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Trajectories of mining territories: an integrated and interdisciplinary concept to achieve sustainability

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Abstract

This paper introduces several notions and a collection of manuscripts compiled for a special section of *The Extractive Industries and Society* on the temporal and spatial trajectories of mining territories. These papers were developed from presentations delivered at two international conferences held in 2018: the TRAMIN (“Socio-environmental Trajectories of Mining Territories”) conference and the Social Geology session at the RFG (“Resources for Future Generations”) conference, that took place respectively in Chambéry (France) and Vancouver (Canada). The introduction paper situates these pieces in the wider literature, exploring the connections between mineral resources and the development of societies that exploit, transform and sell them. It also argues that using a polyphonic notion such as “trajectories” allows for the adoption of an interdisciplinary approach leading to key insights on sustainability for mining territories.

Keywords

Mining territories, territorial trajectories, interdisciplinary approach, social geology

1. Introduction: Mines and societies

The extraction of mineral resources has contributed to the development of human societies since prehistoric times. Hematite was extracted and transformed for parietal art during the late Palaeolithic. Native metals, especially copper, gold and silver were first mined out for tool carving and jewellery during the Neolithic. The use of metals spread out as metallurgical processes (smelting) developed during the Late Neolithic and antiquity. Apart from jewellery and tool carving, gold and silver have been used for trade and money since antiquity, thus initiating development of monetarized societies. The ancient civilizations that controlled silver mines, such as the Athenians and subsequently, the Spartans, grew wealthy and expanded their territories by producing military equipment and financing armies for war (Flament, 2008). From antiquity to the industrial era, metals have been intensively mined out for manufacturing tools and other necessary goods, and for funding local and national economies. The extraction of mineral resources significantly increased during the 18th and 19th century, with the development of industries and infrastructures (railways, transportation, manufacturing, etc.) and personal consumption (clothing, building, furniture, etc.). The technical skills developed in mining territories together with the development of infrastructures for ore transportation and trading, contributed to developing new industries in these territories. Mining, therefore, frequently appears to be one of the first steps of territorial development and of other industrial or economic development (Barbier, 2012). Today, due to the development of high-tech industries and to the transition to low-carbon energies, metal needs have evolved and a wider variety of minerals are used and mined, such as base metals, trace and rare earth elements (nickel, molybdenum, cobalt, lithium, graphite, etc.).

Mining, as an activity with the potential to cause serious environmental impacts (some irreversible) but which is important economically, raises concerns in communities and sometimes accentuates or provokes tensions. Various types of conflicts are likely to arise

during mine construction and operation, and often even after mine closure, as local people may struggle with environmental impacts for decades in case of ineffective remediation or its absence (Merino Acuña, 2015; Arsel et al., 2016; Vargas, 2019; Smart, 2020). Conflicts are likely to be related to the struggle for transversal resources (like water and energy) between mining companies and local communities (Forget, 2015; Bos and Grieco, 2018), or to contrasting visions about territorial development. The role of governance, and the way it intertwines with local, national, and global politics, is also a key issue (Liping et al., 2015; Coumans, 2019; Haikola et al., 2020). Social sciences widely documented the notion of the “social license to operate” (Moffat and Zhang, 2014; Zhang et al., 2015; Vanclay and Hanna, 2019), the changes affecting territorial identity or the construction process of a mining identity (Harner, 2001; Ballesteros and Ramirez, 2007; Parmenter and Trigger, 2018), as well as uneven distribution of mining benefits, environmental injustices and unequal power relations (Bridge, 2004; Bebbington and al., 2018; Rodríguez-Labajos and Özkaynak, 2018). The social aspects of mining are thus key to understanding how this activity distinguishes itself as a human endeavour.

In this paper, we call for analysis of the complex interactions between mining and societies using the lens of “mining territories” and their “trajectories”. As evidenced from the contributions in this special section, an integrative and interdisciplinary approach is the most adapted to characterize and understand in new ways mining territories. We believe that by broadening perspectives through these concepts, more paths towards sustainable solutions in mining will appear.

2. Mines and territories

2.1. Mining territories

A territory can be defined as a geographical entity with a variable extent, which has environmental, cultural, economic, administrative, and social specificities that differentiates it from others. The term “mining territory” hereafter refers to an arrangement of material and symbolic mining resources capable of structuring the practical conditions of the existence of a social collective and of informing this collective in return about its own identity (Debarbieux, 2003). It belongs to the large category of “place” used in geography, history and sociology (Massey, 1991; Casey, 1997). Historical roots and identity create specificities and constitute a resource for local development. Mining territories are therefore identified as portions of space, that are the object of intentions, and that are organised for and by mining activities. They are of various sizes but mostly fall within the sub-national scale, the local scale being generally referred to when addressing these territories. Their specificities are determined by the shape and type of the ore deposit, the techniques used for extraction (open-pit, underground) and mineral processing, the initial configuration of the territory (topography, climate, land use, etc.), the integration of mining activities in the life of the territory (e.g. labour force employed, specific service structures that can serve the population and economic spin-offs).

A mine -- and its associated services -- strongly impacts the site as well as the ecosystem and the neighbouring communities (Forget and Rossi; Scammacca et al., this issue). Mining strongly structures territorial organization through its infrastructures, investments in the territory and local communities, economic aspects, and contributions to the political life and identity of the territory. This territorial structure is configured by negotiations between local landowners (sometimes Indigenous communities) and mining companies (O'Faircheallaigh, 2016), and through interactions with governmental entities. Specific territorial systems can be defined with a much larger meaning than their impact on landscape in mining enclosures. As mining tends to become the main economic activity of the local territory, it has a significant impact on the social and cultural local structures (Admiraal, 2017). It increases economic endowment and inequalities (McDonnell, 2015), can trigger land-use and resources conflicts, and alters community identity (Werner et al., 2019; Horowitz et al., 2018; Smart, 2020).

Different territorial configurations may appear as a result of mining activity, from mining enclaves (Le Meur, 2015; Sidaway, 2007; Magrin, 2013) to the (ideal but infrequent) co-construction of mining territories. Beyond a local territory, a national political economy intercedes structurally in the functioning of the mining sector, both for material reasons - deposits are often located in remote areas, far from existing infrastructures and networks - and strategic reasons linked to regulatory frameworks, to social movements, etc. The logic of mining enclaves exists when local employment is disproportionate to the import of labour power by a "fly in-fly out" system (Saxinger & Gartler, 2017). In contrast, a co-constructed mining territory may appear when the exploitation of the ore deposit cannot be physically separated from the other functions of the territory. Artisanal and small-scale mining generate other types of territories, much more complex than in the case of industrial mining (Kemp & Owen, 2019).

Over the past 20 years, many studies have highlighted the close relationships and interdependence of nature and societies, which should be considered as integrated socio-ecological systems (Berkes and Folke, 1998; Collins et al., 2011), considering: (i) that nature provides ecosystem services to societies (for the definition of ecosystem services, see de Groot, 1987; Costanza et al., 1997), (ii) that nature is impacted by human activities, and (iii) that both natural and social systems respond to endogenous and exogenous drivers (natural and/or anthropogenic), displaying resilience and complex reciprocal feedbacks (Liu et al., 2007). Mining territories can thus be considered as socio-ecological sub-systems, for which the natural and social systems are strongly driven and affected by mining activity, with complex feedback loops (Forget and Rossi; Scammacca et al., this issue).

For the purpose of this paper, four broad types of mining territories will be distinguished based on a temporal approach and on the notion of trajectory (see the y-axis on Figure 1). They are as follows:

- Former mining territories that used to host mining activities in the past, but that no longer have active mines (e.g., many regions in European countries). In these territories, the mining identity has often been lost or relegated to heritage (Hendrychová and Kabrna, 2016; Oakley, 2018). Most raw materials are imported and the social acceptability of new potential mining projects is low (Beauloye et al., this issue).

- Territories with a long mining history and a strong mining identity nowadays, where mining has been taking place for more than a century (e.g., within Ireland, Scandinavia, the USA, Canada, Australia and Chile). There, mining remains one of the main economic activities and social acceptance is rather high (Devenin et al., 2019).
- Territories without any former mining activity, but affected by a relatively recent (over the last decades) and rapid mining boom (e.g., within Latin America and Africa) that frequently generates socio-environmental conflicts (Haslam and Tanimoune, 2016; Walter and Urkidi, 2017).
- Potential mining territories are territories with no former mining activities, but where mining projects are being developed or where advanced exploration is taking place. They may have been inaccessible regions, or areas with minerals in low concentration, or where the mineral resource is currently being re-evaluated (e.g., Mason et al., 2010).

As indicated in Figure 1, the study of the abovementioned mining territories is only relevant at specific time-scales. Indeed, former mining activity may have occurred and structured the territory for tens to thousands of years, so that investigations at a short time-span (less than 10 years) are not relevant. On the opposite, investigation on emergent mining activity and possible future mining activity can only be realized with a short to medium-term perspective (up to ten years). The upper and lower grey triangles in Figure 1 represent areas in which the socio-environmental trajectories are thus either hard to predict or hard to study (e.g. short-term consequences of mining that happened a long time ago).

The contributions gathered in this special section cover the whole range of mining territories and time-scales, thus providing a rather good overview of these territories. The contributions of Balan, Beauloye et al., Jébrak et al., and Méndez even cover different types of mining territories (droplet symbols).

2.2. Trajectories of mining territories

Each mining territory can be defined by its specific socio-environmental trajectory. In physics, a trajectory describes the path of a moving mass in space and time. This dynamic concept has been recently applied to environmental sciences and humanities to describe the “pathways of changes” of socio-ecological systems facing climate change and natural phenomena, to discuss the drivers of these changes (Fazey et al., 2011; Wise et al., 2014), as well as their response and their vulnerability (e.g., Wise et al., 2014; Murphy, 2015; Li and Ford, 2019). It has also been used to describe changes in ecosystem services (e.g., Smiraglia et al., 2016; Locatelli et al., 2017) and overall territorial changes (e.g., Rana and Miller, 2019) from the perspective of sustainable development.

Studies investigating the changes induced by mining activities at the territorial scale are mostly discipline-oriented (e.g., Forget, 2015; Carrizo et al., 2016). Interdisciplinarity is more widely used in economics, development studies, rural studies, geography, regional planning, and political sciences (Watts 2004; Bainton et al., 2011; Kowasch, 2012; Imbun, 2013), but generally, no attention is given to the ore deposit properties nor to the environment. In the approach we are proposing, considering a mining territory as a socio-geo-ecological system,

a territorial trajectory must integrate the interactions between mining-related human activities, societies/communities, and the physical environment, as well as their evolution in space and time. In that perspective, the development of an integrated and multi-disciplinary approach is required, in order to (i) describe the social, economic, cultural, identity, geological, and environmental components of the system, (ii) describe and analyse their response to anthropogenic and natural drivers, (iii) characterize the feedback loops among the system components, and (iv) analyse the role of local policy and governance (Forget and Rossi, this issue).

Investigating territorial trajectories offers a better understanding of present-day territorial structuration and of past changes and their inheritance. Understanding how events that took place in the past currently impact socio-ecological systems is relevant to anticipate future alterations and to develop appropriate adaptation strategies (e.g., Liu et al., 2007; Fazey et al., 2011; Fazey et al., 2016). Learning from the past to prepare for the future is a key to building sustainable territories.

3. Towards an interdisciplinary approach of mining territories

3.1. Mining territories at the crossroads of disciplines

Mining territories are, by their nature, at the crossroads of various scientific disciplines (Erb et al., this issue). To get a full understanding of their evolution and dynamics, one may use different lenses associated with:

- *Geosciences*: detailed geological investigations at the regional and local scales are involved during exploration; a good knowledge of the ore deposit geometry and distribution, local geology, and ore mineralogy is required for exploration, operation, and ore processing.
- *Engineering*: mining productivity has been greatly enhanced in the last 50 years due to technological development in ore processing and exploitation techniques;
- *Environmental sciences*: mining activity (metal extraction and ore processing) strongly impacts the environment through landscape modifications, removal of topsoils (for open-pit mining), dust emission, increased noise, habitat degradation, induced hydrological changes, air, water and soil contamination due to pollution or trace metal dispersion, etc. (e.g., Ripley et al., 1996; Dudka and Adriano, 1997; Younger et al., 2002).
- *Economics*: mining activity, especially the exploration and exploitation phases, is driven by economic interests and profitability. Secondary economic activities, including services to the mine and services related to the growth of human settlements, also develop in a close dependence with mining activity (e.g. Xing et al., 2017). Even though mining is important in structuring the territory, it may override other economic activities and finally lead to weakened economic development outcomes (see Dutch disease and resource curse theories; e.g., Watts, 2004; van der Ploeg, 2010; Thistle 2016)

- *Social and Human sciences*: mining shapes and transforms social and cultural structures and human relationships; it may also increase economic endowment and inequalities, result in land-use and resources conflicts, and reshape community identity (e.g., Batterbury et al., 2018; Horowitz et al., 2018; Werner et al., 2019; Smart, 2020).
- *Political science and law*: mining activities are framed by various laws, regulations, and public policies that oversee environmental protection, labour rights, economic orientations, or land planning, among other issues. The wider geopolitical context also influences corporate and public decision-making, as well as the relative attractiveness of a given mining territory (e.g. Gale, 2019). Power relationships can be particularly salient in such contexts (e.g. Kirsch, 2014).

These fields of knowledge belong to three main groups of disciplines, each a replication of the three components of the mainstream definition of sustainable development (Figure 2):

- economics for all aspects related to economy and wealth;
- social and political sciences for issues connected to power, governance, the social license to operate, social disparities, identity and heritage; and
- natural sciences for assessing ore formation, environmental impacts, risks and vulnerability.

The exploitation of mineral resources is one of the most disturbing forms of anthropogenic activities considering both the social and cultural changes it provokes and its long-term environmental impacts and landscape modifications. Therefore, it essentially follows an unsustainable pathway (e.g., Kowasch, 2018). To achieve a more sustainable development of mining territories, a deeper understanding of the complex relationships between all these aspects is required, which can only be obtained by crossing disciplinary perspectives. For example, the study of ore mineralogy, ore grade, rock and mineral textures, and deposit geometry determine the exploitation mode and ore-processing techniques that will be used in the mill; the type of exploitation and initial transformation circumscribe the local and national economic benefits and environmental impacts. In turn, local and national governance as well as the local and national political contexts directly influence the social impacts of mining. Apart from the researchers' point of view, there are other mechanisms at stake within the industry and society at large in demand for action against climate change and for better sustainability, that contribute to the push for interdisciplinary approaches.

Economic geology (Figure 2) is the part of geosciences focusing on earth materials that can be used for economic and/or industrial purposes. It aims at providing knowledge on the ore genesis, the ore mineralogy and geochemistry, the ore content and distribution of ore deposits, etc., that is relevant for the industry in order to plan more efficient exploration, and to develop more efficient ore processing techniques. However, as proposed by Stuart and Gill (2017), the links with social sciences are key to harness the contributions geosciences can make to sustainability thinking, a stance the editors of this special section are sharing.

Social geology could be defined as the study of the interactions between the geological environment and the social sphere. It represents a third applied geoscience, alongside economic geology and environmental geology. According to social geology, an ore deposit is both a geological and a social object, thus sharing the idea that it is a socio-geo-ecosystem. The characteristics of an ore deposit (its size, its accessibility, its toxicity, its usefulness or its

value, for example) influence the way a community (or even a society) will relate to it, in a physical sense (how it will be used) as much as in a psychological sense (how it will be part of its identity). Social geology helps us consider how geology impacts human beings, and how human communities connect with their geological environment. In some cases, human activities can also impact geology -- as we are seeing with the omnipresence of plastics and the use of “Anthropocene” to describe the current geological era -- but this may be better captured by the idea of *anthropogeology* (Häusler 2018).

If economic geology was born around 1910 (Jébrak and Marcoux, 2015; Arndt, 2015), social geology is a much more recent expression to describe this focus on the nexus between the two spheres. Jébrak (2017) has traced a few articles using the concept, going back no further than 2012 (Mata-Perello et al., 2012), although much more work can be classified as part of this new discipline since social scientists and economists have been considering social dynamics around mining and other earth-related phenomena (like earthquakes) for many decades. The booming literature on the social license to operate can certainly be associated with social geology in many instances.

3.2. The contributions of this special issue to interdisciplinary research on mining territories

Conducting new, interdisciplinary research thus appears to be key in understanding the growth and evolution of mining territories (Forget and Rossi, this issue). Most of the literature on mining and its related territorial developments is currently essentially segmented by disciplines, whereas interdisciplinary studies are essentially restricted within a disciplinary field (either geosciences, or environmental sciences or social sciences). Encouraging interdisciplinary studies across disciplinary fields is not an easy task. Apart from institutional obstacles, scientists interested in pushing for interdisciplinary works must face cognitive obstacles, including methodological and conceptual barriers (Szostak, 2013; MacLoad, 2018). Indeed, in order to understand each other, scientists from various disciplinary fields must share the same language and be ready to open-up to new concepts, methods and ways of thinking. At the same time, few scientific journals interested in mineral resources and extractives industries are open to welcoming papers tackling these topics from the point of view of different scientific disciplines. *The Extractive Industries and Society* is one of very few.

A first step in breaking down barriers among scientific communities and to get to know each other is organising interdisciplinary meetings and meeting sessions. The TRAMIN conference (“Socio-environmental Trajectories of Mining Territories”) was co-organized in Chambéry (France) in October 2018 by Marie Forget (human geography), Magali Rossi (geosciences), Estelle Camizuli (environmental sciences), Kristina Maud Bergeron (political science), Yann Gunzburger (mining engineering), and Agnès Samper (geosciences) for this purpose. It gathered more than 80 scientists from all over the world, in the fields of archaeology, history, human geography, anthropology, political science, economics, environmental sciences and geosciences, in order to discuss the social and environmental impacts of mining on communities' development, and the transformation and conversion of both former and current mining territories. The same year, a session dedicated to Social

Geology was set up by Michel Jébrak and Yann Gunzburger (geosciences) during the international RFG conference (“Resources for Future Generations”) held in Vancouver (Canada).

This special issue of *The Extractive Industries and Society* is gathering papers from people who attended these two conferences. These papers have in common not to focus on isolated mining projects, but to discuss the relationships between mining and its human and physical environment at the scale of a territory. Indeed, the territorial scale is the most adapted to cross disciplines regarding mining activities, enabling apprehension of the various facets of mining.

The papers gathered hereafter have been plotted on Figure 1 and Figure 2. Charting all the above-mentioned contributions on Figure 2 highlights their interdisciplinarity. The papers with the most multidisciplinary approach are located in the center; they investigate the sustainability of socio-environmental trajectories of mining territories. Most of the papers fall into the social geology field.

Jébrak et al. show how mineral resources benefits are kept out of reach of the territory’s community within territories such as French Guiana. Future mining development must therefore integrate the territorial economy benefits, together with impact and risk assessment (Rey et al.; Scammacca et al.), and negotiations with local stakeholders and civil society for decision-making (Le Meur et al.; Rey-Coquais; Richard et al.; Scammacca et al., Beuloye et al.). Social geology appears to be a good approach in order to evaluate and enhance social acceptability and to develop more sustainable mining (Bergeron; Erb et al.), and to avoid social and land-use conflicts (Balan; Méndez).

Zheng et al. investigate the effects of mining on the environment and human health, providing guidelines to live close to an active mine, whereas Camizuli et al. investigate the long-term environmental impacts of mining over centuries. Mining heritage is being discussed considering mine closure, rehabilitation of mining sites and post-mining activities (Bozzuto and Geroldi; Heer et al.; Marot and Harfst), and in the perspective of mine reopening in former mining territories (Balan). Forget and Rossi present a new framework for assessing territorial changes (considering the geological, environmental, economic, social and cultural aspects) during the life cycle of a mining project, from exploration to post-mining activities and rehabilitation.

As mentioned above, the contributions of this special section cover a wide range of territories and time spans (y-axis and x-axis respectively on Figure 1). Mining territories have been studied over a time scale of a couple years up to several centuries. It illustrates the fact that the consequences of mining are long-lasting and may even be perceptible a long time after mining ended (e.g., Zheng et al. and Camizuli et al. who respectively investigated the environmental impacts during mining and hundreds of years after mine closure). The temporal approach allows an analysis of the past through research on very old mines that have left their mark on the landscape and on today’s societies. Mines that are currently mined will themselves leave traces in the very long term. The notion of mining heritage is multiple and contains environmental, social, industrial, and patrimonial aspects (Balan; Bozzuto and Geroldi; Camizuli et al., Heer et al.; Marot and Harfst). Whole territories are structured by places of production and places of use of the resources, and their development

generally goes beyond the mining site alone. Mining projects have to be seen as development projects of the territories, in particular for network development (transportation, energy and communications). Nonetheless, only a few papers examine the case of territories that may face new mining activities in the future (Balan; Beauloye et al.), which demonstrates how difficult it is to anticipate the trajectories of areas that will be concerned by mining for the first time.

4. Perspectives for future research on mining territories

Mining-led development and its effects are the result of complex interactions, at different scales (local, regional, national, international), between private and public actors, between local communities, private companies, and public and political institutions. Taking better account of the spatial and temporal dimensions of mining activities is key to sustainably manage the positive and negative impacts of mining. A broader lens takes into account how stakeholders interplay, how political economy influences decision-making, how conflicts and negotiations sometimes interfere with technical aspects, how public policies and state building guide entrepreneurial endeavours, or how environmental impacts are perceived by communities. It shows why it is important to consider the persistent impacts of mining, for the environment, the economy, and society, in the design and implementation of new projects.

An interdisciplinary dialogue ultimately makes it possible to re-historicize and re-spatialize the issues related to the deployment of mining activities. It allows the highlighting of territorial specificities over a long time span, and underlines the numerous spatial scales related to the study of mining territories. Interdisciplinarity also helps in analysing the footprints on the territory, and the inheritance and management of transverse services (water and energy in the first instance) as a complex system.

In order to face the challenge of developing sustainable mining, geologists must be trained not only in the knowledge of geological objects and processes, but in the relationships between geological objects and processes and the other components of socio-geo-ecosystems (Katz, 2020). By changing our perspective in this way, we could redefine the notions of economic, environmental and social geology as interdisciplinary fields bringing respectively together geologists and economists, geologists and environmental scientists, and geologists and social and human scientists, in regards to the socio-geo-ecosystems characteristics and to local governance.

The analysis of the integration of mineral deposits and mines into their territories and the study of their trajectories makes it possible to define sustainable development strategies, taking into account the past, the present, and the future, and the characteristics and uniqueness of a given area.

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Figure Captions

Figure 1. Overview of the time spans (x-axis) and types of territories (y-axis) covered by the papers gathered in this special section. Papers gathered in this issue: 1: Balan; 2: Beauloye et al.; 3: Bergeron; 4: Bozzuto & Geroldi; 5: Camizuli et al.; 6: Erb et al.; 7: Forget & Rossi; 8: Heer et al.; 9: Jébrak et al.; 10: Le Meur et al.; 11: Marot & Harfst; 12: Méndez; 13: Rey et al.; 14: Rey-Coquais; 15: Richard et al.; 16: Scammacca et al.; 17: Zheng et al.

Figure 2. Overview of the papers gathered in this special section, in terms of the scientific disciplines they rely on. Papers gathered in this issue are listed in the caption of Figure 1.

***Presentness level of mining activity
in the studied area***



