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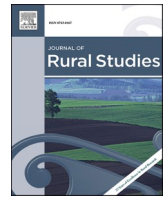
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Mechanization of artisanal and small-scale gold mining in Guinea: Socio-technical trajectory of a rural mining site in Upper Guinea

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ABSTRACT

Since the beginning of the 21st century, artisanal and small-scale gold mining (ASGM) in West Africa has undergone intensification and significant development due to the introduction of increasingly mechanized extraction and processing method. Mechanization generates significant transformations in the socio-technical dynamics of artisanal gold mining. In the specific context of ASGM in Upper Guinea, the article argues that small-scale innovations (ie. 'low noise' or 'low technological level' innovations) are leading to a profound socio-economic transformation of the rural environment over a long period of time. We begin by describing and analyzing the impact of the introduction of minor innovations (metal detectors, *solonins* and fan motors) on ASGM practices. We then examine the political, social and economic changes brought about by the adoption of these new mechanized practices, again at the rural level. Finally, we discuss the transition toward a new socio-technical regime, questioning the reshaping of local governance and its impact on new configurations of land ownership and use in rural areas.

1. Introduction: technical innovations and socio-economic reconfigurations of ASGM practices in Guinea

Since the beginning of the 21st century, the gold mining industry in Guinea has expanded immensely, from small-scale artisanal to industrial operations.¹ Industrial mining has been largely stimulated by significant foreign investment, made possible by successive reforms of the Mining Code, the latest dating from 2011 and amended in 2013, initiated under the aegis of international financial institutions (Campbell and Hatcher, 2019). Artisanal and small-scale gold mining (ASGM) also intensified and expanded considerably following the rise in the price of gold, with two periods of strong growth between 2008 and 2012, and again between 2018 and 2020. This intensification is reflected in a significant increase in artisanal gold exports. In 2013, artisanal gold exports amounted to around 5 tons, whereas this number reached 83 tons in 2021 (MMG, 2018, 2022), exceeding industrial production, which stood at 17.8 tons in the same year.²

This intensification, accompanied by the introduction of increasingly

mechanized methods of gold extraction and processing, has not only boosted productivity but also transformed the socio-technical dynamics of ASGM. This article aims to report on these transformations and their political, social, and economic effects in rural Upper Guinea, where this activity is concentrated.

1.1. ASGM in Upper Guinea

In this area, the tradition of ASGM spans centuries and holds a pivotal position in the local economy. Notably, the historic localities of Bouré and Séké were instrumental in shaping medieval African empires. Throughout history, artisanal miners in these regions employed basic tools and techniques, as highlighted by Diallo (2017), to extract and process gold ore. These are generally buckets, picks, chisels, hammers, and calabashes. These tools are locally manufactured, and their acquisition and maintenance do not require substantial expenditure. What's more, the sites are accessible to all, regardless of origin or level of technical expertise, which differs from active industrial extraction sites,

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¹ By industrial mining, we refer in this article to large scale, capital intensive, legal mining companies.

² Exports from ASGM have risen in unprecedented manner in 2020, especially after the government lowered export fees to 0 (justifying it with a new focus on currency repatriation rather than on leveraging revenues from taxes) and encouraged the activity of Guinean buying and export houses (*comptoirs*). Large shares of gold from ASGM which were otherwise smuggled to Mali started, only then, to be recorded in export national register.

governed by legalized permits and where only officially authorized companies can operate. Despite the open accessibility to ASGM sites, all excavation activities and transactions among different stakeholders remain under the jurisdiction of customary authorities. These authorities adhere to a defined set of norms, principles, and practices, well-documented in literature by (Bolay, 2016; Dessertine, 2016; Lanzano and Arnaldi di Balme, 2017). This adherence establishes a stable socio-technical regime (Geels and Kemp, 2007; Geels, 2004).

The livelihoods of several thousand individuals are directly or indirectly linked to ASGM, (Bolay, 2016; Dessertine and Noûs, 2021; Huntington and Marple-Cantrell, 2021; Seccatore et al., 2014). The discovery of a promising deposit arouses the interest of other populations, attracting them to mining areas, which are often located in rural regions. Historically, farmers have been the first to get involved outside of professional gold miners, as the two sectors are linked by various complementary as well as competitive relationships (Cartier and Bürge, 2011; Hilson, 2011; Hilson and Garforth, 2012; Kamlongera, 2011; Okoh and Hilson, 2011). However, in recent years, ASGM has attracted other stakeholders with more diversified profiles (Mkodzongi and Spiegel, 2020), such as unemployed graduates.

Over recent decades, ASGM has undergone significant transformations, evolving from a predominantly artisanal (done manually) activity, characterized by low levels of mechanization (Shen and Gunson, 2006), to the gradual adoption of more advanced technologies (Bansah et al., 2016; Teschner, 2014). This evolution presents opportunities for transition towards formalization of the activity (Sawadogo & Daï, 2021; Siegel and Veiga, 2009). However, as in many other contexts, formalization policies remain ill-adapted and difficult to apply in this region (Dessertine et al., 2023).

1.2. Mechanization and socio-economic transformations

Since the 2010s, ASGM has seen a series of technical innovations in ore extraction and processing practices. In Ghana, for example, the introduction of crushers - known locally as *Changfa* - by Chinese migrants, has enabled the processing of a significant quantity of low-grade ore (Agyei, 2016; Bansah et al., 2016). In Burkina Faso, the use of cyanide has made it possible to re-mineralize tailings from artisanal processing (Lanzano and Arnaldi di Balme, 2021; Ouédraogo, 2020; Verbrugge et al., 2021). In the DRC, the use of ball mills has reduced investment costs, playing a crucial role in improving the productivity of operations (Bikubanya and Radley, 2022). Lastly, in Guinea, as early as 2012, the introduction of metal detectors considerably improved gold miners' incomes, enabling them to exploit shallow deposits and move rapidly between gold mining sites without establishing permanent residency (Dessertine, 2016). The assembly of these technical innovations constitutes innovation pathways and trajectories that gain to be considered. Focusing on Sierra Leone and Liberia, Hilson & Maconachie (2020) documented two types of trajectories guiding the innovative evolution of the informal ASM sector: on the one hand, that of a burgeoning semi-formal artisanal group with limited capacity to mechanize, and on the other hand, that of a small number of individuals who have managed to overcome crippling financial barriers to secure titles to mine using more advanced technology. More recently, Ekow (2024) proposes a conceptual framework to unravel innovation trajectories in the African ASM sector highlighting resilience as a main driver.

Primarily informal in nature, the mechanization of ASGM, as one kind of innovation trajectory, has raised concerns among authorities, due to the profound socio-economic transformations it creates, already extensively documented in scientific literature. From an economic standpoint, these changes shift ASGM from a subsistence activity, as discussed by Hilson & Garforth (2012), to a more profit-oriented venture, as highlighted by Cortés-McPherson, (2019). These innovations also enable gold miners to exploit richer deposits, creating direct competition with industrial operations (Bolay, 2014; Hilson, 2011; Lanzano and Arnaldi di Balme, 2017). Sociologically, it is becoming

increasingly clear that the current trajectory towards mechanized ASGM is accompanied by the emergence of modes of labor relations.³ On the one hand, these labor relations are described as being marked by growing inequalities, sparking conflicts over resources and fostering a more exclusive interpretation of property (Gagnol et al., 2020; Ribot and Peluso, 2003). These reconfigurations notably result, in particular, in the exclusion of women (Lanzano and Arnaldi di Balme, 2021; Ouédraogo, 2020), the devaluation of the value of their work (Bikubanya and Radley, 2022), and their impoverishment (Conteh and Maconachie, 2021). On the other hand, Rushemuka & Côte (2024), recently proposed to consider the evolution of ASM labor regime, (ie. a set of social relations resulting from local networks and politics, technological production choices, commercial demands) as means to escape from the dissonance between formalization policies and the inner dynamics of the ASM sector. They thus suggest that formalization may not be the most effective analytical starting point for understanding ASM challenges and that a deeper understanding of ASM labor dynamics is needed.

1.3. State of the art: reconfiguring a stable socio-technical regime

We use the concept of the 'sociotechnical system', as an aspect of ASM labor regimes, to analyze current developments in ASGM associated with the introduction of mechanized practices. Work on transitions from one socio-technical system to another has received particular attention from researchers in recent years. The first studies devoted to socio-technical transitions, notably by Rip & Kemp (1997) and Geels (2004, 2005), highlighted the crucial importance of adopting a multi-level perspective. According to them, the transition from one socio-technical regime to another can manifest itself through various transition trajectories, notably intermediate ones, such as reconfiguration (Geels, 2006). In this intermediate transition trajectory, it is the adoption of multiple symbiotic innovations that initiates the transition from one socio-technical regime to another. In this case, the transition dynamic is not based on a process of substitution, but on the accumulation of numerous small changes over time, which ultimately leads to major reconfigurations. We consider that the current changes in ASGM at Balato are part of such a process.

In addition, beyond the 'global' (long-term) approaches often adopted to study transitions (Geels and Schot, 2007), our analysis is anchored in a local perspective (Geels et al., 2016) aimed at objectifying the singular trajectories linked to the introduction of mechanization and the dynamics of the actors involved in artisanal mining. We focus on changes that can be observed over a short period of time, as ASGM has undergone major changes over the past decade in Guinea.

According to the 2011 Guinean Mining Code, amended in 2013, ASGM is defined as "any exploitation whose activities consist of extracting and concentrating mining substances and recovering the marketable products by manual and traditional methods and processes". Beyond this legal definition, ASGM actually encompasses a diversity of actors and forms of exploitation that vary according to the techniques used and the exploitation sites. We postulate here that artisanal gold mining can be considered a relatively stable socio-technical regime, in which the various actors use conventions, norms and routines and ancient techniques sometimes described as local knowledge and know-how, and anchored in a local political and institutional system (D'Avignon, 2018; Lanzano and Arnaldi di Balme, 2017; Bolay, 2016, 2014). This form of gold mining remains the most widespread. Even if national law does not recognize this local governance, the introduction

³ In this article, we will not deal with the reconfiguration of gender relations, but instead focus on the reconfiguration of relations at the level of the local governance of the activity. For this question, we refer, for example, to work on the masculine character of local mining institutions (Bolay, 2022) and on the masculinization of activities after the introduction of metal detectors (Dessertine, 2016) and cyanidation processes (Ouédraogo, 2020).

of new mechanized techniques does not seem to have replaced artisanal extraction techniques or completely challenged the artisanal socio-technical regime.

The question of transition therefore remains, and the aim of this article is to reveal the logic behind it by examining it in the light of more intermediate processes such as reconfigurations. We postulate that these smaller-scale innovations, which we describe as “low-noise”, are more likely to persist and lead to significant transformations, particularly in work organization and land tenure. Although formalization policies have been developed by the state (e.g., gold panning corridors), they remain largely unapplied (Dessertine et al., 2023). Paradoxically, while we remain in the informal realm, we will see that mechanization leads to forms of land privatization - which we will define - and to more capital-intensive modes of work that are close to the formal logics advocated by the state. While it has already been shown in this region that gold mining can help to impose forms of state rationality (Dessertine and Notis, 2021), we find a similar process in gold panning, but no longer according to a logic of “discharge”, where the state appears to discharge its prerogatives following processes of privatization (Hibou, 1998).

In particular, we will show how, on the one hand, mechanization is an opportunity to position certain socio-economic stakeholders in the local governance of the sector and, on the other, how the socio-economic transformations induced by this mechanization are based less on major changes than on the accumulation of minor changes. In doing so, we wish to nuance the commonly held idea of a poverty driven fatality of ASM individual and collective trajectories condemned to illegality and criminality. Bester (2023) has demonstrated that criminalizing and policing the artisanal mining sector is counterproductive and unsustainable. As Hilson and Hu (2022) have shown, ASM livelihood trajectories are complex and hybrid. They demand to better consider the agencies and capabilities of ASM workers on the evolution of ASM territorial dynamics and to reconceptualize ASM as an entrepreneurial and community activity (Arthur-Holmes et al., 2022; Hilson and Maco-nachie, 2020).

In the next section, we present the case study and our methods. Section 3 then presents the technical innovations and socio-economic reconfigurations. Finally, section 4 suggests avenues for discussion on the reconfigurations brought about by this small-scale mechanization, focusing on issues of social change, the repositioning of public authority in a non-formalized farming sector, and the increasingly central role of land ownership.

2. Case study: Balato district, Kintinian sub-prefecture, Guinea

Our work is founded on a case study in the Balato district, within the Kintinian sub-prefecture, located 20 km northwest of downtown Siguiiri. It is based on data collected during field expeditions carried out between April and June 2022, and between February and March 2023. Several types of data were collected: 23 interviews were conducted with gold miners, members of the local population, and local authorities with a link to ASGM activity, including customary authorities, administrative authorities (notably the mayor's office and the prefecture) and local government representatives. These interviews enabled us to collect data on local mining governance and working relationships between the various stakeholders involved.

Moreover, during our extended five-month stay on-site, we systematically gathered ongoing and consistent observations of operational procedures, encompassing techniques, work organization, and relationships. Additionally, we documented informal day-to-day discussions to provide a comprehensive overview of the dynamics at play in the local context.

2.1. Long-term artisanal gold mining

The sub-prefecture of Kintinian and the surrounding villages

correspond to the location of the ancient Bouré region, where according to our interviews, Balato was the first village to be founded. For this reason, the area is commonly referred to as “Bouré-Balato”. The history of this region is deeply intertwined with gold mining, which constitutes an important part of the local identity. ASGM remains the main activity of the inhabitants, and agriculture is underdeveloped, with the exception of cashew plantations, which tend to expand.

Notably, the renown of this region for its gold wealth dates back to the 3rd century, under the Soninké empire (Watts, 2010). The Bouré area has been mined almost continuously since the 12th century, playing a significant role in the political and economic history of medieval West African empires (Mbodj, 2011). In 1892, fell under the French Protectorate, displacing Samory Touré, partially facilitated by the “customary law” agreement related to gold mining (D'avignon, 2018). Throughout the interwar period, gold production experienced a significant surge, contributing to 29% of Guinean exports (Trentadue, 1976). Despite endeavours to industrialize gold mining, it remained artisanal in nature until the post-independence period (D'avignon, 2018), marked from the 1990s onwards by the growing establishment of industrial mining companies such as SAG, Société Aurifère de Guinée.

Prior to the intensification of artisanal activity in the early 2000s, gold mining operated on a primarily seasonal basis, synchronized with the agricultural calendar and taking place during the dry season (Bolay, 2016; Dessertine, 2016) Only women could extend their stay on site for a few extra months, allowing them to support their families during difficult periods (Luning et al., 2014). This seasonal farming system not only attracted agricultural labor from surrounding regions (Bolay, 2016), but also played a role in safeguarding local mineral resources from swift depletion. At this time, gold mining was conducted on a relatively modest scale, focusing on shallow secondary alluvial deposits.

It seems important, at this stage of the site description, to insist on the fact that most of the ASGM activity is carried out in alluvial deposits. Two distinct types of exploitation can be found: either in massive metamorphic rock (birimian green rock), or in less consolidated alluvial deposits (Sangaré et al., 2014). In the case of the massive metamorphic rock deposits, it is necessary to follow lodes with high gold grades. In this case, the rocky ore must be reduced in size using primary crushers, then finely crushed to separate the native gold from the attle. This requires human expertise (observation skills and experience) to follow the lode, eventually underground. This mining process usually involves the use of explosives, or sharp and strong steel tools which are not cheap; It is human energy intensive first to sink the shafts, then to follow the lodes and extract the rock containing the native gold. In the Balato area, this mining process using explosives is not used. The second type of exploitation concerns weakly consolidated alluvial deposits, or secondary deposits. Concerning these deposits, from a mining process point of view, one can make a separation between surface exploitation, and underground exploitation. Concerning surface exploitation, ASGM does not require deep excavation. In the surface deposits, mechanization can be present quite often with mechanical shovels and trucks to recover material from alluvial strata (particularly on sites already mined manually) to supply the crushers. The gold content is not very high, so processing a large quantity would allow a gain. The use of metal detectors is generally attached to surface deposits. The metal detectors are not used for the gold extraction over 1,5 m depth. If the alluvial deposits are found at depths of around 10 m deep, an underground exploitation can be performed to avoid the cost and pain to take away the overburden, *i.e.* the surface level that can be considered as a waste product, above the level with a high enough gold grade. When the sediments have been removed, the mineralized layer can be recognized by experienced miners, the *kaladjantis*, and a drift can be opened. This type of mining requires a much more complex organization than open-pit mining.

2.2. Local spatial effects of a local activity

In Balato, as in other localities in the region, ASGM is a local activity.

As shown in Fig. 1, lode mining (pits), surface mining (using shovels and detectors) and washing sites (ore processing) mainly follow the eastern flank of the settlements, and are more marginally located a little further south.

The map also indicates that the Balato district is home to the SAG (Société Aurifère de Guinée) housing estate, where some of the employees of the industrial mine operating in the vicinity of the locality are housed, and from which we can make out some of the retention basins to the west of the dwellings. The important presence of this mining company will not be considered within this work, although it should be noted that it increases the pressure on gold resources, accelerates the rhythm of its extractions and regularly gives rise to sometimes violent conflicts with gold miners and local populations, already discussed in other works (Dessertine and Noûs, 2021; Dessertine, 2019; Bolay, 2014). We will focus here on so-called informal or clandestine ASGM, sometimes tolerated by the authorities, other times severely repressed, as was the case during major eviction missions carried out by state authorities between 2015 and 2016.

As in many other areas, ASGM has significantly influenced the demographic growth of Balato, with the local population estimated at 30,000 inhabitants⁴ in 2020 according to the president of the district office. Despite this demographic surge, Balato's organization still adheres to principles commonly observed in rural Malinké villages. The Malinké constitute the primary population in this region, ranking among the three largest ethnic groups in Guinea, alongside the Peul and Sous-sous. From this perspective, what is occurring is more accurately described as rural spatial expansion rather than conventional urbanization.

The locality is under the local authority of the Camara family, considered as the founding lineage of the locality, as the first arrivals. Over the years, they have authorized the installation of newcomers, the first of whom head four *kabilas*, a term sometimes translated as "neighborhood", and sometimes as "clan". Certain rights are delegated to these *kabilas*, notably in the land domain: a new arrival will therefore first go before the head of the *kabila* to apply for land under his or her (customary) jurisdiction; only in the last instance will a dispute require the intervention of the village chief, a member of the founding Camara family. The chiefs of these *kabilas* and the village chief are the eldest men in their lineage and, along with the chiefs of the various residences, make up the council of elders. The council also includes women and youth representatives, headed by a president and a chairman respectively. These collectives form the backbone of local customary governance in rural areas and, in the mining context, are accompanied by another institution: the *tomboloma*.

2.3. Local customary mining governance

The historical practice of ASGM in Bouré is characterized by the exploitation of secondary deposits, i.e. shallow alluvial and eluvial deposits, where gold is found in the form of nuggets or flakes within the gravel. With a degree of autonomy that allows them to organize themselves into groups, artisanal miners generally work in mixed teams of between 5 and 15 people, made up of both men and women, within the boundaries of a specific area known locally as *bè*.⁵ Extraction is strictly organized and regulated by local norms, with designated areas for digging, where each shaft is allocated to a group, and the surrounding area is reserved for related activities such as ore washing, and trading.

The operation is being carried out in two phases. The first involves removing the layer of overburden, a layer of less consolidated sediment

some 7–12 m thick above the mineralized gravel, with eventual support of the shaft, in mechanically weak zones. This support, made of timber, leads to the exploitation of forest wood. A team of four diggers, assisted by a *nyado*, use small picks to dig, while the sterile earth is brought up in buckets by women. The *nyado*, chosen by the *tomboloma* from the elders' organization, pays the price of the shaft to the *tomboloma* and, depending on his means, provides financial support to the diggers. The second phase involves extracting the mineralized gravel, which varies in thickness from 0.5 to 0.8 m on average, and rarely exceeds 1.5 m, requiring special expertise. It needs to be able to follow underground, with poor lighting, and based on observation and experience, the layers, or veins, most likely to have a high gold grade. The sedimentary ore is then to be extracted from the underground rich vein or layer, transported back to the shaft, then up to the surface, using *solonins* – a type of pulley. This operation is therefore carried out by a specialized member of the team, called a *kaladjanti*, the most experienced of the initial digging team. During the operation, water may drown the shafts or it may need to be ventilated. In such cases, the miners call on service providers, such as the owners of motor pumps, *fans* and so on. Their presence on the site is regulated by the *tomboloma*, to which they pay a contribution.

The site remains under the customary jurisdiction of the village to which it belongs. It is reconfigured according to the mobility of gold miners, both nationals and those from neighboring countries. This mode of exploitation is also characterized by seasonal mobility, but this intensified and expanded alongside the increase in gold prices in the 2000s, giving rise to forms of professionalization of the activity (Bolay, 2016; Dessertine, 2016). Historically, therefore, the *bè* model has prevailed, whose regulatory principles make it possible to guarantee both activity and open access to the resource, while the reliance on centralized regulation, combined with informal fiscal mechanisms applied to each transaction, makes it possible to promote collective investments at the village level (Lanzano and Arnaldi di Balme, 2017), such as the construction of boreholes, the supply of electricity through generators.

ASGM, as practiced in the Bouré region, is not governed by state legislation, but by a system of governance established and controlled by customary authorities. The *damanfèti* or "mine chief" supported by the organization of elders, plays a role in designating mining sites, setting the mining schedule, and drawing up the principles regulating the activity. The institution of the *tomboloma*, sometimes associated with self-defense groups (Grätz, 2007), puts into practice the principles laid down by the *damanfèti* and the elders. Panella (2007) explains that before mining intensified in the 1980s, their main role was to protect the village from thieves. Over time, their responsibilities have expanded. On the instructions of the village, the *tomboloma* draws the boundaries of the *bè*, marks the points where the holes will be dug, and draws up a site development plan (Lanzano et al., 2017). They act as true corporations, regulating, mediating, and sanctioning all matters related to gold extraction and life in the camps. The *tomboloma* hold regular assemblies and impose penalties for violations of village laws, including theft and murder, often in collaboration with the security and defense forces on site (Dessertine and Noûs, 2021). One of their most challenging tasks is preventing miners from tunneling horizontally into other mine shafts to avoid cave-ins. This regulation requires them to be experienced miners who can intervene in critical situations. Fig. 2 details and characterizes the customary relationships between stakeholders, including the new relationships resulting from the introduction of small mechanized tools, in particular the *solonin*, *fan* motor, and motor pump, which we will describe in the following section. These include the gold panners, the village chief and the *tomboloma*, but also the *kaladjanti* or "chief of the long pickaxe", who is the most experienced miner in the working group, and the *nyado*, the "owner of the well".

The diagram in Fig. 2 shows that in the case of these small mechanized tools, the central institution remains the *tomboloma*. This can be explained by the fact that these tools complement, but do not completely replace, artisanal extraction techniques. We will now explore additional innovations that have facilitated the emergence of new practices, while

⁴ We were unable to obtain an estimate of the number of gold miners.

⁵ There is no literal translation for this term in French. However, we choose to translate it as "activity space", as this term can also be used in an agricultural context to refer to a cultivated portion. Contrary to agricultural usage, in the ASGM context, *bè* represents both the physical space and its mode of operation.

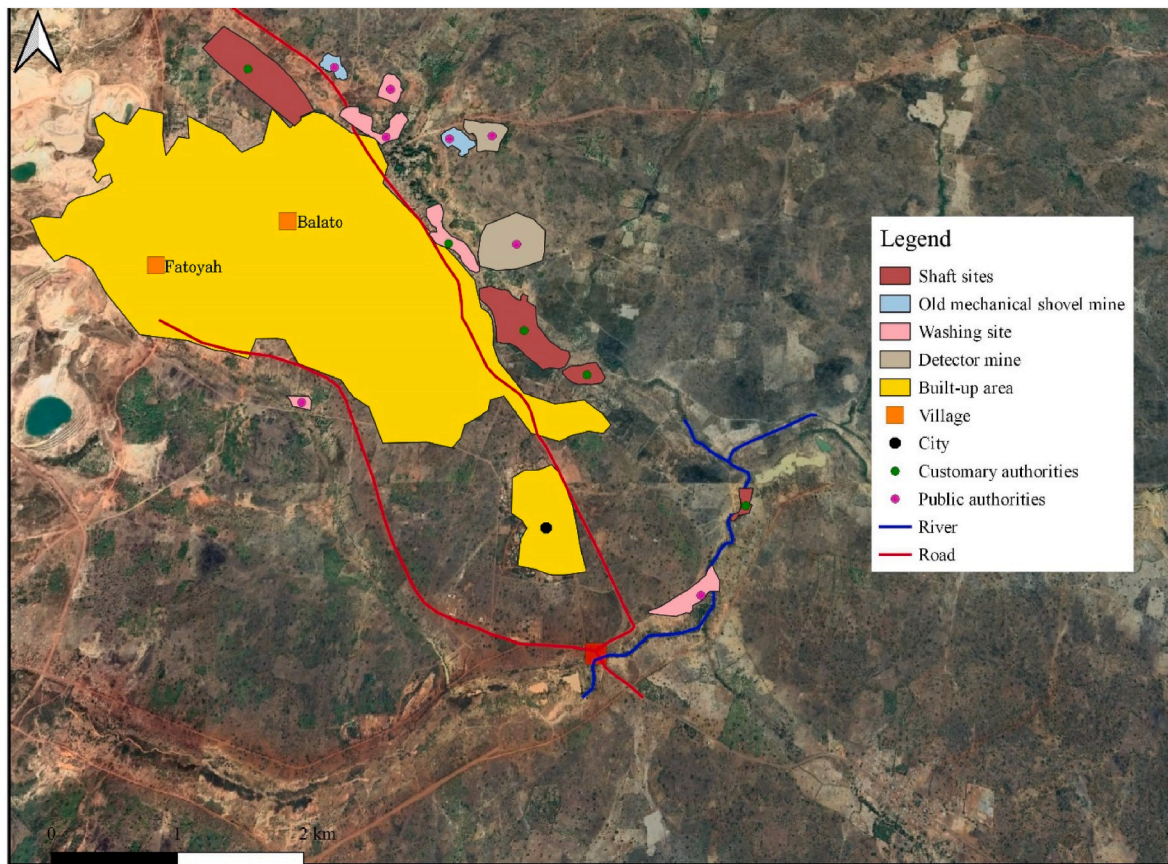


Fig. 1. Presentation of the study area and various activities.

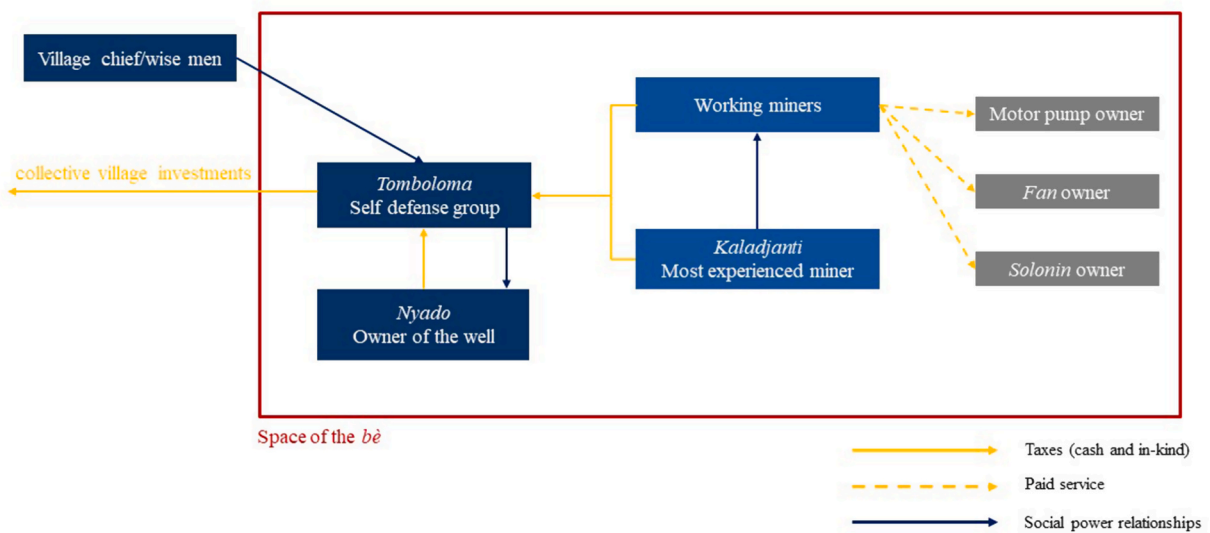


Fig. 2. Sociotechnical dynamics of ASGM in a mechanized context before 2019.

highlighting that these may not be the ones responsible for the most profound changes.

3. Minor technical innovations, major socio-economic reconfigurations

Since the mid-2000s, the Kintinian sub-prefecture has seen the arrival of a series of technical innovations of varying scope (Fig. 3). These innovations need to be integrated into two different, but not necessarily exclusive, forms of mining. The first is lode mining, in which innovations complement more artisanal techniques: motor-driven pumps are used to empty water from shafts, *solonins* make work easier, and *fan* motors ventilate the interior of galleries. Metal detectors can also be used for prospecting inside shafts. But they are mainly used as a surface prospecting and mining tools. This is the second type of mining that is currently being developed. This is demonstrated by the increasingly massive introduction of crushers, which allow large volumes of soil to be processed. This surface mining is outside the space jurisdiction of the *tomboloma*, the *bè*, and gives new stakeholders the opportunity to control access to and management of the resource and, ultimately, to profit from the mining rent. This section describes the gradual and conflicting emergence of new stakeholders in the governance of mechanized methods, particularly deconcentrated government services and customary landowners, and how they sometimes compete with the *tomboloma*. The development of mechanized ASGM has indeed led to a repositioning of public authorities in the local governance of an illegal activity. We show that, while this activity was stimulated by the introduction of large-scale machines such as mechanical shovels and trucks, it is in fact via the smallest tools that it has been perpetuated. We distinguish three technical circuits to analyze the changing positioning of local authorities and their competition for mining rents. These circuits concern firstly crushers (Fig. 4), excavators and trucks (3.1), then metal detectors (3.2) and finally small tools such as *fan* motors and *solonins* (3.3). We will show that, while these last minor innovations tend to fit into the *bè* model, the same cannot be said for crushers and metal detectors. These two techniques will be treated separately because they do not challenge the *bè* model in the same way. While detectors are associated with a high degree of mobility, which prevents *tombolomas* from carrying out in situ taxation, crushers are deployed in areas that are either abandoned or not yet exploited, and from which other actors try to impose their own rules of informal mining taxation. The aim here is to analyze the resulting tensions and competition around this new mining rent.

3.1. The conflicting disappearance of excavators and trucks and the persistence of crushers

The introduction of mechanical shovels, crushers and trucks is part of a wider chain of production associated with the intensification of surface mining, paving the way for the development of small informal open-pit mines. This mechanized surface mining allows the processing of large quantities of soil extracted from the surface layers. It is carried out outside the spaces of *bè* and the jurisdiction of *tomboloma*.



Fig. 4. crusher.

These operations are mainly located in old, abandoned artisanal mines where the skills of the *tombolomas* are no longer applicable, making them accessible to all. This element is fundamental, since control is increasingly being taken over by the district office and the customary landowners, who have seen this as an opportunity to position themselves and profit from the mining rent. These new mining methods – in particular excavators and trucks – required considerable investment, amounting to several thousand euros, a sum that gold miners generally could not afford. They are not part of the knowledge and know-how that circulates between gold miners in times of transnational mobility, as is the case, for example, with Burkinabe well mining techniques (Lanzano and Arnaldi di Balme, 2017). They were rather driven by the adjacent presence of the Société Aurifère de Guinée (SAG). In Balato, investors – sometimes employees of the mining company, but also civil servants or well-connected gold buyers – began leasing mechanical shovels for sums ranging from 5 to 6 million GNF per day, and looking for the most profitable sites. At the time of our survey, the excavators and trucks were already gone – we'll come back to this below – so the figures we were given are subject to some reservation. According to our sources, taxation amounted to 200,000 GNF/day for the site's landowner and 200,000 GNF/day for the district office. The trucks, now under the ownership of investors, went directly to the crusher or shovel sites to buy the ore during loading (Fig. 4). In Balato, the value of the truck's cargo varied between 800,000 and 1,200,000 GNF per load, contingent on the estimated ore grade, and the type of truck, whether it was a "6 or 10-wheeler". Only the district office taxed the use of these machines, charging 50,000 GNF per day.

Thus, a genuine local mining governance parallel to the customary one was put in place following the introduction of these innovations. However, their spread was quickly curtailed a few months after their introduction in 2019. Primarily, due to the fact that they are not only expensive, but also particularly visible, prompting state authorities to

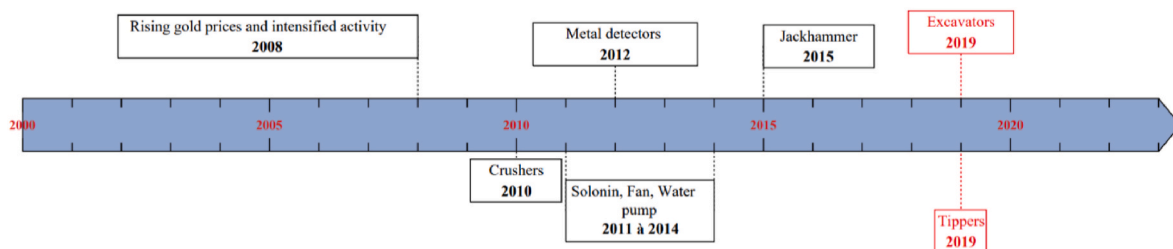


Fig. 3. Timeline of technical innovations (in red, major technical innovations; in black, minor technical innovations). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

ban them more radically. Conversely, informal activities that are not capital-intensive, perceived as subsistence activities and whose exploitation does not compete with the limits of deeper or broader (semi-) industrial exploitation, are more easily tolerated by the authorities. Furthermore, in Balato in particular, these new taxation channels have led to major conflicts between local players, with the district office increasingly gaining access to the biggest slice of the mining rent cake. Following recurrent conflicts, the council of elders and customary authorities decided to ban the use of big machines, such as excavators and trucks.

However, this form of parallel governance did not end with the disappearance of these machines, since it did not call into question the functioning of the surface mining chain. It does have an impact on the amount of soil processed, but the continued presence of crushers is all that's needed for this type of operation to continue.

3.2. The case of metal detectors: the reconfiguration of local powers under strain

Since the 2010s, as in the rest of West Africa and Guinea, the arrival of metal detectors has made it possible to mine gold at relatively shallow depths, ranging from a few centimeters to 2 m (Fig. 5).

This technique involves significant mobility on the part of gold seekers, who frequently travel long distances in search of richer deposits (Dessertine, 2016). Unlike mining in the *bè*, these new methods do not require extended spatial fixation, thereby avoiding the oversight of the *tomboloma* in selecting locations. While mining in the *bè* can last for several weeks or months, gold miners using detectors can cover multiple sites in a single day. Due to their frequent movements between sites and villages, customary authorities find it impossible to exert control over these gold miners. Numerous testimonies also suggest that the *tomboloma*'s historical skills were intricately linked to the organization of the *bè*, and have been surpassed by the advent of this new technique. This shift has paved the way for other entities, notably the youth organization⁶ and the district office, to position themselves in local mining governance.

The youth office is tasked with field collection, operating under the



Fig. 5. Gold prospectors testing the surface the ore with the detector, 2022. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

⁶ As in other West African contexts, this institution plays a leading role in various areas of daily and ceremonial life.

supervision of the commune, to which it reports after completion. With the introduction of metal detectors granting new authority, the district office, in cooperation with the youth office, has initiated the imposition of taxes on crushers and metal detectors. Funds from these collections have enabled the construction of a number of public infrastructures in the village, including schools, a guest house and the headquarters of the sub-prefecture. Mechanization has thus led to a repositioning of public authorities at local level, where they had previously had little or no involvement.

However, after the period of massive influx of metal detectors, which began in 2012 and continued until around 2015, combined with the disappearance of the use of mechanical shovels, the district office's sources of funding dwindled. Only the crushers, now installed just about everywhere, remain in operation. Meanwhile, the wells in the *bè* continue to attract gold seekers. In fact, Balato remains one of the few sites we visited in the Bouré area to which artisanal gold miners still come, despite the scarcity of gold in recent years.

In the following section, we discuss how this involvement of local authorities in the governance of ASGM appears to be a step towards total control of the sector by local public authorities.

3.3. The case of other small tools (*fan motors and solonins*): setting up specific commissions to transform practices

Since 2010, small tools have been introduced to improve productivity. For example, to overcome the challenges posed by the lack of oxygen at great depths, miners have introduced *fan* motors combined with small *tigers* to provide better ventilation. The use of semi-mechanized crushers made it possible to process not only gravel blocks that could not be processed manually, but also large volumes of low-grade gold ore. To raise the ore, a pulley known locally as a *solonin* was also introduced to facilitate extraction. Finally, downtown crushing plants were set up to reduce the hard rock to a fine powder, which is then washed to recover the precious ore.

Following the decline in the use of the more imposing equipment, the district office expressed its desire to also take over tax collection in the *bè*, accusing the *tomboloma* of embezzlement. This accusation is to be taken seriously, as gold mining revenues destined for this institution are supposed to serve the common interest (Lanzano and Di Balme, 2017). A conflict then broke out within the village. Initially, the customary authorities did not support the district office. However, its members eventually managed to convince the council of elders by highlighting the small tools used in the *bè*, such as the *solonin* and *fan* motor (Fig. 6). With the support of the wise men, other members joined the board. Subsequently, commissions were formed to collect taxes according to the tools used. Thus, there is a commission dedicated to *solonins*, a commission for *fan* engines, a commission for motor pumps and a commission for crushers.

The intervention of the district office in the *bè* led to adjustments in the organization of work. On the one hand, diggers have lost the freedom to choose their *solonins*, motorized pumps and *fan motors* for their wells, and the owners of these tools have also faced tax increases. In this new configuration, when a new *bè* is opened, the *tomboloma* proceeds with the distribution of wells as before. When the diggers start digging, the owners of *solonins*, *fans* and motor pumps register with the district office, whose members then pass through the *bè* to allocate a *solonins* and *fan motors* to each new well. At the time of the survey, the tax paid by each owner was set at 70,000 GNF. A motor pump is also allocated to each well to extract water, and the well owner was then required to pay 150,000 GNF to the district office.

This growing involvement of the district office in local taxation has weakened the *tomboloma*. Its members have had no option but to rely on money from quotas imposed following conflicts and the weekly road-blocks they erect for women and street vendors.

By controlling tax collection in the *bè* at the expense of the *tombolomas*, the governance of ASGM has undergone a reconfiguration,



Fig. 6. a) Solonin and b) fan.

shifting some of the *tombolomas*' prerogatives to the district office. The *tombolomas*' loss of power, and the district office's decisions to increase its workforce and take over the distribution of *solonins*, *fans* and motorized pumps, are having an impact on the way gold miners choose their working methods (Fig. 7).

The introduction of new technologies is therefore deeply embedded in the sociotechnical contexts. They occur through incremental changes by a series of small challenges to what is accepted as true, correct, just and legitimate as Carvalho et al. (2017) discussed, innovation is a social interactive learning process which is the result of a social construct that interacts with environmental institutions and processes, creating new currents of thought based on environmental pressures. The sustainability of this small innovations in the production chain depends on their capacity to cope with pre-existing sociotechnical conditions and to foster stable sociotechnical reconfigurations. We can suppose that these new technologies are progressively institutionalized, through mechanisms of diffusion among the ASM communities, the local context is crucial to the

extent to which practices are institutionalized by actors who agree to adhere to them, conform to standards and follow rules, more or less passively, without questioning them. Further long-term research work is needed to document and analyze these institutional dynamics at work, in order to better explain how institutions, play a role in dynamic developments, rather than explaining inertia and stability (Geels, 2004).

4. Discussion

ASGM is generally associated with the use of simple techniques and an abundant but unskilled workforce (Hilson, 2009). It has long been associated with a largely unmechanized activity, requiring modest investment and focusing on the exploitation of primary or secondary deposits with a high level of risk (Shen and Gunson, 2006; Hilson, 2002) Its definition must also take into account its legal or illegal, formal or informal status (D'avignon, 2018). According to the 2011 Guinean Mining Code, amended in 2013, ASGM is defined as "any operation

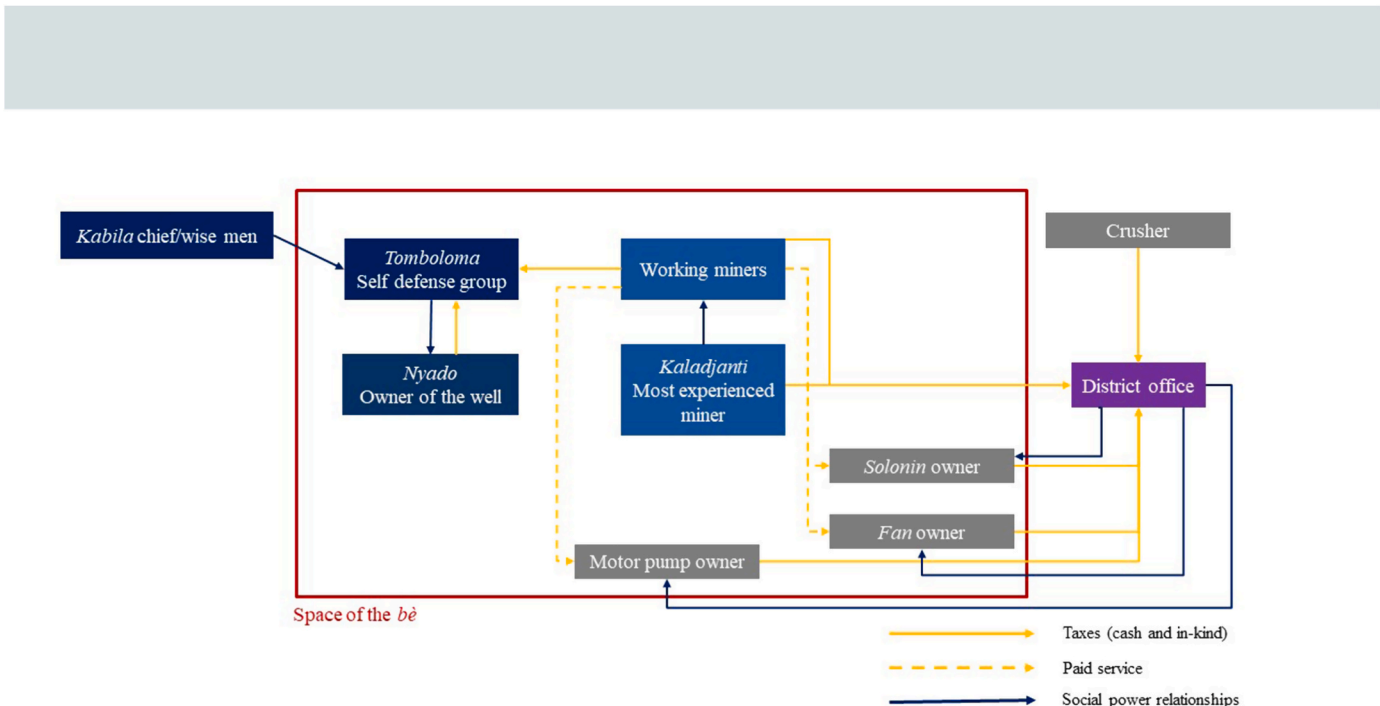


Fig. 7. Sociotechnical dynamics of ASGM in a mechanized context after 2019.

whose activities consist of extracting and concentrating mineral substances and recovering marketable products by *manual and traditional methods and processes*. This single artisanal characterization seems to be becoming obsolete in light of the increase in mechanized techniques. To what kind of trajectory does this mechanization refer? On what principles is it based? How does it transform the relationship to work and to the land?

4.1. Accumulation or substitution of small technical innovations?

Although gold extraction and processing practices are becoming increasingly mechanized, we do not consider that Balato has entered into a technical transition process as such. Indeed, for transition to occur, there must be a process of substitution (not necessarily linear or unilateral) (Geels and Kemp, 2007). In our view, the current technical progression of artisanal ASGM on the site in question is the result of an accumulation of small innovations, rather than a radical technical substitution.

Since the introduction of the first technical innovations around 2010, we have seen a cumulative process whereby new mechanized tools are constantly being integrated into the previous artisanal system. These tools are now more widely integrated into the gold mining chain, with crushing, for example, reducing lode rock to powder more quickly than by hand, and sensors speeding up lode prospecting. It's not uncommon these days to see gold miners going down into shafts with a detector to identify the presence of a lode, rather than just doing a surface search. Mechanized tools thus complement the artisanal technical system, without calling it into question, but rather improving its productivity: mining can be carried out at greater depths or over larger areas, the work is less tiring, the "waste" from artisanal mining becomes a potential resource thanks to cyanidation, and so on. In addition to enabling technical improvements, the most widely used tools are simple to use and therefore relatively accessible.

However, while some of these new techniques represent a technical improvement also in surface mining (and so differ in this respect from industrial mining), they require greater investment than artisanal mining alone. Whether we're talking about the use of small machines or larger-scale machinery, the acquisition of such equipment requires investments often estimated at several thousand dollars. This capital intensification poses several limitations.

Firstly, it leads to the emergence of new players and encourages the development of more asymmetrical power relations between investors and the workforce. This process has already been partly analyzed in Guinea (Dessertine et al., 2023), but also in other contexts where mechanized ASGM induces increasingly more capital (Verbrugge, 2014). In our case, we can distinguish at least three types of investment, depending on the tools used. The shovels and other expensive equipment used at Balato were mostly owned by foreigners - mainly Indians and Chinese - and then rented by senior officials or gold buyers. This chain, informally managed by the prefecture, led in part to the conviction of the former prefect and the prefectural director of mines for environmental degradation in 2022.⁷ The commune has since regained control, although the use of shovels has not become widespread in favor of more accessible tools. In the case of crushers and detectors, which are much less expensive, middle-level officials and even villagers have managed to invest and enter the mining circuit. This was the case, for example, of a woman we met in 2013 from a village near Kankan who had sold some of

⁷ <https://mosaiqueguinee.com/2022/12/sigui-ancien-prefet-et-lex-dire-cteur-condamnes-par-le-tribunal-de-premiere-instance/>.

her livestock to buy a few dozen detectors.⁸ Finally, *fan* motors and *solonins* are much more affordable (250–350,000 GNF), allowing gold miners to invest for themselves.

Secondly, in this context, this increase in capital does not appear to be a driving force for formalization. In fact, investment relies upon occasional informal financing, notably from civil servants based in large towns who, by virtue of their status, are not in principle authorized to apply for legal permits, or from landowners who oblige workers to sell back the gold obtained at the end of the week.

Under these conditions, the prospect of a linear transition to formalized activities seems highly unlikely (Banchirigah, 2008). On the contrary, informality persists through the involvement of new players who profit from ASGM revenues and have no interest in seeing the activity come to an end (Van Bockstael, 2014).

4.2. Reconfiguration of local authorities

In Guinea, local governance is characterized by a complex interplay between customary and public authorities (Rey, 2016). On one hand, customary powers, rooted in ancestral practices, wield significant influence over the daily life of communities, especially regarding matters such as access to land, natural resources and conflict resolution (Rey, 2016). They are also sometimes consulted in decision-making by public authorities, as witnessed through the dispute between the *tomboloma* and the district office in the management of the *bè*. On the other hand, despite being initiated by the central government, decentralization is not without its challenges. Decentralized power is frequently marginalized by the central state, particularly concerning subsidies, and encounters difficulty integrating into territories where it needs to coexist with customary authorities. This results in decentralized structures being less representative of communities, further emphasizing the dominance of customary powers at the local level.

However, the evolution of ASGM towards mechanized extraction and processing methods has transformed power dynamics at the local level. The introduction of metal detectors, mechanical shovels, crushers, and other technologies has facilitated the rise of the district office in the governance of ASGM. Unlike artisanal ASGM in the *bè*, which requires spatial fixation, the use of detectors by gold miners increases their mobility, making them difficult for customary authorities to control. The public authorities saw these changes as an opportunity to regulate this new form of ASGM, leading to a reconfiguration of local powers. This involvement has continued right through to the control of tax collection in the *bè*.

4.3. When land creates a direct access to mining rents

As in other regions of West Africa, land tenure practices in Guinea evolve within a pluralism of land tenure systems (Dessertine and Noël, 2021; Dessertine, 2019; Rey, 2011). In rural areas of Upper Guinea, customary land tenure is mainly applied at the expense of national land ownership law. This type of tenure is characterized by "tutorship" relationships that enable land use to be transferred from the representative of the founding lineage to a newcomer, placing the latter in an asymmetrical power relationship (Dessertine, 2017). In this context, land ownership is centralized at village level (Benkalha et al., 2016), even though the management of its use may be delegated to neighborhood/s/clans (*kabila* in the Maninka language). Nevertheless, the distinction between land ownership and use tends to fade in common practice, as land users are seen as managers of the land granted to them. In other

⁸ Women can be involved in investment, particularly because in this Malinké region, when a woman marries, her dowry consists of oxen and cows (the number of which varies according to the customs of the villages in the region), allowing her to build up a small herd that can be sold for different purposes and at different times in her life.

words, in everyday use, it is accepted that there are several customary landowners and the land authority of the village lineage is rarely mobilized. This same centralized logic can be found in historical artisanal mining areas, but around the institution of the *tomboloma*: the customary landowner of a piece of land can delegate the right to use and administer it in return for remuneration.

The transition to mechanized mining has led to a fragmentation of mining governance, with observable shifts favoring public entities like the district office in the taxation of mechanized ASGM, often to the detriment of the customary authority of the *tomboloma*. Concurrently, customary landowners have seized opportunities arising from the altered power dynamics. They are now playing an increasingly influential role in governing mining activities on their land by directly imposing taxes on machines operating within their territories. Some of these landowners directly finance and install mechanized ASGM operations on their land, in return for which the miners are obliged to sell the gold back to them, often for less than the market price. Locally known as *djati*, they are increasingly taking a central role in local mining governance.

This rise in power can be seen in their negotiating power with the authorities. During our fieldwork, Burkinabé gold miners,⁹ who had been financed and installed by a *djati* on his plantation, were arrested. It was the *djati* himself who came to negotiate with the authorities to release the workers, which they did, in return for an undisclosed sum.

Customary land ownership is thus becoming an increasingly privileged means of accessing directly to mining rents, helping to fragment local mining governance that was previously centralized at village level. However, the institution of the *tomboloma* has not completely disappeared. Rather, it has been reconfigured at neighborhood/clan or *kabila* level. In Balato, the founding lineage delegated land management to the village's four *kabilas*. Faced with the intensification of logging, each *kabila* decided to form its own *tomboloma* to organize logging on its own estate. The growing importance of land issues in local and customary mining governance is also reflected in the increasing number of *damanfeti* ("mine chiefs"). Each lineage also chooses its own group of *damanfeti*. Local mining governance thus seems to be following two trends that testify to a process of territorialization: on the one hand, the fragmentation of local customary institutions at the *kabila* or neighborhood level, and on the other, the emergence of the district level, an administrative level that in a way supplants the village level.

Mechanization of ASGM thus reinforces "hybrid" modes of land management in rural areas (Dessertine and Noûs, 2021), where the boundary between formal and informal on the one hand and propertisation and formalization on the other is particularly blurred. We describe here a form of propertisation without state formalization, in an informal context. These more or less silent evolutions at work in the Balato district of Upper Guinea, presage more profound transformations of the artisanal mining system. Indeed, for Saldarriaga-Isaza et al. (2013) ASGM can be considered as a common pool resource, ie. as a system where the extraction of resource units by one user subtracts from the quantity of the resource potentially available to others. To a certain extent, this mode of organization is mainly due to the non-ownership inherent in illegality and non-formalization: when the extraction is illegal, the resource is under "open access," and almost anybody can dig up gold. But, "hybrid" modes of land management in auriferous rural areas challenge this ASGM definition. Our conclusions suggest that we should observe the transformations at work in the ASGM not from the

governmental and institutional point of view of formalization and legalization, but from the point of view of the gold miners themselves, and the way they construct and negotiate the gradual transformation of their practices (Fisher et al., 2023). These "hybrid" modes of land management are the pathways constructed by gold miners coping with inappropriate national mining laws, by recomposing resource frontiers (Fisher et al., 2021). In other words, our article demonstrates how mechanization contributes to the evolution of "gold lifeways" as described by Fisher et al. (2023), encompassing how gold and its extraction are embodied in lived experience intertwining matter, social organization, land tenure and technological choices. It gives expression to different strands of ASGM evolution toward formalization.

5. Conclusion

In this study, our aim was to document and analyze the social, economic and political changes brought about by artisanal and small-scale gold mining in Upper Guinea, particularly after the introduction of small-scale mechanized technical innovations.

Scholars discussing sociotechnical transitions commonly argue that they occur through substitution (Berkers and Geels, 2011; Geels, 2006). The ongoing trend in mechanization we documented in this article exemplifies transformations arising from a cumulative adoption of small-scale mechanized tools, rather than a radical technological substitution.

This conclusion must be put in perspective with the incidence of the temporal frame of reference on the studying of socio-technical trajectories. The nearly day-by-day documentation of evolutionary trajectories, led on a short period (one year) undoubtedly amplifies the attention paid to the accumulative processes. A more macroscopic analysis, on the scale of decades for example, would no doubt tend to erase these accumulations, highlighting only the major innovations. As a result, if this ongoing accumulation of small innovations makes it difficult to draw definitive conclusions about the sociotechnical trajectories of ASGM in Upper Guinea, it does, however, highlight trends that deserve the attention of research and public authorities. We have highlighted how this minor, "low-key" mechanization of artisanal gold mining has led to a competition between customary authorities and public institutions to capture rent. The current state of our research consolidates our hypothesis that this competition can lead to a partial reconfiguration of power at the local level. Although the *tomboloma*, which no longer represents the village as a whole but rather family or clan entities, may continue to play a key role in conflict management and the delimitation of the *bè*. But, the ongoing loss of control over the tax levy, now managed by the public authorities, may contribute to a redistribution of power. If finally adopted locally, this transfer of tax prerogatives from customary authorities to public bodies may foster a change in the way mining rents are managed, in a context where public entities are struggling to integrate into a rural environment which is still largely dominated by customary powers.

Finally, our conclusion questions the relevant spatial scale and boundary for the observation of socioecological evolution. The study of socio-technical developments often invites us to go beyond the boundaries, as they often transcend administrative boundaries such as the *bè*, the village, the region, or even the country. For instance, we have thus observed that technical accumulation is not limited to the *bè* model and is even associated with the overcoming of its spatial and jurisdictional limits. What's more, it is accompanied by a complex articulation and interdependence between mechanized techniques based on circuits inspired by those of the industrial sector and those of immigrant gold miners. Moreover, the mechanization of ASGM may transform relationship to space: in a rural environment dominated by tutelage relations and a topocentric conception of space (Dessertine, 2021), the intensification of subsoil mining places the focus on the materiality of the land and its subsoil, transforming it into a direct access to mining rents. As a result, customary landowners may increasingly favor

⁹ We specify their nationality because it is not insignificant here. The Burkinabé are often described by Guinean populations as the most professional gold miners, the ones who import knowledge and know-how (Lanzano and Di Balme, 2017), and are also often the ones particularly targeted by eviction operations. The fact that they were taken prisoner here is therefore also partly explained by their precarious position as foreigners and those responsible for disseminating the activity.

privatization practices, including informal ones, through increasingly precise delimitations and direct taxation of machines operating on their land.

CRedit authorship contribution statement

Ibrahima Kalil Doumbouya: Writing – original draft, Methodology, Investigation, Formal analysis. **Anna Dessertine:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization. **Marc Vinches:** Supervision. **Juliette Cerceau:** Writing – review & editing, Writing – original draft, Supervision, Formal analysis, Conceptualization.

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Data availability

No data was used for the research described in the article.

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