







FINAL TECHNICAL REPORT

Management and Stabilization of Mining and Industrial Wastes

International Research Chair Initiative

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Wastes (2009-11), Professor (2011- present)	Stabilization of Industrial and Mine Wastes			
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Acronym List

- AMD: Acid mine drainage
- **AP: Acid generation potential**
- **APW: Alkaline phosphate wastes**
- NP: Neutralization potential
- **OCP: Office Chérifien des Phosphates**
- CDRT : Centre du Développement de la Région du Tensift
- **GIS : Geographic information system**
- ICP_AES : Inductively coupled plasma atomic emission spectroscopy
- IDRC-RC : International Development Research Centre- Research Chair
- UCA : Université Caddi Ayyad
- UQAT : Université du Québec en Abitibi Témiscamingue
- **SEM : Scanning electron microscopy**
- **XRD : X-ray diffraction**









i. Basic Project Information

Abstract

With its rich and diverse mineral resources and its geological formations belonging to the whole geological series, Morocco has a long mining tradition, spanning several centuries. A succession of orogenic belts (from the Precambrian to the Tertiary) is endowed with various types of deposits. Morocco, like many other countries with large mining industries, is increasingly concerned about the serious environmental problems that mine wastes can cause, particularly around abandoned mines. In this context, the IDRC Research Chair in "Management and Stabilization of Mining and Industrial Wastes" aims to create a centre for advanced technology in mining and industrial wastes in Morocco. The project will train highly qualified staff and transfer knowledge to mine operators. Several universities, research laboratories, and mining companies (OCP and Managem groups) participated in this research project.

Since 2009, the project has developed, both in the laboratory and in the field, cost-effective restoration methods adapted to semi-arid climatic conditions to manage and stabilize harmful mine wastes. Environmental characterization and reclamation research activities have been conducted at nine mine sites: Tiwine (Mn), Tiouit (Ag, Au, Cu) and Zgounder (Ag) in the Anti-Atlas; the Erdouz mine (Pb, Zn) in the High Atlas; the well-known Kettara mine (FeS) in the Jebilet Massif; the Zaïda and Mibladen mines (Pb) in the Upper Moulouya (between the Middle and High Atlas); and the Jerada (anthracite) and Touissit (Zn, Pb) mines in eastern Morocco. Furthermore, the project team has investigated new technologies for the recycling and valorization of non-polluting mine wastes.

In terms of training, Cadi Ayyad university and UQAT collaborated to create high-quality training opportunities in the field of mining environment research. We trained 2 postdocs, 12 PhD students (5 already defended their dissertation; the remaining 7 will shortly defend their dissertations), and 21 master's students in engineering (4 of them come from Burkina Faso, Benin, Mali, and Mauritania, in Western Africa).

A significant outcome of work to date is the restoration of the abandoned Kettara mine site, which had been leaching heavy metals into the soil and water table for decades. IDRC funding and collaboration with UQAT have made this effort possible. Indeed, the promising results of the Kettara field investigation validated the reclamation scenario of this site through the reuse of phosphate mine wastes as a store-and-release (SR) cover. Studies of other mines are sufficiently advanced to propose and implement cost-effective ways to remediate or mitigate their tailings or to valorize their tailings as raw materials for bricks and ceramics, for example.

Keywords: Morocco, Mine wastes, Acid Mine Drainage, Stabilization, Recycling, Semi-arid Climate

ii. The Research Problem

Morocco, with its large share of the world's phosphate reserves, is the leading exporter of phosphate and its derivatives. The country's global market share is more than 30%. Other substances mined include base metals (copper, lead, zinc), precious metals (gold, silver), economic commodities (fluorite, barite), and other





elements (manganese, iron, cobalt, etc.).

Officially there are 240 mine sites in Morocco. These vary from small scale underground mines producing 100 tons per day to large scale open- pit mines operations producing thousands of tons of ore per day. There are also many closed mines, about 200 of various sizes with different polluting potential. No post-closure plan has been put in place to manage the decommissioning of these mines or to control the negative impacts they may have on their surrounding environment. Rock piles and tailings ponds contain considerable quantities of mine wastes (waste rock and tailings) that lie exposed to weathering conditions and elements, often without containment structures or rehabilitation or mitigation plans. Given the magnitude of the problem, it is surprising that only a few studies have examined the environmental and social impact of abandoned mines across Morocco.

In a global context of metal shortages and continued demand, mitigating the environmental impacts of mining operations has become a major worldwide concern. In fact, closed mines are notorious for their negative environmental impacts, making them restoration or at least mitigation priorities. However, in Morocco, as well as in many other developing countries, additional work needs to be done. This project focused on two elements of a wider solution: 1) generating evidence of the risks of abandoned sites in Morocco; and 2) developing new low cost technologies to reduce the health and environmental risks posed by abandoned mines.

After a mine has been closed, the health and environmental risks of mine waste depend strongly on its acidgenerating potential as well as how the waste was contained. That is why abandoned mines, containing reactive tailings, are especially problematic and why the IDRC Research Chair focused on them.

The following map (Figure 1) identifies the abandoned mines that were investigated between 2009 and 2014: Tiwine (Mn), Tiouit (Ag, Au, Cu) and Zgounder (Ag) in the Anti-Atlas; the Erdouz mine (Pb, Zn) in the High Atlas; the Kettara mine (FeS) in the Jebilet Massif; the Zaïda and Mibladen mines (Pb) in the upper Moulouya (between the Middle and High Atlas); and the Jerada (anthracite) and Touissit (Zn, Pb) mines in eastern Morocco.



Figure 1. Location of some of the abandoned mines in Morocco investigated in the framework of the IDRC Research Chair in Management and Stabilization of Mining and Industrial Wastes

iii. Objectives

iii.1. General Objective

The IDRC Research Chair in "Management and Stabilization of Mining and Industrial Wastes", undertook multidisciplinary R&D to manage industrial wastes, particularly those from the mining industry, and to preserve natural resources in Morocco. Once tested in Morocco, the findings will be applicable to other mines located in semi-arid climate, especially those in Africa.

iii.2. Specific Objectives

The specific objectives of the project were to:

- 1. Create a research centre well equipped for advanced technology in mining and industrial wastes in Morocco.
- 2. Train highly qualified persons in the mine environment thematic and transfer knowledge to mine operating enterprises in Morocco.









- 3. Develop a comprehensive database of mine sites, mine wastes, and geological and geographical features (using a Geographic Information System, GIS).
- 4. Estimate the impact on human health and the environment of the mine wastes of closed mines.
- 5. Develop through studies in the laboratory and the field, cost-effective restoration methods to manage and stabilize the wastes as well as to reclaim mine sites adapted to semi-arid climates.
- 6. Validate the reclamation design of the Kettara mine (school site).
- 7. Develop alternative uses for mine waste and ways to recycle mine waste.

One of the major challenges raised during the project was the inability to conduct field research on the impact of mine waste on human health. The team did not receive the necessary authorizations to conduct this work.

iv. Methodology

The chair program's global methodology is presented in figure 2. First, the team developed a comprehensive database of selected mine sites, detailing their geological and geographical features, and of estimates of the environmental impact of waste on abandoned mines. Nine sites (Zeida, Mibladen, Touissit, Kettara, Jerada, Boubker, Tiouit, Zgounder, and Tiwine) were chosen for their environmental impact levels, tonnage, and geographical distribution. A thorough characterization of each waste material was conducted. In fact, the physical, chemical, and mineralogical as well as geochemical and environmental properties of tailings samples were assessed with advanced techniques. (e.g., ICP_AES, SEM, XRD, column leaching, geophysical techniques).

The results obtained made it possible to classify each mine site and develop suitable rehabilitation scenarios. For sites that were generating acidic waste, we undertook *in situ* rehabilitation scenario testing such as desulfurization and coverage techniques. Most of this work was done at the Kettara mine site.

For non-acid generating mine sites, the team researched recycling and secondary-use applications, especially in the construction sector, such as using waste as cementing materials, as additives in mortars or concrete, or as raw materials for bricks and ceramics. The team undertook joint projects with the OCP and Managem to understand the possibility of reusing, respectively, phosphates tailings and calamine by-products.







IDRC Research Chair Management and Stabilization of Mining and Industrial Waste



Methodology

STEP I Develop a comprehensive database of mine sites, geological and geographical features, and estimates the wastes' impact on the environment and health in many Moroccan abandoned mines 9 Closed mine sites were chosen based on their tonnage, environmental impact...: Tiwine (Mn), Tiouit (Ag, Au, Cu) and Zgounder (Ag), Erdouz mine (Pb, Zn), Kettara mine (FeS), Zaïda and Mibladen mines (Pb), Jerada (coal) and Touissit (Zn, Pb)

1- Wastes global characterization

- ✓ Total volume (geophysical techniques)
- ✓ Physical properties (PSD, Gs, LA, W_{abs})
- ✓ Chemical composition (ICP, S_{SO4}, S_{total}, C_{total})
- ✓ Mineral composition (XRD, SEM)
- ✓ Environmental behavior (ABA, Leaching tests)



Classify mine sites in term of acid generation potential

2- Wastes environmental impact

- Surface and ground water sampling and analyses (ICP, chromatography, pH, Eh, conductivity)
- ✓ Soils sampling and analyses (ICP, XRD, SEM)



Classify mine sites in term of acid generation potential

STEP 2

Developing rehabilitation scenarios Depending on the <u>Acid generation potential</u>

Acid generator	Uncertain	Non-generator			
Reuse/Rehabilitation in site	u Ala	Recycling out of sites			
Backfill		Cementing materials			
Desulfurization	A	Additives in mortars/concrete			
Covers techniques		Bricks			
Stabilization/Solidification		Ceramics			
Kettara mine site (School site) Tiouit mine	Zeida and Mibladen mine sites	Touissit and Jerada mines Calamine and Phosphates tailings			
Covers technique	Recycling as aggregates for mortars and	Recycling as raw materials for bricks and			
Desulfurization	concretes ceramics				

Fig.2. Schematic illustration of the global methodology





v. Main Project Activities

From 2009 to 2014, the IDRC Research Chair in "Management and Stabilization of Mining and Industrial Wastes" presented an important opportunity for Moroccan researchers and students to improve their knowledge on mine wastes characterization and management as well as mine site reclamation. They had access to UQAT's unequalled expertise and know-how in the field of mining environment research. During the project's five years the IDRC Research Chair undertook a wide variety of research activities, in the laboratory as well as in the field. The IDRC RC:

- Created of a laboratory equipped with equipment (e.g., ICP-AES, C/S analyzer, and columns for lixivation tests)
- Carried out of several field trips, in particular to nine of Morocco's most important Moroccan closed mines (Zeida, Mibladen, Touissit, Kettara, Jerada, Boubker, Tiouit, Zgounder, Tiwine)
- Characterized and evaluated the impact of the mine wastes on the environment
- Trained of a large number of highly qualified persons (2 post-docs, 12 Ph.D. students, and 21 master's students in engineering. The students came from different locations in Morocco and from Western African countries.
- Cultivated an active scientific network in Morocco which included UCA, and important universities and schools.
- Developed through laboratory and field studies, cost-effective restoration methods that are adapted to semi-arid climates and that will manage and stabilize harmful wastes in Morocco
- Developed research on recycling and valorizing mine wastes
- Realized the large scale implementation of instrumented experimental cells in the field (Open Sky Laboratory) for the control of AMD (Acid Mine Drainage) at the abandoned Kettara mine site using alkaline phosphate wastes from neighboring phosphate mines.
- Implemented a comprehensive database of the Kettara mine site, (using GIS)
- Edited and published top-quality articles in well recognized international journals
- Participated in International conferences
- Published press releases and was interviewed by numerous regional and national media
- Agencies
- Organized the first International Congress on the Management of the Mining Wastes and Closed Mines, organized by the IDRC Research Chair from 3 to 6 April 2012
- Meet with stakeholders including the Ministry of Energy, Mining, Water and Environment, NGOs, local collectivities, and major mining companies (such as OCP and Managem).









vi. Project Outputs

The IDRC funding and collaboration with and knowledge transfer from UQAT (Canada) led to tangible benefits for students, industry partners, government agencies and residents living in proximity of abandoned mine sites.

vi. 1.Student training

A large number of students received advanced training through the program. As listed in Table 1, the following persons received high quality training in the field of mining and environment: 2 post –doctoral fellows; 12 Ph.D. students (5 have defended their dissertations, 6 will defend shortly, and 1 has just started research), 21 master's students in engineering and 8 undergraduates. The students came from different locations in Morocco as well as from Western African countries (Burkina Faso, Mali, Mauritania, and Benin).

During the recruitment process, we achieved gender equity by training an equal number of men and women. The students were offered training opportunities in the following multidisciplinary fields: hydrogeology, geophysics, soil pollution, water pollution, materials sciences, GIS, recycling and reuse of mine wastes, physiochemical characterization and geo-technique.

	Trainees supervised by the IDRC Research Chair (IDRC RC)	Trainees supervised by the Canada Research Chairholder	Trainees co-supervised
Undergraduate	1. Jihane KNIDIRI		
Students	2. Saïd KHALLOUK		
	3. Yassine AIT KHOUIA		
	4. Abdellatif EL GHALI		
	5. Abdeljalil AIT KHOUIA		
	6. Hassan Tariq AIT		
	OUFKIR		
	7. Lahcen ETTAGHZAOUI		
	8. Abdelaziz AIT		
	OUHADDOUCH		

Table 1. List of trained students*





	1. Yassine TAHA	1. Khadija BABI	1. Kamal KHALDI
Master's	2. Abdeljalil AIT KHOUIA	2. Jihane KNIDIRI	2. Mohamed
students	3. Mamadou DIARRA	3. Chafia HADJARA	Lamine DIABY
	4. Soufyane SABIR	4. Habib	KASSAMBA
	5. Lamia AJAL	MOUSTAPHA	3 Etienne PARENT
	6. Abdessamad KHALIL		
	7. Maryeme CHAOUI		
	8. Abdellah EL AZHARI		
	9. Siham LGHOUL		
	10. Lucie Kabore		
	YAOBNÉRÉ		
	11. Hamza TALIBI		
	12. Mohamed FALL		
	13. Khadija EL AZHAR		
	14. Siham Difi		
PhD students	1. Abdessamad KHALIL		1. Abdelmalek GOUMIH
	2. Mohamed LOUTOU		2. Bruno BOSSE
	3. Meriem LGHOUL		3. Yassine TAHA
			4. Rabei ARGANE
			5. Omar OUAKIBI
			6. Assia ELYAZIJI
			7. Mounia BATTIOUI
			8. Samiha NFISSI
			9. Houyame YOUNES
Post-doctoral	Souad LOOMAN		Mariam FL ADNANI
Fellows			

* Only the students funded through the IDRC grant are listed. The project involved other students through other grants

vi. 2. The Training Environment:

	Not at All	Minimal	Moderate	Significant	Don't know
CRC				х	
IDRC RC				х	

The IDRC Research Chair, as well as its related infrastructures at UQAT and UCA, provided support for excellence in research and innovation. For example, it allowed the chair holders to increase and strengthen their competencies in the management and stabilization of mining and industrial wastes. Sharing the acquired experience allowed students to grow their skills and make their knowledge more relevant.

The implementation of project activities in both countries has increased and stimulated students' interest in mine environments and waste management. The laboratories involved have received an increased number of requests and applications to their graduate programs.









The availability of UQAT's equipment has significantly helped all of the research activities. Finally, the IDRC funding made it possible to create a research centre with the necessary equipment to study mining and industrial wastes in Morocco.

vi. 3.Research outputs

Table 2 shows the team's research production from 2009 to 2014. The main areas of research were hydrogeology, geophysics, soil pollution, water pollution, materials sciences, GIS, recycling and reuse of mine wastes. The team published five indexed (Scopus) articles per year, which is twenty times the average annual publication (0.25) of a researcher at Cadi Ayyad University.

Туре	Total number of Research Outputs		
Journal articles (published / accepted)	20		
Journal articles (in submission)	7		
Conference papers	15		
Presentations (non-academic)	58		
Books			
Book chapters			
Newspapers / other media			
Theses			
- MA / MSc	18		
- PhD	5		

vi. 4. Significant research findings

vi. 4.a. The assessment of the environmental impact at Kettara.

The first part of the IDRC RC focused on assessing the impact of AMD (acid mine drainage) on the surrounding environment of the Kettara mine site, as well as cost-effective means of containing the further release of heavy metals into the environment. During this phase, the scientists working with the IDRC RC used advanced technologies.

A GIS based environmental database, including data about geochemistry, hydrochemistry, hydrology, geology and land soil cover was established for Kettara (Khalil et al., 2014b). This environmental database was used to establish a web-based GIS Decision Support System. Web-based environmental data for Kettara will be of great interest to decision makers assessing the environmental impact at Kettara and implementing a rehabilitation program (Khalil et al., 2014c). Furthermore, geochemistry was coupled with GIS technology,



remote sensing and spectroradiometry to reveal the impact of AMD on the Kettara soil (Khalil et al., 2013 Khalil et al., 2014a). This method was demonstrated to be an efficient way of mapping heavy metal pollution in the Kettara soil. Moreover, this research led to a novel approach to mapping heavy metal pollution in any area by using satellite imagery data only. Figure 3 illustrates soil and water pollution at the Kettara mine site



Fig3. Photos illustrating soil and water pollution at Kettara mine site

Ouakibi et al., 2013 evaluated the quality of surface water in many locations around the mine site at different times of the year in Kettara (Figure 3). In addition Khalil et al. (2014b) and Lghoul et al. (2014) studied the hydrochemical behavior of groundwater around the Kettara mine site, and the water's suitability for domestic uses. This research found that groundwater in some contaminated areas was four times above acceptable thresholds for human consumption; this data was communicated to health authorities. Finally, Lghoul et al 2012, 2013) used advanced geophysical methods (electrical resistivity tomography and seismic refraction) to determine (i) the nature of the geological substrate on which the mine wastes are deposited as well as the substrate's impermeability to effluent contamination and (ii) the internal structure of mine wastes in order to highlight the conductive zones that may help the spread of leachate from the surface toward groundwater table.

ivi. 4.b. Development of Kettara reclamation program

In order to control the AMD generated at Kettara, Ouakibi et al., 2013 tested different passive treatment systems that prevent water from reacting with mine tailings. Lab and small open air tests indicated that alkaline phosphate wastes (APW) from a nearby phosphate mine (belonging to OCP) could prevent water infiltration. Additional APW testing by Hakkou et al., 2009 and Bossé et al., 2013, 2014 confirmed its ability to prevent water infiltration and oxidation of mine wastes at Kettara. On the basis of these important findings, the team designed a store-and-release (SR) cover that used capillary barrier effects and that prevented water percolation by storing and evaporating water during wet and dry climatic periods.

A field investigation was conducted on the effectiveness of store-and-release (SR) covers made with different phosphate mine wastes to reduce water infiltration and to control AMD. Four instrumented experimental cells and one inclined field experimental cell were constructed with a SR layer placed over a capillary break layer made of acidic coarse-grained materials. Cover performance and hydrogeological behavior under natural and extreme climatic conditions were monitored using lysimeters, tensiometers, suction and soil moisture



sensors (Bossé et al. 2013, Bossé 2013). Figure 4 shows the different stages of experimental field cells construction



Fig. 4. Photos illustrating the field cells construction. **a**: Preparation of the four cells platform, **b**: transportation of phosphate mine wastes, **c**, **d**, **and e**: construction of the instrumented cells, f: simulation of the extreme rainfall event (150ml/24h)

The important finding of this research is that the store-and-release cover made of phosphate limestone waste can limit deep water infiltration even during extreme simulated rainfall (150 mm/d). Not only is this method



effective, but it is also cost-effective as it uses a phosphate mining by-product that is widely available in Morocco to control AMD at the Kettara mine.

After five years of work and research implementation, the rehabilitation scenario of the abandoned Kettara mine (school site) is almost performed. The business plan of the reclamation is being finalized (see annex1). Thanks to IDRC funds and the transfer of UQAT (CRC) knowledge, the Kettara mine site will be the first site restored in North and West Africa.

During this research, the team developed fruitful collaboration with two major Moroccan mining companies: OCP and Managem. OCP is interested in finding a productive use for waste generated from phosphate mining. Managem has mining activities with AMD problems in Marrakech region. Both of these companies funded the implementation of the experimental cells (about \$10,000.00 CAD) and provided tons of phosphate by-products to realize them.

vi. 5. Research on new technologies for the recycling and valorization of non-polluting mine wastes

vi. 5. a. Studying the feasibility of using Upper-Moulouya mine tailings to manufacture mortar and concrete

This research sought to assess the use of low sulfide tailings or sulfide free tailings as aggregates for the manufacture of cement and mortar. At present, there is an uncontrolled reuse of these tailings and very little understanding of their structural and health implications. Tailings were sampled from four abandoned mine sites in Morocco, and a thorough physical, chemical and environmental characterization was determined. Various mortar mixtures containing different proportions of tailings were investigated according to several parameters (e.g., workability, setting time, density, water absorption, compressive strength, and drying shrinkage. The leaching of metals was also evaluated.

Overall, it was observed that the use of low sulfide tailings as aggregates at 30% substitution level of sands produces cement mortars with good mechanical properties. The lead and zinc fraction serves as an active set retardant for cement mortars reducing their setting time. The leaching of metals was also successfully stabilized. However, the use of tailings with high zinc concentrations (3%) seems to expressively inhibit cement hydration of mortars. Moreover, incorporating tailings in mortars successfully prevented the leaching of heavy metals (Rabei et al. 2014a, 2014b).

vi. 5. b. Assessment of the potential use of phosphate tailings in ceramics

Morocco possesses around 75% of the world's phosphate reserves and is the third largest producer of phosphate. During ore phosphate beneficiation, fluorapatite is separated from associated gangue minerals by a combination of various mineral processing units involving crushing and screening, washing, and/or flotation. This process generates a large volume of waste, which is stockpiled in tailings ponds (phosphate sludge ponds). For instance, in 2010, the amount of sludge created was about 28.1 million metric tons. This waste constitutes a potential source of pollution, reduces arable lands and disfigures the landscape.

To date, there is no research published on the potential re-use of phosphate tailings. The potential use of phosphates sludge in the field of ceramic has been assessed. The research results are summarized in Loutou et al. (2013). The preliminary results show that this industrial waste can be used for various applications such as lightweight aggregates to improve its plasticity by mixing them with local clay. Ceramics with high









mechanical properties were obtained that can compete with commercial products.

vi. 5. c. Valorization of calamine by-products as a construction material

One of our industry funded projects, supported by Managem, investigated the feasibility of calamine waste as a substitute for clay in the manufacture of red clay bricks. Technical characteristics assessment of clay bricks manufactured with calamine wastes shows that an increase in the substitution of clay by calamine wastes decreases mechanical strength and increases porosity. Clay bricks with up to 30% of calamine waste substitution comply with ASTM standards. To include more than 30% of calamine wastes in clay bricks was possible with the addition of recycled glass. We found that clay bricks containing 30% recycled glass, 40% calamine wastes and only 30% of clay can comply with ASTM standards.

vi. 6. Characterization of Jerada coal mine wastes

The chemical behavior of mine wastes in the Jerada coal district (one of the most problematic site in Morocco) district was studied (Battioui et al. 2014). Laboratory investigations demonstrated that recycling mine wastes from the Jerada coal mine may be feasible. However, further research is needed to confirm their long term performances.

vi.7 Additional funding related to the IRCI research program

The additional funding sources related to the IRCI research program are listed in Table 3.

Project title	Funding Agency	Role in the project	Start date (year) / end date (year)	Value (indicate currency)
Les ressources en eau dans la	Action Intégrée (AI N.	Collaborator	2009-2012	30 000 euros
région de Marrakech, prospection	MA/09/209) Comité Mixte			
et caractérisation de nouvelles	Interuniversitaire Franco-			
ressources, sources de pollution,	Marocain- Programme			
périmètre de protection : apport	VOLUBILIS-			
de l'outil géophysique				
Los recursos hidráulicos en la	Al N . A/025780/09) Comité	Collaborator	2010-2012	15000 euros
región de Marrakech, prospección	Mixte Interuniversitaire			
y caracterización nuevos recursos,	Maroco-Espganol. Agence			
fuentes de contaminación,	Espagnole de coopération			
perímetro de protección:	international			
contribución de la herramienta				
geofísica				
The impact of the vegetation on	Ministère de l'Enseignement	Coordinator	2014-2017	3.600.000,00
the performance of the store-and-	Supérieur, de la		The contract	MAD
release cover made with the	RechercheScientifique		will be signed	
phosphate mine wastes to control	etde la Formation des		next October	

Table3. List of additional funding sources related to the IRCI research program





ARD pollution in Kettara mine	Cadres (Maroc)			
CRC Integrated mine waste	Canada Research Chair	Holder	2003-2011	900 000 CAD
management				
Research Centre on Concrete	FRQNT	Member	2007-2016	550 000 CAD
Infrastructure				per year
Valorisation de rejets industriels et	NSERC, Discovery Grant	Holder	2013-2018	130 000 CAD
miniers comme constituants				
d'ouvrages civils et miniers				

vii. Project Outcomes

Collaboration between research chairs

For five years, the project team had access to UQAT's unequalled expertise and know-how in the field of mining environment, and this contributed to the success of training, research and knowledge transfer goals.

Fieldwork opportunities for students training

- During the IDRC RC project, the team published five indexed scientific articles per year, many of which involved graduate students as authors. This represents ten times the average annual publication (0.25) per researcher at Cadi Ayyad University.
- Moreover, the three most important Moroccan mining companies (OCP, Managem, and CMT) and their federation (FDIM) sponsored the international congress (GESRIM). This sponsorship demonstrates the companies' preoccupation with waste issues and interest in working with academics and students.
- Meriem Lghoul's thesis was selected as Université Cadi Ayyad's best thesis of 2014.
- The Ph.D. student Rabei Argane presented twice at the distinguished 3rd International Symposium on Sustainability through Resource Conservation and Recycling '14 (SRCR '14), Falmouth, Cornwall, UK, June 12-13, 2014.
- One of the female post-doctoral researchers (M El Adnani) was recruited to be an assistant professor at Ecole Nationale de l'Industrie Minérale (ENIM school, Rabat) thanks to her activities and experience in the IDRC RC project.
- The research program led to the following training / curriculum development outcomes:
 - Since 2011, Rachid Hakkou has delivered annually the course Sustainable Development of Mines to master students coming Western Africa (Cameroun, Ivory Coast, Niger, Mali and Burkina Faso) at the International Institute for Water and Environment Engineering, Ouagadougou, BURKINA FASO (http://foad-2ie-edu.org).
 - The University de Liège, Faculty of Applied Sciences (Polytechnic School) (Belgium) has invited Rachid Hakkou, from 11th to 17th November 2012, to deliver a course on Sustainable Development of Mines. The students came from Africa in the framework of the "Stage International en Environnement et Gestion Durable des Ressources Minérales" funded by the Belgium international cooperation agency (CUD Belgium).









- Mostafa Benzaazoua was invited to ENSA in Tanger to teach an intensive one-week environment undergraduate course in June 2011.
- On the margin of the 2nd International Symposium on Innovation and Technology in the Phosphate Industry, SYMPHOS 2013, 7-13 May2013, Agadir Morocco (www.symphos.com).
 Mostafa Benzaazoua and Rachid Hakkou delivered the short course "Mining and Sustainable Management and Mine Waste Recycling".

New avenues for knowledge, policy, and technology transfer

The five year project implementation supports co-operation, capacity building, and know-how exchange between the university and the most important Moroccan mining companies in a perspective of mutual interest.

The first stage of co-operation with Moroccan mining companies was the International Congress on the Management of Mining Wastes and Closed Mines (GESRIM 2012), organized on 3-6 April 2012, in Marrakech. 180 participants from 14 countries participated. The Congress' main partners were IDRC (Canada), UCA (University Cadi Ayyad), UQAT (University of Quebec in Abitibi-Temiscamingue), GEODERIS (France), BRGM (France), INSA-Lyon (National Institute for Applied Sciences) and the International Mine Water Association.

The three most important Moroccan mining companies (OCP, Managem, and CMT) and their federation (FDIM) sponsored the congress to show their preoccupation with the issues discussed at the congress. This achievement clearly demonstrates the benefits of working in a partnership. This has also benefited scientific research by increasing companies' involvement in and concern with controversial practices. While more work remains to be undertaken, the international congress has made a huge contribution to sensitizing mining companies of the threat of mine wastes to the environment and local communities. Following the Congress, joint research activities were initiated, including: "Assessment of the potential use of sludge phosphate as base-material of ceramics production" with OCP and "Evaluation of the potential reuse of the Calamine plant wastes (ONA, Morocco) as a building material in the construction domain" with Managem. Moreover, the GESRIM 2012 Congress greatly improved policy makers understanding of the complexity and importance of environmental issues related to mining activities.

The organization of the international conference "Tackling Mine Wastes through Better Management Practices", held on 4-7 May 2014, in Marrakech, is another interesting outcome of the five year project.

The following outcomes show the recognition of the of IDRC RC's expertise in mine reclamation:

• The biggest Moroccan mining companies (Managem and OCP) have regularly requested advice and expertise on mine waste management. For example, Mostafa Benzaazoua and Rachid Hakkou were requested to prepare a course on post-mining management during the international conference organized by the OCP group (one of the leading companies in Phosphate exploitation): 2nd









International Symposium on Technology and Innovation in the Phosphates Industry from the 6th to the 10th of May 2013 in Agadir City Morocco (<u>http://www.symphos.com/</u>).

- In April 2013, the governor of the Midelt region and the president of the Zeida community consulted the IDRC RC about risks associated with tailing-based mortars used illicitly in uncontrolled construction nearby the abandoned mine of Zeida. A response describing the main concerns was provided.
- During the World Mining Congress, 11–15 August 2013, Montréal, Canada (http://www.wmcexpo2013.org), Mostafa Benzaazoua chaired the "Tailings, Water, and Mine Site Rehabilitation" track and Rachid Hakkou chaired the "Abandoned Mine Restoration" session.
- Rachid Hakkou was invited by the Closing Workshop of the IGCP/SIDA: Addressing Environmental and Health Impacts of Active and Abandoned Mines in Sub-Saharan Africa, 26–28 May 2014, Prague, Czech Republic, to present the oral communication "Environmental challenges facing closed mine sites reclamation in Morocco."
- Rachid Hakkou and Mostafa Benzaazoua were invited to the symposium Mines and the Environment (November 6 to 9, 2011) Rouyn-Noranda, Québec, Canada.Rachid Hakkou and Mostafa Benzaazoua were invited to present their findings to the Colloque des Entretiens Jacques Cartier: "L'industrie minière et le développement durable : une perspective internationale francophone," 19–20 November 2014, Québec, Québec, Canada.

viii. Overall Risk and Recommendations

Overall project assessment can be summarized as following:

1. The quality of financial management is a key component of a project's success. It is therefore important that an external institution manage the financial aspects to avoid long term procedures by the Moroccan universities. The project's activities suffered from some delays that influenced the performance and efficiency of the overall research program. Significant support in this respect was provided by UQAT's management of a large proportion of the grant and the involvement of, CDRT (a Moroccan NGO) in the management of our project funds contributed to efficient financial management.

Furthermore, professors at Moroccan universities who hold (national or international) projects in Morocco are not exempt from teaching duties (unlike their Canadian colleagues). The IDRC chair holder was not relieved of his workload during the program's five years.

2. The post implementation sustainability of this project is a major challenge. It is important that factors threatening the project's sustainability be articulated, as much as possible, at the elaboration and design stages. Tools and plans to enhance sustainability and to maximize expected returns on investment should be identified and elaborated. Support by OCP and Managem in this project was instrumental in testing.









- **3.** Double degree agreements between Canadian and Moroccan universities should be established for PhD students.
- 4. The Canadian embassy in Morocco should be involved in the project's activities, and its staff, including the ambassador, could attend the project's major events. This involvement can reinforce collaboration and highlight shared scientific achievements.

Furthermore, to consolidate the future of mining and environment research in Morocco, the following recommendations have to be considered:

- Continuing to develop research on the development of a Geographic Information System (GIS) after the establishment of web-based GIS Decision Support System for a group of abandoned mine sites in Morocco. Decision makers and academic scientists will use this system to assess and monitor the mine's pollution impact in these abandoned sites.
- **2.** Offering new training opportunities to master's students from Morocco and undergraduate students from Western Africa.
- **3.** Developing research on new technologies for the recycling and valorization of non-polluted mine wastes.
- **4.** Investigating the feasibility of clay substitution by calamine waste in the manufacture of red clay bricks, widely used building materials in Morocco. This process, based on a thermal treatment of raw materials at 900 to 1100°C, will allow the heavy metals of the calamine wastes to be fixed in the matrix of sintered clay bricks.
- 5. Studying the feasibility of further using abandoned mine tailings as aggregates for the manufacture of mortars and concretes with acceptable properties.
- **6.** Validating the Kettara mine reclamation design by continued monitoring of the impact of the slope and the vegetation on the performance of the cover.
- **7.** Assuring knowledge and skills transfer to mine operators and Western African countries dealing with the same environmental risks of mining.
- **8.** Consolidating the existing laboratory intended for mine waste characterization and aqueous solution analysis.
- 9. Reinforcing collaboration with mine operators in Morocco.
- 10. Pursuing the ongoing research and transfer activities corresponding to the reclamation and stabilization of mine wastes in Arid and semi-arid climates. We will carry out follow-up research on environmental Geographic Information System (GIS) technology after the implementation of a web-based GIS Decision Support System. We will also pursue more in-depth research on new technologies for the recycling and valorization of non-polluted mine wastes.
- **11.** Post-IRCI scenarios should also be investigated in order to consolidate the future of mining and environmental research in Morocco.

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