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Assessment of mining potential for the establishment of a gold panning corridor in the Loulo area (Western Mali): An effective environmental management tool

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Abstract

Mali's mining potential has been well documented by previous studies conducted by the government and mining companies. In addition to industrial mining, the study area is subject to a considerable influx of artisanal gold miners. This study aims to propose solutions for regulating artisanal gold mining in Mali's mining areas. The methodology involved conducting a survey, geotechnical studies, and inverse circulation drilling (IRC) in the rural commune of Sitakily/Loulo. This research revealed the discovery of significant gold deposits exploited by artisanal miners in Sadiola, Yaléa, Segala, Tabakoto, Loulo, Gounkoto, and Fekola. Furthermore, upon receiving the drilling results, a sorting of the levels yielding grades greater than or equal to 0.2 g/t was carried out. These results have demonstrated the full mineral wealth of the area under study in western Mali. Furthermore, these deposits are currently the primary source of mass migration to mining sites and the establishment of makeshift camps around the villages of Satkili, Loulo, Gounkoto, and Fekola. To better optimize artisanal gold mining and ensure effective environmental management, Mali must create designated gold mining corridors.

Keywords: Mining potential; Gold mining; Gold deposits; Drilling; Corridor; Environmental management

1. Introduction

Artisanal mining in Mali generates approximately 729 billion CFA francs annually, or US$1.23 billion. The average income of an artisanal miner varies between US$618 and US$9,904, depending on the mineral wealth of the sites, the scale of the operation, the role of the gold panner in the work, and the number of days worked per year. Known for its beautiful yellow color, its luster, and its malleability, gold has long been coveted by humankind for crafting jewelry, for use in trade as currency, and as a safe haven asset during times of crisis. Its uses have evolved considerably, expanding into the fields of electronics, decorative arts, medal making, and more. In January 2023, global annual gold production exceeded 3000 tonnes, of which 80-85% was from industrial sources and 15-20% from artisanal sources (United States Geological Survey (USGS), January 2023).

Artisanal mining, practiced in most of the world's gold-bearing provinces, employs over 40 million people globally, and more than 250 million depend on it. It generates revenues of over USD 35 billion annually. Mali, the fourth-largest African gold producer in 2022 (50 tonnes), behind Burkina Faso (70 tonnes), Ghana (90 tonnes), and South Africa (116

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tonnes), is a West African country covering an area of 1,241,238 km^2. Its population is projected to reach 20,537,000 in 2024, representing a growth rate of 3.7%. The country's population was estimated at 22,084,853 in 2022. Artisanal and small-scale mining employs approximately 512,605 people, including 298,307 in the Kayes region, 162,898 in Sikasso, and 51,400 in Koulikoro. This significant contribution to wealth and job creation demonstrates that artisanal mining is an important socio-economic activity that should be organized, formalized, and regulated. Therefore, if better organized within a designated corridor, it could significantly reduce the unemployment rate, estimated at 4.2% in 2020 according to INSTAT, and increase the extractive sector's contribution to Mali's GDP (9.74% in 2020), government revenue (20.73% in 2020), and export earnings (82.01% in 2020), according to the 2020 report of the Extractive Industries Transparency Initiative (EITI) in Mali. This research is part of the Mining Sector Governance Project (PGSM) and aims to propose solutions for regulating artisanal gold mining in Mali's mining areas.

1.1. Study area

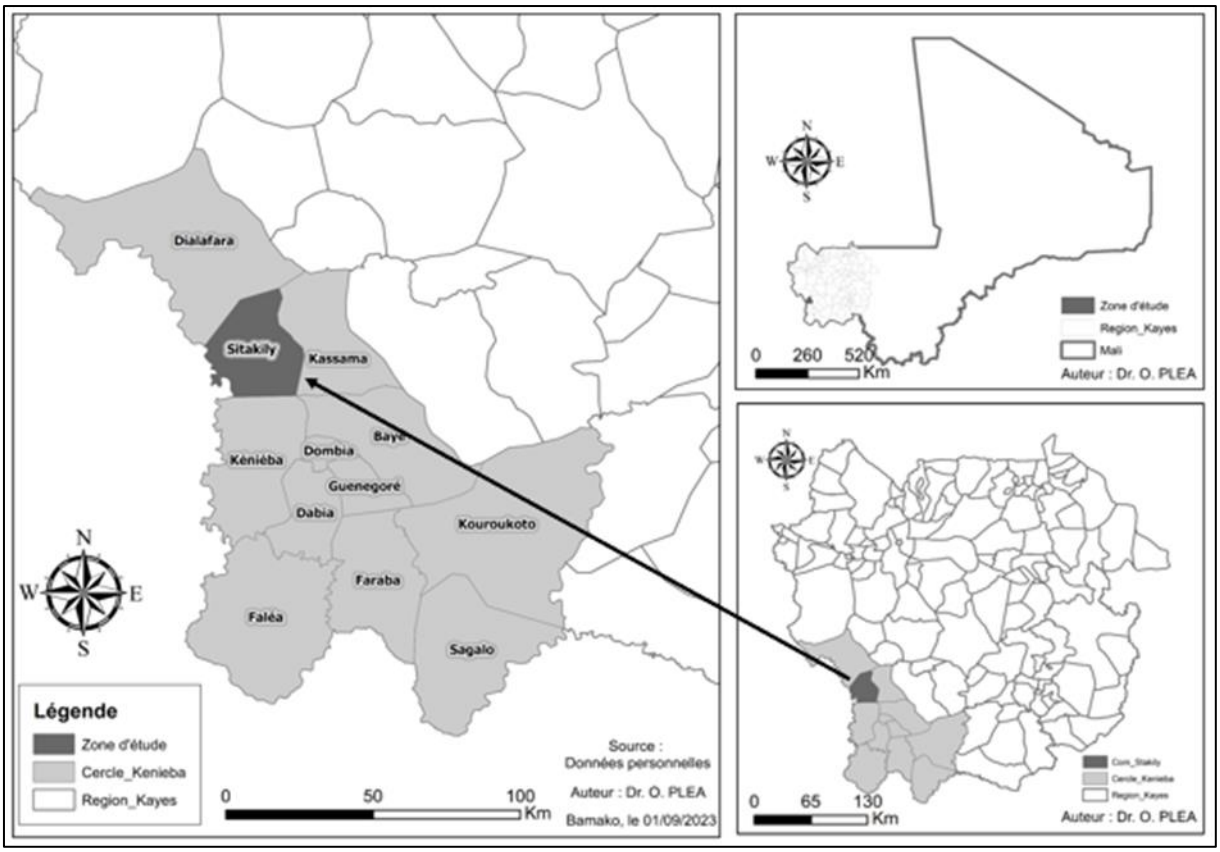

Figure 1 Location of the study area

The study area is located in the commune of Stakily (Kéniéba district) in the extreme southwest of Mali. It borders Senegal and runs along the Falémé River. It lies in the western part of Mali, just east of the Falémé River, which serves as the natural border between Mali and Senegal. The geology is dominated by the Lower Proterozoic Birimian series, which are exposed in an erosion window known as the Kédougou–Kéniéba window. The geology is also marked by the major structure known as the Mali-Senegal Shear Zone (Senegal-Malian Fault), which separates the volcanic rocks of the Sabouciré Formation from the turbidites of the Kofi Formation.

2. Methods and data

2.1. Méthods

To carry out this research, a survey and geotechnical studies were conducted between June and August 2023 in the rural commune of Sitakily/Loulo. These studies allowed for the observation, identification, and evaluation of all mining potential in the Loulo area. Given the geography of the area, the study focused on the sites of Sakola, Sangaré-Djoura, Kounda, and Djdjan.

2.2. Data

In addition to field visits, reverse circulation drilling (IRC) was carried out over a 46 km^2 area to establish the lithological profile of the gold mining sites. Reverse circulation drilling (IRC) is a powerful system for large-diameter wells in alluvial formations. It allows for high-quality sampling due to the cuttings collection method. The cuttings are brought to the surface through the center of the drill string, thus minimizing contamination and preserving sample integrity. This is crucial for accurate geological analysis. These methods were used to quantify the gold potential and richness of the study area.

3. Results and discussion

3.1. Mining potential

Exploration work in the Kéniéba window has led to the discovery of significant gold deposits: Sadiola, Yaléa, Segala, Tabakoto, Loulo, Yaléa, Gounkoto, and Fekola (Figure 2). A key regional characteristic of these deposits is their proximity to major structures: Fekola, Gounkoto, Loulo, and Sadiola are located near the Senegal-Mali Shear Zone (SMSZ), while Yaléa, Ségala, and Tabakoto lie on replicas of the Kéniéba-Médinandi (K-M) structure, which likely originates on the SMSZ. Another characteristic is the presence of substantial intrusive bodies: Moussala granite at Loulo and probably a deep body at Yaléa; granodiorite at Segala and Tabakoto; and diorite at Sadiola, where diorite bodies form part of the deposit's roof. Several linear regional structures transgress the zone. These are:

- First-order structures: Senegal-Mali;
- Second-order structures, oriented north to northeast; these are the Farandi and Yaléa shear structures. The first phase of mineralization coincided with this event;
- Third-order structures, oriented northeast to east-northeast; these are reactivated reverse faults and north-trending shear zones. These reactivated transverse structures are present in all major deposits and mineralized sites. They are responsible for the re-concentration leading to the creation of high-grade zones.

There is a strong spatial relationship between the gold deposits, regional structures, lower-order structures, lithologies with rheological contrasts, and intrusive bodies. These structures extend over 50 km in a north-northeast direction throughout the area.

The main types of alteration associated with the mineralization include quartz-tourmaline, sulfides, albite, silicification, hematite, and carbonates (including carbonate remobilization).

Exploration work undertaken in the Loulo permit by Randgold Resources has identified three types of mineralization:

- Gold mineralization associated with brittle deformation related to reverse faults and thrust faults in the competent host rocks at Loulo 0, Loulo 2, and Yaléa Ridge (quartz-tourmaline);
- Shear-related mineralization in the sequence of polygenic limestones, quartzites, and breccias (Yalea and P125);
- Stockwork and breccia mineralization associated with thrust faulting in the reverse fault wall.

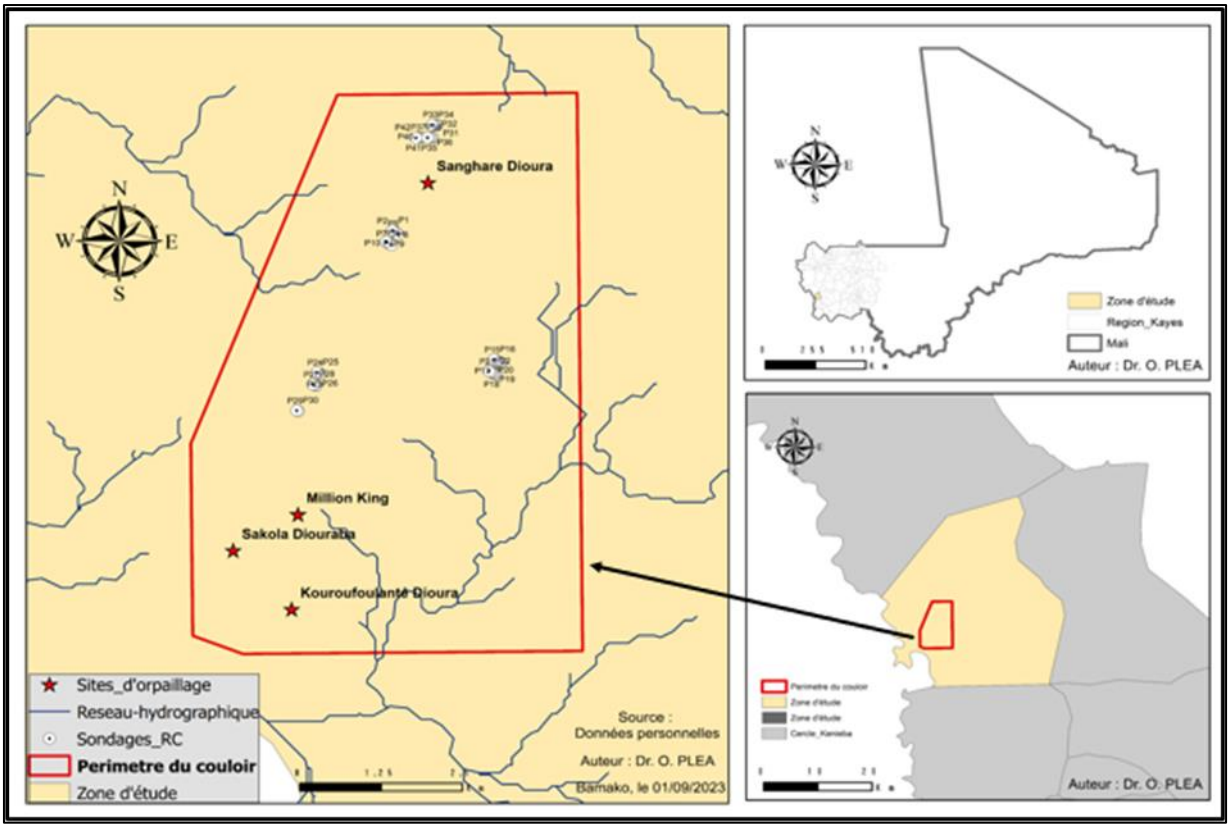

Figure 2 Location of the different exploration prospects within the 46 km^2 area affected by Barrick

Several artisanal gold mining sites are identified within these prospects. In the northern part of the area (Toulou prospect), mining operations are located along N020 structures. The spoil exhibits shear stresses with graphite formation. Mining has reached depths exceeding 30 meters, remaining within the saprolite. The depth of the alteration zone prevents the exposure of fresh rock. Meteorite alteration has rendered the rocks unrecognizable. The shafts and the mining pit follow a northeast direction (Figure 3). In places, felsic quartz veins injected along the structures exhibit tectonic offset in a sinistral movement.

These veins appear to fill N020 fractures with a dip of 60-70° W. The mineralization is hosted along parallel N020-N030 structures, within fine- to medium-grained, reddish-pink altered material. The degree of alteration is very advanced and complicates lithological and structural observation

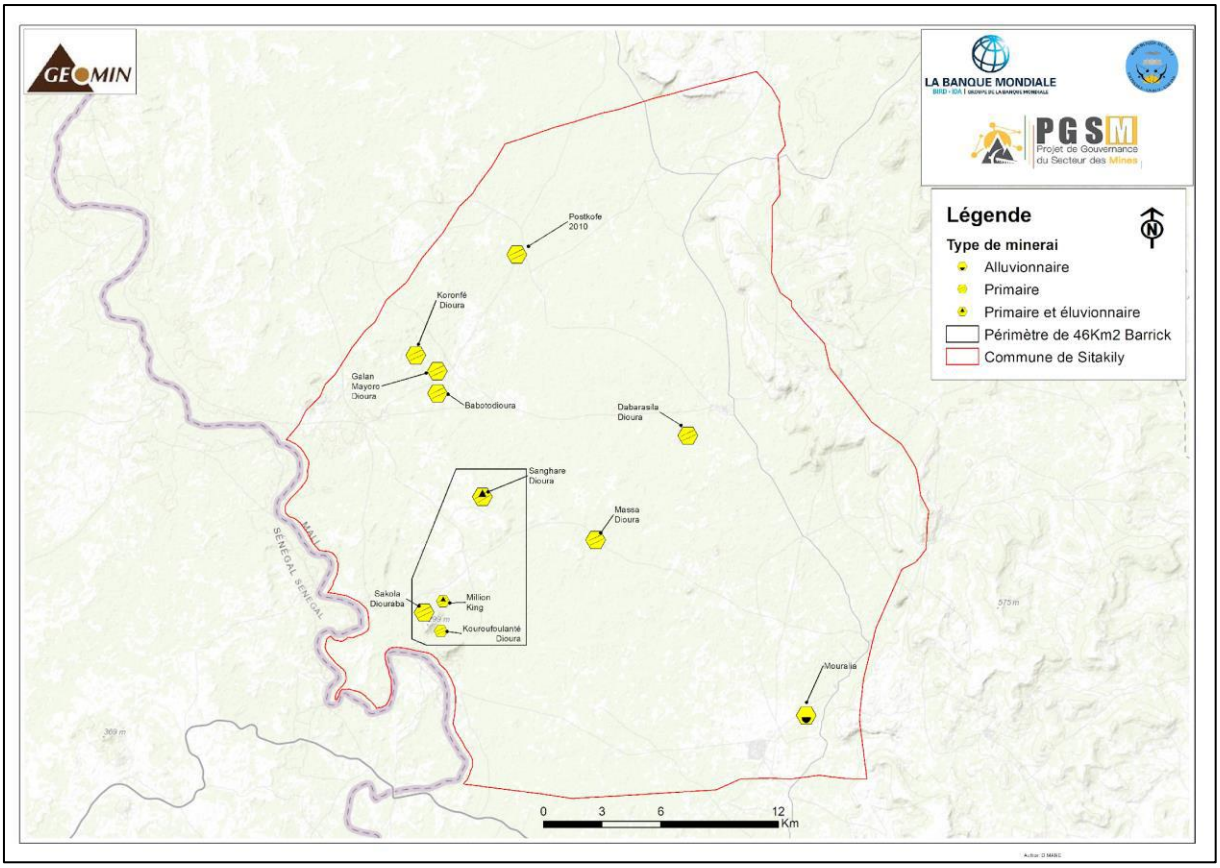

Figure 3 Typology of the deposits exploited by artisanal miners in the commune of Sitakily

3.2. Estimation of the Number of Processing Units by Type:

To arrive at a realistic estimate of the number of artisanal miners at the gold panning sites, the methodology consisted of combining socio-economic surveys and direct observation. Specifically, at each site, questions regarding the number of miners, their distribution by sex, and their nationality were asked of a representative sample of mining teams. The number of mining teams, which is equivalent to the number of active shafts on the site (shafts currently being exploited), was quantified.

The collected data were interpreted as follows:

- Calculation of the average size of a mining team at each site. It should be noted that the number of members in a team can exceed fifty, but there is always a core group of between six and eight people per team;
- Average distribution of teams between men and women
- To obtain the number of artisanal miners at each site, the average size of each team was multiplied by the number of mining teams (number of active pits).
- To obtain the distribution of workers by gender, the number of workers at each site was multiplied by the proportion of men or women in a team.

Gold panners are highly mobile and can quickly leave one gold panning site for another. Indeed, as soon as they receive information about the discovery of a new gold-producing area, many workers rush to this new area, sometimes abandoning productive pits. This characteristic of gold panning means that any information on the number of workers and production is only valid at the time of collection.

These data reflect the situation at the sites visited between April 25 and May 24, 2023. Our estimates were based on a sample of 13 sites, out of a total of 19 sites in the commune of Sitakily, according to interviews with community representatives (known locally as "Tombolomas") and members of the Chamber of Mines. Based on data collected during baseline socio-economic surveys, artisanal gold mining in the commune of Sitakily employs approximately 7,850 people, including 6,255 men and 1,595 women.

3.3. Gold Production Estimation

Production estimates are also based on socio-economic surveys and direct observation. The international expert team, including the artisanal mining specialist, the ore processing expert, and socio-economists, collected relevant data on the number of bags produced by a team of miners, the average weight of a bag, and the average quantity that can be obtained.

Nineteen samples were also taken from both primary and eluvial ore to confirm the gold panners' claims. Regarding the alluvial deposits, the study relied on expert opinion and the gold panners' responses to estimate average grades.

The calculations were therefore based on the following baseline data:

- average grade of vein ore: 1 g/70 kg bag (approximately 14.2 g/t);
- Average grade of eluvial ore: 0.1 g/bag, or 1.42 g/t
- Average grade of alluvial ore: 0.05 g/bag, or 0.71 g/t;
- Quantity of bags produced by a team of miners working on the primary ore: 17.5 bags/day
- Quantity of ore produced by a team of miners working on the primary ore combined with eluvial ore: 25 bags/day;
- Quantity of ore produced by a team of miners working on the alluvial ore: 35 bags/day
- Number of days worked per week under normal conditions: 5 days
- Number of months worked: 12 months
- Prospecting success rate: 50%

Based on this information, the annual quantity of gold produced at the 13 sites studied is estimated at 1,017,786 g. By extrapolation, the production of the 19 identified sites in the commune of Sitakily is estimated at 1,487,533 g, rounded to approximately 1.5 tonnes of gold.

Figure 4 below shows the distribution of the quantity produced per site studied in the commune of Sitakily.

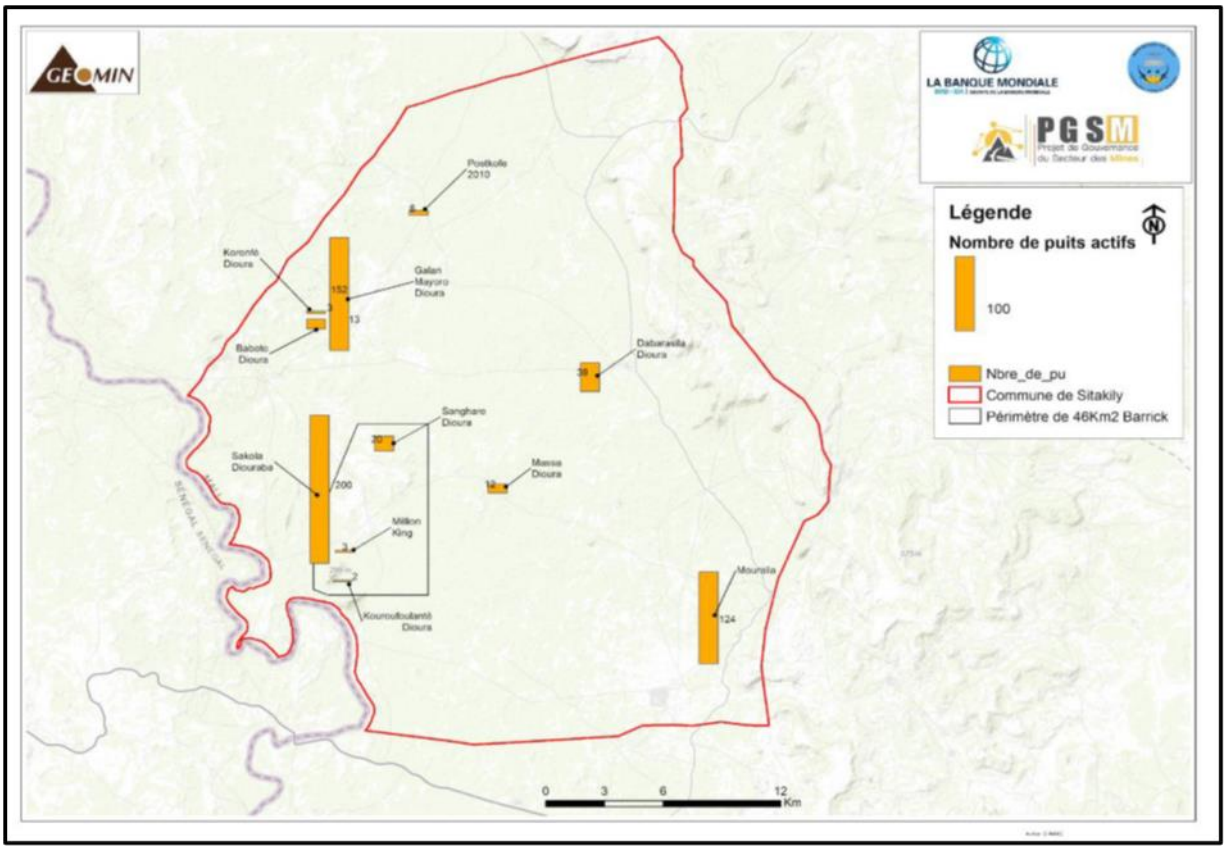

Figure 4 Number of active wells per extraction site (source: extracted from the PGSM study report)

3.4. Estimation of results from borehole sample analysis (RC)

The results presented here come from a composite of ores from RC boreholes carried out during the geological and mining exploration phase (Figure 5: lithological profile of the study area). Upon receipt of the borehole results, a sorting of the levels that yielded grades greater than or equal to 0.2 g/t was carried out for the purposes of the demonstration mission. This sorting resulted in a total of thirty-four (34) metric levels, of which thirty-one (31) could be located, extracted, and weighed individually. These levels were then mixed, homogenized, and ground in a disc mill. The resulting composite ore is in powder form (a few hundred microns). Its average grade was obtained by weighting each level with its corresponding grade. A weighted average grade of 1.5 g/t was obtained on a total weight of 335 kg of composite material. The recovery percentage was calculated based on this grade of 1.5 g/t (Geomin, gold recovery technology demonstration mission report).

At the various drilling points, mineralization was observed in all three sections (two sections from the recent RC program and one section from Barrick Gold's RAB work). It extends over an approximate length of 200 m at an average depth of 21.5 m. Four major intercepts were identified.

	Au > 0.5g/t							ZONE
N°	Hole ID	From	To	Sample No.	Sample_Type	Wgh	Au (g/t)	
1	P08	29	30	L0423	PRIMARY	1,415	23,32	
2	P08	30	31	L0424	PRIMARY	1,8467	1,18	ZONE 1
3	P17	0	1	L0891	PRIMARY	1,4293	3,5	
4	P17	22	23	L0915	PRIMARY	1,6686	3,58	
5	P17	23	24	L0916	PRIMARY	1,6893	1,64	ZONE 2
6	P28	22	23	L1523	PRIMARY	1,3732	1,28	
7	P28	24	25	L1525	PRIMARY	1,2418	2,22	ZONE 3

Figure 5 Results of ore sample analyses taken from the study area

Grades vary from one point to another. High gold grades are between 1 and 3 g/m^3 for the mineralized layer. This layer outcrops in the active beds but is generally covered by barren or weakly mineralized sediments.

4. Conclusion

The geotechnical and structural investigations carried out in the Kéniéba study area (Kayes, Mali) confirm exceptional mining potential, evidenced by the discovery of major gold deposits: Sadiola, Yaléa, Segala, Tabakoto, Loulo, Gounkoto, and Fekola. These prospects closely align with the dominant tectonic structures: Fekola, Gounkoto, and Loulo overlie the Senegal-Mali shear zone, while Tabakoto exploits branches of the Kéniéba-Médinandi structure. A distinctive lithological character emerges with feldspathic intrusions: Moussala granite (Loulo), probable granodiorite at Yaléa, granodiorite at Segala/Tabakoto, and porphyritic diorites at Sadiola (forming the roof of the deposit). Indeed, artisanal gold mining, generating more than 30 tons per year and over 50,000 informal jobs, represents a vital socio-economic driver for Mali, particularly within a regulated "gold mining corridor." Nevertheless, it suffers from serious dysfunctions: lax governance, insecurity, environmental degradation, water pollution exceeding World Health Organization (WHO) standards, and health risks (respiratory illnesses, accidents: 20% mortality), without urgent measures – operational (training, mechanization), security (zoning), environmental (rehabilitation), and hygiene and safety (mobile clinics), etc. These problems will exacerbate social and environmental vulnerabilities in the Kéniéba region of Mali. Properly managed, the gold mining sector will propel Kéniéba into a sustainable mining hub, boosting Mali's GDP by 15% by 2030. However, it currently suffers from several issues which, if not addressed, risk worsening the social and environmental situation. Strong measures must be taken at the operational, governance, security, environmental, health, and safety levels.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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