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Understanding small-scale gold mining practices: An anthropological study on technological innovation in the Vale do Rio Peixoto (Mato Grosso, Brazil)

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A B S T R A C T

Artisanal and small-scale gold mining in the Amazonian countries has undergone important technological improvements in recent decades. Nevertheless, this type of mining is largely associated with the use of rudimentary, low-tech and often manual methods, with inefficient gold recovery. This article aims at investigating how innovations and improvements in the technology used in small-scale gold mines are connected to a broader perception of the miners about the integration of more modern and effective techniques. A technographical approach enabled the understanding of mining practices as embodied cultural knowledge and to fill the information gap between the study of materials and techniques with the study of people and communities. We discuss how the technology of small-scale gold mining in the region of Peixoto de Azevedo (Mato Grosso, Brazil) has changed since the early 1980s, giving particular attention to the recent introduction of two main innovations: the mechanized exploration drill and the cyanidation process. In this region, miners are successfully organized in cooperatives efforts to mutually reinforce the integration of innovative and effective techniques. Finally, we introduce the three notions of foresight (*visão*), agility (*agilidade*) and development (*desenvolvimento*) that emerged during fieldwork and conceptually frame the likeliness of acceptance and promulgation of innovations in this context. Sustainable mining may only succeed if a wider vision of the future of the sector (foresight) joins public policies that facilitate the practical process of innovation during each phase of its realization (agility) in order to achieve an advanced social status of the local community (development).

1. Introduction

Artisanal and small-scale gold mining (ASGM) in the Amazonian countries has undergone important technological improvements in recent decades. Nevertheless, this type of mining is largely associated with the use of rudimentary, low-tech and often manual methods, and inefficient gold recovery (Hilson and Van Der Vorst, 2002; Veiga et al., 2014a). Small-scale gold mining in the Brazilian Amazon region has been discussed in a vast literature since the 1980s (Cleary, 1990; Hemming, 1978; Schmink and Wood, 2010). Like elsewhere, the majority of the studies focus on the legal, social, political, health and environmental aspects of mining (Hilson, 2002; Hinton et al., 2003; Sousa et al., 2010, 2011a, b; Urkidi, 2010). The technology of the extractive activity is not the main topic of attention in popular and academic literature, notwithstanding some important exceptions (Teschner et al., 2017). In this article we start from the premise that the study of technological and organizational features of small-scale gold mining is essential in improving the activity in terms of efficiency in gold recovery and lowering the negative impacts on the health of the population that are directly and indirectly involved, as well as on the natural environment where mining takes place. The technological and organizational characteristics of the mining process correspond closely to its material surroundings and the social settings in which it functions. Understanding the connections and "logics" of the activity may therefore contribute to positive changes (Cremers et al., 2013; Salman, 2016).

The promotion of less impactful practices in the small-scale mining sector is not simply a matter of introducing alternative practices, as they cannot be detached from the context in which they are developed and used. An integrated approach that incorporates social, cultural and environmental aspects is also

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essential to the local development of better mining practices and to achieve more effective knowledge (www.GOMIAM.org; Cremers et al., 2013). The choice of a particular technology and its use has direct consequences for gold production, working conditions and the impact on the environment in the local context. Knowhow may provide the empirical basis to approach the wider economic and social as well as the political, cultural and environmental consequences of gold mining.

Small-scale gold extraction entails several steps depending on the type of deposit (primary, where gold is embedded in quartzite rocks; or secondary, where gold has washed away and been deposited along watercourses) and the use of specific tools, from simpler ones (such as a gold pan) to more mechanized ones (pumps, grinding mills, and excavators) (Cleary, 1990; Hinton et al., 2003; Seccatore and de Theije, 2017). Although small-scale gold miners throughout the Amazon use different kinds of tools, these are all largely based on similar technological principles of which the outcome is considered poor and rudimentary (Telmer and Veiga, 2009). This image ignores how ASGM has changed into a more mechanized activity with a larger number of investors and employees (de Theije and Heemskerk, 2009; de Theije and Bal, 2010; Teschner et al., 2017; Veiga, 1997; Veiga et al., 2006). Furthermore, and despite the simplicity of the extraction process, there is, technically seen, considerable room for improvement. For example in alluvial mining, improvements might regard both using more efficient tools (such as more powerful hoses, grinding mills that do not lose gold-containing material, green-fueled motor pumps, etc.) and optimizing practices (such as the re-use of water in order to re-filter the gold). However, often technologies are unknown, or not feasible for a number of reasons, or not applied because of social obstacles or cultural resistance. For example, in connecting mining practices in Suriname to the socio-political situation occurring in small-scale gold mining in the country, Seccatore and de Theije (2017) show how a possible reorganization of the sector towards cleaner production and more responsible extraction technologies is not likely to occur as long as miners operate in a politically unstable country where access to the mining grounds remains insecure. Additionally, if innovation occurs, it is often in some parts of the production chain and not in others. Although the technology of gold extraction has continued to evolve over the past decades, there is evident room for further improvement, notwithstanding national and international programs for upgrading ASGM in the Brazilian Amazon (Sousa et al., 2011; Spiegel and Veiga, 2005; Veiga et al., 2004).

Thus, to understand how the gold is extracted and produced and how the technologies are selected and develop over time, we must recon the human agency in the social processes, knowledge diffusion and use of skills in technology (Jansen and Vellema, 2011).

The aim of this article is to show how new technologies are being developed and adopted in the practice of mining communities in order to achieve a more sustainable gold extraction. Our focus on the social and economic processes of technological development and adoption will generate insights in some of the conditions for change in the small-scale gold mining sector in the Amazon and beyond.

In this research we will look at small-scale gold mining in the Vale do Rio Peixoto in the state of Mato Grosso, Brazil (Fig. 1).

Mato Grosso is the one of the largest national gold producer, (see data from the Brazilian National Department of Mineral Production in Table 1).

Since early 2000s, the increase in the exploitation of Mato Grosso deposits is a direct consequence to the increased price of gold (from 271 USD/troy ounce in 2001 up to the record high of 1669 USD/troy ounce in 2012, data from World Gold Council, www.gold.org); the costs of mining gold have considerably risen as well, from 280 USD/troy ounce in 2005 up to 566 USD/troy ounce in 2010 causing a new gold rush, especially in the northern part of the state. One of the largest gold extraction areas is located in the *Reserva Garimpeira of Peixoto de Azevedo* (3,275,294 km^2) that includes the municipalities of Peixoto de Azevedo, Novo Mundo, Nova Guarita, Matupá, Marcelândia, Terra Nova do Norte and Nova Santa Helena. Considered the second largest in Brazil, it produces around 200 kg of gold per month and a revenue of R$3 million monthly. Analogous to the other regions, the extraction of gold in Peixoto de Azevedo (14,257,260 km^2 and 30,812 inhabitants, data from IBGE 2010) began in the 1980s, but from the 1990s to the early 2000s, the extreme fluctuation of the gold price caused a population decrease in the municipality (from 90,000 citizens in Peixoto to 10,000) and an increase in agricultural activities (Barbieri and Sawyer, 2007; Souza et al., 2008). As the price of gold began to rise again in early 2000s, gold extraction activities further increased, generating a strong local economy that directly and indirectly relies on mining (Fig. 2).

In Vale do Rio Peixoto, the miners are organized in a cooperative that endeavors to integrate innovative effective techniques that also diminish the destructive impact on the environment. At present the Cooperativa de Garimpeiros do Vale do Rio Peixoto (COOGAVEPE) includes more than 5000 miners. In the last few years it has taken action to legalize most of the *garimpos*[1] and develop new sustainable technologies. Founded in 2008, the cooperative brings together the miners, owners, managers, workers, and gold buyers of the region Vale do Rio Peixoto de Azevedo. The organization was created by a group of miners from Peixoto de Azevedo with the support of the state of Mato Grosso government agency Companhia Mato-Grossense de Mineração (METAMAT). The first objective was to obtain legal access to areas for the extraction of gold by the local small-scale miners. At the time, this was a priority as the government began to monitor illegal mining and fine those involved. The creation of the cooperative allowed people to obtain legal access to lands previously granted only to large mining companies, which occupied much of the land in the Vale do Peixoto region but did not develop the exploration activities for which they had the licenses.

This formalization, through the legalization of mining licence and registration of mine owners and workers, allowed the growth of the local economy and the generation of jobs as a result of more operational mines in activity, as well as the increase of IOF (Imposto sobre Operações Financeiras, i.e., the tax contribution to the municipality), which in turn should be converted into improvements in infrastructure and health in the community. Far from being solely an operational and administrative organization, COOGAVEPE develops environmental awareness campaigns among miners and the local community, and develops (pilot) projects for re-management and reuse of land after the end of the extraction. During the fieldwork, the researchers visited projects for fish farming and fruit plantations, as sources of income and working positions in the region after the exhaustion of gold.

Vale do Rio Peixoto represents an interesting case for the study of technological innovation for two reasons. Firstly, in the past decade miners in this region have taken many steps to improve technology by integrating more appropriate and effective techniques and adapting existing knowledge to new situations. Secondly, agencies and cooperatives have been active in promoting a responsible use of the mining techniques and natural environmental restoration projects in order to decrease the destructive impact of small scale gold mining (Fig. 3a and b).

[1] *Garimpo* is the Portuguese word identifying artisanal small-scale mine of gold or gems. A miner is a *garimpeiro*.

Fig. 1. Map of the study area.

Table 1
Gold production (t) of Brazil from 2012 to 2016 (Data from the annual reports of the Brazilian National Department of Mineral Production). Mato Grosso is one of the main states participating to the national gold production. Almost half of the national production of *garimpos* comes from legalized *garimpos* of Mato Grosso.

State	Production of gold (t)				
	2012	2013	2014	2015	2016
Minas Gerais	29.71	31	32.99	31.34	30.73
Goias	5,84	8.36	9.74	10.95	10.12
Mato Grosso	**5.39**	**7.48**	**5.55**	**3.92**	**2.83**
Pará	4.48	7.48	9.10	19.74	22.95
Amapa	–	5.18	4.91	4.03	4.55
Bahia	8.05	5.03	5.12	5.7	6.28
Rest of Brazil	3.23	3.47	3.69	1.19	0.34
TOT BRAZIL	56.7	68[a]	71.1[b]	76.87	77.8

[a] The total official production from *garimpos* in 2013 was 11,6 t (47,1% from Mato Grosso and 40,19% from Pará).
[b] The total official production from *garimpos* in 2014 was 9,9 t (44,1% from Mato Grosso and 41,7% from Pará).

In the following sections we will discuss how the technology of small-scale gold mining has changed since the early 1980s, giving particular attention to the introduction of two main innovations that occurred in the region of Peixoto de Azevedo: the mechanized exploration drill and the cyanidation process. Finally, we will introduce three notions of foresight (*visão*), agility (*agilidade*) and development (*desenvolvimento*) that conceptually frame the likeliness of acceptance and promulgation of innovations in this context.

2. The conceptualization of innovation

A useful device to understand technological change in small-scale mining is the analytical distinction between invention and innovation (Schumpeter, 1934, 1942). Invention is the creation and establishment of something new, while innovation is an invention that becomes economically successful and earns a profit. Schumpeter analyzed the role of innovation in the evolution of cultural systems on the basis of its economic value. Building on this work, contemporary evolutionary research in the social sciences is geared toward identifying innovation not only as a product but also as a process (O'Brien and Shennan, 2010). In these theories, innovation is the product of a *social* process that includes the inception of an idea and its economic profit. In fact, innovations are novelties that have successfully been diffused throughout the population (Henrich, 2010, 2001). The process of adoption depends on many factors such as necessity, mental and economic status or propensity to take risks. Individual inventiveness is just one of several sources that trigger innovations. Cultural interconnectedness plays an important role too, i.e. people that are highly interconnected in a given community stimulate the diffusion of a novelty more than the

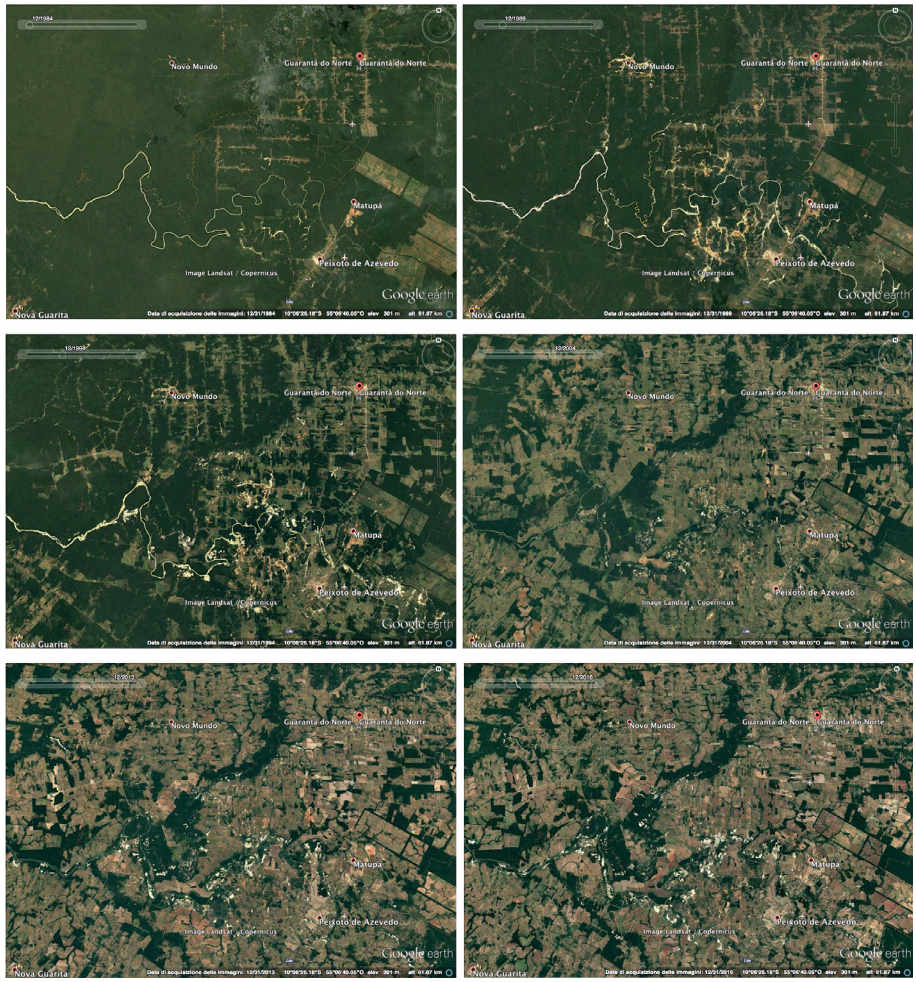

Fig. 2. The changes in the landscape in the Vale do Rio Peixoto in 1984, 1989, 1994, 2004, 2013 and 2016. The rise of mining activities is very clear till early 80s (top panels). In 1994 the drop of the price of gold corresponded with an abandonment of mining in favor of agriculture. The mines are barely visible from satellites (mid panels). In the last decade, the mining activity has started again in particular along the river Peixoto (lower panels).

sole inventive capacities of a single person. The sharing of ideas through cultural learning abilities connects individuals and drives the flow of information concerning knowhow and consequently the decision to adopt a novelty (Muthukrishna and Henrich, 2016).

The adoption and diffusion of the novelty in the community is the fundamental feature of an innovation; it is the expression of the social process. A current distinction generally adopted by technologists, in fact, separates the concepts of invention and innovation on the basis of scale: whereas the former occurs only on the scale of the individual, the latter implies the adoption of an invention on a collective scale (Roux, 2010). The analysis of the manner in which a cultural trait spreads throughout a population (and hence becomes an innovation) was studied within economics (Schumpeter, 1942, 1934), anthropology (Barnett, 1953), and sociology (Rogers, 1995). In the 1980s, the population-genetics-inspired mathematical models of Cavalli-Sforza and Feldman (1981) and Boyd and Richerson (1985) were introduced into anthropology to demonstrate and predict the cultural-transmission mechanisms (who copies what from whom and how). According to these authors, many elements characterize the innovation process such as economic benefits, simple application, and necessity to overcome a problem, increased efficiency, inventiveness as well as personal psychological situations.

With respect to the environmental impact of small-scale gold mining, Sousa et al. (2011a, b) have shown that top-down approaches such as legislation and government projects, have not produced tangible actions or evidence of considerable technological innovation on the ground to reduce environmental impacts. Hinton et al. (2003) point out that participation reveals itself to be an effective bottom-up measure essential in the innovation process. The implementation of new technology is likely being more successful when the miners actively contribute to the development process. In fact, they express their innovative potential by inventing or modifying tools and practices (Jønsson et al., 2013). In addition, if an innovation has been effectively demonstrated, miners will be encouraged to continue implementing the method, and also may be willing to try other innovations.

In order to study innovations of small-scale gold mining technology in relation to the social mechanisms of the activity, we apply a technographic methodology (Jansen and Vellema, 2011) that combines the description of mining extraction technology with the anthropological view on culture.

3. Methods

The technographic approach (Jansen and Vellema, 2011) requires an integrated methodology that combines the study of technical conditions with social processes. It provides the

Fig. 3. Gold mining in Vale do Rio Peixoto. (a) An alluvial deposit. (b) A miner showing one of native plants he re-planted after the mining operation were ceased.

interdisciplinary methodology necessary to analyze social, political, economic and cultural processes together with concrete technological change. This approach enables the understanding of mining practices as situated actions (i.e., embodied cultural knowledge) and fills the information gap between the study of materials and techniques with the study of people and communities. Field data were gathered through observations and formal descriptions of mining technology (i.e., to record who is doing what and using which tool) and through semi-structured interviews (i.e., to access the flow of information and knowledge within the community). This project is the first application of a technographical approach to the study of small-scale gold mining practices.

In particular, observations aimed at understanding the practical process of extraction and the technology applied in gold mining. Moreover, this method highlighted the dynamics, the proximity and the rhythm of people working together. It provided an overview of the type of relationship and the role that each participant played in the scenario of the gold mine. Semi-structured interviews aimed at accessing the flow of information and knowledge within the community. They were addressed to professionals directly involved in the gold mining process, such as owners of mines, miners, excavator operators and to any other individual whose work was indirectly related to mining such as geologists, personnel of the local secretary of environment, or mining equipment salesmen for a total amount of 60 participants (Fig. 4). Many of our interlocutors lived and/or worked in Peixoto de Azevedo so that this town represents the nerve center of the organization of the mining activities. Living there during the entire field data collection allowed us easy access to the people directly or indirectly linked to mining, also outside their working hours. Moreover, the staff of the COOGAVEPE is composed of geologists, biologists and administrative personnel that are in constant contact with miners. These functionaries facilitated our contacts with research participants both by taking us on their visits to mining sites and in their office in the town of Peixoto de Azevedo.

The structure of the interviews was flexible according to the role of the interlocutor in the mining activities and focused, among other issues, on i) how innovations were introduced and how technology changed through time, and ii) how the research participants think this sector may change in the future, especially in terms of technological change and environmental restoration. Photo documentation represented an important tool of investigation that helped with categorizing each phase of the extraction process as well as keeping track of our observations. Data were collected from January to March, 2017, in the mining region of Vale do Rio Peixoto covered by COOGAVEPE, and included the municipalities Peixoto de Azevedo, Matupá, Guarantã do Norte and Terra Nova do Norte.

4. Small-scale gold mining technologies: two examples of new practices

In small-scale gold mining, innovation is synonymous with improvement. The improvement may entail increased efficiency and economic benefits of a particular technique, but also a cleaner and less environmentally impactful one. Miners have often been considered as the type of people that do not have the opportunity or the skill to look forward, or that the majority of them only think of immediate benefits regardless of the risks for themselves or the environment (Veiga et al., 2006). This view does not allow for perception of the small revolutions that have been occurring in the

Fig. 4. Fieldwork methods. Interviews often took place in the mining sites.

technology of this sector. For example, the mechanization of some phases of gold extraction brought advantages both to the mine-workers that could work in less strenuous conditions and to the owners that could expand the areas of mining (Fig. 5 a,b,c).

The necessity to cut operating costs is without doubt an important incentive to search for innovation in technology. Increasing the scale of an operation without spending more in fuel and workers is one such innovation. A mine owner pointed out that changing from 6-cylinder motors to 8-cylinders increased his production considerably without impacting the mode of organizing work roles or increasing fuel consumption in such a way that cutting costs might have become imperative.

Moreover, mechanization led to an increased specialization in work roles. For example, miners that maneuvered the excavators now dedicated their work time solely to this activity. A 20 years old miner confirmed that he had a long phase of training before he was allowed to operate the excavator by himself. He had moved from his parents' house to live in the *garimpo* so that he would have more time as an apprentice assisting an experienced operator. He was aware of the risks for himself and his coworkers, and he understood how important it is to learn to operate such a machine expertly, as excavating a few centimeters off target could make the excavator fall into the mining pit, causing a disaster.

4.1. Manual mining and after

In Brazilian mining, the past "*época manual*" ("the manual period" as local people express it) identifies a period of time from the late 70s to the early 90s, when the price of gold suddenly dropped. The work was much harder than it is today, and is defined as *manual*, as each phase of the process relied only on physical labor: removing the vegetation, digging the pit, crushing the stones and so on. During the *época manual*, the tractor was the only machine that was sometimes used, mostly to remove vegetation. The use of heavy equipment became feasible when, simultaneously with the rise of the gold price from 2004 onward, main highways were paved causing a decrease in the prices for excavators and tractors, facilitating their transport from southern regions. The introduction of excavators accelerated the entire mining process. Digging a pit required just a few days instead of weeks. It also made a major difference in the quality of working life.

Other tools also improved, becoming more efficient. In the manual time, the hoses were smaller in diameter and the intake of water was much lower. And when the water source was too far

Fig. 5. The use of excavators indicates the recent mechanization of the gold extraction procedure and allowed miners to work less strenuously than in the past (a), to move bigger amount of soil (b) and over larger surfaces (c).

Fig. 5. (*continued*).

from the mining pit, creative solutions were used to reach it: miners would cut coconut shells in half and juxtapose them one to the other to form a pipeline. Also ingenious was the use of raw goatskin to line the sluice boxes with. The stiff hairs of the goatskin placed against the grain were excellent for trapping the gold nuggets in the mixture of gold, water and, mud sediment that was sluiced over it. The goatskin has been replaced by specialized carpets, made of plastic with small plastic grip nails. The hoses and pumps became bigger, and nobody used coconut pipelines anymore.

4.2. The exploration drill

One of the most delicate phases of the whole mining operation is deciding where to dig a mine. In mining engineering textbooks, it is pointed out that the research of mineral deposits is a multidisciplinary geologic discipline that implies the identification of a mining target through a combination of geo-scientific data (i.e., geological, geochemical, geophysical and remote sensing) (Moon et al., 2006). Proving the size and quality of a deposit implies an underground investigation that is structured in two main activities:

the prospection and the physical exploration (Lins, 1992). The prospection entails the geological mapping of the area to produce a detailed report that constitutes the basis for generating a target of drilling. Physical exploration is geological mapping that requires the identification of the surface mineralization.

Physical exploration can be done by less formally trained people. The details of the soil in a landscape (as a very different appearance from the surrounding rocks) allow to visually identifying those anomalies that characterized the outcrop of a mineral deposit. Interestingly, despite the precision of more sophisticated survey methods, there is no formal obstacle that hinders a miner from the discovery and evaluation of a deposit (Lins, 1992). Often it is only necessary to have an experienced “eye for ore” (Moon et al., 2006). Artisanal gold miners, in fact, usually rely on this kind of reconnaissance techniques. Results from a survey by the GOMIAM Research Project in four Amazonian countries (Surinam, Brazil, Peru and Bolivia, for a total of 119 respondents) show that miners' preferred method is based on their own experience of looking for gold in the soil (49%), or following in the paths of other miners (13%) or simply by trial and error (11%) (Fig. 6).

The adoption of alternative, innovative exploration methods could, however, increase the production and as a result also decrease the environmental damage. Replacing old rudimentary methods with modern mechanization is one of the solutions; inspections with expert geologist and geophysicists would be useful also. A combination of innovative skills, willingness, education and financial resources are the necessary elements for changing in favor of a more efficient and cleaner technology (Hilson and Van Der Vorst, 2002).

The physical exploration implies an initial phase of pitting and trenching in order to confirm the geological source of the anomalies identified with the visual prospection and a following phase of specific drilling. This physical exploration entails an underground inspection with several side effects. Often, these actions are destructive to the environment as sites may be deforested and left exposed with no vegetation or topsoil left and the trenches that were dug left abandoned without proper restoration (Maponga and Ngorima, 2003) (Fig. 7), but still this procedure remains fundamental as there would be a much more impacting effect if a mine would be opened and then abandoned because there was no gold.

Seccatore et al. (2014) proposed a model that overcomes this “gambling effect” and the uncertainty of not finding gold that characterizes artisanal mining and demonstrates that a small-scale mine will be more sustainable and efficient if miners invest in a basic initial geological exploration at the early stage of business. Such geological exploration would prove the “minimum mineral reserve”, the minimum amount of gold able to return the investment committed to upgrading artisanal mines into sustainable and profitable small-scale industrial extractive units (Marin et al., 2016).

Nevertheless, Vale do Rio Peixoto has been a cradle of innovations in the technology of small-scale gold mining. The COOGAVEPE cooperative continues to actively strive for the highest possible level of efficiency and has also become a platform for knowledge sharing and communication among professional members as well as with other parties, e.g. encouraging collaborations among miners and geologists. This resulted in the introduction of the mechanization of the new hydraulic drilling machine, which was a major novelty in the past decade.

Beyond environment, in fact, a drilling survey might face both logistical and geological problems. Drilling the old way was an inefficient and expensive manual process requiring about eight people working for a week to manually extract samples of soil at 7 or 8 m of depth. The cost was about R$200 per drilling meter (approximately US$60). The new way of probing uses a preliminary

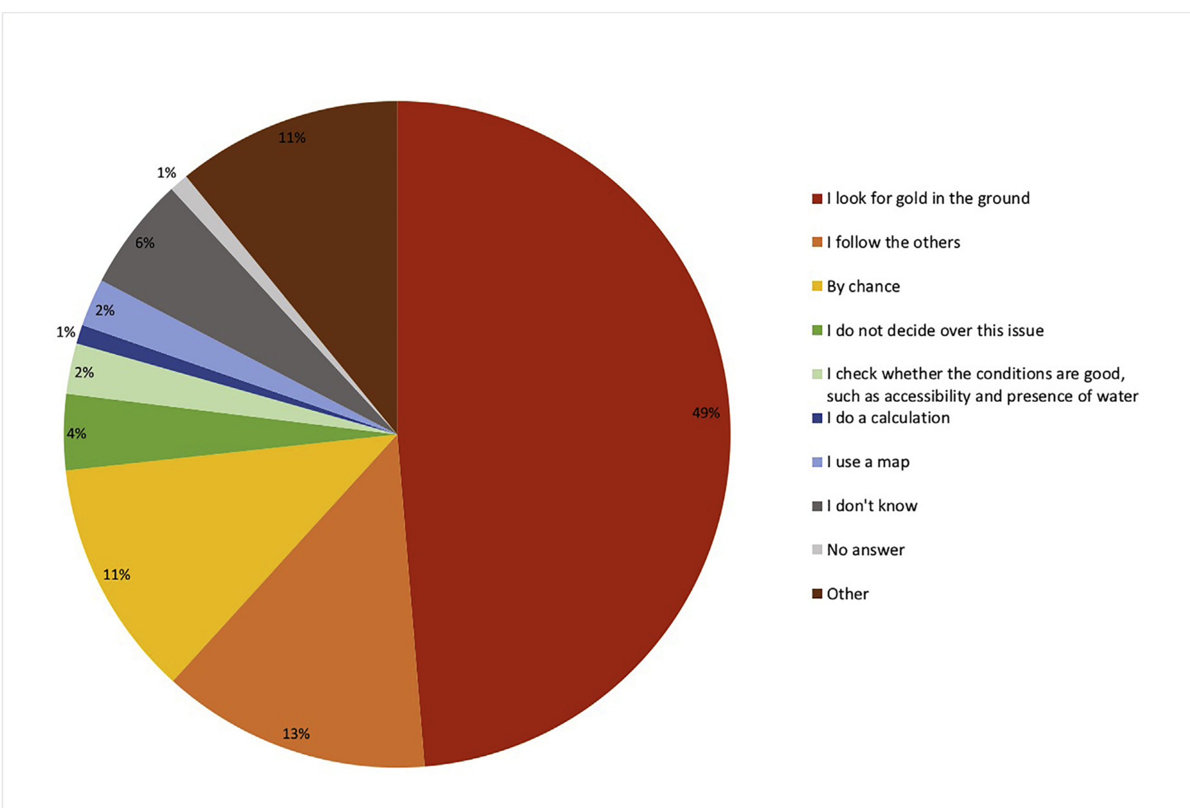

Fig. 6. Results of the survey about miners' preferred method of prospection in four Amazonian countries.

Fig. 7. A geologist of the local cooperative inspecting what remains of a prospected site.

assessment tool that extracts samples of deep soil to inspect the quantity, quality and distribution of gold in a specific area. With the new probe it is possible to go 20 m deep in much less time for a cost of about R$35 (US$ 10) per meter. The drill rig can be placed on a tractor and moved to wherever the operator wants it (Fig. 8 a and b).

The necessity to cut costs, accelerate the speed of this preliminary phase and work independently were the main reasons that motivated a local miner to design and develop a more efficient probe. He told the authors of this article that he worked together for an entire year on the idea with a geologist and an engineer. The constant back-and-forth among them created a flow of modifications that resulted in the development of a functional prototype. Five years later most mine owners in Vale do Rio Peixoto had bought their own probe and the "miner-inventor" earned a small fortune that he invested in his own mine to make it one of the biggest in the region. This example reveals an open attitude to change and innovation to overcome technical obstacles and find solutions to previously unrecognized problems. Moreover, this innovation resulted from ingeniously modifying and recombining existing knowledge in the collaboration between people with different backgrounds and experiences. Finally, the

Fig. 8. (a) The old and manual prospection probe. (b) The mechanized probe (courtesy of Metamat, Companhia Mato-Grossense de Mineração).

implementation was ensured by the interconnectedness within the network of community members and the cooperative.

The narrative of the president of the miners' cooperative COOGAVEPE on this successful innovation, exemplifies the understanding of social process in the diffusion of new technologies. He emphasized the sequence of actions that was necessary to introduce new technology in Vale do Rio Peixoto. First, he stated, introducing a novelty requires time. One of the tasks of a president of the cooperative is to start exploring and testing new ideas before completing and putting them into practice. Miners, geologists and engineers must work together for a successful result. Then, an action of "persuasion" follows. Showing, explaining and publicly discussing the benefits of acquiring the novelty triggers its adoption by the entire community. Demonstrating the trade-offs between costs and benefits in terms of economic income and expenses plays a key role in this phase. Clearly, the entire process is the result of teamwork, of reinforcing and taking advantage of the established set of relationships among the miners.

Another aspect concerning public relation with local people appears to be exceptional in Vale do Rio Peixoto. Moon et al. (2006) report that many projects, that were formally and technically excellent, failed to obtain support for further development as, at the exploration stage, companies excluded the local population opinion hindering them from forming impressions on the nature of the exploration work. An efficient way of starting mining operations should aim at establishing good relations both on a governmental side and without conflict at a community level. The success the innovation of mining technology in Vale do Rio Peixoto can also be attributed to the long-term commitment of the cooperative in endorsing high quality relationships with the local community.

4.3. *The cyanidation process in small-scale gold mining*

Amalgamation, which is the final phase of gold extraction, also needs technological improvement. At present, mercury is the most common substance used to separate gold particles from the soil, particularly when the gold is fine as in alluvial ore. Telmer and Veiga (2009) argue that small-scale miners prefer this procedure, as it is cheap, simple, quick, easily accessible, independent, and reliable. However, mercury constitutes a severe risk to human health and the environment (Gibb and O'Leary, 2014; Spiegel and Veiga, 2010) (see also the 2017 UN Environmental Report for updated data). The contamination effects of mercury on the human body consist of exaggerated emotional responses, gingivitis and muscular tremors, but due to the difficulties of a reliable diagnosis, symptoms are often confused with fever, alcoholism, malaria or other tropical diseases (Veiga et al., 1999), and people tend not to link them as a direct cause from the use of mercury. When mercury is transformed into methylmercury, even stronger effects of poisoning occur (known as the Minamata disease), with symptoms of visual constriction, numbness of extremities and impairment of hearing, speech and gait (Eto, 1997; Grandjean et al., 1999). Despite efforts by governments and agencies to spread information about the dangers of its use, including applied training programs, such as the UNIDO project that was carried out in nearby Tapajós (Sousa and Veiga, 2009; Spiegel and Veiga, 2010; Veiga et al., 2006), miners continue using mercury. Miners are not convinced of the danger of mercury poisoning and mercury is frequently used in the process of crushing, grinding and gravity concentration despite the availability of mercury-free concentration methods. Removing mercury from the mining process through the adoption of improved technologies that allow for a reduction in emissions is an essential step towards environmentally responsible gold mining. The upcoming international ban on the use of mercury may be a catalyzer for the adoption of other technologies (Veiga et al., 2004).

An alternative method to recover gold is cyanidation. Cyanide dissolves fine gold present in low-grade ores or in flotation concentrates, and when properly implemented, it can produce high gold recoveries. However, for small-scale miners this process requires more skill and investment than simple amalgamation does. Moreover, although cyanide is not regarded as a persistent toxin, it is a deadly poison in high concentrations, thus becoming a serious health threat to a wide range of ecological entities. Nevertheless, cyanide has been used for over a century at large-scale gold mines all over the world and the evidence is that it can safely be used as a gold leaching reagent without significant risk to human life or the environment (Hilson and Monhemius, 2006).[2] Gold mining operations use very dilute solutions of sodium cyanide, typically in the range of 0.01% and 0.05% cyanide (100–500 parts per million) (Logsdon et al., 1999). Despite the fact that low concentrations of cyanide are naturally present in nature (for example, in many insects and plants, including a wide range of vegetables, fruits and nuts, where it provides protection against predators), there is justifiable public concern about its use, as it is a toxic substance that can be lethal if ingested or inhaled in sufficient amounts. One of the major health and environmental concerns with some chemicals is that they do not decompose readily and can thereby accumulate in the food chain, as mercury does. Natural physical, chemical and biological processes, instead, transform cyanide into other less toxic chemicals, and since cyanide oxidizes when exposed to air or other oxidants, it decomposes, does not persist and does not give rise to chronic health or environmental problems when present in low concentrations.

There is an ongoing debate on the use of cyanide as more environmentally beneficial in the mining industry. Hinton et al. (2003) argue that for ASGM, the acceptance of a particular new cleaner technology may be achieved on the basis of three criteria: i) economic benefit, (i.e., the technology must be inexpensive to operate and it must generate obvious financial benefits); ii) improved or comparably simple application, (i.e., the technology must be easy to use and would ideally utilize readily available resources); and iii) quick recovery of the mineral, (i.e., this important economic mineral must be efficiently extracted). The cyanidation apparently satisfies only two of these three criteria, as it is cheap and efficient. Cyanidation, in fact, is a delayed process (up to 20–30 days) in comparison with mercury, which is immediate, and this constitutes one of the main reasons why miners are reluctant to switch to this practice (Veiga et al., 2014b, 2014a). Nevertheless, cyanidation can recover more gold so in the long term it balances the cost of delay.

The miners in Vale do Rio Peixoto who made the switch to using cyanide, instead of mercury, do not refer so much to the upcoming ban on mercury as their main motivation. Instead, the cyanidation centers were installed by miners who found grinding mills and mercury not efficient enough to extract gold embedded in the stones of primary deposits of their mines. Thus, the motives for innovation are to be found in the internal dynamics of the production process.

However, miners working on secondary deposits sometimes also sell the concentrate containing the mercury that remains after the amalgamation phase to these centers, as cyanide is able to efficiently extract even the finest particulate of gold. Unfortunately,

[2] Cyanide is one of only a few chemical reagents that dissolve gold in water. It is a common industrial chemical that is readily available at a reasonably low cost. For both technical and economic reasons, cyanide has been the chemical of choice for the recovery of gold from ores since 1887, and now it is safely used and managed to extract gold all around the world (Hilson and Monhemius, 2006).

in this second case, additional pollution problems occur. Mercury and cyanide, in fact, like gold and cyanide, form soluble complexes, and additional mercury is released into the atmosphere when the cyano-mercury complexes are degraded (Telmer and Veiga, 2009).

The cyanide used in large-scale mining and its adoption by small-scale miners in Peixoto has provided some insights on the acquired skills and investments that miners are achieving in this region. It can also entail an awareness of the specialization of labor. Some owners of *garimpos* are intending, in the near future, to completely eliminate the amalgamation phase and sell the concentrate directly to a center where cyanidation extraction is to be implemented. This would mean that they would specialize more on the mechanical extraction phase (whether a primary or secondary deposit), whereas the recovery of gold would be undertaken in a different place. As these centers have not yet been constructed, we cannot analyze the outcome of this process at this time. This would , however, represent a major form of improvement for small-scale miners and open new opportunities of development of the sector.

Moreover, according to a local chemist, new breakthroughs have led us to believe that cyanidation procedures will be overtaken by newer and more efficient methods in the next few years. In fact, other alternative techniques that involve the use of pesticide agents commonly used in agriculture have already been locally tested and have resulted in higher percentages of gold recovery (well above 90%). This brings to mind how the main concept of the innovation process is being used to integrate new elements not previously intended for a particular goal. Nevertheless, although some innovations can be transferred and forwarded, and other chemical processes are less complicated than they may at first seem to be, only medium and large-scale mining industries are developing and adopting them. For now, small-scale miners do not use these innovations because the extraction of secondary deposit gold is relatively easy and the implementation of new chemical processes requires notable investments and a different set of licenses.

5. Discussion of notions of technological innovation

The case of the drilling survey and cyanidization by the miners in Vale do Rio Peixoto is particularly helpful in understanding how a technological innovation was adopted in this community. The incentives for such innovations have various reasons. In Table 2 we summarize the main obstacles (Hanai, 1999) that hinder the use of more sustainable practices and how and why the community of miners of Vale do Rio Peixoto overcame them by developing their own solutions. Some issues are more urgent than others. The shift to cyanide was also motivated by the ban on mercury, a policy coming from outside the community but taken up by COOGAVEPE, and not only for economic reasons. Even so, the less obvious the (immediate) advantage of an innovation is, the more difficult the acceptance and distribution may be. In the analysis of the conversations with our research participants, we found that three words popped up in every interview. These emic notions may reveal the attitude in relation to technological innovation and the likeliness of acceptance and distribution in the local context. In the discourse of the miners and other actors in the sector, the notions foresight (*visão*), agility (*agilidade*) and development (*desenvolvimento*) are key terms to explain the state and technology of ASGM in their region. We will explain each of them.

5.1. Foresight

Foresight (visão) concerns the awareness of a wider "view of action". This notion emerged as an explanation for the fact that only some people possess the capacity to forecast and anticipate the future.

On an individual level, many experienced miners recalled their younger years by saying that they had lacked foresight and should have played their cards better by thinking more about the future, saving their money and behaving wiser. This would have allowed them to retire or achieve more financial benefits at their present age. Some attribute this "living for the present" to the excitement caused by suddenly having a huge amount of money ("gold fever"), or the short-term planning used in mining secondary deposits (because they think it may not last long). Seccatore and de Theije (2017) also attribute the reasons for such a short-term outlook to the informality and insecurity of the mining activity in particular with respect to access and rights to mining ground. Miners live

Table 2
The main obstacles to the use of more sustainable practices (Hanai, 1999) and how and why the community of miners of Vale dos Rio Peixoto developed its own solutions.

Obstacles to a more sustainable mining practices	Small-scale mining	Large-scale mining	The example of Vale do Rio Peixoto
Exhaustion of deposit	There is a short period of time between initial operation and the exhaustion of deposit	There is a long period of time between initial operation and the exhaustion of deposit	There is a medium period of time between initial operation and the exhaustion of deposit [a]
Mobility of *garimpeiros*	High mobility (often due to the small size of deposit)	Low mobility (the same site can be exploited for decades)	Medium mobility (most of miners are established in this community since the late 70s)
Licenses	Difficulties in obtaining mining licenses without burocratical support. Many miners still work illegally	Large companies have specific personnel and consultants to care about legal aspects	Miners organized themselves in an efficient cooperative that works constantly on burocracy and legal aspects concerning licenses
Property of land	Usually miners do not own the land where they extract gold	Usually companies own the land where they extract gold	The majority of the lands are property of the cooperative or there are legal accords between the owners of land and the managers of mines
Heterogeneous nature of mining techniques	It is difficult to standardize the technologies on such small deposits and in heterogeneous areas	Large companies implement standardized technologies due to the size of deposits	There is a strong effort in standardizing technologies due to the longer time of exploitation of a mine. There is also a strong effort in developing and adopting new technologies
Lack of technical assistance	There is no investment of time and money in technical assistance	Larger companies invest and relies on their own technical personnel	The cooperative provides technical assistance (geologists, geophysics, engineers, biologists)
Unsuitability of legislation (especially regarding environment)	Legislation nowadays takes more into account the needs of ASGM but still there is not a full application from garimpeiros	Large companies relies on their own technical personnel to implement effective environmental restoration plans	Despite the high level of legal mines in the region more efforts are necessary for a full implementation of environmental restoration plan

[a] The medium life of a *garimpo* can reach several years of activity. It is long enough to establish more permanent mining camps, and it is also reflected in the development of the towns in the region. Moreover, once a deposit is exhausted the mining operation (and the miners) move to another place but always in the same region.

always on the “threshold between richness and poverty”. This “threshold condition” enables everybody to live for today and not to invest in a secure future. One day they may recover all their debts and expenses and even make a high profit, or that day may never come. It is an uncertain and extremely inconstant occupation.

Nevertheless, there are individuals who have the capacity to limit the uncertainty or deal effectively with it. People working at a managerial level (such as the owners or managers of a mine) reached that position thanks to the ability of thinking ahead beyond their present needs. All research participants working at this level shared a start as a simple miner who wanted more for their families and co-workers. They also carry the responsibility of their foresight ability in terms of supporting the local economy of the region that, directly or indirectly, relies on their mining activity. As a consequence, they are more likely to think of and invest in innovation, and the skill of planning for the future plays a critical role in this process.

The role of the cooperative COOGAVEPE in terms of foresight is exemplary. The current president of the cooperative embodies this ability, as he has the capacity of looking forward and his horizon is wide open to any kind of technical improvements. He is able to recognize the importance of collaborations and uses his network to contact e.g. an inventor from São Paulo to find out about alternative and more efficient methods in different phases of gold extraction (such as how to increase the grasp efficiency of the carpets in the sluice boxes). This openness in looking for novelties is also encouraged in the collaboration with some miners who share the same interest.

5.2. Agility

Agility (agilidade) is the capacity that society and government should have in facilitating the process of change. Political and social influences may well determine which innovations are to be selected for further development. And beyond that, it is the economic selection environment with all its constraints and stimuli that affects the diffusion of an innovation (Freeman, 1991). According to Freeman, the interactions between strategies and decisions of firms largely determine the growth, survival or disappearance of innovating firms as well as improvements in technology.

This also works on a local and smaller scale. In terms of technological change, the mechanization of the prospection probe represented one of the biggest improvements in the region in the last years, but besides that, other small modifications were prompted by local conditions. Small novelties made the extraction process smoother and more efficient and did not require too much time to be accepted by the miners. One such innovation was the addition of metal bars with two wheels on each side inside the grinding mill. These pieces were initially engine parts of a truck, but once added to the inside of the mill, they helped to optimize the grinding process and limited the loss of water that contained gold through the sides of the mill. The owner of an equipment store explained that this novelty arose from the inventiveness of a miner, and that he had embraced the idea and set up an entire line of production in the back of his store for the piece (Fig. 9 a, b and c). He explained that solutions to new problems emerge from everyday practices that depend on cooperation to be implemented. This is a clear example of how an innovative process easily spread among workers.

On a bigger scale, the concept of agility involves politics. Brazil has an elaborate set of laws and regulations for small-scale gold mining (Cremers et al., 2013; de Theije et al., 2014). To obtain a mining license for a given area, miners are requested to present a set of documents regarding the geological and environmental impact of the mining action, which includes a detailed plan for the restoration of degraded areas. In practice these requirements turn into one of the major problems affecting miners: bureaucracy.

Bureaucracy is the main obstacle to the flexibility that people need in this sector to be able to develop. Bureaucracy is like a giant, slow elephant that miners have to deal with every day. The main struggle regards the red tape involved to obtain work permits. The license entails a lot of paper work and a considerable amount of money (about R$60,000, or US$18,000). The COOGAVEPE team assists miners to collect the necessary documents as quickly as possible, such as geo-referenced maps of the mining area, details about the type of extraction, details about the equipment, environmental impact assessment, and a plan to restore the degraded area. After the completed file has been handed in it may still require from 6 to 12 months to be approved. According to Sousa et al. (2011a, b), 29,888 small-scale miners' permits had been submitted from all over Brazil in 2008, but only 106 had been approved by the National Department of Mineral Production. The rest of these applications had accumulated in regional offices (Kolen et al., 2013). The expectation is that from 2018 the new mining legislation and Nacional Mining Agency (ANM) will remedy the main bureaucratic obstacles for the ASGM sector.

At the time of our research in 2017 an additional requirement was causing more delay than usual. Strict requirements concerning the presence of archeological evidence and artifacts in a specific area had recently been added to the list. Miners were now required to present an archeological study of their area to prove there were no remains of earlier inhabitants. Not only was such a report expensive to obtain, there were also no archeologists available to carry out the study. This added requirement thus caused a pile of applications for licenses that could not be completed. Many protests due to the evident difficulties of finding experts in the field for inspections, the high price of consultancy and the small number of archeological findings present in the areas eventually led to its abrogation from the list of essential documents for obtaining the license.

Whereas the Brazilian mining authorities are not perceived as an example of agility for the benefit of the mining sector, the cooperative COOGAVEPE is the vehicle that facilitates miners to deal with this long process of bureaucracy. The miners declare they could not do it all alone. One miner said he thought that in addition to bureaucracy, there is a hidden problem that he called the “inequality” that characterizes the entire country of Brazil: the majority of miners does not want to spend days going after documents (he said “to fight for legalization”, like he was doing); but they rather prefer to work illegally, and in doing so, they discredit the image of the whole sector. The persistence of the informality of ASGM in Brazil is partly attributed to the complex and slow bureaucracy (Mathis and de Theije, 2018) and limits the agility of actors in the sector.

5.3. Development

The literal translation of *desenvolvimento* is ‘development’, and the word is used a lot by the mining population of Vale do Rio Peixoto. However, in social scientific analysis it is a problematic and controversial concept to deal with (Alkire, 2010). The complexities of the term seem not to exist in its local usage, where development exclusively refers to economic growth without considering wider welfare in terms of better services, education, public health, etc.

The following example might help in understanding how

Fig. 9. (a and b) The local entrepreneurs of the mining equipment showing the new metal addition to a traditional grinding mill. (c) The line of production of the new pieces set up behind the shop.

development is conceived in the mining community. The owner of a mine proudly explained that by giving work to more than ninety miners, he was automatically also providing for their families. So, thanks to him, all these people were spending money in the town, which stimulated the local economy and "local development", as he called it. This nicely illustrates the link between gold mining and the local economy and how its development stimulates the economic growth and prosperity of the town. Peixoto de Azevedo belongs to the municipalities in the country that receive most revenues from the IOF-gold taxation (Mathis and de Theije, 2018).

ASGM has the same economic structure of any other activity (Veiga et al., 2006); and therefore, every improvement in mining technology that increases gold production is promoted in order to trigger an improvement in the economy of the town. The story of the miner, matches the "trickle-down effect" where society would benefit from increased production and employment generated

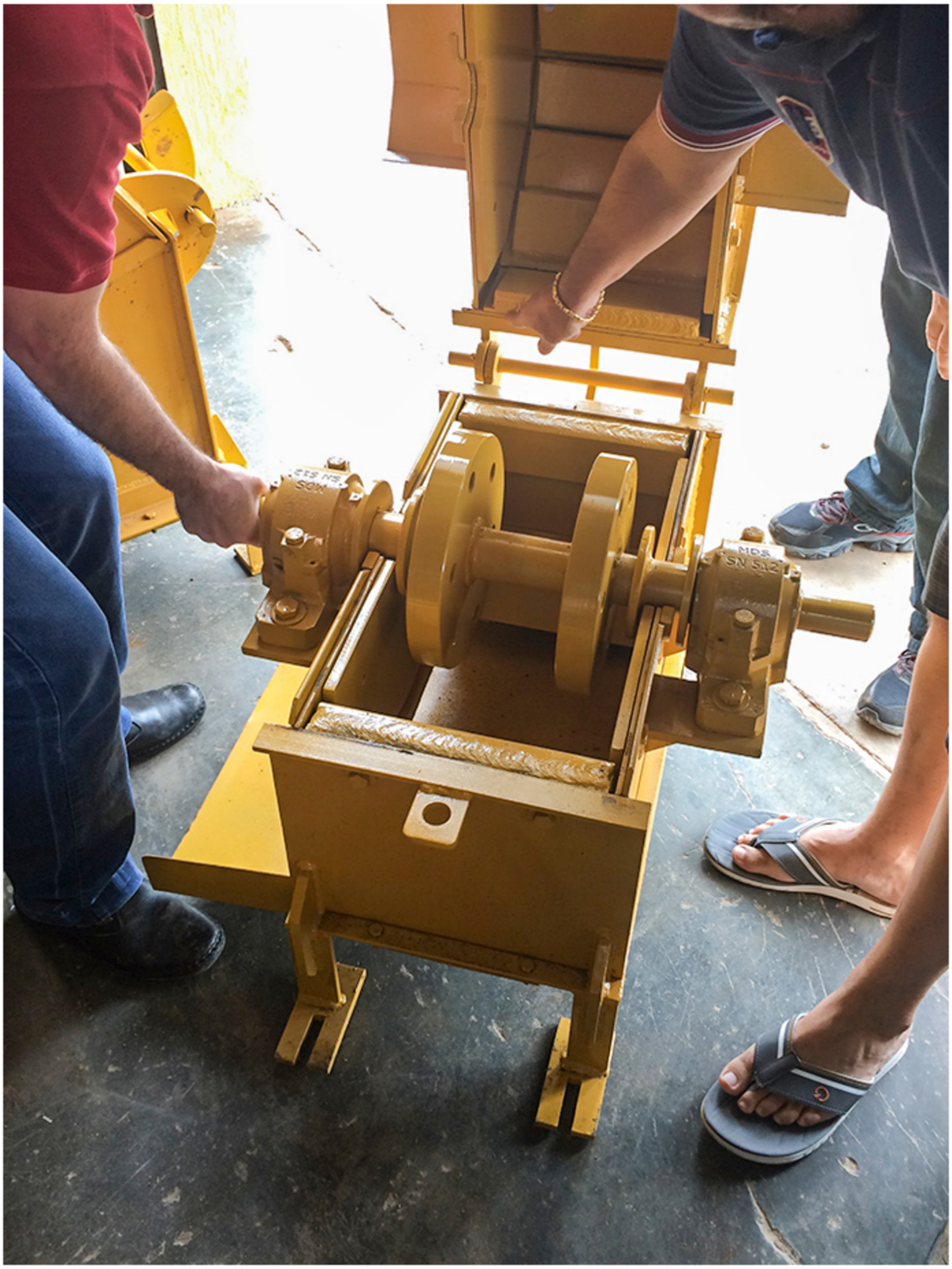

Fig. 9. (*continued*).

through the investments of richer people (Gardner and Lewis, 1996). In this framework, the exploitation of gold resources is supposed to represent the most concrete possible way to achieve not only a livelihood opportunity but also a higher standard of economic prosperity in everyday life. Many miners often remarked that nowadays it is not possible to distinguish an owner of a mine from a mineworker as they share the same lifestyle. They both usually own a house, a car or a motorbike and even wear the same clothes. Therefore, development, considered for these economic aspects, is an essential part of the local culture and an expression of the ambition of local community to improve their life status .[3]

Economic growth does not necessarily lead to enhanced standards of living (Gardner and Lewis, 1996). Pieterse (1998) highlights

[3] From the end of the 1970s, this region was populated with migrants usually from the poorest regions of northeastern Brazil or from the overpopulated south of the country. This means that many of the older people are first generation "colonizers" who moved to the region exactly to exploit the forest and make a profit out of natural resources. Indigenous people were largely ignored in this process of "colonization" of the Amazon.

Fig. 9. (*continued*).

the fundamental role of people's subjectivity rather than large-scale international institutions. Currently, development is becoming more oriented towards local actors and the essential condition for local development is participation. This reflects exactly another layer of the situation in Peixoto. Development is a prominent part of the discourse surrounding COOGAVEPE. The aim of the cooperative is to develop socio-environmental projects for a conscientious mining process that contributes not only to the growth and development of mineral extraction but to the preservation of the environment as well as promoting social care actions in the local community, beyond the group of miners per se. In collaboration with other local institutions, such as the "*Desenvolve Mato Grosso*" (Develop Mato Grosso), an organization of local actors for local actors, COOGAVEPE has a key function in connecting and helping small entrepreneurs to access public funds and grants. A further step towards an innovative development of the mining sector would be endorsed by promoting collaborations between the local community and state and federal universities. The dialogue between academic experts (geologists, biologists, archaeologists, anthropologists, etc.) and local miners creates the conditions for more comprehensive technological innovation.

6. Conclusion

This article aims at investigating how innovations and improvements in the technology used in small-scale gold mines are connected to a broader perception of the miners about the integration of more modern and effective techniques. The technographical approach appeared to be the best manner to understand the motivations and practices developed by the mining actors. The discourses about technology of small-scale gold mining in Vale of Rio Peixoto provide direct insight in the economic and political context as well as environmental issues. In recent decades, miners in this region have succeeded in several efforts to improve the local technology of gold extraction and promote a responsible use of the mining techniques. Moreover, agencies and miners' cooperatives have been active in endorsing a sustainable way of mining along with natural environmental restoration projects in order to decrease the destructive impact on the environment.

The diffusion of technological innovations in small-scale gold mining is not well documented in academic literature and the example of the mining practices adopted in Vale do Rio Peixoto sheds light on some of the factors that are important to take into consideration. In a wider perspective, our study case outlines the necessity and possibility of improvements through bottom-up technological improvements in order to achieve cleaner and more effective production. It reinforces the idea that small-scale gold mining is an independent production unit that does not necessarily have to transform into a larger mining company by emulating the same procedures of bigger companies (see differences in Table 2). In fact, in Peixoto, small-scale gold miners have found alternative ways to organize their work and overcome technical obstacles by means of new experiments, new assemblages and new purposes for old tools. Adapting current practices into more efficient and sustainable ones have effective consequences also on the workload of miners. Although mining remains a strenuous activity, more efficient tools and practices contribute in more bearable work conditions.

The most effective medium for achieving a more sustainable mining occurs when technological innovation joins social innovation through a mutual reinforcement of initiatives to overcome technical barriers. Nevertheless, more sustainable mining may only succeed if public policies facilitate the practical process of innovation during each phase of its realization. Social participation and partnerships among government, universities and local cooperatives are key factors for the development of this sector. Small-scale gold mining in Brazil is a growing sector that should be directed towards a cleaner and a more sustainable methodology, and policymaking actions should rely on a community-based approach (as also suggested by Hilson et al., 2007). Therefore, understanding the relationships that connect the professional figures in a dynamic community is key to accomplishing a more sustainable technology. A further innovation should be on the organizational level since many small-scale miners are reluctant to change their methods despite the fact that improving mining technology implies an increase in gold production and an improvement in environmental impact. In the area of Vale do Rio Peixoto, miners are successfully organized in a cooperative that together endeavors to mutually reinforce the integration of innovative and effective techniques. The three concepts that emerged during fieldwork of *foresight*, *agility* and *development* explain how technological innovation may spread into the miners' community. The technological change may be achieved if a wider vision of the future of the sector (foresight) joins the facilitation in the realization of improvements (agility) in order to accomplish an advanced social status of the local community (development).

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