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Application of geoethics to university education based on a mining geoethical dilemma case study in the Catalonian Potassic Basin (Spain)

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Abstract

This research presents the usefulness of geoethics to be applied to university education through a mining case study related to the subsidence problems in the Barri de l'Estació neighbourhood (Sallent municipality) in the Catalonian Potassic Basin located in the eastern Ebro Basin (Catalonia, Spain). The geological studies carried out on the subsidence, which give a valuable insight of the problem, do not intend to provide a solution to the conflict between the local residents and the mining activity. Instead, a geoethical dilemma is used to explore different possible geogovernability scenarios. The application of the geoethical dilemma model derives from the benefits to expose different values and attitudes in order to qualitatively evaluate which would be the steps to achieve a resilient and geodiverse territory where mining and protection of the environment are not mutually exclusive, but complementary. Four scenarios are evaluated: geoecological tragedy, environmental preservation, geoengineering, and territorial resilience. The case study is taken as an example of how geoethics could be included in the curricula of the Geology degree of the Universitat Autonoma de Barcelona (UAB). Therefore, the research makes some recommendations to meet the commitment of the university to implement ethical competences to the teaching of geosciences. The paper is based on the research carried out by a geosciences student,

who is hereby included as a co-author, having obtained the degree in geological sciences at UAB.

Keywords: Geoethical dilemma, Geoethics, Geodiversity, Geogovernance.

1. Introduction

According to Peppoloni and Di Capua (2021a, p.19) "Geoethics consists of research and reflection on the values which underpin appropriate behaviours and practices, wherever human activities interact with the Earth system." The concept of geoethics, as used in this research, relates to society and geosciences (Peppoloni and Di Capua 2022). The interaction of these disciplines is known as social geosciences (Stewart and Gill 2017). Mining activities may pose a great risk for humans and the environment when good practices and management of georesources are not taken into consideration throughout the whole mining cycle. Such negative impacts include, among others, health issues on humans, disturbance of local markets, human rights and labour abuses, and ecosystems' functional disruptions (Bilham 2021). Nevertheless, mining constitutes an essential activity for society welfare providing raw materials for all kinds of manufactured products and services in relation to human rights such as drinking water, health, and housing[1]. Indeed, mining brings many benefits to society when legal frameworks are followed and enforced (IGF 2020; EITI 2019), corporate social responsibility practices are effective, and transparency and social participatory processes are taken into consideration (Bice 2016; TI Australia 2022). However, the geography of mineral deposits determines the mining activity location and it shapes the environmental and social risks, hazards, and associated economic vulnerabilities. Therefore, mining activities are not excepting of social and environmental conflicts (Bandera 2014) and corruption (Dougherty 2019).

[1] https://www.un.org/en/about-us/universal-declaration-of-human-rights (accessed 7 December 2022).

Furthermore mining plays an important role in geopolitics (Sarpong 2021) and it can have a considerable negative impact on the economy directly affecting poverty (Álvarez 2015)[2].

The relationship between mining activities, the environment, and society are frequently related to anthropic hazards, as is the case of the subsidence of the Barri de l'Estació neighbourhood in the Sallent municipality, where subsurface mining (room and pillar mining method) was developed, increasing an on-going geological subsidence and forcing evacuation of inhabited areas. Sallent, as well as Cardona, Suria, and Basareny located in the Bages county of Central Catalonia, have been traditional potash mining settlements since the beginning of the 20th century. Mined potash is used in agricultural fertilisation and marketed in two different types: to obtain complex fertilizers and for direct fertilisation.

As a result of the subsidence in the area, several actions and prevention plans were carried out, such as: "Compilation, analysis and synthesis of geological information on the subsidence process in Sallent (2005-2009)" (Geocat Gestió de Projectes S.A. 2009), "Study of the land collapse process affecting the Estacio and Rampinya neighbourhoods of Sallent (Bages)" (Institut Cartogràfic de Catalunya 2003), and "Emergency action plan for subsidence risk in the Barri de l'Estació (Sallent)" (PROCICAT 2012), with the participation of several Catalan regional authority administrations[3] including universities, the Geological Institute of Catalonia, and the General Directorate of Environmental Quality and Climate Change. Geological studies were not enough to provide an agreed pathway in how to develop the mining activity that was exempt of social conflicts in the region. By framing the situation as a geoethical dilemma, different scenarios are described considering attitudes and values, in order to explore possible solutions to improve coexistence of communities with mining activity, recognizing that a mining tradition is part of Bages county's cultural identity.

Taking a case study approach to the mining geoethical dilemma, the research highlights the importance of geoethical thinking and proposes to include geoethics in the teaching of geosciences at the UAB to meet the current existing needs and demands according to the strategic academic plan, as described in the Ethical Responsibility framework of the UAB (Ros i Badosa 2021). The plan calls to develop ethical competences to be applied to the different academic degrees before the academic year 2023-2024.

[2] Mining closure may have economic negative impacts on labour markets at local and regional levels and it usually makes a region economically mining dependent with associated risks of being affected by raw materials' global financial markets. Hereby, the paper refers to integral poverty in a broad sense in relation to ecological and spatial justice.

[3] Generalitat de Catalunya: https://web.gencat.cat/en/inici/index.html (accessed 7 December 2022).

The document "Guide to work and evaluate the general competences of the UAB" (Ros i Badosa 2021), produced by the vice-chancellery for Academic Programming and Quality and in collaboration with the vice-chancellery for Students and Employability and the Teaching Quality Office, draws five general skills to be developed. Among these proposed five skills, there is the skill CG03: «Act with ethical responsibility and respect for fundamental rights and duties, diversity and democratic values». The aforementioned document also describes the proposals for application, activities, and evaluation to help to carry out the task. Given this situation, the contribution of geoethics to the Geology degree is considered as a valuable input.

2. Methodology and materials

In recent years, a number of tools have been developed to prevent and mitigate mining-related conflicts (Vanclay et al. 2015; TI Australia 2022). Nevertheless, it must be acknowledged that the relation between mining, society, and environment is deeply embedded in societal and cultural perceptions playing along with political power dynamics (Adey 2011; Falck 2016; Valladares and Booelens 2019) that, in turn, refer to values and beliefs in how humans relate to the geosphere (Bellaubi 2021a,b).

A short survey using Google Analytics shows the growing interest in geoethics during recent years (Figure 1), as well as the number of publications addressing the issue between mining and ethics. In this sense is necessary to highlight the White Paper on Responsibility Mining that sets the Best Practices for Responsible Mining (Arvantidis et al. 2017). In turn, dissemination of geoethics relies on the International Association for Promoting Geoethics (IAPG), a multidisciplinary, scientific platform for widening the discussion and creating awareness about problems of geoethics and ethics applied to the geosciences[4].

[4] https://www.geoethics.org (accessed 7 December 2022).

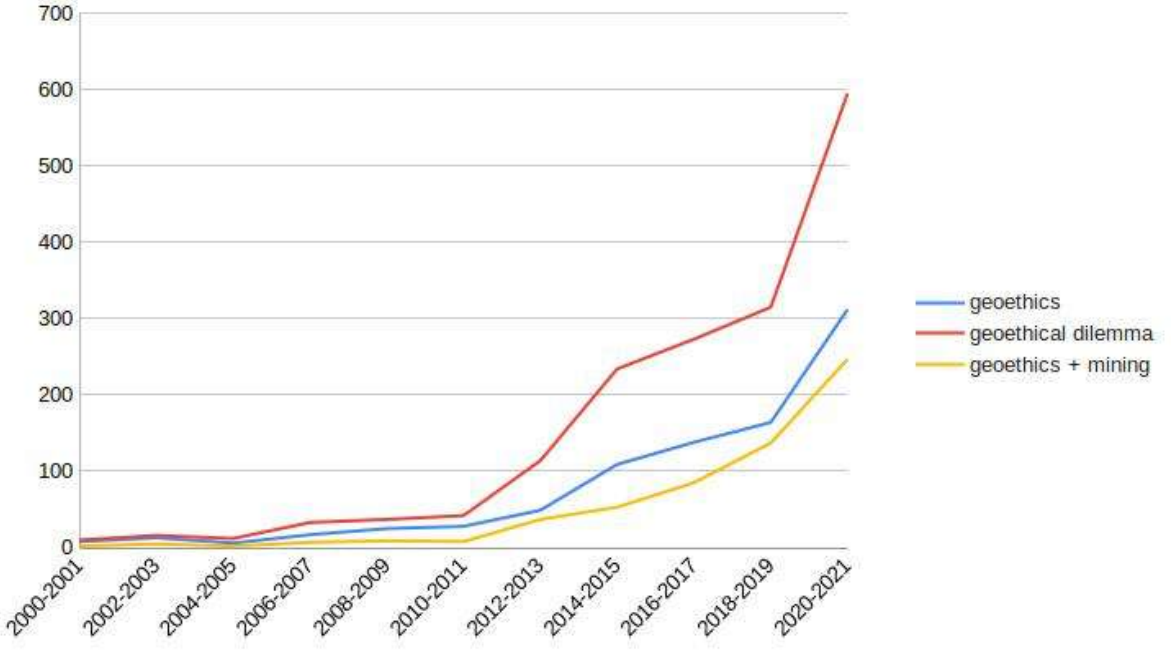

Figure 1. *Evolution of geoethics publications (accumulated) (Source: authors).*

However, the geoethics discipline is not yet very well known among geoscientists and academic institutions teaching earth sciences as well as earth science professionals, and the added value of code of conducts, anticorruption measures, legal frameworks, and corporate social responsibility initiatives is not clearly perceived between scholars and professionals, despite increasing evidence (Jouini et al. 2022; Procesi et al. 2022; Ribeiro et al. 2021; DeMiguel et al. 2021; Marjanović et al. 2022). This is the case with the geosciences department at the UAB where a short survey was administered to professors and academic staff in order to describe the current situation on this topic in the Geology degree. Furthermore, teaching guides and curricula where examined.

The analysis of 43 teaching guides of the Geology degree at the UAB[5] showed two phrases where ethics was mentioned: "Valuing the problems of moral and ethical aspects of research and recognise the need to follow professional codes of conduct" (found in 10 teaching guides) and "Demonstrate ethical and civic

[5] Guides are updated yearly: https://www.uab.cat/web/estudiar/llistat-de-graus/pla-d-estudis/guies-docents/geologia-1345467811508.html?param1=1228117321093 (accessed 7 December 2022).

behaviour during field trips" (found in 1 teaching guide).
Therefore, deontological ethics is considered in 25% of the subjects taught. The results were complemented with 15 interviews with professors and other academic staff (Table 1). From the answers, it can be concluded there is a lack of knowledge about geoethics and its applications, as well as the lack of necessary knowledge to apply it to geosciences teaching. A second round of interviews was carried out to figure out, according to the answers of the interviewees, what could be the feasible ways to apply geoethics to the geosciences teaching in case they saw it as necessary. The answers have been taken into account to develop a proposal on how include the subject of geoethics in the Geology degree at the UAB.

	Yes	Not sure	No
Do you know what geoethics is?	1	1	13
Have you heard about it?	1	7	7
Do you think it is important?	9	2	4
Are you willing to apply it to the teaching?	7	4	4
Do you know how to apply it to the teaching?	0	0	15

Table 1. *Results of the interviews (Source: authors).*

Given the lack of knowledge on geoethics, which contrasts with the existing scientific publications and dissemination efforts at international level, it seemed interesting to show the application of geoethics through a geoethical dilemma to the conflict between mining and society in Bages county[6] as a case study. Considering the result of the geoethical dilemma, the value of teaching geoethics may be acknowledged in order to meet the academic requirements of the Geology degree. This research-based advocacy aims at using research methodologies to change cultural patterns and behaviours as well as influence attitudes and inform decision making. There are other methods to deal with the complexity of geoethical conflicts arising from mining activities (Boon 2020), but unlike the other methods, the geoethical dilemma has a pedagogical approach that unfolds as an agreement process.

[6] Bages county in central Catalonia is located a few kilometres west of the UAB.

2.1 The geoethical dilemma

The geoethical dilemma appears as a geogovernability (Bellaubi and Bustamante 2018) research-based advocacy tool to inform decision making in order to address geoethical challenges in land use derived from geogovernance conflicts (Masson Vincent et al. 2022). In this sense, geogovernability goes beyond georesources management and envisions a resilient territory grounded on values and principles, rather than solutions, by the interpretation of possible future scenarios[7] using geoprospective methods (Voiron 2012) considering interactions of cultural capital (Bourdieu 1986) in relation to geodiversity (Brilha 2016).

In this research, the geoethical dilemma is presented as a visualisation of past, present, and future scenarios considering the geoethical values of social actors who come into conflict with respect to the use of georesources and the resulting land use. The scenarios are qualitatively described by observation and data analysis, although a social-ecological mathematical modelisation is possible (Bellaubi and Pahl-Wostl 2017). Each scenario has a level of uncertainty according to the information available and the outcome scenarios depend on how the dilemma is posed and on the actors who intervene. In the elaboration of the geoethical dilemma, four scenarios are created in the form of a matrix: geoecological tragedy, environmental preservation[8], geoengineering, and territorial resilience. The description of the scenarios, highlighting underlying values, makes it possible to approach territorial development and land use planning from a spatial justice point of view (Soja 2010). The scenarios do not have statistical treatment of data or show trends or correlations, but present an interpretation and understanding of attitudes, social practices, and behaviours considering the values in the relation between the human and the geosphere.

The scenarios are built taking into account two variables, socio-economic vulnerability and geological impact (following the work of Cendrero and Panizza 1999 and Mata-Perelló et al. 2012), which are the result of two actors' interaction holding different values on geological objects either under economic utilitarian values (georesources) or considering their intrinsic value (geosites) (Bellaubi et al. 2021), which in turn reflect on attitudes in mining managerial practices, adopted technical solutions from an environmental geology point of view, and performance outputs in terms of impact and vulnerability (Bellaubi and Boehm 2018). Social

[7] By possible scenarios, we refer to the concept of contingency (Pont Vidal 2019).

[8] The difference between preservation and conservation can be found at https://www.usda.gov/media/blog/2016/03/22/conservation-versus-preservation (accessed 7 December 2022).

actors who are not directly affected by the conflict provide additional information to describe each scenario as realistically as possible. The tragedy scenario is associated with an attitude where the actors prioritise economic values; this causes negative environmental impacts and increases socio-economic vulnerability. In a geoengineering scenario, geoengineering solutions are implemented trying to reduce the negative vulnerability on the human activity. On the contrary, in an environmental preservation scenario, the intrinsic value of the environment is prioritised. The resilient territory scenario describes a situation in which the different actors who intervene in the territory assume an attitude of collaboration among themselves, according to principles of solidarity and responsibility; hence, the territory enhancing its geodiversity (Ellis et al. 2021) while enduring its cultural capital. In practice reaching a resilient territory scenario requires geoprospective methods (Voiron 2012) combining territorial prospective and participatory social-ecological modelling through a continuous agreement (concertation) process[9].

2.2 The case study method

The geoethical dilemma is developed through a case study. A case study is a qualitative research methodology (Alvarez and San Fabian 2012) with the following characteristics.

a) A description of the context is carried out and the relationship between the particular situation and its context is observed.
b) It has a holistic approach. Reality is seen as taking into account all the phenomena in their complexity.
c) They are faithful to the phenomenon being investigated through a reflection of the peculiarity and particularity of the situation.
d) They are heuristic. They aim to awaken readers' willingness to understand.
e) They are the result of empirical data analysis, observations, and participatory interviews.
f) They study current phenomena and, therefore, there is a renewal of information and constant involvement on the part of the researcher.
g) They interrelate data and have numerous sources of information and analysis.

[9] https://www.lisode.com/home/ (accessed 7 December 2022).

Alvarez and San Fabian (2012) suggest doing a case study when the object to be investigated is diffuse, complex, hidden or controversial. Therefore, it is recommended to use this method to analyse situations and problems strongly linked to the context in which they occur. In the case study of this research, there is a strong link between the socio-economic context and the geological process of subsidence resulting from the mining activity.

As mentioned, the selected case study relates to the mining conflict in the Sallent area in Bages county and more specifically to Barri de l'Estació in Sallent. The case has appeared in the media when a total of 522 people were relocated from their homes in 2009 due to the cracks and fractures of the inhabited buildings. The reason for the damaged buildings was associated to the subsidence in relation to the on-going mining activities, although lately geological studies demonstrated the subsidence is inherent to the geological characteristics of the subsoil and the mining activities exacerbated the natural process.

The case study unfolds as follows. Firstly it presents the local geology of the Catalonia Potassic Basin, trying to clarify the subsidence process associated with mining activities in Barri de l'Estació of the Sallent municipality. The next step formulates the geoethical dilemma, qualitatively describing past, present, and future possible scenarios with the information available in the public domain considering how mining activities are currently carried out in other locations of the Catalonian Potassic Basin. The discussion of the results reflects on how framing the case as a geoethical dilemma allows interactions and synergies between geology and society to be identified and analysed when considering the different values of the actors involved in the conflict, in order to foresee the possible impacts and vulnerabilities in land use and the environmental planning associated to mining activities.

3. The case study of Barri de l'Estació (Sallent)

3.1 Socioeconomic context and subsidence

Sallent is a municipality of 65.63 km² in Bages county (province of Barcelona) and extends on both sides of the Llobregat river (Figure 2). During most of the 20th century, it was a town that developed from potash mining (Fàbrega and Enfedaque

2017). Currently, potash deposits are exploited by Iberpotash[10], which is part of the ICL mining group involving around 1100 workers. Total production is estimated at 1 tn/year of potash of which 80% is exported. After the discovery of the Súria potash mines in 1912, Spain invested in the search for more potash deposits in the Catalan Potash Basin. This investment paid off with the enlargement of mining activities between 1918 and 1934 in the mines of Súria, Cardona, Sallent and Balsareny municipalities. From that moment until the present day, several mines were exploited except for Balsareny, which did not come into operation. The Cardona mine stopped its operation in 1990 and Sallent and Súria have suffered various problems (work accidents, flooding, cavity collapses), but they are still in operation under different technical conditions than originally planned (Fàbrega and Endefaque 2017).

Figure 2. *Location of Barri de l'Estació neighbourhood in Sallent municipality (Source: Google Earth).*

[10] https://www.icliberia.com/productos/potasa/ (accessed 7 December 2022).

The case study focuses on the problems related to the subsidence of the Barri de l'Estació that caused the evacuation of the neighbourhood (see Figure 3). At present, the neighbourhood is an unoccupied space. Subsidence is a progressive and more or less regular local or regional sinking of the Earth's surface that does not consider the lateral movement, the duration or the scale of the phenomenon (Diccionari de la Geologia de l'institut d'Estudis Catalans 1997). In this case study, subsidence is due to combined anthropogenic and natural geological factors: mining activities conducted in soil prone to subsidence because of the dissolution of salts. The degree of involvement of each factor cannot be determined due to a need for further geological studies.

Figure 3. *Evolution of Barri de l'Estació from 2009 to present. Nowadays, the neighbourhood remains an empty space (Source: Google Maps. Photos: authors).*

The Barri de l'Estació neighbourhood is located on the potash exploitation limits of the old Enrique Mine, which was operational between 1923 and 1974 with a depth of 260 meters and exploited intensively. The mining exploitation method was through a system of rooms supported by pillars occupying 20% of the surface (MONTSALAT Civic Platform)[11].

The mine has been in the spotlight since 1934, when it was found it was suffering from several water intrusions. As a result of flooding in 1954, a gallery was drilled to find the cavity where the water had accumulated. The cavity was 28 m in diameter and about 110 m deep and had filled up with many materials that detached from both the walls and the ceiling of the cavity. This large cavity was

[11] The MONTSALAT Civic Platform brings together, since 1997, environmental groups and neighbourhood associations directly affected by the proximity of saline debris or salinized water to their properties: https://montsalat.cat/ (accessed 7 December 2022).

used to dump the brine generated by the mine (PROCICAT 2012).

Due to various problems (occupational accidents, insufficient maintenance, water infiltration), the mine was abandoned in 1976-1977 and it was filled with waste materials with a high content of NaCl to stabilise the processes of salts' dissolution and, consequently, soil collapse (Geocat Gestió de Projectes S.A. 2009). Unfortunately, in 1997, it was noticed that several buildings in the neighbourhood suffered from cracks and soil settlements. Facing the situation, the Department of Territorial Policy and Public Works of the Catalan regional authority commissioned the Geological Institute of Catalonia to carry out studies to determine the magnitude of the problem. As a result, monitoring of the area was agreed to determine the evolution of the subsidence and preventive and control measures were put in place. The work carried out included implementation of a high-precision alignment network and application of InSAR techniques[12], geophysical studies, geotechnical subsoil drilling, movement controls, in-situ and ex-situ tests, geological and hydrological studies, and geomechanical modelling. The objective of the studies was to delimit the different stratigraphic units and to know where the water infiltration occurred. One of the methods used to estimate the levels of subsidence in Sallent was the calculation of the angular distortion, as shown in Figure 4 (Rodriguez-Lloveras et al. 2017).

As indicated in the Emergency Action Plan (PROCICAT 2012)[13], the relationship between subsidence and damage to buildings depends on different factors (subsidence rate, mining exploitation time, typology and orientation of geological structures). For this reason, vulnerability maps were made showing the inhabited buildings in the Barri de l'Estació neighbourhood (Figure 5). The Emergency Action Plan (PROCICAT, 2012) mentioned the basic protection measures for the population with the information and evacuation procedures in the event of a foreseeable collapse of the soil and collapse of the buildings.

[12] https://www.usgs.gov/programs/VHP/insar-satellite-based-technique-captures-overall-deformation-picture (accessed 7 December 2022).

[13] PROCICAT, Territorial civil protection plan of Catalonia, is applied to manage risks or emergencies not included in the special plans and which may affect a considerable volume of people at the same time, or which may have significant repercussion. https://interior.gencat.cat/es/arees_dactuacio/proteccio_civil/plans_de_proteccio_civil/plans_de_proteccio_civil_a_catalunya/plans-territorials/procicat/index.html (accessed 7 December 2022).

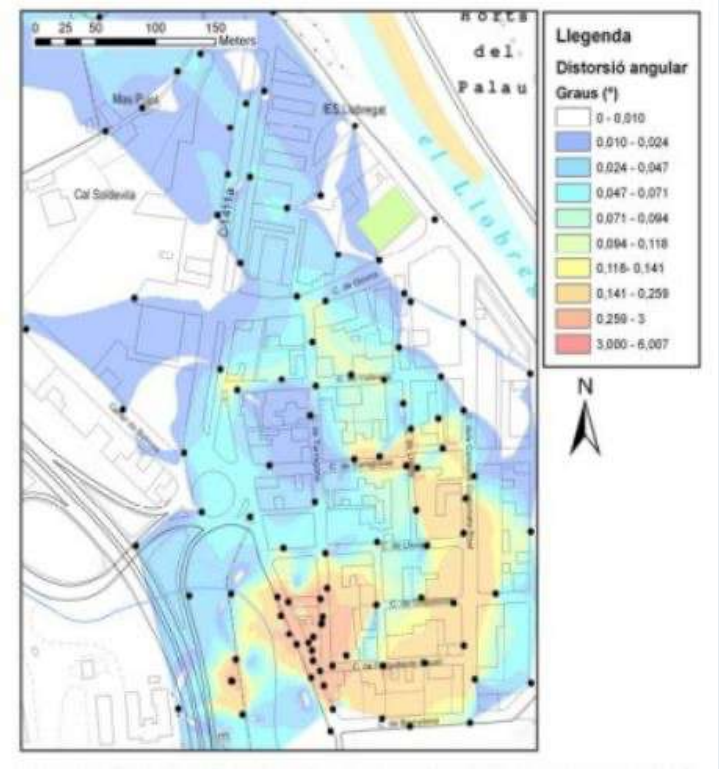

Figure 4. *Representation of angular distortion in Barri de l'Estació (Source: PROCICAT 2012).*

It must be noticed that while the cracks in the buildings were growing and the problem in relation to the subsidence became more evident, the Sallent City Council continued to catalogue the area as suitable for urban development and issued construction licences. It was in 2000 when the land use type was modified by the General Direction of Urbanism and Planning (Catalan regional Authority). As a result of this land use change, negotiations took place to compensate for the economic losses and the resettlement to geologically safer neighbourhoods. To carry out the resettlement, the Catalan Soil Institute (INCASOL)[14] built two apartment blocks for social housing for 40 families in Sallent city (MONTSALAT Civic Platform).

The studies carried out determined an emergency evacuation plan for 522 people who could be resettled from their homes in case of activation of the plan. It also

[14] https://incasol.gencat.cat/es/inici/index.html (accessed 7 December 2022).

took into consideration potential interruptions with gas, water, and electricity services in case of emergency. Also a High School was involved in the emergency plan as being affected by possible damages.

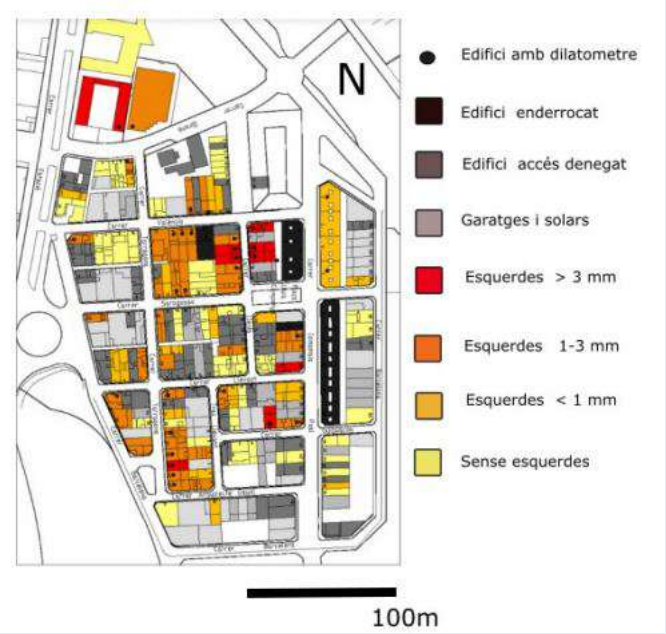

Figure 5. *Buildings with crack damage ("esquerdes") in 2012 (Source: PROCICAT 2012). Deep grey: collapsed building; grey: building with forbidden access due to damage; light grey: empty lot; black dot: measurement point.*

3.2 Geology[15]

From a geological point of view, Bages county is located in the NE sector of the Ebro Basin. This sedimentary basin is limited to the north by the Pyrenees and to the southeast by the Catalan Coastal Ranges.

The evolution of this sedimentary basin is related to the progression of the Pyrenean reverse-thrust faults complex towards the south and the simultaneous formation of the Serralades Costero Catalanes. The basin was replenished with sediments that reflect a transition from marine to continental conditions during the Eocen and Oligocen periods (56 Ma until 13 Ma). From the end of the

[15] This section is a geological synthesis of the book "Excursiones geológicas por la Cataluña Central" (Oms et al. 2016).

Priabonian (Upper Eocene) to the Miocene, sedimentation was characterised by a succession of lacustrine systems (carbonates and evaporites) interspersed with alluvial fan systems that received sediments from the active margins of the Basin. As a result of the precipitation stage of the evaporites (chlorides and sulphates), in the Bages region there is a deposit of halite (sodium chloride). Sylvite (potassium chloride), usually mixed with halite, forms a more extensive deposit. Another evaporite that is associated in a smaller proportion to the previous ones is carnallite (hydrated magnesium and potassium chloride). The total thickness of the evaporitic sequence reaches 300 m. The potash unit is part of this sequence and consists of a lower sylvite member (about 5 m thick) and an upper carnallite member (up to 40 m thick). The sylvite member was mined for potash until 2020.

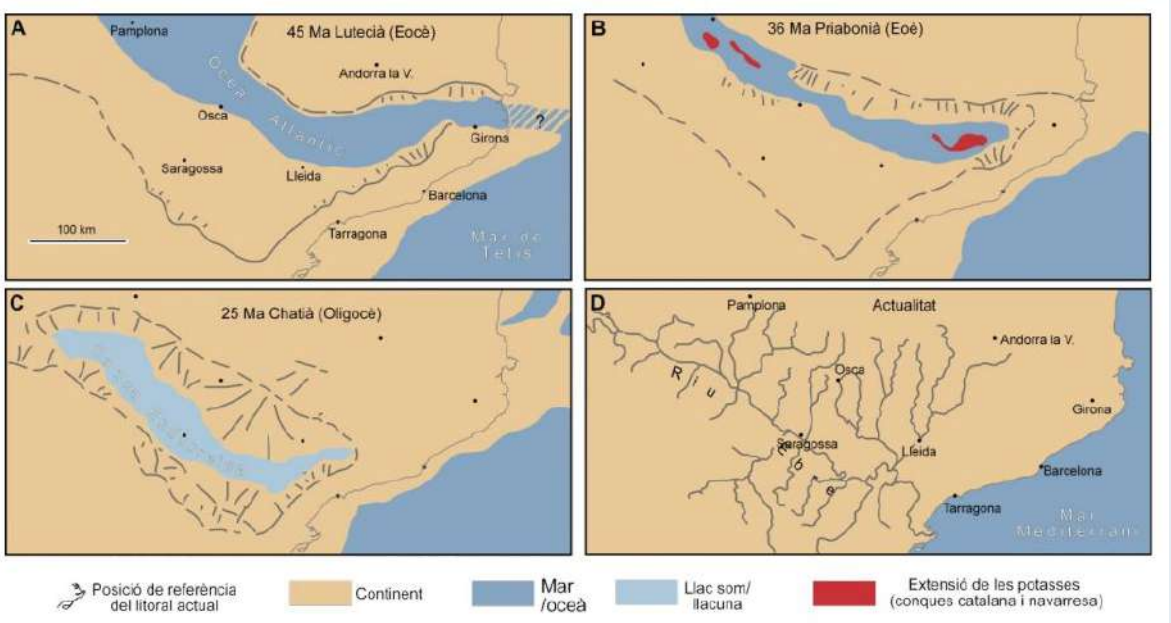

Figure 6. *Paleogeographical evolution of the eastern part of the Ebro Basin during the Paleogene (A, B and C) compared to the present time (D). Legend: continent (grey), sea (dark blue), lake (blue), potash basin (red) (Source: "Excursiones geológicas por la Cataluña Central," Oms et al. 2016, p. 44).*

From oldest to most modern, the following stratigraphic units are established in the study area (Figure 7):

- *Santa Maria Gp*: set of formations (limestones, marls, and sandstones) of

marine origin (reef, prodelta and deltaic front environments).

- *Òdena Fm*: chalks that mark the beginning of evaporitic precipitation at the end of marine sedimentation in the Ebro Basin.
- *Cardona Fm*: evaporite deposits (chlorides) that present the following units:
- *Lower chloride unit*: banded halite interval. About 200 m thick.
- *Upper unit of chlorides*: interval of banded halite and potassium chlorides (sylvite and carnallite), which alternates with thin sheets of grey clays. The thickness of this unit varies between ten and a hundred meters. At the base of this unit are the exploited layers of potash (in some areas, there are two close layers, one almost 3 m thick and the other around 1 m thick).
- *Halite interval alternating with grey shales*. Thickness of several meters.
- *Artés Fm*: shales and sandstones of the alluvial system (alluvial fans) from the Catalan Coastal Chain. Includes outcrops of lacustrine limestones (Sallent limestones). It has a maximum thickness of about 800 m.
- *Barbastre Fm*: grey chalks with a laminated appearance formed in endorreic lagoons. They do not surface in the study area.
- *Súria Fm*: sandstones and red shales of mixed alluvial and lacustrine character. They come from sedimentation in the distal parts of the Pyrenean alluvial system. The upper part of this formation is characterised by episodes of shallow carbonate lakes. They have a thickness of 400 m.

In the study area, the rock strata are deformed (salt tectonics) due to the plastic nature of the salt. When subjected to great pressures, during the Alpine orogeny, the plasticity facilitated an upwards (diapirism) movement with a surface emergence given its lower density compared to the rocks above it. These rocks were also affected by folds and faults, highlighted in the study area by the reverse-thrust fault of Sallent, which is part of the "Falla del Guix" complex with associated normal and reverse faults[16]. Frequently, the rocks of the previous formations are covered by detritus materials from the Pleistocene and Holocene.

Figure 8-A shows a simplified diagram of the main reverse fault associated with the Sallent thrust, which takes advantage of the plastic characteristics of the evaporites and affects the Cardona, Súria, and Artés formations.

The geological configuration of the Falla del Guix complex, the brine resulting from the saline materials extracted from the exploitation of the Fm. Cardona, and the presence of the Soldevila stream and the Llobregat river have favoured the

[16] https://elmedinaturaldelbages.cat/es/geologia-es/la-geomorfologia/falla-del-guix-sallent-2/ (accessed 7 December 2022).

formation of several underground sinkholes and voids. One of these voids ("Bófia") is located under the Barri de l'Estació neighbourhood (Figure 8-B).

It should be noted that before mining activity began, the existence of some of these sinkholes was already known. These "drop-out" sinkholes are formed by a geological process that consists of the infiltration of subsurface water where there are rocks susceptible to being dissolved - as is the case with the Cardona and Barbastre formations. These materials are below a relatively strong clay-cohesive soil, so the progressive dissolution of the underlying material causes the creation of underground caverns and the sudden collapse of the clay soil. The geochemical processes trigger a natural subsidence that occurs when the waters of the Llobregat river and the Soldevila stream penetrate into the subsoil through the fractures of the "Falla del Guix" complex. When the water reaches the levels of carnallite [KCl $MgCl_2$ 6(H_2O)] of the Cardona formation, the dissolution of chlorides occurs, releasing potassium, magnesium, and chlorine ions, in addition increasing the amount of water by releasing 6 water molecules.

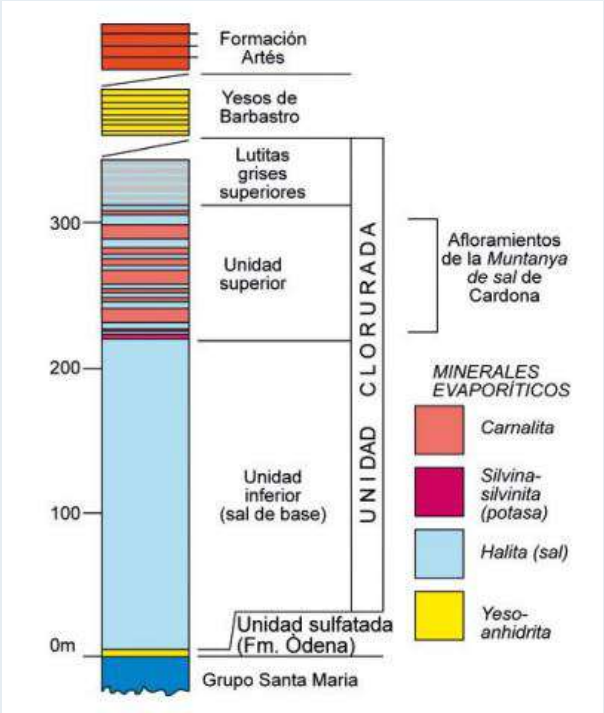

Figure 7. *Eastern evaporitic succession of the Ebro Basin (Source: "Excursiones geológicas por la Cataluña Central", Oms et al. 2016, p. 34).*

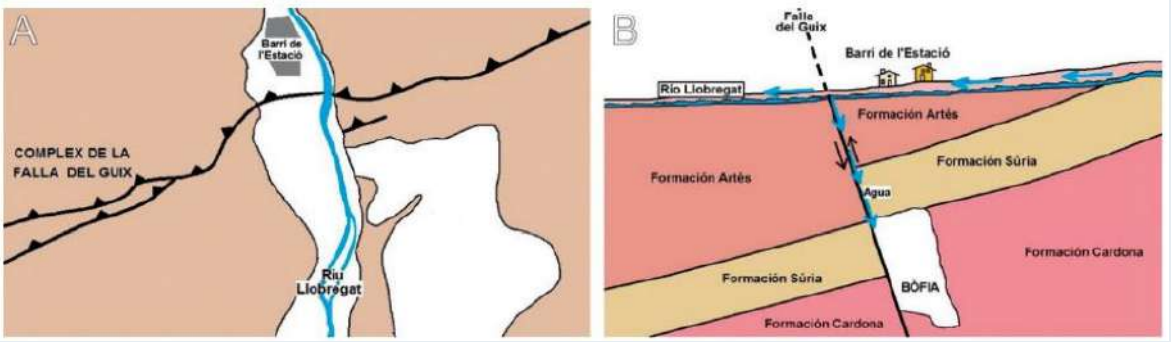

Figure 8. *A) Location of the Llobregat river, the "Falla del Guix" (Guix reverse fault) complex, and the Barri de l'Estació neighbourhood. B) Geological diagram showing the stratigraphic units, the "Falla del Guix" (Guix reverse fault) complex, the surficial water flow of the Llobregat river, the water infiltration along the reverse fault, and the underground cavity (Bófia) (Source: "Excursiones geológicas por la Cataluña Central", Oms et al. 2016, p. 141).*

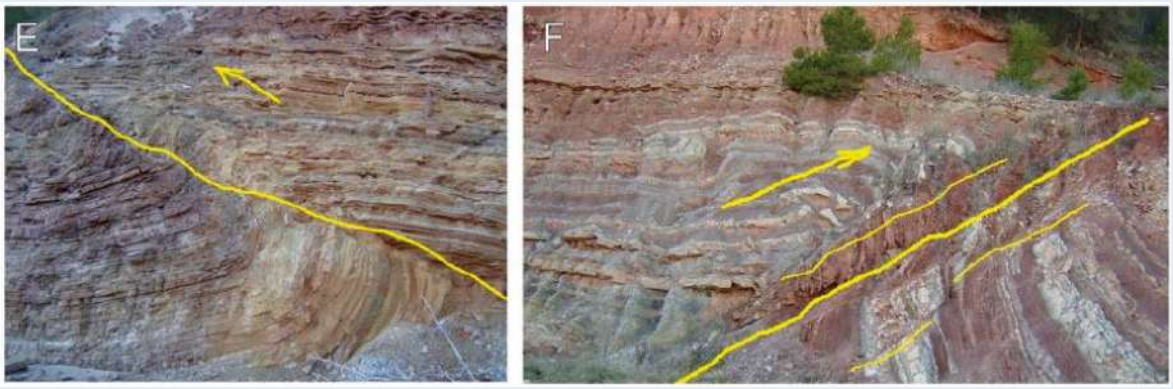

Figure 9. *E) Aspect of one of the fractures of the "Falla del Guix" (Guix reverse fault) complex in the surroundings of Sallent. F) Aspect of a reverse fault of the "Falla del Guix" (Guix reverse fault) complex (Source: "Excursiones geológicas por la Cataluña Central", Oms et al. 2016, p. 140).*

4. Geoethical dilemma scenarios

In order to frame the Barri de l'Estació case study as a geoethical dilemma, the specific situation and outcome in terms of impact and vulnerability are described

in the geoecological 'tragedy' scenario. The three other scenarios, called environmental preservation, geoengineering, and territorial resilience, are based on current situations within the Catalonia Potassic Basin that may serve as possible alternatives in terms of land use pathways if different mining managerial practices are taken into consideration according to utilitarian and intrinsic geoethical values that, in turn, shape technical solutions with associated vulnerabilities and impacts. These are likely to be comparable cases, due to the stratigraphic lateral continuity of mined strata within the basin[17] and the similar social and environmental setting. The impact and vulnerability of each scenario is summarised in Table 2.

Regional administration as observers	Local population Mining activity is broadly accepted because of economic benefits	Local population Preservation of natural heritage becomes a priority
Mining company. Mainly seeking economic benefits.	1. Geoecological Tragedy (Barri de l'Estació, Sallent). Impact: underground mining causes subsidence increasing the process of natural subsidence in the area. Vulnerability: relocation of the neighbourhood with economic losses and closure of the mine.	2. Environmental Preservation (Mina Muga). Impact: land reclamation, transformation of the landscape damaged by mining in green areas for the population. Vulnerability: The mining company must close and make a high investment without further profit.
Mining company. Corporate social responsibility (CSR) implementation.	3. Geoengineering (Muntanya Cogullo). Impact: soil stabilisation by refilling cavities, treatment of mining debris on the surface (leakages, visual impact). Vulnerability: Economic costs of technological investment without necessarily improving corporate image.	4. Territorial Resilience (Geoparc Catalunya Central). Impact: Responsible mining committed to protection of the cultural and geological heritage, territory as "living lab". Vulnerability: Need of agreements beyond political agendas between civil society and mining company, administration investment.

Table 2. *Description of the geoethical dilemma scenarios.*

[17] Steno's Principles of Stratigraphy are applied: https://www.geologyin.com/2014/03/stenos-principles-of-stratigraphy.html (accessed 7 December 2022).

4.1 "Geoecological Tragedy" scenario

This scenario refers to the impacts in relation to the problem of subsidence related to the mining activity in the Barri de l'Estació neighbourhood. The situation has been previously described in detail in section 3.1. Although it was not possible to have access to the anthropic hazard maps of the specific area, a map where the activity of the old Enrique Mine overlays the Barri de l'Estació neighbourhood is shown in Figure 10. The map clearly shows the galleries of the mine occupied almost the entire subsoil of the neighbourhood Barri de l'Estació.

The interpretation of the situation regarding the actors' values and attitudes suggest the mining company that operated in the area for years continued to do so even though it was known that it was likely there would be impacts due to subsidence when underground mining of potash is carried out with water infiltration. Perhaps there was not enough environmental control at that time or not enough control measures were taken into consideration in favour of obtaining rapid economic benefits for the company and, more indirectly, for local economic development through jobs and infrastructure.

4.2 "Environmental Preservation" scenario

In the environment 'preservation' scenario, intrinsic environment values by local communities are put up-front and the mining activity is forced to stop due to social pressure[18], but with associated economic vulnerability effects by the ceasing of a regional economic activity. The closure of miming activities implies a restoration of the area affected by the mining activity. It should be taken into account that normally, and contrary to the case of what happened in Sallent, restoration plans are created in parallel with the progress of the mining activity or previously, according to regional and national environmental legislation. In the presented case study, the restoration plan was not made timely to cover negative environmental impacts and was made afterwards.

The law considers some of the restoration and reclamation methods by filling up cavities with debris and demolition materials. In this case, the "Guide for the rehabilitation of mining holes with construction and demolition waste" applies and elaborated by the Spanish Ministry for the Ecological Transition (Alberruche del

[18] One of the most active environmental organizations is the MontSalat Civic Platform (see note 12).

Campo et al. 2018). It is important to note that beyond legal regulations, a key element is to develop these plans in collaboration with local communities; the benefit to the mining company being that it makes it much more likely that they will retain community support to develop future mining activities. This may involve a kind of external independent or citizens' monitoring to follow up if restoration and reclamation are implemented according to the approved plans.

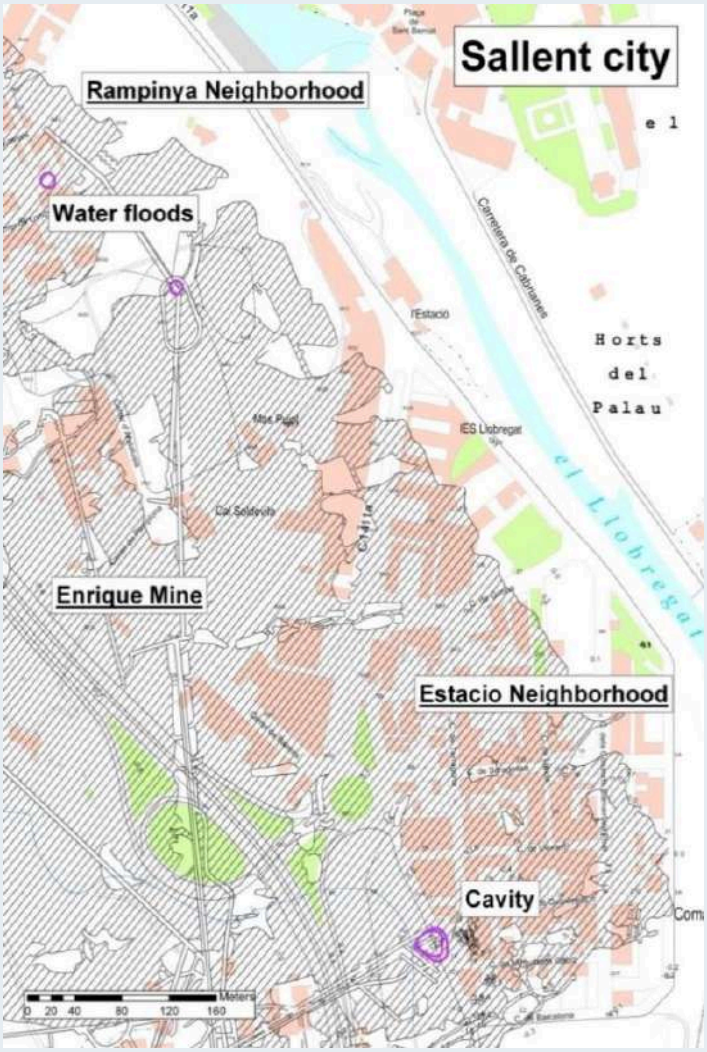

Figure 10. *Location of the limits of the Enrique Mine and the entry points of the different flood events (Source: Rodriguez-Lloveras et al. 2017).*

An example of a rehabilitation plan in a potash mine on the western side of the Potassic Basin (Navarra) is la Mina Muga (Figure 11)[19] operated by Geoalcali. The rehabilitation plan includes a preliminary draft of definitive abandonment of the mining site, where the measures are defined in order to guarantee the safety of people and property. In the case of Mina Muga, an underground mining method is carried out, as in Sallent. The refilling of the Muga Mine is done with the same debris from the Muga mine, thus eliminating the temporary superficial deposits, as happens with the case of "Muntanya de Sal del Cogulló", a mountain of salt debris from the mine located in Sallent[20]. Once the mining activity is dismantled, the plan indicates that the surface will be conditioned to recover its previous natural state. To carry out this task, soil and vegetation are brought in, including in some cases fauna (Geoalcali 2020).

After all the treatment described in the appropriate restoration plan is concluded, the area can be rehabilitated as a green space, or flora and fauna protection space, intended for the educational, cultural, and leisure benefit of the local population.

Figure 11. *Exploitation plan in Mina Miga (Source: Geoalcali 2020).*

[19] https://www.geoalcali.com/muga/ (accessed 7 December 2022).

[20] https://elmedinaturaldelbages.cat/es/factores-ambientales/impactos-ambientales/escombrera-salina-de-cogullo-sallent/ (accessed 7 December 2022).

4.3 "Geoengineering" scenario

The 'geoengineering' scenario prioritises the economic utilitarian value of the georesources often in hand with corporate social responsibility (CSR) voluntary initiatives to minimise health, environmental, and social community concerns. However, the implementation of geoengineering solutions based on increasing efficiency rationale faces the so-called Jevons paradox, leading to the opposite effect that solutions are trying to correct[21]. Furthermore, CSR approaches fail to consider cultural aspects (Jenkins and Yakovleva 2006), not only in terms of geoheritage (geo-mining historical heritage), but the importance of geographies in relation to local identities. This is due to the fact that the cultural-spiritual dimension does not fall under sustainable approaches; however, the cultural-spiritual dimension is key in rebuilding local communities' cohesion (McIntosh 2020), fostering local-based economies, citizens' engagement in decision making (especially when participatory processes are increasingly bureaucratised), and environmental protection[22]. CSR usually fails in going beyond compliance aiming to develop excellence management practices (Bellaubi and Boehm 2018), setting compensatory mining rates or recognition of territorial identities (Bellaubi 2021a,b)[23].

In the case study location of Sallent, ICL is implementing the Phoenix Plan[24]. This project developed by the ICL group and presented in the year 2011-2012, proposes different stages in the mining activities considering a CSR approach. In the first phase, the company mentions their aim to make the exploitation environmentally sustainable. To carry out this step, there is a plan to move workers from Sallent to the Súria Mine, enabling the logistical treatment plant to remain in place in the Sallent and Balsareny mines. Another relevant point to make the exploitation sustainable is the management of the "Muntanya de Sal del Cogulló". For this reason, management methods will be adapted at the same time the exploitation in the Sallent area will stop. The method used in order to

[21] https://econation.one/blog/the-paradox-of-efficiency/ (accessed 7 December 2022).

[22] The specialist group on Cultural and Spiritual Values of Protected Areas (CSVPA) of the International Union for Conservation of Nature - World Commission on Protected Areas (IUCN-WCPA) promotes cultural and spiritual values in nature conservation beyond protected areas developed, https://csvpa.org/ (accessed 7 December 2022).

[23] This is an important point when addressing ecological justice considering representation (political dimension), redistribution (economic dimension), capabilities (social dimension), and recognition (cultural dimension) (Kortetmäki 2016). In turn, spatial justice (Soja 2010) highlights the geospatial dimension of the embeddedness in the Human-Geosphere relationship. In this sense, spatial justice overcomes the utilitarian-intrinsic values dichotomy (Bellaubi et al. 2021).

[24] https://icl-group-sustainability.com/reports/the-phoenix-plan/ (accessed 7 December 2022).

remove the salt mountain debris will take 50 years to be accomplished (ICL Iberia Magazine 2019).

Figure 12 shows a diagram of the planned treatments to be carried out around the salt debris mountain. The corrective measures considered to eliminate the mountain of debris in the long term are: two perimeter channel networks for each reservoir that prevent runoff water from entering the reservoir (red lines in Figure 12) and, on the opposite side, a network that collects the brine and sends it to a dam (green lines in Figure 12). The water will also be analysed to see the geochemical evolution of the Cogulló Mountain (ICL, 2011-2012)[25].

Figure 12. *Management of the salt debris of Muntanya del Cogullo (Source: ICL 2019).*

[25] https://icl-group-sustainability.com/reports/managing-the-salt-deposit/ (accessed 7 December 2022).

4.4 "Territorial resilience" scenario

This scenario presents a situation where synergies between mining activity, local communities, and environmental protection are brought together considering the positive outcomes of previous scenarios, lessons-learnt, and the "know-how" in terms of social learning and adaptive management (Pahl-Wostl et al. 2007). The scenario does not intend to represent an "optimal" outcome, but a comprehensive future and desirable visualisation of a territory embedding utilitarian and intrinsic values of geological objects as relational goods (Bellaubi et al. 2021). This visualisation unfolds in territorial development plans generating resilient territories by sharing a common vision based on geoethical values and principles[26] by following an agreement process.

The resilience of a territory goes in hand with the robustness of social institutions (Williaarts et al. 2013). Based on Turner et al. (2003), resilience and robustness may define the ability to cope in view of possible impacts and vulnerabilities, increasing the capacity to adapt by enhancing geodiversity and transforming institutions through innovation at the same time as enduring cultural capital, so territorial innovation is related to resilient communities. This goal is achieved by considering public-private-community partnerships, such as social-ecological spiritual entrepreneur ventures (Ramis Pujol et al. 2015), civic entrepreneurship[27], economy of communion as a business model (Fernández-Fernández and Diaz de la Cruz 2019), or community benefits agreements (CBA) that do not result from the application of specific legislation and policies, but rather from local collaboration through a multifaceted system response to a territorial challenge (Soja 2010).

To move towards this territorial outcome in the Bages County, it is necessary to consider responsible mining management practices. As stated in the White Paper on Responsible Mining, "Responsible mining demonstrably respects and protects the interests of all stakeholders, human health and the environment, and contributes discernibly and fairly to broad economic development of the producing country and to benefit local communities, while embracing best international practices and upholding the rule of law" (Arvantidis et al. 2017, p. 2).

The visualisation of this scenario is shown in Figure 13, taking as starting point the Geopark of Central Catalonia[28] located in Bages county and considering the areas of geological and mining interest that coexist with the mining activity. In

[26] An example can be found in the Cochabamba's Water Agenda (Bellaubi and Bustamante 2018).

[27] https://www.galgael.org/ (accessed 7 December 2022).

[28] https://www.geoparc.cat/en/ (accessed 7 December 2022).

order to reach this scenario, stakeholder involvement is necessary to look after the joint interests of the social actors sharing cultural values who are willing not only to engage, but commit to a continuous agreement process (concertation) that looks at a common territorial development strategic vision.

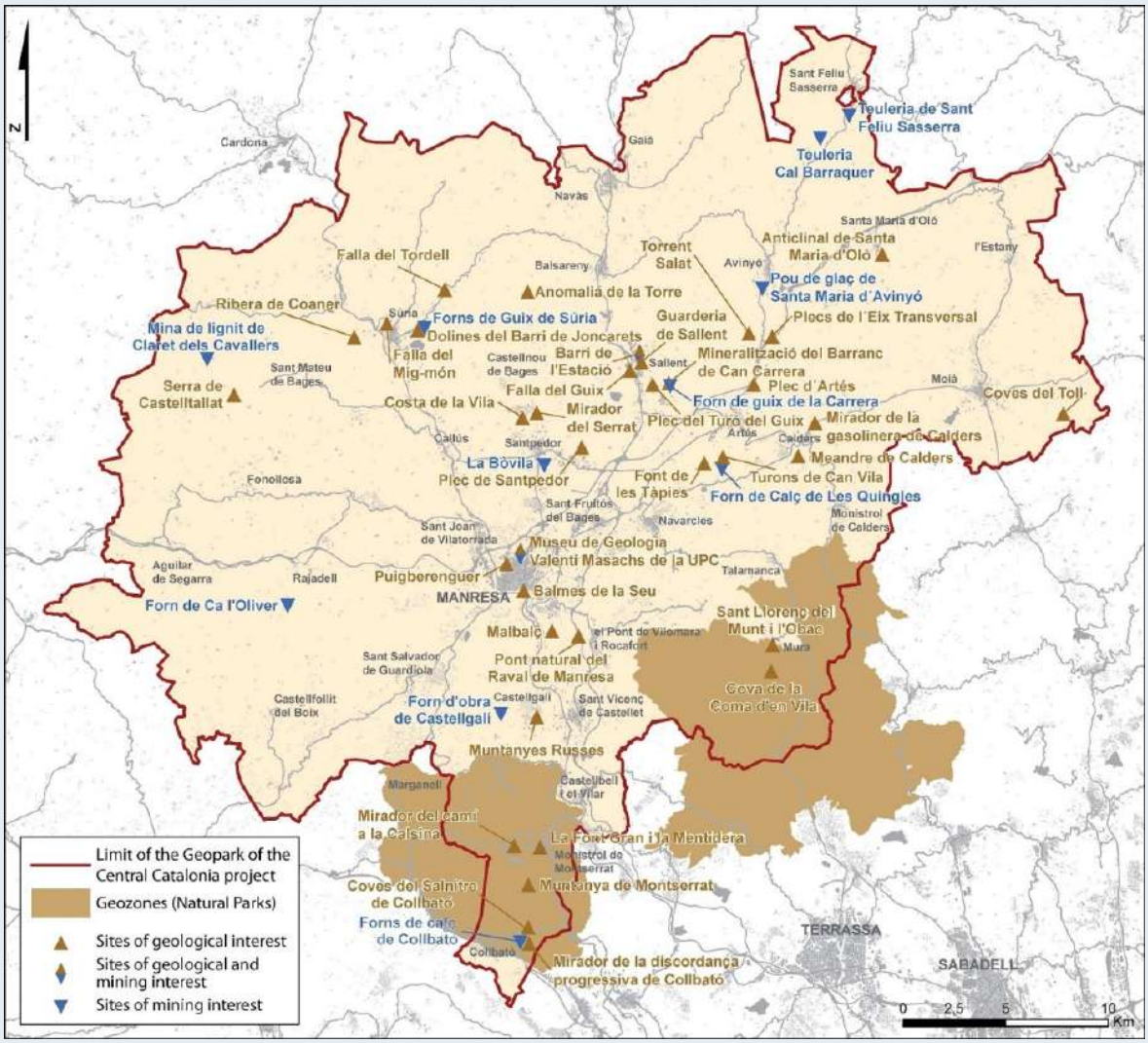

Figure 13. *Main interesting point in the Geopark of Central Catalonia (Source: Mata-Perelló et al. 2007).*

The Geopark of Central Catalonia, designated by UNESCO in 2015, emerges as a social need to respond to the request to protect the natural and cultural heritage of Central Catalonia (Climent Costa et al. 2011; Oms et al. 2019). Bearing in mind that inside the Geopark mining activities coexist with natural protected areas, such as the Montserrat Nature Reserve & Natural Park[29] and other kinds of economic activities affecting land use, it makes the situation very challenging. The Geopark aims to use the territory as a pilot area for geodiversity in collaboration with the Planning and Sustainability Department of the Catalan regional authority. Thus, the Geopark should monitor the preservation of land use in two different cases: development land and legally protected spaces (Climent Costa et al. 2011).

The coexistence of georesources exploitation with the protection of the environment is not new and has antecedents with the American model that integrates preservation (natural parks) and conservation (forest parks). This means the Geopark could develop into a resilient and innovation territory taking into account the sustainable development goals (SDGs)[30], becoming a "Living-lab" where nature-based solutions could be implemented in facing social-ecological challenges (Lupp et al. 2021). The EU defines Living-labs[31] as "user-centered, open innovation ecosystems based on a systematic user co-creation approach integrating research and innovation processes in real life communities and settings. In practice, Living Labs place the citizen at the centre of innovation, and have thus shown the ability to better mold the opportunities offered by new ICT concepts and solutions to the specific needs and aspirations of local contexts, cultures, and creativity potentials" (Lupp et al. 2021, p. 6). An interesting ongoing experience of a Living-lab as a resilient community and territorial innovation in southern Catalonia is CRIT® carried out by Fundació Cívica INNOMNIUM. CRIT® is a model of territorial innovation in which, from territorial challenges and considering geoethics, solutions are developed and agreed, with participation by local knowledge communities to identify, implement, and certify each of the phases of public, private, and community initiatives through digital tools[32].

According to this idea, the territory of the Geopark becomes a space for research and dissemination, civic entrepreneurship which allows innovation, fostering public

[29] Christian monastery with centuries old hermitages, which has been a pilgrimage centre since the 14th century. Today, it is the most heavily visited protected area of Spain. Category V in the IUCN Protected Landscape classification: protected area managed mainly for landscape/seascape conservation and recreation.

[30] https://sdgs.un.org/goals (accessed 7 December 2022).

[31] European Commission. *The European Agenda for Research and Innovation 2014–2020*; European Commission: Brussel, Belgium, 2013; Available online: http://s3platform.jrc.ec.europa.eu/living-labs (accessed 7 December 2022).

[32] https://www.innomnium.cat/ (accessed 7 December 2022).

investment, and local initiatives where it is possible to interact with the cultural and geological heritage without this implying the closure of the mining activity.

To consider the Geopark of Central Catalonia as a "Living-lab" territory would mean citizens are involved in the creation of a resilient territory and innovative initiatives, co-living with mining activities and enabling geogovernability. A few examples would be: the monitoring of subsidence, water and soil quality or follow-up of ongoing restoration plans under a citizens science approach[33], universities and educational institutions carrying out educational and professional training practices in the mining sector for students at the UPC School of Mines and the faculties of geology of the University of Barcelona and the UAB. The private sector could develop civic entrepreneurship hubs and start-ups related to innovation in the mining sector, whilst the mining company could open participation of shareholding to local associations or invest in geotourism under geoethical principles (Peppoloni and Di Capua, in press) to protect the geo-mining historical heritage (Llurdes et al. 2016), or even invest in health and environmental well-being regional projects in a way mining benefits are reinvested in the prosperity of Bages county. This would make the mining activity more transparent for citizens (Riberio et al. 2021), at the same time that ICL group goes beyond compliance of CSR policies, being involved and promoting local investments. Under this view, ICL does not only seek economic benefit, but boost social and environmental welfare and engages in a management excellence competency.

Discussion

The geoethical dilemma applied to the case study of the Barri de l'Estació neighbourhood in the Sallent municipality in relation to mining activities allows, through the description of different scenarios, exploring solutions involving the agreement between the society and the mining activity, and considering the protection of the environment in Bages county.

Agreement is only possible if room for transparent, scientifically informed dialogue is enabled with the participation of the society (associations, town council, and neighbourhood associations) and the mining company operating in the region. The dialogue must be open to the participation of the Geopark of Central Catalonia, the Cartographic and Geological Institute of Catalonia, and other observers in the region. It is

[33] https://citizenscience.org/ (accessed 7 December 2022).

worth mentioning that in Catalonia a similar process was initiated in the Tordera Delta[34]. The following three points are proposed to start this dialogue process:

1. To establish monitoring of subsidence progression due to mining and to geological processes. For this, it is necessary to deepen the geological knowledge and develop a soil subsidence model while involving the population in active monitoring of subsidence. This could help to define social geoscience research projects with universities using a citizens' science approach (Procesi et al. 2022).
2. To promote models of mining activity compatible with the environmental protection for resilient territorial development, meaning enhancing geodiversity that is at the core of biodiversity[35] whilst enduring cultural capital. The importance to the mining activity in relation to the geo-mining historical heritage of the area is an opportunity to enlarge the Geopark's activities by looking at other geoparks that have been successful in doing so[36].
3. Although the application of quantitative methods is widely used in the study of environmental geology and geoecology, including social agents in such models is useful in reducing the uncertainty of scenarios and enabling mining adaptive management based in social learning. Reaching resilient territorial scenarios requires geoprospective methods that combine land-use forecasting and participatory modelling of social-ecological systems[37].

The geoethical dilemma as a research-based advocacy tool applied to different fields of the geosciences, such us geological risks (Bellaubi et al. 2021), geological heritage (Bellaubi and Lagunov 2020), and hydrogeology (Bellaubi and Arasa 2021), allows us to highlight the importance of geoethics in social geosciences. The application of the geoethical dilemma gives an added value to the interpretation of the relationship between human and geosphere in order to better understand the impacts and vulnerabilities involved and find feasible and fair solutions. The geoethical dilemma has a clear pedagogic (Peppoloni and Di Capua 2021b) and critical thinking approach because it builds on previous scenarios highlighting lessons learnt and know-how on empirical observations strengthening the importance of social geosciences. The geoethical dilemma provides a broader

[34] https://www.udg.edu/ca/campuspatrimoni/Detall-noticies/eventid/11186?iframe=true (accessed 7 December 2022).
[35] https://www.geodiversityday.org/ (accessed 7 December 2022).
[36] The case of the Scottish geoparks seems to be a good reference https://www.nwhgeopark.com/ (accessed 7 December 2022).
[37] Some examples can be found at http://cormas.cirad.fr/indexeng.htm (accessed 7 December 2022).

vision about how the society interacts with the geological environment in a way that strengths environmental land use planning and strategic territorial development when agreement between the actors is considered.

As a result, it seems important and timely to propose a plan regarding teaching of geoethics in the Geology degree at UAB considering the suggestions of the interviews carried out with researchers and academic staff at the UAB. This plan would aim to be completed in one academic semester following five steps:

1. An assessment phase to gain an overview of the importance of social geosciences and geoethics in research, education, and corporate sector and what are the competences that society expects from a geoscientist.
2. Training of academic staff through seminars and courses given by professionals in the field of geoethics and members of the IAPG. This point could also help to fulfil the duties of academic staff to maintain continuing and updated training.
3. To create a working group to review curricula and teaching guides and training for students.
4. Development of subjects and case studies to be conducted in field trips on environmental geology topics (geological risks, hydrology and hydrogeology, palaeontology and geoheritage, geotourism) using the geoethical dilemma method and others[38].
5. The acquired knowledge is exposed by students in the classroom, but open to the public that use a project working approach.

Conclusion

This research shows the importance of geoethics in the field of geosciences using a geoethical dilemma framing a case study related to mining geology. The application of the geoethical dilemma model to a case study is appropriate to reflect on the potential solutions derived from the coexistence between society and mining activity. The case of the subsidence related to the mining activity in the Catalonian Potassic Basin realistically displays the challenges and issues between society and geology.

At the same time, the case study clearly shows the necessity to include geoethics in the academic curricula of the Geology degree at the UAB, helping geoscientist

[38] An example can be found at https://serc.carleton.edu/geoethics/index.html (accessed 7 December 2022).

students and researchers to reflect on the broader aspects of the Human-Geosphere relationship in ethical terms (Peppoloni and Di Capua 2022). It is by teaching of geoethics in the different geosciences disciplines that Earth science professionals are prepared to face real challenges at the geology-society interface (Vasconcelos et al. 2016), expanding the knowledge of environmental geology into social geosciences.

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