Postmining management in France : situation and perspectives

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POST MINING MANAGEMENT IN FRANCE : SITUATION AND PERSPECTIVES

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ABSTRACT: *Even if most French mines are definitively closed, potential risks remain present above the abandoned sites. In addition to surface instability, some mining sites may be affected by dangerous gas emissions, flooding events or environmental impacts. Those kinds of disorders strongly influence the land use management of the concerned areas. This paper presents French mining historical context and identifies the major kinds of residual risks and harmful effects that may affect abandoned mine sites. The prevention policy applied to the national territory is then discussed and prospects for further developments are proposed.*

KEYWORDS: *post-mining management, prevention, hazard, regulation.*

1 Introduction

For several centuries, France has been a powerful mining country. This activity, which was an important source of wealth for the national industry, also provided some dangers. Mining history is strewn world-wide with dramatic accidents resulting in many minors death. Those accidents are notably due both to instability (Coalbrook, South-Africa, 437 fatalities in 1957) or gas/dust explosion (Courrières, France, 1099 fatalities in 1907).

During the last three decades, under the combined effect of diminishing resources and international competition, most mining operations were gradually forced to close down in France. This does not lead to the complete and permanent elimination of risks and harmful influences likely to affect surface land. During the period following operations, traditionally known as the "post-mining" period, several kinds of disorders may develop, sometimes as soon as the work has ceased but also much later.

Apart from surface instabilities, some old mining sites may be affected by dangerous gas emissions. The irreversible disturbance to underground water circulation caused by mining operations may also be the source of nuisance, both for the water circulation scheme and its quality. These phenomena may have major consequences for people, activities and property on the surface (support work or development, moving populations). They are also likely to have a major influence on regional development in mining areas.

This paper briefly describes French mining context that led to the present situation. After an overview of the most frequent risks and effects that can develop above abandoned mine sites, the global systematic risk prevention policy applied in France to prevent dangerous situations is described and the prospects for further developments are addressed.

2 French mining context

2.1 Historical context

Like many European countries, France has a long mining tradition. The extraction of raw materials contributed, in a decisive way, to the French industrial power development. The first important mining expansion took place during Gallo-Roman period (e.g. gold, silver, lead, copper, iron). Mining activity then took the form of a high number of local small-scale mining sites, throughout the country.

After the fall of Roman Empire, mining exploration and extraction declined during nearly one millennium. Under the influence of Central Europe, prospecting and mining activities re-started at XIth-XIIth centuries. It is however the industrial revolution (XVIIth-XVIIIth centuries) that has really leads to the development of French mining activity. Technological improvement contributed then to transform an activity, which up to that period was mainly "hand-made", into a real industry. This leads to the large mining basins (coal, iron, salt), which contributed largely to the prosperity of French industry.

After the Second World War, the mining activity expanded once again for re-building the country and limiting the nation's energy dependence towards other European countries. Then, the significant decline of raw material prices and/or the exhaustion of some major fields gradually generated the decline of French mining activity. This decline, initiated at the beginning of the 1960s for coal and iron and at the beginning of the 1980s for other substances, accelerated since the early 1990s. The closure of the last iron mine occurred in 1995 and the last uranium mine closed down in 2001. The mining of potash stopped in 2003 and the last extraction of coal panel closed down in 2004.

2.2 Recent post-mining disorders in Lorraine iron ore basin

In 1995, the last iron mine closed down in Lorraine region (NE of France), after almost one century of mining extraction. Consequently, the dewatering system stopped with, as a logical consequence, the progressive rise of the water level within the underground mining works. In October 4, 1996, few months after flooding initiation a major subsidence event occurred in the city of Auboué, with vertical amplitude of about two meters. The phenomenon resulted in severely cracked houses and deformed roadways.

About 70 buildings had to be demolished and 150 families, victims of damage, had to be re-located (figure 1). In the following months, other instabilities developed in the nearby cities of Moutiers (90 other families moved in may 1997), Moyeuvre, Roncourt, etc. Other types of disorders also developed at the same period: flood of basements, oxygen-deficient air in cellars connected to the mining galleries due to mine gas accumulation, etc.

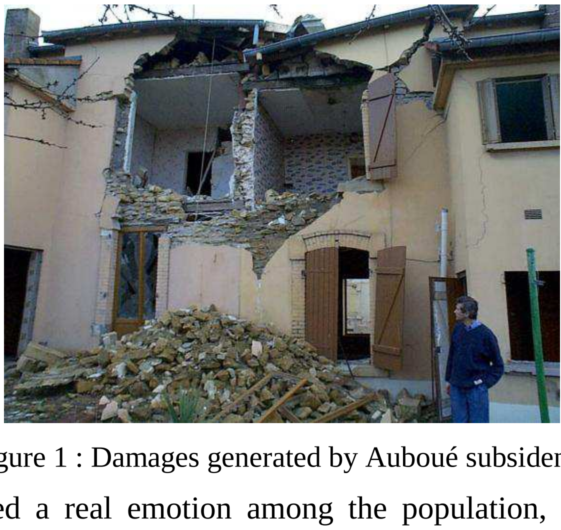

Figure 1 : Damages generated by Auboué subsidence

These disorders provoked a real emotion among the population, who was already hardly affected by the economic difficulties related to the mine closure and the decline of the steel industry (Vila & al., 2001). The local population was organised in "defence associations" in order to express requests in terms of: victims' compensation, post-mining risks prevention and land-use management of the post-mining area (more than 100 cities concerned in the basin).

In parallel, the subsidence events initiated an awakening, at top level of the State, of the seriousness of the "post-mining" management challenge. A search to bring innovative and adapted answers to those sensitive problems was then instigated and some improvement of the French mining legal scope was rapidly proposed, leading to the design of a global systematic prevention policy. This policy is nowadays applied to all French post mining sites in order to avoid/limit further crisis similar to that of the last decade in Lorraine region.

3 Potential risks and harmful effects during post-mining period

Several risks and/or harmful effects may persist for a long time after a mine closure. Even no longer mined, these abandoned sites may indeed generate non-desired consequences for people and goods and disturb occupation or economic development on surface.

An abandoned mine can generate underground water flow changes as well as surface instabilities that can sometimes be dangerous for people or properties. They can also result in potentially dangerous or toxic gas emission or result from discharge of chemical substances toxic for the environment (rivers, soil and air). The main risks and harmful effects encountered in different French abandoned mine fields are briefly described below.

3.1 Modification of water flow

At the end of mining operations, stopping the dewatering pumping system induces a progressive flooding of the mine workings. This leads to the development of an underground reservoir which discharges at one or more points, into the surface hydrographical network.

During mining activity, major modifications may have irreversibly altered the initial conditions in the supporting rock formation. Extraction work may for instance have led to surface subsidence or created artificial groundwater vents. In addition, benefiting from mine dewatering, some previously wet surface sectors may take benefit of this "dry period" to undertake development in terms of surface and/or underground occupation.

It is therefore essential to pay careful attention to the possible consequences of groundwater rising on surface property and activities after the end of dewatering. Among the risks potentially encountered, one may quote: e.g. modification of the discharge scheme, (re)appearance of wet zones or marshes, flooding of sub-surface soil and topographical low points, risks of sudden flooding.

3.2 Surface instability

Mining operations consist of extracting large quantities of material with the intention of marketing part of it as valuable ore. These excavations, whether underground or open-cast, irreversibly alter the rock formations in which the ore is found.

Concerning **underground workings**, the extraction method depends mainly on geological context (e.g. depth, ore structure). Regarding residual risks, one considers two main methods: one providing voids treatment (backfilling, goafing) during and after extraction and the other leading to persistent residual voids, even after mine closure.

For the first one (e.g. longwalls), surface instability is often limited to continuous subsidence (able to damage buildings and infrastructure) that take place mainly during mining activity and reaches a stable state quite rapidly. For operations leading to large persistent residual voids (e.g. rooms and abandoned pillars), the mine workings stability may be affected by a bad design and the “rock weathering effect”. Apart from subsidence possibility, this type of operation may also be the source of discontinuous subsidence (e.g. sinkholes, massive collapses) that may develop long time after closure. This is why those potentially dangerous events (figure 2) are very difficult to predict (Didier and Josien, 2003).

Figure 3. Sinkhole in a French urban area (source CETE/MEEDDAT).

In **open-cast mining**, extraction consisted of digging large pits from which the ore is extracted. The choice of operating method is based on the optimisation of economic profitability (limiting the volume of waste to be cleared) and the stability of the mine structure (avoiding too steep slopes). These rocky fronts often eventually suffer instabilities from simple rock falls to the massive slumping of an entire slope front. The combination of rock fracturing and the morphology of the slopes of the pit generally determine the volume of rock mass which is potentially unstable. The nature of the surrounding rock formation also plays a major role on instability.

For further information, one may consult the international state-of-the-art report of the “international mine closure commission” chaired by the author (Didier & al., 2008).

3.3 Mine gas emission on surface

A disused partially flooded underground mine constitutes an underground reservoir in which mine gasses may accumulate. Depending on both the ore and the surrounding rocks, the residual mine atmosphere may differ significantly in terms of composition from one site to another (Tauziède & al., 2002). Under the effect of various mechanisms, usually resulting from the pressure gradient between the underground workings and the outdoor atmosphere (e.g. rising groundwater, atmospheric pressure drop), mine gases may be forced to the surface through natural (e.g. fractures, cracks) or artificial (e.g. shafts, drifts) drains.

Depending on the type and the composition of mine gas, surface gas emissions may constitute several risks or nuisances for people and property. The safety of surface occupants may be affected if the gas is trapped in non-ventilated spaces (cellars, underground networks, etc.). The main dangers for people are: ignition or explosion (methane), intoxication (CO, CO_2, H_2S…), asphyxia (oxygen deficit) or irradiation (radon).

3.4 *Water and soil pollution*

Environmental modifications and disturbances induced by mining operations are likely to cause deterioration of environmental parameters in the mine surroundings. This deterioration mainly affects underground or surface water and sediments and soils. It may also concern the atmosphere, particularly in the presence of ionizing radiation or toxic particle emissions.

The environmental impact results from complex and varied physico-chemical phenomena, closely linked to the type of substance mined and the mineralogy of the surrounding rock formations as well as the mining method used (Younger, 2001). To assess the importance of environmental risks and nuisances, it is usual to reason in terms of "sources" (e.g. pollutant type and toxicity), "vectors" (e.g. water, soil, air) and "targets" in contact with this pollution (e.g. human activities, ecosystems).

4 Post-mining management policy in France

4.1 *French Mining Legal Scope and its recent evolution*

In France, only the materials that have been considered as strategic for national sovereignty are "eligible for concession" and their extraction is considered to be a “mine” (e.g. hydrocarbons, salt, metals, potash). Other ones (e.g. limestone, gypsum, slate) are considered as “quarries” with a regulatory scope quite different to the Mining Law. The French mining legal scope stipulates that when the mining activity ceases (concession revocation or waiver), the exploited area returns to the “concessible” domain. If the former operator has disappeared or is failing, the State is responsible for any eventual annoyance resulting from mining.

To face the post-mining problems, French State decided to apply a systematic prevention policy in order to identify potential harmful effects before they occur and thus to be able to prevent future accidents and social crisis. This policy represents a kind of “bet”, assuming that the large amount of money invested in the prevention step will be cost-effective at long-term by reducing drastically victims and damages compensating costs.

To apply this ambitious policy, the French mining legal scope was considerably reinforced during the last decade. Several major acts have thus been voted by French Parliament related to post-mining risk management.

4.2 *Contribution of the Mining Operator: planning and securing*

As soon as a “Mine Opening Procedure” elaborated, the concession holder has to explicit the mine closure scenario as well as a rough estimate of its cost. Thus it is now necessary to anticipate the closure of mine workings and to prepare the management of the post-mining period, even prior to the beginning of the exploitation. The relevance of the suggested closure scenario contributes to the acceptability of the opening procedure.

This perfectly fits a global risk prevention approach, making it possible to avoid the too many cases known in the past for which exploitations stopped without neither any planning nor any optimised preparation during mining activity. The international experts in mine closure agree today on the fact that the closure of a mine must be planned (Mackenzie & al., 2006) even prior to the opening (e.g. rehabilitation financing plan, mobilisation of competencies).

In France, after the end of extraction, the Concession-Holder must elaborate a “Mine Closure Procedure” that need to be transmitted to the Authorities at least six months before the closure of the mine. The elaborated documents must assess the long-term consequences of the definitive closure of the mine workings on the environment and define the counter-measures, financially reasonable, which are considered as the most appropriate and which could guarantee a hazard level in compliance with the surface occupation (Didier & al., 1999).

The application is examined by various administrative services and local councils. The Prefect can either validate the technical proposals or prescribe further measures which were not planned by the Concession-Holder but are felt necessary. If the Concession-Holder fails to complete the prescribed works, the Prefect designates a third party to perform measures required to secure the site at the Concession-Holder’s expenses.

4.3 Contribution of the State: land use management

4.3.1 The Mining Risk prevention Plans

It is the State responsibility to evaluate residual risk and to integrate it in the management of the regional planning. The French tool to integrate mining and post-mining risks in land use management is called Mining Risk Prevention Plan (MRPP).

MRPP process concerns potentially dangerous phenomena. It aims to recognise the areas which are the most sensitive at the long term, to risks or harmful effects related to mining and to establish prevention, protection and safety measures adapted to the various identified post-mining constraints (Didier and Leloup, 2006).

A PPRM elaboration may be divided in 4 major stages:

- The data collection stage aims to collect available information. It requires very careful data search both on-site and from archives. It leads to the elaboration of an informative map that presents to locals past disorders due to the disused mine.
- The hazard evaluation stage aims to locate and to hierarchise the exposed zones, according to the intensity of the foreseeable phenomena and their pre-disposition to occur in each zone. It leads to the establishment of hazard maps.

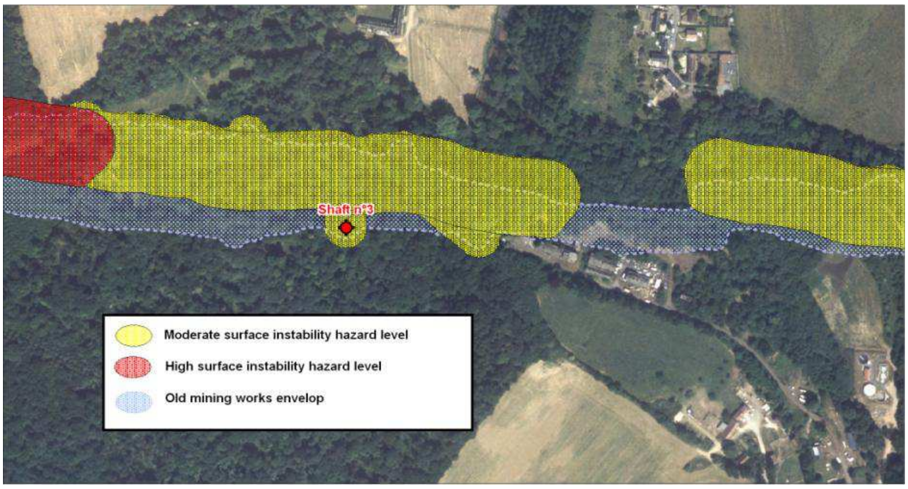

Figure 3 Example of a hazard map above abandoned iron mines (NW of France)

- The vulnerability appreciation stage aims to characterize the existing and/or projected vulnerability in the areas subjected to one or more phenomena. In particular, the most sensitive equipment or buildings (e.g. hospitals, schools) are listed.

- The regulation stage aims to define homogeneous zones in term of land use management (e.g. prohibitions, regulations or recommendations). The principle of this zoning is a “crossing” between hazard levels and nature of surface occupation. Directly connected to this zoning, regulation rules are established in order to manage, in a clear and operational way, the land use occupation for each zone subject to hazards.

4.3.2 The Mining Sites Screening Process

About 3000 mining titles (concessions, exploration agreements) have been granted throughout the whole metropolitan French territory. It would be impossible to consider, both for financial and timing reasons, implementation of MRPP processes on all those sites. Thus, it was essential to define priorities in identifying the most sensitive sites. This has been the main objective of the “Mining Sites Screening Process”: to hierarchise priorities of future PPRM implementation and to identify as quickly as possible the critical contexts requiring urgent safety measures.

This innovating process has consisted in reviewing all French mining sites in order to classify them according to their level of risk (mostly due to potential surface instabilities). The sites selection methodology has consisted in ranking progressively, through various stages, the sites according to available data (Poulard and Franck, 2006).

The first stage uses the information available in the French mining sites data-base and associated GIS. This information makes it possible to localise mining works and provide technical data for a simple risk evaluation. For the identification of equipment and infrastructures on surface, recent topographic maps (scale 1/25000) have been used. The crossing of the mining information available in the data-base, with the kind of surface occupation enables to eliminate a first group of sites being either without any risk of surface instability or far away from any surface interest.

The sites that have not been “eliminated” in the first step require complementary information on mining data and surface occupation (e.g. archives research, site visit). With the new collected data, the remaining sites are classified according to their “risky” character using a decision-aid software based on multi-criteria analysis. The criteria list and the respective weight of each criterion have been established by an expert panel. This ranking process made it possible to recognise the 200 most critical sites. For these specific sites, simplified risk evaluation and cartography were undertaken systematically.

5 First experience feedback and prospects

5.1 Work Progress

The Mining Sites Screening Process has been accomplished since beginning of 2008. It thus took nearly 3 years. The first results indicate that approximately 60% of the reviewed mining titles do not generate any risk of surface instability, because of the absence either of significant hazards or of goods or interest on surface. Approximately 30 % of the mine sites may generate potential future risks, but with a limited extent (very local phenomena). Finally about 10 % of the abandoned mine sites may generate sensitive risky situations and require further risk assessment studies. Except for few large coal and iron basins, the existing French mining sites are, for a very large majority, of rather restricted extension. Nevertheless, they have often developed very close to and even just under inhabited areas.

For this reason, the risk of sinkhole development is the most common phenomenon feared, related to shallow abandoned mining works (few tens metres deep) as well as to the sectors characterised by numerous mine openings (shafts, adits). The very old brown-coal and hard-coal mines, generally quite shallow, are very representative of this kind of very old mine sites.

Since 2000, about sixty abandoned mine sites located throughout France have been analysed on the basis of preliminary MRPP procedure. To these sites, one has to add the whole Lorraine iron ore field whose analyse has been initiated before MRPP set-up. For this basin, about a hundred under-mined cities have been analysed, producing hazard and risk maps.

The MRPPs implemented have concerned the main mining ores exploited in France. One may quote metal mines (e.g. lead-zinc of Centre and Brittany, copper in the Alps, uranium in Centre-West), major iron ore fields (Lorraine, Normandy) and many coal basins (e.g. Provence, Centre-South). The next important step of MRPP implementation will be the major salt basins (e.g. Lorraine, Jura, South-West).

Until now, most risk analysis was dedicated to "surface instability" hazard. Although generally less sensitive, hazards related to mine gas emission has also been highlighted in many abandoned mining sites. Locally, "environmental hazards" have also been identified in some unfavourable contexts mainly resulting from the exploited ore (e.g. lead, zinc, silver).

5.2 Experience feedback on MRPP implementation

The results of the Screening Process have been of the first use for the French Authorities, who now benefit from an overall view of the post-mining sites scattered on the territory. Potentially sensitive "forgotten" mining sites have been identified. This led to the definition of prevention measures contributing to reduce risk in hazardous areas. This also enables a reliable planning of the future MRPP to be performed. About hundred new disused mining sites have thus been listed and planned for the five coming years.

Since the process initiation, Mining Risk Prevention Plans contributed to prevent numerous potential risky situations resulting from post-mining hazards. In sensitive areas in terms of surface occupation (high level of stakes, social pressure for urbanism development) the existence of disused mining works appeared to be generally not sufficient to limit or, at least, regulate urban development. One of the major advantages of a MRPP is that it makes possible to define strict regulation rules that lead to organise city expansion.

In the areas with low surface occupation, MRPP enables to formalise the knowledge related to the existence of disused mining works, which is often unknown by citizens, especially when the mine was closed down long time ago. MRPP allows thus to update and to synthesise the available data. It also assists the local Authorities, who often have no competencies concerning post-mining risk management, to define clear urbanism rules in the sectors where the location of buildings is possible.

To be as efficient, rapid and inexpensive as possible, MRPP process is designed to exploit only available data at present state of knowledge (no systematic borehole campaign for voids detection). This may induce some over-estimation of the risk level (precaution principle), for example in defining hazard zoning in the areas where mining works are only supposed to be present. This conservative approach is not always very easy to understand by local people. It presents however the advantage to define, for future surface developers, the location and precise characteristics of technical investigations that need to be performed prior to new building projects.

In this regard, the “new” Mine Closure Procedure (produced by mining operators) contributes to enhance considerably the state of available knowledge. Risk evaluation and mapping are then much more precise and reliable, reducing by the way the extension of the sectors where the constraints are defined only by presumption. Nevertheless, such closure applications are only available for the recently closed mines.

In case the “technical phase” of MRPP develops quite rapidly (more than 10 per year), the “regulatory phase” will require much more time. This is basically due to the fact that it is of first importance to manage this step of the procedure in partnership with the local Authorities as well as several administration services. Regular meetings and exchanges have thus to be organised in order to elaborate concerted regulations. This difference between the advance rate of technical and regulatory phases leads to an increasing gap between the number of hazard assessment analysis accomplished and the number of MRPP officially approved by the Prefect.

5.3 Prospects for further developments.

The post-mining risk prevention policy has proven its efficiency during the last 5 years. More than 100 cities have been analysed in order to evaluate the post-mining hazard that need to be taken into account in order to manage city development in the future. The global approach appears very useful in facilitating collaborations between technical experts, administrative services and local authorities. Due to this encouraging feedback, the possibility to extend the process to other problems than instability is being considered.

As an example, due to the lack of an operational methodology, the environmental hazard assessment has, up to now, been reduced to strict minimum. Just few cases, with serious problems, have generated environmental hazard maps. Methodological tools and approaches are presently being developed. They will be operational in the coming years. Besides hazard assessment, one may also raise the question of the definition of regulatory principles related to those harmful effects.

One may also note that post-mining risk prevention is a multi-hazard and multi-risk process (surface instability, gas emission, environmental impacts, flooding event, etc.). Coupling and combining different phenomena is a very complex task concerning hazard identification and characterisation. New scientific knowledge and technical tools are needed in this complex field. The objective will be even more complicated concerning transcription of multi-hazard phenomena in terms of regulatory measures. Some classical measures adapted to certain kind of hazard prevention have to be prohibited in case other hazard phenomenon may also develop at the same place. Flooding events and subsidence movements may thus contribute, for example, to prescribe incompatible measures for the design of building foundations.

Finally, “long term effect” remains for sure a major challenge for experts in the coming years. Governing physico-chemical processes have to be well understood in order to explain why some mining structures that have been stable for a long time, may fail several decades after mine closure. Only a significant scientific and technical progress will make possible to better predict where, and when, hazardous situations may develop over an under-mined area.

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