A decade of change—mineral exploration in West Africa

by D. Pohl*

Introduction

The past decade has seen rapid expansion in the West African mineral exploration environment. This expansion has been largely driven by changes in

- ➤ Political climate
- ➤ Fiscal and legal regimes
- ➤ Exploration approaches
- ➤ West African geology.

Major regional mapping and geochemical surveys by the UNDP, and the BRGM in the late 1970s and early 1980s laid the foundation for the rapid development of mineral exploration and resources during the past decade. An additional driving impetus was the discovery by native artisanal miners of many significant new gold occurrences at Libiri, Essakan, Bouda and Tirahori, during the great droughts of the late seventies and early eighties.

The successful democratization of Ghana's military-led regime, the replacement of military regimes in Mali and Guinea by multiparty governments and the peaceful passing of Côte d'Ivoire's Houphouet-Boigny signalled a more mature political climate, conducive to resource extraction, particularly by foreign entities. Unfortunately the positive political developments in Ghana, Mali, Burkina Faso, Niger, and Côte d'Ivoire have been offset by political instability in Togo and Benin, civil war in Liberia, Sierra Leone, Congo and Guinea Bissau, as well as a secessionist movement in Senegal.

Ghana led the way with major positive changes in mining law and fiscal regimes covering the mining industry. Mining laws in Mali, Burkina Faso, Côte d'Ivoire have now converged toward those in Ghana, Australia, Canada and the U.S.A. However, a vestige of socialist-marxist idealogy remains in that most governments retain a carried interest in all mineral properties. Even this attitude may fall by the wayside also, as has been the case in Tanzania. Tax laws are now, generally, in line with those in developed countries and in many instances countries offer favorable tax treatment to the mining industry.

Geological survey departments and Ministries have changed dramatically for the better during the last decade, largely through donor funding for reorganization, computerization and fundamental field surveys. This has resulted in greater transparency of operation, faster processing of, or the reduction of, red tape, and better availability and distribution of new geological and technical data.

But a note caution of is in order. The recent move to make local geological survey departments self-sufficient enterprises may be counter-productive and as such should be resisted by the minerals industry. After an initial capacity building effort largely funded by foreign aid, local geological surveys became very responsive to the minerals industry. However, of late, the pressure to generate income has seen dramatic rises in costs and fees for the mining industry without any corresponding increase in quality or services rendered. In some instances there has even been a decline in service. The concept of public service and essential national investment must be reinforced.

On the exploration side, the trend has been to utilize new geochemical survey techniques developed in Australia which has similar problems of deeply weathered soils and cover, and to extensively use airborne magnetics and radiometrics to look through deep overburden. Responsible analytical laboratories have been established in most West African countries and offer healthy competition to the previously monopolistic government laboratories. The availability of low-cost percussion drills has fueled a movement toward pattern drilling and even regional sampling by drilling. Interestingly, one of the earliest and best geochemical indicators used in West Africa, artisanal mining activity, may be diminishing

* *Sanu Resource Inc. Los Angeles, U.S.A.*

This paper was presented at the SAIMM Symposium: Mining in Africa '98, *14–15 Sep. 1998.*

in its usefulness. Native mining has a detection limit of about 200 ppb gold. Rising standards of living, the low price of gold and absence of catastrophic drought all put downward pressure on artisanal exploration and exploitation. Artisanal miners are now following exploration companies rather than vice versa.

Political, fiscal and legal change may have been the key in bringing mining companies to West Africa but it will be the expansion of the understanding of the geological framework of West Africa that will keep them there. From a geological perspective there has been a revolutionary change in the knowledge and understanding of West African geology. The discovery of new styles of mineralization, such as Sadiola, Essakan, Ayenfuri, Abosso and diverse tectonic environments are expanding the possibilities for discovery of gold and basemetal resources in West Africa. It has been the use of detailed mapping, high-precision age determinations coupled with high-resolution airborne magnetics and EM data that fueled these changes. But our knowledge base is still fragmentary and contains many unresolved questions. For progress in understanding to grow, cooperation and funding from mining companies, universities and government agencies will be required.

Early Proterozoic geology of West Africa

Fundamental to the understanding of the Birimian supercrustals, is the reconciliation of conflicting paradigms of the stratigraphy and geodynamics established locally by different groups of geologists and researchers and then extrapolated throughout the Early Proterozoic Birimian province.

All the Early Proterozoic supracrustal rocks with the exception of some late silici-clastic basins in Ghana and Côte d'Ivoire (Tarkwaian System) have been assigned to the Birimian Supergroup (Archambault, 1935, 1943; Tagini, 1971; Bessoles, 1977; Kesse, 1985). (A note on nomenclature: Kitson's original definition used the term Birrimian to describe rocks in the Birim River valley of southern Ghana but following a request by the Ghana Geological Survey (Kesse and Barning, 1985) the spelling has been changed to Birimian to conform to the official place name of the type locality.)

British and Ghanaian concepts

Kitson (1919, 1928) first defined the Birimian from outcrops of clastic and metavolcanic rocks in the Birim River valley of southern Ghana. Junner in a series of reports between 1927 and 1940 subdivided the Birimian of southwestern Ghana into a lower sedimentary series and an upper volcanic series. This view was supported by Bates (1955). The lower meta-sediments consist of slate, phyllite, argillite, greywacke and tuff. The upper Birimian consists of mafic extrusive and intrusive rocks, minor greywacke and phyllite, and silicic lavas and pyroclastics. The stratigraphy was established on the basis of the dominant west-dipping nature of the supracrustal succession and the recognition that the contact between the Birimian section and the Tarkwaian System was overturned. The contact between the upper and lower Birimian was defined as the first appearance of volcanic rocks.

Junner (1940) also defined the Tarkwaian System consisting of a succession of arenaceous sediments unconformably overlying the Birimian. The succession begins with basal heterolithic conglomerates and arenites of the Kawere Group followed by quartz pebble conglomerates and arenites of the Banket Series which are in turn overlain by two sequences of sandstone and phyllite, the Upper and Lower Huni Sandstones and Phyllites.

Junner's proposed stratigraphy became the paradigm for the Birimian in West Africa.

The tonalite-trondjheimite-granodiorite (TTG) complex granitoids associated with Birimian greenstone belts in Ghana were divided into three major groups (Kesse 1985), a foliated, biotite-bearing batholithic plutonic series, the Cape Coast type, and interpreted as pre- or syntectonic; a hornblende-bearing, porphyritic, post-tectonic granodiorite, the Dixcove type and the post-orogenic Bongo granites. The inferred age relationships between these granitoid groups has recently been challenged and modified by German work on the Birimian in Ghana. They divide the granitoids into those intrusive into the volcanic belts (functionally equivalent to the Dixcove type), those intrusive into sedimentary basins (broadly equivalent to the Cape Coast type) and post-orogenic plutons (Bongo type).

Francophone concepts and contributions

The concept of an ensialic rift setting for Birimian sedimentation and volcanism was first introduced by Arnould (1961) and enthusiastically supported by most subsequent francophone workers in spite of the absence of basement-Birimian sedimentary contacts or rift-filling sedimentary successions. The extension of this geodynamic model of the Birimian led to the concept that each Birimian belt or basin recorded the same history.

Problems with this global stratigraphy and in particular with correlation of conglomerates within volcanic sequences with the Tarkwaian of Ghana led Tagini (1971) to invert the stratigraphy of the Birimian in Côte d'Ivoire. He proposed a lower volcanic and sedimentary sequence separated in time by a weak tectono-metamorphic episode from an upper sedimentary unit. The hypothesis was based on a postulated synclinorial structure for the Comoé and Haute Comoé flysch basins and their marginal volcanics as well as the perception of greater deformation in the marginal units.

Bard (1973, 1974, 1976) and Papon (1973) opposed Tagini's (1971) as well as other previous Birimian stratigraphic correlations. Bard, instead, proposed a simple distinction between volcanogenic (type 1) belts and sediment or flysch-dominated (type 2) belts.

Finally, the monumental work on the Birimian and west African gold deposits by Milesi *et al.*, (1989), comes almost a full circle in defining Birimian stratigraphy. Again, the Birimian Supergroup is divided into a lower sedimentary and volcanoclastic unit (B1) topped by a carbonate member and an upper volcanic unit (B2). Heeding the suggestion by Cahen *et al.*, (1984), Milesi *et al.*, now include the Tarkwaian as an intraformational unit at the top of the Upper Birimian (B2). The main criteria for dividing the Upper from the Lower Birimian are the number of deformation phases evident in each unit, a notoriously suspect procedure in view of the strongly contrasting rock strengths between flysch and massive volcanics and in view of the numerous craton-scale shear structures penetrating the Baoule-Mossi domain (Milesi, *et al*., 1989; Pohl *et al*., 1994).

Implicit in the Milesi *et al*., (1989) synthesis, but not referred to directly, is the requirement for a sialic crust to produce the vast volumes of lower Birimian sediments.

German-Ghanaian synthesis

Affirming the conclusions of Papon (1973), and Bard (1974) in Côte d'Ivoire, Hirdes and Leube (1989), Leube *et al.*, (1990) present major and trace element evidence that the Birimian volcanic belts and flysch belts are penecontemporaneous. They suggest that the belts are facies equivalents of volcanic arc-basin depot systems and demonstrate the progressive changes from volcanic centre to proximal-shelf to distal turbidite facies. Additionally they attempt to show, albeit less successfully, the geochemical equivalence of the volcanics and the derived clastics. They thus divide the Birimian into sedimentary basin and volcanic belts. They accept the Tarkwaian in its traditional stratigraphic position as a successor basin to the Birimian.

Dating in Ghana by Davis *et al.*, (1992) of granitoids intrusive into Kumasi and Sunyani flysch basins and into the Ashanti and Sefwi volcanic belts shows the 'volcanic belt' granitoids (Dixcove type) to be 30-60 Ma older than the flysch basin granitoids (Cape Coast type). This data inverts the British-Ghanaian interpretation that Dixcove granitoids are younger than Cape Coast granitoids.

Definition of Birimian

My proposed definition of the Birimian is an assemblage of supercrustal rocks deposited between 2200 Ma and 2000 Ma. A variety of lithologies are represented but are dominated by fine–medium grained, turbidite clastic sediments, often with a large immature volcanoclastic component, and volcanic rocks. Minor sedimentary components are manganiferous phyllites, cherts, carbonates and quartz arenites. The volcanic rocks consist of dominantly tholeiitic mafic lavas, with lesser amounts of andesite lavas and felsic volcanics.

The Tarkwaian problem

Fluviatile-deltaic clastic basins which unconformably overly Birimian volcanics and metasediments in southern and western Ghana were defined as the Tarkwaian System by Junner (1940). Other arenaceous sequences in the Birimian province (in Côte d'Ivoire, Burkina Faso, Mali) are presumed correlatives (Milesi *et al*., 1989; Turner, 1992; Bonkoungou, 1994). Milesi *et al.* (1989) included all such clastic sequences in the Tarkwaian but made them intraformational within the Upper Birimian. Leube *et al*., (1990) interpret the Tarkwaian as fluviatile intra-montane basins postdating the Birimian. I proposed that the Tarkwaian represents a foreland thrust basin resulting from the collision of Birimian volcanic arcs (Pohl, 1993). An alternative interpretation of the Tarkwaian as an intra-arc rift is proposed by Carlson (in prep.). Intercalated felsic volcanics in presumed correlative basins in the Boundiali belt (Turner *et al*., 1993), Kayes Inlier and at Essakan (Pohl *et al*., 1995) support such an interpretation. Detrital zircon ages from the Tarkwaian (Hirdes and Saager, 1988;) Houndé belt correlatives (Bonkoungou, 1994) and Birimian flysch basin sediments, as well as, dated intrusive relationships indicate that although they share similar Birimian arc source terranes, the Tarkwaian marks a regional shift from deep marine to subaerial deposition circa 2130 Ma. This switch from submarine to terrestrial deposition reflects the post-accretionary, uplift of a structurally thickened, composite arc terrane. In this interpretation, the Cape Coast plutons represent the reestablishment of arc magmatism through thickened arc basement.

Definition of Eburnean magmatic event

The regionally extensive tonalite-trondjheimite-granodiorite (TTG) complex which surrounds the Birimian supracrustal belts was assigned to the Eburnean Orogeny (Bonhomme 1962; Bessoles, 1977; Yace 1984), a poorly defined orogeny that supposedly rejuvenated an Archean basement, deformed the Birimian supracrustals and saw the intrusion of voluminous syntectonic and post-orogenic granitoids. Bonhomme's (1962) Eburnean event was dated at approximately 2000 Ma but this was extended by Yace (1984) to include granite emplacement between 2500 and 1600 Ma. Recent radiometric dating of the Birimian volcanics and TTG intrusives has shown,

- ➤ the almost complete absence of rejuvenated or any older Archean crust within the Mossi-Baoule domain. Any Archean signatures are present only at the margins of the Birimian province against the Archean Man Shield and Nigerian Shield
- ➤ the Birimian volcanics and TTG complex are locally penecontemporaneous
- ➤ the Eburnean Orogeny was shortlived, extending from ≈2200–2000 Ma. The youngest post-orogenic granitoids and gabbros have been dated around 1980 Ma (Hirdes *et al*., 1987: Carlson, 1997). However, even post-tectonic granitoids have been affected by the regional NNE shearing.

Dating of granitoids in the Nangodi belt by Carlson (1996, 1997, 1998, in prep.) has shown that correlations based on mineralogy and or geological environment are not regionally valid. Each belt-basin couple appears to have granitoid suites with unique chemistries and intrusive histories.

How many orogenies ?

Lemoine (1985a, 1985b, 1986, 1988; Lemoine *et al*., 1985) reduced the Eburnean Orogeny lasting from 2300 Ma to 1600 Ma (Yace 1976), to two orogenies, the Burkinian from 2250–2150 Ma and the Dabakalian from 2150–1850 Ma. In reality it appears that there is an episodic younging of magmatic ages from east to west across the entire Birimian province. Magmatic zircons dated at 2195 Ma in central Burkina Faso (Lompo, 1991), 2184 Ma in southern Ghana, younging through 2144–2150 Ma in southern Mali (Liégeois *et al*., 1991) and central Côte d'Ivoire (Lemoine, 1988), to 2098–2067 Ma in western Mali (Milesi *et al*., 1989). This strongly suggests a series of diachronously docking volcanic arcs, with episodic magmatism rather than specifically defined orogenies.

Rate of orogenic events

The evidence from southern Ghana indicates that the time between volcanism and intrusion of adjacent sedimentary basins is 30–60 Ma. In northern Ghana Carlson, (1994, 1997, 1998, in prep.) has shown that the progression from structural imbrication of ocean floor assemblages with flysch sediments and calc-alkaline arc volcanic and intrusion of post-tectonic granitoids took less than 30 Ma. Such rates of tectonism are similar to modern prograding arc-trench systems.

The oldest Birimian magmatic rocks are recorded in southern Ghana and east-central Burkina Faso (2195–2175 Ma) and the youngest occur in western Mali (2098–2067 Ma). Thus, approximately 1500 km of juvenile crust was added to the West African craton in approximately 115 Ma. This rate of crustal accretion is unmatched in the modern record and appears to be much more like those ascribed to the Archean (Abouchami, *et al.,* 1990; Boher *et al*., 1992; Taylor *et al*., 1988, 1992).

Are there modern analogs?

Notwithstanding the very high rates of crustal accretion during the Early Proterozoic, a modern analog for the Birimian appears to be the Indonesian and Philippine volcanic arcs (Pohl, 1993; Pohl and Carlson, 1993). These volcanic arcs, with their associated submarine sedimentary basins exhibit many of the tectonics features and environments of the Birimian.

The Indonesian archipelago is being deformed and accreted to the Australian craton by the latter's northward migration. New Guinea is already part of the Australian plate. Major strike slip faults marking the interiors of Sumatra and New Guinea are similar in scale to the Sassandra, Brobo, Wango-Fitini and other shears in the Birimian. Eventually the entire Indonesian and southern Philippine arcs will be accreted and buttressed between the Australian and Asian plates. Arc volcanics will alternate with marine flysch basins and these will be stitched together by accretionary batholiths. Early-formed epithermal gold and porphyry copper-gold may be preserved during this process but the dominant mechanism for gold mineralization will be the remobilization of early gold mineralization into mesothermal shear-hosted deposits and accretionary and post-tectonic granitoids.

A diversity of gold occurrences

A decade ago the gold target in West Africa was a shear-zone hosted quartz vein, preferably a second Ashanti. However, as exploration has developed, a large diversity of genetic types has been discovered (Milesi *et al*., 1991, 1992). The majority of the new discoveries have been only cursorily described but the range of genetic types now extends from high level epithermal deposits, through skarn or contact deposits, thrust fault-hosted occurrences, to vein stockwork (Pohl *et al*., 1995) and the more typical mesothermal vein deposits. This has also expanded the opportunities for discovery in the Birimian. A short list of occurrences with some examples is given here.

- Shear–Zone Hosted Vein: Ashanti, Prestea, Poura, Belahouro
- Disseminated, Shear-Zone Hosted: Bogosu, Konongo
- Breccia Disseminated: Syama, Sabodala
- Intrusive Disseminated: Ayenfuri
- Epithermal: Sanu Tinti, Sadiola?
- Porphyry copper-gold: Diénémera
- Tourmalinite: Loulo, P64
- Intrusive Contact: Ity, Morila, Sadiola?
- Stockwork: Bouda, Guibare, Essakan
- Extension Vein Stockwork: Kalana
- Paleoplacer: Tarkwa

Conclusions

The past ten years have seen many profound, and on balance mostly positive changes in the mineral exploration environment in West Africa. Governments have looked to the minerals industry to become the engine for economic growth and written legal and fiscal legislation to encourage the minerals industry. Mining and fiscal legislation is now largely in line with more developed countries. The almost universal retention of a carried interest in mining properties by governments in West Africa remains an onerous hindrance to the rapid development and exploitation of new discoveries. A concerted effort should be made by the minerals industry to remove this impediment to development. On the political front, Ghana, Mali, Burkina Faso, Côte d'Ivoire, Senegal, Guinea and Niger are developing stable, multiparty political institutions, but civil war, insurrection and relicts of one party or military governments are casting long shadows of uncertainty on Sierra Leone, Liberia, Togo, Benin, Congo, and Guinea Bissau. The unfortunate consequence is that these politically unstable nations can negatively impact not only their neighbours but the general perception of West Africa as a secure investment environment.

After a long hiatus, regional airborne surveys have again been flown in Ghana and are planned for Burkina Faso. Where these surveys are made available at a reasonable cost to the mining industry, they have stimulated exploration and generated new concepts for exploration. In my opinion the funding of airborne regional surveys by governments in West Africa remains a cost-effective investment for governments. Increasing exploration activity has created a virtuous circle of more demand for drilling and other contractor services with healthy competition and a resulting decrease in costs. This in turn has resulted in more and better exploration. Drill availability is up and costs are down, allowing for pattern drilling for buried targets and cheaper drill out of resources.

The geological database and understanding of the Birimian has increased dramatically during the last decade largely through BRGM, UNDP, FED, CIDA and BHP Minerals, funding of academic research. Unfortunately, these funding sources, have been severely cut back or redirected over the past few years, in part as a result of the successful entry of many exploration companies into West Africa; the research programmes having achieved the desired result. Competition among explorers has also to a degree reduced the flow of new geological information. The long term of exploration rights, 3–7 years, in West African countries results in exploration information only slowly becoming publicly available. An open file system is nominally in place in most

West African countries but unfortunately is not being effectively implemented by some governments. In view of the long-term nature and security of tenure of exploration rights, I would like to make a plea for greater openness and timeliness in the distribution of geological data by the minerals industry and governments. A sharing of data would be mutually beneficial to all explorers.

The most significant changes in our understanding of the Birimian has been the recognition that the Birimian represent a series of juvenile, Early Proterozoic, accreted terranes rather than ensialic rifts in an Archaean basement. Calc-alkaline magmatics arcs built upon tholeitic oceanic crust are the norm rather than bimodal rift-related volcanism. The extremely rapid growth of Early Proterozoic juvenile Birimian crust indicates heat flows and mantle extraction rates more characteristic of the Archean rather than Phanerozoic time. Such 'Archean-like' of crustal growth rates, by analogy with the Canadian and Yilgarn Shields, may be the key to the abundance of gold occurrences in the Birimian. To stretch the analogy even further, it may host VMS deposits in similar abundance to the Canadian Shield. Because of the currently small database, increasing our understanding of West African geology will surely increase exploration success.

References

ABOUCHAMI, W., BOHER, M., MICHARD, A., and ALBAREDE, F. A major 2.1 Ga old event of mafic magmatism in West Africa: an early stage of crustal accretion. *Journal of Geophysical Research*, v. 95, n.B11, 1990. pp. 17605–17629.

ARCHAMBAULT, J. Rapport géologique provisoire sur la region centrale du sud de la Côte d'Ivoire. *Dakar Serv. Mines*, A.O.F., 1935. 38 p.

ARCHAMBAULT, J., BOUIGE, L., and BONNAULT, D. Carte géologique au 1:500,000 et notice explicative feuille Bouaké-Ouest. Gouv. Gen. A.O.F., Dakar. 1943.

ARNOULD. Compte rendu des principaux résultats acquis par l'analyse lithologique des séries birrimienes des régions voisines de Bouaké. *Soc. Geol. Prosp. Min.*, Bouaké, 1959. 10 p.

BARD, J.P. Evolution géotectonique du craton Ouest-Africain en Côte d'Ivoire: éléments d'un nouveau schema. In, *African Geology (Proc. 2nd. Conf. African Geology*, Addis Ababa, 1973), Tsegaye Hailu, (ed.); Ibadan: Geol. Soc. Afr. 1976.

BARD, J.P. Classification et origines des granitoides éburnéens du craton Ouest-Africain. *C.R. Acad.* Sci, Paris, D281, 1975. pp. 867–870.

BARD, J.P. Les grand accidents du craton Ouest Africain en Côte d'Ivoire: des décrochements post-éburnéen(?). *C.R. Acad. Sci*. Paris, t.278, série D, 1974a. pp. 2609–2611.

BARD, J.P. Remarques a propos de l'évolution géotectonique du craton ouest-Africain en Côte d'Ivoire. *C. R. Acad. Sci.* Paris, D, vol. 278. 1974b. pp. 2405–2408.

BATES, D.A. Annual Report, Gold Coast Geological Survey, Accra. 1955.

BESSOLES, B. Géologie de l'Afrique. Le craton Ouest-Africain. *Mem. Bur. Rech. Géol. Minière,* Fr., n88, 1977. 402 p.

BOHER, M., ABOUCHAMI, W., MICHARD, A., ALBAREDE, F., and ARNDT, N. Crustal growth in West Africa at 2.1 Ga. *J. Geophys.,* Res., vol. 97, B1, 1992. pp. 345–369.

BONKOUNGOU, I. Le Tarkwaien du Sillon de Houndé (Burkina Faso): Un ensemble volcano-detritique acide calco-alcalin à 2,15 Ga. Unpubl. These de Doctorat, Univ. Nantes. 1994.

BONHOMME, M.G. Contribution a l'étude géochronologique de la plate-forme de l'ouest Africaine. Thèse 3e cycle, Clermont Ferrand, Ann. Fac. Sci. Univ. Clermont-Ferrand, 5, *Géol. Mineral.*, 1962. 62 p.

CAHEN, L., Snelling, N.J., Delhal, J., and Vail, J.R. Geochronology and Evolution of Africa. Oxford, *Clarendon Press,* 1984. 512 p.

CARLSON, C. Recognition of an Early Proterozoic ophiolite allocthon in the Birimian Nangodi greenstone Belt, NE Ghana. Proc. Ninth Intern. *Geol. Soc. Africa*, Accra, Ghana, vol. 9, 1993. pp. 107–118.

CARLSON, C., and BOWRING, S. Birimian 'belt' versus 'basin' intrusive sequence contradicted in ~ 2.1 Ga Nangodi greenstone belt, Ghana, West Africa. *Geol. Soc. Amer.*, Abstracts with Programs, vol. 26, no. 7, 1994. p. A406.

CARLSON, C. Paleoproterozoic intraoceanic accretionary tectonics recorded in the 2.1 Ga Birimian Nangodi Greenstone Belt, NE Ghana. Abstract, EOS, *Transaction, Amer. Geophys. Union*, vol. 78, no. 46, 1997. p. F720.

CARLSON, C. Paleoproterozoic intraoceanic tectonics recorded in the ~ 2.1 Ga Birimian Nangodi Greenstone Belt, NE Ghana. Abstracts with Programs SEG, Orlando. 1998.

CARLSON, C. In prep. Structural evolution, U/Pb geochronology and tectonic significance of the ~ 2.1 Ga Nangodi greenstone belt, West Africa: An Early Proterozoic example of plate driven accretionary orogenesis. Ph.D. thesis, Univ. Southern Calif.

DAVIS, D.W., HIRDES, W., SCHALTEGGER, U., and NUNOO, E.A. U-Pb age constraints on deposition of Birimian and gold-bearing Tarkwaian sediments in Ghana, West Africa. *Precambrian Research*, vol. 67, 1994. pp. 89–107.

HIRDES, W., DAVIS, D.W., and EISENLOHR, B.N. Reassessment of Proterozoic granite ages in Ghana on the basis U/Pb zircon and monazite dating. *Precambrian Research,* vol. 56, 1992. pp. 89–96.

HIRDES, W., and LEUBE, R. On gold mineralization of the Birimian Supergroup in Ghana/West Africa. Ghanaian-German Mineral Prospecting Project, *Geol. Surv. Dept*. Ghana; BGR, Hanover, Germany. 1989.

HIRDES, W., SAAGER, R., and LEUBE, A. New structural, radiometric and mineralogical aspects of the Au-bearing Tarkwaian group of Ghana. *Bicentennial Gold 88*, Melbourne. 1988. pp. 146–148.

JUNNER, N.R. The Geology of the Obuasi goldfields. *Gold Coast Geol. Surv.* Mem. 2, 1932. 71 p.

JUNNER, N.R. Gold in the Gold Coast. *Ghana Geol. Surv.* Mem. 4, 1935. 67 p.

JUNNER, N.R. The geology of the Gold Coast and western Togoland. *Bull. Geol. Surv. Gold Coast*, vol. 10, 1940. 40 p.

JUNNER, N.R., HIRST, T., and SERVICE, H. The Tarkwa goldfield. *Gold Coast Geol. Surv.* Mem. 6, 1942. 75 p.

KESSE, G.O. The Mineral and Rock Resources of Ghana. *Balkema,* Rotterdam, 1985. 610 p.

KESSE, G.O. and BARNING, K. Technical report on Ghana: UNESCO Geotraverse of the Birimian system in Southern Ghana. *Unesco and Geological Survey Dept. Report,* Accra, Ghana, 37 p with Appendix, 1985. 55 p.

KITSON, A.E. *Report* Geol. Surv. Gold Coast 1919.

KITSON, A.E. Provisional geological map of the Gold Coast and western Togoland, with brief descriptive notes thereon. *Gold Coast Geol. Surv. Bull.* no. 2. 1928.

LEMOINE, S. Mise en évidence d'une tectonique tangentielle éburnéenne dans la synforme birrimienne de Fetekro (Côte d'Ivoire), implications possibles pour l'orogenese éburnéenne. *C. R. Acad. Sci.* Paris, t.301, série II, 1985a. pp. 195–200.

LEMOINE, S. Quelques aspects nouveaux de l'orogenèse Éburnéenne en Côte d'Ivoire. *Colloq. Géol. Afr. 110eme Congr. Nat. Soc.* sav., Montpellier, fasc. VI 1985b. pp. 53–65.

LEMOINE, S. Histoire précambrienne de la région de Dabakala (Nord-Est de la Côte d'Ivoire). In, Les Formations Birrimiennes en Afrique de l'Ouest. *CIFEG Publication Occasionnelle* no. 10, 1986. pp. 71–76.

LEMOINE, S. Evolution géologique de la région Dabakala (NE de la Côte d'Ivoire) au Protérozoique inférieur. Possibilités d'extension au reste de la Côte d'Ivoire et au Burkina Faso. Thèse Doc. Sci., Université Blaise Pascal, Clermont-Ferrand, 1988. 388 p.

LEMOINE, S., TEMPIER, P., BASSOT, J.P., CAEN-VACHETTE, M., VIALETTE, Y., WENMENGA, U., and TOURÉ, S. The Burkinian, an orogenic cycle, precursor to the Eburnean of West Africa. *Coll. Afr. Geol. 13th,* St. Andrews, 1985. 27 p.

LIÉGEOIS, J.P., CLAESSENS, W., CAMARA, D., and KLERKX, J. Short-lived Eburnian orogeny in southern Mali. Geology, tectonics, U-Pb and Rb-Sr geochronology. *Precambrian Research*, vol. 50, 1991. pp. 111–136.

LEUBE, A., HIRDES, W., MAUER, R., and KESSE, G.O. The early Proterozoic Birimian supergroup of Ghana and some aspects of its associated gold mineralization. *Precambrian Res.* vol. 46, 1990. pp. 139–165.

LOMPO, M., CABY, R., and ROBINEAU, B. *C.R. Acad. Sci.*, Paris, II 313, 1991. pp. 945–950.

MILÉSI, J-P., LEDRU, P., FEYBESSE, J-L., DOMMANGET, A., and MARCOUX, E. Early Proterozoic ore deposits and tectonics of the Birimian orogenic belt, West Africa. *Precambrian Research*, vol. 58, 1992. pp. 305–344.

MILÉSI, J.P., FEYBESSEE, J.L., LEDRU, P., and 21 OTHERS. Les minéralisation aurifères de l'Afrique de l'Ouest; Leurs relations avec l'évolution lithostructurale au Protérozoique inférieur. *Chron. Rech. Miniére* No. 497, 1989. pp. 3–98.

MILÉSI, J.P., LEDRU, P., ANKRAH, P.T., JOHAN, V., MARCOUX, E., and VINCHON, C.H. The metallogenetic relationship between Birimian and Tarkwaian gold deposits in Ghana. *Mineralium Deposita*, vol. 26, 1991. pp. 228–238.

PAPON, A. Géologie et minéralisations du sud-ouest de la Côte d'Ivoire. *Mem. BRGM* Fr., no. 80, 1973. p 284.

POHL, D.C. The Birimian supergroup of West Africa. Summary report of the geology and exploration potential. BHP Minerals Unpubl. Internal Report, 1993. 100 p.

POHL, D.C. and CARLSON, C. A Plate tectonic re-interpretation of the 2.2-2.0 Ga Birimian province, Tarkwaian System and metallogenesis in West Africa. *Proc. 9th Intern. Conf. of Geol. Soc. Africa*, Accra, Ghana, 1993. pp. 378–381.

POHL, D.C., CARLSON, C., and LEAKE, M. Mega C-S structural grain of the Early Proterozoic Birimian Province of West Africa and its implications. *Geol. Soc. Amer.*, Abstracts with Programs, vol. 26. no 7. 1994. p. A-406.

POHL, D.C., KABORÉ, E, B., BENNELL, M., HANSSEN, E., and NIKIÉMA, S., *et al.* Essakan Stockwork Gold Deposit – Burkina Faso: Phase One Completion Report. BHP Minerals Unpubl. Internal Report, 1995. 33 p.

TAGINI, B. Esquisse structural de la Côte d'Ivoire: Essai de tectonique. Thèse d'Etat, Universite Lausanne et Bull. SODEMI, Abidjan, 1971. 302 p.

TAYLOR, P.N., MOORBATH, S., LEUBE, A., and HIRDES, W. Geochronology and crustal evolution of Early Proterozoic granite-greenstone terrains in Ghana/West Africa. Internat. Conf. on the Geology of Ghana with special emphasis on gold, Abst., 75th Anniv. *Ghana Geol. Surv. Dept.*, Accra, Ghana. 1988.

TAYLOR, P.N., MOORBATH, S., LEUBE, A., and HIRDES, W. Early Proterozoic crustal evolution in the Birimian of Ghana; constraints from geochronology and isotope geochemistry. *Precamb. Res.*, vol. 56, 1992. pp. 97–111

TURNER, P., HALL, R.P., HUGHES, D.J., and WHALLEY, J.S. The sediment-dominated Boundiali-Bagoé supracrustal belt and neighbouring granitic rocks, northern Côte d'Ivoire, West Africa: A Tarkwaian connection? *Journal of African Earth Sciences*, vol. 17, no. 1-11 1993.

YACÉ, I. Le volcanisme éburnéen dans les parties centrales et méridonales de la chaîne précambrienne de Fétékro en Côte d'Ivoire. Thèse d'Etat, Abidjan. 1976. ◆