PRECAMBRIAN OF WEST AFRICA

by

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A key topic in the forthcoming seminar co-sponsored by IUGS, IGCP and the Geological Society of Africa ("Precambrian of Africa and its Mineral Resources", January 19-21, 1981 in Accra, Ghana) will be the geological evolution of the various cratonic regions in Africa. In this article, Dr. Black reviews the evolution of the West African craton, which appears to have been stabilized by the Eburnean orogeny 2150 Ma ago. Emphasis is on problems of internal correlation and the nature of possible greenstone belts, as well as the Himalayan-type collision between the complex Pan African Taureg and Benin-Nigeria shields and the passive West African craton.

West African craton

In 1964, W.Q. Kennedy identified the West African craton: stable since 1700 Ma ago, it is bounded to the north, east and southwest by Pan African belts (600±100 Ma), and to the west by the Hercynian Mauritanides (Fig. 1). Its limits are sharply defined by geochronological data, thrusting of the more recent orogenic belts toward the craton, and by gravity anomalies (Bayer and Lesquer, 1978).

Archean and Lower Proterozoic

The Man shield (Figs. 1 and 2) comprises a western domain consisting essentially of Archean rocks modelled by the Liberian events (3000-2500 Ma) and almost unaffected by later deformation, and an eastern domain comprising both reactivated Archean basement and Lower Proterozoic schist belts which have been folded, metamorphosed and invaded by granitoids during the Eburnean event (2150±100 Ma).

In the western domain, the Archean of W Ivory Coast (Papon, 1973) consists of migmatized meta-arkoses injected by amphibole-hypersthene-diorite gneisses, acid granulites and by amphibolites and pyroxenites, overlain by magnetite-bearing quartzites and itabirites. Barrovian metamorphism varies from amphibolite to granulite facies. Intrusive granitoids include mesozonal porphyritic granites, late aplitic granites, and gneissified granodiorites and granites. In Liberia, a crystalline basement has been distinguished from metasedimentary formations. The basement complex consists largely of tonalitic and granitic gneisses, augen gneisses and granites, but includes some pelitic schists, calc-schists, amphibolites, and hypersthene-bearing para- and ortho-granulites.

The metasedimentary rocks in the Nimba Mountains (Ivory Coast) comprise a lower group of basal conglomeratic quartzites associated with ultrabasic rocks, amphibole schists representing metavolcanics and intercalated calcareous and pelitic sediments, and an upper group composed of phyllites and itabirites with intercalated silicate iron formations. Metamorphism is much weaker than in the surrounding basement complex, and although the presence of an unconformity is not proven, it has nevertheless been suggested by numerous authors.

Similarly in Sierra Leone, the Archean has been divided into two groups: the Mano-Moa granulites and the Kambui Group. The granulites vary from acid to basic and are both ortho- and para-derived. The Kambui Group, metamorphosed in the almandine amphibolite facies, consists of a meta-volcanic sequence of amphibolite and amphibole schists, mica-schists and pelitic gneisses, ferruginous magnetite-bearing quartzites, and small lenses of cordierite-anthophyllite-cummingtonite gneiss commonly in contact with ultrabasic intrusions. Here again the existence of a break between the two units has been a matter of controversy, but recent studies seem to confirm the existence of an unconformity.

In Guinea, the Simandou series, composed of magnetite-bearing quartzites, biotite schists and amphibolites, also appears to be unconformable on a basement complex and probably corresponds to the northern prolongation of the Nimba series. Geochronological studies of the basement

Figure 1. Schematic map of major Precambrian units of West Africa. 1.Archean (Kasila Group) 2.Lower Proterozoic (Marampa Group) 3.Upper Proterozoic (Rockell Group) 4.Metamorphosed undifferentiated Precambrian and Lower Palaeozoic 5.Archean 6.Lower Proterozoic (Birrimian) 7.Middle Proterozoic (Tarkwdian, Guelb el Hadid Group) 8.Upper Proterozoic (Supergroup 1) 9.Vendian-Cambrian (Supergroup 2) 10.Cambrian (Obosum Group) 11.Archean 12.Polycyclic basement, mainly Lower Proterozoic 13.Upper Proterozoic volcano-detritic formations (Pharusian) 14.Cambrian (Serie pourpre) 15.Undifferentiated Precambrian apparently stabilized around 730 Ma 16.Vendean, Tirine Group.

complex have yielded Rb-Sr rocks isochrons* of 2609±100 Ma, 2656±103 Ma (W Ivory Coast), 2709±44 Ma (Liberia), 2881 Ma (Sierra Leone), conventional ages in the range 3000-2500 Ma, and biotites ages of 1800-1500 Ma indicating Eburnean rejuvenation.

In the eastern domain, Archean rocks have been strongly affected by the Eburnean orogeny and are intruded by Eburnean granites. In SW Ivory Coast they are relatively well preserved, but Liberian metamorphism is less intense and may be overprinted by Eburnean metamorphism and deformation. Recent studies in Sierra Leone indicate the extent of an early thermal event around 2960 Ma followed by a later one around 2750 Ma. In the centre of Ivory Coast, relicts of what are considered to be Archean rocks occur in zones largely occupied by Eburnean granites separating the Birrimian schist belts.

*All quoted Rb-Sr ages have been recalculated using an ⁸⁷Rb decay constant of = 1.42x10⁻¹¹yr⁻¹.

Figure 2. Schematic geological map of the Man shield (after Bessoles, 1977).

The Lower Proterozoic Birrimian schist belts (Fig. 2) occur either as elongated deep troughs containing flysch deposits (Type I) or as broad shallow basins (Type II); the former are predominant in Ivory Coast and western Upper Volta, whereas the latter are widely developed in eastern Upper Volta, Niger and Ghana (Papon, 1973). Type I belts of southern and central Ivory Coast are very similar and consist of greenstones, metabasalts (including pillow lavas), volcano-sedimentary rocks composed of metarhyolites, rhyolitic and dacitic tuffs, quartzites, phyllites, and a persistent goudite** horizon, overlain by flysch-type deposits.

Type II belts contain little or no greenstones and flysch. They are essentially subcontinental deposits and are composed of volcano-sedimentary sequences in which acid volcanism predominates. Basic to intermediate lavas may be present in relation to subvolcanic intrusions, and some ultrabasic bodies have been reported. The sedimentary formations are represented by sericite-schists, greywackes, quartzites, metaconglomerates and calc-chlorite schists.

In Ghana, where the Birrimian was first defined, it has been divided into a lower sedimentary unit, consisting of phyllites, greywackes, tuffs and subordinate quartzites, and an upper volcanic unit composed of basic and intermediate lavas and tuffs often displaying spilitic characteristics, interstratified with greywackes and graphitic phyllites, and overlain by manganiferous phyllites and goudites. The Tarkwaian is a 4000 m thick gently folded molassic sequence which overlies the Birrimian unconformably. Similar molassic deposits occur in E Ivory Coast and in Upper Volta.

In the Type I belts, the Birrimian is intruded by foliated granodiorites probably about 2200 Ma old, by syntectonic 2-mica granites which are characteristic of the Eburnean and

which have yielded ages around 2100 Ma, by post-tectonic granodiorites and diorites dated around 2040 Ma, and a late group of plutons including syenites dated around 1640 Ma. Eburnean granites occurring between the belts intrusive into reactivated Archean gneisses are generally biotite granites and monzonites. In the eastern part of the Man shield, where Type II belts predominate, 2-mica granites are subordinate, and the majority of syntectonic and post-tectonic granites contain biotite and amphibole. Some late alkaline plutons have been reported in Niger.

Recent structural studies by P. Tempier and G. P. Bard have shown that the Birrimian has been affected by several phases of deformation. A new classification including a Lower and Upper Birrimian and two major Eburnean events has been proposed, but it is perhaps premature to extend it throughout the entire shield.

The Kenieba and Kayes inliers consist essentially of epizonal Birrimian volcano-detritic sequences containing flysch intruded by a variety of Eburnean granites.

The Reguibat shield, like the Man shield, is composed of Archean rocks in the west and centre, whereas Lower Proterozoic rocks are predominant in the east (Fig. 1). The Archean Amsaga Group in the west has been divided into a migmatitic and a metamorphic unit comprising at the base typical granulites: plagioclase-rich quartzo-feldspathic rocks containing hypersthene or amphibole intimately associated with pyroxenites and amphibolites and anorthosites, followed by garnet[±]biotite[±]sillimanite[±]cordierite leptynites and garnet-cordierite gneisses, overlain by amphibolites, marbles and ferruginous quartzites.

The group is intruded by metagabbros, anorthosites and serpentines and cut by small massifs of biotite granite and by

**Goudite is quartz spessartite rock.

beryl-tourmaline pegmatites. Metamorphism varies from low pressure granulite facies to amphibolite facies. The Fderik (Fort Goureaux) iron deposit consists of banded hematite ironstones in an epizonal allochthonous unit which may be of Lower Proterozoic age. In the central part of the shield the Archean includes abundant leptynites, biotite and muscovite gneisses, amphibolites, marbles and quartzites; the ferruginous quartzites so typical in the west are absent here.

The grade of metamorphism decreases toward the east, but syntectonic granites are abundant in this zone and include 2-mica granites, porphyritic biotite granites, granodiorites and diorites. Rb-Sr isochrons have been obtained on the gneisses indicating that a major event occurred around 2700 Ma, whereas the granites have yielded ages around 2400 Ma. Eburnean reactivation has produced biotite ages falling in the range of 2000-1500 Ma.

In the eastern part of the shield, Archean rocks are represented by leptynites, amphibolites, garnet gneisses, and migmatites. The Lower Proterozoic consists of various formations of volcano-detritic and volcanic origin, which may or may not have been subjected to metamorphism. The Yetti Group, which resembles the Birrimian of the Man shield, has been affected by greenschist metamorphism and by two main phases of deformation. Sheets of an unmetamorphosed Lower Proterozoic sequence composed of sandstones and conglomerates and containing pebbles from the Yetti Group and tuffs, have been thrust SW and tectonically over the Yetti Group. High-level Eburnean granitoids are very abundant in the eastern part of the shield and include porphyritic biotite adamellites, coarse pink biotite-amphibole granites, sub-volcanic gabbros, diorites, and granite porphyries which have invaded a thick, extensive sequence of rhyolites and ignimbrites (Aftout) with subordinate dacites and andesites toward the base. Sub-volcanic alkaline granites and a nepheline syenite ring-complex are also present.

Geochronological studies indicate the Aftout event to be over 2000 Ma old, but some late granites and syenites have given younger ages (1970-1560 Ma). The Guelb el Hadid Group, formed by coarse detritic material, is unconformable on the other formations and is considered to be an Eburnean molasse.

To summarize, Archean rocks of the West African craton display very similar features and may be regarded as typical Archean granulite-gneiss terrain locally associated with

greenstone belts (Kambui Group). In the Lower Proterozoic, there is a marked contrast between the Birrimian schist belts of the Man shield and the little disturbed volcano-clastic and extensive rhyolitic volcanism of the eastern Reguibat shield.

More detailed structural studies are required to understand the true nature of the Eburnean orogeny. Most authors favour an intracontinental model similar to some of those proposed for greenstone belts, involving the formation of deep troughs by rifting, followed by deformation, metamorphism of the trough deposits, accompanied by remobilization of Archean basement and intrusion of granites. Analogy to greenstone belts may be superficial in view of the relative scarcity of basic volcanics, absence of komatiites, and the presence of tangential tectonics described in the Yetti and in Upper Volta.

Upper Proterozoic cover

The central and eastern margins of the craton are gently down-warped to form the Taoudenni and Volta basins (Fig. 1). These cratonic formations are characterized by deposition on a plane surface, wide extension and great homogeneity in facies, and a very slow rate of subsidence estimated at between 5-15 mm/1000 years. In both the Taoudenni and Volta basins, one can distinguish the following: Supergroup 1, sedimentation of which started around 1000 Ma ago; it consists essentially of sandstones overlain in the Taoudenni basin by stromatolite-bearing limestones and dolomites; and Supergroup 2 of Vendian-Cambrian age, with the triad continental tillite barite-limestone-silexite at the base. In the Volta basin, Supergroup 2 is overlain by the Obosum Group, a continental red detritic sequence interpreted as the molasse of the Pan African belt to the east.

A major change in sedimentation occurred in the Gourma region of the Taoudenni basin (Fig. 1) around 800 Ma ago (the interval corresponding to the unconformity between Supergroups 1 and 2), due to rifting along the eastern margin of the craton leading to the development of a passive continental margin. In Mali, a triple point coincides with an embayment in the craton: the Gourma - with more than 8000 m of sediments, consisting of a terrigenous clastic phase at the base, followed by differentiated carbonate deposits, and ending with prograde continental clastic deposits - is thought to be a "failed" arm which evolved as an aulacogen, a comparable situation to that of the Benue with regard to the Gulf of Guinea in the Cretaceous.

Flat-lying fluvial sandstones overlying folded Upper Proterozoic formations of the Gourma aulacogen, Mali.

The Gourma trough, orientated WSW-ENE perpendicular to the edge of the craton (Fig. 1), is marked by positive gravity anomalies which can be traced westward across the craton where it splits into two branches. The Gourma formations are overlain unconformably by fluvial sandstones which display transport directions toward the NE and E and which may be equivalent to Supergroup 2. Although detailed stratigraphical correlations have not yet been established with the Volta basin, recent work indicates passage from platform deposits to thick shelf deposits as one goes eastward toward the edge of the craton.

Pan African belts

Ten years ago, R. Caby drew attention to the existence of an Upper Proterozoic island arc and marginal trough volcano-detritic assemblages in western Hoggar, and M. Leblanc recognized ophiolites at Bou Azzer (Morocco) along the northern edge of the West African craton. Burke and Dewey (1970) presented a plate tectonic model suggesting a Himalayan-type situation for most of the crust situated east of the craton. Since then, evidence has accumulated to confirm that the Pan African should be regarded as a modern type belt which resulted from collision between the passive margin of the West African craton and the active margin of a continent to the east (Black et al., 1979), represented by the Tuareg shield to the north and the Benin-Nigeria shield to the south.

The Tuareg shield (Fig. 1) is divided from W to E by major N-S shear zones into the following tectonic domains: (i) the Pharusian belt, comprising a western and an eastern branch, both characterized by the abundance of Upper Proterozoic volcano-detritic material; (ii) the polycyclic central Hoggar-Air domain, essentially composed of ancient gneisses reactivated and injected by abundant granitoids during the Pan African; (iii) the eastern Hoggar-Ténéré domain which was apparently to a large extent stabilized at an early stage of the Pan African, around 730 Ma. The crust forming the shield is composed largely of Archean and Lower Proterozoic ortho- and para-gneisses which have been subjected to high-grade amphibolite or granulite facies metamorphism and which yield ages of 2250 ± 100 Ma. Middle Proterozoic rocks, largely absent on the craton, are represented by several supracrustal sequences including Al-rich quartzites, pelitic schists and associated alkaline orthogneisses. A "Kibaran" event (1200-900 Ma) has been recorded in the Hoggar-Air polycyclic domain where a supracrustal sequence, with large-scale recumbent folds of Pennine-type overthrust to the NW, has undergone Barrovian metamorphism in high grade amphibolite facies with widespread migmatization, and is structurally unconformable on a basement of Eburnean or Archean age.

The Upper Proterozoic in the western Pharusian belt is represented by remnants of a platform sequence of quartzites and stromatolite-bearing marbles ("série à stromatolites") comparable to those overlying the craton, which are in turn overlain by extensive thick volcano-detritic and volcanic formations displaying characteristics of island arc and modern active continental margins, and suggesting the existence of an open ocean separating two continents.

An early phase of Pan African deformation (around 680 Ma) involved refolding of huge crystalline nappes in high-grade Barrovian metamorphic conditions and transport of nappes from N to SSE and from S to NNW. This major N-S collisional event in the western Pharusian branch is contemporaneous with the obduction of ophiolites along the northern margin of the craton in Morocco.

The later E-W collision with the West African craton (around 600 Ma) affects the entire Tuareg shield overprinting the earlier tectonic pattern. Prior to collision, the palaeogeographical picture along the western edge of the shield is that of an island arc to the west (Tlemsi), and a cordilleran-type continental margin to the east (Iforas). The former is composed of greywackes with turbidites, conglomerates, and occasional Al-rich pelitic layers (probably representing deep

sea clays) overlying dacitic breccias and a thick metabasalt unit, injected by a large volume of pre-tectonic gabbros and quartz-diorites. The latter is marked by flysch-molasse-type deposits and associated andesites, shallow sea volcano-detritic deposits and continental andesites, which display typical calc-alkaline trace element patterns with pronounced LREE enrichment and La/Yb ratios characteristic of modern continental margins with steeply dipping Benioff zones. Oceanic closure is marked by a suture outlined by a string of positive gravity anomalies which may be followed over a distance of 2000 km along the eastern margin of the craton.

West of the suture, nappes (comprising both units from the passive margin - mylonitized quartzites and blue-amphibole-bearing metabasalts and serpentines, which may represent oceanic material), have been thrust westward onto the craton. In the Gourma aulacogen, the sediments have been strongly deformed and piles of pellicular nappes have been transported W and SW over about 80 km. Whereas the schists forming the external nappes have been metamorphosed in the greenschist facies, the quartzites and eclogitic micaschists of the internal nappes are the result of high pressure metamorphism estimated at 15 Kb and a temperature around 650°C. A striking feature of the external zone of the Pan African belt west of the suture and on the passive margin of the craton is the complete absence of autochthonous Pan African magmatism.

East of the suture, in the western Pharusian branch, the late Pan African collisional event produced polyphase deformation in the amphibolite facies close to the suture, which passes eastward into N-S open and tight folds of high structural level metamorphosed in the greenschist facies, and important movement along shear zones. A composite calc-alkaline batholith, initiated around 615 Ma with spectacular dyke swarms, was emplaced in the Iforas in a zone of rapid uplift leading to unroofing and outpouring of horizontal rhyolites, followed by emplacement of alkaline ring-complexes dated at 590 Ma. The molasse to the Pharusian belt is represented by the "Série pourprée" which is partly of Lower Cambrian age.

In the eastern Pharusian branch, several Upper Proterozoic volcano-sedimentary units have been identified and the lowermost unit has been cut by granitoids dated at 880-830 Ma. N-S trending folds of high structural level in the north pass southward into tight folds with associated greenschist metamorphism grading to amphibolite facies and migmatites around syntectonic granites dated at 650-620 Ma. Late to post-tectonic granites yield ages in the range 600-530 Ma.

East of the shear zone, which marks the limit of the Pharusian belt, Pan African reactivation of the polycyclic central Hoggar-Air domain is characterized by greenschist metamorphic overprint, intense deformation localized along N-S schist belts, large-scale granite emplacement (650-600 Ma), producing locally low pressure-high temperature metamorphism superimposed on earlier mineral assemblages, and movement along shear zones. The N-S trending belts of low grade metasediments of assumed Upper Proterozoic age associated with predominant acid volcanism are believed to represent intracratonic troughs formed along shear belts, which have subsequently been underthrust, metamorphosed and sheared. This appears to be the case for the Tiririne fold belt formed along the boundary between the central Hoggar-Air domain and the east Hoggar-Ténéré domain. The Tiririne formation, which displays the characteristics of a molasse and contains a tillite, unconformably overlies granites dated at around 730 Ma, contains sills emplaced at 660 Ma, and is cut by granites at 604 ± 13 and 585 ± 14 Ma.

Although it is difficult to relate Pan African granitoids to subduction zones, there is an overall zonality. Diorites and granodiorites with low initial strontium ratios predominate in the Pharusian domain, whereas adamellites and K-rich varieties abound in the polycyclic central Hoggar-Air domain, suggesting that fusion related to crustal thickening may have played an important role.

The Benin-Nigeria shield (Fig. 1) is the southern prolongation of the Pan African belt. To the west, it is thrust onto the West African craton or, in most cases, on the Volta Basin. Along the western edge of the shield, in Togo and Benin, three structural units have been distinguished: (i) the *Buém unit*, non-metamorphic or anchizonal, tectonically overlies the Volta basin, the thrust zone commonly marked by lenses of serpentine. It is equivalent to Supergroup 2 of the Upper Proterozoic cover of the craton, and is especially thick at the horizon of glacial deposits which are marine, in contrast to continental facies in the Volta basin; (ii) the *Atacora unit* has been subjected to polyphase Barrovian metamorphism in greenschist to amphibolite facies, the grade increasing toward the east. It overthrusts the Buém unit and even the cratonic basement, and consists essentially of quartzites and micaschists equivalent to Supergroups 1 and 2 of the Volta basin; (iii) the *Benin Plains unit*, in continuity with the Nigerian basement to the east, was previously interpreted as Archean (Dahomeyan). It flatly overthrusts the Atacora unit and consists of reworked Eburnean para- and ortho-gneisses, basic and ultrabasic rocks, supracrustal muscovite-quartzites, biotite-muscovite gneisses and schists which are believed to be equivalent to the Atacora unit, migmatites and syn- and post-tectonic granitoids, including late alkaline granites of Pan African age which have yielded Rb-Sr whole rock isochrons of 638-588 Ma and biotite ages of 540-510 Ma, and locally low-grade volcano-sedimentary deposits preserved in grabens which may represent relicts of the Pan African molasse. The basic and ultra-basic complexes occur close to the thrust front and have been subjected to granulite facies metamorphism. Although their age is unknown, they are very similar to the assemblage tectonically emplaced along the suture in Mali, where they represent tholeiitic magma emplaced at the base of the crust around 800 Ma ago.

In SW Nigeria, the basement consists of charnockitic rocks of unknown age and a gneissic complex comprising banded gneisses, migmatites, quartzites, schists, biotite-amphibole gneisses, amphibolites, leptynites and marbles, metamorphosed in the almandine-amphibolite facies. They are cut by foliated granites, which have yielded Lower Proterozoic ages (Rb-Sr whole rock isochrons of 2267 ± 30 Ma, 2283 ± 70 Ma), and by porphyritic granites, subordinate quartz-diorites, and 2-mica granites which are considered to be Pan African. The

bulk of the metasediments is therefore probably Lower Proterozoic, but a dating of 2750 Ma indicates the presence of some Archean rocks, while Pan African rejuvenation produced biotite Rb-Sr and K-Ar ages around 500 Ma. A psammitic group overlies unconformably the other formations and may be either Middle or Upper Proterozoic.

Such supracrustal belts are widely developed in NW Nigeria but there is still considerable argument over their true age. Several authors regard them as Middle Proterozoic, and on the basis of Rb-Sr dating of metasediments (which have given ages of 1100-1200 Ma) believe in the existence of a "Kibaran" event. Others class these belts as Upper Proterozoic, the metamorphism and deformation being entirely Pan African. It should be noted, however, that all "Kibaran" ages (and this also applies to the Tuareg shield), have been obtained by Rb-Sr and K-Ar methods on metasediments; so far no granites have yielded this age.

The central part of Nigeria, locus of the Jurassic alkaline ring-complexes, is occupied by abundant Pan African granitoids which have been dated at 700-500 Ma. In NW Nigeria, volcano-detritic material, including dacites and shonshonites of Cambrian age, occur in grabens and probably represent Pan African molassic deposits.

Considering the Pan African belt east of the West African craton as a whole, what is striking is that the Pharusian cordilleran type assemblages are preserved in a re-entrant of the craton. To the south, the Benin-Nigerian shield is directly thrust onto the passive margin of the craton. Here, the oceanic opening was either very small, or the oceanic crust and active margin have been entirely subducted. One notes the similarity between the shear pattern of the Tuareg shield and that of NE Asia produced by the collision with India (Fig. 3). Pan African reactivation of the polycyclic central Hoggar-Air domain and of the Benin-Nigeria shield may represent the deep structural level of the same processes which are now at work in Asia.

Southwest of the West African craton (in Liberia and Sierra Leone), a Pan African Rockellides belt consists of rejuvenated Archean granulites (Kasila Group), the Marampa schists (which may be Birrimian or Archean), and folded and metamorphosed Upper Proterozoic Rockell Group which have

Figure 3. Comparison between Cenozoic and Recent fault-thrust pattern of NE Asia (after Molnar and Tapponnier, 1978) and Pan African tectonics in West Africa. Dotted areas represent Tertiary and Late Pan African deformation respectively.

been thrust toward the craton. Further north, the Hercynian Mauritanides may include units affected by the Pan African.

Conclusion

The crustal evolution of western Africa has, to a large extent, been determined by the Eburnean (2150-150 Ma) which stabilized the West African craton, and by the Pan African which led to the formation of Gondwanaland. New geological insight should point to new directions in mineral exploration (Fig. 4). The fundamental problems noted in this paper may be solved through international cooperation, meticulous field-work, and more sophisticated laboratory studies.

For an up-to-date bibliography, consult recent publications by Bessoles (1977); Bessoles and Trompette (1980); Bertrand and Caby, (1978); Caby et al. (1981); and Affaton et al. (1980).

References

- Affaton, P., Sougy, J., Trompette, R., 1980, The tectono-stratigraphic relationship between the Upper Precambrian and Lower Paleozoic Volta basin and the Pan-African Dahomeyide orogenic belt (West-Africa): *Amer. J. Sci.*, 280, pp. 224-248.
- Bayer, R., Lesquer, A., 1978, Les anomalies gravimétriques de la bordure orientale du craton ouest-africain: géométrie d'une suture pan-africaine: *Bull. Soc. géol. Fr.*, 20 (6), pp. 863-876.
- Bertrand, J.M.L., Caby, R., 1978, Geodynamic evolution of the Pan-African orogenic belt: a new interpretation of

the Hoggar shield (Algerian Sahara): *Geol. Rundsch.*, 67 (2), pp. 357-388.

- Bessoles, B., 1977, *Géologie de l'Afrique. Le craton ouest-africain: Mém. Bur. Rech. géol. min., Fr.*, 88, 402 p.
- Bessoles, B., Trompette, R., 1980, *Géologie de l'Afrique. La chaîne pan-africaine "zone mobile d'Afrique centrale (partie Sud) et zone mobile soudanaise": Mém. Bur. Rech. géol. min., Fr.*, 92, 396 p.
- Black, R., Caby, R., Moussine-Pouchkine, A., Bayer, R., Bertrand, J.M., Boullier, A.M., Fabre, J., Lesquer, A., 1979, Evidence for late Precambrian plate tectonics in West Africa: *Nature*, v. 278, 5701, pp. 223-227.
- Burke, K., Dewey, J.F., 1970, Orogeny in Africa, in Dessauvage, T.F.J. and Whiteman, A.J. (eds.), *African Geology: Proceedings, Conference on African Geology*, Ibadan Univ. Press, Ibadan, pp. 583-608.
- Caby, R., Bertrand, J.M., Black, R., (in press), Pan-African oceanic closure and continental collision in the Hoggar-Iforas segment, central Sahara, in Kröner, A. (ed.), *Precambrian Plate tectonics: Elsevier, Amsterdam*.
- Molnar, P., and Tapponnier, P., 1978, Active tectonics of Tibet: *J. Geophys. Res.*, v. 83, B11, pp. 5361-5376.
- Papon, A., 1973, *Géologie et minéralisations du Sud-Ouest de la Côte d'Ivoire: Synthèse des travaux de l'opération SASCA 1962-1968, Mém. Bur. Rech. géol. min., Fr.*, 80, 284 p.
- Routhier, P., 1980, Ou sont les métaux pour l'avenir?: *Mém. Bur. Rech. géol. min., Fr.*, 105, 409 p.

Figure 4. Mineral occurrences of West Africa (after Blanchot, BRGM, unpublished, and Routhier, 1980). The main deposits of the West African craton (Archean and Lower Proterozoic) are Fe, Au, Mn, and diamonds toward the margins of the craton. Cu occurs in the Hercynian Mauritanides and in the Pan African along the northern edge of the craton, but surprisingly few showings have been located in the Pharusian belt. Note the presence of phosphates in the Upper Proterozoic passive margin of the West African craton. Sn, W, Nb-Ta, and U are Pan African metals; uranium tends to be concentrated in the sedimentary cover.

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