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A review of the current state of knowledge on gold mineralisation in Benin Republic, West Africa

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ABSTRACT

Gold in Benin occurs as primary and alluvial forms in various deposits and occurrences. The mineralisation has a regional distribution covering, in particular, the Atacora area (Natitingou) and the regions of Bembèrèkè, Djougou and Dunkassa which are between the 9th and 11th parallel north. The data collected during previous work allow us to recognise the main style of primary gold as being quartz-vein hosted. This style occurs principally in quartzite, mica schist, schist and amphibolite lithologies, outcropping in the criss-crossing of the faults and the rugged relief. The mineralised veins are milky, deformed and gold is associated with sulphides and tourmaline. In these veins, gold exhibits three forms: free native metal, tellurides, and combined or included in sulphides. These gold-bearing quartz veins would proceed from hydrothermal solutions related to granitic mass. Classical characteristics available about the primary gold mineralisation in Bénin are inadequate to better clarify its geodynamic context. However, it has some similarities with deposits of the Precambrian terranes in adjacent countries (Pourra deposit in Burkina Faso and Kalana deposit in Mali) which are characterised by epigenetic gold deposits in Precambrian metamorphic terranes. Also, the vein gold of Bénin are mostly located in Precambrian metamorphosed sedimentary and volcanic formations; these could also have the epigenetic disseminated gold style like in some West African deposits (Ashanti deposit).

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Introduction

The Bénin Republic, bound by coordinates 6°15'N–12°30'N and 1°00'E–3°40'E, is a West African country located in the inter-tropical zone, with a total land area of 112,622 km². It is a strip of land, bordered by Niger, Burkina Faso, Togo, Nigeria and the Atlantic Ocean (Figure 1); with fairly rugged relief and an average altitude of 200 m.

The Beninese territory is part of the Pan-African Dahomeyides Belt; the southern section of the Pan-African Belt of West Africa (Affaton 1990; Castaing et al. 1993; Trompette 1994; Attoh et al. 1997; Peuca et al. 2005). The Belt extends from the Hoggar mountains, through the Gulf of Benin, and continues eastwards into Central Africa and farther south into Northeast Brazil where it is called the Brasiliano Belt (Caby 1989; Caby et al. 1991; Castaing et al. 1993; Trompette 1994; Monie et al. 1997). The suite of rocks in the Dahomeyides Belt has been affected by high pressure and high temperature metamorphism and is of Neoproterozoic age (Affaton, 1990; Castaing et al. 1993; Attoh 1998; Ferré et al. 2002).

The Pan-African Belt of West Africa has long been known for its gold endowment and gold production, with informal artisanal mining having taken place for

centuries (Robertson and Peters 2016). In Benin, gold occurs both as primary mineralisation and secondary mineralisation (alluvial deposits; Chermette 1938, 1939; Chermette and Olori-Togbé 1966; Kriatov et al. 1980, 1995; Kirov and Boboé 1983; Yessoufou 1991). However, little is known on the economic potential and host rocks for gold mineralisation.

Intense artisanal mining was done in the Benin Republic from 1939 to 1954, during which about one tonne of gold was extracted from the Perma placer in the Atacora Region (Chermette and Olori-Togbé 1966; Kirov and Boboé 1983; Kirov et al. 1983). Since then, the Atacora Formation bearing the mineralisation has been the subject of systematic research that led to the discovery of lode gold mineralisation. Gold placers were also identified in the tributaries of the Perma River and in the valleys of the Sina-Issiré and Sarga rivers. Mand'huy (1962); Kirov et al. (1980, 1995) and DGM and OBRGM (2007) identified an area north of Kaoundé between the basement and the Atacora Unit, as promising gold mineralisation zones which require more study. Apart from these areas, gold mineralisation is recognised in other parts of Bénin, particularly in the territory of the Bembèrèkè, Dunkassa and Djougou geological sheets.

However, since the discovery of this resource at different parts of Benin Republic, no thorough studies have been made on the nature of the mineralisation. Most of the available data on gold mineralisation is limited to unpublished internal company reports and a few conference abstracts. The alteration patterns in the gold-bearing rocks, the genesis of the gold-bearing fluid and structural control on mineralisation are not well known. These are important in understanding the mineralisation style of gold, and useful in designing exploration programmes.

This paper is aimed at reviewing the current state of knowledge on gold mineralisation in the Benin Republic. The gold deposit types and localities are highlighted, and estimated reserves are presented. A forecast of the extent of mineralisation is made on

the basis of the knowledge of gold metallogenesis in the Precambrian.

Geological setting

Regional geology

The Pan-African Dahomeyides Belt corresponds to the southwestern segment of the larger Brasiliano/Trans-Saharan belt (Trompette 1994). It is set up toward the West of the Volta Basin, and even directly on the West-African Craton at Ghana (Accra sector) (Figure 1). The Belt resulted from the continental collision between the Benino-Nigerian shield and the southeast margin of the West-African Craton during the Neoproterozoic (Caby 1989; Affaton 1990;

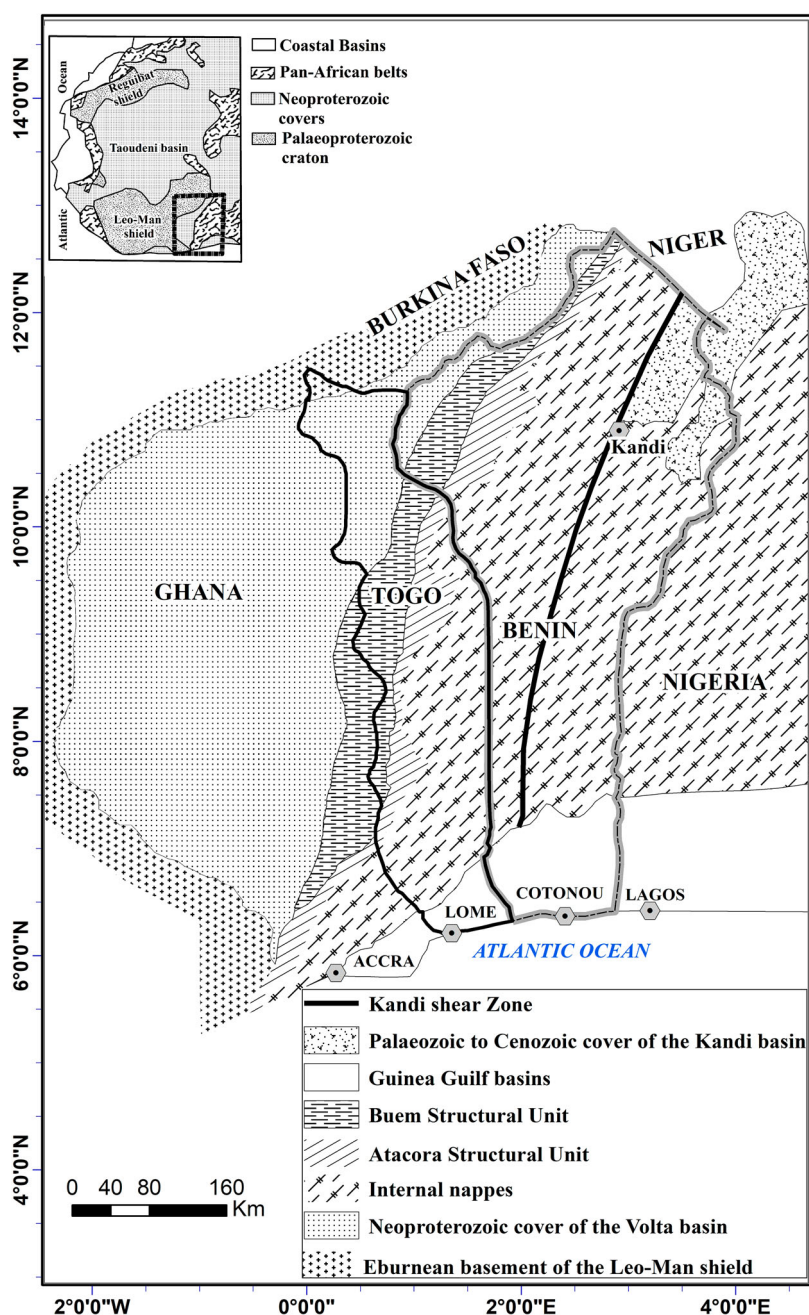


Figure 1. Geological map of the Volta Basin and the Pan-African Dahomeyides Belt (modified, Chala et al. 2015).

Affaton et al. 1991). It is composed from East to West of internal nappes, suture zone and external nappes.

The external nappes thrust over the West African craton are derived from tectonic and metamorphic passive margin sedimentary deposits (Middle to Late Proterozoic). This area displays middle-to high-pressure metamorphism, such as the Kante and Atacora nappes. The most external nappes form the Buem and Atacora structural units that are made up of anchizone shale and sandstone, jasper, phyllite and varied quartzite with greenschist-facies assemblages. The suture zone (intermediate nappes) consists of basic and ultrabasic massifs, metasedimentary rocks and orthogneiss tectonically overlying the western external nappes and underlying the eastern internal nappes (Caby 1989; Affaton 1990; Affaton et al. 1991; Castaing et al. 1993; Tairou et al. 2012). The internal nappes constituting the Benino-Nigerian shield are made up of high-grade commonly anatectic gneiss including orthogneiss and granulite, which are derived from Archaean plutonic rocks (such as granite and charnockite), thoroughly deformed, recrystallised and remobilised during the Neoproterozoic thermo-tectonic events (Caby 1989; Castaing et al. 1993). The internal nappe rocks are intruded by thrust-related and syn- to late transcurrent shear zone-related granites (Neves et al. 2000; Caby 2003; Attoh et al. 2013; Dawai et al. 2013; Adissin Glodji et al. 2014). Important transcontinental shear zones occur along the Pan-African/Brasiliano Belt among which the Kandi Shear Zone in Dahomeyides and the Trans-Brasiliano lineament in Northeast Brazil show a good correlation between Northeast Brazil and West Africa (Nigeria-Benin-Togo-Ghana) (Caby 1989; Trompette 1994; Neves 2003; Arthaud et al. 2008; Dos Santos et al. 2008).

Geological overview of Benin Republic

Belonging to the Dahomeyides Orogenic Belt, the Bénin Republic is underlain by crystalline basement and sedimentary units. The crystalline basement, which constitutes about 83% of Beninese territory, lies unconformably on three sedimentary basins: the Coastal Sedimentary Basin to the South, the Kandi Basin to the Northeast and the Volta Basin that represents the foreland of the Belt to the Northwest (Pougnét 1957; Affaton et al. 1978; Bessoles and Trompette 1980) (Figure 2). The crystalline basement encompasses the Buem (shale, sandstone and volcanic rocks) and Atacora (sandstone, quartzite, conglomerate, mica schist, schist, phyllite and amphibolite) structural unit, the suture zone (basic and ultrabasic rocks, granulite/eclogitic assemblages) and Beninese plain structural unit (various gneisses, migmatite and granulite; Boussari 1975; IRB 1989; Affaton et al. 1991; Adissin Glodji 2012; Chala et al. 2015).

The Atacora quartzite is an orthogneiss suite considered as Eburnean equivalents (2000 ± 200 Ma) that was extensively rejuvenated during the Pan-African thermo-tectonics, at c. 610 Ma (Caen-Vachette et al. 1979; Affaton et al. 2000; Agbossoumonde et al. 2007; Kalsbeek et al. 2012). The suture zone assembles rocks highlight the Pan-African subduction-collision process between 640 and 610 Ma (Affaton et al. 1991; Attoh 1998; Agbossoumonde et al. 2004; Duclaux et al. 2006; Attoh et al. 2007). The Beninese plain structural unit (so-called internal structural unit) rocks are remobilised and rejuvenated to Pan-African late-tectonic by syenomonzonite granite. It is also overlain by volcanic and sedimentary formations restricted to a narrow tectonic basin, such as Pako, Barou, Daho-Mahou, Lanta basins made up mafic to silicic volcanic and subvolcanic rocks (rhyolites, basalt, dolerite, andesite and trachyte) and intrusive rocks (granite and gabbro) associated with sediments (Boussari 1975; IRB 1989; Affaton 1990; Adissin Glodji 2012; Adissin Glodji et al. 2014).

The polyphase deformation (Dn-Dn + 4) identified in the Pan-African Dahomeyides Belt has been recognised on outcrops in Benin in granitic rocks. These deformations are characterised by foliations, lineation, folds, dextral and sinistral shear planes, faults and faults system (Affaton et al. 1991; Tairou et al. 2007; Chala et al. 2015). The Atacora Unit is composed of an antiform, and the Buem structural unit comprises synformal folds on the scale of kilometres. In the Internal nappes, folds and the metamorphism decrease from east to west (Affaton 1990; Affaton et al. 1991; Chala et al. 2015). The Kandi Shear Zone activity started around 610 Ma and affected the basement rocks, including Palaeoproterozoic granulite and Neoproterozoic gneiss, migmatite and granitic rocks (Adissin Glodji 2012). The metamorphic rocks from the Kandi Shear Zone display a steep to vertical N-S trending foliation, a sub-horizontal mineral lineation together with kinematic indicators of a dextral transcurrent mega-shear zone. Granitic rocks in the internal zone derive from both high-K calc-alkaline and alkaline magma (Adissin Glodji et al. 2012; Adissin Glodji et al. 2014). Also, a synkinematic fabric is observed in most granitic intrusions.

The Volta Basin is split into three groups: two groups (I and II) of Meso- to Neoproterozoic ages (1100–600 Ma), whereas the third group is of the Palaeozoic age (500–300 Ma; Affaton 1990; Affaton et al. 1991). The first group is made up of two sandy sequences interstratified with an argillitic to silty sequence, whereas the second group consists of tillite, dolomitic limestone associated with argillite, siltstone and phosphorite. The latter group (III) corresponds to the Pan-African Dahomeyides Belt molasse with argillite, siltstone, sandstone and conglomerate. The Kandi basin is composed of (1) Palaeozoic Wèrè (continental) and Kandi (marine) Formations; (2) Mesozoic

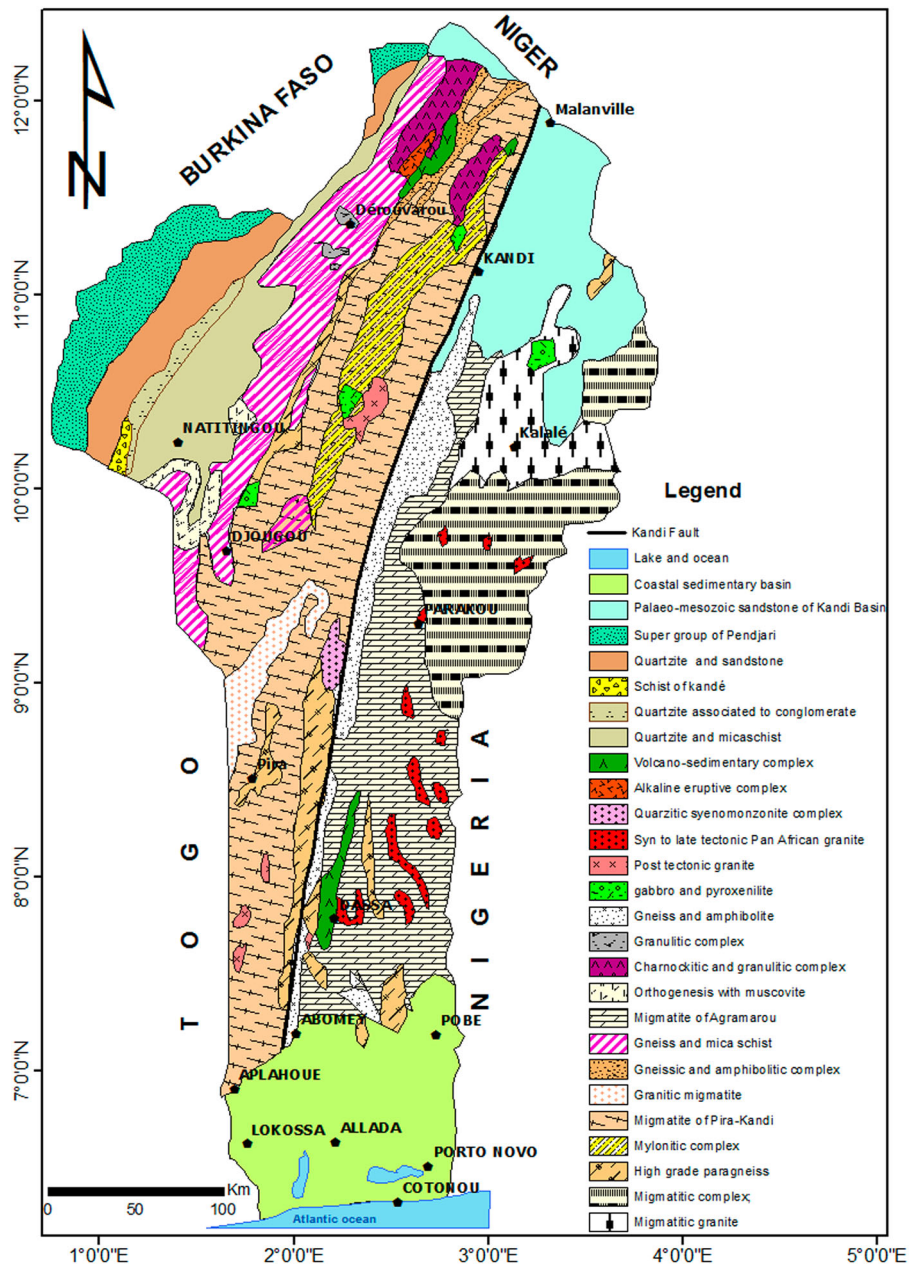


Figure 2. Geological map of Benin (modified after OBRGM and DGM, 2007).

Sendé (continental) Formation and (3) Continental terminal and Quaternary formations of Cenozoic age (*Institut de Recherches Breda IRB 1982*).

The coastal sedimentary basin is part of the Bénin bay, a large basin that stretches from the Keta basin (Ghana) to Southwest Nigeria where it is bordered by the Niger Delta Basin. This coastal basin is characterised by eight litho-stratigraphic units which have Turonian-Coniacian to early Holocene ages (*IRB 1989*).

The Bénin Republic hosts numerous mineral resources located in various metallogenic regions. The major mineral deposits which have been or are currently being mined include limestone, gold, marble, iron, gravel, ornamental stones, kaolin and columbo-tantalite (COLTAN). The minor resources are chromium, lead, nickel, manganese, spodumene, tourmaline, beryllium and monazite (*OBRGM 2000; DGM and OBRGM 2007*). Gold mineralisation is hosted in

quartz veins within quartzite, schist, mica schist and amphibolite and also in alluvial deposits (*Kirov et al. 1976, 1981; Kriatov et al. 1980, 1995; DGM and OBRGM 2007*). However, the lode gold has received the most attention in terms of exploration.

Type of gold mineralisation in Bénin

Gold mineralisation occurs as primary and secondary (alluvial) in various host rocks. The mineralisation can also be classified using the tonnage of the deposits and occurrences (*Figure 3*).

Primary gold mineralisation (quartz-vein gold deposits)

Primary gold mineralisation studied currently in Bénin is found mostly in auriferous quartz veins hosted in

different lithologies and geologic settings. These auriferous quartz veins and their host lithologies are highlighted below including the Perma and Kouandé deposits (OBRGM and DGM 2007) and a number of smaller occurrences (Yarra, Pessoulou, Nia-Nianou, Nibiori, Ana, Sarédarou, Lougou and Alibori).

Perma area: The auriferous quartz vein of Perma is located in the Atacora Unit and are the most important deposit and consists of 36 auriferous quartz veins. Of these veins, the most valuable in terms of grade are the Patrick and Kamara veins. Estimated reserves on 26 major veins amounted to 900 kg of gold and a grade from 5 to 300 g per tonne with an average grade of 9 g t⁻¹ (De Vaucorbeil 1965; Kirov et al. 1976, 1981; Kriatov et al. 1980, 1995; Yessoufou 1991). The Perma area consists of quartzite, micaceous quartzite, mica schist, schist and amphibolite (Lehingue and Roignot 1964; Kriatov et al. 1980; Yessoufou 1991).

Kouandé area: Quartz vein deposit of Kouandé located in the Northeast of Perma, occurs along the

structural contact between the basement and the Atacora quartzite rocks. It consists of auriferous quartz veins of Nimbéré, Daro, Kouba and Tansé sectors (De Vaucorbeil 1965; Kriatov et al. 1980, 1995). The gold grade is from 0.20–2.40 g t⁻¹, but in some places like Nimbéré village, it grades up to 64 g t⁻¹. The quartz-bearing veins are hosted in white mica-chlorite schist and in quartzite and white mica-quartz schist of Atacora (De Vaucorbeil 1965; Mackallor and Stager 1967; Kriatov et al. 1980). This deposit covers a 600 km² area and gold is associated with lead, silver and copper mineralisation.

The gold mineralisation of Yarra is located about 20 km north of Sinendé in the Alibori NNE-SSW mylonitic zone (Rezende et al. 2011). It is an area mainly composed of diorite and granodiorite outcrops intruded into gneiss containing biotite, amphibole and minor garnet. The mineralisation is related to quartz veins associated with a tectonic zone striking 110°. Gold is hosted both in the vein and eluvial deposits. The mineralised veins have an average thickness of 0.65 m and their erosion with drainage of the area by runoff has generated placer deposits. The mineralised zone is oriented NNE and extends for 5 km with a width from 40 to 300 m. The gold content in the veins grades between 3 and 5 g t⁻¹; that of the alluvial deposits is 0.8–3 g t⁻¹ (Kriatov et al. 1980, 1995).

The mineralisation of Pessoulou is located west of Sinendé in the contact zone between the Eburnean granite and white mica-chlorite schist. The contact is complex with a series of faults that are oriented north-east that controls the porphyry granite dykes and quartz veins. Generally, quartz veinlets and gneiss contain low gold and silver grade (Kriatov et al. 1980, 1995). However, quartz veins related to the contact zone of granites has 3.1 g t⁻¹.

The mineralisation at Nia-Nianou is hosted in a sector composed of gneiss with intercalations of amphibolite lenses. These rocks are intersected by granite dykes and three auriferous quartz veins. The lodes are more mineralised than gneiss, amphibolite and granite rocks. Gold mineralisation is associated with galena and kyanite (Kriatov et al. 1980, 1995). The presence of gold grains in the Mari River tributary draining the mineralised zones has prompted mining interest in the area. Moreover, the concentration of reddish sand in the alluvial deposits of the upstream part of the Mari River is suggestive of the possible occurrence of garnet gems in the locality (Rezende et al. 2011).

The gold mineralisation of Nibiori was discovered in the lower part of Nibiori River, north of Pessoulou. It is related to numerous quartz veinlets in a zone made up of granite and gneiss. The gold grade is low with 0.3 g t⁻¹; and associated with silver and copper.

The Ana, Néana and Kpoua river basins comprise the gold mineralisation sector at Ana, south of Ségbana.

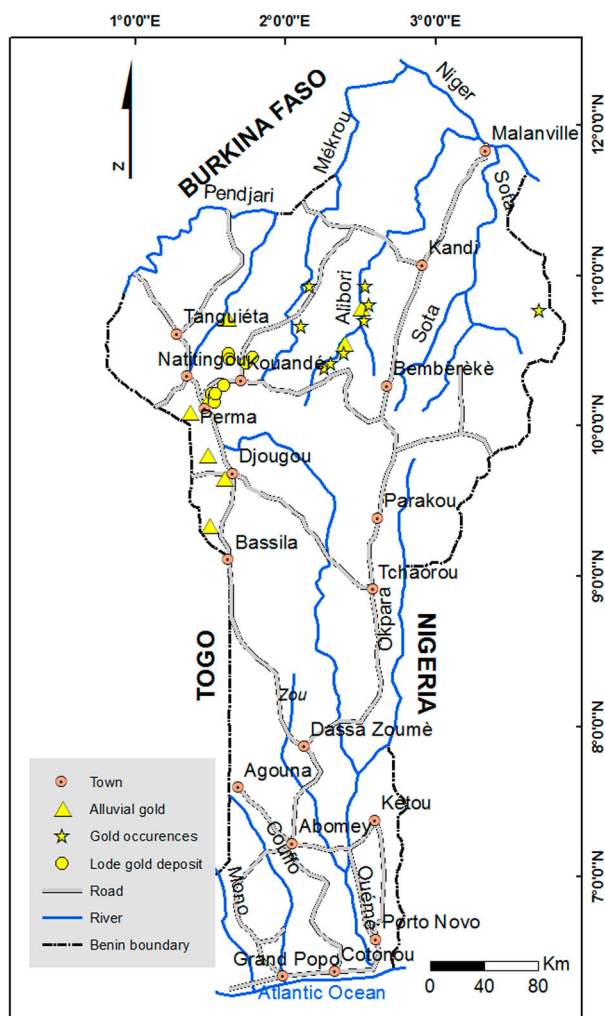


Figure 3. Map of gold location in Benin Republic (based on previous prospecting works and Benin's geological and Mineral Commodity map covering the Natitingou, Bembèrèke, Dun-kassa and Djougou sheets [Sheets NC-31-XIV, NC-31-XV, NC-31-XVI, NC-31-VIII]).

It is an area mainly composed of amphibolite and gneiss comprising mainly biotite and amphibole. These rocks are migmatites and gold occurrence was determined by analysis of migmatic amphibolite (Kriatov et al. 1980). The gold grade is up to 3 g t^{-1} .

The alluvial gold occurrences of Sarédarou occur on the left bank of the Sarédarou River. It is an area consisting of mylonite containing quartz, feldspar, biotite and hematite. The mineralisation is associated with quartz zone extending over 2800 m^2 where eluvial deposits host gold with grades up to 0.1 g t^{-1} (Kirov et al. 1981; Kriatov et al. 1980, 1995).

The Lougou gold mineralisation is in the township of Sinendé in an area of schist containing quartz, white mica and chlorite. It is related to a quartz vein zone where the gold grade is 0.2 g t^{-1} . Gold is associated with chalcopyrite, bornite, sphalerite, galena and silver (Kirov et al. 1981; Kriatov et al. 1980, 1995).

The North Alibori gold mineralisation is on the left bank of the Alibori River. The area is mainly composed of white mica -chlorite schist with quartz veins. In the north of the area, these rocks are in contact with a large granitic mass. The gold content of the largest vein (300 m long and 20 cm thick) is 0.3 g t^{-1} (Kriatov et al. 1980, 1995) (Table 1).

Main sites of placer (alluvial) gold deposits

Placer gold deposits occur in the valleys of the Perma, Sarga and Sina-Issiré rivers in the Atacora region on the Natitingou sheet where they are continually being mined.

Perma placer

The Perma placer was mined from 1939 to 1959 by mining companies with a production of one t of gold. However, research in untapped areas has revealed a further 400 kg of production during this colonial

period. The average gold grade in the gravel bed is estimated at 1 g m^{-3} (Mand'huy 1962; Kirov and Boboé 1983; Kirov et al. 1983). The alluvial gold of Perma has since been exploited through artisanal mining. The Perma River drains various quartzite lithologies constituting the Atacora Structural Unit.

Sarga placer

The Sarga alluvial placer extends over 4 km and the gold grade is about 1 g m^{-3} , with a reserve of 760 kg (Kirov et al. 1983; Depciuch and Azonsi 1983). The area mainly consists of white mica-quartz schist, quartzite, quartz-white mica-chlorite schist, sandstone, conglomerate and dolomite (Kriatov et al. 1995). Research shows that the auriferous layer has a thickness of 0.5–5 m, with an average of 1.6 m.

Sina-Issiré placer

The highest gold grades in the Sina-Issiré placer are observed in alluvial deposits of the major bed of the river and in the first accumulation terrace. The thickness of the auriferous layer at Sina-Issire is 1–2.5 m and it is covered by 10 m of sandstone and clay-gravelly deposits, which also contains gold. The total thickness of the mineralised layer can be up to 5 m. At 3 m depth, the water table makes estimation difficult, but the gold grade varies from $0.1\text{--}0.4 \text{ g m}^{-3}$ (Kirov and Boboé 1983). The host lithologies around the placer are gneiss and amphibolite (Kirov et al. 1981; Kriatov et al. 1980, 1995).

All these three placers' deposits described are located in the Atacora region on the Natitingou sheet. Moreover, two gold placer deposits have been identified on the Bembèrèkè sheet (Alibori placer and Western Koundé placer), whereas three gold placer deposits are being mined on the Djougou sheet.

Alibori placer

This placer encompasses a part of a right tributary of the Alibori River. The tributary erodes the area of quartz veins to which is bound the Yarra gold mineralisation. The width of the tributary bed hosting the mineralisation does not exceed 2–2.5 m. The gold content varies from 0.02 to 0.23 g m^{-3} (Mackallor and Stager 1967; Kriatov et al. 1995).

Koundé placer

It occurs on the right tributary of the Alibori River whose confluence is located south of the Téro River. The area is made up white mica schist and shale developed in contact with the lower Proterozoic granite (Kriatov et al. 1995). In this contact zone, auriferous quartz veins serve as sources for the Western Koundé

Table 1. Geological and economic parameters of vein gold deposits and occurrences areas.

| Quartz vein gold area | Township | Host rock/Surrounding outcrops | Grade (Au) g t^{-1} |
|-----------------------|------------|--|------------------------------|
| Perma (deposit) | Natitingou | Quartz vein, quartzite, schist, mica schist, amphibolite | 5–300 |
| Kouandé (deposit) | Kouandé | Quartz vein, schist, quartzite, orthogneiss | 0.2–2.4 / 64 |
| Yarra | Sinendé | Diorite, granodiorite, gneiss, quartz veins | 3–5 |
| Pessoulou | Sinendé | granite, quartz veins, schist | 3.2 |
| Nia-Nianou | Kérou | Various gneiss, granite | – |
| Nibiori | Sinendé | Quartz veins, granite, gneiss | 0.3 |
| Ana | Ségbana | gneiss, amphibolite, quartz veins | 0.03–3 |
| Sarédarou | Gogounou | Quartz, mylonite | 0.1 |
| Lougou | Sinendé | Schist with quartz- white mica-chlorite, quartz veins | 0.2 |
| Alibori | Gogounou | White mica schist, Schist with white mica-chlorite, quartz veins | 0.3 |

placer. The Koundé placer is of low grade (0.04 g m^{-3}) and the gold is irregularly distributed in the alluvium. Thus, the Western Koundé mineralisation is not of economic interest (Mackallor & Stager 1967).

Alédjo-Koura placer

The placer of Alédjo-Koura is located in the Kakpan and Iwowou river basin (tributaries of the Nialo or Mono rivers) northwestern of Bassila; very close to the border with the Togo Republic. The zone consists mainly of micaceous quartzite, mica schist and schist of Atacora; gneiss and orthogneiss, intersected by quartz veins, pegmatite, and mafic and felsic intrusions. The gold content obtained in the alluvium varies from 1.19 to 1.4 g m^{-3} under the coverage of 2 m sandy layer (Yèvidé et al. 1992).

Tansar placer

The mineralisation is hosted in sandy and gravelly strata. Its grade is from $0.05\text{--}0.15 \text{ g m}^{-3}$ and the gold is associated with iron oxides, biotite and tourmaline (Chala et al. 2004). This gold placer is situated about 16 km southwest of Djougou in the area composed of gneiss with biotite and garnet, mica schist and amphibolite. These rocks are associated with concordant or discordant milky-white or smoky quartz veins strike $110\text{--}120^\circ$. They are also folded and affected by peridirectional faults (BRGM and OBEMines 1984).

Tomí placer

Discovered in the Sansrou River basin northwest of Pabégou, the country rocks include micaceous quartzite, micaceous gneiss, mica schist and amphibolite. The gold grade varies from 0.11 to 1.60 g m^{-3} . Gold is more abundant in the major river bed but also in the large alluvium (50–100 m) of the Upper River, and sandy layers cover mineralised gravel level (Chala et al. 2007).

The characteristics of these placers are summarised in Table 2.

Laterite mineralisation

No previous work has described auriferous mineralisation in lateritic profiles. However, it appears from the observations made in the Atacora area as part of an ongoing thesis, that the Gnannganmou and Souroukou sectors would be suitable for laterite gold. Already, some artisanal miners have begun exploration of these laterites in search of gold (Figure 4). In Souroukou area, for example, the thickness of weathered lateritic profiles over mineralised schist is up to 5 m. This area is therefore currently under investigation for lateritic gold mineralisation.

Table 2. Geological and economic characteristics of alluvial gold in Bénin.

| Placers area | Township | Host rock/surrounding outcrops | Grade (g m^{-3}) | Reserve (kg) |
|--------------|------------|--|-----------------------------|--------------|
| Perma | Natitingou | Clayey soil, soil, gravel, sand pebbles, sandstone-quartzite, micaceous quartzite | 1 | 400 |
| Sarga | Kouarfa | Sandy, sandstone, conglomerate dolomite, schist, quartzite | 1 | 760 |
| Sina-Issiré | Natitingou | Pebbles, clay-gravelly, sandy soil, sandstone | 0.1–0.4 | - |
| Alibori | Sinendé | Sandy, soil, diorite | 0.02–0.23 | - |
| Koundé | Gogounou | Sand, soil, white mica schist, shale, granite, quartz vein. | 0.04 | - |
| Alédjo-Koura | Bassila | Sandy, gravel, quartzite, mica schist, gneiss, orthogneiss, schist, quartz veins. | 1.19–1.4 | - |
| Tansar | Djougou | Sandy, gravel, gneiss with biotite and garnet, mica schist with two micas, schistose amphibolite | 0.05–0.15 | - |
| Tomí | Copargo | micaceous quartzite, micaceous gneisses, micaschist, schistose amphibolite | 0.11–1.6 | - |

Characteristics of the quartz-vein deposits

Quartz-vein hosted deposits in the Bénin Republic, as in the rest of West Africa, occur in all lithologies, i.e. in mafic formations (e.g. *Ana, Néana and Kpoua*), in felsic units (Yarra, Pessoulou) and in metasedimentary rocks (e.g. Perma, Kouandé deposits).

Structure

In outcrop, two structural types of veins can be distinguished: type-1 veins and type-2 veins. Type-1 veins are concordant, deformed and mineralised. Type-2 veins are discordant, undeformed and generally barren. They have a typical buckshot texture (Boyle 1979; Dowling and Morrison 1989) and can be observed to cross-cut the type-1 veins. This suggests that they occurred at the end of the regional deformation events.

Petrography and mineralogy of ore

In Benin, types-1 veins are milky, whereas types-2 veins are white and vitreous. Based on their mineralogy, types-1 veins can be further subdivided into quartz-sulphide and quartz-tourmaline veins (sulphides and tourmaline rarely occur in the same veins).

Quartz-sulphide veins are exemplified by the Perma and Pessoulou deposits. In these deposits, gold exhibits three forms: free native metal, tellurides and combined or included in sulphides. Gold of the Perma deposit is often associated with pyrite (FeS_2), chalcopyrite (CuFeS_2), galena (PbS), sphalerite (ZnS), covellite (CuS), silverite (Ag_2S) and tetrahedrite ((Cu,



Figure 4. Artisanal miner's site for auriferous laterite in Gnagnamou.

Fe)₁₂Sb₄S₁₃); oxide such as magnetite (Fe₃O₄), hematite (Fe₂O₃), rutile (TiO₂), azurite (Cu₃CO₃(OH)₂); and gangue minerals such as quartz, muscovite, chlorite and carbonate (Kirov et al. 1976; Kirov et al. 1981; Depciuch and Azonsi 1983; Kirov and Boboé 1983; Yessoufou 1991). The sulphide content is usually low (less than 5%) and pyrite is by far the most common sulphide. In the Pessoulou area, gold is associated with lead, silver and copper mineralisation. Within both deposits, muscovite, carbonate and chlorite occur in the vein alteration halos in the locations. However, the chemical composition of these minerals, as well as that of native minerals, varies with respect to host-rock lithology.

Quartz-tourmaline veins are exemplified by the mineralisation of Kouandé where quartz veins are hosted in white mica-chlorite schist, quartzite and white mica-quartz schist rocks. Gold would be concentrated in layers of tourmaline as globular grains, typically at the terminations of tourmaline crystals and as small grains filling fractures or cleavages. Uncommonly, gold is accompanied by silver (Kirov et al. 1976; Kirov et al. 1981).

Perma and Pessoulou deposits present similarities with Pourra deposit in Burkina Faso and Kalana deposit in Mali (Melesi et al. 1989, 1992), with Taparko and Gangaol deposits, whereas deposit of Kouandé shows similarities with Guibaré deposit in Burkina Faso (Béziat et al. 2008).

Genesis of primary gold mineralisation

Currently, in Bénin, no study of fluid inclusion on lode deposit has been published. A review of data collected

shows that most of the previous work have been based on the mineralogical paragenesis and the structural control to propose the genesis of auriferous quartz veins.

Mineralogy

Based on mineralogical assemblages of gold ore, Kirov et al. (1981) classified the deposition model as follows (Figure 5): a pneumatolytic phase at high-temperature characterised by the presence of tourmaline is monitored over time and continuously by the hydrothermal phase with the deposition of medium temperature minerals as pyrite. The phase finally reaches the low temperature hydrothermal phase with deposition of tetrahedrite; galena, sphalerite and gold. The last phase would be the hydrothermal alteration, which is characterised by the secondary chlorite alteration of ferromagnesian minerals and the alteration of plagioclase. This last phase, already at low temperature and pressure, leads to the formation of vitreous, barren quartz veins.

Furthermore, green schist mineralised have undergone the formation of albite and tourmaline and contain both pyrite and native gold which are often found in cracks of pyrite.

According to Kirov et al. (1976), the sulphide elements such as copper, lead and zinc associated with Perma deposit are most commonly found in hydrothermal deposits at various degrees. Consequently, these lode gold deposits would be of hydrothermal origin. This hypothesis is confirmed by the abundance of tetrahedrite that is a characteristic mineral of deposits of hydrothermal origin (Allaby 2008).

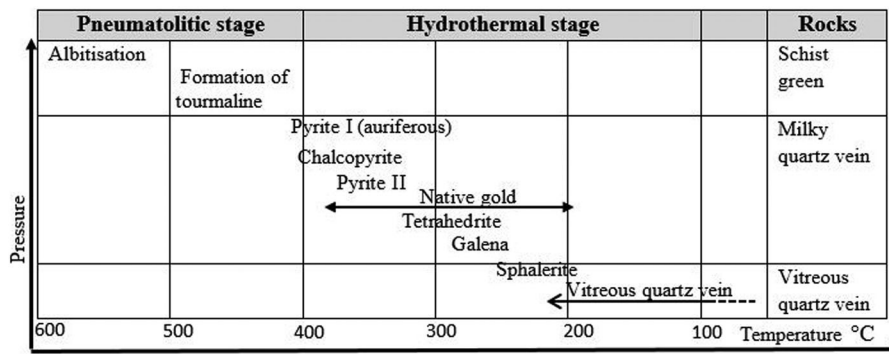


Figure 5. Diagram illustrating the successive stages of mineralisation in Atacora zone (Kirov et al. 1981).

Yessoufou et al. (2001, 2011) highlighted that the emplacement of Perma deposit has undergone two phases. The first involved the formation of white to milky quartz under the high-temperature phase ($605\text{--}575^\circ \pm 10^\circ\text{C}$) and the second low-temperature phase ($355\text{--}275^\circ \pm 75^\circ\text{C}$) which is marked by mercury occurrence in the mineralogical composition. The presence of mercury suggests that the lode gold of the Perma area was emplaced at 270°C . Also, the chlorite, K-feldspar, Ca-feldspar and sulphur in the lode mineralisation have not undergone any metamorphic and tectonic deformation, thus indicating that these veins and veinlet post-date the fold phase of the Atacora Belt (Yessoufou et al. 2001).

Structural control

From the descriptions of the various gold deposits and occurrences above both in the Atacora rocks and the basement formations, the primary gold studied so far in Benin is principally related to quartz veins hosted in quartzite, mica schist, schist and amphibolite.

In the Atacora area (on the Natitingou sheet), the tectonic control of veins is evidenced by the criss-crossing of the faults and the rugged relief. Auriferous lodes are related to the intersection points of faults of different directions, and to the contact zone of the basement and Atacora structures. Interpretation of aerial photographs, LANDSAT imagery, gravity data (El Hadj Tidjani et al. 1993, 1997; El Hadj Tidjani 2000) and analysis of lithological contacts (Affaton 1975; Kirov et al. 1976; Affaton et al. 1991; Kriatov et al. 1995) showed that quartz veins are related to batholiths of granites at depth. In this zone, quartz veins would also have been emplaced during magmatism in the already open pathways (i.e. cracks and crevices) in country rocks (Kirov et al. 1981). Similarly, Yessoufou (1991) and Yessoufou et al. (2011) have pointed out that the gold-bearing quartz veins of Atacora area proceed from hydrothermal solutions related to granitic rocks.

In the basement (Bembèrèke, Djougou and Dunkassa Sheets) the quartz veins are also associated with tectonic zones. The proximity of the quartz veins and granitic masses is visible, and the veins often appear

in the contact zones of granite with the surrounding formations. Thus, the emplacement of granitic masses plays a fundamental role in the formation of quartz veins especially in the zones of tectonic dislocation, which is in agreement with the study of Woodward (1993). The close connection between the quartz veins and the granite suggests that they are hydrothermal veins resulting from the injection of hydrothermal solutions related to granites in the fractured zones.

Discussion

All primary gold deposits and occurrences that are studied in Bénin occur in Precambrian belts that have undergone regional metamorphism and show a relation with structural control (i.e. formed synchronously with deformation). In addition, mineralisation occurs within or adjacent to quartz veins. These major characteristics would be shared by many other epigenetic gold deposits in Precambrian metamorphic terranes (Goldfarb et al. 2005). Therefore, all mineralised sites can be classified as orogenic-type gold deposits, as defined by Melesi et al. (1989, 1992), Groves et al. (1998), Groves et al. (2003) and Goldfarb et al. (2005). Deposition of gold clearly occurs well after the emplacements of these igneous bodies (Beziat et al. 2000).

Based on structural and textural evidence, the formation of quartz veins and gold precipitation would be synkinematic and synmetamorphic, which explains why undeformed type-2 veins are barren as they were emplaced after the peak of the Pan-African orogenic event.

In addition to quartz vein gold, it could have the epigenetic disseminated gold style which displays the common feature of containing a high proportion of invisible or as very fine disseminated particles within strata like in some West African deposits.

Spatio-temporal extension of gold mineralisation in Bénin: a perspective study

Apart from the areas where gold mineralisation has been established in Bénin, it is possible to envisage other parts of the Bénin territory where research

could lead to interesting occurrences. This would involve investigation and study of quartz veins as well as large areas of tectonic activity; identification and prospecting of all volcano-sedimentary basins in Bénin including those of Barou, Pako, Alibori and Idaho Mahou; exploring contact areas of granitic masses with basement formations; more detailed scientific studies on the auriferous metallogenic zones already identified and all placers surrounding the gold-bearing quartz veins; and to study the meta-conglomeratic levels of the external unit of Atacora. According to Affaton (1990), the meta-conglomerate represents the metamorphosed and deformed lateral equivalent of supergroup I formations of the Volta Basin resulting from the dismantling of the West African craton. Already, Lehingne and Machesseau (1962) showed the gold mineralisation associated with an

intra-formational conglomerate in the Atacora quartzite of Tanékas located in the northwest of Djougou.

Conclusion

In Bénin, many gold occurrences are highlighted in the territory between the 9th and the 11th latitudes, particularly in the Atacora area (Natitingou) and in the Bembéréké, Dunkassa and Djougou regions belonging to the basement. These areas of mineralisation are mainly hosted by quartz veins which are interstratified in various quartzite, schist, mica schist and amphibolite occur in shear zones. Gold-bearing quartz veins are associated with sulphides and oxides minerals and would be from hydrothermal related to magmatism. The existence of several structures favourable to mineralisation proves that it is possible to discover gold

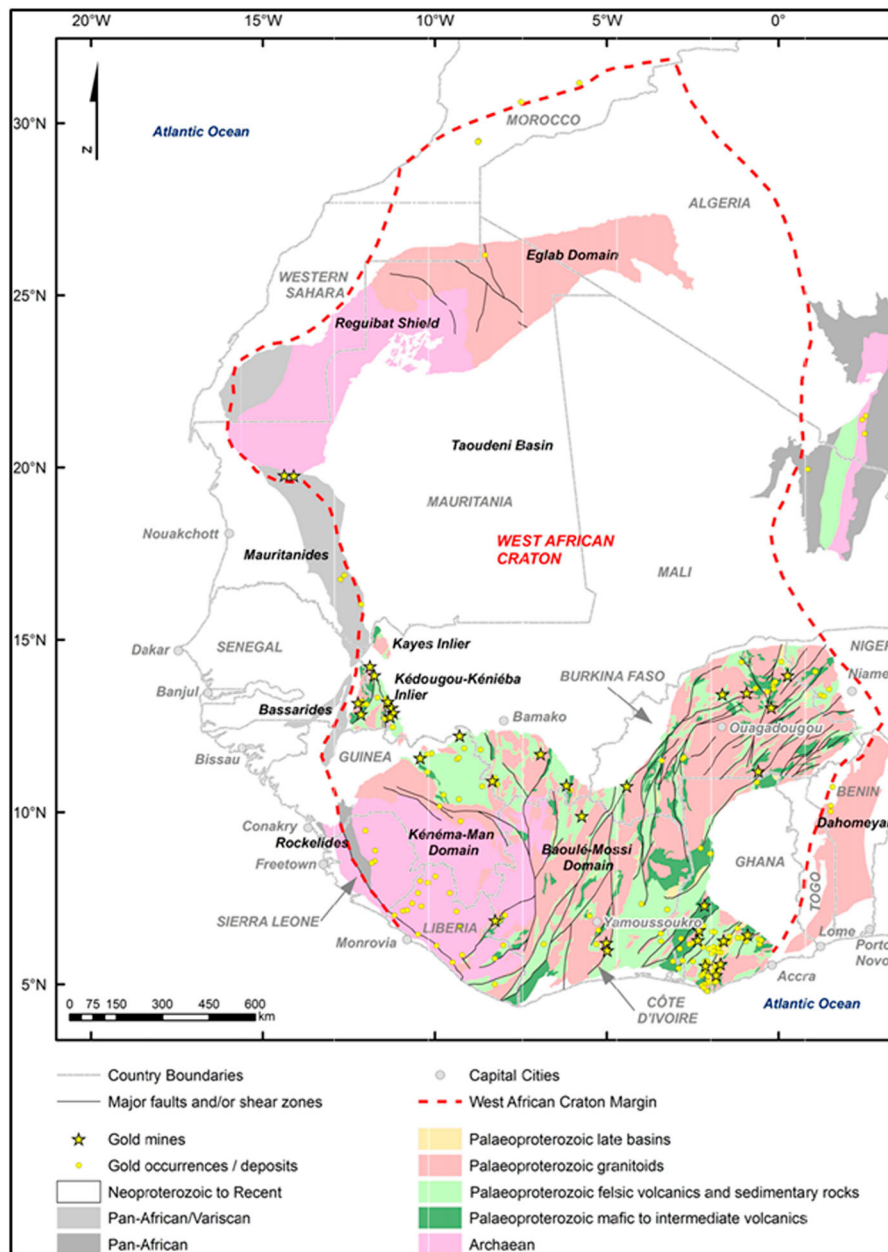


Figure 6. Generalised geological and structural map of the West African Craton showing the distribution of gold mines, deposits and occurrences (Robertson and Peters 2016).

deposits through research focused on their geological and metallogenic contexts, which is in agreement with Robertson and Peters (2016); which showed Bénin is located close to big gold deposits in Ghana and Burkina Faso (Figure 6). There is a reason to believe that the mineralisation potential could extend into Bénin as similar-aged rocks to those hosting big deposits in West Africa appear to extend into the country.

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References

- Adissin Glodji L. 2012. La zone de cisaillement de Kandi et le magmatisme associé dans la région de Savalou-Dassa (Bénin): étude structurale, pétrologique et géochronologique [Thèse de doctorat]. Saint-Etienne: Université Jean Monnet Saint-Etienne (France) et Université d'Abomey-Calavi (Bénin), 260p.
- Adissin Glodji L, Bascou J, Yessoufou S, Ménot RP, Villaros A. 2014. Relationships between deformation and magmatism in the Pan-African Kandi Shear Zone: Microstructural and AMS studies of Ediacaran granitoid intrusions in central Bénin (West Africa). *J Afr Earth Sci.* 97:143–160. <https://doi.org/10.1016/j.jafrearsci.2014.04.012>.
- Affaton P. 1975. Etude géologique et structurale du Nord-Ouest du Dahomey, du Nord Togo et du Sud-Est de la Haute Volta. *Travaux Laboratoire Sciences Terre, Uni St-Jérôme.* 10:201.
- Affaton P. 1990. Le bassin des Volta (Afrique de l'Ouest): une marge passive, d'âge protérozoïque supérieur, tectonisée au Panafricain (600±50 Ma) [Thèse de doctorat d'Etat]. Marseille: Université Aix-Marseille III, 462p.
- Affaton P, Kroner A, Seddoh KF. 2000. Pan African granulites formation in the Kabye of northern Togo (West Africa): PbePb zircon ages. *Int J Earth Sci.* 88:778–790. <https://doi.org/10.1007/s005310050305>.
- Affaton P, Lassere JL, Lawson LT, Vincent PL. 1978. Notice Explicative des cartes géologiques à 1/200000 de la République du Togo et de la République Populaire du Bénin entre les 9è et 10è de Latitude Nord (Feuille Bassari-Djougou et Feuille Parakou- Nikki). *Rapp. Bur. Nat. Rech. Min. du Togo (B.N.R.M.) Bur. Rech. Geol. Min. Fr. (B.R.G.M.) et Off. Béninois Mines (OBEMINES),* 70p.
- Affaton P, Rahaman MA, Trompette R, Sougy J. 1991. The Dahomeyide orogen: tectonothermal evolution and relationships with the Volta basin. In: Dallmeyer RD, Lécorché JP, editors. *The West African Orogens and Circum-Atlantic Correlatives.* Berlin: Springer-Verlag. p. 107–122. https://doi.org/10.1007/978-3-642-84153-8_6.
- Agbossoumondé Y, Guillot S, Menot RP. 2004. Pan-African subduction-collision event evidence by high-P coronas in metanorites from the Agoue-Massif (southern Togo). *Precambrian Res.* 135:1–21. <https://doi.org/10.1016/j.precamres.2004.06.005>.
- Agbossoumondé Y, Menot RP, Paquette JL, Guillot S, Yessoufou S, Perrache C. 2007. Petrological and geochronological constraints on the origin of the Palimé-Amlamé granitoids (south Togo, West Africa): a segment of the West African Craton Paleoproterozoic margin reactivated during the Pan African collision. *Gondwana Res.* 12 (4):476–488. <https://doi.org/10.1016/j.gr.2007.01.004>.
- Allaby M. 2008. *A Dictionary of Earth Sciences.* 3rd ed. Oxford: Oxford University Press. 633p.
- Arthaud MH, Caby R, Fuck A, Dantas EL, Parente CV. 2008. Geology of the northern Borborema Province, NE Brazil and its correlation with Nigeria, NW Africa. *Geological Society, London, Special Publications.* 294:49–67. <https://doi.org/10.1144/SP294.4>.
- Attoh K. 1998. High-pressure granulite facies metamorphism in the Pan-African Dahomeyide orogen, West Africa. *J Geol.* 106:236–246. <https://doi.org/10.1086/516019>.
- Attoh K, Corfu F, Nude MP. 2007. U-Pb zircon age of deformed carbonatite and alkaline rocks in the Pan-African Dahomeyide suture zone. *West Africa Pre Res.* 155:251–260. <https://doi.org/10.1016/j.precamres.2007.02.003>.
- Attoh K, Dallmeyer RD, Affaton P. 1997. Chronology of nappe assembly in the Pan-African Dahomeyide orogen, West Africa: evidence from 4°Ar/39Ar mineral ages. *Precambrian Res.* 82:153–171. [https://doi.org/10.1016/S0301-9268\(96\)00031-9](https://doi.org/10.1016/S0301-9268(96)00031-9).
- Attoh K, Samson S, Agbossoumondé Y, Nude PM, Morgan J. 2013. Geochemical characteristics and U-Pb zircon LA-ICPMS ages of granitoids from the Pan-African Dahomeyide orogen, West Africa. *J Afr Earth Sci.* 79:1–9. <https://doi.org/10.1016/j.jafrearsci.2012.09.015>.
- Bessoles B, Trompette R. 1980. Géologie de l'Afrique: La chaîne panafricaine: «zone mobile d'Afrique centrale (partie sud) et zone mobile soudanaise », B.R.G.M., Orlé ans, France, 397p.
- Béziat D, Bourges F, Debat P, Lompo M, Martin F, Tollon F. 2000. A Palaeoproterozoic ultramafic-mafic assemblage and associated volcanic rocks of the Boromo greenstone belt: fractionates originating from island-arc volcanic activity in the West African craton. *Precambrian Res.* 101:25–47.
- Beziat D, Dubois M, Debat P, Nikiema S, Salvi S, Tollon F. 2008. Gold metallogeny in the Birimian craton of Burkina Faso (West Africa). *J Afr Earth Sci.* 50:215–233.
- Boussari WT. 1975. Contribution à l'étude géologique du socle cristallin de la zone panafricaine (Région centrale du Dahomey). *Doct Sci Terre Géol Appl Besançon, Fr.* 236(p):105.
- Boyle RW. 1979. The geochemistry of gold and its deposits. *Geol Surv Can Bull.* 280:169–182.
- BRGM-OBEMines. 1984. Notice Explicative de la carte géologique à 1/200 000è Feuille Djougou-Parakou-Nikki. 38p.

- Caby R. 1989. Precambrian terranes of Benin-Nigeria and Northeast Brazil and the late Proterozoic South Atlantic fit. *Geol Soc Am Special Paper*. 230:145–158. <https://doi.org/10.1130/SPE230-p145>.
- Caby R. 2003. Terrane assembly and geodynamic evolution of central-western Hoggar: a synthesis. *J Afr Earth Sci*. 37:133–159. <https://doi.org/10.1016/j.jafrearsci.2003.05.003>.
- Caby R, Sial AN, Arthaud MH, Vauchez A. 1991. Crustal evolution and the Brasiliano Orogeny in North-east Brazil. In: Dallmeyer RD, Lécorché JP, editors. *The West African Orogens and Circum-Atlantic Correlatives*. Berlin: Springer. p. 373–397. https://doi.org/10.1007/978-3-642-84153-8_16.
- Caen-Vachette M, Pinto JM, Roques M. 1979. Plutons tertiaires et mésozoïques dans le socle cristallin de la chaîne pan-africaine au Togo et Bénin. *Rev Gbol Dyn GBogr Phys*. 21:351–357.
- Castaing C, Triboulet C, Feybesse JL, Chèvremont P. 1993. Tectonometamorphic evolution of the Ghana, Togo and Benin in the light of the Pan-African/Brasiliano orogeny. *Tectonophysics*. 218:323–342. [https://doi.org/10.1016/0040-1951\(93\)90322-B](https://doi.org/10.1016/0040-1951(93)90322-B).
- Chala D, Adjinoukou A, Houndonougbo P, Yevidé H, Vedogbèton N. 2007. Rapport de mission de la prospection des indices d'or de la Région de Tomi (Commune de Copargo, Arrondissement de Pabegou). Bénin: OBRGM, Rép. 12p.
- Chala D, Adjinoukou A, Idohou N, Yevidé H, Vedogbèton N. 2004. Rapport de mission de la prospection des indices d'or de la Région de Djougou, « Projet amélioration des données géologiques et minéralogiques du Bénin. Bénin: OBRGM, Rép. 39p.
- Chala D, Tairou MS, Wenmenga U, Kwekam M, Affaton P, Kalsbeek F, Tossa C, Houéto A. 2015. Pan-African deformation markers in the migmatitic complexes of Parakou-Nikki (Northeast Benin). *J Afr Earth Sci*. 111:387–398. <https://doi.org/10.1016/j.jafrearsci.2015.08.009>.
- Chermette A. 1938. Relations entre les amphibolites et la présence d'or dans la région de Natitingou (Haut Dahomey). *Bull Service Mines AOF*. 2:5–8. Dakar.
- Chermette A. 1939. Le gisement d'or filonien de la Perma, Service Mines AOF, Dakar. 9p.
- Chermette A, Olori-Togbé G. 1966. Les recherches minières de la République du Bénin. Publication N.G.B. Paris 17è. 14p.
- Dawai D, Bouchez JL, Paquette JL, Tchameni R. 2013. The Pan-African quartz syenite of Guider (north-Cameroon): magnetic fabric and U–Pb dating of a late orogenic emplacement. *Precambrian Res*. 236:132–144. <https://doi.org/10.1016/j.precamres.2013.07.008>.
- Depciuch T, Azonsi F. 1983. Rapport sur les travaux géochimiques de l'or dans le secteur Irikouakou-Sarga, Nord zone Atacora. OBEMINES, RB, 89p.
- De Vaucorbeil H. 1965. Rapport sur la prospection filonienne et volante effectuée dans la région Nord-Natitingou. Abidjan: BRGM. 60p.
- Direction Générale des Mines (DGM) et Office Béninoise des Recherches Géologiques et Minières (OBRGM). 2007. Orientations et plan d'actions stratégiques de développement du secteur minier en République du Bénin. Cotonou: Commission ad hoc. 77p.
- Dos Santos TJS, Fetter AH, Neto JAN. 2008. Comparisons between the northwestern Borborema Province, NE Brazil, and the southwestern Pharusian Dahomey Belt, SW Central Africa. *Geol Soc Lond Special Publications*. 294:101–120.
- Dowling K, Morrison G. 1989. Application of quartz textures to the classification of gold deposits using north Queensland examples. *Econ Geol*. 6:342–355.
- Duclaux G, Menot RP, Guillot S, Agbossoumonde Y, Hilaret N. 2006. The mafic complex of the Kaby_e massif (north Togo and north Benin): evidence of a Pan-African granulitic continental arc root. *Precambrian Res*. 151:101–118. <https://doi.org/10.1016/j.precamres.2006.08.012>.
- El-Hadj Tidjani M. 2000. Application de la gravimétrie à l'interprétation géophysique de la chaîne Panafricaine des Dahomeyides et du bassin volcano-sédimentaire de Daho-Mahou (Bénin-Afrique de l'Ouest) [Thèse de doctorat]. Bénin: Université d'Abomey-Calavi. 243p.
- El-Hadj Tidjani M, Affaton P, Louis P, Lesquer P, Socohou A, Caby R. 1993. Gravity characteristics of the Northern part of Dahomeyides: continental aggregation-collision orogeny and smoothing in the Pan African (600+100 Ma). *J African Earth Sci*. 17(2):203–211. [https://doi.org/10.1016/0899-5362\(93\)90036-P](https://doi.org/10.1016/0899-5362(93)90036-P).
- El-Hadj Tidjani M, Affaton P, Louis P, Socohou A. 1997. Gravity characteristics of the Pan-African Orogen in Ghana, Togo and Benin (West Africa). *J African Earth Sci*. 24(3):241–258. [https://doi.org/10.1016/S0899-5362\(97\)00041-9](https://doi.org/10.1016/S0899-5362(97)00041-9).
- Ferré E, Gleizes G, Caby R. 2002. Obliquely convergent tectonics and granite emplacement in the Trans-Saharan belt of Eastern Nigeria: a synthesis. *Precambrian Res*. 114:199–219. [https://doi.org/10.1016/S0301-9268\(01\)00226-1](https://doi.org/10.1016/S0301-9268(01)00226-1).
- Goldfarb RJ, Baker T, Dubé B, Groves DI, Hart CJR, Gosselin P. 2005. Distribution, character, and genesis of gold deposits in metamorphic terranes. *Econ. Geol*, 100th Anniversary vol., p. 407–450.
- Groves DI, Goldfarb RJ, Gebre-Mariam M, Hagemann SG, Robert F. 1998. Orogenic gold deposits: a proposed classification in the context of their crystal distribution and relationship to other gold deposit types. *Ore Geol Rev*. 13:7–27.
- Groves DI, Goldfarb RJ, Robert F, Hart CJR. 2003. Gold deposits in metamorphic belts: overview of current understanding, outstanding problems, future research, and exploration significance. *Econ Geol*. 98:1–29.
- Institut de Recherche Breda. 1982. Notice explicative de la carte géologique à 1/200000. Feuille de Malaville. 150p.
- Institut de Recherche Breda. 1989. Notice explicative de la carte géologique à 1/200000. Feuilles Pira-Savé, Abomey-Zagnanado, Lokossa-Porto-Novo. 77p.
- Kalsbeek F, Affaton P, Ekwueme B, Frei R, Thrane, K. 2012. Geochronology of granitoid and metasedimentary rocks from Togo and Benin, West Africa: comparisons with NE Brazil. *Precambrian Res*. 196–197:218–233. <https://doi.org/10.1016/j.precamres.2011.12.006>.
- Kriatov BM, Biterman IM, Gamaleia JN, Karpov LM, Migdissov SA, Nikitine AI, Rozanov VI, Rounov BE, Tchernov SA, Chtchenikov VA. 1980. La constitution et les substances utiles du territoire de la République du Bénin entre le 10ème et le 11ème parallèle de latitudes Nord. Rapport du levé de prospection géologique à l'échelle de 1/200000 entre les 10ème et 11ème parallèles de latitudes Nord effectués en 1977-1980. OBEMINES, RB. 393p.
- Kriatov BM, Biterman IM, Gamaleia JN, Karpov LM, Migdissov SA, Nikitine AI, Rozanov VI, Rounov BE, Tchernov SA, Chtchenikov VA. 1995. Notice explicative de la carte géologique à 1/200,000: Feuilles Sansanné-Mango, Natitingou, Bembèrèkè; 1ère Edition, Mémoire n° 4. OBEMINES, RB. 67p.

- Kirov M, Boboé F. 1983. Rapport sur l'exploitation pilote de l'or alluvionnaire de la rivière Tapapokounta-Secteur Perma. OBEMINES, RB. 102p.
- Kirov M, Boboé F, Aclinou C. 1983. Evaluation des réserves géologiques de l'or alluvionnaire de la rivière Perma, section Perma-zone Atacora. OBEMINES, RB. 85p.
- Kirov M, Kouglevi JC, Depciuch T. 1976. Rapport sur la prospection géologique et géochimique pour l'or primaire dans la zone XIV-Perma. Rec. Min. en Rép. Pop. du Bén. BEN/74/009, Cotonou. 55p.
- Kirov M, Kouglevi JC, Depciuch T, Henry PO, Ihéta B, Akibou T. 1981. Rapport sur les travaux de recherche géologique et aurifère dans la zone de l'Atacora. Rec. Min. en Rép. Pop. du Bén. BEN/76/004, Cotonou. 102p.
- Lehingue J, Machesseau J. 1962. Rapport d'ensemble sur les prospections effectuées dans la région des Tanékas et dans le bassin de la Sina-Issiré. BRGM, Octobre 1962, Abidjan. 59p.
- Lehingue J, Roignot R. 1964. Gisement primaire de l'or dans le bassin de la Perma. Abidjan: BRGM. 15p.
- Mackallor AJ, Stager KH. 1967. Recherche de minerais dans la partie septentrionale du Dahomey, Afrique-Occidentale. BRGM, Décembre 67, Abidjan. 73p.
- Mand'huy R. 1962. Rapport des travaux sur la prospection alluvionnaire systématique pour l'or sur un panneau minéralisé dans le BIEF 5 de la rivière Perma. BRGM, Juin 1962, Abidjan, 11p.
- Milési JP, Feybesse JL, Ledru P, Dommanget A, Ouedraogo MF, Marcoux E, Prost A, Vinchon C, Sylvain JP, Johan V, et al. 1989. West African gold deposits in their lower Proterozoic lithostructural setting. *Chron Rech Min France*. 497:3-98.
- Milési JP, Ledru P, Feybesse JL, Dommanget A, Marcoux E. 1992. Early Proterozoic ore deposits and tectonics of Birimian orogenic belt, West Africa. *Precambrian Res*. 58:305-344.
- Monié P, Caby R, Arthaud MH. 1997. The Neoproterozoic Brasiliano orogeny in northeast Brazil: 40Ar/ 39Ar and petrostructural data from Ceara. *Precambrian Res*. 81:241-264.
- Neves SP. 2003. Proterozoic history of the Borborema province (NE Brazil): correlations with neighboring cratons and Pan-African belts and implications for the evolution of western Gondwana. *Tectonics*. 22:1031. <http://doi.org/10.1029/2001TC001352>.
- Neves SP, Vauchez A, Feraud G. 2000. Tectono-thermal evolution, magma emplacement, and shear zone development in the Caruaru area (Borborema Province, NE Brazil). *Precambrian Res*. 99:1-32. [https://doi.org/10.1016/S0301-9268\(99\)00026-1](https://doi.org/10.1016/S0301-9268(99)00026-1).
- Office Béninoise des Recherches Géologiques et Minières. 2000. Potentialités minières du Bénin. Cotonou: MMEH, OBRGM. 50p.
- Peuca JJ, Capdevila R, Drareni A, Mahdjoub Y. 2005. The Eglab massif in the West African craton (Algeria), an original segment of the Eburnean orogenic belt: petrology, geochemistry and geochronology. *Precambrian Res*. 136:309-352. <https://doi.org/10.1016/j.precamres.2004.12.002>.
- Pougnet R. 1957. Le précambrien du Dahomey Bulletin de la Direction Fédérale des Mines et de la Géologie de l'Afrique Occidentale Française, Dakar, n°22. 186p.
- Rezende N, Vedogbeton N, Gnaha E, Falola E. 2011. Exploration de reconnaissance des indices et mineralisations d'or, de titane, de niobo-tantalite et d'autres substances minérales dans les communes de Sinende (Département du Borgou), de Gogounou (Département de l'Alibori), de Pehunco et de Kerou (Département de l'Atacora). Compagnie Béninoise des Mines, Rapport N° 07/CBM/11. 36p.
- Robertson M, Peters L. 2016. West African Goldfields. Episodes. 39(39):155-176. <https://doi.org/10.18814/epiiugs/2016/v39i2/95773>.
- Tairou MS, Affaton P, Anum S. 2012. Modèle d'empilement tectonique panafricain au Sud-Est du Ghana: cas de l'unité structurale de l'Akwapim dans le secteur de Peduase. *Afr Geosci Rev*. 19(1 & 2):77-91.
- Tairou MS, Affaton P, Gelard JP, Aite R, Sabi BE. 2007. Panafrican brittle deformation and paleostress superposition in the northern Togo (West Africa). *C R Geosci*. 339:849-857. <https://doi.org/10.1016/j.crte.2007.08.001>.
- Trompette R. 1994. Geology of Western Gondwana (2000-500 Ma). Pan-African-Brasiliano Aggregation of South America and Africa. Rotterdam: Balkema. 350p.
- Woodward AL. 1993. Structural control of lode gold deposits in the Pony Mining District, Tobacco Root Mountains, Montana. *Economic Geol*. 88:1850-1861. <https://doi.org/10.1016/j.econgeo.1993.11.011>.
- Yessoufou S. 1991. Structure géologique et la composition minéralogique du gisement d'or de Perma, Rép. du Bénin [Thèse de doctorat]. Moscou: Uni. Lumumba. 236p.
- Yessoufou S, Kaki C, Agbossoumondé Y, Yalo N, Yevidé H. 2011. La morphologie de particules d'or associées à la dégradation des filons de quartz peu sulfureux à Perma, au Nord-Ouest du Bénin (Afrique de l'Ouest). Morphology of gold grain associated with weathering auriferous veins of Perma, Northwestern of Benin (West Africa). *Rev CAMES Série A*. 12(1):70-75.
- Yessoufou S, Trofimov NN, Yevidé H, Kaki C. 2001. Genèse et conditions physico-chimiques de formations du gisement d'or de Perma dans les formations néoproterozoïque de la Chaîne de l'Atacora (Bénin). *Rech Sc Univ Lomé (Togo)*. 5(2):221-235.
- Yevidé H, Tossa C, Akibou OT, Vedogbeton N, Kouglevi JC, Amoussou C. 1992. Rapport sur la prospection minière des indices d'or du secteur d'Alédjo-Koura (Atacora). OBEMines, Rép. Bénin. 15p.