Available online at www.sciencedirect.com
SCIENCE DIRECT®

Journal of African Earth Sciences 43 (2005) 166–195

Journal of African Earth Sciences

www.elsevier.com/locate/jafrearsci

# Paleozoic basins in West Africa and the Mauritanide thrust belt

Michel Villeneuve

*FRE CNRS 2761, Université de Provence, Case 67, 3, Place Victor Hugo, 13331 Marseille cedex 03, France*

Received 10 December 2004; accepted 18 July 2005
Available online 3 November 2005

**Abstract**

The evolution of the Paleozoic basins of West Africa is strongly depending on the structuration of the different belts which are surrounding the West African Craton. We distinguish the "Taoudeni Basin" located in the center of the craton from the basins located on the West African Craton margin (Tindouf, Tamale and several troughs limiting the western side of the Taoudeni Basin). Other basins are located on top of the Pan-African or Hercynian belts (Bové, Kandi, Ouallen in Semmen and Diourbel basins) or on top of the Proterozoic shields (The Ghana basins). Some are evidenced underneath the Mesozoic–Cenozoic coastal basins (Bové and Ghana basins).

The sedimentation started with the Marinoan glacial event (620–580 Ma) and ended with the carbonates of the Early Carboniferous. The main tectonic or climatic events that occurred during this period are registered by the sediments. Among them are, the "Série pourprée glaciogenic deposits, the Pan-African II tectonic event (550–500 Ma) which affects the southwestern part of the Taoudeni Basin, the Late Ordovician glaciogenic event, the Early Silurian marine transgression, the Early Devonian marine regression and the Hercynian tectonic event (330–270 Ma) which affects the Paleozoic basins located on the western and northern parts of the West African Craton.

The second part of this paper is devoted to a synthetic review of the Mauritanides Belt which is extending from Southern Senegal to the Moroccan High Atlas. This belt includes both old Pan-African belts and Paleozoic sediments (belonging to the western part of the Bové, Taoudeni and Tindouf basins) tectonised and metamorphosed during the Hercynian orogen.

The third part points out the close relationships between the Paleozoic basins and the main tectonic event for the main periods of the West African Craton evolution.

*Keywords:* Paleozoic; West Africa; Basins; Mauritanide Belt; Paleogeography; Pan-African II orogen; Hercynian orogen

## 1. Introduction and structural setting

The West African Craton (Fig. 1) is surrounded by several upper Proterozoic and Paleozoic fold belts. Fold belts linked with the Trans-Saharan suture zone fringe the eastern margin of the West African Craton (CWA). This mobile zone can be traced from Benin to Morocco successively with the Dahomeyides, Hoggar–Iforas, Ougarta, and Anti-Atlas fold belts. These belts were folded and metamorphosed at around 600 Ma (Black et al., 1979; Caby et al., 1982).

The western margin is a polyphased mobile zone that can be traced from Liberia to Morocco. The Rokelides and Bassarides belts represent two distinct Pan-African events cross-cut northward by the Hercynian Mauritanides Belt.

The Archean (−2500 Ma) and Birrimian (2000–1700 Ma) basement of the West African Craton (Fig. 1) is mainly exposed along the Reguibat Shield (in the North) and on the Ivory Coast Shield (in the South). Smaller inliers also exist westwards of the craton, along the Bassarides and Mauritanides belts (Kenieba and Kayes inliers) and at the core of the Anti-Atlas belt.

The cratonic sedimentary cover is well represented in the huge Taoudeni Basin (which is centered on the less rigid portion) and in the Tindouf Basin (northern edge of the Reguibat Shield) and also in smaller basins outcropping along the borders. Among them, we can quote (Fig. 3):

---

*E-mail address:* mville@up.univ-mrs.fr

1464-343X/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jafrearsci.2005.07.012

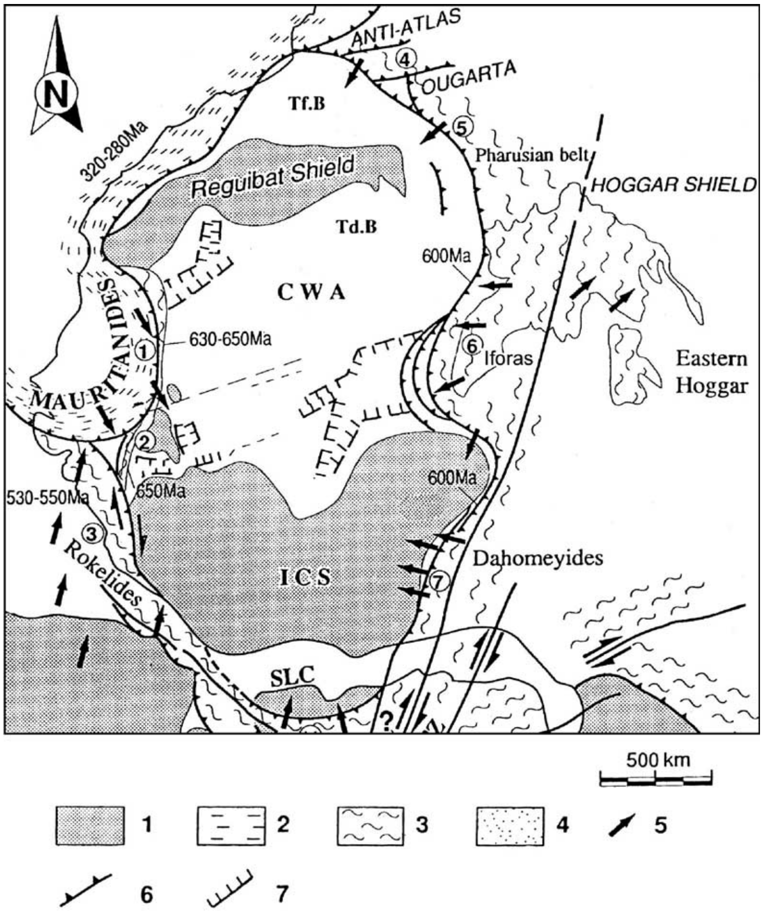

Fig. 1. *The main structural features of the West African Craton* (after Villeneuve and Cornée, 1994, modified). Encircled numbers: 1—Mauritanides Belt; 2—Bassarides Belt; 3—Rokelides Belt; 4—Anti-Atlas Belt; 5, 6 and 7—Trans-Saharan Belt. TfB = Tindouf Basin, Tdb. = Taoudeni Basin, CWA = West African Craton, ICS = Ivory Coast Shield. *Legend*: 1—Crystalline basement; 2—Main Hercynian Belts, 3—Pan-African Belts, 4—Foreland basin, 5—Thrust directions, 6—Thrusts, 7—Basin boundaries.

- On the western side, the Bové Basin and the Faleme to Rokel-River troughs.
- On the eastern side, the Reggane Basin, the Hoggar basins, the Tamale Basin (Volta area), the Kandi Basin and The Ghana basins (including three separate basins). A late Paleozoic basin (the Diourbel Basin) concealed under the Mesozoic Senegalo–Mauritanian Basin, is evidenced from seismic and core-drill data.

Among these basins, only two are filled with Proterozoic and Paleozoic sediments (the Taoudeni and Volta basins) the others are filled mainly with Paleozoic sediments.

In the Taoudeni and Volta basins, the sedimentation started around 1000 Ma and lasted till the end of the Carboniferous (Fig. 2). The sedimentary pile (2000–3000 m thick on average) represents a thin peel over the basement owing to the size of the basin (mean diameter 1000–1500 km). These rocks are largely exposed on the borders of the basin, but are concealed in the center under a thin Mesozoic–Cenozoic cover. No substantial deepening of the central part of the basin occurs, but part of these flat laying, unmetamorphosed, sediments thicken in subsiding peripheral troughs, or sub-basins, and is laterally involved in the Pan-African or Hercynian belts.

Several tectonic events are affecting the deposition of the Proterozoic and Paleozoic cover and it clearly appears that the origin and deposition in the Taoudéni and peripheral basins were partly controlled by the geodynamic evolution of the surrounding fold belts.

Only two tectonic events were involved in the structuration of the Paleozoic basins: the Pan-African II tectonic event linked to the Rokelide fold belt (Villeneuve and Cornée, 1994) in the southwestern part of the West African Craton (550–500 Ma) and the Hercynian Mauritanide fold belt which outcrops on the western side, from Senegal to Morocco.

But, unfortunately, no specific tectonic or climatic event is separating the Proterozoic from the Paleozoic in West Africa. So, the limit between them is highly debated due to the lack of fossils and to the small amount of radiometric datations. However, an expensive disconformity is mentioned between the basal Proterozoic sequence (Super-Group 1) and the first occurrences of Cambrian microfossils. We use this disconformity as the base of the Paleozoic basins in West Africa.

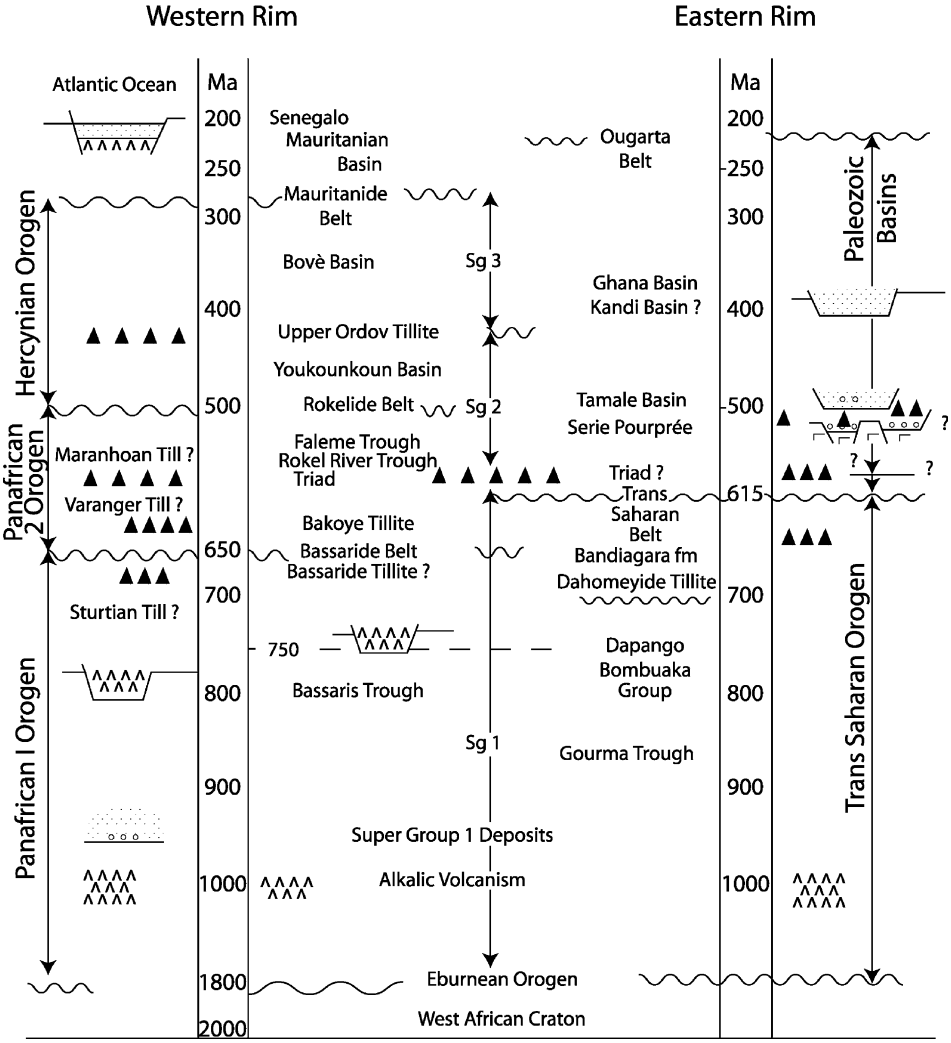

Fig. 2. *Diagram of the main geological events in West Africa. Legend*: 1—Tillitic formation, 2—Volcanic formation, 3—Coarse-clastic formation, 4—Basal conglomerates.

Fig. 2 points out this great disconformity previously to the deposition of the "Triad"(Deynoux, 1980) which is an assemblage of illites, carbonates and pelites dated between 600 and 530 Ma. On the western part there is an erosional unconformity associated with a low angular unconformity but, on the eastern part, the Triad may be younger than the Trans-Saharan fold belt. The genuine age of these deposits is firmly debated because the shales associated with the glacial level has been dated at 630 and 595 Ma by Clauer (1976) and Clauer and Deynoux (1987). But on the eastern part, Bertrand-Sarfati et al. (1995, 1997) gave an age between 556 and 519 Ma. Moreover, the microfossils from the cap carbonates in the Senegalese Triad provide a lower Cambrian age (Culver et al., 1988; Culver and Hunt, 1991). Although the age of deposition is uncertain, this "Triad" is considered, by most of the authors, as the basal level of the Paleozoic cover in spite of the 545–540 Ma age limit between the Vendian and the Cambrian, proposed by the International Committee on Stratigraphy. In the Taoudeni Basin it is located at the base of the Super-Group 2 which is unconformably covering the Super-Group 1 considered as fully included in the Proterozoic cover.

A second erosional disconformity capped by glacial deposits occurred at the end of the Ordovician. This unconformity is separating the Super-Group 2 and the Super-Group 3 in the northwestern part of the Taoudeni Basin (Trompette, 1973).

The upper part of the Paleozoic basins is not uniform. In the western part the last deposits are Devonian, while in the Tindouf Basin they are Middle Carboniferous, and in the eastern part they are Lower Permian, just before the Ougarta tectonic event took place.

Finally, it appears that the limits between the main sedimentary units are of climatic origin in the central Taoudeni Basin and of tectonic origin in the boarder basins.

The main geologic events of the West African Craton are summarized in Fig. 2.

## 2. The Paleozoic basins

### 2.1. The Taoudeni Basin

Firstly, this name was assigned to a tiny basin located in the northeastern part of the syneclise, around the village of Taoudeni, in the Hank Basin (Villemur, 1967). Later on, the whole central depression which extends over 2,000,000 km$^2$ was called the "Taoudeni Basin". Villeneuve and Cornée (1994) proposed the name of Hank basin for the initial Taoudeni Basin in order to prevent any confusion.

The large Taoudeni Basin has been divided into eight different sub-basins (Fig. 3) but only three sub-basins contain a large amount of Paloezoic sediments, namely, the Adrar Basin (NW), the Hodh Basin (central), and the Hank Basin (NE). According to the cross-section in Fig. 4, the Adrar and Hodh basins are separated by the "Khatt High" and the Hank Basin is separated from the Proterozoic failed aulacogen of Gourma (Hoffman, 1991)

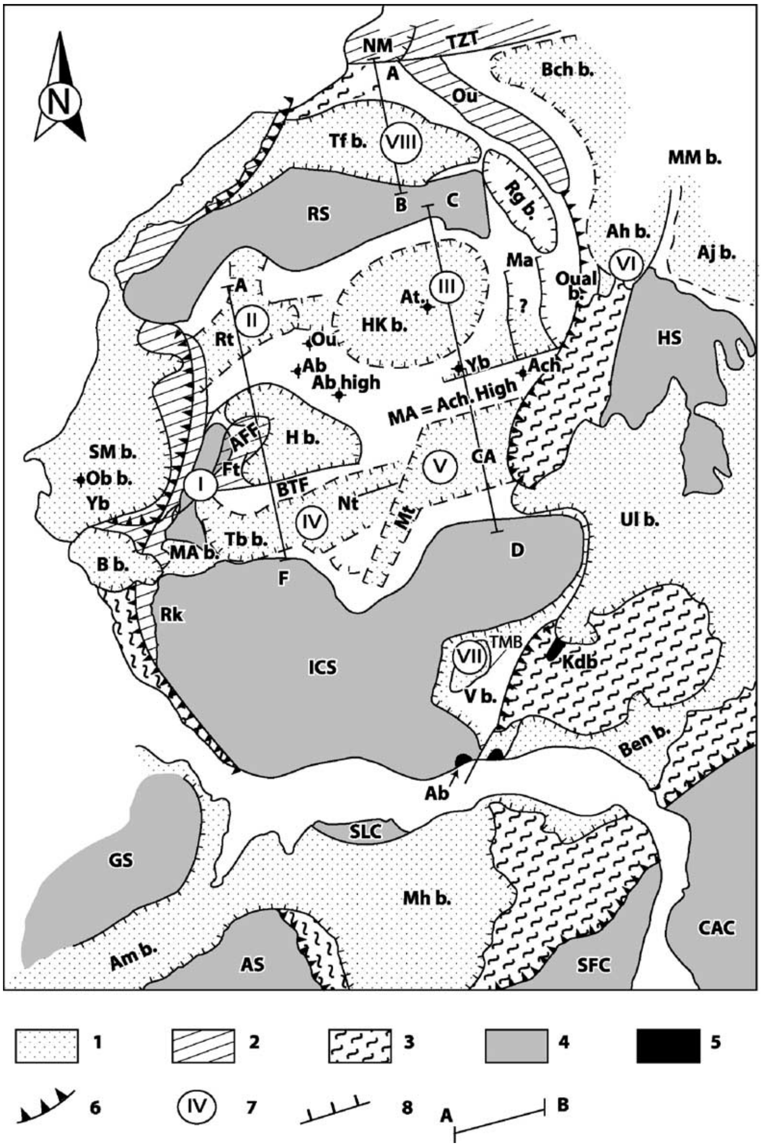

Fig. 3. *Structural sketch map of the West African basins* (after Villeneuve and Cornée, 1994, modified). TZT = Tizi n'Test fault zone, Ou = Ougarta belt, RS = Reguibat Shield, HS=Hoggar shield, ICS = Ivory Coast Shield, Bch.b = Bechar Basin, MM b. = Mac Mahon Basin, Ah b. = Ahnet Basin, Aj b. = Ajjer Basin, Ul b. = Iullimeden Basin, Ben b. = Benoué Basin, Gh b. = Ghana Basin, SM b. = Senegalo–Mauritanian Basin, Tf b. = Tindouf Basin, Rg b. = Reggane Basin, Hk b. = Hank Basin, A = Adrar Basin, Rt = Richat Trough, Hb = Hodh Basin, Ft = Faleme Trough, BTF = Bissau–Tombouctou fault, Tbb = Tambaoura Basin (or Bakoye Basin), Mab = Madina–Kouta Basin, Yb = Youkounkoun Basin, Bb = Bové Basin, Kdb = Kandi Basin, Rk = Rokelide Trough, Nt = Nara Trough, Mt = Mopti Trough, GA = Gourma Aulacogen, Vb = Volta Basin, Tmb = Tamale Basin, Ab = Ghana Basin, Oual.b = Ouallen in Semmen Basin, Amb = Amazonian Basin, Mhb = Maranhao Basin, Dbb = Diourbel Basin, Ma = Achkaikar High, Abo High = Abolag High, AFF = Affolé High, Abo = Abolag Well, Oua = Ouassou Well, Atu = Atouila Well, Yba = Yarba Well. *Legend*: 1—Sedimentary rocks, 2—Hercynian orogen and foreland of the Rokelide Belt, 3—Pan–African orogens, 4—Precambrian shields, 5—Thrusts and location of logs in Fig. 7, 6—limits of basins, AB—location of cross-sections of Fig. 4.

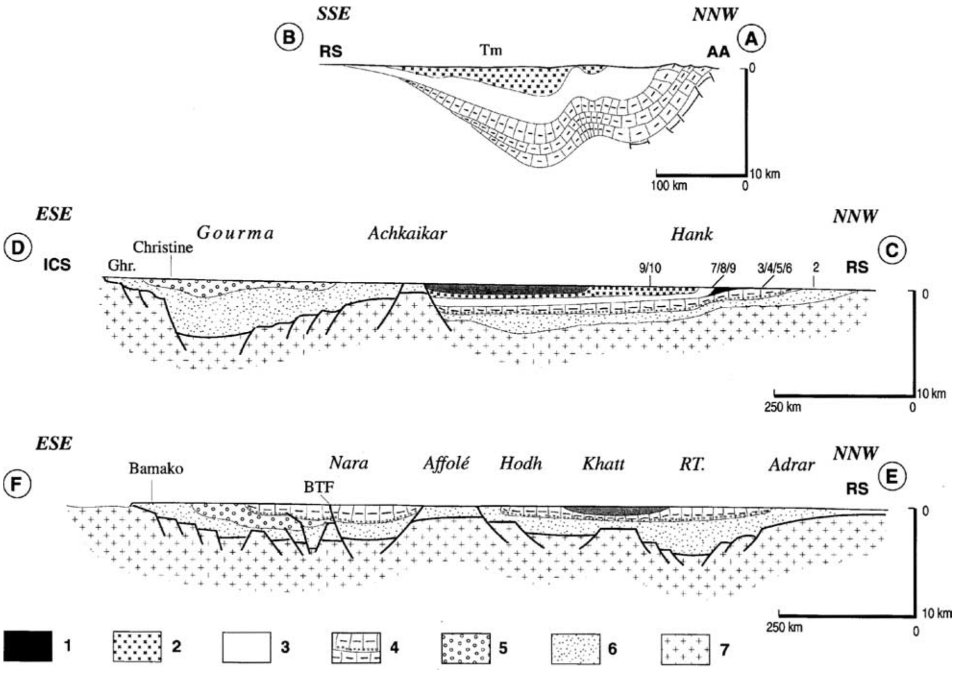

Fig. 4. *Geological N–S sections across the Tindouf and Taoudeni basins. Legend*: 1—Mesozoic–Cenozoic deposits, 2—Carboniferous deposits, 3—Silurian–Devonian deposits, 4—Late Neoproterozoic to Cambrian–Ordovician sediments, 5—Bakoye Group, 6—Late Proterozoic sediments, 7—Crystalline basement.

by the "Achkaikar High". The depth in these basins does not exceed 5–6 km. The tectonic activity along the main faults was very important during the Proterozoic times. Later on, these faults were reactivated in tectonic response to the surrounding tectonic stresses (Fig. 5).

### 2.1.1. The Adrar Basin

The cross-section in Fig. 6a shows a monocline structure gently dipping towards the South. According to Deynoux (1980) and Trompette (1973) these sedimentary formations have been divided into four super-groups separated by three main disconformities. The lithostratigraphic succession is shown in log IV (Fig. 7).

*Super-Group 1* belongs to the Proterozoic and consequently out of our topic.

*Super-Group 2* starts with glacial deposits resting with an erosional and angular unconformity on Super-Group 1 or directly on the basement. The glacial deposits are capped by a thin and discontinuous horizon of calcareous dolomites ("cap dolomites") in turn overlain by bedded cherts and green shales. This lithostratigraphic association (diamictites–dolomites–bedded cherts) known as "the Triad" has been used for long as a marker horizon (Zimmermann, 1960; Leprun and Trompette, 1969). They rest on a paleo-surface that resulted from a long erosional period following epirogenic uplift and tilting of the cratonic platform generally considered as related to the major Pan-African I tectonic event (Villeneuve and Dallmeyer, 1987). Although the Precambrian/Cambrian time line is not coincident with the unconformity between the Megasequence 1 and Megasequence 2, we consider this large unconformity as the base of the Paleozoic in the Taoudeni Basin.

The "cap dolomites" usually occur as a single persistent 3–5 m thick horizon, which rests unconformably on different terms of the glacial deposits or in places directly on the preglacial substrate. The 200–300 m thick marine green shales and siltstones of the Téniagouri Group rest in sharp contact on the cap dolomites. This group includes, in its lower part, bedded cherts and siliceous shales including occasional limestone horizons, thin layers of sponge debris, volcanic ash and phospharenites (Trompette, 1973; Bertrand-Sarfati et al., 1997). The green shales of the Téniagouri Group pass upward into 250–300 m thick shallow marine to lagoonal detrital deposits (Atar Cliff Group), red in color, hypersaline in character, deposited under warm and relatively dry climatic conditions (Trompette, 1973). The rest of the megasequence (Oujeft Plateaux Group) consists of 300 m thick fluvial cross-bedded sandstones unconformably overlain by 400 m thick transgressive shallow marine scolithus sandstones whose upper part provided inarticulate brachiopods suggesting an approximate age ranging from Late Cambrian to Early Ordovician (Legrand, 1969).

*Super-Group 3* includes, above an erosional and locally angular unconformity, Late Ordovician glacial deposits and post-glacial Silurian shales with graptolites.

*Super-Group 4* corresponds to the Devonian and Carboniferous deposits which rests unconformably on the Silurian shales or on the Ordovician glacial deposits.

Because the cratonic platform remained emerged since the Carboniferous, it is only sparsely covered by thin

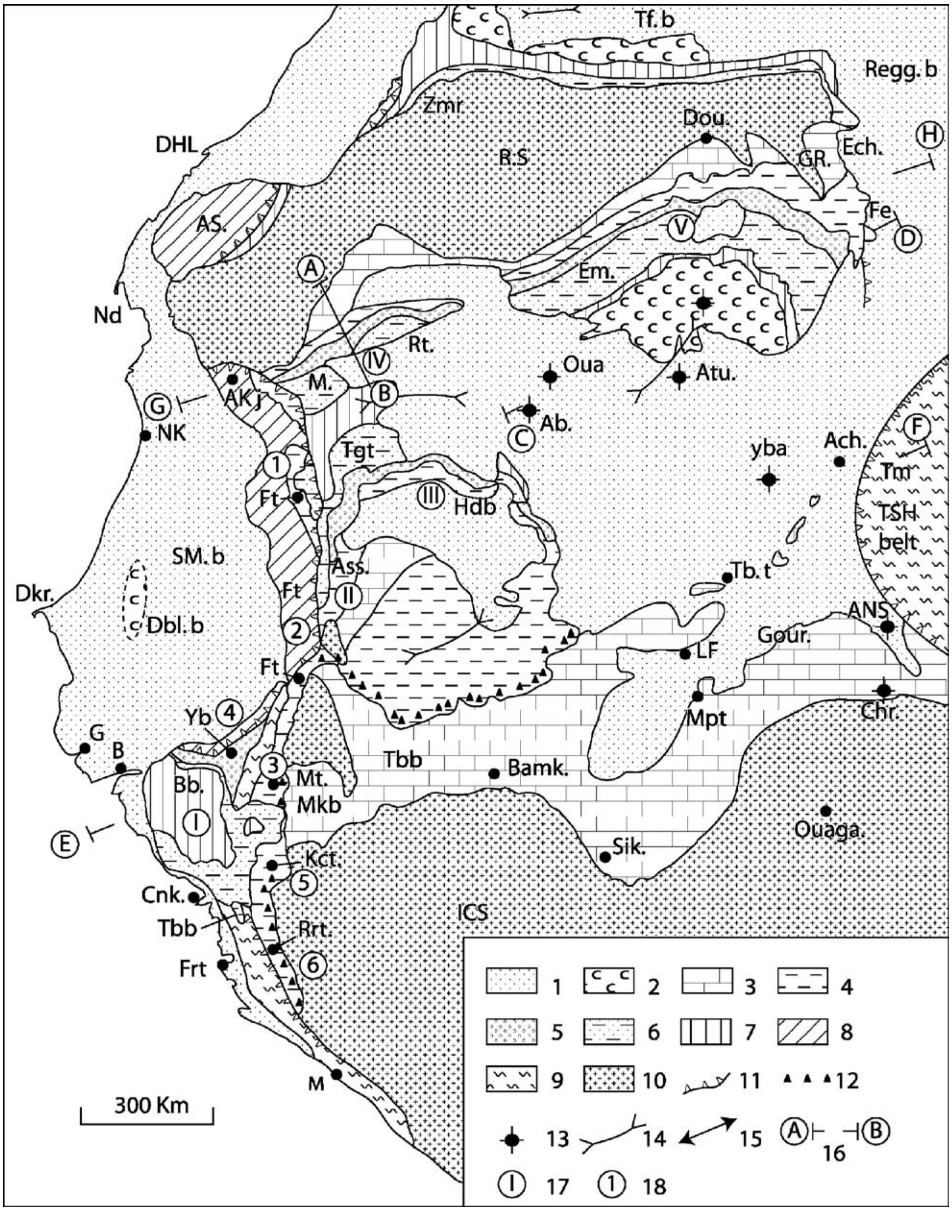

Fig. 5. *Geological sketch map of the Taoudeni Basin*. RS = Reguibat Shield, ICS = Ivory Coast Shield, Ki = Kedougou inlier, SM b. = Senegalo–Mauritanian Basin, Tf b. = Tindouf Basin, Regg b. = Reggane Basin, Hk b. = Hank Basin, Adr = Adrar Basin, Rt = Richat Trough, Hhb = Hodh Basin, Tgt = Tagant, Ass = Assaba, Ft = Faleme Trough, Tbb = Tambaoura Basin (or Bakoye Basin), Mkb = Madina–Kouta Basin, Yb = Youkounkoun Basin, Bb = Bové Basin, Dbl = Diourbel Basin, Kbt = Komba Trough, Klt = Kolente Trough, Rrt = Rokel-River Trough, Tbb = Taban Basin, Nt = Nara Trough, Tbt = Tombouctou Trough, TSHb = Trans-Saharan Belt, Tm = Timimoun, Ach = Achkaikar, Abo = Abolag Well, Oua = Ouassou Well, Atu = Atouila Well, Yba = Yarba Well, Zm = Zemmour, AS = Adrar Souttouf, Ech = Erg Chech, EM = El Mreiti, GR = Grizzim, Fe = Fersiga, Dhl = Dahkla, Akj = Akjoujt, Nd = Nouadhibou, NK = Nouakchott, DKR = Dakar, G = Gambia, B = Bissau, CNK = Conakry, FRT = Freetown, M = Monrovia, BMK = Bamako, SIK = Sikasso. *Legend*: 1—Mesozoic–Cenozoic sedimentary rocks, 2—Carboniferous deposits, 3—Late Proterozoic cover, 4—Eocambrian to lower Cambrian deposits, 5—Late Cambrian to Early Ordovician deposits, 6—Cambrian–Ordovician deposits, 7—Silurian–Devonian deposits, 8—Mauritanides Belt, 9—Bassarides and Rokelides belts, 10—Crystalline basement, 11—Thrusts, 12—Tillites, 13—Core drill, 14—Syncline, 15—Anticline, encircled "roman" numbers = stratigraphic logs in Fig. 7, encircled "arabic" numbers = stratigraphic logs in Fig. 9. AB and CD cross-sections in Fig. 6, EF = cross-section in Fig. 19.

Mesozoic–Cenozoic continental deposits including Quaternary dunes and lacustrine systems.

### 2.1.2. The Hank Basin (Fig. 6b)

This basin studied by Villemur (1967) exhibits a syncline structure according to the oil wells and a sequence stratigraphy more or less similar to that of the Adrar one (log V, Fig. 7). The green shales, on top of the glaciogenic level, give way to red pelitic deposits looking like the "Série pourprée" of the Hoggar area (Caby and Moussu, 1967). The Cambrian–Ordovician sequence is made with cross-bedded sandstones and scolithus sandstones. The Late Ordovician glacial sequence and the Silurian shales are very thin (100 m). The Devonian sequence is made of

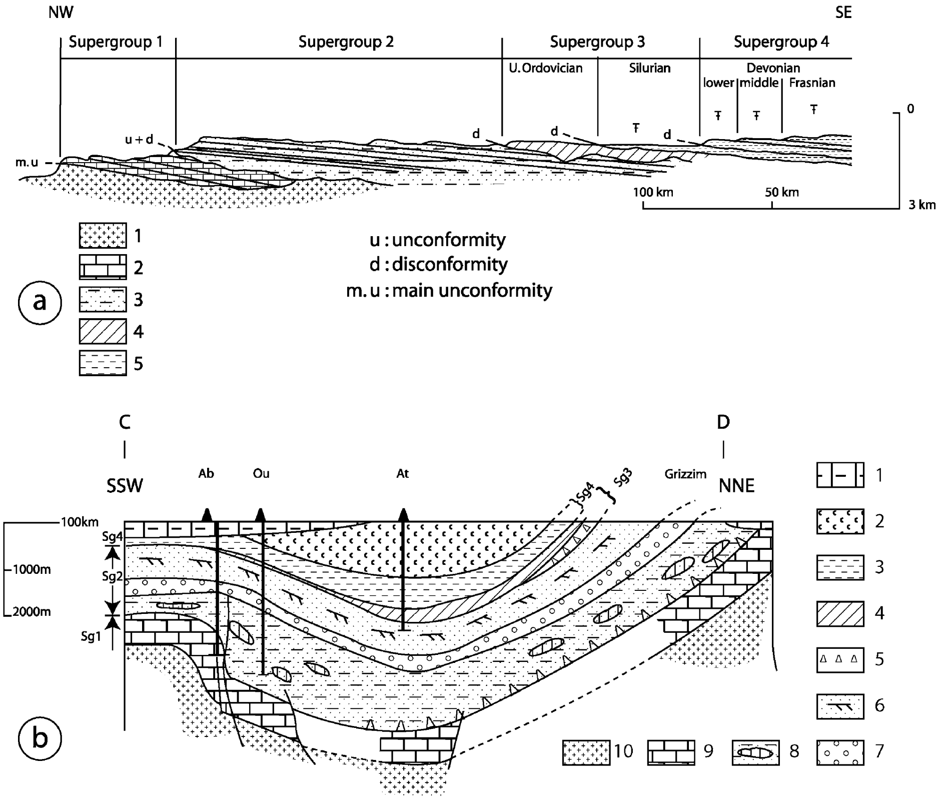

Fig. 6. *Geological cross-sections of the Adrar (a) and Hank (b) basins.* (a) *Adrar cross-section, modified from* Lécorché et al. (1989). (b) *Hank cross-section. Legend*: 1—Mesozoic–Cenozoic sedimentary rocks, 2—Carboniferous deposits, 3—Devonian deposits, 4—Late Ordovician and Silurian sediments, 5—Tillites, 6—Ordovician sandstones, 7—Late Cambrian–Early Ordovician. 8—Late Neoproterozoic–Middle Cambrian, 9—Late Proterozoic, 10—Crystalline basement.

shales and limestones. A lot of carbonate, evaporites and pelite of Carboniferous age (600 m) are completing the sequence.

### 2.1.3. *The Hodh–Nara Basin*

This basin studied by Marchand (1955), Bourguet (1966), Delpy (1967) and Deynoux (1980) shows a lithostratigraphic sequence very similar to that of the Adrar one (Fig. 7, log III). The difference is a red sequence with shales and dolomitic levels and a lack of scolithus in the Cambrian–Ordovician sandstones. The Late Ordovician glacial level (Tichit group) and the graptolitic shales of Silurian are well developed. On top, some woodstones of probably Cretaceous age, have been observed by Marchand (1955).

### 2.1.4. *The Assaba–Tagant Basin*

This basin separated from the Hodh Basin by the Affolé High, was studied by several geologists, among them Lepage (1983) and Lafrance (1996). The lithostratigraphic sequence (Fig. 7, log II) shows a very thick and complex basal sequence with several volcanic and glaciogenic levels associated with BIF (banded iron formations) expressing a marine volcanogenic environment. An erosional unconformity is evidenced inside the Cambrian–Ordovician sandstones. But the Silurian black shales are missing.

Fig. 7 presents the main stratigraphic correlation between the different parts of the Taoudeni Basin. The Bové Basin, presented later, is included in this figure. The main erosional disconformities are very useful to correlate the sequence stratigraphy columns. The basal sequence changes laterally. The green color turns red from the West to the East. The Cambrian–Ordovician scolithus sandstones are located to the North and to the West. A synthetic lithostratigraphic column of the Taoudeni Basin is shown in Fig. 8. Finally 14 unconformities, four supergroup and 14 groups ranging from the end of the Late Proterozoic to the end of the Carboniferous are identified.

## 2.2. *The Northern Tindouf Basin (Fig. 9)*

The Tindouf Basin forms an elongated WSW–ENE trending (800 km) asymmetrical trough (Fig. 4). Only the two flanks of the basin are exposed, the central part is concealed below the so-called Hamadian formations of Cretaceous, Tertiary and Quaternary age (Fig. 9a). Its gently dipping southern flank wedges out southward, onlapping the Reguibat Shield, while its thicker and more complete northern extension, exposed in the Anti-Atlas area, was partly involved in the Pan-African mobile belt and later on uplifted and deformed by the Hercynian and Alpine orogens (Destombes et al., 1985). These gentle

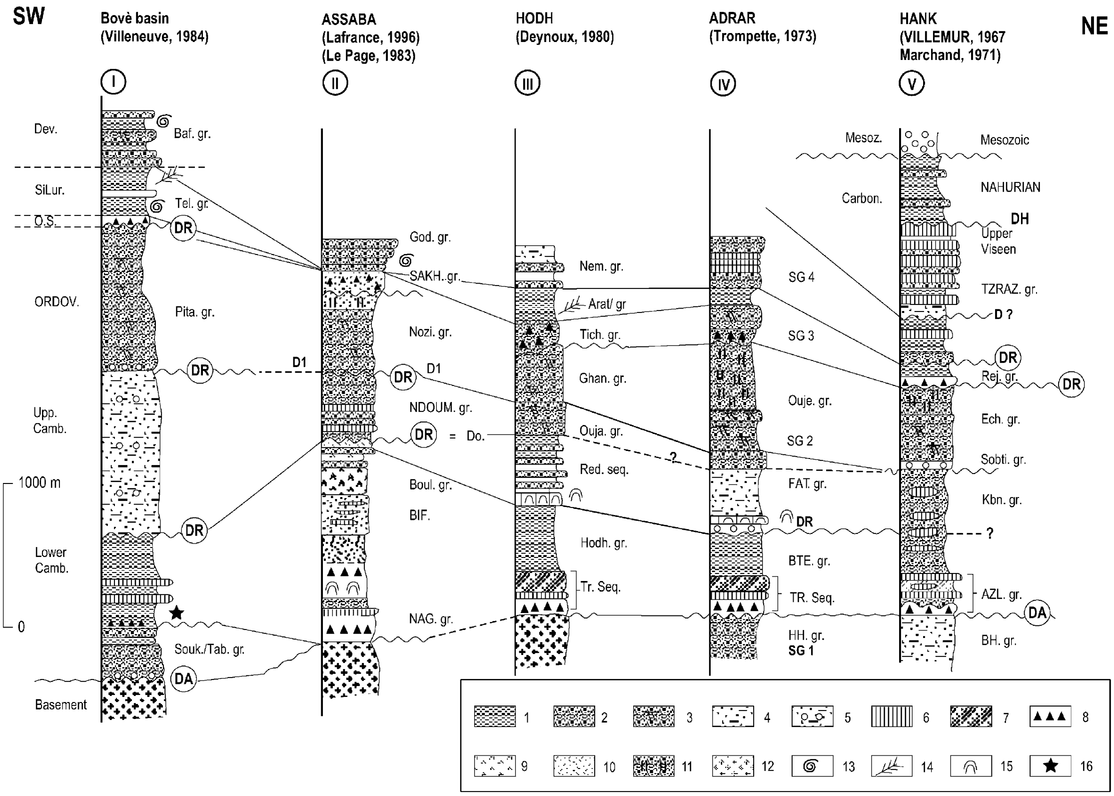

Fig. 7. *Stratigraphical successions in the Toudeni Basin.* Localisation of logs in Fig. 5, SG1 = Super-Group 1, SG2 = Super-Group 2, SG3 = Super-Group 3, SG4 = Super-Group 4, DR = Erosional unconformity, DA = Angular unconformity, DH = Hercynian unconformity, Souk/Tb.gr. = Soukouta or Taban Group, Youk.gr = Youkounkoun Group, Pita gr. = Pita Group, Tel.gr = Telimele Group, Baf.gr. = Bafata Group, Nag.gr. = Nagara Group, BIF = Banded Iron formations, Boul.gr. = Bouly Group, Ndoum.gr. = Ndoumeli Group, Ndei.gr. = Ndeio Group, Sakh.gr. = Sahka Group, God.gr. = Godiovol Group, TR.seq. = Triad, Ouja.gr. = Plateau Oujaft Group, Ghan.gr = Ghaneb Group, Tich.gr. = Tichilit al Beida Group, Arat.gr = Aratane Group, Nem.gr. = Nema Group, Ten.gr = Teniagouri Group, Fat.gr = Falaise d'Atar Group, Ouje. gr. = Oujeft Group, Azl.gr = Azlaf Group, Kbn. gr = Kreb en Naga Group, Ech. gr. = Erg Chech Group, Meja. gr = Mejahouda Group, Terazz gr. = Terazza Group. *Legend*: 1—Shales, 2—Sandstones, 3—Cross-bedded sandstones, 4—Pelites, 5—Conglomeratic shales, 6—Limestones, 7—Cherts, jaspers, 8—Tillites, glacial deposits, 9—Basic volcanic formations, 10—Rhyolitic formations, 11—Sandstones with scolites, 12—Metamorphic basement, 13—Brachiopods, 14—Graptolites,15—Stromatolites, 16—Microfossils.

deformations are exposed in Fig. 9b. To the NE the Tindouf Basin is limited by the Hercynian Ougarta Belt, and to the West by the Dhlou Belt which is a part of the Hercynian Mauritanide Belt. Close to the Tindouf city, the Paleozoic sediments have a thickness of about 10,000 m.

Stratigraphical studies have been driven by petroleum geologists (Liouville and Graverot, 1963; Graverot and Planchon, 1964) or by members of geological services (Sougy, 1964; Destombes et al., 1969).

Most of the southern exposed flank (Fig. 9c) consists of Late Ordovician glacial deposits overlain by Silurian shales and by a thick sequence of Devonian and Early Carboniferous shales and limestones (reds beds). Southwestward, in the Zemmour area, older rocks appear below the Late Ordovician erosional surface. They consist of dolomitic carbonates and intervening shales (El Tlethyate Group), which thin out rapidly toward the basement. These carbonates are unconformably overlain and overlapped by sandstones and shales (Oumat el Ham Group) whose fossiliferous upper part provided Tremadoc and Arenig ages (Sougy, 1964, 1969; Destombes et al., 1969). Because of stromatolites similar to those of the Atar Group (Magasequence 1 of the Taoudeni Basin), a late Proterozoic age has been proposed by Sougy (1964). This suggests an important time gap on top of the carbonate rocks over which no evidence of glacial event, or Triad association, has been found. The onlapping geometry of the sedimentary sequences over the basement also suggests that the Reguibat Shield was an uplifted area during most of the Late Proterozoic and Early Paleozoic times. It probably acted as a shoal between the highly subsiding Tindouf Basin and the epeiric Taoudeni Basin. This hypothesis is enhanced by radiometric datations on metamorphic rocks of the Adrar Souttouf Belt (South of the Dhlou Belt) which are older than 650 Ma (Villeneuve et al., in press).

Along the northern flank (Fig. 9c) the Paleozoic cover starts with the Adoudounian limestones (Jeannette and Schumacher, 1976; Jeannette et al., 1981). The Adoudounian succession (up to 4000 m thick) corresponds to the restored epicontinental sedimentation. It consists of a

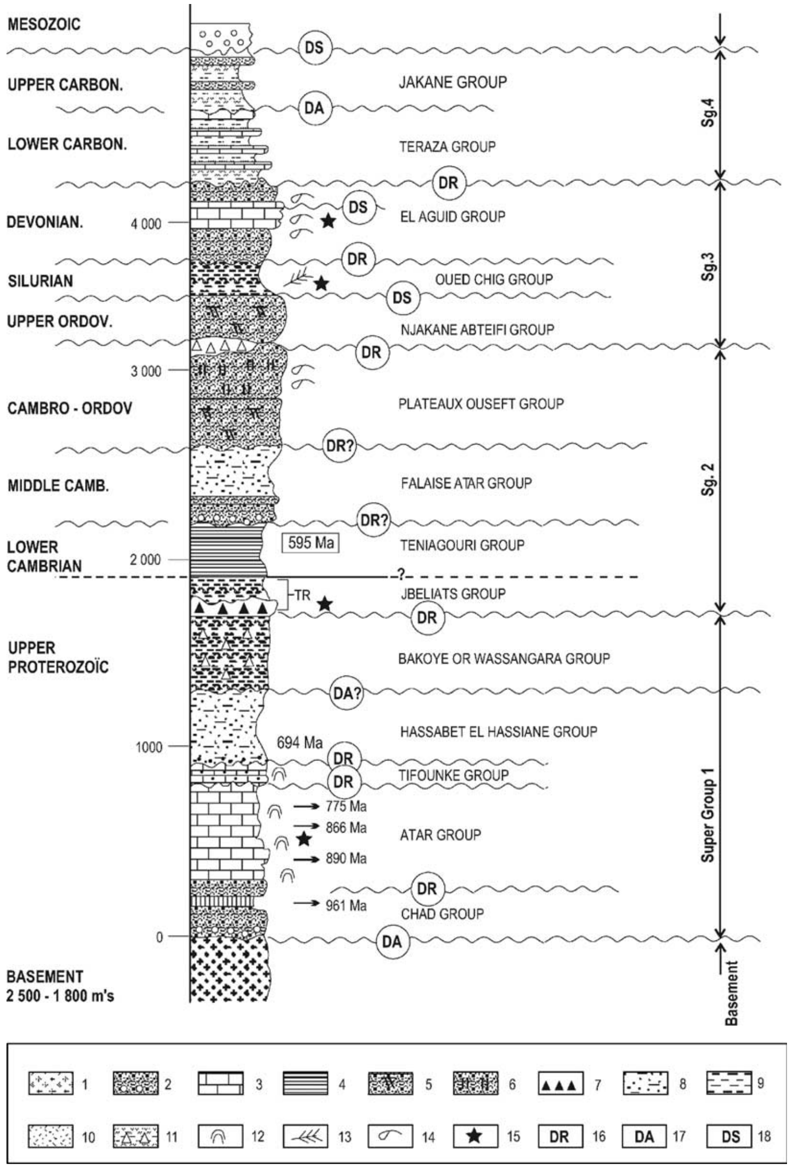

Fig. 8. *Synthetic stratigraphic sequence of the Taoudeni Basin. Legend*: 1—Basement, 2—Conglomerates and sandstones, 3—Limestones, 4—Shales and cherts, 5—Cross-bedded sandstones, 6—Sandstones with scolitus, 7—Glacial deposits, 8—Pelites, 9—Shales, 10—Sandstones, 11—Glacial conglomeratic shales, 12—Stromatolites, 13—Graptolites,14—Brachiopods, 15—Microfossils, 16—Erosional unconformity, 17—Angular unconformity, 18—Stratigraphic unconformity.

lower and upper limestone formation with a reddish sandy to shaly formation (''Série Lie de Vin'') in between (Destombes et al., 1985). The Lower Limestone formation is contemporaneous with the Jbel Boho volcanism that provided an U/Pb zircon age of 534 ± 10 Ma (Ducrot and Lancelot, 1977). Stromatolites of Vendian age are present within the ''Série Lie de Vin'' (Schmitt, 1978), and the Upper Limestone formation contains the first Early Cambrian trilobites (Boudda and Choubert, 1972). The Adoudounian limestones are capped by the Tabanites sandstones and by the shales and limestones of the Ordovician (Zini sandstones). Late Ordovician, Silurian, Devonian and Early Carboniferous, starting with the ''Deuxieme Bani ''sandstone reper level, are also well represented in this northern flank. The erosional disconformity related to the Late Ordovician glaciation exist on both flanks of this Tindouf syneclise. Borocco and Lefèvre (1954) pointed out the paleogeographical history of the basin, with drastic changes in direction of the transgressions from the Cambrian–Ordovician (transgression from the North-East) to the Silurian and Devonian (transgression from the North-West).

The Tindouf Basin was deepest far from the Reguibat shield. The deep is encrising to the East (Regganne basin), to the North-East (Ougarta), to the North (Anti-Atlas) and to the West (Zemmour). According to Sougy (1964) the connection with the Taoudeni Basin over the Reguibate shield, occurred only after the Late Ordovician glacial event.

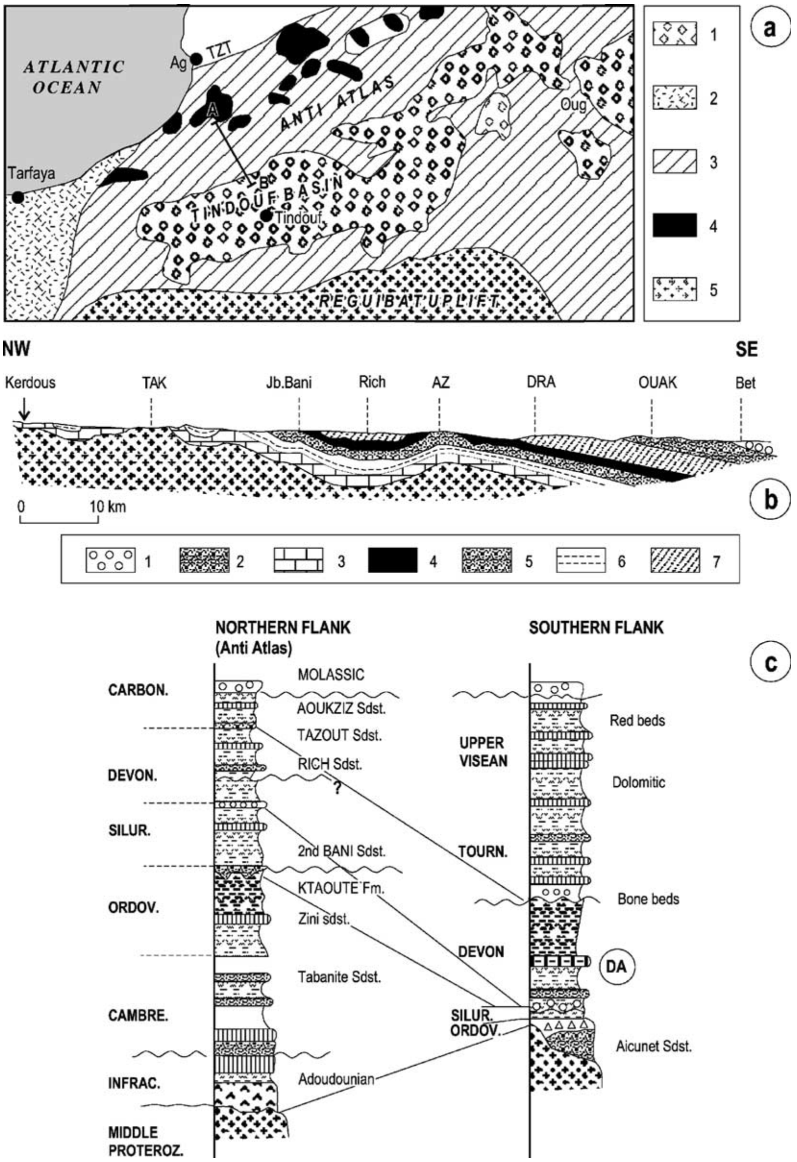

Fig. 9. *The Tindouf Basin*; (a) *Geological sketch map*. *Legend*: 1—Mesozoic–Cenozoic cover of the Tindouf Basin, 2—Meso-Cenozoic of the coastal basins, 3—Late Noeproterozoic to Paleozoic sedimentary formations, 4—Anti-Atlas Pan-African inliers, 5—Crystalline basement. (b) *Geological section across the northern flank* (*Anti-Atlas area*). *Legend*: 1—Mesozoic–Cenozoic deposits, 2—Carboniferous deposits, 3—Late Neoproterozoic to Early Cambrian deposits, 4—Silurian deposits, 5—Ordovician deposits (Ktaoua and Bani beds), 6—Middle Cambrian deposits, 7—Devonian deposits (Rich series). (c) *Stratigraphic successions on the northern and southern flanks of the Tindouf Basin*.

### 2.3. The Western Paleozoic basins

They limit the Taoudeni Basin to the West. Most of them are parallel to the western margin of the West African Craton and parallel to the Rokelide and Mauritanide belts Some of them are tectonically affected by the Pan-African II Orogen (Rokelide Belt) and the others are affected by the Hercynian orogen (Mauritanide Belt). However, one of them, the Bové Basin, is different. It unconformably covers the Rokelide Belt and is folded by the Hercynian Orogen of the Mauritanide Belt. So, it will be considered separately.

From Akjoujt (Mauritania) to the Liberia, five elongated basins and trough have been distinguished (Fig. 5):

- the Faleme Trough from Akjoujt to the South of Senegal;
- the Komba Trough and the Youkounkoun Basin in Northern Guinea;
- the Kolente and the Taban troughs in Southern Guinea;
- the Rokel-River Trough in Sierra Leone.

#### 2.3.1. The Falémé Trough (FT)

The Falémé Trough (Fig. 10, logs 1 and 2), well studied by Bassot (1966), Chiron (1973), Lepage (1983), Dia (1984) and Lafrance (1996) fringes the western rim. It is partly (to the West) tectonised and metamorphosed. The lithostratigraphic sequence changes from the North to the South.

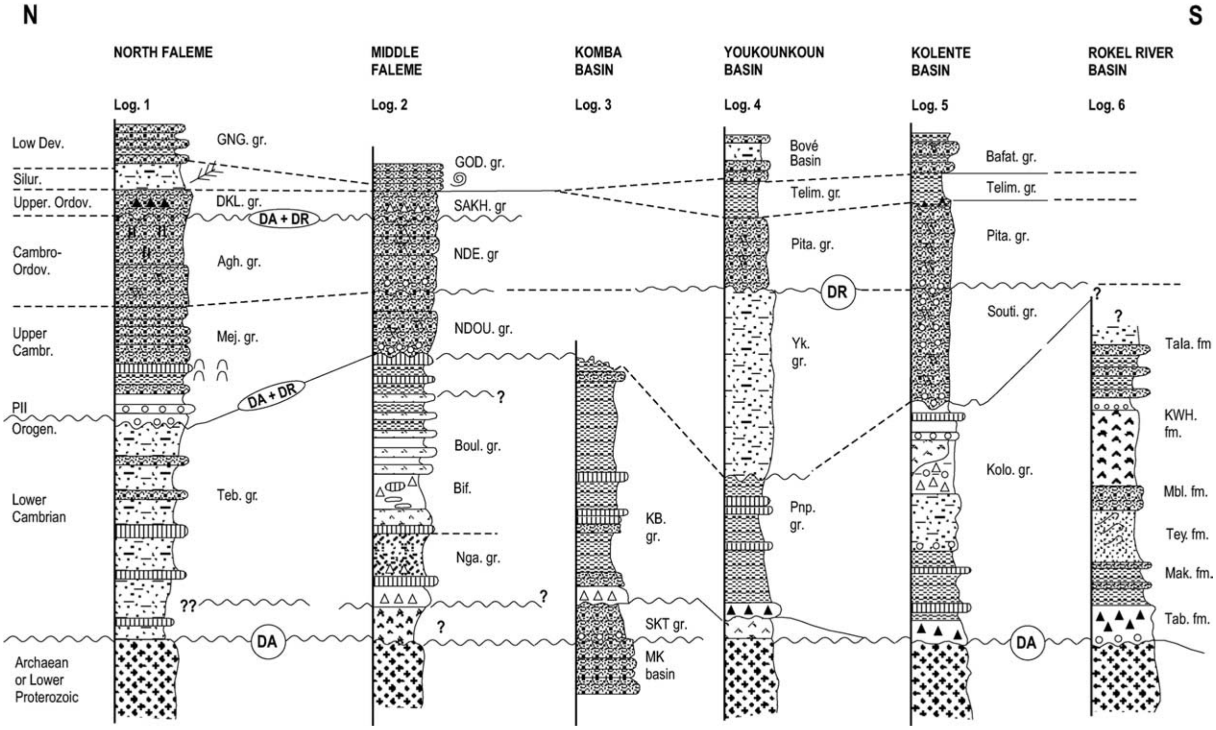

Fig. 10. *Stratigraphic successions of the Western basins and troughs*. Localisation of logs in Fig. 5, DR—Erosional unconformity, DA—Angular unconformity, DH—Hercynian unconformity, Teb.gr. = Tichilit al Beida Group, Mej.gr. = Mejeria Group, Agh.gr. = Agouaoujeft Group, Dkl gr = Dikkel Group, Gng.gr = Gneigara Group, Nga.gr. = Nagara Group, Youk.gr = Youkounkoun Group, Pita gr. = Pita Group, Tel.gr = Telimele Group, Baf.gr. = Bafata Group, BIF = Banded Iron formations, Boul.gr. = Bouly Group, Ndoum. gr. = Ndoumeli Group, Ndei.gr. = Ndeio Group, Sakh.gr. = Sahka Group, God.gr. = Godiovol Group, TR.seq = Triad, Tich.gr. = Tichilit al Beida Group, MK basin = Madina–Kouta Basin, Skt.gr. = Soukouta Group, Kb. gr. = Komba Group, Pnp.gr = Panampou Group, Kol.gr = Kolente Group, Souti gr. = Mont Souti Group, Tab.fm. = Tabe formation, Mak. fm. = Makani formation, Tey.fm = Teye formation, Mbl. fm = Mabole formation, KwH. fm = Kasewe Hill formation, Taia fm = Taia formation. *Legend*: 1—Shales, 2—Sandstones, 3—Cross-bedded sandstones, 4—Pelites, 5—Conglomeratic shales, 6—Limestones, 7—Cherts, jaspers, 8—Tillites, glacial deposits, 9—Basic volcanic formations, 10—Rhyolitic formations, 11—Sandstones with scolites, 12—Metamorphic basement, 13—Brachiopods, 14—Graptolites, 15—Stromatolites, 16—microfossils.

The Early Cambrian sequence (Tachilit el Beida Group) is more complicated in the southern part with a large amount of volcano-sedimentary formations (Nagara and Bouly groups). Diamictites, laminites with lonestones, and turbiditic sandstones are generally present in the lower part of the sequence and are interpreted as glacio-marine deposits (Bassot, 1966; Culver and Williams, 1979; Villeneuve, 1984; Culver and Magee, 1987; among others). The Triad, previously described by Bassot (1966) at Walidiala (Eastern Senegal) is located at the base of the Mali Group although the cap dolomites are lacking very often. But carbonate intercalations might appear higher within the marine shales. According to Chiron (1973), the Triad equivalent is covering a red hematitic sandstone formation (the Sangarafa Séries), but in the Faleme Trough, the base of the Paleozoic basin is not as clear as in the West African platform. Lafrance (1996), for example, has evidenced several glaciogenic levels interbedded with hematitic and turbiditic formations. These materials are ascribed to the tectonic and volcanic activity of the Massar fault. The Late Cambrian which consists of sandstones, limestones and red shales to the North (Mejeria Group) exhibits only red sandstones to the South (Ndoumeli Group). The Cambrian–Ordovician consists of cross-bedded white sandstones to the South (Ndeio Group) and sandstones with scolithus to the North (Agouaoujeft Group). The Late Ordovician glaciogenic sediments (Dikkel and Sakkha groups) and the Devonian shelly sandstones (with brachiopods) exist on both parts. But, the Silurian black shales are lacking in the South (Drot et al., 1978). The erosional inconformity between the Late Cambrian Ndoumeli Group and the Cambrian–Ordovician Ndeio Group clearly expressed in the southern part, has not been evidenced to the North.

### 2.3.2. *The Komba Trough (KT) and the Youkounkoun Basin (Yb) (Fig. 10; logs 3 and 4)*

The Komba Trough and the Youkounkoun Basin are separated by the Bassaris ridge (Pan-African I belt).

The main stratigraphic studies have been performed by Villeneuve (1984, 1990). On the Birrimian Kegougou inlier and on top of the Madina–Kouta Basin (Super-Group 1), the Komba lithostratigraphic sequence starts with a glaciogenic formation (which can be related to the Triad of the Taoudeni Basin). However, in the northern part of the Komba Basin, this glaciogenic formation is overlying red conglomeratic deposits (the Soukouta Group) which can be older than the glaciogenic event. The glaciogenic formation is capped by a sequence of green shales and pelites with some interbedded limestones (Mali Group). In the Komba Trough, the Mali Group is intruded by a large volcanic dyke parallel to the trough (the Koubia Group).

*In the Youkounkoun Basin*, the glaciogenic formation unconformably overlies a red conglomeratic formation (Villeneuve, 1984) very similar to that of the Soukouta Group. It is capped by a green volcano-sedimentary sequence with dark-green limestones interbedded (the Panampou Group). The Panampou Group is itself unconformably overlain by 2000–2500 m of red-arkosic and conglomeratic sandstones (the Youkounkoun Group). The Panampou Group is gently folded whereas the Youkounkoun Group is totally flat. Nevertheless, in the northern part of the basin, the Youkounkoun Group is folded by the Hercynian Orogen together with the Paleozoic (Cambrian–Ordovician to Devonian) sediments of the Bové Basin.

### *2.3.3. The Kolenté (log 5, Fig. 10) and Taban troughs (Klt and Tbb)*

*The Kolenté Trough* looks like the Komba Basin. From the base to the top we see the following formations:

- a basal conglomerate with glaciogenic elements (which was previously ascribed to the Late Ordovician glacial event by Tucker and Reid (1973) in the Sayona-scarp mountain);
- a green and red argillites formation with several carbonate levels in the middle;
- a thick sandstone (200 m) formation with several conglomeratic beds;
- a black and green shaly formation with conglomeratic levels (glaciogenic aspect),
- a volcano-sedimentary formation called the "Bania formation" made of spilites, brecchias, basaltic lavas with argillite and jasper levels interbedded.

This trough is folded and possibly metamorphosed on its western side.

*The Taban Trough* is located in the southernmost part of the Bové Basin. There are three different North–South trending narrow troughs. According to Boufeev (1968), they are filled with 2200 m of sandstones and conglomeratic sediments with a great number of rhyolitic clasts. At first, these sediments were considered as being younger than the Rokel-River and Kolente troughs (Allen, 1968). But Culver and Williams (1979) proposed to correlate them with the tillitic formations of the Kolente or Rokel-River troughs. This hypothesis was adopted by Latiff et al. (1997) but Villeneuve (1991) favored a more ancient deposition than the Kolente Proterozoic or Cambrian tillite. The Taban formation could be an equivalent of the Soukouta Group or conglomeratic sandstones unconformably covered by the glaciogenic level located at the base of the Panampou Group (Youkounkoun Basin). The Taban sandstone beds exhibit an average depth of 45° to the North-East.

### *2.3.4. The Rokel-River Trough (Rrt) (log 6, Fig. 9)*

The Rokel-River group in Sierra Leone (Allen, 1968; Culver and Williams, 1979; Culver et al., 1991; Latiff et al., 1997) contains from the base to the top:

- the Tabe–Makani formation (180 m): basal polymict conglomerates overlain by thin shaly sandstone;
- the Teye formation (200 m): purple shales, variegated silty shales with quartzite bands;
- the Kasewe Hill formation (200 m): grey–green augite andesites, dacitic lavas and tuffs;
- the Taia formation: grey–green shales and mottled reddish while shales with feldspathic sandstone bands.

According to Culver et al. (1991) the Rokel-River Trough is an "aulacogen". But for Latiff et al. (1997) it is a half-graben structure controlled by the Western Kukuna fault. Latiff et al. (1997) favored a normal fault with an East dipping, whereas Culver and Williams (1979) favored a West dipping reverse fault. Anyway, the southern end of the Rokel-River Trough is a syncline structure underlined by a basal tillitic level. Folding and metamorphism seem to be increasing westward but the poor outcropping cannot allow us to conclude about the thrusting of the inner metamorphic formations of the Rokelide Belt over the Rokel-River Trough. Boufeev (1968) found outcrops of sedimentary shales matched with metamorphic rocks on the western side of the Kolente Trough. However, close to Monrovia (Liberia), Thorman (1976) pointed out a metamorphic formation thrusted over the Rokel-River sediments, in the "Gibi mountain klipp".

### *2.3.5. The Bové Basin (Bb) (Fig. 11)*

The Bové Basin outcrops mainly in the Fouta Djalon mountains (Guinea). It also outcrops in Guinea Bissau and in the southeastern part of Senegal (Fig. 11a). Flat upon the Bassarides and Rokelide belts, it is slightly deformed to the North (in Senegal and Northern Guinea Bissau) by the Hercynian Mauritanide orogen. Due to the activity of the NW–SE faults, it looks like a NW–SE trending syncline (Fig. 11).

According to Villeneuve (1984) and Villeneuve and Da Rocha Araujo (1984), the stratigraphy includes three groups with, from the base to the top (Fig. 11c):

- the Cambrian–Ordovician Pita Group;
- the Silurian Telimélé Group;
- The Devonian Bafata Group.

*The Pita Group* (250–930 m) includes three formations with from the base to the top: the Guemeta formation, the Kindia formation and the Mont Gangan formation.

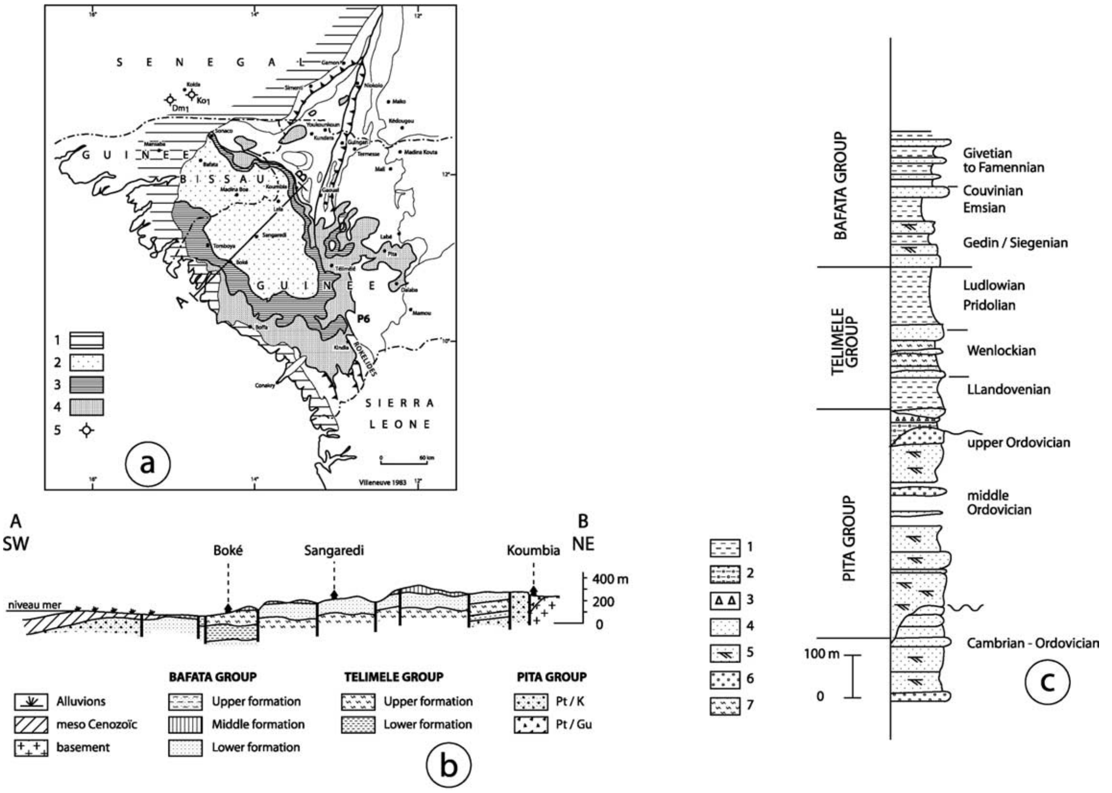

Fig. 11. *The Bové Basin*. (a) *Geological sketch map*. *Legend*: 1—Mesozoic–Cenozoic deposits of the Senegalo–Mauritanian Basin, 2—Devonian deposits (Bafata Group), 3—Silurian deposits (Telimele Group), 4—Cambrian–Ordovician deposits (Pita Group). (b) *Geological section across the Bové Basin*. (c) *Stratigraphic succession*. *Legend*: 1—Argilites and shales, 2—Conglomeratic sandstones, 3—Glaciogenic deposits, 4—Sandstones, 5—Sandstones with cross-bedding, 6—Conglomerates, 7—Shales.

The Guemeta formation includes red sandstones and conglomerates. It represents the Rokelide molasses and should be correlated to the upper part of the Youkounkoun Basin. The Kindia formation is mainly represented by white fluviatile and deltaic sandstones. The Mont Gangan formation includes conglomeratic argillites or sandstones which could be correlated to the Late Ordovician tillite. None of these formations release any fossils excepting the latest Kindia levels where Roman'ko (1974) found some Late Ordovician graptolites.

*The Telimélé Group* (150–330 m) includes black shales and grey laminated sandstones interbedded. Seven formations are distinguished and dated by graptolites, brachiopods and microfossils (Villeneuve, 1984). The oldest one displays a Early Llandovery age and the younger one includes brachiopods of the Pridolian. These formations reflect the Silurian transgression over the West African Craton.

*The Bafata Group* (150–430 m). Also includes seven formations. The alternations of sandstones and shales with ripple-mark structures reflect, according to Villeneuve (1984), a deltaic environment. The lower formation displays brachiopods of Gedinian (Villeneuve, 1984) and the younger one displays brachiopods of Famennian (Bechennec, 1980).

Small knots in Senegal, show Lower Devonian sandstones (Gedinian/Siegenian) directly on top of the sandstone of the Cambrian–Ordivician Pita Group. This indicates a lack of the Silurian shales to the North of the Bové Basin.

According to seismic profiles (Villeneuve et al., 1993), the Bové Basin extends to the North and to the West below the Cenozoic coastal basins (Fig. 12). In the Guinea offshore, the Cambrian–Ordovician sandstones could be very thick (Fig. 11a), with several thousands of meters. A Carboniferous cover is also suspected in this seismic section.

### 2.3.6. The Diourbel Basin (Dbl) (Fig. 11c)

Early Carboniferous red shales and conglomeratic sandstones have been picked in the Diourbel core drill. These rocks dated with pollens or fragments of leaves, cannot be directly correlated with the Bové Basin. We cannot choose between a northern extension of the Bové Basin or a Carboniferous "Piggy back basin" on top of the Hercynian Belt.

### 2.3.7. Conclusions

To conclude this part devoted to the western Paleozoic basins and troughs, we point out three differences between the troughs and the inner basins of Taoudenni and Tindouf:

- There is a large influence of the tectonic during the sedimentary process going with a large amount of volcanic rocks.

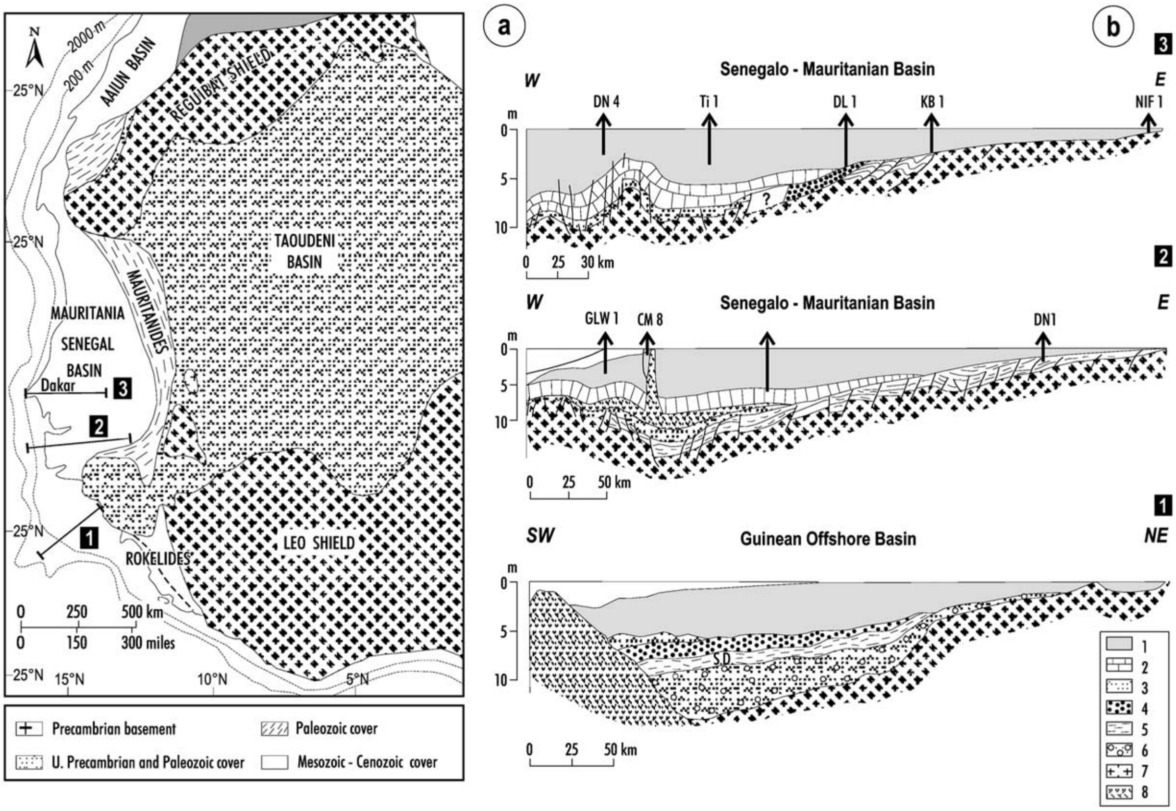

Fig. 12. *Northern and western extensions of the Bové Basin*. (a) *Geological sketch map of West Africa* with location of cross-sections in (b). (b) *Geological cross-sections*. *Legend*: 1—Mesozoic–Cenozoic sediments, 2—Jurassic carbonates platforms, 3—Triassic sandstones, 4—Carboniferous deposits, 5—Silurian–Devonian deposits, 6—Cambrian–Ordovician deposits, 7—Basement of the Bové Basin, 8—Triassic salt.

- The sedimentation has been very important due to the tectonic activity. That could explain the number of glaciogenic levels, in opposition to the single basal glaciogenic level of the Taoudeni Basin.
- The base of these troughs is not always filled with glaciogenic sediments.

### 2.4. The Eastern Paleozoic basins

#### 2.4.1. The Bandiagara sandstones

Eastwards, in Mali and Burkina Faso, the discontinuity below the Bandiagara sandstones may correspond to the unconformity covered by the Triad. However, no clear evidence of glacial input has been found in the Bandiagara sandstones, as it would be expected for the lower part of Super-Group 2 of the Taoudeni Basin. Moreover, the current directions in the sandstones indicates an area source from both sides of the Gourma basin but not from the Trans-Saharan Belt. The Bandiagara sandstones may be older than the Trans-Saharan Belt and consequently of Ante-Cambrian age.

#### 2.4.2. The Hoggar basins (Ouallen and in Semmen)

In northwestern Hoggar, the molassic mega-unit, generally called the "Série Pourprée", is preserved in more or less isolated residual basins (Fig. 3) where it may reach 8000 m in thickness (Caby and Moussu, 1967; Caby, 1983, 2003; Ait Kaci Ahmed and Moussine-Pouchkine, 1987). These basins rest upon the Eastern orogenic belt (Trans-Saharan Belt metamorphosed around 615–590 Ma). Rock sequences vary from area to area but consist dominantly of continental to marine molassic facies with a variable degree of deformation due to graben tectonics. Caby and Fabre (1981) described, at the basal part of the molassic mega-unit, a Triad association that they consider as "strikingly similar in lithology to the Triad sequence of the Taoudeni Basin". According to Allegre and Caby (1972), the deposition of the "Série Pourprée" is younger than 560 ± 10 Ma, age of Pan-African late orogenic granites. It has been slightly metamorphosed and folded before 510 Ma. This age limit is the age of the "scolithus sandstones" outlining the onset of the Tassili transgression at the boundary between Cambrian and Ordovician (Legrand, 1983). Allegre and Caby (1972) provide also an age of 519 ± 11 Ma for the ignimbrites and rhyolites, which overly the carbonate horizon of the so-called Triad of Caby and Fabre (1981). Caby (2003) considers a 580–520 Ma age bracket for the uplift and molassic stage of the Trans-Saharan Belt.

#### 2.4.3. The Tamale Basin (Tmb) (Fig. 13)

The Tamale Basin corresponds to the upper part of the Volta Basin (Fig. 13a). It unconformably overlies this

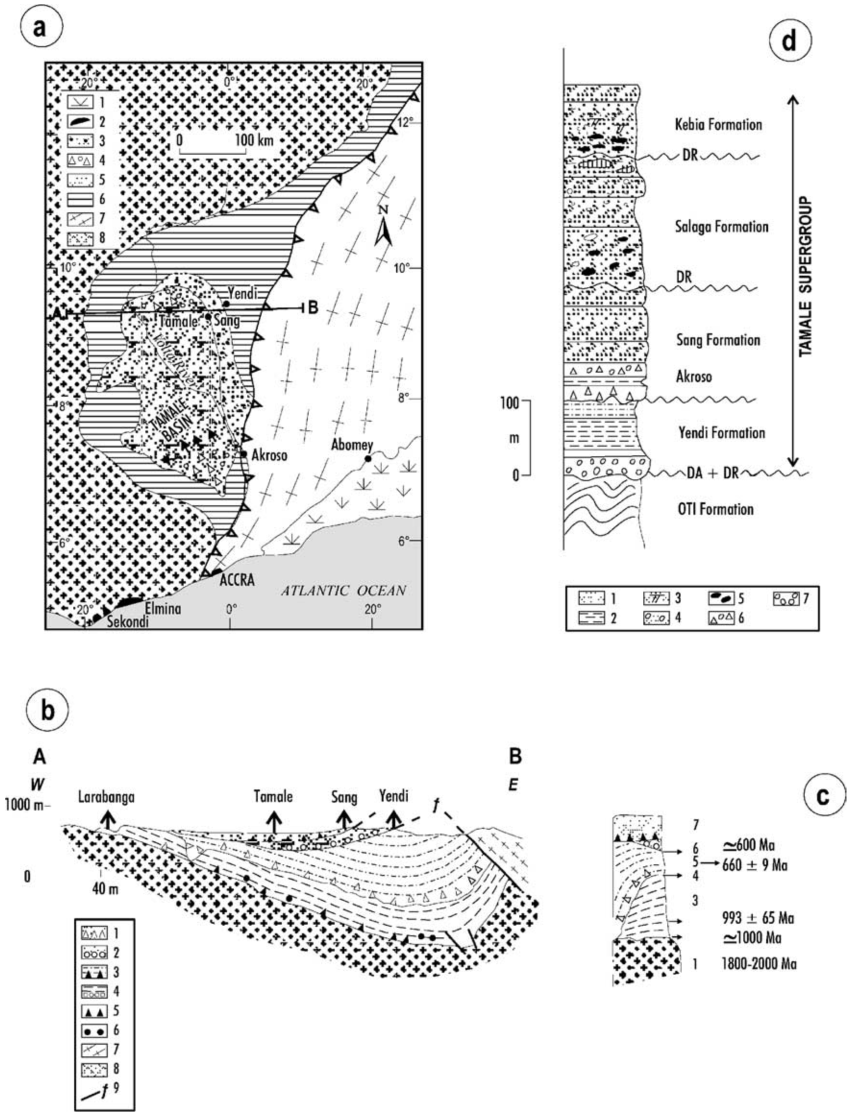

Fig. 13. *The Tamale Basin*. (a) *Geologial sketch map of the Volta and Tamale basins. Legend*: 1—Coastal basins, 2—Paleozoic Ghana basins, 3—Tamale formations, 4—Glaciogenic deposits, 5—Sandtones and conglomerates deposits, 6—Formations of the Volta Basin, 7—The Pan-African basement, 8—the Ivory Coast Shield basement. (b) *Geological section across the Volta and Tamale basins. Legend*: 1—Akroso, Sang and Salaga formations, 2—Yendi formation, 3—Oti or Pendjari Super-Group, 4—Dapango–Bombouaka Super-Group, 5—Glaciogenic deposits, 6—Conglomerates, 7—Pan-African Dahomeyide Belt, 8—Taoudeni crystalline basement. (c) *Schematic stratigraphic succession of the Volta Basin. Legend*: 1—Ivory Coast basement, 2—Birrimian–Volta Basin unconformity, 3—Dapango–Bombouaka Group, 4—Unconformity between the Dapango–Bombouaka and Oti groups, 5—Oti Group, 6—Unconformity between the Oti and the Tamale groups, 7—Upper part of the Tamale Group. (d) *Stratigraphic succession of Tamale Basin. Legend*: 1—Sandstones, 2—Shales, 3—Cross-bedded sandstones, 4—Conglomeratic sandstones, 5—Sandstones with soft particles, 6—Glaciogenic conglomerates (tillites or mixtites), 7—Conglomerates, DA = angular unconformity, DR = erosional unconformity.

Volta Basin (Fig. 13b) overridden by the Trans-Saharan Dahomeyide Belt (600–615 Ma). Consequently the Volta Basin filled with more than 3500–5000 m of clastic sediments is supposed to be Proterozoic (Affaton, 1987; Affaton et al., 1991; Bertrand-Sarfati et al., 1991). However, the lack of reliable radiometric datations cannot exclude the upper part of the Volta Basin from the base of the Paleozoic.

*The Tamale Super-Group (500 m)*, which includes the different formations of the Tamale Basin is mainly exposed in Ghana (Obossum beds). Well studied by Huddleston (1944), Junner and Hirst (1946) and Affaton (1987), it is mainly continental in nature and made up of reddish very coarse-grained conglomeratic sandstones including shales, siltstones and calcareous horizons. Lithostratigraphic sequence (Fig. 13d) shows four different formations with two possible glacial levels. One near the base of Yendi formation and the second one at the base of the Sang formation. According to paleocurrent measurements, the source-rocks is the Pan-African Dahomeyides Belt. An internal progressive unconformity, lined by polymictic conglomerates of possible glacial origin (Junner and Hirst, 1946), attests the westward migration of depocenters going with the intermittent uplifts of the Pan-African domain. Hence, the Tamale Super-Group is probably Paleozoic in age. According to Affaton (1987) it could be younger than the lower part of the "Série Pourprée" (Hoggar basins). Clauer et al. (1982) proposed an age ranging from 520 Ma (Early Cambrian) to 486 + 19 Ma (Early Ordovician).

#### *2.4.4. The Kandi Basin (Kdb) (Fig. 14)*

It is a tiny basin (9000 km$^2$) located along the Trans-Saharan Belt like the Hoggar basins (Fig. 14a). According to Alidou et al. (1986) and Alidou (1987) this basin, firstly ascribed to the Mesozoic, is mainly Paleozoic. The geological cross-section (Fig. 14b) shows its limitation by several fault zones parallel to the Dahomeyide Belt (Konaté et al., 1994).

The stratigraphic column includes three main sections (Fig. 14c):

- the Lower section (Paleozoic);
- the "Continental intercalaire" (Early Cretaceous);
- the "Continental terminal" (post Middle Eocene).

The Lower section (500 m) includes three formations. Two of them are barren of fossils (the Were and Goungoun formations) but the third one contains Cruzanias (trilobites traces) and Arthrophycus (palmed worms traces) ascribed to the Early Paleozoic (Ordovician) by Alidou et al., 1986).

Lateral equivalents of the Kandi Basin, are found in intra-mountainous grabens of the Dahomeyides Belt which forms the internal Benin Plain Unit (Bassins of Logozohé and Idaho-Mahou, North of Abomey). They are regarded as the internal molassic assemblage that lies with a major unconformity, upon a strongly tectonised and metamorphosed infra-structure. Radiometric datations on volcanic layers interbedded with the Paleozoic sediments display according to Affaton (1987), a Late Ordovician age (451 + 3 Ma).

#### *2.4.5. The Ghana basins (Ghb) (Fig. 15)*

The fossiliferous sequences of the Accra, Sekondi and Takoradi basins (Late Ordovician to Late Carboniferous age) after Mensah (1973), Bär and Riegel (1974), Chaloner et al. (1974) and Cheng (1982), which form limited outcrops along the Atlantic coast (Fig. 15a), do not belong

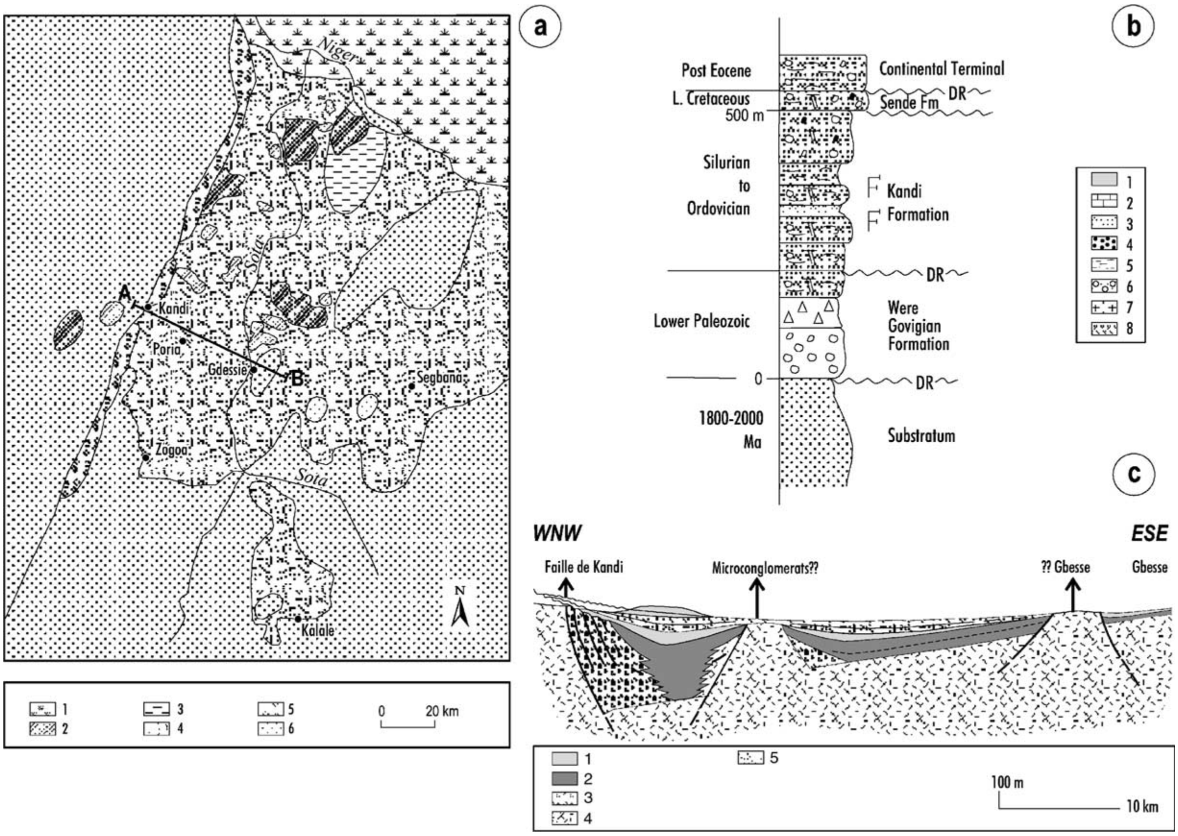

Fig. 14. *The Kandi Basin.* (a) *Geological sketch map of the Kandi Basin. Legend*: 1—Mesozoic–Cenozoic formations of the Iullimeden Basin, 2—Continental terminal, 3—Sendé formation (Cretacé), 4—Kandi formation, 5—Were-Goungoun formation, 6—Pan-African basement (Dahomeyide Trans-Saharan fold belt). (b) *Geological section across the Kandi Basin* between Sansorro and Gbessie, after Konaté et al., 1994, modified. *Legend*: 1—Conglomeratic and sandy shales, 2—Limestones, 3—Cross-bedded sandstones, 4—Glacial conglomerates, 5—Shales, 6—Fluviatile conglomerates, 7—Granites, 8—Pan-African metamorphic basement. (c) *Stratigraphic succession of the Kandi Basin. Legend*: 1—Siltites, 2—Sandstones and shales, 3—Sandstones and conglomerates, 4—Conglomerates and brecchias, 5—Pan-African basement.

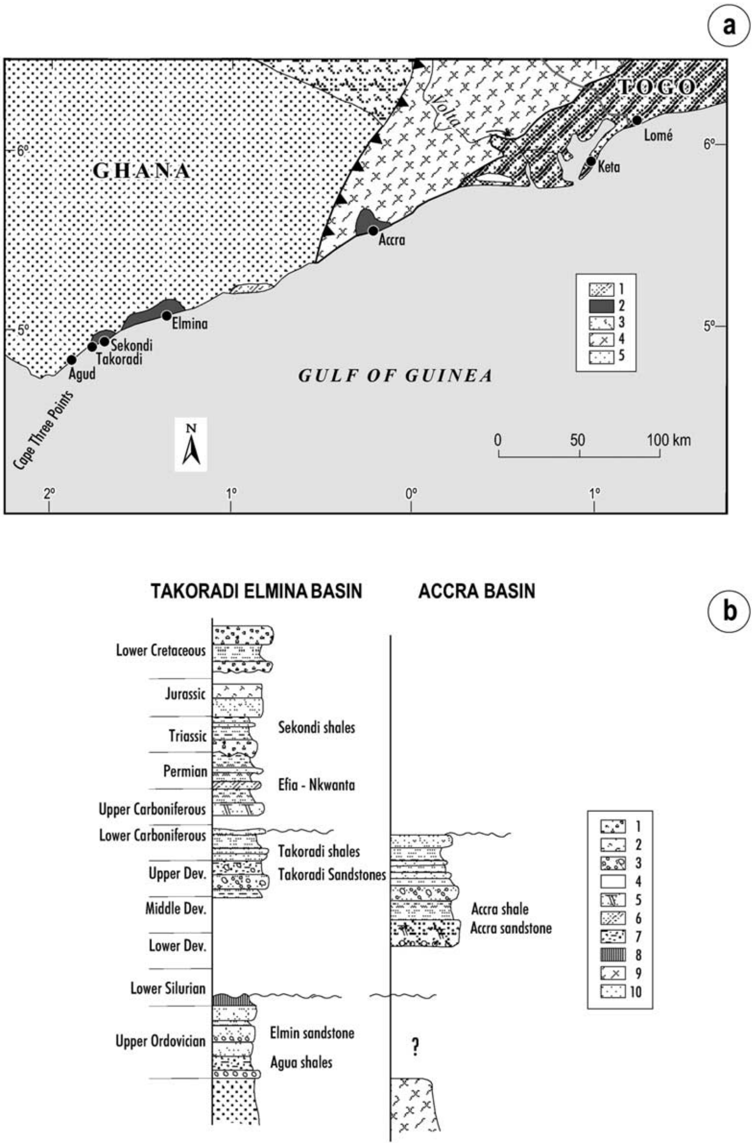

Fig. 15. *The Ghana basins*: (a) *Location of Paleozoic basins along the Ghanean coast* (*Accra, Elmina, Sekondi and Takoradi basins*). *Legend*: 1—Ivory Coast Shield, 2—Paleozoic basins of Ghana, 3—Volta Basin, 4—Pan-African Belt, 5—Mesozoic–Cenozoic coastal basin. (b) *Stratigraphic succession of the Takoradi and Accra basins*. *Legend*: 1—Conglomeratic sandstones, 2—Volcanic sills, 3—Conglomerates, 4—Shales, 5—Sandstones with cross-bedding, 6—Cherts, 7—Glaciogenic deposits, 8—Shales with blocks, 9—Pan-African basement, 10—Birrimian basement.

to the Volta Basin. They are remnants of the Brazilian Maranhao and Parnaïba intra-cratonic basins preserved on the West-African plate. The stratigraphic sequence represents more than 1300 m of Paleozoic sediments ranging from the glacial deposits of the Ajua schists (Late Ordovician to Early Silurian) to the Early Carboniferous schists of Takoradi exhibiting an other glacial level (Fig. 15b). The Devonian is well represented with several levels of sandstones and shales exhibiting fossils traces of Arthophycus (palmed worms) and Spyrophyton. Several levels with pollens allow us to complete the stratigraphic scale. Two other Paleozoic basins are evidenced underneath the Mesozoic sediments. The first one in the Keta Basin located in the eastern part of the Ghana off-shore (Kjemperud et al., 1992) and the second in the Tano Basin, which straddle the Ghana–Ivory Coast boundary (Tucker, 1991).

### 2.4.6. Conclusions

This study evidences a relative stable sedimentation on the center of the West African Craton which is strongly influenced by climatic events like the Late Precambrian or the Late Ordovician glaciogenic events. On the contrary, in the basins fringing the craton, the sedimentation is strongly influenced by tectonic events occurring along all sides of the craton. The two main orogenic episodes occurring in the Paleozoic times are the Pan-African II (550–500 Ma) and the Hercynian (330–270 Ma), on the western and northern margins.

Correlations between the central basins and the bordering basins are not easy because the rapid facies changes, the variability of the thickness deposition and the obliterating of the climatic effects by the tectonic effect, on the bordering basins.

## 3. The Mauritanides fold belt

### 3.1. Generalities

On the western side of the craton, Sougy (1962a) recognized two different orogenic belts: the Mauritanides to the North and the Rokelides to the South. Later on, Villeneuve (1984) distinguished three different belts, from North to South: the Mauritanides, the Bassarides, and the Rokelides (Fig. 1).

The western mobile zone is considered as polyphased by various authors. According to new structural data (Villeneuve, 1984; Villeneuve et al., 1990) and $^{40}$Ar/$^{39}$Ar radiometric data (Dallmeyer and Villeneuve, 1987; Dallmeyer and Lécorché, 1989), three different tectonic events occurred, namely:

- the Pan-African I tectonic event in the Bassaride Belt (Villeneuve, 1984) at around 650–660 Ma;
- the Pan-African II tectonic event of the Rokelide Belt (Allen, 1969; Thorman, 1976; Culver and Williams, 1979; Villeneuve, 1984, 1990; Culver et al., 1991) around 550–500 Ma;
- the Hercynian tectonic event responsible for the internal nappes emplacement in the Mauritanide Belt (Sougy, 1962b) around 320–270 Ma.

The external nappes of the Mauritanides Belt are thrusted over the Devonian rocks of the Taoudeni Basin, in Mauritania while in Guinea the Cambrian–Ordovician to Devonian sediments of the Bové Basin rest upon both Bassarides and Rokelides belts (Sougy, 1962a; Bassot, 1966; Villeneuve, 1984). The Bassarides fold belt does not affect the Paleozoic formations meanwhile parts of the Paleozoic formations are tectonically affected by the Rokelides and the Mauritanides fold belts. Although the Rokelides Belt involves the Early Cambrian sediments, it is related to a Pan-African orogen (Pan-African II).

### 3.2. Structure of the Mauritanides Belt

The Mauritanides fold belt (Fig. 16) which extends from the Morocco to Guinea Bissau, over more than 2500 km, fringes the western edge of the West African Craton (WAC). The Mauritanides Belt is generally thrusted over the craton and its sedimentary covers. The main external Hercynian thrust affecting the Paleozoic sediments is called the HFT (Hercynian Front Thrust). The Mauritanides fold belt is largely covered by the coastal Mesozoic–Cenozoic basins.

From the North to the South, three main parts have been distinguished: the Northern Mauritanides (from Agadir to Nouadhibou), the Central Mauritanides (from Akjoujt to Kidira) and the Southern Mauritanides (from Kidira to Bissau).

From the West to the East, Lepage (1986) distinguished four different lithostructural units:

- the "foreland unit" corresponding to the undeformed of less deformed cratonic zone;
- the "Para-autochthon unit" made with a similar material, but more deformed and slightly metamorphosed. These two units are separated by the HFT (Hercynian Front Thrust);
- the "Infra-structural allochthons" with a large part of Archean or Pan-African I basement matched with the Late Neoproterozoic and Paleozoic sedimentary cover. This unit is strongly deformed and locally tightly metamorphosed;
- the "Supra-structural allochthons" with basement and Paleozoic covers both schistosed and metamorphosed.

Considering the large Mesozoic coverage and the intense transversal faulting, it is geologically more appropriate to consider separately six different sections, instead of the three parts above mentioned.

#### 3.2.1. Anti-Atlas section (I, Fig. 16)

The Paleozoic sediments of the Anti-Atlas already mentioned as the northern flank of the Tindouf Basin, are folded by the Hercynian orogen. But Pan-African or Middle Proterozoic inliers outcrops in the anticlines cores. The folding is considered as Middle Carboniferous or more recent.

#### 3.2.2. Zemmour section (II, Fig. 16)

This is located in the southwestern part of the Tindouf Basin, has been investigated by Sougy (1964), Destombes et al. (1969) and Ratschiller (1970). They worked on the foreland, meanwhile Dacheux (1967) worked on the "Dhlou Belt" which corresponds to the para-autochthon unit. The geological scheme (Section 1, Fig. 17) shows the Hercynian Front Thrust (HFT) separating the Zemmour syncline from the "Dhlou Belt". The lower part of the sedimentary cover corresponds to the El Tlethyate limestones correlated (Sougy, 1969) with the Super-Group 1 of the Taoudeni Basin. The Cambrian–Ordovician sandstones are overlapping these El Tlethyate stromatolitic Precambrian limestones and also the metamorphic Reguibat basement. There is a lack of a large part of Cambrian deposits.

#### 3.2.3. Adrar Souttouf section (III, Fig. 16)

This section is located on the western part of the Reguibat uplift. The Adrar Souttouf area has been very poorly investigated by geologists due to the number of political conflicts that occurred here, from the Middle of the 20th century. The first geological maps have been produced by Alia Medina (1949). Later on Sougy (1962a) evidenced the thrusting of the western metamorphic belt over the Paleozoic "tegument" (Ordovician to Devonian) in the vicinity of Aoucert. This has been confirmed by Arribas (1968), and Sougy and Bronner (1969). Recent works (Le Goff et al., 2001 and Villeneuve et al., in press) point out the Pan-African age of the western metamorphic belt. This

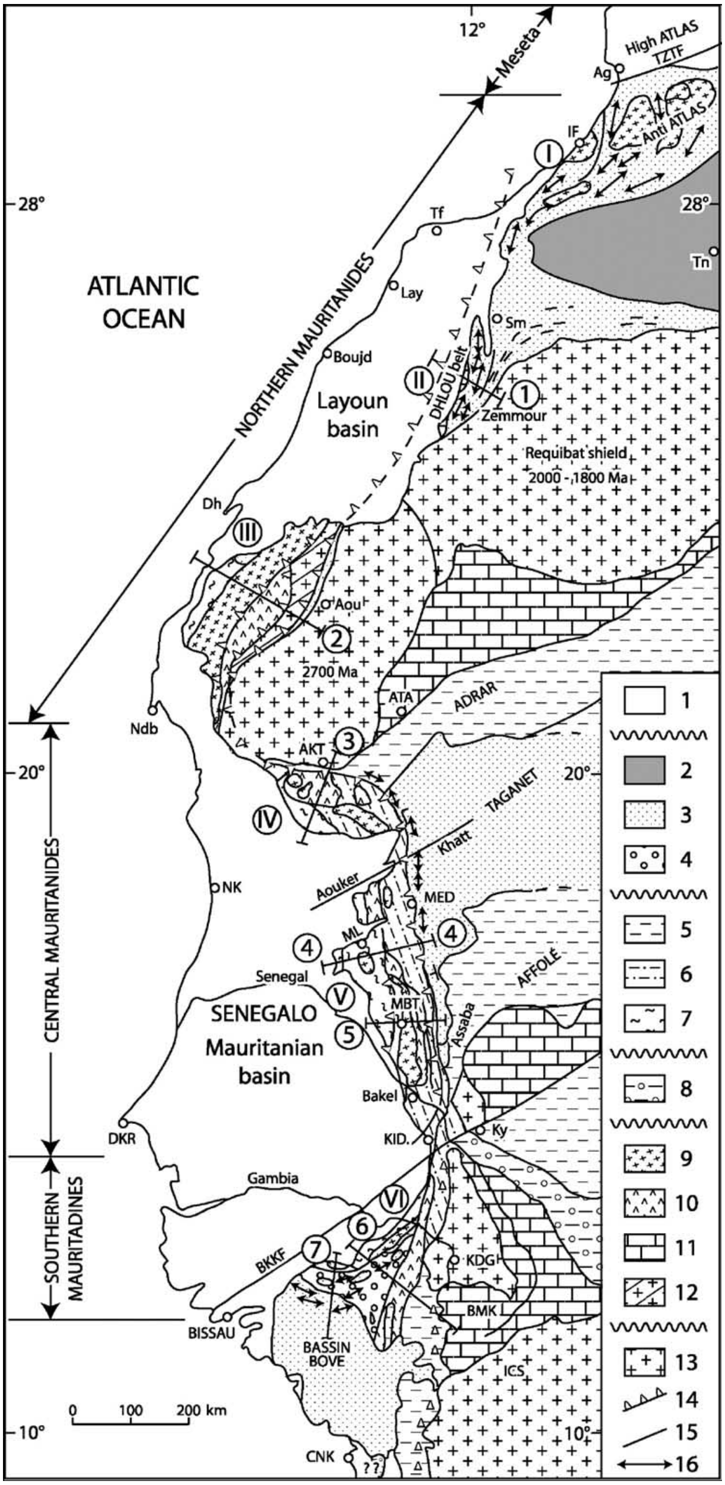

Fig. 16. *Geological scheme of the Mauritanides Belt*. Encircled "roman" numbers = I—Anti-Atlas sections, II—Zemmour section, III—Adrar Souttouf section, IV—Akjoujt section, V—Moudjeria–Bakel section, VI—Koulountou section. Encircled "arabic" numbers = Cross-sections shown. TZT = Tizi n'Test fault zone, Aouker–Khatt F = Aouker Fault zone, BKKF = Bissau–Kidira–Kayes fault zone, BMK = Madina–Kouta Basin; Yb = Youkounkoun Basin, Bb = Bové Basin,. RS = Reguibat Shield, ICS = Ivory Coast Shield, Ki = Kedougou inlier, SMb. = Senegalo–Mauritanian Basin, Tfb. = Tindouf Basin, Zm = Zemmour, AS = Adrar Souttouf, IF = Ifni, Tf = Tarfaya, Boujd = Boujdour, Sm = Smara, Tn = Tindouf, Dh = Dahkla, Aou = Aoucert, Akj = Akjoujt, Ndb = Nouadhibou, NK = Nouakchott, DKR = Dakar, CNK = Conakry, Ky = Kayes, KDG = Kedougou. *Legend*: 1—Mesozoic–Cenozoic sedimentary rocks of coastal basins, 2—Carboniferous deposits, 3—Paleozoic deposits of the foreland, 4—Youkounkoun Group, 5—Shales of the Late Neoproterozoic to Devonian in the foreland, 6—Sediments of the Late Neoproterozoic to Devonian in the Mauritanides Belt, 7—Metamorphic rocks from the Late Neoproterozoic to Devonian sediments in the western unit of the Mauritanides Belt, 8—Bakoye Group, 9—Calc-alkaline Pan-African granites in the Mauritanides Belt, 10—Ultrabasic rocks of the belts, 11—Late Proterozoic cover (Super-Group 1), 12—West African cratonic basement included in the Mauritanides Belt, 13—West African Craton basement, 14—Thrusts, 15—Fault, 16—Main fold.

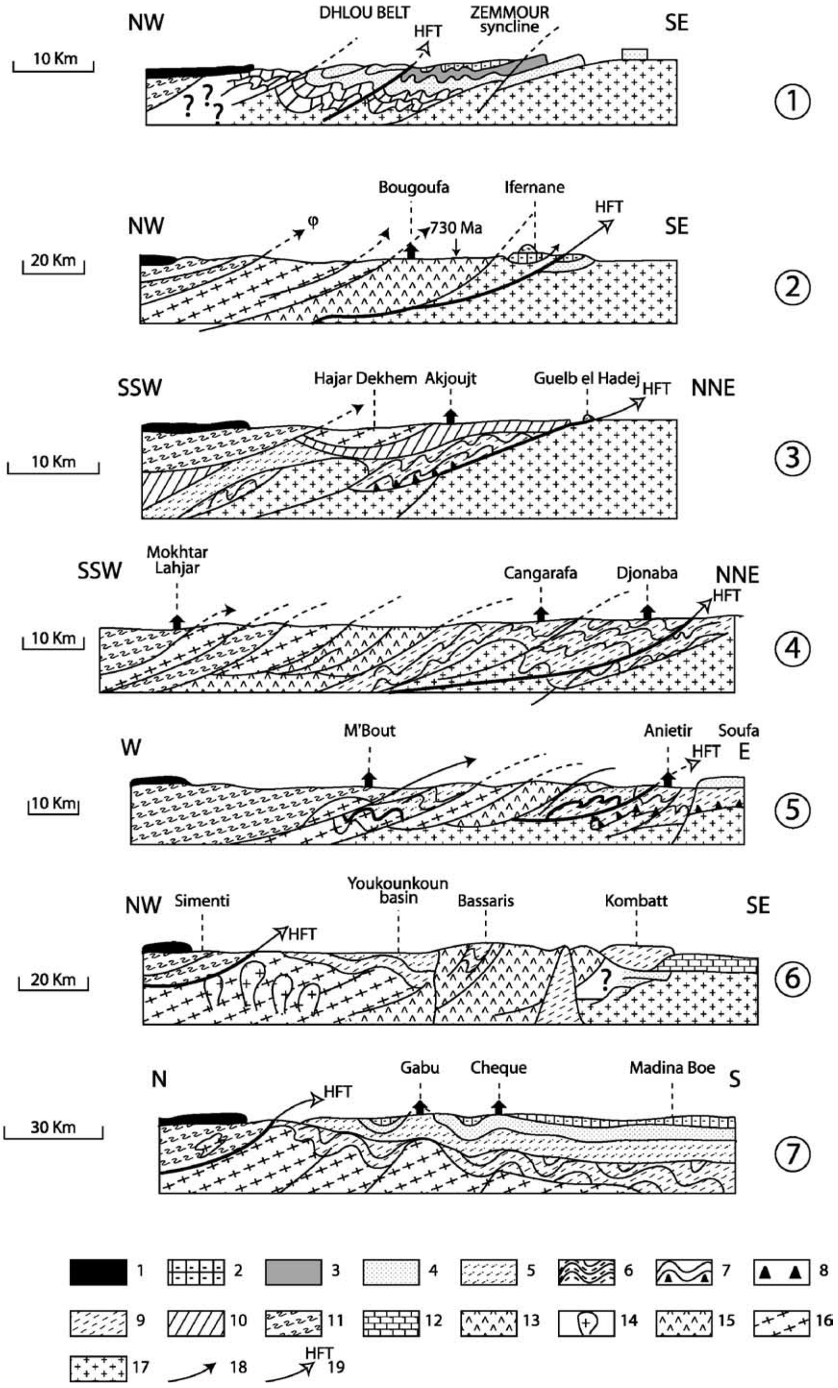

Fig. 17. *Geological cross-sections in the Mauritanides Belt* (location in Fig. 16). *Legend*: 1—Mesozoic–Cenozoic of coastal basins, 2—Carboniferous deposits, 3—Silurian–Devonian, 4—Cambrian–Ordovician, 5—Youkounkoun Group in the foreland, 6—Youkounkoun Group in the folded belt, 7—Late Neoproterozoic and Cambrian in the folded belt, 8—Late Neoproterozoic and Cambrian in the foreland basins, 9—Akjoujt Group, 10—Metamorphosed Late Neoproterozoic to Devonian in the western units of the Mauritanides, 11—Late Proterozoic cover (Super-Group 1), 12—Ultrabasic rocks of the belts, 13—Calc-alkaline Pan-African granites in the Mauritanides Belt, 14—Granitic intrusions, 15—West African Craton basement, 16—Tillites or Mixtites, 17—Thrust, 18—Foreland main thrust.

Pan-African Belt was obviously remobilized during the Hercynian orogen. The schematic cross-section (2 in Fig. 17) evidences four main allochthons units thrusted over the Paleozoic tegument. From the East to the West we identify:

- the Ifernan unit (probably a sheet belonging partly to the Archean basement of the Reguibate uplift with very low metamorphic units of unknown age);
- the Bougarafa unit exhibiting an ophiolite dated at 730 Ma;

- the Gezmayet unit displaying a 670–633 Ma age for the metamorphic episode;
- the Fadrat al Garod unit exhibiting a metamorphic material of unknown age.

Contrary to the previous interpretation, the Adrar Souttouf Belt does not correspond to a Hercynian klippen but corresponds to a lot of different units stacked from the West to the East, during both Pan-African and Hercynian orogens.

#### *3.2.4. Akjoujt section (IV, Fig. 16)*

This is one of the better studied, thanks to copper mining, and it is also one of the most complicated and debated section. First investigations by Marcelin (1964), Tessier et al. (1961) and Lécorché (1980) evidenced several nappes thrusted over the Paleozoic sedimentary cover, specially in the Guelb el Hadej (northern part). In this Guelb, a metamorphic unit from the "infra-structural allochthon unit" is thrusted over the "foreland unit" represented by the Cambrian green shales of the Super-Group 2. Section 3 (Fig. 17) shows, at least, five nappes stacked, from the base to the top:

- a granitic sheet;
- a volcano-sedimentary sheet metamorphosed "Série d'Akjoujt";
- a quartzitic sheet "nappe des quartzites";
- a sedimentary sheet very similar to the foreland cover but with volcanic material "unité des regs";
- a volcano-sedimentary sheet strongly metamorphosed "Agualilet formation".

Recently, Martyn and Strikland (2004) evidenced a disconformity between two volcano-sedimentary sequences. This observation opens a new hypothesis in favor of the outcropping of the Pan-African I orogen in this part of the Mauritanides.

#### *3.2.5. Mejeria–Kidira section (V, Fig. 16)*

This section is limited to the North by the "Khatt fault zone" and to the South by the "Bissau–Kidira fault zone". It was investigated by Lille (1967), Chiron (1973), Lepage (1983), Dia (1984), Rémy (1987), Ould Souelim (1990), Lafrance (1996) and Diop (1996).

The contact between the para-autochthon and the foreland (HFT) has been mapped in several points by Lafrance et al. (1993). It is close to the Assaba cliff. Two geological sections (Sections 4 and 5, Fig. 17) point out, from the East to the West, the following units or nappes:

- The "para-autochthon unit" which is more or less identical to the foreland material but with some volcanic layers generally interbedded with the basal glacial sequence. But the matching of volcano-sedimentary rocks belonging to the Pan-African I belt with the Cambrian sedimentary and volcanic rocks, have to be taken into account. Volcanic rocks of Devonian age (Hamdallaye formation) cannot be excluded (Lafrance, 1996).
- The ophiolitic and metamorphic complex. These complexes are correlated to the Pan-African I oceanic rocks stacked in the vicinity of the Pan-African suture zone.
- The calc-alkaline granitic complex matched with metamorphic and sedimentary. The metamorphic complex can be connected to the Pan-African I active margin and the sedimentary layers to the Paleozoic sedimentary cover.
- An inner metamorphic unit (supra-structural allochthons). The Paleozoic sedimentary cover is firmly suspected for the origin of this internal metamorphic unit.

The divergent interpretations between Chiron (1973) who favored a Pan-African basement remobilized by the Hercynian orogen and Lepage (1983) who favored an unique Hercynian belt, are overtaken. Radiometric data display a lot of Pan-African ages in this section. These radiometric measurements favor the Chiron hypothesis.

#### *3.2.6. The southern section (VI, Fig 16)*

This area, studied mainly by Bassot (1966) and Villeneuve (1984), is structurally different from the northern ones. The Hercynian and the Pan-African belts are geographically separated. The Hercynian Front thrust (HFT) is now on the western side of the Pan-African I Belt. The Hercynian Belt is turning to the West meanwhile the Pan-African Belt is extending to the south. Section 6 (Fig. 17) shows that the main parts of the Pan-African I Belt (Bassarides Belt) and its Paleozoic cover, are unaffected by the Hercynian orogen. Section 7 (Fig. 17) shows, on the contrary, a folding of the Paleozoic pile in the northern part of the Bové Basin The disconformity between the green Cambrian shales and the red Cambrian–Ordovician deposits is the result of the Pan-African II tectonic event related to the southern Rokelide belt. Beyond the Hercynian Front Thrust, a metamorphic unit (The Simenti unit), thrusted over the Niokolo Koba and Bové basins sediments, display a radiometric age of 270–280 Ma (Dallmeyer and Villeneuve, 1987). This is in contrast with the Bassaris metamorphism which displays several radiometric ages around 660 Ma (Dallmeyer and Villeneuve, 1987).

### *3.3. Geophysical and geochronological data*

Very few geophysical data are available on this part of West Africa. The main one concerns the gravimetry. Gravimetric measurements were performed in Senegal by Creen and Rechenman (1965), in Guinea Bissau by Amorin Ferreira (1966) and in Guinea by Akmetjanov et al. (1976). The gravimetric scheme (Fig. 18a) points out a large North-South "Bouguer anomaly" parallel to the central Mauritanides Belt. It is interpreted by Guettat (1981) as a mantellic uplift located approximately 160 km (Fig. 18b) to the West of the HFT (Hercynian Front

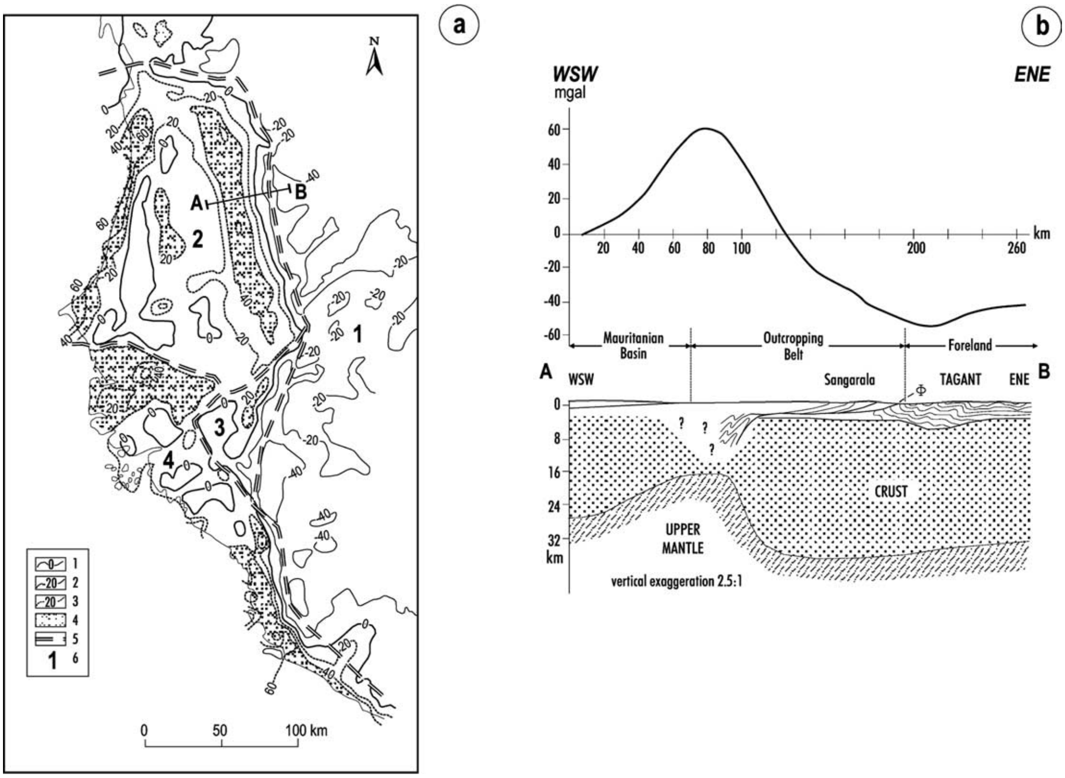

Fig. 18. *Gravimetry of the West African Craton western margin.* (a) *Gravimetric scheme* (after Villeneuve et al., 1990, modified). *Legend*: 1—0 Bouguer contour line, 2—Negative contour line, 3—Positive contour line, 4—Main positive anomaly, 5—Gravimetric sector boundaries, 6—Number of gravity sectors. (b) *Interpretation of the gravimetric anomaly* after Roussel and Lécorché (1983) modified.

Thrust). Guettat et al. (1982) connected this huge gravimetric anomaly to a fossil subduction zone. The main question is to decide which is the orogenic event related with this anomaly. Guettat et al., 1982 ascribed this anomaly to an intra-Ordovician (Taconic) event. Unfortunately, this tectonic event has not been evidenced by structural and radiometric data. Others tended to correlate this anomaly with the Pan-African I or the Hercynian orogen. In southeastern Senegal and northern Guinea, where the Pan-African and Hercynian belts are geographically separated, a tiny "Bouguer anomaly" (Gamon anomaly) was correlated to the Pan-African I orogen of the Bassarides Belt (Ponsard et al., 1982).

Other geophysical investigations using magneto-telluric methods (Ritz and Robineau, 1986) or seismologic device (Dorbath et al., 1983) also argue for a suture but without more success concerning the age of the incipient orogen.

Geochronological data are rather few in number. Lille (1967), Bassot et al. (1963), and Bonhomme and Bertrand-Sarfati (1982) present a lot of results using both argon/potassium and strontium/rubidium method. Clauer et al. (1982) dated the sediments using the Ar/K method and Dallmeyer and Villeneuve (1987), and Dallmeyer and Lécorché (1989) the metamorphic formation with the Ar/Ar method. Blanc et al. (1986) and Le Goff et al. (2001) by U/Pb on zircons and Villeneuve et al. (in press) by K/Ar are completing this radiometric panel. Each method requests a specific interpretation regarding the geodynamic evolution. It is not possible here to develop the advantages and the limits of each one. But a statistic treatment of geochronological data (Fig. 19) points out several peaks. The main three are:

- 680–620 Ma (Pan-African I orogen);
- 600–590 Ma (opening of troughs at the western margin of the West African Craton);
- 330–270 Ma (Hercynian orogen).

The Pan-African II orogen (550–600 Ma) and the Taconic event (440 Ma) supported by Lécorché (1980) in the central Mauritanides is not registered by geochronological data. Indeed, the statistical treatment of geochronological data gives an appropriate method to unravel the geodynamic evolution. Obviously, a metamorphic episode dated by Ar/Ar does not have the same geodynamical significance as a volcanic or granitic intrusion dated by zircons. Moreover, the geographical distribution of measurements may introduce an important discrepancy regarding the global information. For example, the 600–590 Ma peak includes nearly 10 measures coming from the same area (Oued Amour).

### 3.4. Structural scheme and geodynamic evolution

To conclude this part devoted to the structure of the Mauritanides Belt we propose to take into account five

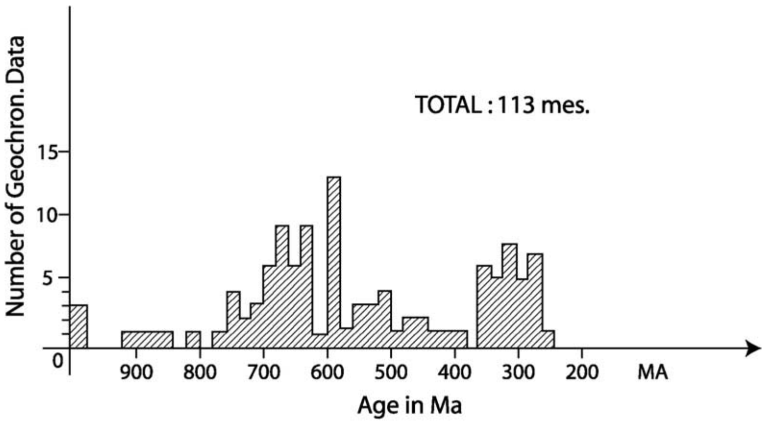

Fig. 19. *Geochronological diagram of the Mauritanides area*. Number of radiometric data versus age in Ma (millions years). Total data: 113.

units instead of the four previously accepted. The foreland unit, the para-autochthon unit, and the supra-structural allochthon unit are very similar to the previous one but the "infra-crustal unit" is divided into two parts taking into account the occurrence of basaltic and ophiolitic material, on the one hand and the presence of calc-alkaline granites and rhyolites, on the other hand.

To summarize we are distinguishing, from East to West:

- A foreland unit with part of the West African basement and sedimentary deposits.
- A "para-autochthon unit" with sedimentary and volcanic rocks mainly of Paleozoic age.
- An "ophiolitic, metamorphic and sedimentary unit". The ophiolites and metamorphic rocks come from the Pan-African I basement and the sedimentary and volcano-sedimentary rocks (basaltic and andesitic) come from the Paleozoic sedimentary cover.
- A "calc-alkaline granitic and ryholitic unit" with sedimentary or slightly metamorphosed rocks on top. The granitic and rhyolitic complex belong to the Pan-African I active margin and the sedimentary rocks to its Paleozoic cover. An unconformity underlined by a conglomeratic formation has been evidenced by Lille (1967) and by Chiron (1973) in this unit.
- A "supra crustal allochthon unit" including volcanic rocks (rhyolites and prasinites) volcano-sedimentary rocks (rhyolitic tufs) and metamorphic rocks coming from the Paleozoic sediments. The metamorphism display a Hercynian age.

The geodynamic evolution of the Mauritanides Belt during the Paleozoic time can be summarized as follows:

- *At the end of the Proterozoic and at the beginning of the Cambrian*, several troughs, parallel to the West African margin, opened on a Pan-African I basement. There are, at least, two horsts and grabens, from the East to the West. A graben corresponding to the Faleme Trough (foreland and para-autochthon units), a horst corresponding to the "ophiolitic and calc-alkaline units", a graben corresponding to the "supra crustal allochthon unit" and finally a horst concealed underneath the Senegalo–Mauritanian basin and reported by Chiron (1973). Grabens and horsts are filled with volcanic, volcano-sedimentary and sedimentary rocks interbedded with one or several glaciogenic levels.
- During the *Late Cambrian and until the Ordovician times*, a detritic material from the erosional process of the Rokelides Belt (Pan-African II orogen) is filling up the horsts and grabens.
- At the *end of the Ordovician times*, glacial sediments are covering the northern part of the Mauritanides.
- During *the Silurian and the Devonian times*, marine deposits are covering the Mauritanide area but volcanic material intrudes the sediments, like in the "Hamdallaye basin" (para-autochthon unit).
- At the end of the *Early Carboniferous times* (Visean), the collision between the West African and the North-American cratons (WAC and NAC) give way to the Appalachian–Mauritanian Belt. Consequently, the post Hercynian sedimentation moved to the North-East of the West African Craton.
- The splitting of the Appalachian and Mauritanides Belt occurred during the Triassic with the opening of the Atlantic Ocean.

### 3.5. Conclusions on the Mauritanides Belt

The subdivision between a Pan-African basement and several Paleozoic basins or troughs both remobilized by the Hercynian orogen, can explain the divergent interpretations previously proposed for the Mauritanides Belt.

Geologists who worked in areas where the Paleozoic sediments are dominant and the Pan-African basement largely concealed, concluded to the existence of a single Hercynian Belt (Sougy, 1962a; Bassot, 1966; Lepage, 1983; Lécorché, 1980) but geologists who worked in areas where the Pan-African basement is largely outcropping (Chiron, 1973; Villeneuve, 1984) concluded to a large involvement of the Pan-African basement in the Hercynian Mauritanide Belt.

However, the geodynamic model presented here has to be completed by news observations and data. Indeed, too many questions remain unsolved. For example:

- the lack of Early Paleozoic deposits in the northern part (Adrar Souttouf section);
- the correlations between the "Triad" (at the base of the cratonic Paleozoic basins) and the basal sedimentary or volcano-sedimentary levels in the Paleozoic troughs of the Mauritanides Belt;
- the significance of Middle Devonian ophiolitic material in the "para-autochthon unit" (Hamdallaye ophiolites) evidenced by Lafrance (1996);
- the tectonic effects of the Panfrican II in the central part of the Mauritanides proposed by Lécorché et al. (1989) with the support of radiometric data;
- the significance of the Taconic event supported by Lécorché (1980), in the Akjoujt section;
- the lack of carboniferous or Permian molassic deposits from the Hercynian orogen, in the Mauritanides area.

## 4. The West African Craton evolution during the Paleozoic

Correlations between the stratigraphic successions either in Fig. 7 (Taoudeni Basin) or in Fig. 10 (western Paleozoic troughs) evidence several disconformities and a lot of lateral facies changes. For example, the red and conglomeratic sandstones of the Youkounkoun Group turn into red pelites and shales with thin beds of limestones, when we go to the North. The Silurian is absent in eastern Senegal and relatively thick in Guinea and in the northern part of the Taoudeni Basin.

All these stratigraphic and sedimentological changes can be related to the main climatic events that occurred in the central Taoudeni Basin and to the tectonic events that underwent on the edges of the West African Craton. During the Paleozoic period, the southwestern margin suffered the Pan-African II orogen (550–500 Ma), the western and northern margin suffered a Hercynian orogen meanwhile the Eastern margin registered gentle compressive deformations.

Our geodynamic reconstruction will be limited to the Taoudeni Basin and its connected basins. Two main parts will be considered separately: the northern and the southern parts.

### 4.1. Evolution of the southern part

Figs. 20 and 21 show the southern part of the Taoudeni Basin along an East–West section that extends from the Bové Basin to the Adrar des Iforas, through the Tambaoura Massif and the Gourma Aulacogen.

- *From the Late Proterozoic to the Early Cambrian* (Fig. 20a), a Paleozoic cover starting with the "Triad" is covering this area from the Idrar des Iforas (in the Trans-Saharan Belt) to the Western Guinea where it is connected to the Komba Trough. The molassic deposits of the "Série pourprée" are located in intra-montagnous grabens opened in the Trans-Saharan Belt.
- *From the Late Cambrian to the Lower Ordovician* (Fig. 20b). Molassic deposits of the Youkounkoun Group are infilling intra-mountainous grabens like the Youkounkoun Basin whereas a sandstone-conglomerate cover is developing to the Eastern part of the WAC.
- *From the Middle to the Late Ordovician* (Fig. 20c), fluviatile and deltaic sandstones originating from the "Ivory Coast Shield" are covering the southern part, from the Florida (Villeneuve, 1984) to the Hoggar shield. The Late Ordovician tillite, well represented in the northern part, is not clearly evidenced in this southern part, even in the Mt. Gangan formation (Bové Basin).
- *From the Silurian to the end of the Devonian* (Fig. 20d), the sea very well developed in the northern part has probably invaded the southern part. This is argued by deltaic or marine deposits. But locally (Southeastern Senegal) there is a lack of Silurian deposits (Drot et al., 1978).
- *From the Late Carboniferous to the Early Permian* (Fig. 20e), the Hercynian Mauritanides Belt is thusted over the Paleozoic cover but no sediments from this period were produced in this southern part of the WAC.

### 4.2. Evolution of the northern part

Fig. 21 presents the main steps of the Northern Taoudeni Basin evolution.

- *From the Late Proterozoic to the Early Cambrian* (Fig. 21a) a green sedimentary succession, with the "Triad" at the base, is covering the Northern Taoudeni Basin from the Trans-Saharan Belt to the Akjoujt area where a deep trough (Faleme Trough) is opening.
- *From the Late Cambrian to the Early Ordovician* (Fig. 21b) the sedimentary materials with argillites, sandstones and stromatolitic limestones exhibit a red color due, probably, to a global climatic change.
- *From the Middle Ordovician to the Late Ordovician* (Fig. 21c). Sedimentation is white with cross-bedding sandstone to the South and tigillitic sandstones to the North, because of an erosional process in the Rokelides Belt. Upper Ordovician "tillitic" formations are recorded in many places (Deynoux, 1980; Deynoux and Trompette, 1981).
- *From the Late Ordovician to the Silurian* (Fig. 21d), the Silurian sea coming from the NE or the NW, through the Reguibat Shield, was generating black shales with graptolites and brachiopods.

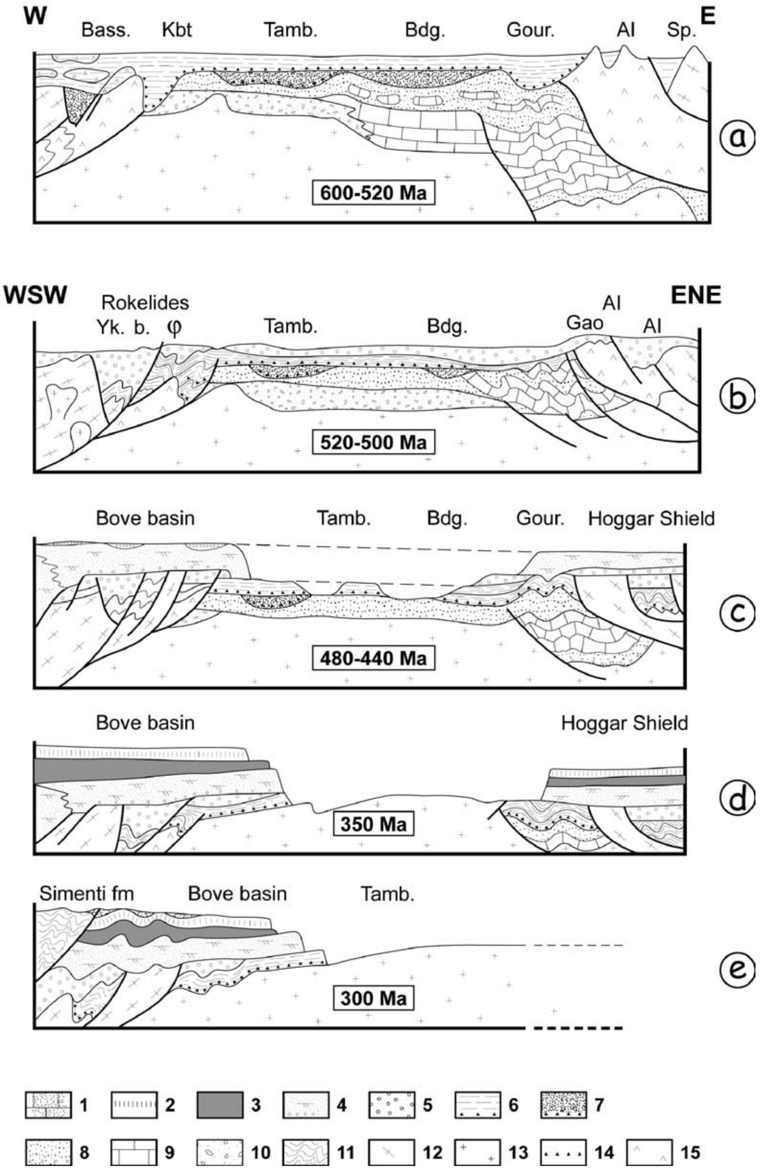

Fig. 20. *Tectonogram of evolution on the southern part of the Taoudeni Basin*. a—Infracambrian, b—Cambrian, c—Ordovician, d—Late Devonian/Early Carboniferous, e—Late Carboniferous, Ykb = Youkounkoun Basin, Bass = Bassaris Belt, KbT = Komba Trough, Tmb = Tambaoura, Bdg = Bandiagara, Gour = Gourma, AI = Adrar des Iforas Belt (Trans-Saharan Belt), Sp = "Série pourprée" grabens, *Legend*: 1—Carboniferous deposits, 2—Devonian sediments, 3—Silurian sediments, 4—Cambrian–Ordovician deposits, 5—Conglomerates and sandstones of the Youkounkoun Group, 6—Eocambrian to Cambrian "Green série" and "Série pourprée", 7—The Bakoye and Bandiagara groups, 8—Gourma Aulacogen formations, 9—Stromatolitic limestones of the Gourma, 10—The Segou Group (base of Super-Group 1), 11—Metamorphic formation of the Hercynian Belt, 12—Pan-African basement, 13—West African Craton basement, 14—Glacial deposits.

- *From the Early to the Middle Devonian* (Fig. 21e), there was a continuation of marine deposition but the Reggane and the Ahnet basins began to be individualized.
- *From the Middle to the Late Devonian* (Fig. 21f), the eastern basins are more individualized whereas a volcanic activity was developing in the western part.
- *From the Late Devonian to the Early Carboniferous* (Fig. 21g), the Carboniferous deposition is strongly developed in the eastern basins (Hank, Reggane and Ahnet) meanwhile the Mauritanides Belt was arising, on the western part.
- *From the Late Carboniferous to the Early Permian* (Fig. 21h), The Hercynian Mauritanides Belt was developing to the West and also to the North in the Ougarta Belt meanwhile the Eastern Paleozoic basins (Hank, Reggane and Ahnet) were separated by the Erg Chech and the Ahnet horsts.

### 4.3. Conclusion about the geodynamic evolution of the WAC

This geodynamic evolution is dominated by several marine transgressions coming from the oceans bordering this part of the Northwestern Gondwana margin and by the arising of the Hercynian Belt on the western and northern margins of the WAC.

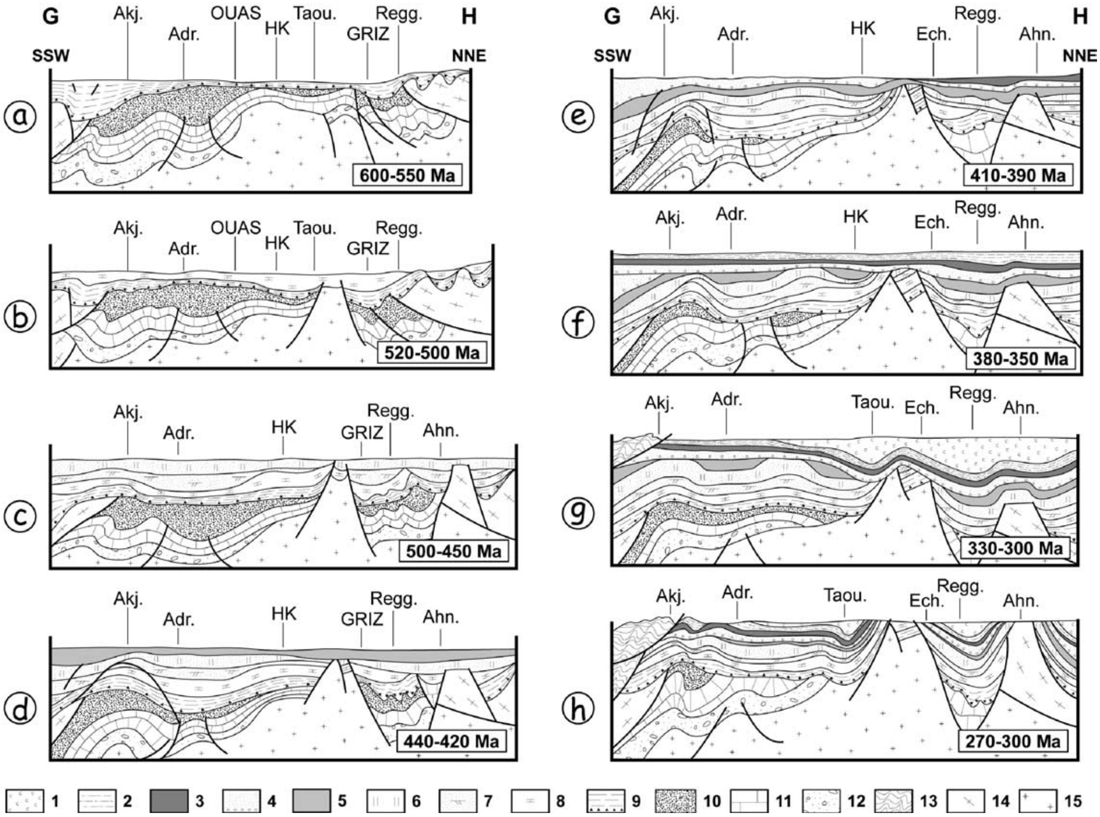

Fig. 21. *Tectonogram of evolution along the northern part of the Taoudeni Basin.* a—Late Neoproterozoic, b—Cambrian, c—Ordovician, d—Silurian, e—Early Devonian, f—Late Devonian, g—Carboniferous, f—Late Carboniferous–Early Permian. Akj = Akjoujt, Adr = Adrar de Mauritanie, Ouas = Ouassou, Hk = Hank, Taou = Taoudeni, Griz = Grizzim, Ech = Erg Chech, Regg.b = Reganne Basin, Ahn = Ahnet Basin. *Legend*: 1—Carboniferous deposits, 2—Devonian sediments, 3—Silurian sediments, 4—Cambrian–Ordovician deposits, 5—Sandstones with scolitus, 6—Conglomerates and cross-bedded sandstones, 7—Cambrian–Ordovician "Red série" with sandstones, pelites and limestones, 8—Late Neoproterozoic to Cambrian "Green série" and "Série pourprée", 9—The Bakoye and Bandiagara groups, 10—Gourma Aulacogen formations with the stromatolitic limestones of the Gourma, 11—The Segou Group (base of Super-Group 1), 12—Metamorphic formation of the Hercynian Belt, 13—Pan-African basement, 14—West African birrimian basement.

The main oceans are the Cambrian Prototethys (Iapetus Ocean), the Ordovician Rheic Ocean and the Silurian to Carboniferous Paleotethys (Theic Ocean, Moldanubian Ocean or Cimmerian Ocean) reported by Von Raumer et al. (2002). On this northwestern margin of Gondwana, the Paleozoic basins are connected to Paleozoic basins of North Africa, to the Florida subsurface Paleozoic Basin (the Suwanee Basin studied by Chowns and Williams, 1983; Villeneuve, 1988) and to the inner Gondwana basins of North-East Brazil (Amazonian Basin, Maranhao Basin) and South-East Ivory Coast Shield (Ghana basins) (Fig. 22).

After Thery (1982) and Villeneuve (1984) the inner Paleozoic basins were isolated from the others during the regressive periods (Late Ordovician, Early Devonian, Late Devonian and Early Carboniferous) and connected during the transgressive periods (Early Silurian and Emsian–Couvinian). The "Paynesville sandstones" (close to Monravia, Liberia) ascribed to the Devonian, could be a witness of the Florida/Amazonian connection during the Emsian transgression (Thorman, 1976).

These transgressions fed the Paleozoic basins until the uplift of the Hercynian Belt. This uplift, obviously, stopped the sedimentary process by the disappearance of the oceans, in this part of Gondwana.

A geodynamical anomaly is the small development of the Hercynian molasses around the Mauritanide Belt. There is a lack of Late Carboniferous or Permian basins with coarse clastic sediments along the Mauritanides Belt. We cannot decide between a nondeposition or a drastic erosional process.

Another element guiding the geodynamic evolution is the basement of the West African Craton is the transverse faults zones (for example the Bissau–Kidira–Tombouctou fault zone) which have been reworked by the Pan-African and Hercynian orogens. Two areas (the Ivory Coast and the Reguibat shields) were uplifted and played a major role as source-rocks of basinal materials. They also controlled the spreading of seas during the transgressive periods and became wall-marks in the belt developments.

## 5. Conclusions

Globally, the West African Craton (WAC) appears with its "guitar shape" as a classic cratonic domain where the sedimentation fed by the marine transgression of the

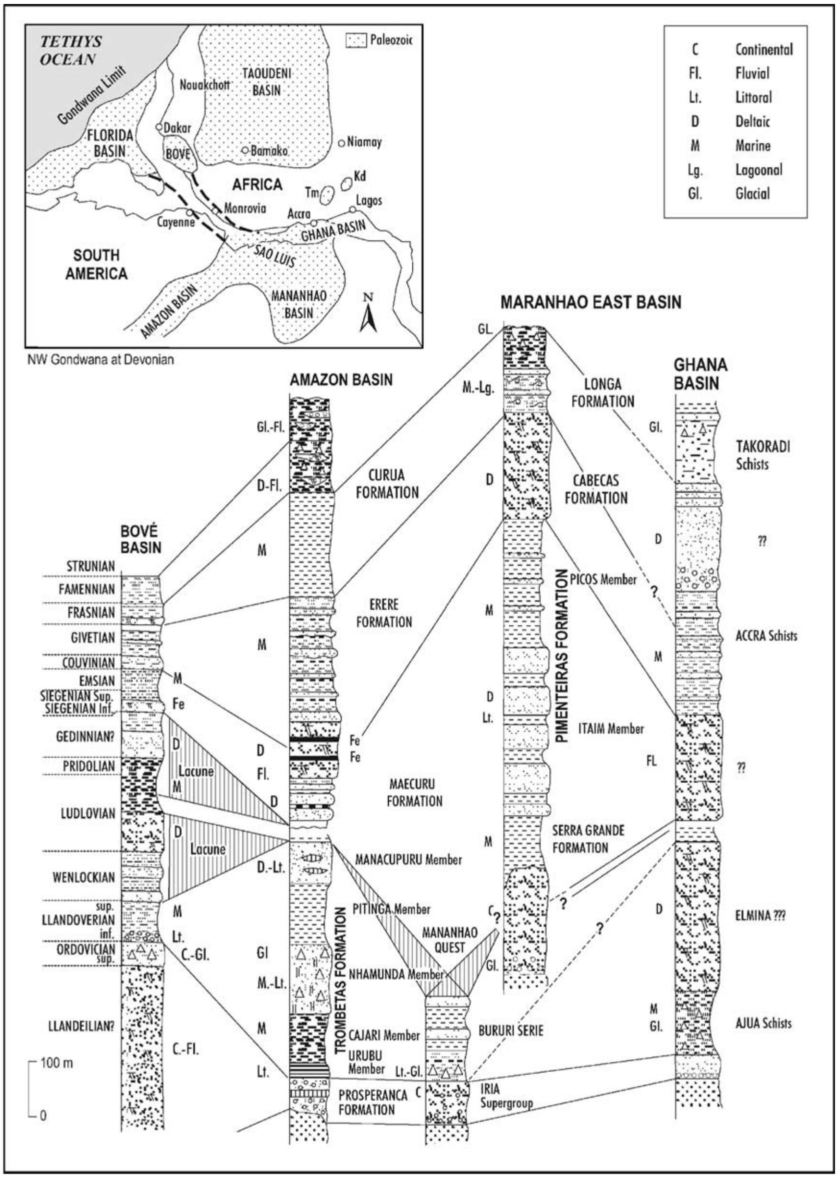

Fig. 22. Correlations between the main Paleozoic basins on the northwestern margin of Gondwana.

bordering oceans, was controlled by three main elements: the climatic element (glacial or warm periods), the basement faulting and the tectonic events (Pan-African II and Hercynian). The first two are dominant in the central part of the craton and the third one is dominant on the bordering areas.

But, there is an important lack of information. If the main geodynamical events are evidenced with a relatively good knowledge, numerous smaller events have been probably neglected.

The main tectonic events (Rokelides and Mauritanides belts), the main climatic events (Late Neoproterozoic and Late Ordovician glaciations alternating with the Llandovery and Emsian transgressions) and the main volcanic active periods (Cambrian and Middle Devonian) are recorded. But, certainly, numerous tectonic or sedimentological events remain unknown regarding a period extending over 300 Ma.

The main questions concern the correlations between events looking similar. One of them is related to the synchronicity of the glacial events related to the "Triad" which concerns a 100 Ma period (from the end of the Pan-African I orogen until the Early Cambrian "cap dolostones" of Walidiala). Many glacial events could have occured during such a long period. The second one concerns the synchroneity of the disconformities recorded both in the central basin and bordering basins. In the central basins the disconformities were carried out by the major climatic events (some of them of worldwide extension) whereas in the bordering basins or troughs, the disconformities were carried out by the tectonic events related to the collisions with neighboring cratons (Hoggar Craton for the

Trans-Saharan Belt, Guyana Craton for the Rokelides Belt and North American Craton for the Mauritanides Belt).

On the other hand, the correlations between the sedimentary "sub-autochthon unit" and the metamorphic "supra-crustal allochthon unit" are not well understood.

This synthetic view of the West African Paleozoic basins and belts points out the necessity of new and appropriate studies. Despite the number and the quality of the previous works, this country, as large as Western Europe, does not support a scientific comparison with many European belts and basins.

## References

Affaton, P., 1987. Le bassin des Volta (Afrique de l'Ouest): une marge passive d'âge Protérozoïque supérieur, tectonisée au Panafricain (600 + 50 Ma). Thèse Université Aix-Marseille III, Marseille, p. 292.

Affaton, P., Rahaman, M.A., Trompette, R., Sougy, J., 1991. The Dahomeyide Orogen: tectonothermal evolution and relationships with the Volta Basin. In: Dallmeyer, R.D., Lécorché, J.P. (Eds.), The West African Orogens and Circum-Atlantic Correlatives. Springer-Verlag, Berlin, pp. 107–122.

Ait Kaci Ahmed, A., Moussine-Pouchkine, A., 1987. Lithostratigraphie, sédimentologie et évolution de deux bassins molassiques intramontagneux de la chaîne Pan-Africaine: la Série pourprée de l'Ahnet, Nord-Ouest du Hoggar, Algérie. J. Afr. Earth Sci. 6, 525–535.

Akmetjanov, B.S., Loutsenko, V.F., Diallo, H., 1976. Carte des anomalies de Bouguer (1/500000) et résultats des travaux géophysiques en Guinée (Conakry) occidentale. In: "notice de la carte géologique de la République de Guinée". Feuille de Gaoual, Rapp: Technoexport, Conakry, pp. 184–205.

Alia Medina, M., 1949. Caracteristicas morphograficas y geologicas de la zona septentrional del Sahara Espanol. Inst. Ciencas. Nat. José de Acosta, Ser. Geol. 2, 260p.

Alidou, S., 1987. Etude géologique du bassin Paléo-Mésozoique de Kandi, Mém. du CIFEG, no. 13, Paris, 119p.

Alidou, S., Lang, J., Roman, Seilacher, A., 1986. Eléments de datation en faveur d'un âge Paleozoique et Mésozoique du bassin de Kandi (Nord-Est Bénin, Afrique de l'Ouest). J. Afr. Earth Sci. 5 (4), 339–344.

Allegre, C., Caby, R., 1972. Chronologie absolue du Précambrien de l'Ahaggar occidental. C.R. Acad. Sci., Paris 275, 2095–2098.

Allen, P.M., 1968. The stratigraphy of a geosynclinal succession in western Sierra Leone. Geol. Mag. 105, 62–73.

Allen, P.M., 1969. Geology of part of an orogenic belt in western Sierra Leone, West Africa. Geol. Rundshau 58, 588–620.

Amorin Ferreira, H., 1966. Observacoes gravimetricas no territorio da Guinea Portugese. Servicio Meteorologica Nacional, Lisboa, 9p.

Arribas, A., 1968. El Precambrico del Sahara Espanol y sus relations con las series sedimentarias mas modernas. Boletin Geol. Minero LXXIX-V, 445–480.

Bär, P., Riegel, W., 1974. Les microflores des séries paléozoïques du Ghana (Afrique occidentale) et leurs relations paléofloristiques. Sci. Géol. Bull., Strasbourg, Fr. 27, 39–58.

Bassot, J.P., 1966. Etude géologique du Sénégal oriental et de ses confins guinéo-maliens. Mem. Bur. Rech. Geol. Min., Paris, 40, 322p.

Bassot, J.P., Bonhomme, M., Roques, M., Vachette, M., 1963. Mesures d'âges absolus sur les séries précambriennes et paléozoïques du Sénégal oriental. Bull. Soc. Géol. Fr. 5, 401–405.

Bechennec, F., 1980. Etude géologique du Nord-Est de la Guinée Bissau. BRGM, rapport. 79, 41p.

Bertrand-Sarfati, J., Moussine-Pouchkine, A., Affaton, P., Trompette, R., Bellion, Y., 1991. Cover sequences of the West African Craton. In: Dallmeyer, R.D., Lécorché, J.P. (Eds.), The West African Orogens and Circum-Atlantic Correlatives. Springer-Verlag, pp. 65–82.

Bertrand-Sarfati, J., Moussine-Pouchkine, A., Amar, B., Ait Kaci Ahmed, A., 1995. First Ediacaran fauna found in Western Africa and evidence for an Early Cambrian glaciation. Geology 23, 133–136.

Bertrand-Sarfati, J., Flicoteaux, R., Moussine-Pouchkine, A., Ait Kaci Ahmed, A., 1997. Lower Cambrian apatitic stromatolites and phosphoarenites related to the glacio-eustatic cratonic rebound (Sahara, Algeria). J. Sediment. Res. 67, 957–974.

Black, R., Caby, R., Moussine-Pouchkine, A., Bayer, A., Bertrand, J.M., Boullier, A.M., Fabre, J., Lesquer, A., 1979. Evidence for Late Precambrian plate tectonics in West Africa. Nature 278, 223–227.

Blanc, A., Caruba, C., Caruba, R., Dars, R., Ohnenstetter, D., Peucat, J.J., 1986. Age archéen du socle de la fenêtre de Bou Naga (Mauritanie); age panafricain des massifs intrusifs alcalins, 11eme Réunion ann. Sciences Terre, Clermont-Ferrand, p. 19.

Bonhomme, M., Bertrand-Sarfati, J., 1982. Correlation of Proterozoic sediments of Western and Central Africa and South America based upon radiochronological and paleontological data. Precamb. Res. 18, 171–194.

Borocco, J., Lefèvre, R., 1954. Notes paleogéographiques sur le bassin de Tindouf. Rapp. CEP, Alger, 13p.

Boudda, A., Choubert, G., 1972. Sur la limite inférieure du Cambrien au Maroc. C.R. Acad. Sci., Paris 275D, 5–8.

Boufeev, Y.B., 1968. Notice explicative de la carte géologique de la République de Guinée au 1/200000, Serv.Geol. Guinée, Conakry, 182p.

Bourguet, L., 1966. Synthèse hydrogéologique et aménagement hydraulique du Sud-Est Mauritanien. Rapp. BURGEAP, no. 415, Nouakchott, 88p.

Caby, R., 1983. Les molasses pan-africaines en Afrique occidentale: synthèse des données stratigraphiques, paléogéographiques et géochronologiques. In: Conrad, G. (Ed.), Bassins sédimentaires en Afrique. Trav. Lab. Sci. Terre, St-Jérôme, Marseille, vol. 15(A), pp. 11–12.

Caby, R., 2003. Terranne assembly and geodynamic evolution of central-western Hoggar: a synthesis. J. Afr. Earth Sci. 37, 133–159.

Caby, R., Fabre, J., 1981. Tillites in the latest Precambrian strata of the Touareg Shield (central Sahara). In: Harland, W.B., Hambrey, M.J. (Eds.), Earth's Pre-Pleistocene Glacial Record. Cambridge Univ. Press, pp. 146–149.

Caby, R., Moussu, H., 1967. Une grande série détritique du Sahara: stratigraphie, paléogéographie et évolution structurale de la Série pourprée de l'Aseg'rad et le Tanezrouft oriental (Algérie). Bull. Soc. Géol. Fr. 9, 876–882.

Caby, R., Andréapoulos-Renaud, U., Gravelle, M., 1982. Cadre géologique et géochronologique U/Pb sur zircons des batholites précoces dans le segment pan-africain du Hoggar central (Algérie). Bull. Soc. Géol. Fr. 7, 677–684.

Chiron, J.C., 1973. Etude géologique de la chaîne des Mauritanides entre le parallèle de Moudjeria et le fleuve Sénégal (Mauritanie). Mem. BRGM, 84, 284p.

Chaloner, W.G., Mensah, M.K., Crane, M.D., 1974. Non-vascular land plants from the Devonian of Ghana. Paleontology 17, 925–947.

Cheng, K.Ly., 1982. Sedimentology of nearshore marine bar sequence from depositional regressive shoreline deposits of the central coast of Ghana, West Africa. J. Sediment. Petrol. 52 (1), 199–208.

Chowns, T.M., Williams, C.T., 1983. Pre-Cretaceous rocks beneath the Georgia coastal plain. Regional implications. U.S. Geol. Survey, Prof. Paper 1313-l, 42p.

Clauer, N., 1976. Géochimie isotopique du strontium des milieux sédimentaires. Application à la géochronologie de la couverture du craton ouest-africain Sci. Géol. Mem., Strasbourg, 45, 256p.

Clauer, N., Deynoux, M., 1987. New information on the probable isotopic age of the Late Proterozoic glaciation in West Africa. Precamb. Res. 37, 89–94.

Clauer, N., Caby, R., Jeannette, D., Trompette, R., 1982. Geochronology of sedimentary and metasedimentary rocks of the West African Craton. Precamb. Res. 18, 53–71.

Creen, Y., Rechenman, J., 1965. Mesures gravimétriques et magnétiques au Sénégal et en Mauritanie occidentale. Cah. ORSTOM, sér. Geophysique, Paris, 6, 59p.

Culver, S.J., Hunt, D., 1991. Lithostratigraphy of Precambrian–Cambrian boundary sequence in the southwestern Taoudeni Basin, West Africa. J. Afr. Earth Sci. 13, 407–413.

Culver, S.J., Magee, A.W., 1987. Late Precambrian glacial deposits from Liberia, Sierra Leone and Liberia, West Africa. Natl. Geogr. Res. 3, 69–81.

Culver, S.J., Williams, H.R., 1979. The Late Precambrian and Phanerozoic geology of Sierra-Leone. J. Geol. Soc. Lond. 136, 605–618.

Culver, S.J., Pojeta, J., Repetski, J.E., 1988. First record of Early Cambrian shelly microfossils from West Africa. Geology 16, 596–599.

Culver, S.J., Williams, H.R., Venkatakrishnan, R., 1991. The Rokelide orogen. In: Dallmeyer, R.D., Lécorché, J.P. (Eds.), The West African Orogens and Circum-Atlantic Correlatives. Springer-Verlag, Berlin, pp. 123–150.

Dacheux, A., 1967. Etude photogéologique de la chaîne du Dhlou (Zemmour-Mauritanie septentrionale). Laboratoire de Géologie, Université de Dakar, rapp. 22, 45p.

Dallmeyer, R.D., Lécorché, J.P., 1989. $^{40}$Ar/$^{39}$Ar polyorogenic minéral record within the central Mauritanide orogen, West Africa. Geol. Soc. Am. Bull. 101, 55–70.

Dallmeyer, R.D., Villeneuve, M., 1987. $^{40}$Ar/$^{39}$Ar polyorogenic minéral age record of a polyphased tectonothermal evolution in the southern Mauritanide orogen, southeastern Senegal. Geol. Soc. Am. Bull. 98, 602–611.

Delpy, J., 1967. Etudes géologiques dans l'Adrar et le Tagant (RIM). Rapp. Inédit Ministère du Développement, Direction des Mines et de la Géologie, Nouakchott, 257p.

Destombes, J., Sougy, J., Willefert, S., 1969. Révisions et découvertes paléontologiques dans le Cambro-ordovicien du Zemmour (Mauritanie septentrionale). Bull. Soc. Géol. Fr. 11, 185–206.

Destombes, J., Hollard, H., Willefert, S., 1985. Lower Paleozoic rocks of Morocco. In: Holland, C.H. (Ed.), Lower Paleozoic Rocks of the World. John Wiley, New York, pp. 91–336.

Deynoux, M., 1980. Les formations glaciaires du Précambrien terminal et de la fin de l'Ordovicien en Afrique de l'ouest. Deux exemples de glaciation d'inlandsis sur une plate-forme stable. Trav. Lab. Sci. Terre St Jérôme Marseille, (B), 17, 554p.

Deynoux, M., Trompette, R., 1981. Late Precambrian tillites of the Taoudeni Basin. In: Harland, W.B., Hambrey, M.J. (Eds.), Earth's Pre-Pleistocene Glacial Record. Cambridge Univ. Press, pp. 123–131.

Dia, O., 1984. La chaîne panafricaine et hercynienne des Mauritanides face au bassin Protérozoïque supérieur à Dévonien de Taoudenni, dans le secteur clef de Mejeria (Taganet, sud RIM). Thèse Université Aix-Marseille, Marseille, France, 516p.

Diop, C.B., 1996. Structures et circulations de fluides dans un avant pays synschisteux:le système de chevauchement des Mauritanides du Sénégal. Thèse Univ. Nancy, 174p.

Dorbath, C., Dorbath, L., Le Page, A., Gaulon, R., 1983. The West African Craton margin in eastern Senegal: a seismological study. Ann. Geophys. 1 (1), 25–36.

Drot, J., Lardeux, H., Le Page, A., 1978. Sur la découverte de Silurien supérieur au sommet de la série de Youkounkoun au Sénégal oriental: implications paléogéographiques et structurales. Bull. Soc. Géol. Minér. de Bretagne, Rennes 10 (1), 7–30.

Ducrot, J., Lancelot, J.R., 1977. Problème de la limite Précambrien–Cambrien: étude radiochronologique par la méthode U–Pb sur zircons du volcan du Jbel Boho (Anti-Atlas marocain). Can. J. Earth Sci. 14, 2771–2777.

Graverot, R., Planchon, J.P., 1964. Bordure sédimentaire Nord et Nord Ouest de l'axe cristallin Yetti–Eglab. Soc. Petrol. Valence, Rapp 23, 54p.

Guettat, Z., 1981. Etude gravimétrique de la bordure occidentale du craton Ouest africain. These 3ème cycle, USTL, Montpellier, Fr., 185p.

Guettat, Z., Lécorché, J.P., Roussel, J., 1982. Interprétation des anomalies gravimétriques de la marge occidentale du craton Ouest Africain. Bull. Soc. Géol. Fr. 7 (24), 763–776.

Hoffman, P., 1991. Did the breakout of Laurentia turn Gondwanaland inside-out? Science 252, 1409–1412.

Huddleston, M., 1944. Progress report for April 1944, Report Gold Coast geol. Survey, Accra, unpublished.

Jeannette, D., Schumacher, F., 1976. L'Infracambrien volcano-détritique de la bordure occidentale du Massif du Siroua (Anti-Atlas central). C.R. Acad. Sci., Paris 282, 823–826.

Jeannette, D., Benziane, F., Yazidi, A., 1981. Lithostratigraphie et datation du Protérozoïque de la boutonnière d'Ifni (Anti-Atlas, Maroc). Precamb. Res. 14, 363–378.

Junner, N.R., Hirst, T., 1946. The geology and hydrology of the Voltaian Basin. Gold Coast Geol. Surv. Mem. 8, 50p.

Kjemperud, A., Agbesinyale, W., Agdestein, T., Gustafsson, C., Yukler, A., 1992. Tectono-Stratigraphic history of the Keta Basin, Ghana, with emphasis on late erosional episodes. In: Géologie Africaine: coll. Geol., Libreville, recueil des Communic, 6–8 May 1991, pp. 55–69.

Konaté, M., Guiraud, M., Alidou, S., Clermonté, J., Drouet, J.J., Lang, J., 1994. Structuration et dynamique sédimentaire du bassin paléozoïque en demi-graben de Kandi (Bénin, Niger). C.R. Acad. Sci., Paris 318 (II), 535–542.

Lafrance, A., 1996. La zone frontale des Mauritanides méridionales. Thèse université d'Aix-Marseille III, Aix-en-Provence, France, 351p.

Lafrance, A., Houdry, F., Le Page, A., Lécorché, J.P., Villeneuve, M., Caruba, R., 1993. Réactivation de la zone frontale d'une chaîne polyphasée: l'exemple de la chaîne des Mauritanides (Afrique de l'Ouest). C.R. Acad. Sci., Paris 316 (II), 785–790.

Latiff, R.S.A., Andrews, J.R., Wright, L.I., 1997. Emplacement and reworking of the Marampa group allochthon, Northwestern Sierra Leone, West Africa. J. Afr. Earth Sci. 25 (3), 333–351.

Lécorché, J.P., 1980. Les Mauritanides face au Craton Ouest africain: structure d'un secteur clef: la région d'Ijibitène (R.I.M). Thèse Université Aix-Marseille III, Marseille, France, 446p.

Lécorché, J.P., Dallmeyer, R.D., Villeneuve, M., 1989. Definition of tectonostratigraphic terranes in the Mauritanide, Bassarides and Rokelides orogen, West Africa. In: Dallmeyer, R.D. (Ed.), Terranes of the Circum-Atlantic Paleozoic orogens. Geol. Soc. Amer. Bull., Special Paper, 230, pp. 134–144.

Le Goff, E., Guerrot, C., Maurin, G., Johan, V., Tegyey, M., Ben Zarga, M., 2001. Découverte d'éclogites hercyniennes dans la chaîne septentrionale des Mauritanides (Afrique de l'Ouest). C.R. Acad. Sci. 333, 711–718.

Legrand, P., 1969. Description de Westonia chudeaui nov. Sp. Brachiopode inarticulé de l'Adrar Mauritanien (Sahara occidental). Bull. Soc. Géol. Fr. 11, 251–256.

Legrand, P., 1983. Aperçu sur l'histoire géologique de l'Algérie paléozoïque. In: Fabre, J. (Ed.), Lexique Stratigraphique International. Vol. Afrique de l'Ouest, Pergamon Press, Oxford, pp. 96–108.

Lepage, A., 1983. Les grandes unités des Mauritanides aux confins du Sénégal et de la Mauritanie. Thèse Université Aix-Marseille III, Marseille, France, 518p.

Lepage, A., 1986. La lithostratigraphie des grandes zones structurales des Mauritanides, entre le 14° et le 16° parallèle Nord. J. Afr. Earth Sci. 5 (2), 119–134.

Leprun, J.C., Trompette, R., 1969. Subdivision du voltaïen du massif de Gobnangou (République de Haute Volta) en deux séries discordantes séparées par une tillite d'âge Eocambrien probable. C.R. Acad. Sci., Paris 269, 2187–2190.

Lille, R., 1967. Etude géologique du Guidimaka (Mauritanie). Mémoires du BRGM, 55, Orléans, 399p.

Liouville, M., Graverot, R., 1963. Bordure sédimentaire Nord de l'Axe cristallin Yetti-Eglab. Evolution des sédiments de la frontière du Sahara espagnol à l'Erg Chech. Soc. Saharienne de Recherches Pétrolières, 16, 14p.

Marcelin, J., 1964. Plissements superposés, nappes et métamorphisme dans la région d'Akjoujt (Mauritanie). C.R. Acad. Sci., Paris 259, 3291–3293.

Marchand, J., 1955. Rapport de fin de campagne 1954–1955 en Mauritanie. Dir. Min. Géol. A.O.F, Dakar, 29p.

Martyn, J., Strikland, C., 2004. Stratigraphy, structure and mineralisation of the Akjoujt area (Mauritania). J. Afr. Earth Sci. 38 (5), 489–503.

Mensah, M.K., 1973. On the question of the age of the Sekondi Series: Upper Devonian or Lower Carboniferous rocks of Ghana. Ghana J. Sci. 2, 134–139.

Ould Souelim, M., 1990. Les roches mafiques et ultramafiques du Guidimaka (Mauritanie) et les gisements de chromite associés. Thèse Université de Nancy, France, 292p.

Ponsard, J.F., Lesquer, A., Villeneuve, M., 1982. Une suture panafricaine sur la bordure occidentale du craton ouest africain? C.R. Acad. Sci., Paris, sér. II 295, 1161–1164.

Ratschiller, L.K., 1970. Lithostratigraphy of the Northern Spanish Sahara. University of Triestre, Italy, Institut of Geology, mem. 88, 78p.

Rémy, P., 1987. Le magmatisme basique des Mauritanides centrales: une ouverture océanique limitée d'âge Protérozoïque supérieur en sAfrique de l'Ouest. Thèse Univ. Nancy 1, France, 281p.

Ritz, M., Robineau, B., 1986. Crustal and upper mantle electrical conductivity structures in West Africa: geodynamic implications. Tectonophysics 124, 115–132.

Roman'ko, Y.F., 1974. New data on the Paleozoic stratigraphy of West Africa. Dokl. Acad. Nauk. SSSR, Moscow, 217, 420, 423.

Roussel, J., Lécorché, J.P., 1983. Regional gravity trends associated with the Mauritanides orogen (West Africa). In: Schenk, P.E. (Ed.), Regional Trends in the Geology of the Appalachian–Caledonian–Hercynian–Mauritanides orogen, pp. 63–71.

Schmitt, M., 1978. Stromatolites in the Tiout section, Precambrian–Cambrian boundary beds. Anti-Atlas, Geol. Mag. 115, 95–100.

Sougy, J., 1962a. West African fold belt. Geol. Soc. Am. Bull. 73 (7), 871–876.

Sougy, J., 1962b. Contribution a l'étude géologique des guelbs Bou Leriah (Région d'Aoucert, Sahara espagnol). Bull. Soc. Géol. Fr. 4, 436–445.

Sougy, J., 1964. Les formations paléozoïques du Zemmour noir (Mauritanie septentrionale). Etude stratigraphique, pétrographique et paléontologique. Thèse doct. Université de Nancy, France, 679p.

Sougy, J., 1969. Grandes lignes structurales de la chaîne des Mauritanides et de son avant-pays (socle précambrien et sa couverture infracambrienne et paléozoïque), Afrique de l'Ouest. Bull. Soc. Géol. Fr. XI (2), 133–149.

Sougy, J., Bronner, G., 1969. Nappes hercyniennes au Sahara espagnol méridional (tronçon Nord des Mauritanides). In: 5th Int. Coll. Afr. Géol. Ann. Fac. Sciences, Université de Clermont Ferrand, vol. 41(19), pp. 75–76.

Tessier, F., Dars, R., Sougy, J., 1961. Mise en évidence de charriages dans la série d'Akjoujt (RIM). C.R. Acad. Sci., Paris 252, 1186–1188.

Thery, J.M., 1982. Constitution du Nord-Ouest du continent sud-Americain avant les tectoniques andines. T1: Précambrien et Paléozoïque. Thèse Université de Bordeaux, Bordeaux, Fr., 126p.

Thorman, C.H., 1976. Implications of klippen and a new sedimentary unit at Gibi Mountain, Liberia, West Africa, in the problem of Pan-African-Liberian age province boundary. Geol. Soc. Am. Bull. 87, 851–856.

Trompette, R., 1973. Le Précambrien supérieur et le Paléozoïque inférieur de l'Adrar de Mauritanie (bordure occidentale du bassin de Taoudenni, Afrique de l'Ouest). Un exemple de sédimentation de craton. Etude stratigraphique et sédimentologique. Trav. Lab. Sci. Terre St-Jérôme, Marseille, 7(B), 702p.

Tucker, J.W., 1991. Aspects of the Tano Basin stratigraphy revealed by recents drilling in Ghana. In: Géologie Africaine: coll. Géol., Libreville, recueil des Communic, 6–8 May 1991, pp. 153–159.

Tucker, M.E., Reid, D.C., 1973. The sedimentology and context of Late Ordovician glacial marine sediments from Sierra Leone, West Africa. Palaeogeogr. Palaeoclimat. Palaeoecol. 13, 298–307.

Villemur, J.R., 1967. Reconnaissance géologique et structurale du Nord du bassin de Taoudeni. Mém. Bur. Rech. Géol. Min. 51, 151p.

Villeneuve, M., 1984. Etude géologique de la bordure SW du Craton Ouest africain. Thèse, Université Aix-Marseille III, Marseille, 552p.

Villeneuve, M., 1988. Corrélations et évolution des bassins sédimentaires de la marge NW du continent de Gondwana au cours du Paleozoique inférieur (de la Mauritanie au Venezuela). J. Afr. Earth Sci. 7 (2), 451–461.

Villeneuve, M., 1990. Structure et évolution des bassins du Panafricain II dans la partie occidentale du craton Ouest Africain. Bull. Soc. Géol. Fr. (8) VI, 1, pp. 155–165.

Villeneuve, M., 1991. Découverte de la molasse de démantèlement de l'orogenèse du Panafricain I dans la chaîne des Bassarides, Afrique de l'Ouest. C.R. Acad. Sci., Paris 313, 557–564.

Villeneuve, M., Cornée, J.J., 1994. Structure, evolution and palaeogeography of the West African Craton and bordering belts during the Neoproterozoic. Precamb. Res. 69, 307–326.

Villeneuve, M., Da Rocha Araujo, P.R., 1984. Lithostratigraphie du bassin paléozoïque de Guinée (Afrique de l'Ouest). Bull. Soc. Géol. Fr. 7 (26), 1033–1039.

Villeneuve, M., Dallmeyer, R.D., 1987. Geodynamic evolution of the Mauritanides, Bassarides and Rokelides orogens (West Africa). Precamb. Res. 37, 19–28.

Villeneuve, M., Bonvalot, S., Albouy, Y., 1990. L'agencement des chaînes (panafricaines ethercyniennes) sur la bordure occidentale du craton ouest africain. C.R. Acad. Sci., Paris 310 (II), 955–962.

Villeneuve, M., Rochet, J., Faye, M., 1993. Héritages structuraux panafricains et hercyniens sur la marge africaine de l'océan Atlantique, entre la Mauritanie et le Libéria. Bull. Soc. Géol. Fr. 164 (6), 851–860.

Villeneuve, M., Bellon, H., El Archi, A., Olivet, J.L., Rehault, J.P., in press. Mise en évidence du Panafricain I dans l'Adrar Souttouf (Sahara marocain). C.R. Geosci.

Von Raumer, J.F., Stampfli, G.M., Borel, G., Bussi, F., 2002. Organisation of pre-variscan basement areas at the North-Gondwanan margin. Int. J. Earth Sci. 91, 35–52.

Zimmermann, M., 1960. Nouvelle subdivision des séries anté-gothlandiennes de l'Afrique occidentale (Mauritanie, Soudan, Sénégal). In: 21st Sess. Int. Geol. Congr. Copenhagen, part VIII, pp. 26–36.