with flexible tectonics

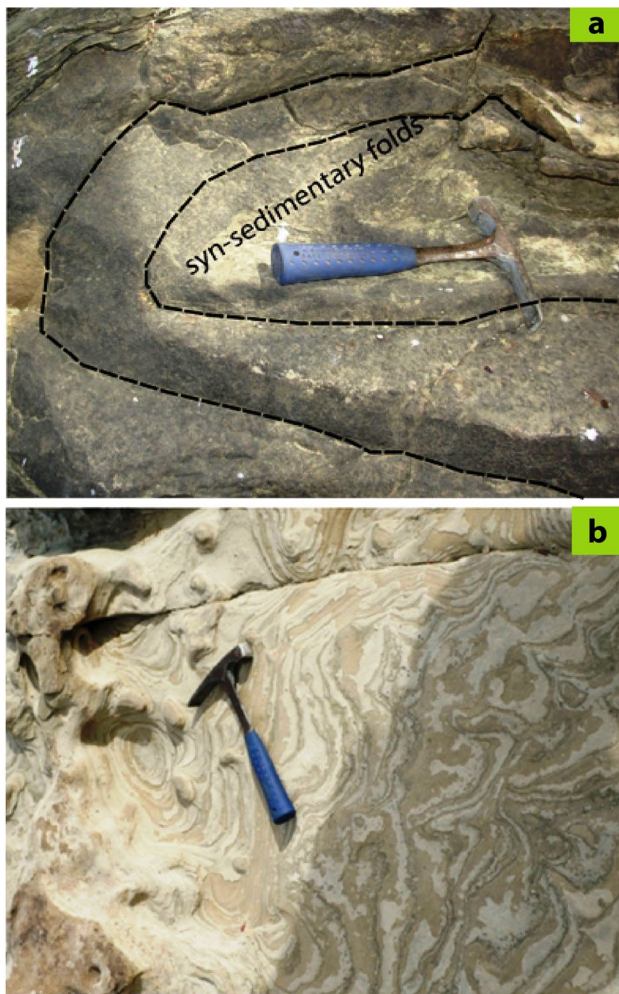


Fig. 7 Flexible tectonic in the Babouri-Figuil basin: a-sedimentary syn fold, b-convoluted bedding

(Balla Ondo et al. 2014), it is structurally considered to be an asymmetrical syncline in its southern part in the NE-SW direction. The geological section on the Sorawel-Faourou outcrop was made at the widest point (7.5 km) of the basin (Fig. 9). It highlights this E-W-oriented asymmetric syncline in the southern part of the basin. From NE to SW of the section, there is a dissection of the layers that would be due to the rise of a magmatic intrusion. The syncline consists of a layer of fine sandstone, marly limestone on the northern flank, and the overall direction of the layers is south, whereas on the southern side, this syncline begins on a layer of coarse sandstone followed by a layer of limestone. The dips of the layers of the southern flank are up to 55° in the general Northern direction, before they are cut by a fault. This subsidence (SW-NE) is perpendicular to the major fracture direction (N120E) generally SE-NW. It is therefore the cause of the abundance of fractures observed in the basin.

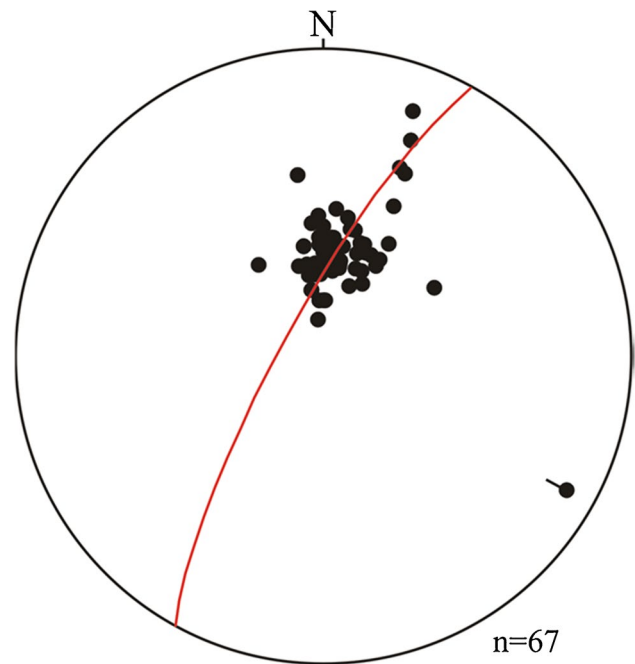


Fig. 8 Stereogram of the poles of schist planes

This subduction has favored a tilting of the sedimentary successions, tabular at the beginning, into low-lying in the basin. They are formed by alternations of soft layers and erosion-resistant layers and give rise to a cuesta relief (Fig. 10). The cuesta consists of a front, more or less steep due to the interruption of the resistant layer, a depression along the foot of the abrupt and dug in the soft layers and a reverse which corresponds approximately to the back of the inclined resistant layer (Fig. 11). In front of the front, isolated reliefs testify to the former extension of the resistant formation: they are the control mounds (Fig. 11) with the appearance of fairy chimneys. Various factors shape the morphology of the cuesta in this outcrop: the differential erosion in these formations conditions more or less the steep character of the front; the dip and the relative thickness of the resistant formation control more or less the rectilinear aspect of the front.

Stratigraphy

The proposed sequential cut was established from the detailed analysis of two main section: the Sorawel-Faourou section in the center, over the largest width of the basin, and the Mayo-Figuil section in the east of the basin over the smallest width. These lithological columns indicate four deposition phases (Fig. 12). Study of the lateral (spatial) relationships between the facies of the above-mentioned columns indicates that a good part of the sedimentary strata is generally dipping south. The other half has a dip completely opposite to the first (North), highlighting a syncline

Fig. 9 Geological section, Hos-séré Sorawel-Hosséré Faourouo, on the largest width of the basin

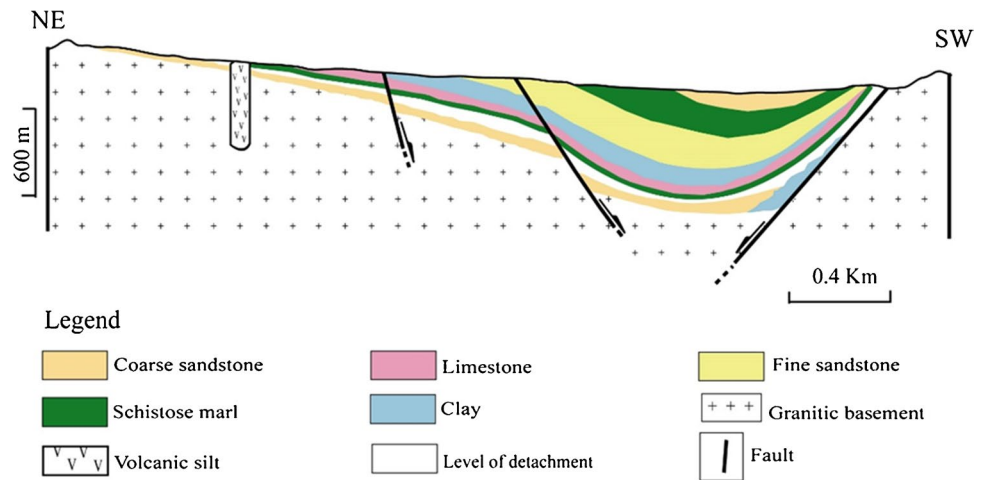


Fig. 10 Panoramic view of the layout of the layers after subduction

within the basin. The correlation of these lithological sections delineates the deposition phases below:

The lower limit of the first (1) retrograde sequence of the Sorawel-Lombel section is characterized by a variation of sandstone facies carrying thicker layer (Fig. 13a). The low level of the deposition of this sequence corresponds to fine sandstone banks. This sequence ends with a succession of layers of medium sandstone.

The lower limit of the second sequence (clay sequence) is materialized by a change in texture and facies. It is a clay level in which limestone layer and a layer of sandstone are located when it is correlated to the Mayo Figuil Sect. (2).

The aggrading deposit of the third phase presents at its lower limit schistose marls that interbedded a layer of fine sandstone. This results in a rhythmic sedimentation of alternating fine sandstone, siltstone and schist marls (3) (Fig. 13b). The whole process reflects a rhythmic filling in a lacustrine environment. It is on this sequence that two types

Fig. 11 Block diagram illustrating the theoretical layout of the cuestas in the Mayo Tafal outcrop

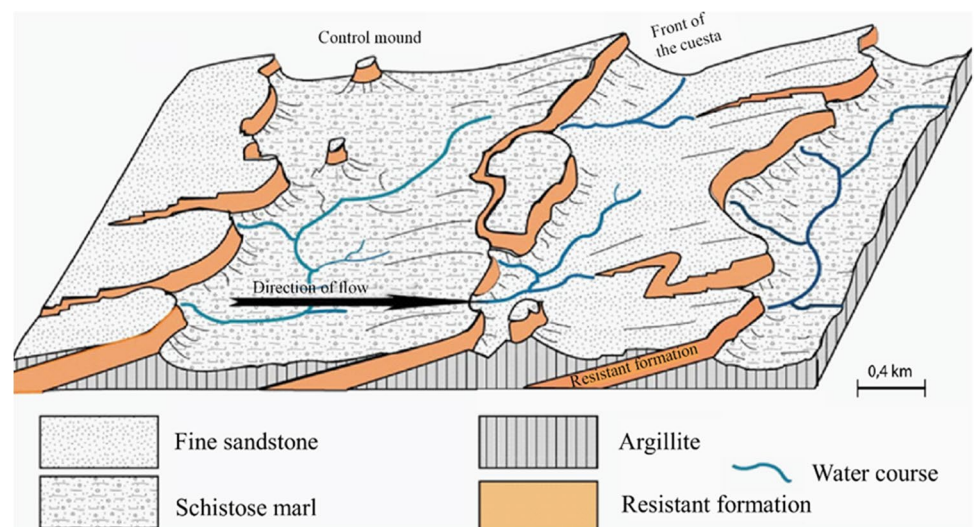
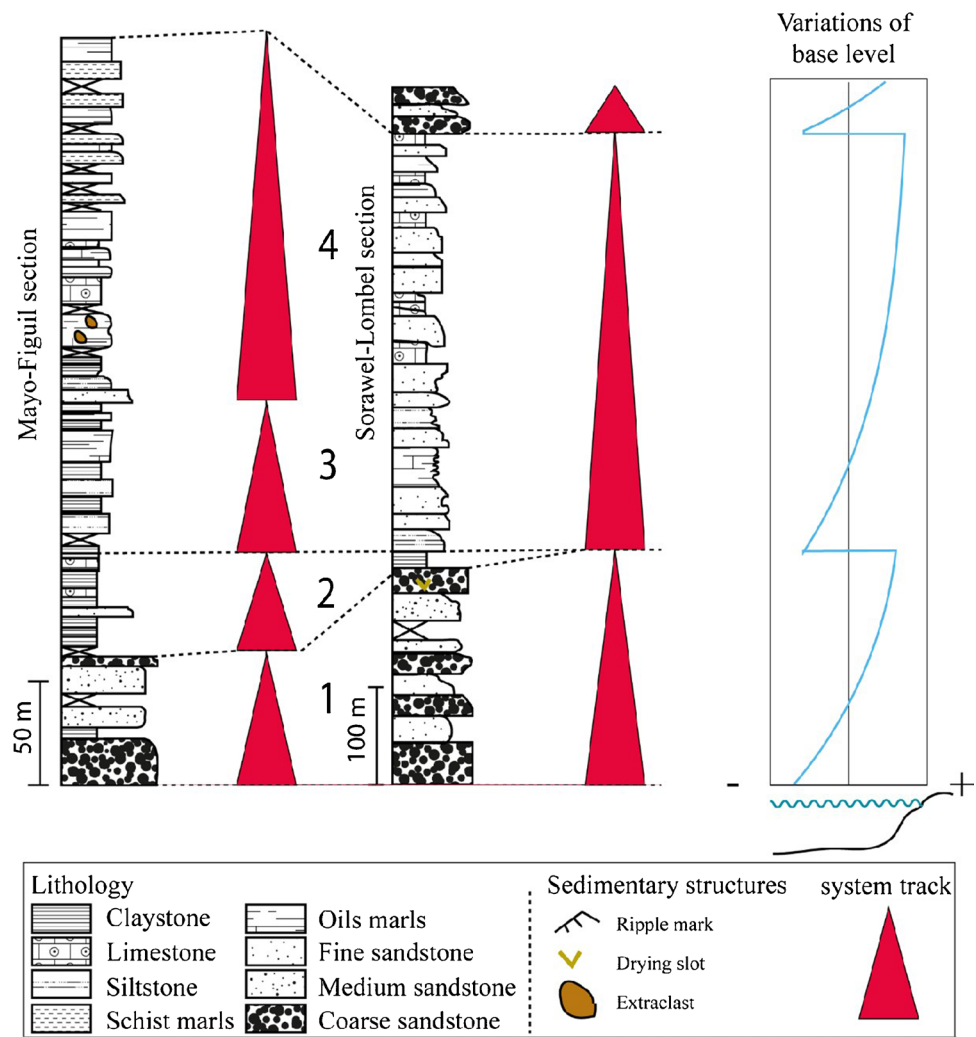


Fig. 12 Correlation of basin sections based on sequential analysis



of dinosaur footprints can be observed on the slab of a layer of schistose marls: one tridactyl (Fig. 13c) and the other circular (Fig. 13d).

The fourth phase, similar to the third, is more remarkable for its calcareous layers, fine sandstones and especially a thick layer of schistose marls containing ferruginous plates more than 5 cm thick (4) (Fig. 13e). These last two can be identified in a single sequence called marno-silt-grained sandstone sequence.

Paleo-climatic and palaeoenvironmental indication

The presence of the flora genus *Metapodocarpoxylon* (Roch et al. 1953) allows us to affirm that the Babouri-Figuil basin integrates well in the models of the lower Cretaceous floristic provinces (the "anterior-albian micro floristic province of West Africa-South America" of Herengreen and Chlonova (1981); the "north erngondwanian province" of Brenner (1976); the "northerndwanian province" of Doyle et al. (1982); the "phytogéo-province III with *Dicheiro-pollis*

etruscus" of Srivastava (1978). Discovered silicified wood (Balla Ondoa et al. 2014) has very clear and incomplete growth zones. This aspect indicates unstable climatic factors (presence of marked seasons). The abundance of conchostraceae such as *Estheries* confirms a paleo-swampy environment under hot and humid climate, with seasonal periods of drying which favored the spread of their eggs (Defretin-Lefranc 1967). Nevertheless, the abundance of coarse to basic conglomeratic sandstones reflects fluvial sedimentation environment.

Discussion

The Babouri-Figuil basin generally comprise conglomeratic sandstone facies with a massive structure at its base. These lithofacies are derived from hyper-concentrated mass flows or high-density subaqueous turbidity currents, which are rapidly and directly deposited from turbulent suspensions (Ghibaudo 1992). Horizontally stratified

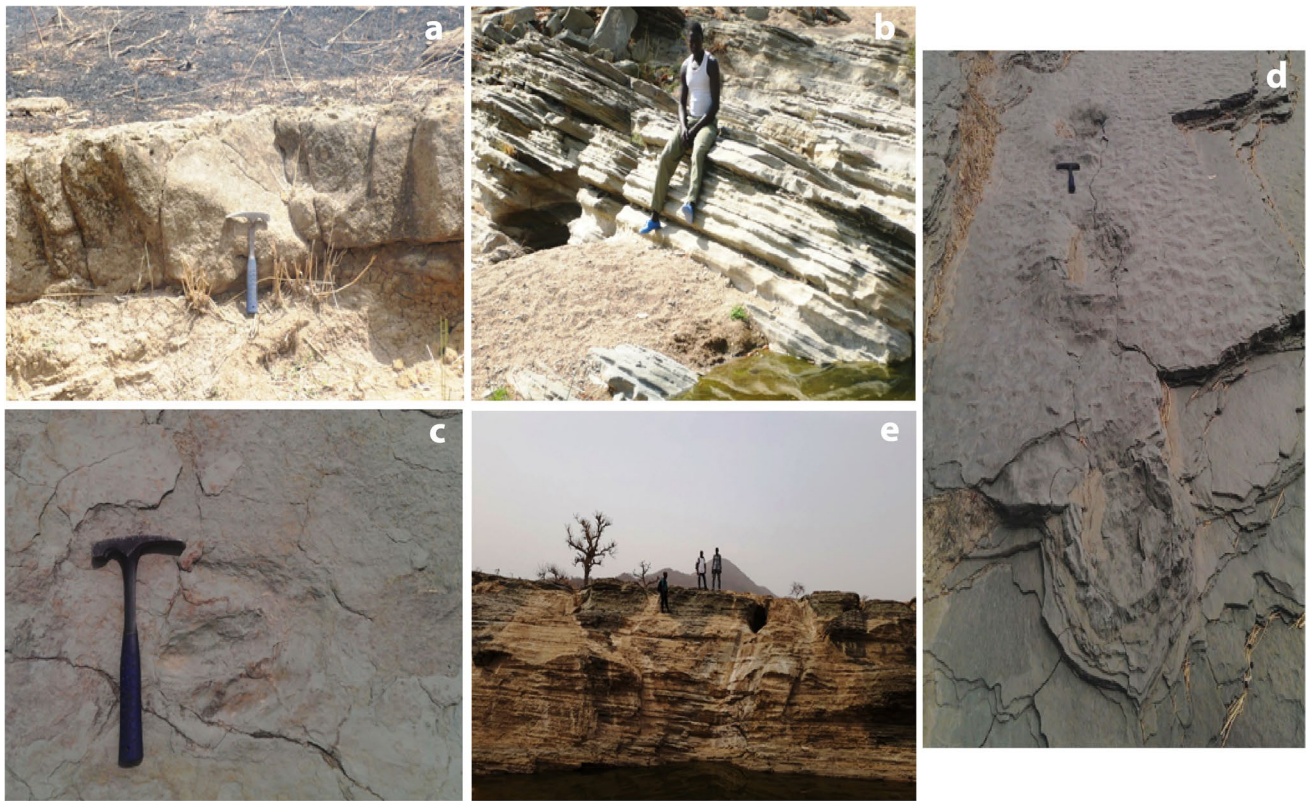


Fig. 13 Different levels of sequences. a-basic sandstone, b-rhythmic sedimentation sequence, c-steps tridactyl dinosaur, d-steps circular dinosaur, e-powerful schist marl layer

sandstones are formed by high-to-medium-energy planar/laminar flows (Miall 1978; Harms et al. 1995) or by traction mats (Potsma 1990). The siltstones, shale marls and clays in the upper part of the basin result from the suspension of a quiet environment or a pulling current (Miall 1996). The study of cross-sectional surveys in the basin by Balla Ondo et al. (2014) using magnetic susceptibility (MS) curves presents a complexity in terms of an accurate correlation of microfacies. These curves make it difficult to apply the concept of sequential stratigraphy, which limits parasequences by their note. This is because variations in magnetic susceptibility values are theoretically directly related to variations in sea level (Crick et al. 2001). Da Silva and Boulvain (2006) show that it results theoretically from a parallelism between the curves of microfacies and magnetic susceptibility in carbonate rocks. The development of alluvial sediments in the Babouri-Figuil sedimentary basin thus suggests a continuous subsidence over the entire basin filled by significant sedimentary flows. Nevertheless, the actual stratigraphic analysis of these lithological logs shows four sedimentation sequences. In the Babouri Figuil basin, the short-term sequences are between half a meter and ten meters thick and are composed of five to more than twenty layer of

variable thicknesses in the Mayo Tafal. They are mostly limited by flooding surfaces. Type one dominates in the Mayo Tafal and is characterized by a shallower depositional environment and thinner layer, which may reflect a decrease in available space. The second type can be seen in the Sorawel-Lombel section. In its lower part, banks are increasingly thicker and may be associated with an increasingly deep depositional environment. Strasser et al. (1999) show that deepening and/or shallow water levels which can be explained by autocyclic phenomena or water level fluctuations are a motif on the vertical evolution of sedimentary facies within a short-term sequence. The vertical stacking of facies in the Mayo Tafal and Mayo Louti sections shows a generalized aggrading tendency in view of the monotony of the sedimentary deposits. However, within this aggradation, a retrograde unit can be distinguished in the upper part of the Mayo Tafal section. Clastic dykes recognized in the basin are evidence of lithostatic pressure due to sediment weight over unlithified sediments. This has induced fractures, and soft sediment deformation illustrated by the presence of localized folds. The third phase of deformation described in the North Cameroon domain, essentially brittle and materialized by diaclases that were revealed in the Garoua trough and in

the Babouri-Figuil and Mayo Oulo sedimentary basins by Moreau et al. (1987), and consequently the multitudes of fractures observed within the Babouri-Figuil basin.

Conclusion

It consists of a medium to coarse conglomeratic sandstone facies and a fine-facies summit of schistose marl, fine sandstone, siltstone and even limestone. These assemblages have allowed us to establish a sedimentation model reflecting a generally positive sequence. Based on correlations made on the basis of sequential stratigraphy, the lithological logs present four deposition sequences. The detailed sedimentology studied in this basin made it possible to highlight two types of Paleoenvironments: a fluvial one, by the presence of basic medium to coarse conglomeratic sandstones and another fluvio-lacustrine one by the presence, not only of fine sediments, but also by its fauna and flora. Finally, the tectonic study of the Babouri-Figuil basin shows that, this basin is an asymmetrical syncline toward the south of the basin. The directions of the diaclasses and fractures are generally oriented N120E. This overall direction is perpendicular to the direction of subsidence of the syncline. It is therefore the cause of the abundance of fractures observed in the basin. Given the configuration of the basin, we are led to believe that this basin composed of fluvial sediments and associated submarine volcanism, originating from the Yola branch of Nigeria, which extends into Cameroon, and belonging to the Benue Gap, could be a small graben formed in an extended north–south context.

Funding Armel Zacharie Ekoa Bessa testify on behalf of all co-authors that the authors received no specific grant from any funding agency in the public, commercial or not-for-profit sectors for the article indicated by the title “Tectono-sedimentary framework of the Cretaceous intracontinental Babouri-Figuil Basin (Benue Trough, North-Cameroon).”

Declarations

Conflict of interest The authors declare that they have no competing interests.

Ethics approval Hereby, Armel Zacharie Ekoa Bessa consciously assure that for the manuscript: “Tectono-sedimentary framework of the Cretaceous intracontinental Babouri-Figuil Basin (Benue Trough, North-Cameroon)” the following is fulfilled: (1) This material is the authors’ original work, which has not been previously published elsewhere. (2) The paper is not currently being considered for publication elsewhere. (3) The paper reflects the authors’ research and analysis truthfully and completely. (4) The paper properly credits the meaningful contributions of co-authors and co-researchers. (5) The results are appropriately placed in the context of prior and existing research. (6) All sources used are properly disclosed (correct citation). Copying of text must be indicated as such using quotation marks and giving proper reference. (7) All authors have been personally and actively involved in substantial work leading to the paper and will take public responsi-

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