[AMERICAN JOURNAL OF SCIENCE, VOL. 280, MARCH, 1980, P. 224-248]

THE TECTONO-STRATIGRAPHIC RELATIONSHIPS BETWEEN THE UPPER PRECAMBRIAN AND LOWER PALEOZOIC VOLTA BASIN AND THE PAN-AFRICAN DAHOMEYIDE OROGENIC BELT (WEST AFRICA)

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ABSTRACT: Two unconformities, the older marked by a tillite, make it possible to distinguish three major lithostratigraphic sequences within the Volta Basin: (1) *a lower sequence,* discordant upon the basement of the Dorsal of Léo, essentially clastics commencing around 1000 m.y. ago; (2) *a middle sequence,* of approximately Vendian age (680-570 m.y.), essentially flyschoid, commencing with a tillite associated with barote-bearing limestones and silexites; (3) *an upper sequence,* of red continental shales and sandstones, which represents the molasse of the Dahomeyides.

The lower and middle sequences, more or less folded and metamorphosed in association with basement, form the Pan-African Chain (about 600 m.y.) of the Dahomeyides, which comprises 3 major structural units. These units are affected by an important phase of thrusting notable for the emplacement of thrust nappes of basement gneisses. The thrusting was accompanied by low-grade metamorphism which, in the eastern units, is superimposed upon an earlier mesozonal metamorphism and associated folding.

INTRODUCTION

West Africa comprises (fig. 1) three major structural units: (1) an ancient Precambrian basement with a Paleozoic and also in part late Precambrian cover, *the West African craton;* (2) fold belts bordering the craton, which were developed during the *Pan-African* (around 600 m.y.) or the *Hercynian* (350-300 m.y.) *orogenies;* (3) Mesozoic-Cenozoic sedimentary basins.

The ancient metamorphic basement is present as the Dorsal Reguibat in the north and the Dorsal of Léo in the south. It is made up of older Precambrian (2700 m.y.), which dominates in the west, and Middle Precambrian (2000-1800 m.y.), which dominates in the east. The sedimentary cover of Late Precambrian and Paleozoic age forms the Taoudeni, Tindouf, and Volta Basins. The North and the South Hoggar Plateaus (fig. 1) are, on the other hand, uniquely Paleozoic. The Pan-African chains border the West African craton: to the southwest the *Rokelides,* and to the east the *Dahomeyides,* the *Gourma chain,* and the *Hoggar chain* (Pharusides). The western side of the craton is bordered by the *Mauritanides,* essentially Hercynian (post Frasnian), though in its southern part, it probably contains Caledonian and Pan-African portions.

The association of the Volta Basin and the Dahomeyides, in their northern part, is particularly appropriate for a study of the relationships

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between a cratonic basin and a Pan-African chain, because of the relatively well exposed terrane and the analogies between the lithofacies of the basin and the chain.

The first coherent syntheses of this zone are found in the works published (1940-1960) by the Geological Surveys of Ghana, those of French West Africa (Togo, Dahomey now Benin, Upper-Volta), and to a lesser extent that of Nigeria. The early views of the British geologists working in Ghana were synthesized by Junner (1940) who distinguished six assemblages from youngest to oldest (fig. 2A): Voltaian/Buem/Akwapimian = Togo Series/Tarkwaian/Birrimian/Archaean. The concept of the French geologists working in Togo and Benin was summarized by Roques (1948) and for the zone considered here, by Aicard (1957) and Pougnet (1957) who distinguished (fig. 2B) in order of increasing age:

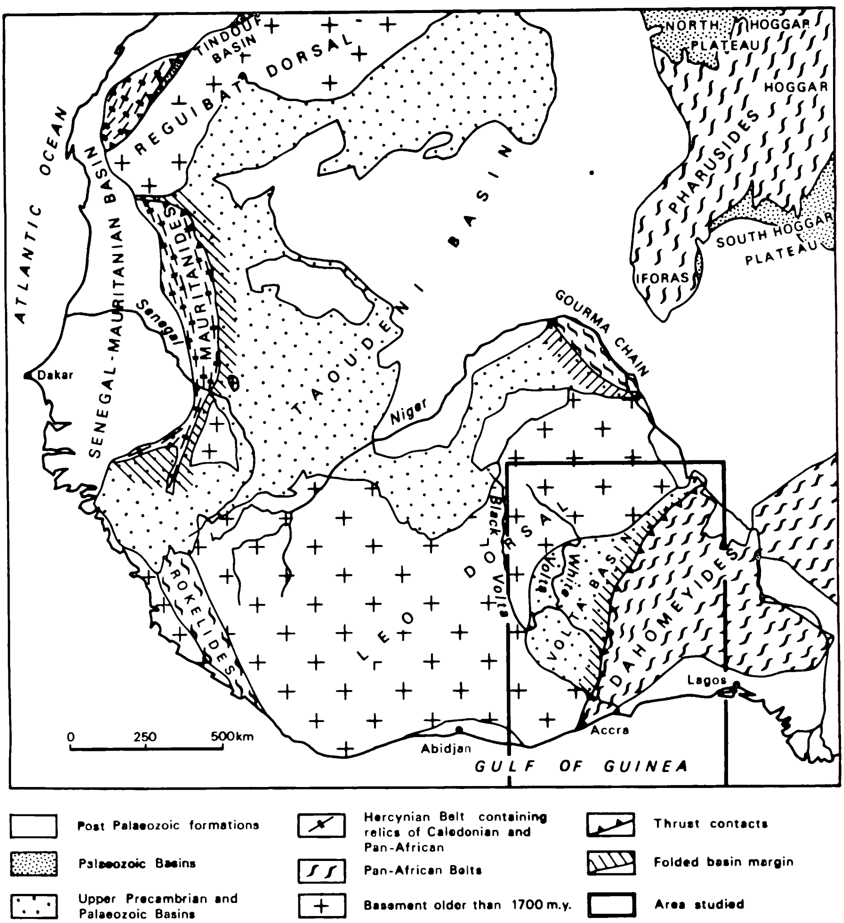

Fig. 1. Generalized structural map of West Africa.

Voltaian/Buem/Tarkwaian/Birrimian = Kandé-Boukombé Series/Atacorian = Akwapimian/Dahomeyan or Archaean. Junner (1940) as well as Roques (1948) constructed a succession of different series which for them represented distinctive chronostratigraphic units; the differences between the two concepts were basically a result of the classification systems used. Roques (1948) essentially based his arguments on the intensity of metamorphism and of folding, believing that the older rocks are the most strongly deformed and metamorphosed.

The hypothesis proposed by Junner (1940) and Roques (1948) of a vertical succession of chronostratigraphic units can now be replaced by

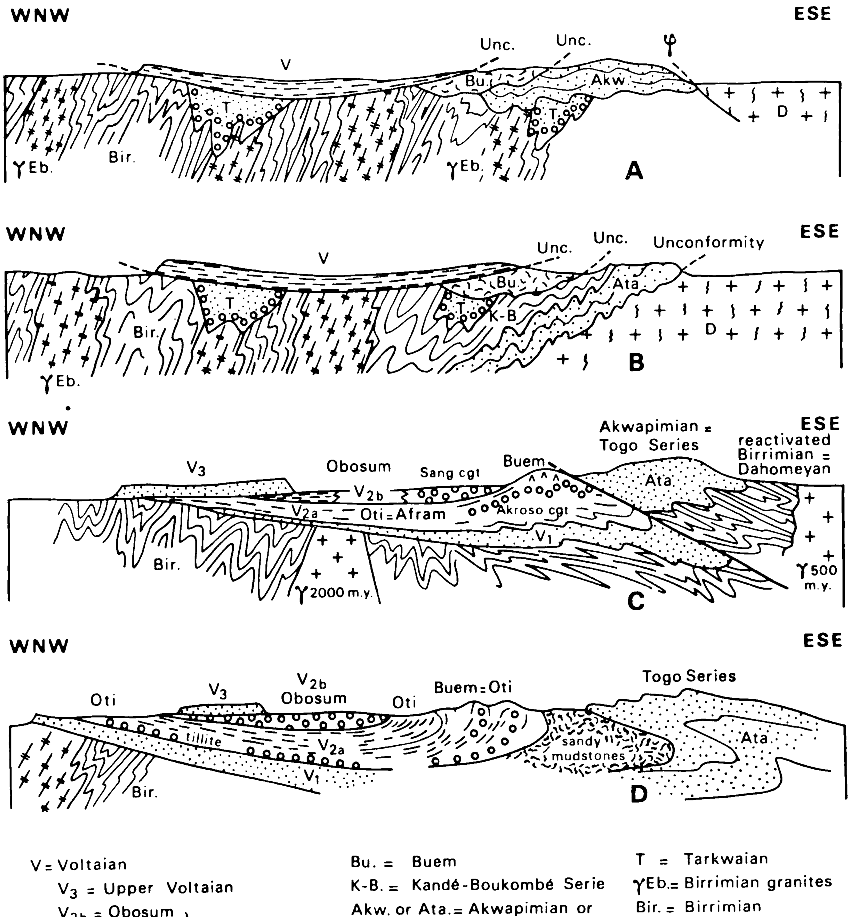

Fig. 2. Structure of the Volta Basin and the Dahomeyides (Sougy, 1970). (A) according to the geologists of Ghana, especially Junner (1940) and Junner and Hirst (1946); (B) according to francophone geologists and especially Roques (1948); (C) according to Grant (1969), the lithostratigraphy used in this figure being that of Junner and Hirst (1946); (D) according to Bozhko (1969a).

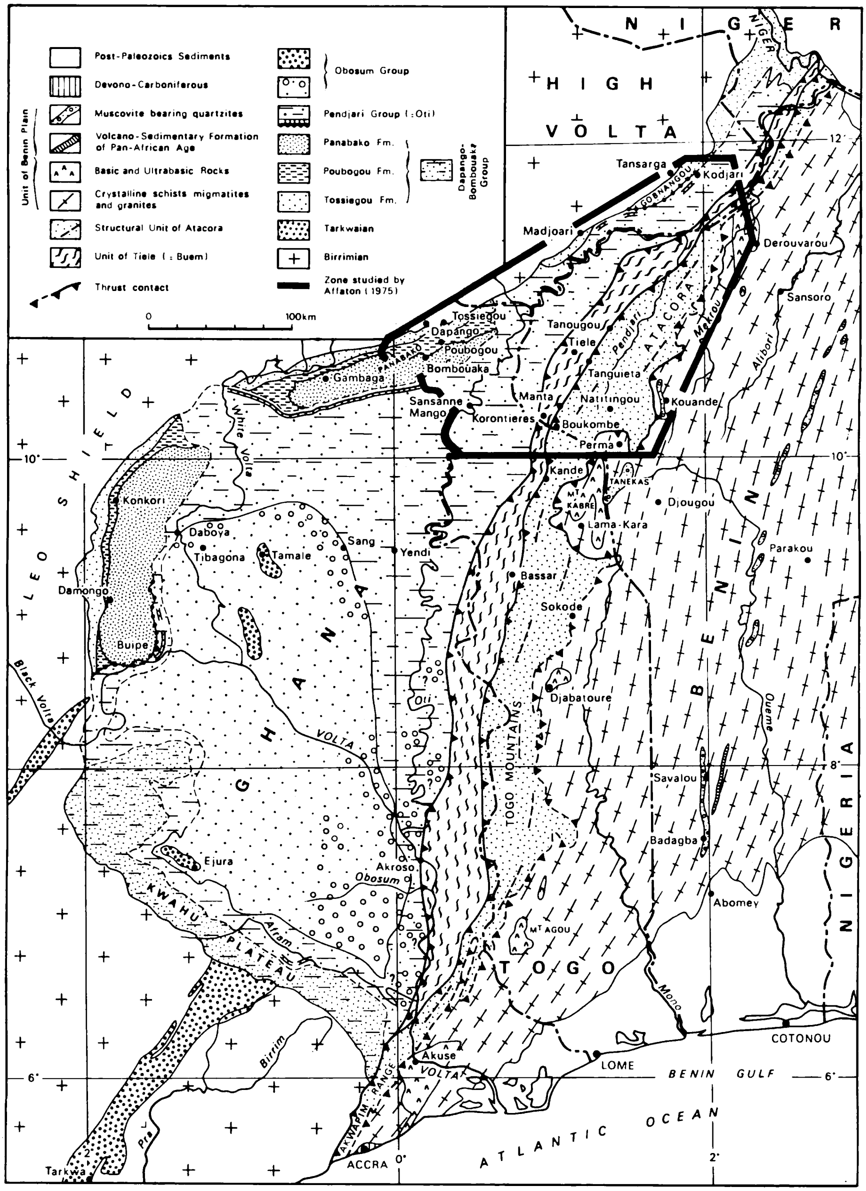

Fig. 3. Generalized structural map of the Volta Basin and the Dahomeyides modified from Sougy (1970).

a new concept of the stratigraphy, which views the stratigraphic assemblage in terms of a lateral evolution, with deformation and metamorphism increasing toward the east (fig. 2C-D). The first real evidence for this concept was provided by the radiometric age studies of Bonhomme (1962) and Jacobson, Snelling, and Truswell (1963) who assigned a Cambrian age to the Dahomeyan event, previously considered to be Archaean. In order to explain this age, Kennedy (1964) proposed the individualization, on the eastern border of the West African craton, of a zone affected by a tectono-thermal event, which he called the Pan-African, with an age of 600 to 500 m.y. Not until the papers of Black (1966, 1967), Grant (1967, 1969), and Bozhko (1969a and b) did the idea evolve that this region had undergone a full orogenic cycle at the boundary between the Precambrian and the Paleozoic (fig. 2C-D).

In detail, however, the interpretations of the lateral evolution from the cratonic basin into the Dahomeyide orogenic belt differ. According to Black (1967) the Voltaian represented the molasse to the Dahomeyides and was consequently interpreted as being discordant to the rocks of the orogenic belt. On the other hand, Grant (1967, 1969) and Bozhko (1969a and b) considered the Voltaian to be the lateral equivalent of the Buem and the Atacora and the Dahomeyan to represent an older basement material.

Thus it is possible to distinguish (figs. 3 and 4) a *stable zone* to the west, corresponding in general terms to the *Volta Basin.* In this zone the basinal sequence is discordant upon the Dorsal of Léo, which is formed

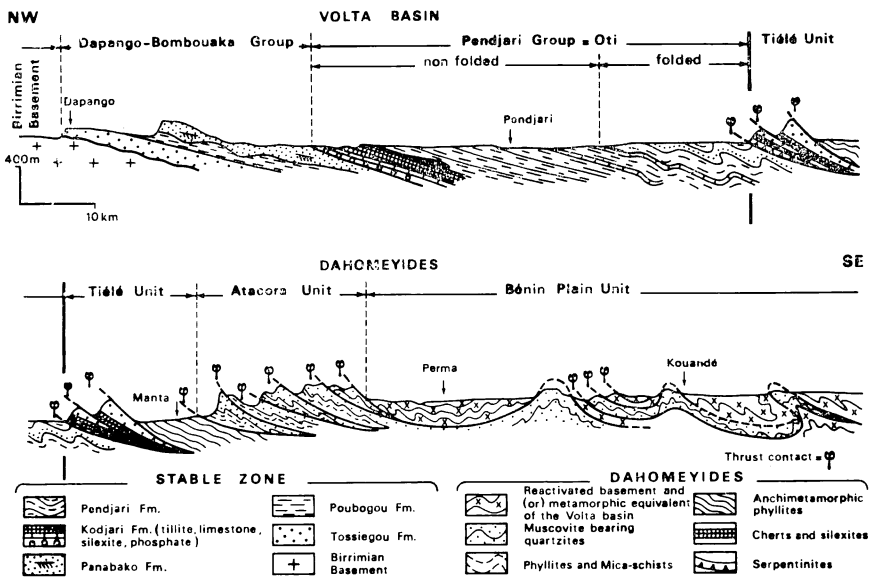

Fig. 4. Generalized structural cross section of the northern part of the Volta Basin and the Dahomeyides, (Affaton, 1975).

by the Birrimian and the Tarkwaian. To the east is the *mobile zone* of the *Dahomeyides* which comprises, from west to east, a series of different structural units corresponding to the Buem, the Atacorian, or Akwapimian, and for certain authors the Dahomeyan. This new concept, which is in accord with the results of radiometric age studies, is dependent in certain areas on the reinterpretation of earlier results. Affaton's thesis (1975), which forms one of the principal bases of this paper, allows us to test this new hypothesis with a detailed field and laboratory study of the northern part of the Volta Basin and the Dahomeyides.

THE STABLE ZONE: THE VOLTA BASIN

In an hypothesis concerning the evolution of the lateral facies variations from west to east, it is imperative to establish a viable lithostratigraphy for the Volta Basin. Until recent years (Grant, 1969), the lithostratigraphic succession adopted was that of Junner and Hirst (1946) (fig. 2C):

1. A lower unit (the Lower Voltaian $V_{1\text{-}2}$).—At the base of this unit is a series of sandstones and quartzites 60 m thick, which are in places conglomeratic (V_1). The central part, the Oti Formation (V_{2a}) is 250 m thick; it begins with a tillite and contains shales, siltstones, and sandstones with thin layers of limestone and arkose. The upper part of the lower unit is the Obosum Formation (V_{2b}), 150 m thick, generally red beds with sandstones, arkoses, shales, and layers of conglomerate which have certain characteristics of glacial deposits.

2. An upper unit (the Upper Voltaian V_3).—This comprises more than 300 m of sandstones and quartzites.

During recent years, detailed studies (Leprun and Trompette, 1969; Saunders, 1970; Affaton, 1975), the results of core-drilling (Bozhko, 1969a), and the syntheses of Sougy (1970, 1971) have shown the lithostratigraphy of Junner and Hirst (1946) to be incorrect in certain major aspects.

In the north of the Volta Basin (fig. 3), a tillite occurs above a striated pavement, making a slight angular unconformity with its substrate (Leprun and Trompette, 1969; Affaton, 1975). This permits two groups to be distinguished: at the base the Dapango-Bombouaka Group and above the discordance the Pendjari Group.

The Dapango-Bombouaka Group

The Dapango-Bombouaka Group occurs in the massifs of Gobnangou, Madjoari, and Dapango (fig. 3). It contains two hard sandstone formations which form escarpments. The lower sandstone is called the Tossiegou Formation, and the upper the Panabako Formation; between them occurs the Poubogou Formation which occupies a depression.

The *Tossiegou Formation* (170-500 m) lies unconformably above the Precambrian Birrimian basement and comprises fine sandstones and quartzites, which occasionally contain thin beds of conglomerate or siltstone. The *Poubogou Formation* (80-160 m) is exposed only in the

Dapango massif. It is an assemblage of shales and siltstones which contains intercalations of sandstone and limestone. The *Panabako Formation* (200-400 m) comprises mauve feldspathic sandstones and quartzites of medium to coarse grain. The rocks are characteristically cross bedded and certain facies are reminiscent of the Old and New Red Sandstones of Europe.

The Pendjari Group

The rocks of the Pendjari Group form the plain drained by the Pendjari or Oti River (fig. 3). They rest generally with a slight angular unconformity upon the Dapango-Bombouaka Group, though in some places they cut abruptly through the rocks of this group to lie on the underlying Birrimian basement. The Pendjari Group comprises a lower unit, the Kodjari Formation, and an upper unit, the Pendjari Formation (Affaton, 1975).

The *Kodjari Formation,* several tens of meters thick, comprises from base to top a lenticular mixtite, a carbonate layer that locally contains baryte, silexites, and more or less argillaceous siltstones which locally, at Arly and Kodjari, pass into rocks rich in calcium phosphates.

The mixtite, 0 to 12 m thick, contains boulders of various rock types which may exceed 1 m^3. The boulders vary from angular or polyhedral to rounded; they have flat polished surfaces with striations and locally have pitted surfaces. *The mixtite is interpreted as a tillite sensu stricto,* because at Tansarga it rests on a striated pavement (Leprun and Trompette, 1969) with striations and grooves oriented N 100°. The sense of displacement of the ice is uncertain but was probably from west to east.

The carbonate layer, 1 to 5 m thick, which locally contains blocks of basement materials of 0, 5 m^3, buries an irregular topography at the top of the mixtite. In places it acquires a brecciated structure or is contorted as a result of slumping. The silexites, 25 to 50 m thick, are normally micaceous and argillaceous, with thin intercalations of limestones and tuffs (ignimbrites with quartz shards) and locally contain siliceous microfossils. At Kodjari they are capped by several tens of meters of argillaceous siltstones, which may contain lateral development of calcium phosphate lenses (general thickness in the order of 10 m), for example to the northeast in Benin and Niger.

The association tillite-carbonate with baryte-silexite, also called the *"triad",* is identical with that of the Taoudeni Basin (Trompette, 1973) and provides, as in that basin, a major key to the lithostratigraphy of the Volta Basin.

The *Pendjari Formation* is a thick succession (2500-4000 m, according to Affaton, 1975), in places rythmically bedded, and the principal rock types are shales (commonly silty), argillaceous siltstones, sandstones, and graywackes. The rocks are normally greenish and commonly show graded bedding. Study of the crystallinity of the aluminous illites shows that these shales were affected only by mild diagenesis. The Pendjari Formation approaches the character of flysch in certain features, which we qualify as flyschoid. The abundance in the graywackes of fresh grains of labradorite associated with montmorillonite suggests penecontemporaneous basic volcanism.

Structure of the Volta Basin

In the northern part of the Volta Basin, at its periphery, the dip is gently toward the southeast. Toward the southeast, on the other hand, approaching the Dahomeyides, the Pendjari Formation is folded (fig. 4) with subhorizontal axes oriented north-northeast-south-southwest to northeast-southwest; the folds are asymmetric and verge northwest.

Conclusions—Age of the Formations

The lithostratigraphy of the Volta Basin can be subdivided into three discordant groups (fig. 5): the groups of Dapango-Bombouaka and Pendjari distinguished by Affaton (1975) plus the Obosum Group exposed only in Ghana (Annan-Yorke and Cudjoe, 1971). The latter group, of dominantly continental sandstones, contains at its base approx 400 m of sandstones, commonly coarse or even conglomeratic, which have certain features indicating a fluvio-glacial origin, according to Junner and Hirst (1946). It also contains several layers of red shales and siltstones. The top of the group comprises approx 100 m of white quartzites best exposed at Tamale (fig. 3). The Obosum Group was interpreted by Grant (1969) and Bozhko (1969a) as representing the molasse of the Dahomeyides, sediment being transported from east to west during the uplift of that chain. Our observation of Atacora quartzites in the pebble material of the conglomerate, at Sang, confirms this view.

This lithostratigraphic scheme is quite different from that proposed by Aicard (1957) and Junner and Hirst (1946) (fig. 2A). The following correlations can be proposed between Junner and Hirst's stratigraphy and ours:

Obosum Group = V_{2b} + a small part of V_3

Pendjari or Oti Group = V_{2a}

Dapango-Bombouaka Group = V_1 + a small part of V_{2a} + the major part of V_3

The sedimentation in the Dapango-Bombouaka Group is of platform type with clastic deposits that are partly continental, particularly the red clastics of the Panabako Formation. The base of the Pendjari Group is marked by glacial deposits of a continental ice-sheet, which are succeeded by marine carbonate deposits, then by silexites in part of volcano-sedimentary origin, and by the flyschoidal and thick Pendjari Formation.

Thus the Dapango-Bombouaka Group corresponds to the progressive transgression of the sea on the craton, whilst the Pendjari Group, if one excepts the basal continental and glacial part, was probably contemporaneous with basic volcanism and characterized by marine sedimentation in a zone becoming less stable.

The age of the Volta Basin formations is not well known (fig. 5). The Dapango-Bombouaka and Pendjari Groups are earlier than the major Pan-African thrust movements, which were responsible for the mise en place of the major structural units of the Dahomeyides (fig. 4). Bonhomme (1962) suggests that these movements occurred approx 600 m.y. ago, on the basis of Rb/Sr studies (Rb/Sr ages quoted in this paper are based on $\lambda^{87}Rb = 1.47 \cdot 10^{-11}\ y^{-1}$) on biotites from the Kouandé gneiss. Bonhomme obtained an age of 592 ± 8 m.y., which probably represents the age of uplift and cooling of this gneiss and so is slightly younger than the Pan-African thrusting. On the other hand, the Obosum Group in Ghana, which according to Grant (1969) postdates this deformation, is possibly at least in part Cambrian.

More precisely the lower part of the Pendjari Formation has been dated, away from the chain, in Ghana, at approx 620 m.y. by the K/Ar method on glauconite (Bozhko, 1969a) and, at the Upper-Volta/Benin frontier, at 638 ± 8 m.y., by the Rb/Sr method on illite (Clauer, 1976). This would indicate that the Kodjari tillite is of Late Precambrian age.

Comparison with the Taoudeni Basin suggests that sedimentation began in the Volta Basin around 1000 m.y. ago, and, as a working hypothesis, we suggest the following scheme for the three groups:

1. The Dapango-Bombouaka Group commenced sedimentation around 1000 m.y. ago, continuing until approx 680 to 650 m.y. It represents the equivalent of a thicker succession in the Taoudeni Basin.

2. The Pendjari Group would thus have begun slightly earlier than 638 m.y., around 650 m.y., and ended at approx 600 m.y. In Ghana, Bozhko (1969a), studying mainly spores and stromatolites, concludes that the rocks of the equivalent Oti Formation have a Vendian age (680-570 m.y.).

3. The Obosum Group is younger than 600 m.y. and probably partly Cambrian.

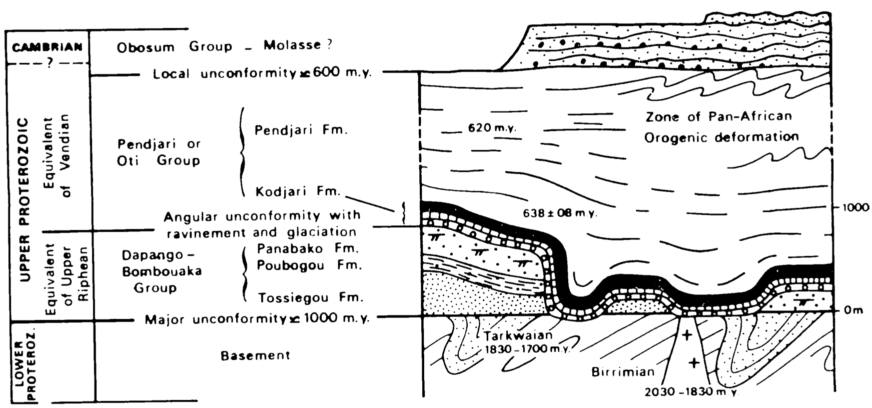

Fig. 5. Generalized lithostratigraphy and possible chronostratigraphy of the Volta Basin, especially after Bozhko (1969a) and Affaton (1975).

THE MOBILE ZONE: THE DAHOMEYIDES

The mobile zone corresponds to the Dahomeyides which, in the zone studied, contain from west to east three major structural divisions (Affaton, 1975): the Tiélé Unit (= Buem), the Atacora Unit (= Kandé-Boukombé Series + Atacorian or Akwapimian or Togo Series), and the Benin Plain Unit (= Dahomeyan).

The Structural Unit of Tiélé

The Tiélé Unit forms a continuous band (avg width approx 15 km), which defines the eastern limit of the Volta Basin (fig. 3). The region is in general a plain locally broken by small hills.

Lithostratigraphy.—Although this unit has a complex structure, with notable thrust repetitions (fig. 4), it is possible to propose a preliminary model for the lithostratigraphy (fig. 6, left). Three major facies can be distinguished: (A) *clastic facies,* (B) *silexites* or *cherts,* (C) *volcanic rocks.*

A. *The clastic rocks.* These rocks form the uppermost and lowermost parts of the succession (fig. 6). They comprise sandstones, fine-grained quartzites, which are often feldspathic and occasionally glauconitic, siltstones, and shales. At Tiélé, the sandstones that overlie the silexites contain possible organic remains in the form of truncated acute-angled cones (Affaton and Kusnir, 1977), 5 to 15 cm in diam and 10 to 30 cm in length. They are oriented with their long axes perpendicular to the bedding. They bear some resemblance to *Vexillum,* though the possibility that they relate to eddies cannot be ruled out. The plagioclase in the feldspathic facies has a mean composition of andesine, that is, a little more acid than the plagioclase in the Pendjari Formation.

B. *The silexites.* These are series of bedded cherts, of massive appearance, sometimes brecciated and normally red.

C. *The volcanic rocks.* These form three assemblages (fig. 6). The first consists of cross-cutting dolerites, with pronounced spheroidal weathering, of unknown age. The second comprises both schistose and massive serpentinites, often chromitiferous, which seem to mark certain thrust planes. The third consists of interstratified volcanics, variolites, basalts,

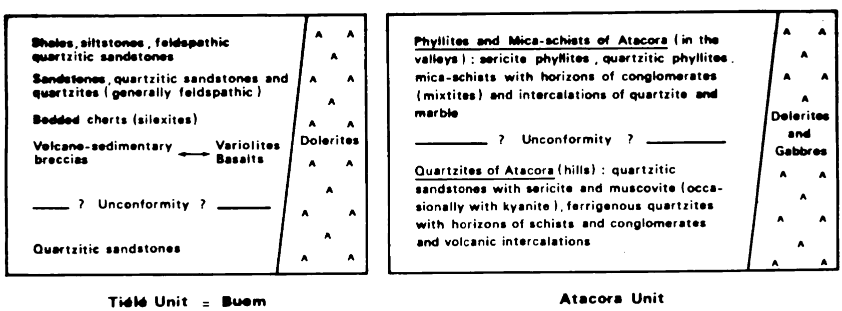

Fig. 6. Schemes for the lithostratigraphy of the Tiélé Unit (Buem) and the Atacora Unit of North Benin (Affaton, 1975).

and volcanoclastic breccias. The latter contain blocks 1 to 100 cm across of plagioclasite, dolerite, siltstone, and silexite embedded in a greenish tuffaceous cement. This spilitic volcanism we consider to be situated in the lower part of the Tiélé Unit or Buem. In Ghana, however, similar facies are placed in the upper part of the Buem.

The main feature that characterizes the Tiélé Unit is the importance of *cataclasis:* the silexites are frequently brecciated, and the sandstones and quartzites boudinaged and injected by quartz veins. In thin section, although certain beds do not show the effects of cataclasis, many others show fractured quartz grains with strained extinction. The grain size of the quartz has commonly been reduced to a fine mortar size, and crystallization of sericite is common, particularly at the ends of elongated quartz grains.

Structure and metamorphism.—The Tiélé Unit is characterized by important thrust tectonics (fig. 4) with no less than two generations of imbrication. The largest and youngest zones of imbrication occur as long and narrow strips up to 10 km, roughly north-south. These structures truncate the smaller and older imbricate zones which are generally steeply stacked like the tiles on a roof and oriented north–northwest–south–southeast to northwest–southeast and plunging to the northeast. The contacts between imbricate zones are often marked by serpentinites and brecciated silexites, which seem to assume the role of a lubricant.

In this unit where brittle faulting dominates, folds are only rarely observed; they vary in scale from centimeters to hundreds of meters, with subhorizontal axes and a general north–northeast–south–southwest orientation. They verge toward the west–northwest and are marked by a rough fracture cleavage. This group of structures is attributed to a phase of folding F_3. The crystallinity of the aluminous illites indicates that the dynamo-metamorphic metamorphism is anchizonal, not far from the limits of anchizone and epizone (Affaton, 1975).

The Structural Unit of Atacora

The Atacora Unit includes the Series of Kandé-Boukombé and the Atacorian of Aicard (1957) and forms a continuous linear strip 5 to 50 km wide. Its western border is formed by the Tiélé Unit (fig. 3). The unit corresponds to the mountains of the Atacora in Benin, the Togo Mountains in Togo, and the Akwapim Range in Ghana. In the southern part of the area studied, however, it begins several kilometers to the west of the escarpment with the phyllites that Aicard (1957) called the Kandé-Boukombé Series.

Lithostratigraphy.—The Atacora Unit (Affaton, 1975) comprises two assemblages: (1) hard quartzites, which form the major topographic features; (2) phyllites, which form the valleys (fig. 6).

1. *The quartzitic sandstones and quartzites,* with a few interlayers of conglomerates, contain metamorphic minerals including sericite and muscovite, also infrequently chlorite, chloritoid, and kyanite.

2. *The phyllites and mica-schists* are commonly sericitic, with variable quartz content. They also contain conglomerate layers. The latter, for example in North Togo, may have the character of *mixtites* containing pebbles and blocks of granite, gneiss, and quartzite in a fine-grained matrix of quartz and mica (Affaton and others, 1975). These conglomerates show varying degrees of deformation.

Marbles are unusual (35 km north-northeast of Boukombé). *Volcanics* interstratified with the other sediments are rare and have often, as in Perma, the character of prasinites. The paragenesis is albite–hornblende–chlorite–epidote. At Tanougou (30 km north-northeast of Tanguieta) there is a massif of dolerite and gabbro. The age of this massif is not known, but it is apparently intrusive into the rocks of the Atacora Unit. One also finds local slices of *remobilized basement*. These are essentially gneissic and have apparently been emplaced tectonically into the rocks of the Atacora Unit.

The lithostratigraphy scheme for the Atacora Unit (fig. 6) is provisional. Thus although a discordance may separate the micaschists and quartzites, it has never been observed.

Structure and metamorphism.—One finds in the unit of Atacora, notably in the marginal zones, imbrications comparable to those described from the Tiélé Unit. Imbricate zones are up to 10 km long, oriented between north–south and north–northeast–south–southwest. The contacts between the imbricate units and the frontal thrust upon the Tiélé Unit are generally better seen on the aerial photographs than on the ground. The whole series of thrusts are related to the phase of thrusting F_3.

A major difference from the structure of the Tiélé Unit is the presence of folds on all scales and several different styles. One can distinguish three groups of folds. (1) *Isoclinal folds:* on the centimeter to meter scale, axes north–northeast–south–southwest, axial plane schistosity (S_2) that dips 10° to 50° toward the east–southeast and is essentially parallel to the stratification (S_0) except at the fold hinges. These folds, which are particularly abundant in the Kandé-Boukombé Series, are related to phase F_2. (2) *Cylindrical to conical folds:* on the centimeter to kilometer scale, with axes varying from north–northeast–south–southwest to northeast–southwest, essentially upright with vertical axial planes or a slight tendency to verge west–northwest or northwest. They develop an axial-plane fracture cleavage (S_3) and belong to the phase F_3. (3) *Open folds* on the 1 to 10 km scale. They form the large anticlinoria or synclinoria, with north–northeast–south–southwest trends, refold the imbricate zone, and are attributed to the phase F_4.

The regional metamorphism is epizonal to mesozonal and related to the first phase of folding F_1.

The Structural Unit of the Benin Plain

The Benin Plain unit forms a vast peneplain (fig. 3) interrupted by local areas of positive relief (granites, basic rocks, quartzites). It was long considered an ancient basement to a discordant cover formed of the units described above (Roques, 1948; Aicard, 1957; Pougnet, 1957).

Lithology.—The Benin Plain Unit contains five main petrographic units. A first assemblage consists of *muscovite-bearing quartzites,* rarely hematitic, with tourmaline and accessory kyanite; a second of more or less *quartzitic sericite schists,* with chloritoid and garnet, also *two-mica schists* with chlorite and garnet. These two facies are well represented in the lower part of the unit and are interpreted as phyllonites. They are considered to be substantially reworked basement material that recrystallized during Pan-African metamorphism. A third assemblage, the most widely developed, is composed of various *gneisses.* These gneisses are generally of two-mica type with garnet, hornblende or actinolite, epidote, chlorite, and zoisite, associated with *leptynites* and *amphibolites.* The fourth assemblage comprises *granites, granitic gneisses,* and *leucocratic migmatites,* with a coarse foliation, commonly associated with and probably passing laterally into leucocratic augen-gneisses with muscovite.

The fifth assemblage comprises *basic rocks,* which form the Derouvarou massif and the Kabré massif near Lama-Kara (fig. 3). The Kabré massif has been studied in detail by Aicard (1957), Péré (unpub. report), and Henry and Scanvic (1973). Its structure, in outcrop, is more or less concentric. The center is composed of amphibolites, pyroxenites, and eclogitic rocks, all characterized by the great abundance of garnet, and metamorphosed according to Henry and Scanvic (1973) in the almandine–hornblende subfacies of the granulite facies. The western border, which corresponds to a thrust plane dipping gently eastward, shows the same rock types now in a retrometamorphic state with the appearance of a talc–serpentine–tremolite paragenesis and generally mylonitic. For Aicard (1957) and Henry and Scanvic (1973), the Kabré massif represents an ancient complex of basalts and gabbros metamorphosed in the granulite facies and later subjected to retrometamorphism, probably coinciding according to the two last authors with the Pan-African orogeny. For Colin and Péré (cited *in* Henry and Scanvic, 1973), it represents an ophiolite complex. In the Derouvarou massif (Autran, Guitard, and Tegyey *in* Vitali and Marchesseau, 1964), an association of basic and ultrabasic rocks is metamorphosed in the granulite facies, together with muscovite or two-mica gneisses of amphibolite facies.

In the north of the Dahomeyides, the Benin Plain Unit is thus composed in part of gneissic and basic rocks of amphibolite and granulite facies, variably retrometamorphosed and associated with mylonites, and in part of quartzites with muscovite and kyanite.

Structure and metamorphism.—The Benin Plain Unit is thrust upon the Atacora Unit (fig. 4). The minimum displacement of the nappe is 40 km in the Perma depression. Its internal structure is complex with at least five phases of folding. (1) A *first phase* (F1) during which the main foliation (S_1) was developed, though no actual folds of this generation have been observed. (2) A *second phase* (F2) with isoclinal folds whose axes trend north–northeast–south–southwest; the folds verge toward the west–northwest and have a well-developed axial-plane schistosity S_2 generally subparallel to the main foliation S_1. (3) A *third phase* (F3), with fold amplitudes varying from a few centimeters to several meters. These folds are essentially cylindrical and have generally subvertical to vertical axial planes, northeast–southwest trending axes, and an axial-plane fracture–cleavage S_3. The major thrusting occurred toward the end of this phase. (4) A *fourth phase* (F4) which produced the large structures such as the Perma Synform and the Kouandé Antiform (figs. 3 and 4). (5) A *fifth phase* (F5) observed in the Kouandé area where an antiform F4 several kilometers across is refolded into a conical synform.

In the study of the metamorphism one can distinguish a quartzitic part of the assemblage, which in the Tanekas massif (fig. 3) is metamorphosed in the amphibolite facies with the paragenesis chloritoid–kyanite–almandine–muscovite–quartz (Alidou and others, 1975), from the gneissic formations in amphibolite and granulite facies. The metamorphism of the quartzites would have occurred, as in the Atacora Unit, during phase F2. On the other hand, the gneisses apparently were metamorphosed during F1 and then subjected to retrometamorphism during F2. This retrometamorphism makes it difficult to evaluate the original intensity of metamorphism of the basement material, which may well have been of high grade.

RELATIONSHIPS BETWEEN THE STRUCTURAL UNITS

The study of the northern part of the Volta Basin and the Dahomeyides permits us to distinguish in the west a stable zone generally corresponding to the Volta Basin (fairly narrow in this region) and in the east a mobile zone where three major structural units may be distinguished. The eastern-most structural unit of the mobile zone, called the Benin Plain Unit, extends toward the east into Nigeria and is poorly known and perhaps in the future will be subdivided into several structural units.

Relations: Volta Basin and Tiélé Unit

In comparing the two lithostratigraphic columns (figs. 5 and 6) one notes the presence in the two successions of silexites associated with a tillite. This tillite (mixtite) is not recognized in the Tiélé Unit but is described in the Buem farther to the south in Togo and in Ghana (Koert, 1910; Junner, 1954; D. T. Lawson, 1972), though its glacial origin has been contested by Bell (1964), who interpreted it as a mudflow deposit.

The association in the Tiélé Unit of silexite and volcanic rocks is not surprising, if one recalls the tuffaceous characters of certain silexite beds of the Kodjari Formation. The shales, siltstones, sandstones, and feldspathic quartzites, which succeed the silexite in the Tiélé Unit (fig. 6), could well be the equivalent of the Pendjari Formation. The presence of sandy quartzites at the base of the Tiélé Unit could be either the sandy base of the mixtite or equivalent to the uppermost part of the

Dapango-Bombouaka Group. *Thus we suggest that the Tiélé Unit can be considered mainly as an equivalent of the Pendjari Group.* The equivalence of the Oti Group (or Pendjari Group) with the Buem (or Tiélé Unit) has already been suggested by Grant (1969) and Bozhko (1969a).

From the structural point of view the Tiélé Unit is thrust onto the Volta Basin (fig. 4), as proposed by Huot and Lelong (1963). The contact is commonly marked by lenticular bodies of serpentinite or silexite, which are usually brecciated. In these two units, one finds a single phase of folding, which apparently is coeval with F3 in the Atacora Unit. It is marked in the Tiélé Unit by imbricate structure and in the eastern margin of the Volta Basin by folds that pass eastward into faulted folds and even minor imbricate structures. The Tiélé Unit is affected by an anchimetamorphism, whereas the rocks of the Volta Basin are not affected by metamorphism.

Relations: Atacora Unit–Tiélé Unit–Volta Basin

In the zone studied the lithostratigraphy of the Atacora Unit is apparently simple (fig. 6). The phyllites or mica–schists (more or less quartzitic) rest, perhaps in discordance, upon the muscovite-bearing quartzites. To these two principal facies are added very rare intercalations of prasinitic greenstones and impure marbles. In Togo are found layers of ferrugineous quartzites locally of itabirite facies (Lawson, 1972), quartzites with heavy minerals (Ilavsky, 1972), and conglomerates of mixtite facies (Affaton and others, 1975); slices of reworked basement rocks are also incorporated tectonically. Finally, in Ghana, Gaisie and Winter (1974) claim to have identified tillites, though as yet a glacial origin for these mixtites has not been conclusively demonstrated.

In terms of its lithostratigraphy, the Atacora Unit shows notable differences from the Tiélé Unit and indeed resembles the Group of Dapango-Bombouaka. In the south extremity of the Volta Basin, where the Kwahu Plateau comes into contact with the Akwapim Range (fig. 3), Shackleton (1971) and Bondesen (1972) have shown that the equivalent of the sandstones of the Dapango-Bombouaka Group passes progressively into the Akwapimian, equivalent of the Atacora, by regular increase in the intensity of folding and metamorphism toward the east. Probably the same thing occurs at the northern extremity of the basin near the "W" bends of the River Niger (fig. 3).

The Atacora Unit seems to be an equivalent of the Dapango-Bombouaka Group, together with slices of reworked basement and possibly relics of the Pendjari Group (volcanics, mixtites?), though at this stage this is still highly speculative.

Following Huot and Lelong (1963), the contact between the Atacora Unit and the Tiélé Unit is supposed to be a thrust plane. The structural features observed in the two units show marked differences. The phase F3, common to the units, is developed in the Atacora as imbricate zones and also as folds. The phase F2 of synmetamorphic folds is confined to the Atacora, and structures of F4 are most clearly seen in that unit.

Relations: Benin Plain Unit–Atacora Unit–Tiélé Unit

The Benin Plain Unit corresponds to a part (area around Djougou) of the Dahomeyan of older authors (fig. 3). According to Black (1967), the Dahomeyan comprises a Birrimian assemblage playing the role of basement composed of granitic gneisses (Kouandé Group of Pougnet, 1957) and of basic rocks (Derouvarou Group) of facies similar to those in the core of the Kabré massif. It also contains a series of cover rocks comprising micaschists (Sansoro Group), gneisses associated with leptynites or with amphibolites (Djougou and Kandi Groups), and muscovite-bearing quartzites (Badagba Group).

In the northern zone studied by Affaton (1975), the quartzites with muscovite and sometimes kyanite appear to correlate with the Atacora Unit and, if this is the case, also with the Dapango-Bombouaka Group. Similarly, if we take into account the radiometric age studies of Bonhomme (1962), the granitic gneisses of Kouandé were emplaced around 1650 ± 220 m.y. (Rb/Sr whole-rock) and would thus belong to the Birrimian basement. The assignment of the other three petrographic associations is for the moment speculative. Thus the Benin Plain Unit comprises facies attributable to *a mainly Birrimian basement* and also to a *cover sequence* preserved as relics, as well as numerous facies still difficult to assign to one or the other.

From the structural point of view, the Benin Plain Unit is overthrust upon the Atacora Unit (fig. 4). The thrust plane, marked by mylonites, originally had a gentle dip but is now refolded by F4 and F5. If one excepts the F1 phase of folding (synmetamorphic and poorly known), the structural elements of the Benin Plain Unit are identical to those of the Atacora Unit.

In the region to the east of Savalou in South Benin (fig. 3), Boussari and Rollet (1974) and Boussari (ms) described a series of volcano-sedimentary rocks (spilitic greenstones, some showing pillow-lava structures; keratophyres; conglomeratic sandstones and conglomerates with pebbles of basement and volcanic rocks), which are non-metamorphic, little deformed, and with certain resemblances to the volcano-sedimentary sequences described from northwest Nigeria (Maradum Group) by McCurry (1975) and from the Hoggar by Caby (ms) in the "Série pourprée".

In the same region, Alidou, Bard, and Jullien (1975) described feldspathic metagraywackes and metaconglomerates with pebbles of basic rocks that have been subjected to several phases of folding and a mesozonal metamorphism followed by a retrograde metamorphism. As the result of a series of hypothetical deductions, they proposed that these conglomerates can be correlated with the tillite of the Kodjari Formation (Volta Basin), and they concluded that the essential part of the "basement of Benin," except the basic rocks like those of Kabré and Derouvarou (Derouvarou Group), represents Voltaian material that has been strongly folded and metamorphosed and not a basement remobilized during the Pan-African orogeny. This hypothesis, which makes the major part of the "basement of Benin" a mesozonal equivalent of the rocks of Volta Basin, even if it cannot be ignored, has as yet not been proven.

In Nigeria, field investigations summarized by Oyawoye (1972), McCurry (1975), and Rahaman (1975), together with radiometric studies, combine to show the complexity of the basement. Three groups of ages predate the Pan-African Orogeny: 2750 m.y., 2200 m.y., and 1100 to 1200 m.y. An age of 2750 m.y. (U/Pb method) obtained by Oversby (1975) on a potassium feldspar from an aplite of the Ibadan region (southwest Nigeria) tends to confirm the proposal of Grant (1970) according to which certain crystalline schists cut by orthogneisses dated at 2200 m.y. possibly represent relics of a Liberian basement.

Birrimian ages of 2205 ± 70 m.y. (Rb/Sr whole rock isochron) and 2200 ± 20 m.y. (Rb/Sr on one sample) were obtained by Grant (1969, 1970) on the orthogneisses of the Ibadan region (southwest Nigeria) and by Hurley, Fairbairn, and Pirson (1966) on the orthogneisses of the Kaduna area (northern Nigeria).

Finally such basement was probably locally remobilized as a result of the Kibarian orogeny (Grant and others, 1972). Ages of 1150 ± 140 m.y. (Rb/Sr whole-rock isochron with a very high initial $^{87}Sr/^{86}Sr$ ratio of 0.739) on the orthogneisses to the south of Ile-Ife (south Nigeria) and ages of 1270 ± 75 m.y. and 1120 ± 70 m.y. (Rb/Sr method on isolated samples) for the orthogneisses to the north of Kaduna (northern Nigeria) suggest tectono-metamorphic reworking of more ancient granites. An age of 873 ± 44 m.y. (Rb/Sr whole rock) on a charnockite (Grant *in* McCurry, 1975) indicates a possible continuation of the mobilization until Pan-African time.

Thus on the scale of the chain a certain number of orthogneisses in Nigeria and in Benin are attributable to the Birrimian, whilst the crystalline schists they intrude may possibly represent local relics of a more ancient Liberian basement (2750 m.y.). The north–south bands of quartzites with muscovite of the Badagba type, which are comparable to the quartzites of the Atacora, are probably to be correlated with the cover sequence of the Volta Basin. However, in Nigeria a few quartzites are proved to belong to the Birrimian basement. The volcano-sedimentary formations described by Boussari (ms) to the east of Savalou have been tentatively correlated with the Obosum Group. Finally the origin of a good number of the facies of this basement remains uncertain.

SYNTHESIS OF DATA FROM THE NORTH OF THE VOLTA BASIN AND DAHOMEYIDES

Definition of the Structural Units–Lateral Facies Evolution

The regional studies of Affaton (1975) permit the definition of four major structural units which now replace the previous chronostratigraphic units. These structural units are the *Volta Basin,* the *Tiélé Unit* (= Buem), the *Atacora Unit,* and the *Benin Plain Unit.* The hypothesis of a lateral facies evolution from west to east through the structural units is confirmed. The Volta Basin is intimately involved in this evolution.

The Dapango-Bombouaka and Pendjari Groups, as they constitute respectively the bulk of the Atacora and Tiélé Units, are both involved in the development of the Dahomeyide orogenic segment. The Obosum Group represents the molasse deposits of the Dahomeyides according to Grant (1967, 1969) and Bozhko (1969a).

The "Dahomeyian basement" of earlier authors, that is, the Benin Plain Unit, comprises *blocks of Birrimian and Liberian rocks* subsequently reworked during Pan-African and perhaps Kibarian orogenies, a *metasedimentary cover* mainly equivalent to the Atacora Unit, and some *unmetamorphosed volcano-sedimentary relics* possibly equivalent to the Obosum Group.

Geodynamic Evolution

The current studies show that the northern part of the Dahomeyides is part of a typical orogen, with *polyphase metamorphism* (including an important phase of retromorphism) and a *polyphase structural development* (fig. 7). The latter includes an important major phase of overthrusting (F3) which controls much of the present-day morphology. It involves also at least two earlier syn-metamorphic phases of deformation (F1 and F2) and at least two post-thrusting phases of deformation (F4 and F5). Structures of the later phases fold tectonic slices and thrust planes into large anticlinoria and synclinoria. The F3 overthrusts are evident, often with sharply transgressive contacts, and are characterized by westward translation and imbrication. This imbrication makes the reconstruction of the lithostratigraphic successions more difficult.

The metamorphic grade and the amount of deformation progressively increase toward the east, both on the scale of the entire chain and within individual units as in the Atacora. *The greatest variation occurs, however, between different structural units.* For example, the

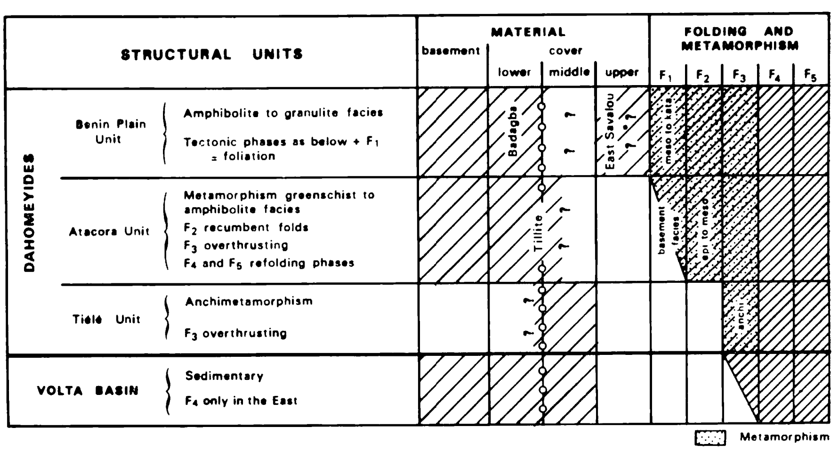

Fig. 7. Comparison of the stratigraphy and structural development of the Volta Basin and the Dahomeyides.

Tiélé Unit shows very weak metamorphism (anchizone) with a single phase of deformation (F3), whereas immediately to the east the Atacora Unit shows the effects of metamorphism ranging from epizonal to mesozonal and two phases of deformation (F2 and F3). In the Volta Basin, the continental glacial deposits of the Kodjari Formation, which are older than 638 ± 8 m.y., together with the flyschoid formation of the Pendjari, predate the major phase F2 of Dahomeyide overthrusting (Trompette, 1972). On the other hand, the Obosum Group postdates the thrusting. Its eastern border is gently folded, presumably by either F4 or F5. The position of F1, synchronous with the Pan-African metamorphism, is difficult to place in the history of the basin, though it is evidently prethrusting.

CORRELATIONS WITH NEIGHBORING PAN-AFRICAN BELTS

Toward the north, it is assumed that the Dahomeyides are continued, after an arcuate bend masked by the recent cover of the Niger Basin, by the Gourma belt, which is oriented west–northwest–east–southeast, then by the Pharusian chain of the Hoggar (fig. 1). Toward the south the Dahomeyides disappear in the Gulf of Benin, and their probable continuation on the other side of the Atlantic is the Caririan belt of Brazil.

The Pharusian Chain of the Hoggar

From the western part of the Hoggar, Caby (1970) has described two major lithostratigraphic assemblages separated by the Pharusian orogenesis. (1) The lower assemblage has at its base the *"Série à stromatolites"* with stromatolites characteristic of the Upper Riphean (1100-680 m.y.) (Bertrand-Sarfati, 1972). The highest part of this lower assemblage is a series of green rocks *("Série Verte")*, which are essentially graywackes with a layer of mixtite (according to Caby, this mixtite and others in the upper assemblage are tillites). (2) The upper assemblage, or *"Série Pourprée"*, has been interpreted as the molasse of the Pharusian chain. It begins with the *Tagengan't Series*, which is fine-grained detrital material of flyschoid aspect, and contains three layers of mixtites and also volcanic rocks dated at 500 ± 10 m.y. (Allégre and Caby, 1972). It is terminated by the *Ouallen-In Semmen Series*, a series of coarse-grained red detrital rocks, containing one layer of mixtite, the top of which is dated at 487 ± 18 m.y. (Clauer, 1976).

Two major phases of deformation have affected the lower assemblage. A major phase of thrusting (D1) with displacements toward the south and the southeast is considered by Caby (ms) to be coeval with metamorphism ranging from the anchizone to the granulite facies. A later phase of shortening (D2) produced folds verging to the west, onto the West African craton. The upper assemblage, only gently folded, was affected by a phase of brittle deformation marked by north–south transcurrent faults.

Correlations with the Dahomeyides are not clearly evident; two hypothesis have been advanced. According to Caby and Moussu (1967) and Caby (ms), the "Série Pourprée" is the equivalent of the Pendjari (Oti) and Obosum Groups. For Trompette (1972), the "Série Pourprée" would correspond to the Obosum Group and the "Série Verte" to the Pendjari Group. In the Hoggar, the synmetamorphic deformations (D1 and D2) are dated at approx 600 m.y. They may be roughly coeval with F2 and F3 of the Dahomeyides.

The Gourma Chain in Upper-Volta, Mali, and Niger

According to Caby, Moussine-Pouchkine, and Davidson (1978), the Gourma is formed in its northeast part by nappes thrust toward the southeast onto a wide autochthonous foreland. This foreland (Reichelt, 1972) is made up of a flat-lying thin epicontinental sequence of shales, siltstones, and minor limestones. Toward the northeast, closer to the nappes, the sequence looks like flysch, thickening to 7000 m and becoming folded and slightly metamorphosed. The allochthonous part is formed by thin external nappes of greenschist facies and internal nappes of mica–schists and quartzites with a high pressure-low temperature metamorphism. The Bourré Horst of Birrimian basement separates internal and external nappes. This would result from the continental collision of a passive margin to the west with an active margin to the east, comprising in Western Mali a 150 km wide young dioritic crust of accreted materials related to an eastward dipping subduction (Caby, 1978). This collision ended about 600 to 550 m.y. as a typical Pan-African event.

The sedimentary formations of Gourma are considered by Reichelt (1972) to predate the "Eocambrian tillite" of the Taoudeni Basin, which is not represented in Gourma, and to be the equivalent of the lower assemblage of Hoggar and consequently of the Dapango-Bombouaka Group. On the contrary, in the hypothesis of Trompette (1972) the Gourma formations could correspond both to the Dapango-Bombouaka and Pendjari Groups.

General Lithostratigraphy of the Upper Precambrian and Lower Paleozoic of West Africa

Three assemblages can be distinguished (Deynoux, Sougy, and Trompette, in press): (1) *A lower assemblage, detrital* (in part carbonates with stromatolites), epicontinental, deposited on a stable craton, represented by the Dapango-Bombouaka Group, the Stromatolitic Series of West Hoggar, and the formations of Gourma. (2) *A middle assemblage* of flyschoid type, argillaceous, principally graywackes with volcanic intercalations, whose base in the Volta Basin is a tillite. These rocks were deposited in a subsident zone; they include the Pendjari or Oti Group and the "Série Verte" of West Hoggar. (3) *An upper assemblage* of dominantly red clastics, often coarse-grained, with intercalations of fluvioglacial and perhaps true glacial deposits; it would include the Obosum Group and the "Série Pourprée" of West Hoggar, often interpreted as molassic facies.

The lower assemblage may have been deposited between 1000 and 650 m.y.; the middle assemblage between 650 and 600 m.y.; and the upper assemblage after 600 m.y., in part at least during the Cambrian period. The major phase of translative movements in the three chains occurred about 600 m.y. ago. It was accompanied in Hoggar and in Gourma by a metamorphism of variable grade, in some places very high. In the Dahomeyides, the major thrusting phase, accompanied by an anchizonal metamorphism, was superimposed upon a major epizonal to mesozonal metamorphism, which at present is difficult to place in the pattern of evolution of the chain.

A CRATONIC OR OCEANIC ORIGIN FOR THE DAHOMEYIDES?

To conclude, it is perhaps interesting to discuss the problem of cratonic or oceanic origin of the chain, although we are aware that insufficient details are known to solve this problem effectively. For Burke and Dewey (1972) the Pan-African chains, and notably the Dahomeyides, were produced by subduction of oceanic crust and collision of two continental plates. However, for Clifford (1972) they represent cratonic chains composed of reactivated continental basement and supracrustal rocks formed during the course of the Pan-African orogenic cycle. We have seen that for Caby (1978) the Pan-African belt of Mali results from the collision of two continental crusts, the west one with a passive margin, the east one with an active margin, with an eastward dipping subduction zone and a young dioritic accreted crust 150 km wide.

The participation of oceanic crust during the formation of the Pan-African chains has been discussed (Caby and Leblanc, 1973). Caby (ms), in the West Hoggar, took the "Série Verte" to represent oceanic material. In the Pan-African belt of Mali, Caby (1978) assumes a protorift with ultrabasic intrusion at about 800 m.y., beginning of an opening ocean before the collision. In the Dahomeyides, oceanic material may possibly be represented by the rare lenses of serpentine in the Tiélé Unit and perhaps also by the ultrabasic massifs along the western border of the Benin Plain Unit (Akuse, Mont Agou, Djabatouré, Kabré, and Derouvarou massifs) (fig. 3). But these ultrabasic massifs are generally assigned to a Birrimian or more ancient basement and are interpreted as ancient associations of gabbroic and basaltic rocks (Pougnet, 1957; Aicard, 1957; Henry and Scanvic, 1973) or as ophiolites (Colin and Péré, *in* Henry and Scanvic, 1973) that have been metamorphosed in the granulite facies and overthrusted during the Pan-African. According to Sagbohan (ms), the western border of the remobilized basement corresponds to a band of positive gravimetric anomaly, with a width of 100 km, without correlation with the surface geology. This anomaly is taken to reflect the injection of dense material of mantle origin at depth. According to this hypothesis, ultrabasic rocks poorly reflected in outcrops may be more dominant at depth. These features are perhaps in favor of the hypothesis of Burke and Dewey (1972). However, the most recent paleomagnetic results (Piper, 1974; Piper, Briden, and Lomax, 1973; McElhinny, Giddings, and Embleton, 1974) support an intracratonic origin for the Pan-African orogeny.

At the present level of erosion, the predominance of sialic crustal material characterizes the Pan-African orogen of western Africa. It is not possible to say with certainty how much of the gneisses represent transformed cover material (Black, 1967; Caby, ms; McCurry, 1971) or if the majority represent reactivated portions of ancient orogens (Grant, 1969; Fitches, 1970). In the northern part of the Dahomeyides the blocks of ancient reactivated basement seem to play an important role.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to the Directors of the Geological Surveys of Benin, Ghana, Upper-Volta, Niger, and Togo for their valuable cooperation in this project. The studies of the clay minerals (mineralogy, crystallinity, isotopic geochemistry) were carried out at the Center of Sedimentology and Geochemistry of Strasbourg by Dr. Clauer, to whom we express our gratitude. Professors B. Sturt, R. Hatcher, Jr., and John Rodgers are thanked for assisting with the English version of this paper and for their valuable comments. This work took place in the framework of IGGP Project n° 108-144 "Precambrian of West Africa and its correlations with eastern Brazil" and with financial help from the Centre National de la Recherche scientifique, Paris and of Aix-Marseille III University, Marseille, St. Jérôme.

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