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How to cite

BESSONG, Moïse et al. First 2D and 3D interpretative models of sedimentation in the Cretaceous Hama-koussou sedimentary basin: Litho-bio-stratigraphy and palaeoenvironment records. In: Journal of African Earth Sciences, 2021, vol. 182, n° 104256. doi: 10.1016/j.jafrearsci.2021.104256

This publication URL: https://archive-ouverte.unige.ch/unige:153775
Publication DOI: 10.1016/j.jafrearsci.2021.104256

Journal of African Earth Sciences 182 (2021) 104256

Contents lists available at ScienceDirect

Journal of African Earth Sciences

journal homepage: www.elsevier.com/locate/jafrearsci

First 2D and 3D interpretative models of sedimentation in the Cretaceous Hama-koussou sedimentary basin: Litho-bio-stratigraphy and palaeoenvironment records

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A R T I C L E I N F O

Keywords:
Stratigraphy
Cretaceous
Hama-koussou sedimentary basin
Benue trough
Cameroon

A B S T R A C T

The Hama-Koussou Basin is one of the offset structures of the eastern end of the Benue Trough in Northern Cameroon. This sedimentary basin is an asymmetrical syncline whose axis is strongly shifted towards the East, filled predominantly with Cretaceous deposits, The basin has experienced at least three (3) phases of sedimentation during its geological history: two (2) fluvial phases with one at the top and the second at the bottom consisting of conglomerate, micro-conglomerate, and sandstone, sandwiching one fluvio-lacustrine phase consisting of fossiliferous claystones and marlstones with intercalations of siltstones and carbonate cemented fine sandstone. Numerous sedimentary structures including planar, oblique, and cross stratifications, convolute bedding, desiccation cracks, ripple marks and loadcast have been recorded. The mineral assemblage is dominated by quartz, plagioclase, mica and microcline, accompagnied by diagenetic phases (iron oxide, silica and carbonate). Clay minerals consist of kaolinite, illite and chlorite/smectite. Palynofloral analysis reveals various taxa indicative of a fluvio-lacustrine environment: These include *Classopollis* sp., *Eucommiidites* sp., *Concavisporites* sp., *Cicatricosisporites* sp, *Araucariacites australis*, *Callialasporites dampieri*, *Callialasporites microvelatus.* The occurrence of *Callialasporites microvelatus* confirms the Cretaceous age whereas age determination for all other samples was uncertain due to scarcity in palynomorphs. Low numbers of bisaccate, grass, and other angiosperm pollen grains may be indicative of a Cenozoic or younger age, although contamination by modern pollens cannot be excluded. The region experienced volcanism represented by explosive and effusive phases, recorded as sills and dykes. Plutonism is characterized by the establishment of intrusive granite. The East-West elongation observed in the HSB is the same in the Mayo-Oulo-Lere and Babouri Figuil basins and can be interpreted as the result of the same tectonic event linked to the opening of the Atlantic Ocean resulting in the formation of the Benue Trough and adjoins basins.

1. Introduction

The Hama-koussou sedimentary basin (HSB) is one of twelve (12) sedimentary basins in the northern part of Cameroon whose geological history seems to be related to that of the Benue Trough that spreads from Nigeria to Cameroon (Fig. 1a and b). Studies carried out in the Yola branch (Allix, 1983; Allix and Popoff, 1983; Benkhelil, 1986, 1988; Benkhelil et al., 1989; Bessong et al., 2011; Bessong, 2012; Ntsama, 2013; Ntsama et al., 2014; Bessong et al., 2015; Bessong et al., 2018) reveal that the formation of some of these basins is related to the opening of the Atlantic Ocean (Fig. 1b). The Hama-koussou Basin, like all other basins in Cameroon, formed upon a Precambrian basement (Koch, 1959;

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https://doi.org/10.1016/j.jafrearsci.2021.104256
Received 3 September 2020; Received in revised form 29 April 2021; Accepted 11 May 2021
Available online 27 May 2021
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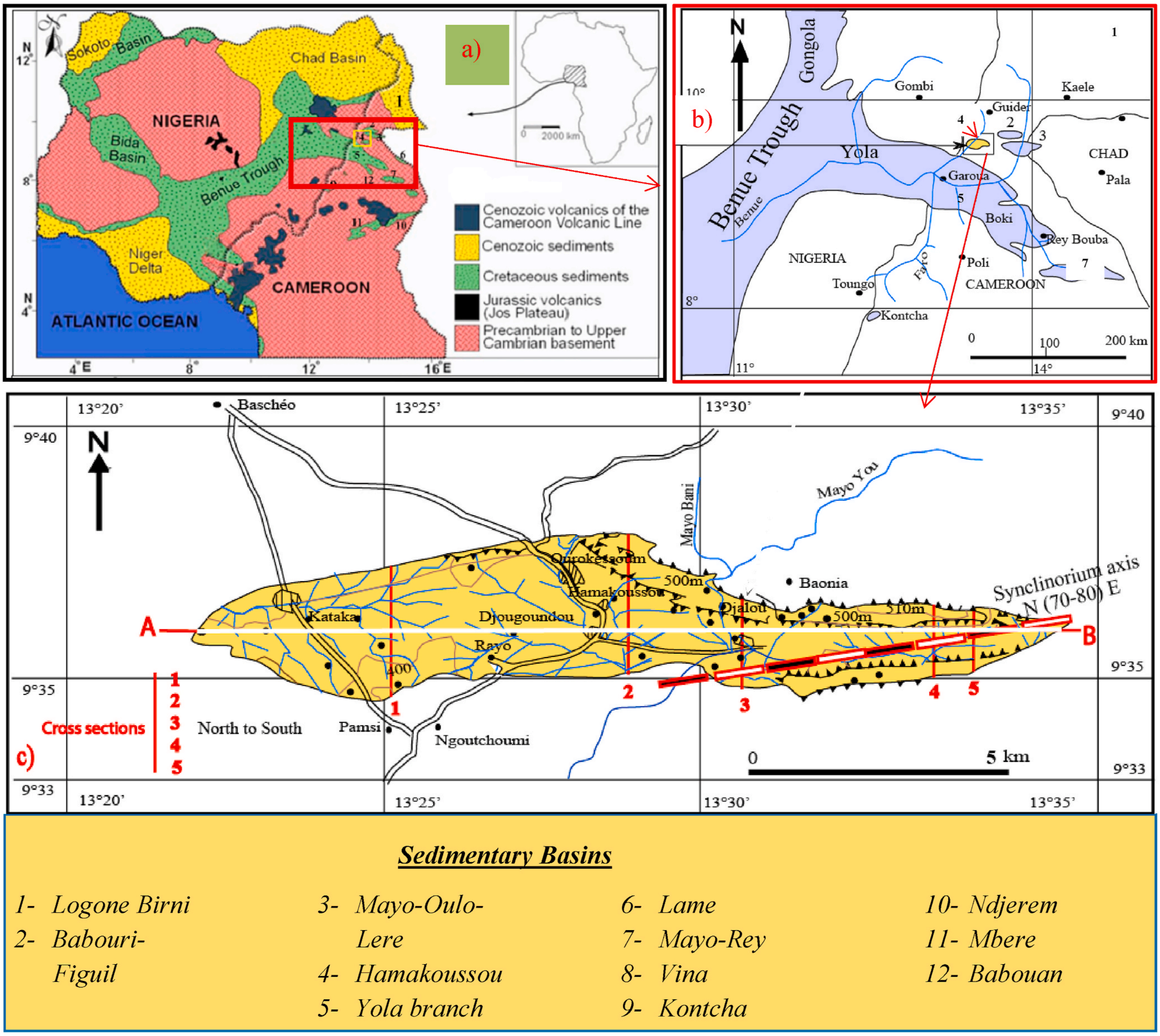


Fig. 1. Sedimentary basins in the northern part of Cameroon (a), the Benue Trough (b) and the Hama-koussou sedimentary Basin with sampled cross sections (c).

Schwoerer, 1965; Ngako, 1986; Toteu et al., 1986; Toteu, 1987; Penaye, 1988; Njel, 1988; Bassahak, 1988; Ngako et al., 1989; Penaye et al., 1989), composed mainly of quartzites, migmatites and granitic intrusions (Fig. 2a). Magnetostratigraphy (Ntsama, 2013), and palynostratigraphic studies (Bessong et al., 2018) revealed the presence of Cretaceous rocks, hosting a large variety of palynomorphs. The intensity of volcanism that has affected the region complicates efforts to establish the genetic relationship between sedimentary deposits and the different phases of volcanism. The current state of knowledge on the evolution of this basin is still introductory and this study seeks to contribute to the understanding of the general geological context and the litho bios-tratigraphy based on lithofacies analysis and palynology, respectively. The main purpose of this paper is to report the 2D and 3D interpretative model of sedimentation according to the litho-biostratigraphic analyses of Cretaceous deposits in the Yola branch. This study will be useful to (1) highlight the link between this basin and adjoins basins associated to the Benue Trough opening in several aspects, (2) improve the litho-bio-stratigraphic framework following the 2D and 3D models developed on the base of high resolution facies analysis according to proposed and (3) be used as a reference for correlation in furthers studies of the numerous basins considered to be analogues of contemporaneous formations linked to the Benue Trough.

2. Geological setting

The HSB is a semi-graben structure extending about 5 km North to South and 20 km East to West. This basin is a dissymmetrical syncline (Defretin and Boureau, 1952; Defretin, 1953; Roch, 1953; Koch, 1959; Schwoerer, 1965; Wakuti and Gall, 1969; Tillement, 1971; Popoff et al., 1983; Maurin and Guiraud, 1989, 1990), controlled by normal syn-sedimentary faults oriented N70 to N90. It is an offset structure of the eastern end of the Benue Trough (Yola Branch) (Popoff, 1988; Benkhelil et al., 1989) (Fig. 1b). The general direction of the sedimentary layers is East-West, except at the level of the periclinal endings. The different North-South mapping (Fig. 1c) profiles carried out in the basin reveals particular structural or morphological characteristics: either a monoclinal structure limited by a fault in the South, or a synclinal structure. In the first case, the rock layers have a normal to slightly discordant bed contact with the basement rock in the northern part. In the South, they are in faulted contact with the latter and the deposits lie directly against the granitic massifs of Goutchoumi following a normal

Fig. 2. Photographs illustrating the main facies recognized in the Hama-koussou, **(a) -** Granitic basement rock cross cut in the main directions N45°E to N130°E, **(b)** Dolerite dyke, **(c) -** Basalt showing an abundance of calcite specks,**(d)** - Volcanic rock, showing pillow lavas structure interbedded with shales and note the presence of dark calcined shale in the bottom of the volcanic rock testifying that this volcanism is syn-sedimentary, **(e) -** Conglomerate-grained massive sandstone, **(f)-** Normal fold N140°E 50 °SW, **(g) -** Facies association made by shale interbedded with marlstone, **(h)** - Fine to medium grained sandstone interbedded with shales.

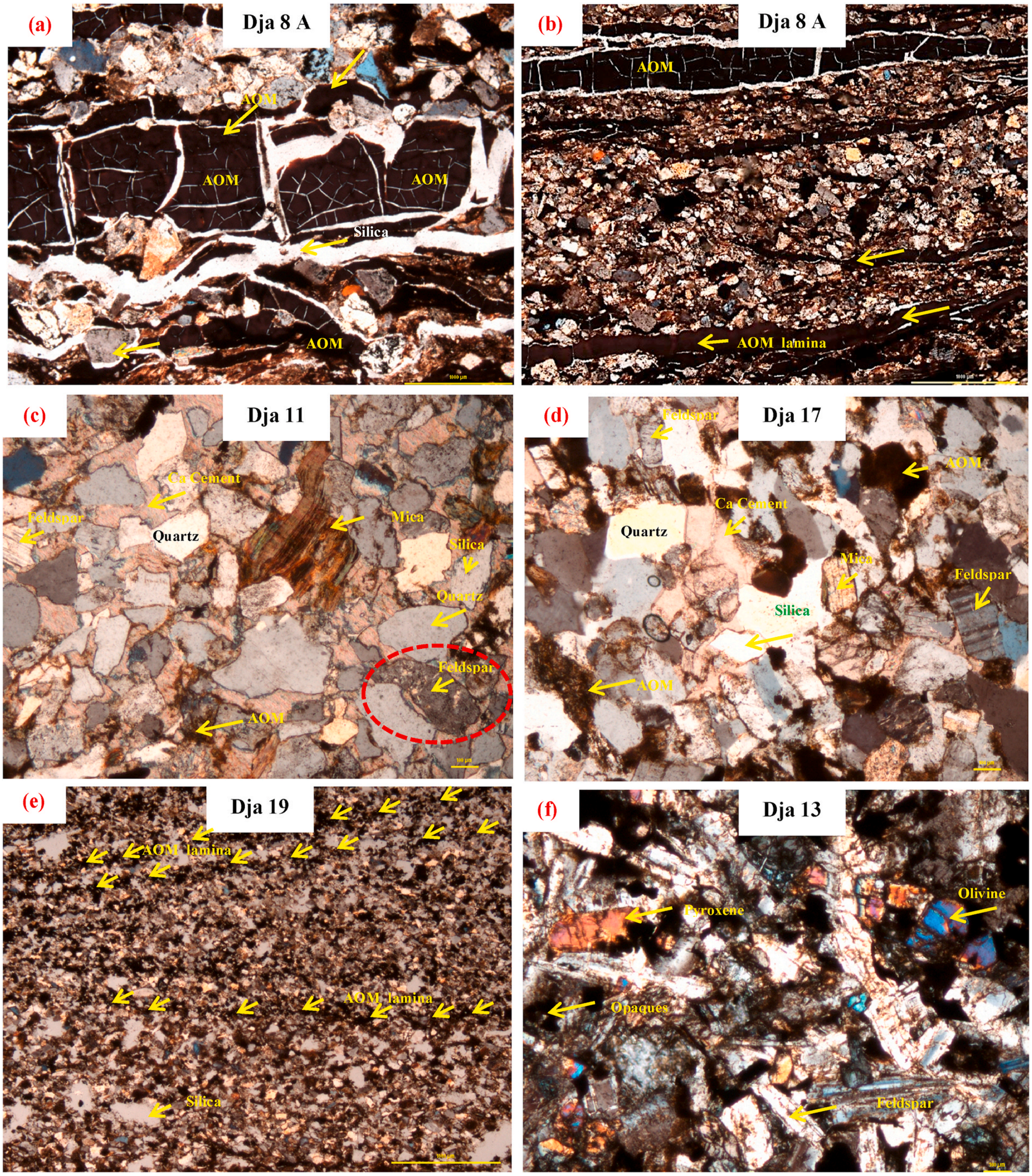


Fig. 3. Photomicrograph showing the mineralogical composition of the Hama-koussou sedimentary basin. **(a)** Representative photomicrograph showing AOM and coalparticle's composition and texture. **(b)** Other minerals identified include in a calcite cement and different types of feldspar; Mica, K-feldspar (KF) **(c)** Poikilotopic calcite cements replacing plagioclase feldspar. **(d)** Poikilotopic calcite and silica cements in a medium to coarse-grained sandstone. **(e)** Amorphous organic matter lamina in a fine grained sandstone, silica cemented. **(f)** Interbedded basalt in sandstone, volcanic structures are recognized by oriented and elongated feldspar.

fault marked by a clearly visible brecciation zone in the eastern part of the basin. The syncline structure appears clearly only in the eastern part of the basin (Fig. 1c) (Djallou, Ouro-Kessoum and You log sections). Its axis is faulted and sometimes injected longitudinally by a volcanite dyke, or by a granitic intrusion (Fig. 2b). The synclinal axis is discontinuous and shows a direction varying between N55 and N80. In the central and western parts of the basin, the southern flank of the syncline is absent. The escarpments, observed near the basin-basement contact, indicate the presence of particular structures clearly visible on the studied sections. These elevations correspond in the North to the topographic point of the edge of a resistant layer (ferruginous sandstone) plunging towards the south and culminating at a constant altitude of 500 m, and to the south, to a very fine and very fissured sandstone zone forming a succession of hills rising to 425 m above sea level. Flora consists of many pieces of silicified wood, described by Dupéron-Laudoueneix (1991), as being essentially homoxylated coniferophytes having blurred or no growth zones and whose degree of lignification has been assimilated to the *Dadoxylon* (*Araucarioxylon* and *Metapodocarpoxylon*). They may be representative of early Cretaceous age (Dupéron-Laudoueneix, 1991).

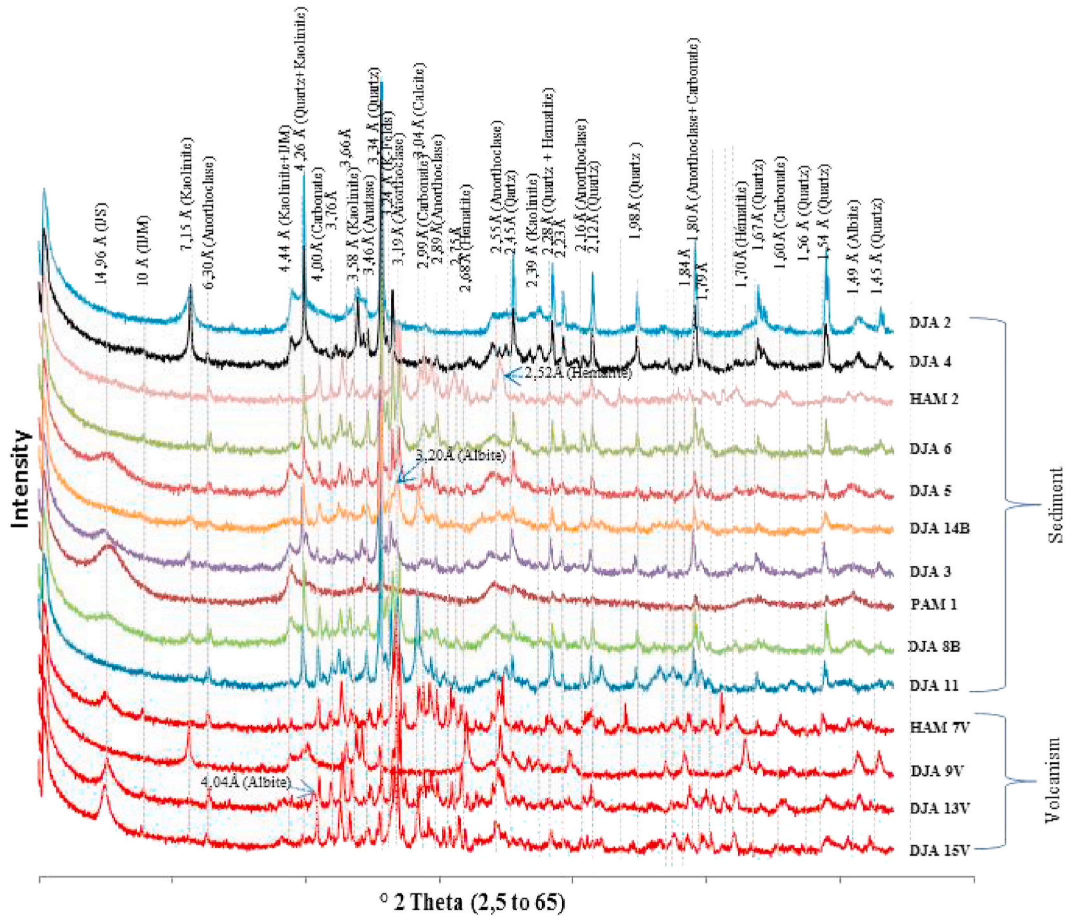


Fig. 4. X-Ray diffraction patterns of volcanic intercalation and sedimentary beds obtained in the range of 2.5–65 °2 théta.

Fauna consists of scales and skeletal fragments of actinopterygian fish of the *Lepidotes* type, remains of chelonians, crocodile and dinosaur bones and teeth fragments. Like the flora, this fauna suggests an early Cretaceous age (Flynn et al., 1987). A mammalian fauna including equines (*Equus E. Mauritanus*), *phacochoerus sp.* and *bovidae* (*Tragelaphini* indet.), whose ages are compatible with the Pleistocene (Flynn et al., 1987; Dejax and Brunet, 1996) is also present.

The black shales of Djallou North, host high amounts of coaly plant matter previously reported by Dejax and Brunet (1996). They include pteridophytes with only one fragment of leaf frond discovered and coniferophytes represented by *Pagiophyllum* and *Brachyphyllum*. The same assemblage also host microflora consisting of about 95% coniferophyte spores and pollens, represented by inaperturate grains of the typical African and South-American regions and indicative of early Cretaceous, precisely Neocomian to Barremian (Dejax and Brunet, 1996). A recent study clearly indicates the presence of a Cretaceous sedimentation highlighted by an association of palynomorphs, which must have continued in the Cenozoic (Bessong et al., 2018).

3. Materials and methods

3.1. Facies analysis

Five lithological sections were measured perpendicular to the direction of the layers and sampled in the basin from North to South (Fig. 1). Facies analysis was based on lithology, texture and grading, sedimentary structures, type of cement, and layout of rock layers. Detailed study of the sedimentological parameters, taking into account the lithology, sedimentary structures, fossil content and the organic matter led to the drawing of 5 lithostratigraphic sections using the Sedlog software (Fig. 5c).

3.1.1. Mineralogy and petrography

Mineral phase determination on pre-selected rock samples pertaining to different facies was made at the University of Lausanne in Switzerland following the procedure described by Klug and Alexander (1974), Kübler (1983) and Adatte et al. (1996), using an XTRA diffractometer, Thermo Scientific ARL; Energy, 45 kV, 40 Ma; CuKα 1 = 1.54060 Å; angle 2°–65° 2° Theta. Thin sections were made, studied and photographed at the University of Geneva in Switzerland using a Nikon microscope equipped with a Nikon camera using NS elements. Three hundred and thirteen samples were taken for mineralogical analysis and fifty samples were selected for the petrographic study according to the similarity of the mineralogical procession.

3.1.2. Biostratigraphy

Four samples (DJA8a and b, DJA17, DJA19) from the Djallou section were selected, representing both flanks of the Eastern syncline; the western part of the basin being monoclinal. Palynological slides were made at GeoTechniques Research Ltd., Sunbury Thames, UK, using standard techniques including the dissolution of carbonates and silica with hydrochloric acid HCl (32%) and Hydrogen fluoride HF (40%) (e.g. Wood et al., 1996). The samples were washed to remove contaminations, oven-dried for 3 h, then pulverized with a hydraulic press and passed over a 125 μm sieve. They were then oxidized in HNO_3 (60%) for 2 min to eliminate impurities like pyrite and to prepare the samples for microscopic observation. Palynostratigraphic zone were assigned to each sample using well documented taxa from the West, North and Central African basins. Sample number is followed by England Finder coordinates; all specimens are at

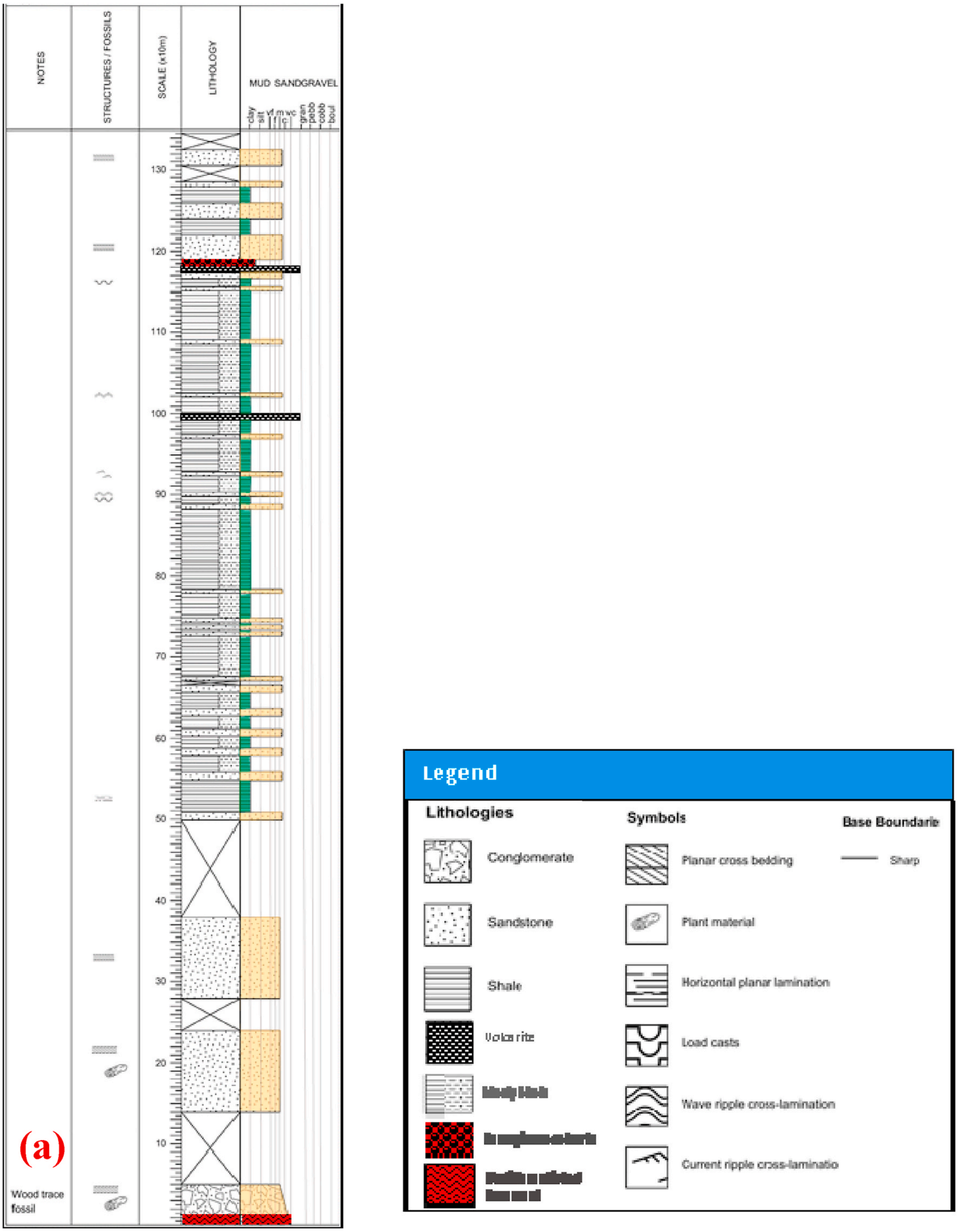


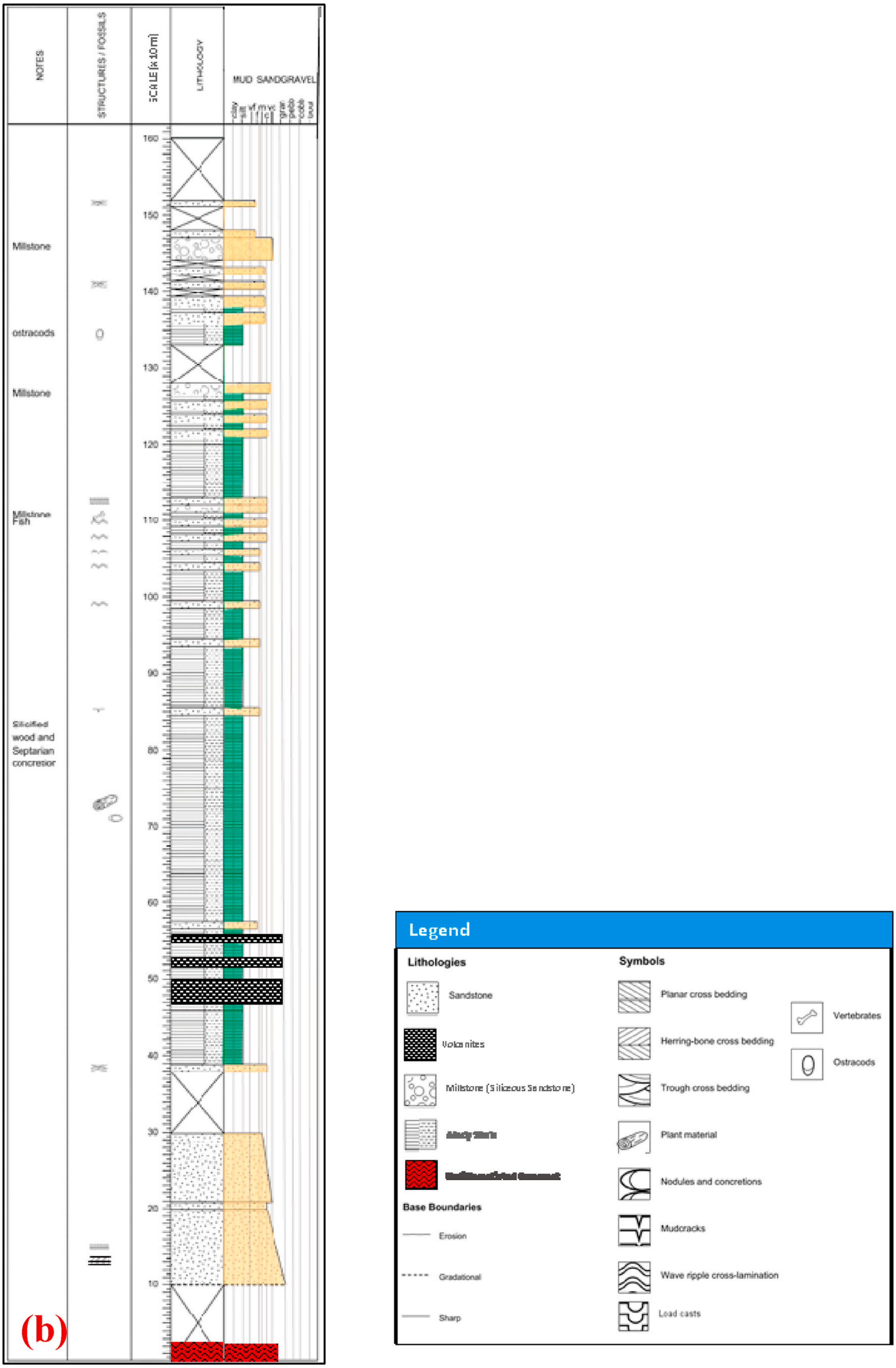
Fig. 5. Lithology of the Hama koussou sedimentary basin along the five cross sections (**a, b, c1** and **c2, d1** and **d2, e1**and **e2**) in the Western and Eastern part.

the same magnification; scale bar = 10 μm. A selection of palynomorphs is shown on Plate 1. The samples taken along the sections and slides studied were deposited at the Institute of Geological and Mining Research (I.R.G.M) in Cameroon.

4. Results

4.1. Facies analysis

The base of the HSB has an average thickness of 260 m. It is constituted from base to top of microconglomeratic to conglomeritic sandstones, followed by a layer of ferruginized quartzite sandstone intercalated by ferruginized shales and polygenic cuirass in the cover zone. The microconglomeratic to conglomeritic sandstones host



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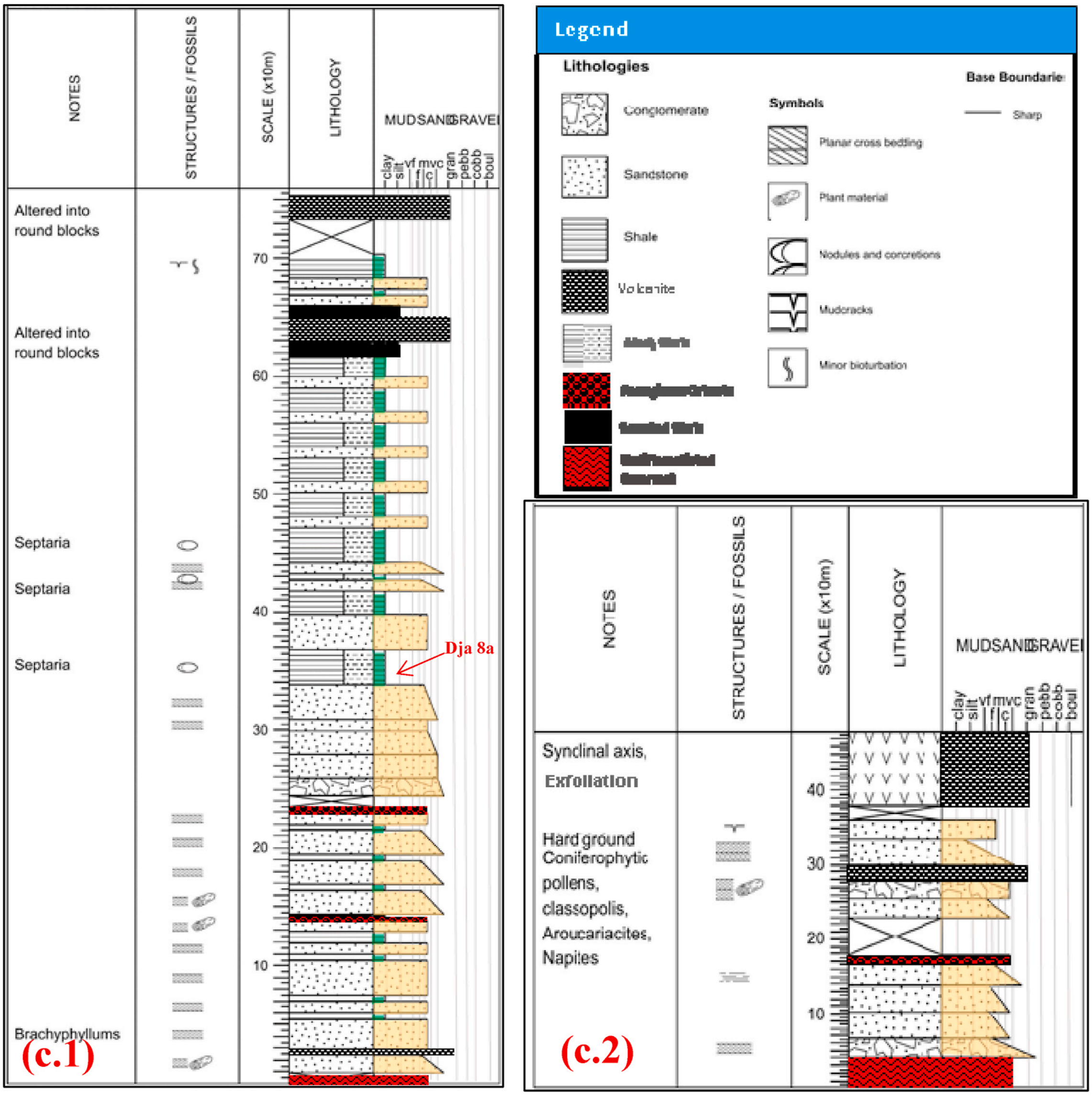

Fig. 5. (*continued*).

subangular basement (granite and quartzite) fragments within a coarse sand matrix which is highly pigmented by iron oxide. The sandstone layer is constituted essentially of medium to coarse grained quartz, trapped in ferruginous cement. It host highly indurated and ferruginized thin (<20 cm) fissile shale intercalations. The sequence is capped by an approximately 10 cm ferruginous cuirass made up of a mix of granitic, sandstone and volcanic blocks and hornfels with an alveolar structure. This section generally presents a reddish-brown coloration due the iron oxide being its main cementing material.Sub-horizontal to horizontal, oblique and trough cross stratifications, current ripples and annelids reptation (bioturbations) are the respective sedimentary structure and fossils commonly hosted on this section.

The central part of the sequence has an average thickness of 840 m and made up essentially of shally-marlstones or marly-shales intercalated by less than 50 cm siltstone to carbonaceous sandstones intervals. Shales are very indurated and fissile. Marslstones from lose to highly indurated tablets which once exposed to surface erosion develop Septaria. The interval is generally greenish to yellowish green in coloration. Siltstone and sandstone intercalations are highly indurated with carbonaceous (calcitic to dolomitic) cement, also forming thin slabs on which sedimentary structures such as flaser bedding, current ripples, and mudcracks can be seen. This assemblage has been affected by fissure volcanism (basalt) with volcanic sills and dykes intrusions (dolerite), resulting in contact metamorphism that sometimes led to the formation of hornfels. These volcanites (mainly basalts) are characterized by the presence of vacuoles stretched in a preferred direction (N90), which sometimes host calcite as secondary mineralization,. They also show characteristic ball structures (pillow lava) due to exfoliation. Numerous sedimentary structures such as horizontal to sub-horizontal stratification, oblique, trough and hummocky cross stratification, slump, dessication cracks, current ripples and diagenetic loadcasts are present.

The uppermost sequence is whitish grey in coloration with an average thickness of 352 m and made up essentially of sandstone with shalley-marsltone or marly-shales intercalations. The sandstone is medium to coarse grained, hosting mainly quartz, feldspars and occasionally garnets and mudclasts. It is cemented by carbonates at its base and siliceous carbonates at its summit. It occurs generally as continuous beds that are sometimes lenticular. The intercalations which are more or less thick are made of shales, shaley-marls or marly-shales hosting septaria and carbonates. These intervals are generally lenticular, greenish with some brownish bands, highly indurated and constitute the site where ostracods described by Colin et al. (1992) were identified. Horizontal stratification, oblique, trough and hummocky cross stratifications, lenticular structures and mudclasts are the dominant sedimentary

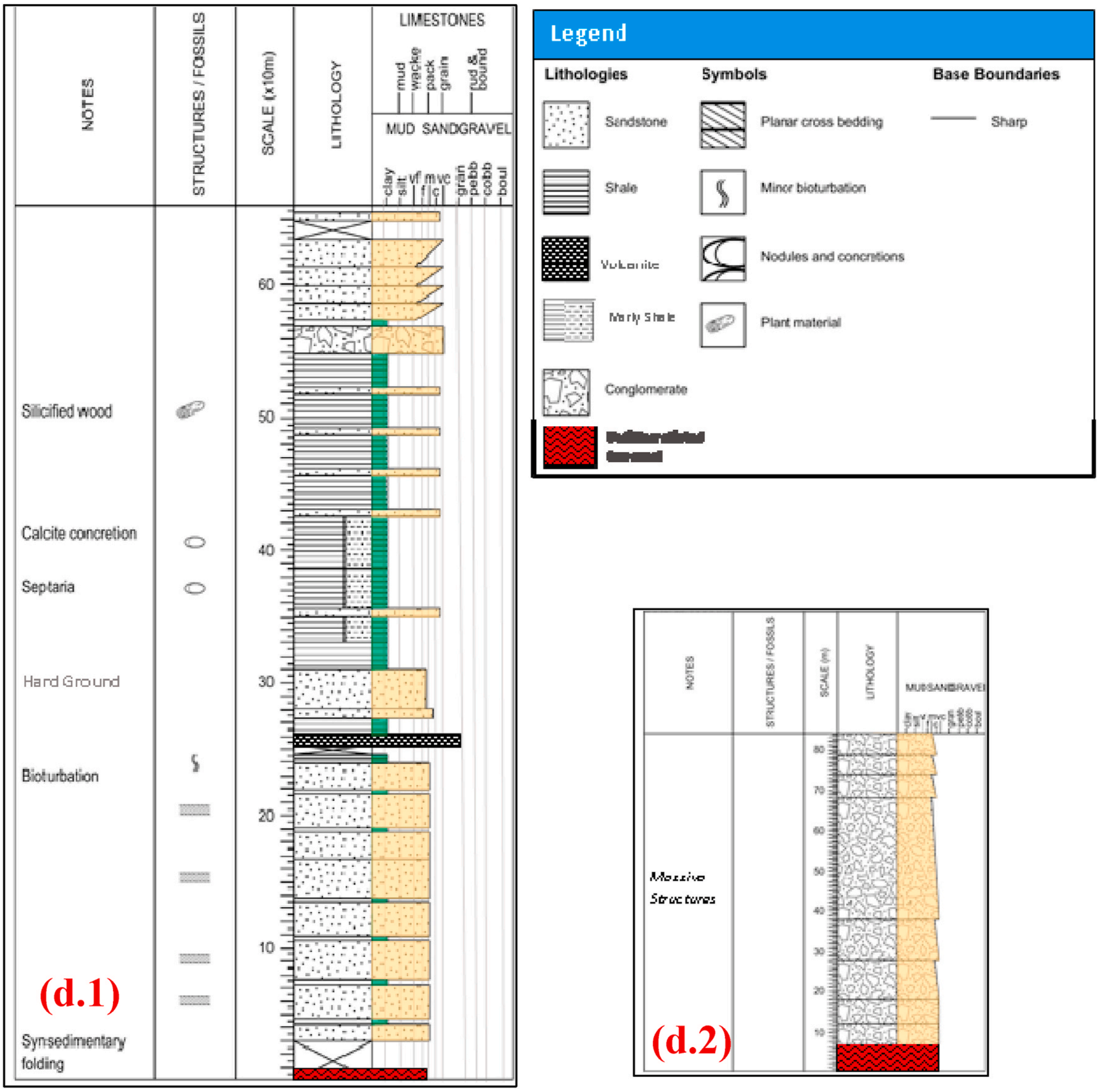

Fig. 5. (*continued*).

structures encountered here.

Two (2) composite lithostratigraphic columns developed from the studied log sections made it possible to define three main depositional units from bottom to top (Fig. 6a and b):

A Basal fluvial system, at the bottom of the section with an average thickness of 260 m, ranging from 180 to about 340 m made up of micro-conglomeratic and/or conglomeratic sandstones, followed by a sequence of more or less ferruginous and cuirassed quartz sandstones (polygenic cuirass). The micro-conglomeritic to conglomeritic layers have mainly coarse sandstone matrix strongly colored by iron oxides (Figs. 2e and 4).

The sandstone intervals consist of medium to coarse quartz with calcite/ferruginous cements and clay matrix (Figs. 2h and 3c and d) interbedded by clay layers (<20 cm) which are very indurated and flaking in platelets. Rusty in color, these shales are strongly ferruginous. Sedimentary structures include planar, oblique (N110E. 10N), crossed, sub-horizontal and horizontal stratifications, ripple marks and bioturbation.

A Middle Fluvio-Lacustrine, with an average thickness of 840 m ranging, from 780 to 900 m, it is made up essentially of clayey-marlstones to marly claystones (Fig. 2g) with intercalations of silt to sandstone (carbonate sandstone) beds of thickness generally not exceeding 50 cm (Fig. 2h). Overall, these rocks are greenish to greenish yellow. The claystone is sometimes highly indurated and cross cut. The marls are either unconsolidated or consolidated, forming tablets in the latter case which, subject to erosion, including multiform structures called Septaria. The Siltstone and/or sandstone beds are highly indurated and cemented by calcitic carbonate with remarkable sedimentary structures such as flaser bedding, and ripple marks. This assemblage is the site of fissural volcanism, including sills and ball-shaped volcanic dykes (Fig. 3f) that induced thermo-metamorphism along the lower walls of the vent with occasional formation of hornfels (Fig. 2d). These volcanoes (mainly dolerites) are characterized by the presence of vacuoles (degassing voids during the cooling of the magma, or tension slits), stretching in a main direction (N90), sometimes making up the seat of secondary mineralization, especially carbonated (calcite) but also pyrite (Fig. 2c and g), and exfoliated in balls (onion peels, Fig. 2b). Numerous sedimentary structures essentially localized at the level of the silty and/or sandstone intervals (Fig. 2h) including oblique, horizontal, cross and trough stratifications, hydrodynamic figures (undulations of beds of greater or less amplitude and wavelength acquired during sedimentation), desiccation cracks, ripple marks and diagenetic loadcasts are present.

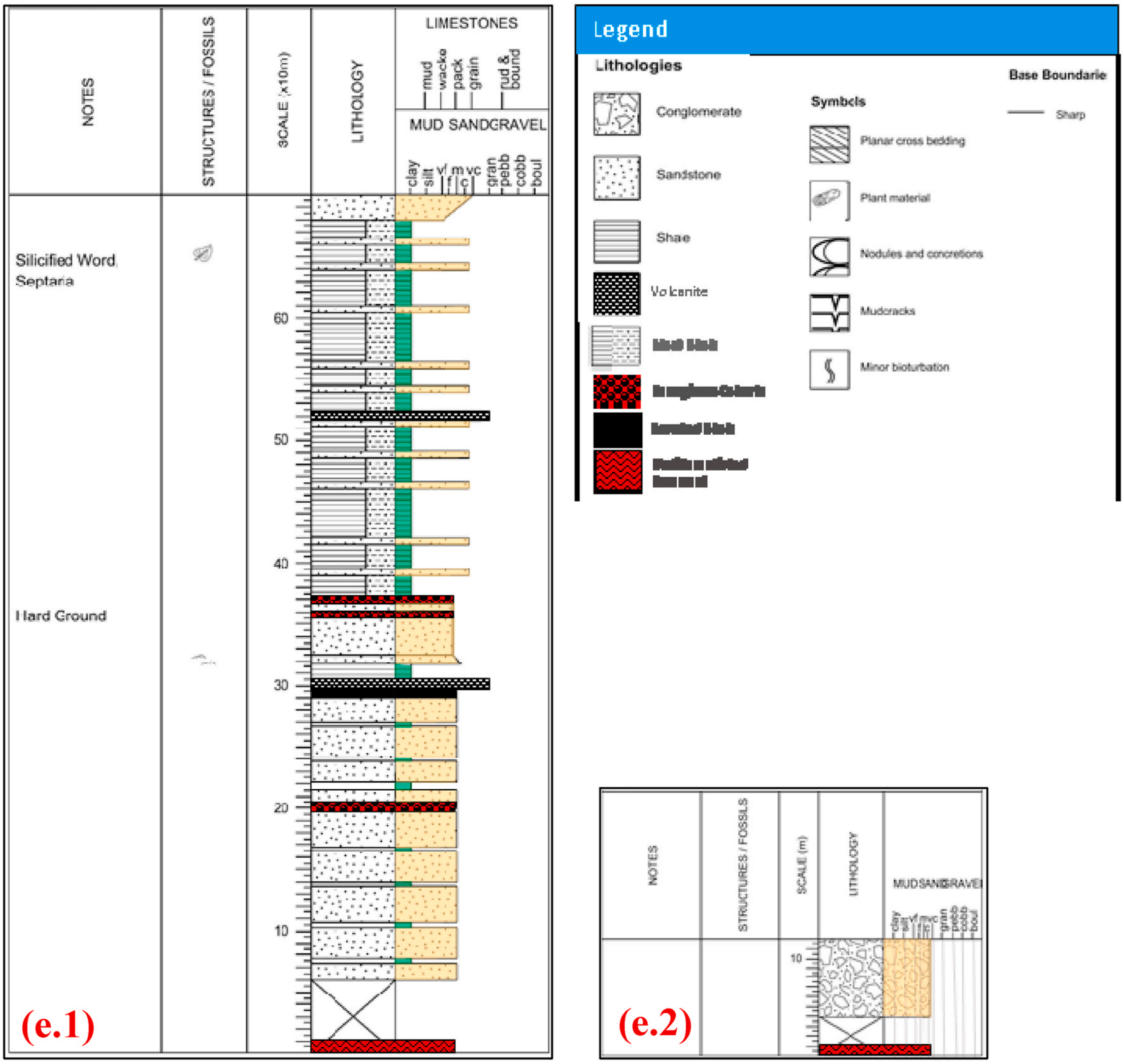

Fig. 5. (*continued*).

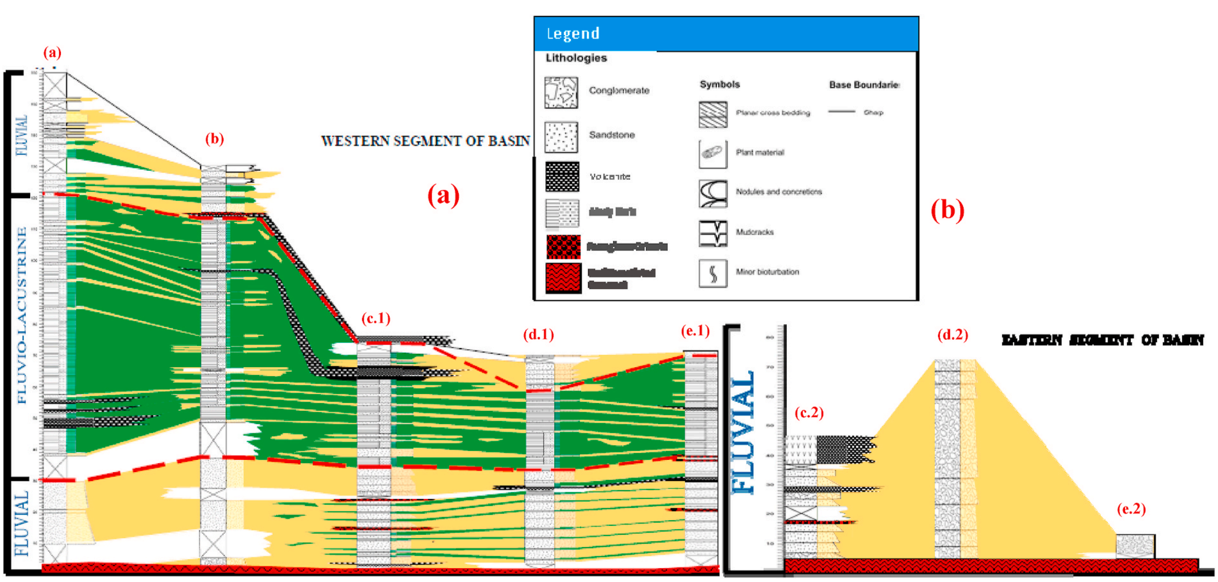

Fig. 6. 2D stratigraphic correlation in the Hama-koussou sedimentary Basin: **(a)** Western part and **(b)** Eastern part of the Hama-koussou sedimentary basin.

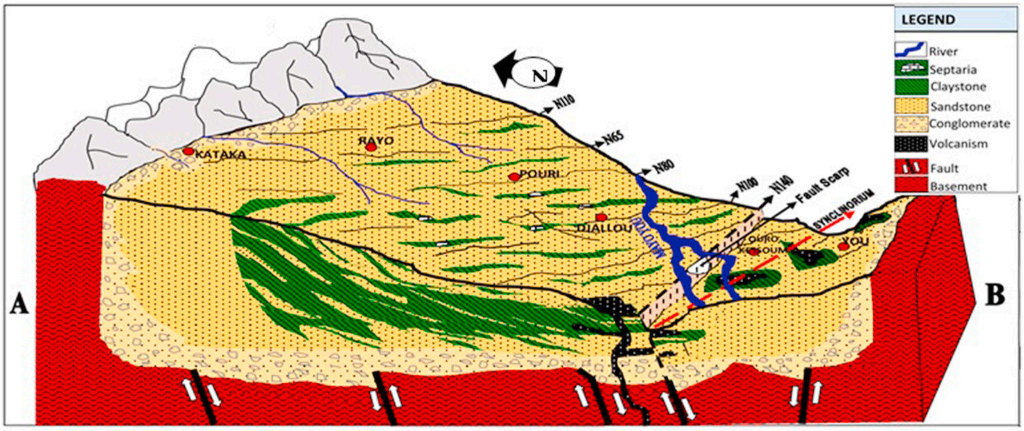

Fig. 7. 3D model of sedimentation in the Hama-koussou sedimentary Basin.

An Upper fluvial system, having an average thickness of 352 m, ranging from 195 to 510 m and made up essentially of pale grey sandstone with clayey marlstone and/or marly claystone intercalations (Fig. 2g). The sandstones here are medium to coarse grained, consisting essentially of quartz and feldspars (Figs. 3 and 4), with the cement being carbonate at the base and siliceous/carbonate at the top (Fig. 3c and d). They occur generally as continuous and sometimes lenticular beds (Fig. 2h). Intercalations are more or less thick, consisting essentially of clays, marly claystone and/or clayey-marlstones (occasionally hosting septaria) and carbonates. These intervals are lenticular, often highly indurated and constitute the ostracode site described by Colin et al. (1992). There is also the presence of two millstone levels. Sedimentary structures encountered here include horizontal, oblique, cross and trough cross stratifications, lenticular structures and soft pebbles. This part of the depositional sequence is strongly imprinted by a double fracture with general directions varying between N90 and N140.

4.2. Biostratigraphy

Rich and varied assemblages of palaeontological materials are hosted in the central part of the basin. Overall, only wood trace fossils were found on the surface of the beds. The fluvial system is characterized by a high concentration of silicified wood with fragments of trunks about 50 cm in diameter, similar to those described in the fluvio-lacustrine system and by a population of ostracods found in a marlstone interval (indurated grey-green marlstone) and described by Colin et al. (1992).

One sample (DJA8a) yielded some palynological residue with palynomorphs allowing for dating. The palynofacies consists mainly of amorphous organic matter (Fig. 3a, b & e), brown translucent phytoclasts and common pollen and spores. Palynomorphs (Plate 1) are composed of gymnosperm pollen (*Araucariacites australis, Callialasporites microvelatus, Callialasporites dampieri, Callialasporites* spp., *Exesipollenites* spp., *Eucommiidites* spp., and *Classopollis* spp.) and a few trilete spores. Angiosperm pollen is not recorded (Bessong et al., 2018). The palynofacies retrieved from other samples (DJA17 and DJA19) are dominated by light brown amorphous organic matter (AOM), translucent and opaque phytoclasts and fungal remains (*Rhizophagites)*. These samples are barren of pollen and spores. No age can be assigned.

4.3. Discussion

4.3.1. Facies analysis

- **Lithology and Structure**

The general direction of the fault varies from N80-90, to N140-150, then to N10-20, respectively, giving the southern margin of the basin an irregular configuration. In the second case, a very dissymmetrical synclinal structure with a much reduced southern flank is observed. This structure appears clearly only in the eastern part of the basin. The West-East elongation observed in the HSB is the same in the Mayo-Oulo-Lere and Babouri Figuil basins can be interpreted as the result of the same tectonic event linked to the opening of the Atlantic Ocean. Plutonism is characterized by intrusive granite in the sedimentary sequence that caused metamorphism contact of the cliffs. This plutonism is contemporaneous with the Cenozoic and correlates with the Mboutou and Koukoumi massifs. It is therefore syn and post-sedimentary (Cretaceous sedimentation). Sedimentary structures including oblique, crossed, horizontal and sub-horizontal stratification, ripple marks and bioturbation are present (Fig. 5a) reflects deposition in a fluvial environment, with variable hydrodynamism, often under shallow water.

This fluvio-lacustrine system, presents alternating layers of sandstone and claystone (Fig. 7). It seems to have been deposited in a medium subject to more varied hydrodynamic conditions, sometimes under low energy (deposition of claystone). The environment, was periodically confined, but remained generally open.

- **Biostratigraphy**

Indeed, the associated faunal assemblage (Lepidotes, crocodiles and dinosaurs) suggests the existence of a shallow lacustrine to lagoonal-lacustrine setting, *Classopollis* spp. clearly indicates an age not younger than Cenomanian. In Cameroon Salard-Cheboldaeff (1990) reported *Classopollis* spp. to occur from the Barremian to Cenomanian, the association of *Callialasporites dampieri* (as *Applanopsis dampieri* in Salard-Cheboldaeff, 1990), *Classopollis* spp., *Eucommiidites* spp. and *Araucariacites australis* in the African basins indicates an Aptian to Cenomanian age. Taking into account previous findings in Cameroon only, the association of these taxa would indicate an Aptian age. The absence of any angiosperm pollen in the sample fits with an Early Cretaceous age, where angiosperm pollen is still very rare (Bessong et al., 2018). Base on this assemblage, the sample can be dated Cretaceous in age, and not younger than Cenomanian, probably Early Cretaceous, possibly Aptian. If the bisaccate pollen grains are in place, the age is Pliocene or younger. Actually, this assemblage hosts new forms compared to what has been previously reported in this region (Dejax and Brunet, 1996). These include the remains of ginkgophytes (leaves) and *Sergipea naviformis* spores. The presence of ginkgophytes indicates a palaeoclimate clearly different from that prevailing in the other part of the basin, involving a particular ecological niche where these plants thrived under a probably more contrasted mildly hot and wet microclimate (Dejax and Brunet, 1996). The *Sergipea naviformis* taxon is also rare in palynological associations of African basins. However, the flora of this area remains largely compatible with a hot and dry

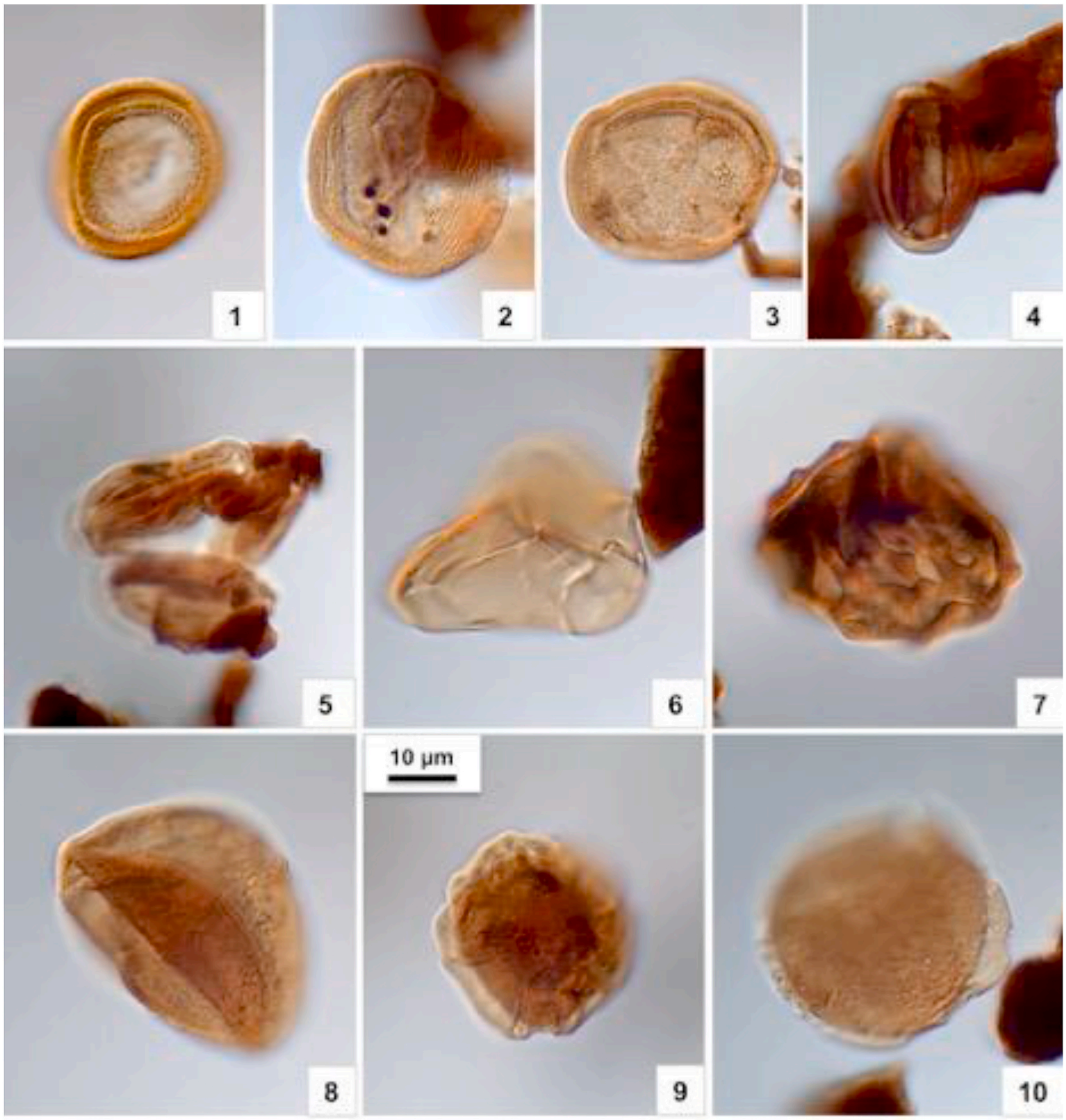

Plate 1. Selection of palynomorphs (pollen and spores) from sample DJA 8a from the Hama-koussou Sedimentary Basin dated Cretaceous. Sample number is followed by England Finder coordinates; all specimens are at the same magnification; scale bar = 10 µm.
1.*Classopollis* sp. Slide DJA 8a, U30.
2.*Classopollis* sp.Slide DJA 8a, N31.
3.*Classopollis* sp.Slide DJA 8a, D35/3–4.
4.*Eucommiidites* sp., Slide DJA 8a, P20.
5.*Eucommiidites* sp., Slide DJA 8a, R11.
6.*Concavisporites* sp., Slide DJA 8a, H28.
7.*Cicatricosisporites* sp., Slide DJA 8a, Z37/1.
8.*Araucariacites australis* (Cookson, 1947) Couper 1953. Slide DJA 8a, Q35/2.
9.*Callialasporites dampieri* (Balme, 1957) Sukh Dev 1961. Slide DJA 8a, W21.
10.*Callialasporites microvelatus* Schulz 1966. Slide DJA 8a, N39/1-2

climate consistent with what is known in another part of the basin. The depositional model therefore corresponds to a sedimentation in an environment alternately from high (sand deposit) to low energy (clay and sand deposits) followed by a strong energy which covers the series by sand. There were, however, some areas of particular microclimate (less warm and rather humid) that allowed the development of particular species such as ginkgophytes and mother plants of *Sergipea naviformis* found in these deposits.

- **Palaeoenvironments**

Indeed, the presence of sandstones with oblique and cross stratifications testifies to sedimentation in a stirred medium, in fluviatile type shallow waters. The absence of desiccation cracks and septaria on the surface of sandstone and clayey marlstone beds indicate that the environment, although was shallow, but did not totally dried out. This interpretation is confirmed by the presence in the assemblage of some ostracods that could live only in a lacustrine environment (Colin et al., 1992). This is the case of Cytheracea, a super-family of which Theriosynoecum is the dominant genus here, which could not stand the complete drying of its biotope. This genus recorded in this study shows a very important structural polymorphism ranging from reticulated forms (rare) to totally smooth forms (clearly dominant) indicative of a certain seasonality. According to Dupéron Laudoueneix (1991), the silicified woods found in this assemblage (Metapodocarpoxylon, Brachyoxylon, Protopodocarpoxylon and Dadoxylon) are fossils of trees that grew around a lake. Metapodocarpoxylon libbanotium (lack of growth zones, which implies a regular water supply). Protodocarpoxylon and Brachyoxylon (presence of narrow tangential strips of final wood irregularly spaced), grew a little further from the banks, while *Dadoxylon,* generally grew in the vicinity of the lake (absence or presence of areas growth). Periods of sub-aerial exposure of varying duration in a hot and dry climate led to the formation of the cuirassed layers. Indeed, the fossil flora found here (Figs. 1c–3) and related to the *Cheirolepidaceae* family (Dejax and Brunet, 1996) is similar to that of the two closest basins, namely Mayo Oulo-Léré and Babouri-Figuil (Boureau, 1953; Brunet et al., 1988; Dupéron-Laudoueneix, 1991). The depositional environment was fluvio-lacustrine with a periodic regime and an overall warm and dry climate as evidenced by the presence of cuirassed intervals (Fig. 6).

5. Conclusions

The Hama-koussou Sedimentary Basin, one of the fault structures of the eastern end of the Benue Trough, experienced at least three (3) phases of sedimentation during its geological history.

- The first phase (Neocomian-Barremian?) occurred during a period of intense tectonic activity. It is characterized by the deposition of sandstone and an explosive volcanic activity which led to accumulation of tufaceous layers in the northern limit of the basin.
- The second phase (Barremian?) led to the deposition of sandstone and clay. It occurred during a period of tectonic calm as evidenced by its characteristic deposits (clay), in a fluvio-lacustrine environment dominated by a hot and dry climate which allowed brief periods of droughts of the lake (presence of mud cracks and septaria);
- The third phase (Albian to Pleistocene?) occurred during a period of resumption of tectonic activity. It is characterized by deposits in a fluvial environment, with hot and dry climate. There is a significant hiatus, no evidence of sedimentation having been recorded. In fact, it appears that most of the sedimentation in this basin occurred during the Cretaceous.

This basin is further affected by two magmatic phenomena: volcanism and plutonism. The volcanism observed here takes place in two phases:

An explosive (Neocomian to Barremian?) phase, occurring during the structuration of the basin and the onset of the first phase of sedimentation; an effusive phase shown by occurrence of sills and dykes of dolerites, basalts and/or trachytes with syn-sedimentary thermo-metamorphism of the cliffs which continues to the Cenozoic? These phase of intense and volcanic activity put in place river systems and also alluvial fan deposits opening into a lake via a river system.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We specifically thank Mr. Nolla Junior Désiré, a researcher at the Cameroon Institute of Geological and Mining Research, who died in 2017 for his friendly contribution during the field campaign. Dear friend and collaborator, you are acknowledged. We are grateful to the Federal Commission for Scholarships for Foreign Students FCS of Switzerland for providing the grant to support this work. The work benefitted from the collaboration of the Universities of Geneva and Lausanne in Switzerland, and the comments of Dr. Susanne Feist-Burkhardt in Germany. Financial and logistical support for field studies was providing by the Institute of Geological and Mining Research in Cameroon. Useful suggestions, careful and constructive comments of the editor and reviewers that have greatly improved the manuscript are acknowledged.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jafrearsci.2021.104256.

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