Mining waste characterization in the perspective of the European mining waste directive
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Mining waste characterization in the perspective of the European mining waste directive

Bruno Lemière, Francis Cottard, Patrice Piantone
BRGM (French GeoSurvey)
Characterisation of mining waste (and more generally extractive waste): purpose

Place in the European mining policy

A key activity in the environmental management of extractive industries

Desired by the European Union in the perspective of improving their sustainability

IPPC applies to mining, but the size (more than 4700Mt of mining waste and 1200Mt of tailings in 2000) and types of waste needed a specific management policy

Characterisation of mining waste: scope

- Waste characterisation applies to:
  - all mines (open cast or underground) and quarries,
  - all mining activities (extraction, beneficiation, restoration),
  - any status (active, closed or abandoned),
  - all commodities (metals, coal or industrial minerals)
Characterisation of mining waste: scope

The main waste categories are extraction waste and processing waste, with markedly different properties, and subsequently of waste forms.

Extraction waste further subdivided in overburden, barren host rocks, and low grade mineralised rocks.

<table>
<thead>
<tr>
<th>Extraction Waste</th>
<th>Processing Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse material abundant, large heterogeneity</td>
<td>Most fine-grained, sandy or silty, homogeneous</td>
</tr>
<tr>
<td>Ore elements in variable amounts</td>
<td>Valorised elements depleted</td>
</tr>
<tr>
<td></td>
<td>Unused elements concentrated</td>
</tr>
<tr>
<td>Mechanically dumped</td>
<td>Slurry decantation</td>
</tr>
</tbody>
</table>

BRGM Environment & Process
Waste categories in the extractive industry

The Mining Waste Directive (2006/21/EC, or MWD) defines
- inert waste (IW),
- hazardous waste (HW)
- non-inert, non-hazardous waste (NINHW)

**HW:** Definition closely derived from the definition of hazardous waste in the Waste Directive (91/689/EEC)

**IW:** Specific definition (MWD, appendix II, and Decision 2009/359/EC)

**NINHW:** No definition: what is neither HW nor IW

NINHW needs appropriate management too

Strategies in order to assess the inert or hazardous character of waste, in relation with the Directive and following a General Guidance still under elaboration.
From waste characterisation to waste management

One major objective of waste characterisation is to contribute to a sustainable and safe management of mining waste facilities (MWFs). Specific dispositions are applicable to:
- extraction waste (waste rock) dumps, mostly in rock heap form, and
- processing waste dumps, mostly as layered fine-grained (tailings) dams, depending on waste characteristics (“Category A mining waste”).

“Kirchheller Heide” Area
(Bottrop, Germany, Deutsche Steinkohle AG)
From waste characterisation to waste management

Detailed and site-specific characterisation programs may be required to meet the requirements of waste facilities approval.

(design of Category A or B mining waste facilities)

Adequate and comprehensive characterisation programs may be expensive and time-consuming. They may however allow significant savings in the MWF construction and operation. Finding out later that a MWF was inadequately built is even more expensive.

Waste characterisation is an important part of efficient mine site management.
A waste facility shall be classified under category A if:

- a failure or incorrect operation, e.g. the collapse of a heap or the bursting of a dam, could give rise to a major accident, on the basis of a risk assessment taking into account factors such as the present or future size, the location and the environmental impact of the waste facility; or
- it contains waste classified as hazardous under Directive 91/689/EEC above a certain threshold; or
- it contains substances or preparations classified as dangerous under Directives 67/548/EEC or 1999/45/EC above a certain threshold.
## Technical Requirements for Waste Characterisation

<table>
<thead>
<tr>
<th>Item</th>
<th>Requirement</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Background information</td>
<td>Should provide basic information on the background and objectives of the extractive operation, for example:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– prospecting, extraction and/or processing activities;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– type and description of method of extraction and process applied</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– nature of the intended product.</td>
</tr>
</tbody>
</table>
# Technical Requirements for Waste Characterisation

<table>
<thead>
<tr>
<th>Item</th>
<th>Requirement</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Geological background of deposit to be exploited</td>
<td>Information on the units to be exposed and which will be the source of the waste. Details required include:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• nature of surrounding rocks, their chemistry and mineralogy, including hydrothermal alteration of mineralised rocks and barren rocks;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• nature of deposit, including mineralised rocks or rock-bearing mineralisation;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• mineralisation typology, chemistry and mineralogy, including physical properties such as density, porosity, particle size distribution, water content, covering worked minerals, gangue minerals, hydrothermal newly-formed minerals;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• weathering and supergene alteration from the chemical and mineralogical point of view.</td>
</tr>
</tbody>
</table>
## Technical Requirements for Waste Characterisation

<table>
<thead>
<tr>
<th>Item</th>
<th>Requirement</th>
<th>Details</th>
</tr>
</thead>
</table>
| 3    | Nature of the waste and its intended handling | Details on all wastes to be generated from prospecting, extraction and processing, including:  
- origin of the waste in the extraction site and the process generating that waste such as prospecting, extraction, milling, concentration;  
- total quantity of extractive waste to be produced;  
- description of the waste transport system;  
- description of the chemical substances to be used during treatment;  
- classification of the waste according to the LOW, including identification of hazardous properties; and  
- type of intended waste facility, final form of exposure of the waste and method of deposition of the waste into the facility. |
## Technical Requirements for Waste Characterisation

<table>
<thead>
<tr>
<th>Item</th>
<th>Requirement</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Geotechnical behaviour of the waste</td>
<td><strong>Laboratory characterization and testing:</strong> compressibility, shear strength, angle of friction, grain size distribution, density (bulk density and specific weight), plasticity, fracturing (if appropriate), liquefaction potential, permeability and erosion potential. Accurate measurements but sample size is generally small. Sampling strategy crucial to ensure representative samples, up scaling of results needs care. <strong>In-situ tests</strong> less accurate, but more “integrating”. Valid for a larger volume. Only applicable to already existing dumps and tailings storage facilities, their relevance for initial testing in the planning stage is limited.</td>
</tr>
</tbody>
</table>
## Technical Requirements for Waste Characterisation

<table>
<thead>
<tr>
<th>Item</th>
<th>Requirement</th>
<th>Details</th>
</tr>
</thead>
</table>
| 5    | Geochemical characteristics and behaviour of the waste | Details on the chemical and mineralogical characteristics of the waste, and of any additives or residuals remaining in the waste, in particular:  
  • evaluation of metals, oxyanion and salt leachability over time by pH dependence leaching test, and/or percolation test and/or time-dependent release and/or other suitable testing;  
  • for sulphide-containing waste, static or kinetic tests should be carried out in order to determine acid-rock drainage and metal leaching over time. |
Characterisation of mining waste: nomenclature

Classification of waste in accordance with the European Waste Catalogue

Waste from extractive industries belongs to class 01: “Wastes resulting from exploration, mining, quarrying, and physical and chemical treatment of minerals”

The six-digit codes in the LOW having an asterisk next to them are hazardous wastes. Wastes without an asterisk are not hazardous wastes.

Hazardous wastes coloured in red: “Absolute” hazardous entries

Hazardous wastes coloured in blue: “Mirror” hazardous entries

The absolute hazardous entries are automatically considered hazardous and their description does not have a reference to “dangerous substances”.

BRGM Environment & Process
August 2011
Characterisation of mining waste: nomenclature

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Wastes Resulting from Exploration, Mining, Quarrying, and Physical and Chemical Treatment of Minerals</td>
</tr>
<tr>
<td>01 01</td>
<td>Wastes from mineral excavation</td>
</tr>
<tr>
<td>01 01 01</td>
<td>Wastes from mineral metallic ore excavation</td>
</tr>
<tr>
<td>01 01 02</td>
<td>Wastes from mineral non-metallic ore excavation</td>
</tr>
<tr>
<td>01 03</td>
<td>Wastes from physical and chemical processing of metallic ore minerals</td>
</tr>
<tr>
<td>01 03 04*</td>
<td>Acid-generating tailings from processing of sulphide ore</td>
</tr>
<tr>
<td>01 03 05*</td>
<td>Other tailings containing dangerous substances</td>
</tr>
<tr>
<td>01 03 06</td>
<td>Tailings other than those mentioned in 01 03 04 and 01 03 05</td>
</tr>
<tr>
<td>01 03 07*</td>
<td>Other wastes containing dangerous substances from physical and chemical processing of metallic ore minerals</td>
</tr>
<tr>
<td>01 03 08</td>
<td>Dusty and powdery wastes other than those mentioned in 01 03 07</td>
</tr>
<tr>
<td>01 03 09</td>
<td>Red mud from alumina production other than the wastes mentioned in 01 03 07</td>
</tr>
<tr>
<td>01 03 09</td>
<td>Wastes not otherwise specified</td>
</tr>
<tr>
<td>01 04</td>
<td>Wastes from physical and chemical processing of non-metallic ore minerals</td>
</tr>
<tr>
<td>01 04 07*</td>
<td>Wastes containing dangerous substances from physical and chemical processing of non-metallic ore minerals</td>
</tr>
<tr>
<td>01 04 08</td>
<td>Waste gravel and crushed rocks other than those mentioned in 01 04 07</td>
</tr>
<tr>
<td>01 04 09</td>
<td>Waste sand and clays</td>
</tr>
<tr>
<td>01 04 10</td>
<td>Dusty and powdery wastes other than those mentioned in 01 04 07</td>
</tr>
<tr>
<td>01 04 11</td>
<td>Wastes from potash and salt processing other than those mentioned in 01 04 07</td>
</tr>
<tr>
<td>01 04 12</td>
<td>Tailings and other wastes from washing and cleaning of minerals other than those mentioned in 01 04 07 and 01 04 11</td>
</tr>
<tr>
<td>01 04 13</td>
<td>Wastes from stone cutting and sawing other than those mentioned in 01 04 07</td>
</tr>
<tr>
<td>01 04 99</td>
<td>Wastes not otherwise specified</td>
</tr>
<tr>
<td>01 05</td>
<td>Drilling muds and other drilling wastes</td>
</tr>
<tr>
<td>01 05 04</td>
<td>Freshwater drilling muds and wastes</td>
</tr>
<tr>
<td>01 05 05*</td>
<td>Oil-containing drilling muds and wastes</td>
</tr>
<tr>
<td>01 05 06*</td>
<td>Drilling muds and other drilling wastes containing dangerous substances</td>
</tr>
<tr>
<td>01 05 07</td>
<td>Barite-containing drilling muds and wastes other than those mentioned in 01 05 05 and 01 05 06</td>
</tr>
<tr>
<td>01 05 08</td>
<td>Chloride-containing drilling muds and wastes other than those mentioned in 01 05 05 and 01 05 06</td>
</tr>
<tr>
<td>01 05 99</td>
<td>Wastes not otherwise specified</td>
</tr>
</tbody>
</table>
Characterisation of mining waste: standards

Objectives of CEN/TC 292 WG8:
Characterisation of waste from the extractive industry

Accompany Europe in waste management through the standardisation of nomenclature, standardized tests required for waste characterisation

Develop and provide standards describing procedures to determine the characteristics of waste, including waste behaviour.

Assist Europe in its regulatory effort on waste and secondary raw materials

=> This includes sampling, pre-treatment, leaching properties, determination of total content of species, determination of sum parameters, assessment of ecotoxicity, proposition of test reports and subsequent terminology.
## Tasks of CEN/TC 292 WG8: Work items

### Characterisation of waste from the extractive industry

<table>
<thead>
<tr>
<th>Work item 1</th>
<th>Work item 2</th>
<th>Work item 3</th>
<th>Work item 4</th>
<th>Work item 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Covering the production of an <strong>overall guidance document</strong> led by Ingar Walder with contributions from others including Hans van der Sloot, Ole Hjelmar, David Bendz and Ferenc Madai.</td>
<td>Covering the production on <strong>sampling examples</strong> led by Margareta Wahlström with contributions from others including Ingar Walder, Irena Twardowska and Jane Turrell.</td>
<td>Covering the robustness and validation study on the <strong>static test</strong> led by Margareta Wahlström with contributions from others including Hans van der Sloot, Ingar Walder and Irena Twardowska.</td>
<td>Covering the production of a document on <strong>kinetic testing</strong> led by Ingar Walder with contributions from others including Hans van der Sloot, David Bendz and Ferenc Madai.</td>
<td>Covering the production of a document on <strong>sampling and analysis of WAD Cyanides</strong> led by Klaus Liphard with contributions from others including Tommi Kaartinen.</td>
</tr>
</tbody>
</table>
## Characterisation of mining waste: standards

<table>
<thead>
<tr>
<th>Project reference</th>
<th>Title</th>
<th>Current status</th>
<th>DAV</th>
</tr>
</thead>
<tbody>
<tr>
<td>00292053</td>
<td>Characterization of waste - Static test for determination of acid potential of sulfidic waste</td>
<td>Under Approval</td>
<td>2012-04</td>
</tr>
<tr>
<td>00292065</td>
<td>Characterization of waste - Acid generation behaviour - Kinetic testing of sulfidic waste from extractive industries</td>
<td>Under Drafting</td>
<td>2012-05</td>
</tr>
<tr>
<td>00292066</td>
<td>Characterization of waste - Overall guidance document for characterization of waste from extractive industries</td>
<td>Under Drafting</td>
<td>2012-05</td>
</tr>
<tr>
<td>00292067</td>
<td>Characterization of waste - Sampling and Analysis of weak acid dissociable cyanide discharged into tailings ponds</td>
<td>Under Approval</td>
<td>2011-07</td>
</tr>
<tr>
<td>00292071</td>
<td>Characterization of waste - Sampling of waste from extractive industries</td>
<td>Under Drafting</td>
<td>2012-05</td>
</tr>
</tbody>
</table>
Characterisation methods for mining waste in Europe

Characterisation methods include:

> those explicitly required by the MWD for assessing the hazardous or inert character of each waste
> those aimed at MWFs management
> those aimed at a good understanding of the geological environment of the MWFs, and therefore playing a significant role in the effectiveness of MWF design, and risk analyses.

Can they really be applicable elsewhere?

> The applicability of characterisation methods outside Europe is also desirable, as it contributes to the sustainability of the mineral supply chain.
Characterisation methods for mining waste

> Specific to mine waste (WG8) (under development)
> General methods applied to mine waste

> Sampling
  - standardised methods (under development)
  - industry good practice (similar to ore evaluation)

> Laboratory methods
  - standardised methods (ISO/CEN, but also US-EPA, ASTM, etc)
  - industry good practice
  - chemical, mineralogical, geotechnical data
  - data quality objectives
Characterisation methods for mining waste

> Field methods
- Site screening, mapping large areas
- Lab sample selection optimisation

> Site methods
- geological investigations
- geophysics
- remote sensing, airborne measurements

Total count K, U, Th

Pollution map

$\frac{\text{U}}{\text{Th}} > 1$
Characterisation and risk assessment

- Critical data from waste
- Waste data included in other investigations
- Waste data orientate other investigations
Inert waste and 2009/359/EC

Disintegrates or dissolves
May burn
Sulphide > 1%
Sulphide > 0.1%
NP/AP < 3
substances potentially harmful to environment or human health As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, V & Zn: “not low enough”
residual process chemicals: “not low enough” (only for tailings)

Accepted on information, or national list

Non inertNH or hazardous waste

Inert waste
Inert and hazardous waste: physical properties

- Carbonate, salt or sulphate content: yes
  - Accessibility to water: fractures, permeability: yes
    - Exposure to hydrolysis or chemical reaction (AMD): no
      - Disintegration or dissolution hazard

- Dissolution compromises rock cohesion: yes
  - Disaggregation, particles washed out: yes
    - Exposure to rain, runoff or discrete water flow: no
      - Non-disintegrable waste

BRGM Environment & Process
 August 2011
Inert and hazardous waste: self-ignition properties

- Sulphide > 1%
- Pyrrhotite > pyrite

Porosity or grain size heterogeneity => access of air oxygen to waste

Non-ignitable waste

Known as self-ignitable: coal, pyrrhotite occurrence

Self-ignition hazard

Calorific value, according to ISO 15170, or coal specific approaches (physical & hydraulic properties (surface area, porosity, moisture content, conductivity), mineralogical and chemical analysis)

yes

no
Inert and hazardous waste: acid generation properties

Potentially acid-generating: sulphide or sulphur occurrence

- Yes

Static tests NP/AP < 1
- Yes

Acid generating (or potentially)

Skinetic tests Acid generation potential ?
- Yes

Acid generating (or potentially)

Acidity neutralisation potential

Non significant acid generation potential

Static tests 1 < NP/AP < 3
- No

Static tests NP/AP > 3
- No

acid generation hazard
Flow Chart showing ARD screening tests, decision nodes and ARD rock type categories
Inert waste and 2009/359/EC

Significant contents in substances potentially harmful to environment or human health As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, V & Zn (plus specific ones) – total digestion or analysis

Reference values for « significant contents » (solid waste or leachate) are nationally defined, or result from geochemical background, or from risk analysis

Partial digestion and extraction sequences:
availability of these substances

Leaching tests: released substances

Inert waste

Non inert NonHaz or hazardous waste

Waste with uncertain acid-generating potential
Hazardous waste and 1991/689/EC

Applicable to usual mine waste
(H4) irritant substances
(H5) harmful substances
(H6) toxic substances
(H7) carcinogenic substances
(H8) corrosive substances
(H10) teratogenic substances
(H11) mutagenic substances
(H13) substances that may release potentially dangerous leachates
(H14) ecotoxic substances

Applicable to specific mine waste
(H3) highly flammable substances:
   COAL WASTE
(H12) may release toxic gases:
   CYANIDE PROCESSING WASTE

Non applicable to mining waste
(H1) explosive substances
(H2) oxidising substances
(H9) infectious substances
Hazardous waste and 1999/45/EC

Types of hazardous waste according to activity which generated them
Some of the following substances may be found in mining waste, due to present or past extraction machinery or processing reagents (refs in Annex I):
5. residue from substances employed as solvents
6. halogenated organic substances not employed as solvents excluding inert polymerized materials
7. tempering salts containing cyanides
8. mineral oils and oily substances (e.g. cutting sludges, etc.)
9. oil/water, hydrocarbon/water mixtures, emulsions
10. substances containing PCBs and/or PCTs (e.g. dielectrics etc.)
11. tarry materials arising from pyrolytic treatment (e.g. still bottoms, etc.)
15. pyrotechnics and other explosive materials
Hazardous waste and 1999/45/EC

Types of hazardous waste according to activity which generated them

The following substances may be found in mining waste, according to the commodity mined (refs in Annex II), and may render it hazardous when they have the properties described in Annex III:

<table>
<thead>
<tr>
<th>C1</th>
<th>Be</th>
<th>C7</th>
<th>Zn</th>
<th>C13</th>
<th>Sb</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2</td>
<td>V</td>
<td>C8</td>
<td>As</td>
<td>C14</td>
<td>Te</td>
</tr>
<tr>
<td>C3</td>
<td>Cr(VI)</td>
<td>C9</td>
<td>Se</td>
<td>C15</td>
<td>Ba</td>
</tr>
<tr>
<td>C4</td>
<td>Co</td>
<td>C10</td>
<td>Ag</td>
<td>C16</td>
<td>Hg</td>
</tr>
<tr>
<td>C5</td>
<td>Ni</td>
<td>C11</td>
<td>Cd</td>
<td>C17</td>
<td>TI</td>
</tr>
<tr>
<td>C6</td>
<td>Cu</td>
<td>C12</td>
<td>Sn</td>
<td>C18</td>
<td>Pb</td>
</tr>
</tbody>
</table>
### Hazardous waste and 1999/45/EC

Types of hazardous waste according to activity which generated them (ctd)

<table>
<thead>
<tr>
<th>C19: sulphides</th>
<th>C36 creosotes (if mine wood was processed on site);</th>
</tr>
</thead>
<tbody>
<tr>
<td>C20: Fluor (not CaF)</td>
<td>C37 isocyanates; thiocyanates</td>
</tr>
<tr>
<td>C21: cyanide</td>
<td>C39 phenols; phenol compounds</td>
</tr>
<tr>
<td>C23: Acidic solutions</td>
<td>C40 halogenated solvents (spills)</td>
</tr>
<tr>
<td>C24: basic solutions or bases in solid form</td>
<td>C41 organic solvents, excluding halogenated solvents (spills)</td>
</tr>
<tr>
<td>C25 asbestos (dust and fibres);</td>
<td>C43 aromatic compounds; polycyclic and heterocyclic</td>
</tr>
<tr>
<td>C32 PCBs and/or PCTs (from spills);</td>
<td>C47 substances of an explosive character</td>
</tr>
<tr>
<td>C48 sulphur organic compounds</td>
<td></td>
</tr>
</tbody>
</table>
Waste management optimisation

Careful separation of hazardous and other waste according to characterisation results allows to reduce the final volume of HW.

Well planned waste repositories for potentially acid generating waste, based on accurate ABA and kinetic tests reduces the risk of later AMD inception (and unplanned expenses...)

Thank you

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Association of Applied Geochemists Council member