Gold in Mali

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Zlato v Mali

Článok sa, okrem stručného úvodu do geológie regiónu, zaoberá popisom hlavných zlatých ložísk Mali, kde sa t.č. ťaží viac ako 20 t zlata ročne. Súčasné objavy zlata v tejto Západoafrickej krajine sú totiž príkladom, ako orientácia geologického prieskumu územia s dobrým potenciálom pre určitú nerastnú surovinu a použitie vhodnej metódy môže viesť k úspechu. Zlato sa v Mali ťaží už od nepamäti, ale ekonomicky významné ložiská (s prepočítanými zásobami 50 až 240 ton Au), sú objavované len v poslednom období. Presnejšie odvtedy, odkedy sa prieskum sústredil na zóny proterozoických epimetamorfovaných vulkano-sedimentárnych hornín (tzv. Birrimian greenstone belts) Západoafrického kratónu, s použitím geochémie, ako jednej z hlavných prieskumných metód. Keď si prieskumári uvedomili, že "Birrimian" môže mať rovnaký potenciál na zlato ako archaické "greenstones", ktoré sú hlavným zdrojom zlata na svete a že geochémia môže byt účinnou metódou pre prieskum krajiny s plochým povrchom, bez východov hornín, ktorá je charakteristická pre väčšinu územia Mali (a celej Západnej a Strednej Afriky).

***Key words**: Mali, West Africa, West African craton, Tuareg shield, Proterozoic, Birrimian, Pan-african orogeny, precambrian greenstones, gold, lode gold, auriferous tourmalinites.*

Introduction

Gold mining in Mali has a long history. In 1433, its renowned emperor Kanku Mussa brought 8 tons of gold on his pilgrimage to Mecca. Local population has exploited gold since immemorial times. Nowadays, several thousands of "artisan" miners exploit numerous sites and their production is estimated at more than 2 tons of gold per year. Industrial mining began in the 1970's (Kalana mine), following a large exploration programme by SONAREM with the soviet assistance (Golder et al., 1965; Boltroukevitch, 1973). In 1984-5, the United Nations assisted project found several gold occurrences and a promising deposit (Syama), using soil geochemistry - an efficient exploration method for prospecting in a flat, outcrops-lacking landscape, that extends over most of the malian territory (Kusnir & Diallo, 1986). Syama deposit lies in epi-metamorphosed proterozoic volcano-sedimentary formations (Birrimian), displaying similarities to archean greenstones that are one of the main sources of gold in the world. Therefore, the discovery and subsequent start of a successful mining of the Syama deposit was followed by an intensification of exploration of the Birrimian greenstone belts (Association BME-MRAC, 1988, Vernhet, 1988, Dommanget et al., 1989). That resulted in the discovery of more gold deposits and opening of new mines; Mali's actual gold production is over 20 tons per year.

A brief description of malian precambrian greenstones gold mineralisation is presented in this article, preceeded by the outline of the country's geology and its mineral deposits.

Mali, its geology and mineral resources

Country summary

Mali, located in West Africa, has a land area of 1 241 000 km^2, a third of which is covered by the Sahara desert. It is a land-locked country, connected by a railway (1 228 km) to the port of Dakar in Senegal (fig.1 & 3). Its population of some 7 milions, concentrated mostly in the southern part of the country, is employed mainly in the agriculture. The developing industrial sector comprises an important mining industry, including a cement plant (Diamou, 50 000 t/y), a phosphate mine (Tamaguilelt, 10 00 t/y) and several gold mines.

Regional geological framework

Mali is situated on two principal structural units constituing the West Africa: the West African craton (in the western part of the country) and the Tuareg shield (in its eastern part). The shields were brought together to the end of Precambrian, between 600 and 550 Ma; the suture zone, on malian territory, is located (fig.1) to the west of the Adrar des Iforas Mts (Bessoles, 1977; Black, 1967).

The West African craton, stabilised at about 1 800 Ma comprises two main outcrops of cristalline rocks: the Reguibat shield to the north (at the northern limit of the malian territory) and the Leo or Man shield to the south. The Leo shield comprises an archean nucleus, in the south-west and the proterozoic Baoul,-Mossi domain, (fig.1 & 2) forming most of the shield (Bessoles, 1977). The latter domain contains relics of the archean rocks and the Birimian formations, deposited during the Lower and Middle Proterozoic, affected by the Eburnean orogenic cycle (most active from 2,000 to 1,800 Ma). It consists of vast granito-gneiss complexes and quite narrow (tens of km) elongated belts of mainly epi-metamorphosed volcano-sedimentary formations (Birrimian, defined in

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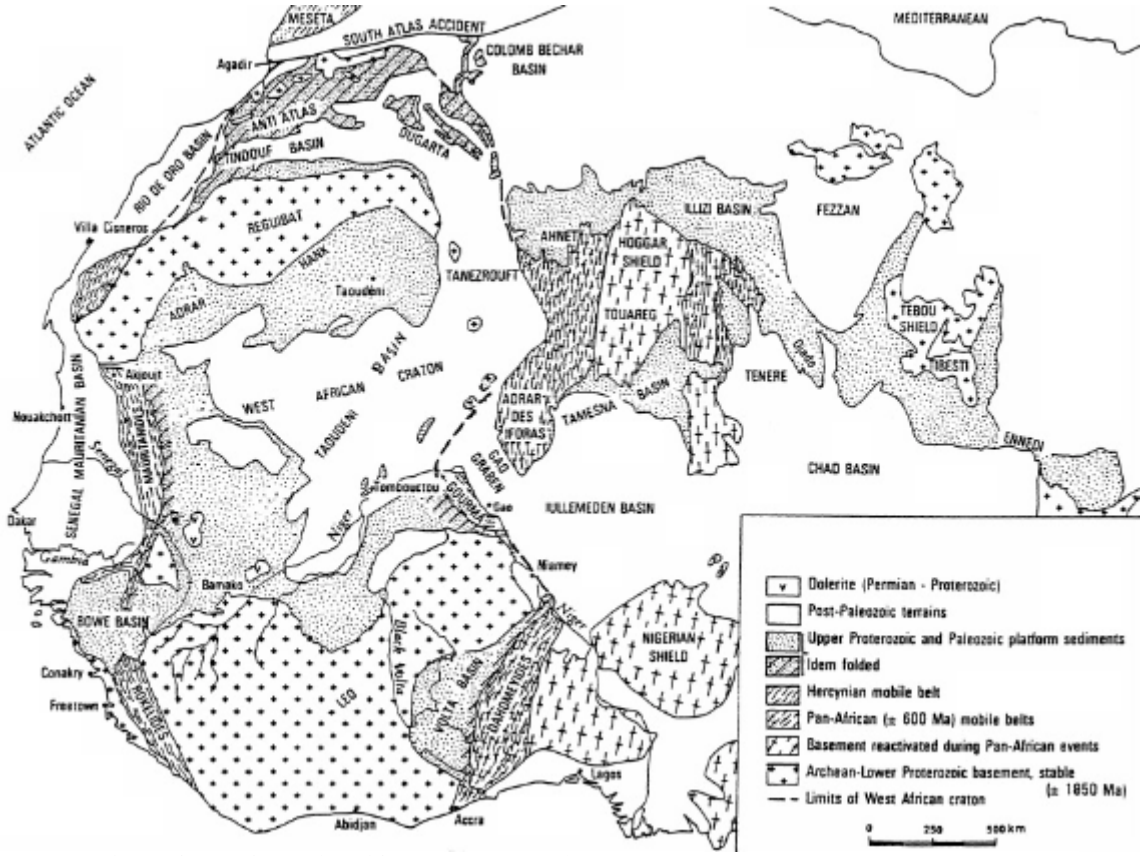


Fig.1. Structural map of West Africa (adapted from Trompette, 1973).

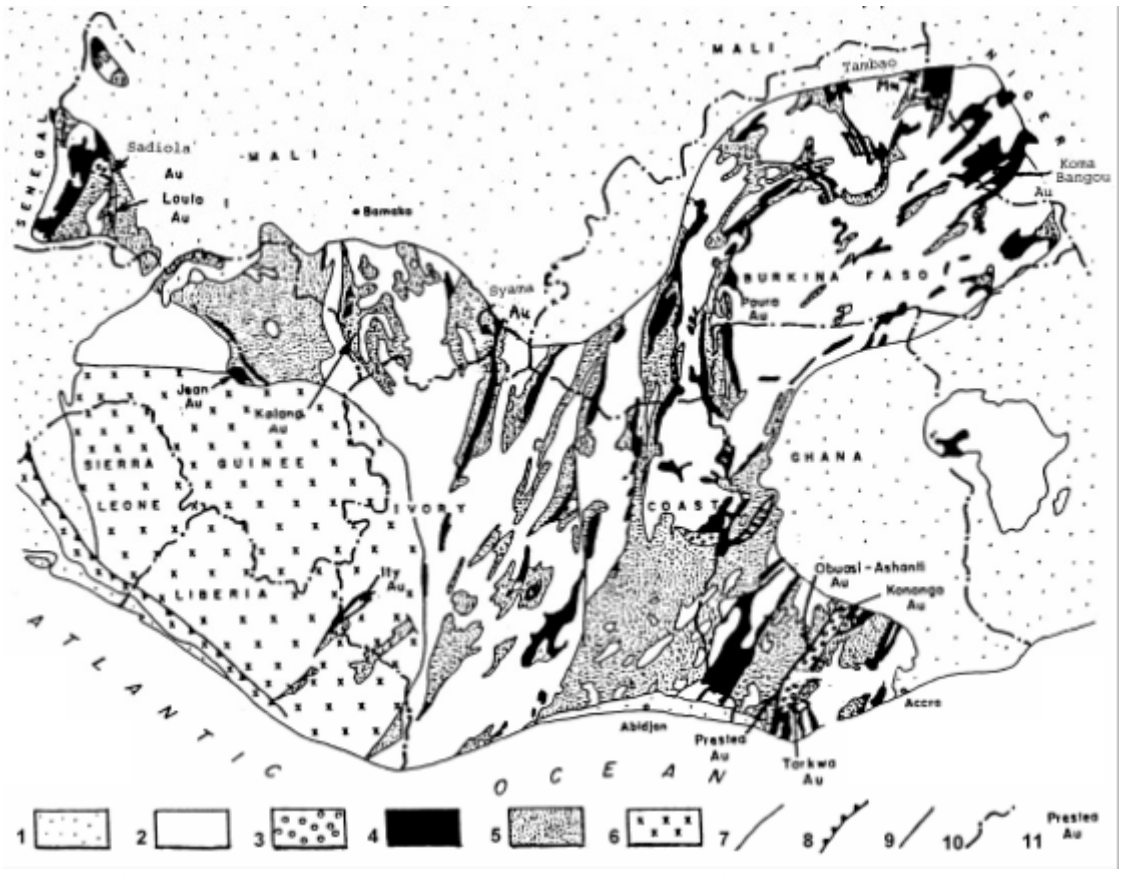


Fig.2. Location of the deposits in the middle Proterozoic shield or West Africa (modified after Olson et al., 1992). 1-post-Brimian cover rocks, 2-granitic rocks and gneiss, 3-conglomerate, „Tarkwaian" in Ghana, 4-volcanic rocks, 5-graywcke and argillite, 6-pre-Birimian basement, 7-contact, 8-reverse fault, 9-fault, 10-international boundary, 11-mineral deposit or mine.

Ghana, see Junner, 1940). These belts, quite alike archean greenstone belts, host most of gold deposits of West Africa. (In Ghana, at Tarkwa, gold is also found in conglomerates, similar to Witwatersrand ones, of a deltaic formation - Tarkwaian -, overlaying Birrimian).

The basement of the West African craton is covered by sediments of the Taoudeni basin, one of the largest intracratonic basins in the world. The sediments, mainly of Proterozoic to Carboniferous age, are folded and slightly metamorphosed during the collision between the West African craton and the Tuareg shield in the south-east (Bronner et al., 1980).

The Tuareg shield is formed by the terrains affected/reworked by the Pan-african orogeny, between 600-650 Ma (Kennedy, 1964). The sedimentary cover of the shield comprises paleozoic and tertiary marine and continental sediments of the Iullemeden basin, to the east and south-east of the Adrar Mts and the Gao graben (fig.1 & 3).

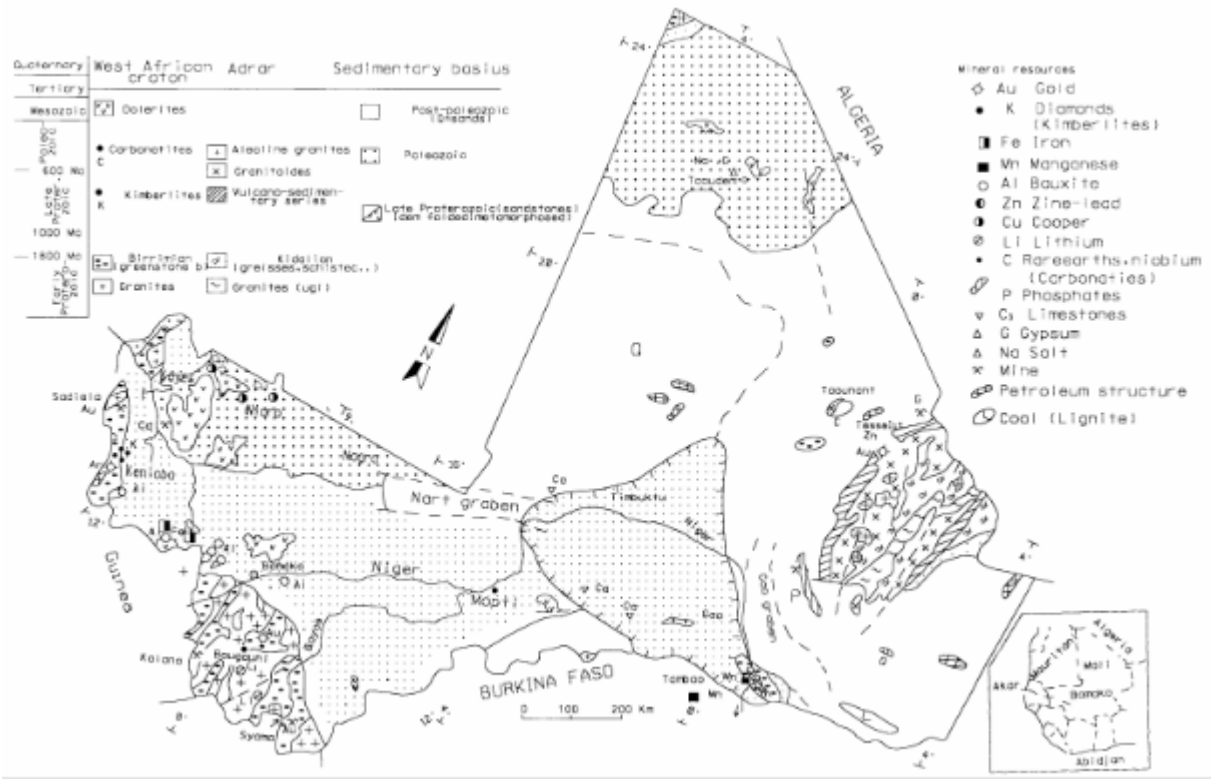


Fig.3. Geological map of Mali. 1-Au, gold, 2-K, Diamonds (Kimberlites), 3-Fe, Iron, 4-Mn, Manganese, 5-Al, Bauxite, 6-Zn, Zine-lead, 7-Cu, Copper, 8-Li, Lithium, 9-C, Rareearths, niobioum (Carbonatites), 10-P, Phosphates, 11-Ca, Limestones, 12-G, Gypsum, 13-Na, Salt, 14-Mine, 15-Petroleum structure, 16-Coal (Lignite).

Outline of Mali geology

Cristalline rocks of the West African craton occur in two large outcrops: Bougouni (about 40 000 km^2) and Kenieba (20 000 km^2) respectively in the south and south-west of Mali and (fig.3) in several small inliers: Kayes, Boure, Taounant (cf. Bassot et al., 1981). Their geology is similar to that of other areas of the proterozoic domain: they consist of vast gneisso-granitic complexes and belts of Birrimian epi-metamorphosed volcano-sedimentary formations (greenstone belts).

In the Bougouni area, the granito-gneissic rocks yielded U/Pb ages on zircon of 2136 ± 6 Ma and 2152 ± 16 Ma, to the west of Bagoe river (Liegeois et al., 1991). K/Ar age of a small dioritic stock near Kalana is 1865 ± 31 Ma (Golder et al., 1965). They contain four Birrimian belts. The eastern-most Bagoe belt, extending along the Bagoe river and hosting the Syama gold deposit, is probably the best studied. It consists mostly of the epi-metamorphosed sediments (schists, greywackes), flanked on both sides by the meta-volcanics (mainly andesites and basalts), locally containing jaspers. A sample of intermediate volcanic rock from this belt yielded an U/Pb age of 2098 ± 5 Ma. The mafic volcanic rocks were probably formed in a narrow extensional graben or rift (Olson et al., 1992). On the east, the volcano-sedimentary sequence is bounded by a slightly metamorphosed conglomerate containing clasts of the volcanic rocks and minor cherts and granites. It is then younger than the volcano-sedimentary series (Kusnir & Diallo, 1986; Kusnir et al., 1989).

In the Kenieba area, granites are few; the area is built essentially by metasediments: schists, greywackes, minor marbles and several horizons of tourmalinised (gold-bearing) sandstones. (An U/Pb age on zircon: 2098 ± 11 Ma). To the north occurs a formation comprising mainly meta-volcanics (andesites, basalts) and a series consisting of coarse sediments: sandstones, greywackes, polymict conglomerates with pebbles of above Birrimian rocks. Some twenty kimberlitic pipes, about 1,000 Ma old, intrude the basement rocks (as well as the sandstones of the Taoudeni basin, see fig. 6).

The Taoudeni basin covers about 2/3 of Mali's territory. It contains mainly sediments of Proterozoic (mostly sandstones, occuring in the south of the country, fig. 3) to Carboniferous of which Devonian and Lower Carboniferous are marine. The overlaying post-paleozoic formations, in the centre and the northeast, are continental, comprising Permo-triassic to Lower Cretaceous and post-Paleocene to Quaternary ("Continental terminal"- Ct). In the west, the basin formations are intruded by large quantities of dolerites, mostly of a permian to jurassic age.

In the centre of the Adrar des Iforas occur possible archean (?) terrains (granulite unit) and early proterozoic formations (gneisses, quartzites, marbles ...), overlaid by the late proterozoic rocks: schists, quartzites, conglomerates etc. Volcano-sedimentary series are found on the east and west of Adrar. An enormous batholite of granitic rocks has been formed in the western part of the massif during the Pan-african event (690-560 Ma). All these terrains were cut by ring complexes of alcaline granites of cambrian age (Fabre et al., 1982).

The area to the south and east of Adrar is formed by the sediments (detritic sandstones, marls, limestones), cambrian to cainozoic in age, of the Iullemen basin, located mostly in Niger. The paleozoic Gao graben (Sudanese strait), to the SW of Adrar, contains essentially mesozoic sediments. They are marine, from Cretaceous to Early Paleogene, including eocene phosphate beds, and continental from Eocene to Quaternary (Ct), containing gypsiferous argilites and oil shales.

The substratum rocks, with the exception of the Adrar Mts., seldom outcrop; most of the Malian territory is covered by recent superficial formations: sands in the north and laterites in the south, hindering the mineral exploration.

Mineral resources

In spite of a quite insufficient exploration of the country, Mali has numerous deposits and occurrences of various minerals (see Traor, et al., 1978 and PNUD/DNGM, 1987). They occur mostly in the west and east of the country; few deposits are known in the centre of Mali, formed mostly by sandy and clayey formations of the Taoudeni basin, covered by the Sahara's dune sands (fig.3).

Gold is the principal mineral resource of the country (see hereafter). Diamonds are known in the Kenieba area, near the senegalese border, where some 20 kimberlite pipes (some diamond-bearing) have been discovered in the proterozoic basement as well as in the sandstones (fig.6).

Ferrous metals. Iron occurs in various geological settings and types of deposits. Probably the most important are the oolitic ironstones in the late proterozoic sediments between Bafing and Bakoye rivers (Bale area), west of Bamako, cropping out on the top of several plateaus. The SONAREM estimation of good quality reserves (50-60 % Fe) is 500 Mt. The Ansongo manganese deposit, in the eastern Mali, is of the same type as the well known Tambao and N'suta (oxides on weathered gondites), but its reserves are only of about 3.3 Mt.

Non-ferrous metals. Large bauxite deposits were discovered in western Mali along Guinean border (extending to Guinea).They are developed mainly on late proterozoic to permian dolerites and occur on the top of plateaus. The thickness of the bauxitic crust is generally of about 10 m and Al_2O_3 content varies from 39 to 48 %. Total reserves are estimated at 1.2 billion tons and about 500 Mt are considered to be of good quality.

Despite large expanses of the volcano-sedimentary formations potentialy interesting for base metals, the only known zinc-lead deposit is Tessalit in the western Adrar (1.7 Mt of ore grading 5-10 % Zn + some Pb and Cu). The mineralisation of kupferschiefer and red beds types in formations of the eocambrian age in the Nioro-Kayes area in the NW of the country, has a quite significant potential for copper.

Mali lithium deposits are the spodumene-bearing pegmatites in the Birrimian, occurring mainly in the SW of the country (Bougouni area). The pegmatite dykes extend up to 1,350 m (Sinsikourou) and are up to 50 m of thickness (Gouna). Reserves could be 300,000 t of spodumene grading about 6% Li_2O.

Rare earths (TR) are found in carbonatites of the permo-jurassic Tadhak alcaline complexes located along the eastern edge of the West African craton. Besides TR, (La, Ce, Nd, Pr, up to 1.8 % Eu_2O_3),the carbonatites contain niobium (pyrochlore), mica and apatite.

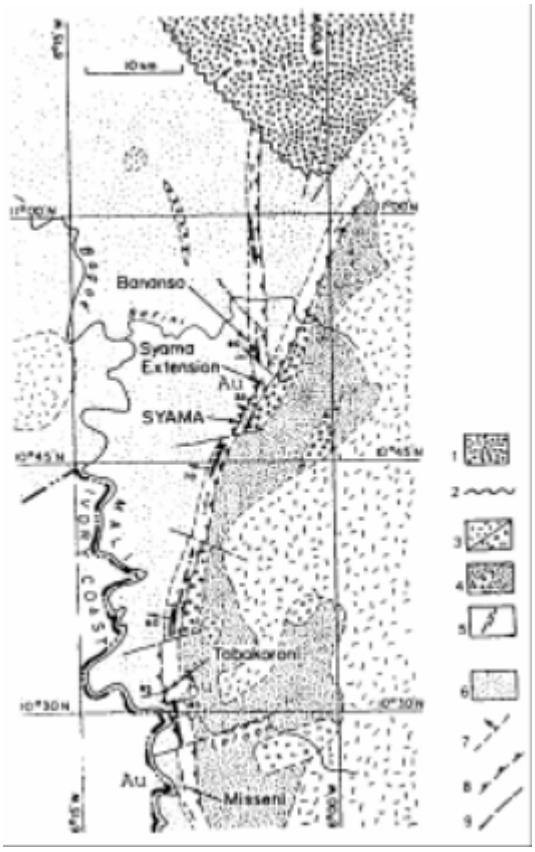
Industrial minerals. Mali has a large number of deposits of various industrial minerals: phosphates, limestones, ornamental stones, baryte, fluorspar, diatomite, kaolin, salt etc. The main phosphates resources are located to the west and south of the Adrar. The phosphate horizon, of middle eocene age, 0.5 to 2.2 m thick, outcrops intermittently over some 250 km and continues further to the east (fig.3). The only prospected Tamaguilelt deposit has a reserve of 11.8 Mt averaging 31.4 % P_2O_5. Economically the most important deposits of limestones exploited for the cement manufacturing, are situated in western Mali, near Bamako-Dakar railway,

SE of Kayes. They are represented by hills & hillocks. The biggest, Gangontery III deposit, has reserves of 59 Mt with the CaO content between 45 and 53 %. The In Kereit gypsum deposit, situated to the north of Adrar, is exploited for plaster manufacturing. In the Taoudeni area, gypsum occurs together with salt (exploited for several centuries), in the quaternary deposits of sebkhas. The only prospected sebkha, covering an area of 5-7x20 km, has reserves of 53 Mt of rock salt, 35 Mt of gypsum, 198 Mt of mirabilite and 336 Mt of glauberite.

Energy resources. Lignite and oil shale occurences have been reported from the sedimentary cover W and SE of the Adrar des Iforas Mts. The volume of oil exploration (geophysics, few wells) carried out since 1957, was quite limited in comparison with the extension of sedimentary formations. The most promising for petroleum are: Gao graben with 4 to 5 000 m thick sedimentary pile, Nara graben, west from Timbuktu and central part of the Taoudeni basin, to the north of this town. The latter area contains several thousand meters of sediments, including potential source rocks (marine infracambrian, cambrian and devonian formations) as well as potential reservoir rocks, oil-bearing in the neighboring countries.

Gold mineralisation

There are several hundred gold occurrences in Mali. The most important deposits have been discovered quite recently, since the mid-1980s, when the exploration (widely using the soil geochemistry) has been focused on the proterozoic Birrimian epi-metamorphosed volcano-sedimentary formations. It was realised (especially after the Syama discovery) that they might have the same gold potential as the archean greenstones.



Archean greenstone belts (for their description see Condie, 1981) have produced over 20 000 tons of gold. If a greenstone source for Witwatersrand gold (>27 000 t produced) is accepted, these terrains have supplied more than a half of the world production today (Bache, 1982; Phillips and Groves, 1984). The deposits are mainly of the vein type in meta-volcanic rocks (Western Australia, Canada, South Africa, India ...) or they are stratabound, in banded iron formation (Barbeton, S. Africa, Morro Velho, Brazil etc, see Boyle, 1979; Knight, 1975; Anhaeusser, 1976). Younger greenstones have been little studied. Their importance in West Africa has been recognized only recently (Goossens, 1983; Kusnir & Diallo, 1986) However in Ghana, industrial gold mining from Birrimian has been carried on for over a century. Ashanti (or Obuasi) deposit alone has supplied 584 t of gold from 1898 to 1986 (average grade of 22.5 g/t !); its reserves are estimated at 126 t (Kesse, 1984). Other important deposits in Ghana: Prestea (over 220 t of gold), Bibiani, Konongo. (Tarkwa conglomerates contain about 200 t Au). There are gold occurrences/deposits in all birrimian greenstone belts, between others (fig.2): Ity and Kouakounianou in Cote d'Ivoire (44 t of gold), Lero in Guinea (7.5 t), Poura in Burkina Faso (known past production and reserves of 55 t), Koma Bangou in Niger (22 t; see Min. An. Review, 1992; Goossens 1983; Dikouma, 1993).

Fig.4. Geologic map of the Bagoe River region showing the location of Syama and other gold prospects (modified from Kusnir and Diallo, 1986).

Greenstone belts gold in Mali

In Mali too, the Birrimian greenstones, occuring in the south-west and the west, covering an area of about 23 000 km^2, host almost all country known gold deposits. For comparison, the greenstone belts of Abitibi, Canada, with 44 gold mines, have an area of some 30 800 km^2. The primary mineralisation is almost exclusively of two types: 1. lode mineralization (with native gold in quartz veins and/or in sulphides disseminated in hosting rocks), 2. statabound mineralization in tourmalinised quartzites (gold mainly in sulphides). To these two types are to be added: 3. eluvial placers, formed on the outcrops of orebodies with gold locally concentrated even in the lateritic duricrust and 4. alluvial placers - main source of gold mined by "artisans". A brief description of the country's main deposits follows.

South-western Mali. In the south of the eastern-most Bagoe belt, gold mineralization occurs over 70 km (fig.4). Lode mineralisation is hosted in a thin sequence of basaltic and andesitic rocks, interbedded with

greywackes, schists and cherts (Kusnir & Diallo, 1986). In the northern part of this area is located Syama deposit, exploited by BHP (an Australian company). The annual production is about 6 tons of gold and geological reserves of 143 tons Au in oxide and sulphides ores. The oxide ore, extending to 35-40 m below the surface, is of an average grade of 3.2 g/t Au, locally reaching 30 g/t, supposedly due to the chemical remobilisation of gold. The average grade of sulphide ores, known to a depth of 500 m, is 4.02 g/t Au. The sulphide ore zone consists primarily of lenticular bodies of quartz-ankerite-pyrite stockwork, that grade (lateraly or verticaly) into sheeted veinlets or breccia zones (fig.5). Pyrite is the principal gold-bearing mineral. The mineralization is hosted mainly in chloritic basalt, in a narrow fault zone. Geometry of the orebodies, occuring en echelon, over 800 m strike, is quite complex; their thicknes varies from several to 50 meters (Olson et al., 1992). The Syama area and deposit shows many similarities to the Ashanti-Obuasi-Prestea belt and mines of Ghana as well as to the archean deposits of the same type.

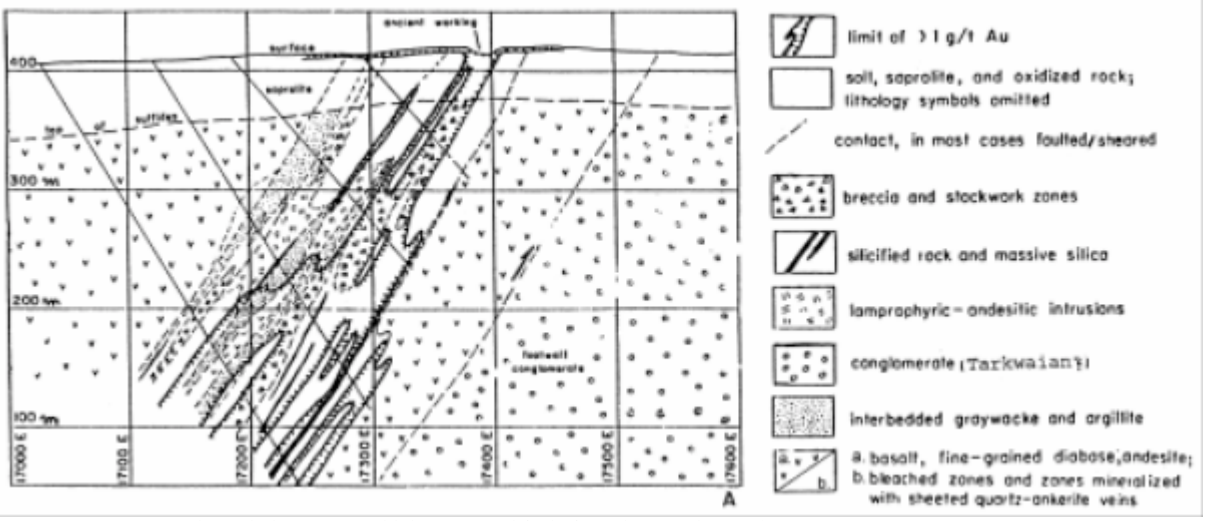


Fig.5. Cross sections through the Syama gold deposit (modified after Olson et al., 1992).

Massigui or Bougouni greenstone belt hosts Morila deposit, located NE of Bougouni, some 25 km SW from Massigui (fig.3) that has a reserve 16.3 Mt at 4.17 g/t Au (68 tons of gold). A 1.8 t/y mine could be opened by the Randgolg Co next year (see Mining Mag., 1998).

From the deposits in the Bale (or Kalana) belt skirting the guinean border, the most important is Kalana, situated to the SW of Yanfolila. It is formed by a set of slightly dipping (10-20°), nearly parallel quartz veins, 0.5 to 4.6 m thick, in the contact with a small dioritic stock, intruding birrimian schists and greywackes. The main deposit comprises 6 veins, extending for some 600 m. To the depth of 200 m, it contains 34.5 t of gold with the ore grading 36 g/t Au (1991 data). It is exploited by the only Mali underground mine, producing about 1.5 t/y Au. The reserves of the quartz reefs to the east of the diorite body (Kalana II deposit) are 10-20 t of gold. Kodieran deposit, which is only 6-7 km NW of Kalana, has 22.5 Mt of ore at a grade of 2.33 g/t Au (52 Mt of gold). A mine with a production of about 160,000 oz/y (4.9 t) of gold is to be opened (Min. Mag., 1997). A number of alluvial placers have been found in the streams/rivers draining the Kalana auriferrous zone; Bale placer contains 4 t of gold in gravels grading 2.2 g/m^3.

Kenieba area (Western Mali, fig.6). A large number of elluvial gold occurrences (in lateritised horizons) and alluvial placers, usually small, is known in this area. The most important lode type deposit is Sadiola Hill, situated in the north of the Kenieba area, 75 km SW of Kayes. It is the biggest gold mine of the country, with an annual production of about 12 t. It contains about 240 t of gold: The total proven and probable reserves of oxide and soft sulphide ores are 56.8 Mt at 2.86 to 3.1 g/t Au (171 t of gold). The inferred resource of hard sulphide, to a depth of 250 m, is 33 Mt at a grade of 2.08 g/t Au (68.6 t Au, see Mining Mag., 1996).

At the Diangoute prospect, some 25 km to the SW of Sadiola, mineralization occurs in extensive quartz-veins stockworks and zones of silicification in quartzite. A resource in excess of 30 Mt containing 60 t of gold is expected. Grades up to 21 g/t Au (on the surface) are reported (Mining Mag., 1997).

Stratabound gold mineralization occurs in slightly metamorphosed tourmalinised sandstones, forming 20-30 m thick beds, quite spread in the Kenieba region (fig.6). Their total length is over 200 km. At Loulo, located close to the Faleme river (Senegalese border), W of Kenieba, they were prospected by a joint venture of the Mali government and the french BRGM. A deposit was found (Loulo 0). The sandstone bed, 10 to 22 m thick, consisting of quartz grains and crypto- to micro-cristalline tourmaline, is mineralized for about 800 m. Gold is found mainly in pyrite, disseminated in stockworks of quartz-carbonate veinlets, containing also some fine native gold and minor arsenopyrite, pyrrhotite and gersdorffite. The geological reserve, to the depth of 150 m, is 28.2 t of gold with an average grade of 4.38 g/t Au (Dommanget et al., 1989).

Eastern Mali. In Darset is the only known deposit in this area. The mineralization is represented by stockworks of quartz veilets (+ some barite) in a volcano-sedimentary series, situated on the western limit of the Adrar Mts. Six reefs, 1.5 to 20 m thick, 150 to 800 m in lenght, contain <1 g/t Au and a weak copper, lead and zinc mineralization. A reserve of 3 t of gold at 4.4 g/t has been delinated by SONAREM (Boltrukevitch, 1973).

Conclusion

Recent gold discoveries in Mali are a good example of a success resulting from the choice to explore a geological setting with a fairly good potential for a mineral resource and the use of an efficient exploration method. Indeed, despite gold mining since immemorial times, the economically important, large deposits (ex. Sadiola with 240 t of gold), have been found only since the mid-1980's, when started the exploration of the proterozoic Birrimian formations (quite alike as archean greenstone belts, one of the main sources of gold in the world) with the use of soil geochemistry as principal exploration method, efficient in the flat, outcrop-lacking country.

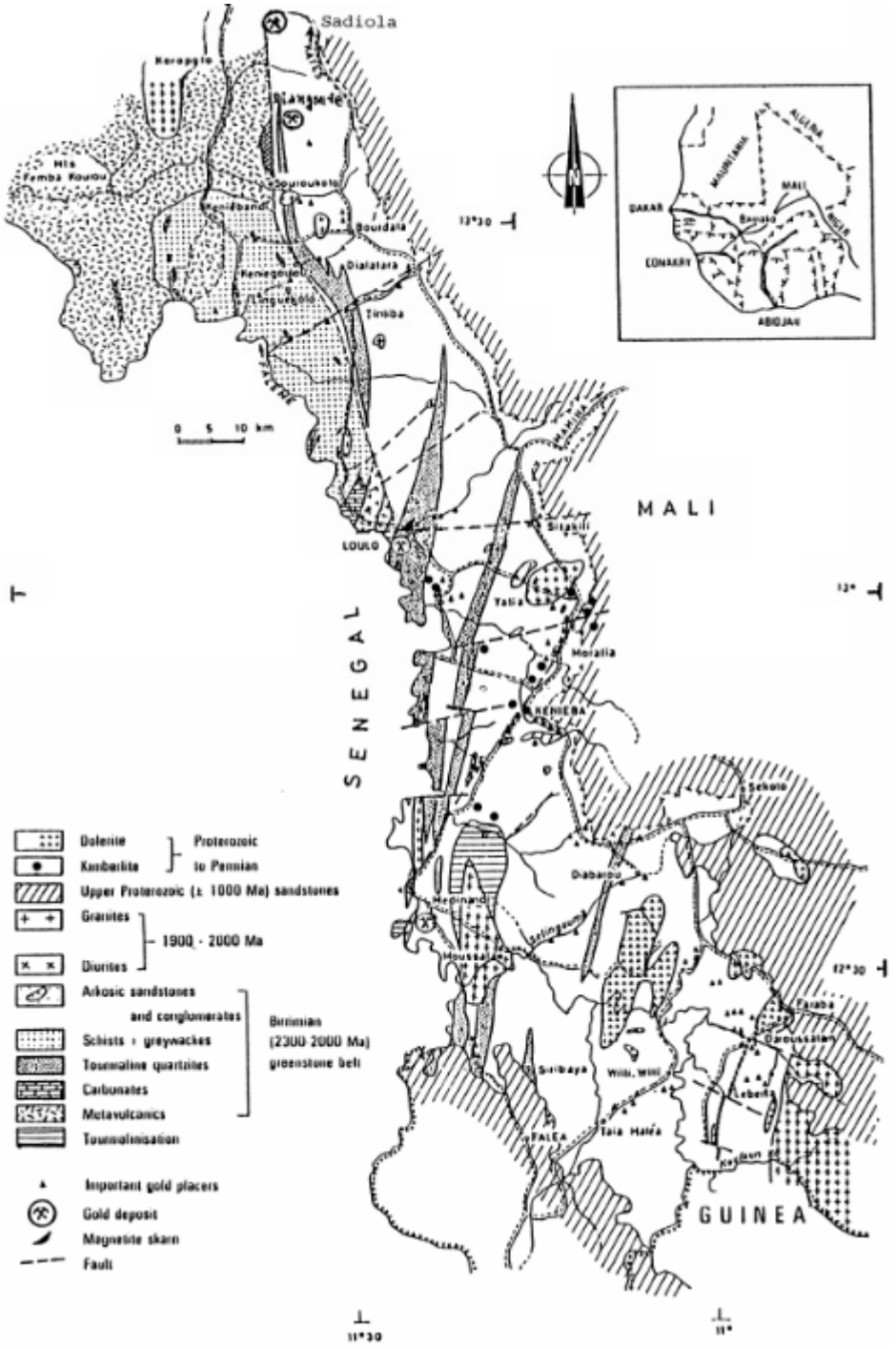


Fig.6. Kéniéba gold province (from Dommanget et al., 1989, slightly modiefied).

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