Residual sludge management: A possible reuse as loam

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Abstract: The management of residual sludge is a current environmental and economic problem for many Italian and Swiss dimensional stone quarries. It may be possible to transfer sludge to local treatment plants where sludge could be treated in order to ensure its reuse. Sludge production is about: 70.000 t/year for Ossola Valley Basin, 16.000 t/year for Luserna Stone District and 8-10.000 t/year for Canton Ticino.

This paper outlines research that has developed a method to convert residual sludge into loam that can be reused for as a fertile substrata for quarry remediation. Case studies in Val d'Ossola, Luserna stone and Canton Ticino basins describe the reuse of this sludge.

It is not feasible to use sludges for farming applications due to their granulometry and physio-chemical nature, as well as their probable contamination brought about by the quarry processing (e.g. TPH: C10-C40). Technological advances have enabled the composting of a mix of residual sludge with green material and nutrients. Bioremediation of this material takes approximately 12 weeks. Initial results indicate that the total petroleum hydrocarbons (range C10-C40) in the dry sludge were reduced by 70% and that the CFU (colonies forming units) increased within 10 weeks. Compost maturity and agronomical parameters indicate that the product is similar to standard forest soil.

The aim of the paper is to indicate the benefit of treating quarry sludge waste.

Résumé: Un problème de l'environnement et économique actuel, raccordé à beaucoup d'industries en pierre dimensionnelles italiennes et suisses, est l'administration de vase restante. La vase pourrait être envoyée aux usines de traitement locales, dans lesquelles on pourrait traiter la plupart de la vase pour garantir sa nouvelle utilisation. La production de vase est de : 70.000 t/année pour la Vallée Ossola, 16.000 t/année pour le district de la pierre de Luserna et 8-10.000 t/année pour le Canton Ticino.

Ce papier expose la recherche qui s'est développée pour convertir la vase restante en glaise qui peut être réutilisée pour la re-naturalisation et les sous strates fertiles pour la réhabilitation de carrières. Quelques études de cas dans Val d'Ossola, pierre de Luserna et Canton Ticino décrivent la nouvelle utilisation de cette vase. L'agriculture des applications de vases n'est pas réalisable en raison de leur granulométrie et les conditions physico-chimiques, aussi bien que leur contamination probable provoquée par le traitement de carrière (par ex. TPH : C10-C40).

Les avances technologiques ont permis le fait de faire du compost d'un mélange (la vase restante avec la matière verte et les nourritures). Le bioremediation de cette matière prend environ 10 semaines. Les résultats initiaux indiquent que les hydrocarbures pétroliers totaux dans la vase sèche (la gamme C10-C40) ont été réduits de 70 % et que le CFU (les colonies formant des unités) augmenté au cours de 10 semaines. La maturité de compost et les paramètres agronomiques indiquent que le produit est semblable au sol de forêt standard.

Le but du papier est d'indiquer l'avantage de traiter le gaspillage de vase de carrière.

Keywords: environmental engineering, wastes management, remediation, case studies, ecology, laboratory tests

INTRODUCTION

Piedmont is the eighth most important producer of Italian dimensional stones and produces 8% of the total produced nationally. The main exploited material is gneiss (from the Ossola Valley basin (VCO) and from the Luserna Stone Basin (LSB)), which represents about 95% of the regional dimensional stone production (Regione Piemonte 2001). A number of commercial varieties of gneiss are produced as dimensonal stone in the Piedmont Region (Ossola Valley and Luserna Stone Basin) and in Switzerland (Canton Ticino). The processing consists of cutting the stone into slabs using a gangsaw with abrasive shot (gangsaw), a diamond frame-saw or by hand-splitting.

The first case study is a so-called, “granites” (a hard and compact gneiss) from the Ossola Valley or Lodrino area in Switzerland. The second case study is related to the “beola” (a gneiss with accentuated natural schistosity from the Ossola Valley and Maggia Valley) (Fornaro et al. 2003).

The environmental problems, associated with this kind of exploitation and production, are the similar to that exerienced by all quarries in the Cotian (Luserna Stone), Pennine (Ossola Valley) and the Lepontine (Ticinese Area) area of the Western Alps. Environmental impacts of quarrying operations are primarily related to the landscape, exploitation and transport impacts, whilst the beneficiation plant impacts are primarily associated with the production and disposal of waste products which includes stone waste and residual sludge (Citran 2000).

Recent increases in industrial dimensional stone production has resulted in a requirement to find solutions to these problems: in particular to the sludge management problem which forms the subject of this research.

Production data for quarries and fabrication plants in the three studied areas (excluding marble production) are summarised in Table 1. Residual sludge production in VCO and LSB, is approximately 90.000 t/year, whilst in Canton Ticino it is about 10.000 t/year. About 60-70% of sludge production comes from the use of a gangsaw which uses abrasive shot, which requires the separation of an iron-rich fraction before reuse, whilst the remaining 30-40% comes from diamond frame-saw production.

Table 1. Production data related to the quarries in the Verbano-Cusio-Ossola district (VCO) and in the Luserna Stone basin (LSB) and Canton Ticino (CT).

	VCO	LSB	CT
Exploited production (m^3/year)	459.000	213.000	170.000
Workable stone production (m^3/year)	182.000	87.000	100.000
Rip-rap production (m^3/year)	127.000	71.000	15.000
Wastes production (m^3/year)	155.000	55.000	50.000
Sludge production (t/year)	70.000	16.000	10.000
Sludge management costs (€/kg)	0.02 – 0.05		-

GEOLOGY, PETROGRAPHY AND TECHINICAL-ECONOMIC FRAMEWORK OF THE VCO AND LSB.

The quarries of the VCO basin are characterised by different silceous rocks, commercially known as:

- Baveno Rose Granite;
- Montorfano White Granite;
- Beola: Beola Favalle, Beola Ghiandonata, Beola Bianca and Beola Grigia
- Serizzo: Serizzo Antigorio, Serizzo Fomazza
- Serizzo Monterosa;
- Symplon White (Regione Piemonte 2000).

From a petrographic point of view, the granites (Boriani et al. 1988a, 1988b, 1992, Pinarelli et al. 1988, 1993) represent a series of plutonic bodies characterised by medium or fine-medium grainsize, which form a multi-phase intrusive complex of Lower Permian age, which was intruded at a shallow depths in the basement of the Serie dei Laghi (review in Boriani 2000).

The Beole, the Serizzi and Luserna Stone represent the geological products of the metamorphic and structural Alpine evolution of granites comparable with the Graniti dei Laghi. The Beola type is a granitic orthogneiss characterised by an "augen" texture with a sparkly grey or a silver white colour with a marked sub-vertical foliation. Geologically, it belongs to the Upper and Middle Penninitic units of the Monte Rosa (White Beola and Beola Ghiandonata), Moncucco-Orselina (Grey Beola) (Bigioggero et al. 1982-83) and Monte Leone (Beola Favalle and Grey Beola) (Bigioggero & Zezza 1997). Blocks are cut into slabs by gangsaw or diamond frame-saws (34%) or by manual wedging (29%).

The Serizzo type is a kind of granite/granodiorite augen orthogneiss characterised by a grey colouration, with a moderated foliated texture. It belongs mainly to the lower Penninitic unit Antigorio (Serizzo Antigorio, Formazza and Symplon White) and also to the Monte Rosa Nappe. Blocks are cut into slabs by gangsaws or diamond frame-saws (40%) or by manual wedging (4%).

The Luserna Stone (Sandrone et al. 2000, 2001) is a leucogranitic orthogneiss characterised by a "micro-augen" texture, with a grey-green colour which locally changes colour to light blue. The Luserna stone has a marked sub-horizontal foliation typical of the Dora-Maira Massif (review in Sandrone et al. 1993) which outcrops over an extensive area (approximately 50 km^2) in the Cottian Alps on the border between the Torino and Cuneo Districts. Blocks are cut into slabs by gangsaws or diamond frame-saws (13%) or by manual wedging (32%).

The Ticinese gneiss and Ossola Valley dimensional stone quarries are located, in the Penninitic Domain, between the Helvetian (in the North and West) and the Austroalpine (in the East), above the Insubric Line (Compagnoni et al. 1991). They occur in the deep structural zone, which outcrops on the axial culmination represented of the Lepontine Dome. This main structure, between Ossola Valley and Ticinese Area, can be subdivided into two different areas:

Toce River to the west, and Ticino River to the east separated by the Maggia Valley. It has been interpreted as a basement nappe stack characterised by many Mesozoic intercalations (marbles, meta-pelite, schists, etc).

Petrographically the rocks of the internal Penninitic Domain (including the Antigorio and Simano rock-stratigraphic units) is characterised by orto-derivates structured with different grades of lamina, and with a gneissic texture (Bigioggero et al. 1977). In particular the metamorphic rocks exploited in the Levantina- Riviera area, are typically light grey or rather dark quartz-rich two-mica (biotite and muscovite) gneiss, with a variable structure from schistose to massive.

In the Alps, quarries are located on the valley sides and a descending production method is used using sub-horizontal slices which exploit systematic discontinuity planes to assist the extraction of regular ornamental stone blocks. Quarry benches are developed using of explosives (using detonating cord as a "cutoff agent" and sometimes blasting powder as a "thrust agent"). The blast holes are parallel and arranged in rows at close intervals. Simultaneous blasting over a wide area enables block movement (Dino et al. 2003). In a VCO quarry the block handling is traditionally performed by a derrick, whilst in LSB it is carried out by large front-end loaders which requires service ramps for each exploited level. The use of diamond wire machines (with sintered tools) is common for granites and gneiss. Producers use "made to measure" diamond wires adapted for the different litho-types to optimise the process and to reduce costs.

VCO quarries are found at altitudes of between 300 and 1300 m above sea level. Typically a quarry employs four people with one of them usually being the owner. Quarrying requires a derrick, an excavator, 1-2 tractor loaders and 6-7 hard rock drillers. Typical production is 5990 m^3/year (Serizzo quarries) and about 4000 m^3/year (Beola quarries).

LSB quarries are located at altitudes of between 900 and 1500 m above sea level in the Bagnolo Piemonte, Rorà and Luserna S. Giovanni municipalities. Typically quarry management requires 2 employees with one of them usually being the quarry owner. Quarrying requires an excavator, a tractor loader and 2-3 hard rock drillers. Annual production is between 3,400 to 8,300 m^3/year.

A typical fabrication plant includes an open-air block storage area, an area where gangsaws, diamond frame-saws, float, and brooming machines are located, and an office building.

In the VCO basin, between 2 to 40 people are employed in the fabrication plants. In small fabrication plants, the storage and the buildings cover less than 1000 m^2 and the energy consumption is only 100,000 kWh/year. A large fabrication plants storage and buildings cover more than 2,000 m^2 and the energy consumption is greater than 700,000 kWh/year. Marketed products consist of slabs (75%), squared blocks (20%), with a small percentage of "*mosaico*" (split face pieces for "crazy" paving), Belgian blocks and kerbstones.

In the LSB, 1 to 30 people are employed in the fabrication plants. Marketable products comprise slabs (70%), kerbstones (20%), the remainder being squared blocks and Belgian blocks. The regional market, accounts for 56% of the total production, with 36% is bound for the national market and approximately 8% (VCO) and 15% (LSB) respectively for international market.

ENVIRONMENTAL ASSESSMENT: LCA AND ECO-BALANCE

As with other sectors of the mining and quarrying industry in developed countries, an evaluation of the environmental impact and "sustainability of production" is required.

The "life cycle assessment" method (LCA) has been used to assess the production process. Evaluation parameters include project design, planning, manufacturing practices, quality standards, and cost control together with environmental impact, energy usage and waste recovery policies/procedures. LCA is a scientific method to evaluate the environmental consequences of a product through its life cycle. The assessment will cover the entire life cycle of the product, from the extraction of raw materials, through the production and the use, to its final disposal.

The "Ecobalance" is a tool to analyse only the specific production cycle, and includes energy and resources consumption, emissions, social effects and direct economic allowance. It is mainly used to evaluate the environmental consequences of a product, process or activity; however any Ecobalance the assessment considers only the activities, within a specific production site. However concurrent use of the LCA's standardization and normalization index enables assessment of the environmental impact of the general system referred to ecological health, human welfare and resource depletion.

Both LCA and Ecobalance are now strategic tools for industrial producers, and they offer an opportunity to advertise an environmentally "friendly" product and to support a "green" marketing activity. Proposed CEE Regulations, may oblige the enterprises to conduct an environmental review to take into consideration wastes, pollution of soil, water and air, noise, energy and resource consumption and, finally, the safety of the workers and the impact on ecosystems [Badino et al. 1995, Lovera et al. 2002].

For dimensional stones production, the recent introduction of the Ecolabel represents a very significant step towards the aim of an eco-compatible quarrying management. It pre-supposes a rational extraction of the raw materials an optimal production plan taking into account, the product specifications, the environmental impact of the wastes produced, and the recycling and utilization of the waste material as a secondary raw material.

In this paper we would like to underline, the third aspect: the recycling and reuse of the waste material, and in particular the treatment and "composting" of residual sludge to produce loam to re-use for quarry remediation. Prior introducing the topic of our research, it is important to introduce the problems connected to residual sludge management from a technical and legislative point of view.

SLUDGE MANAGEMENT

Chemical and physical characteristics

The characteristics of residual sludge depends on the nature of the raw material (quarried stone) and on the method of cutting In this paper we only consider siliceous sludge. The chemical and physical characteristics are shown in Figure 1 and Tables 2 and 3.

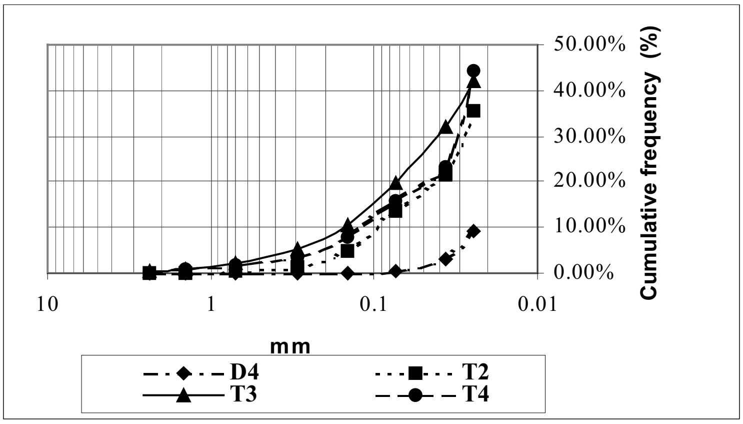

Figure 1. Particle size distribution of residual sludges from gangsaw (Ossola Valley Basin and Luserna Stone Basin). D4: sludge from diamond frame-saw (LSB); T2: sludge from the gangsaw (LSB); T3 and T4: the gangsaw (VCO).

Table 2. Chemical composition range (major elements) for Serizzo (1) and Luserna Stone (3) and relative filter-pressed sludge (2 to 4). The Fe_2O_3 as total Fe.

% wt.	**1**	**2**	**3**	**4**
SiO_2	64.5-68.1	60.6	71.6-75.8	60.3
TiO_2	0.4-1.1	0.4	0.1-0.2	0.1
Al_2O_3	18.3-19.0	13.0	13.1-15.6	13.8
Fe_2O_3	2.4-4.1	15.6	0.8-1.9	8.6
MgO	0.8-1.3	0.9	0.4-1.1	3.9
CaO	2.7-3.8	3.6	0.8-1.2	3.7
Na_2O	2.8-3.8	3.4	2.9-4.7	3.1
K_2O	2.6-3.2	2.1	3.7-5.2	4.2
L.O.I.	0.9-1.0	0.4	0.6-0.9	2.3

Table 3. Preliminary trace elements chemical analyses for 1: Serizzo, 2. VCO sludge from the gangsaw 3: Luserna Stone; 4: LSB sludge from the gangsaw 5. LSB sludge from diamond frame-saw). Column 1: data from HUNZIKER (1966).

ppm	**1**	**2**	**3**	**4**	**5**
Cd	n.d.	< 2.0	n.d.	< 1.0	< 1.0
Co	0-13	10.0	5.0	8.0	118.5
Cr	0-27	160.0	10.0	113.0	21.7
Cu	n.d.	120.0	13.0	174.0	166.0
Mn	500	910.0	350	880	100
Ni	5-60	80.0	n.d.	96.0	2.85
Pb	n.d.	< 2.0	n.d.	25.0	76.0
Zn	n.d.	50.0	n.d.	168.0	99.0

It is essential that an appropriate sludge management process is adopted because unregulated waste tipping may, as a result of groundwater ingress into the fine grained filter-pressed material result in slope instability.

Residual sludge may also be contaminated with heavy metals and petroleum hydrocarbons. The most problematic elements Ni, Cr, Cu, Mn associated with Fe in the abrasive gangue in gangsaw produced sludge and Co and Cu in diamond frame-saw produced sludge. The TPH contamination is a relative recent problem which is related to Canton Ticino quarrying basin and to a lesser extent the LSB and VCO basins. Contamination is related to the age, quality and to the maintenance of the productive plant.

Regulatory Framework

Residual sludges are considered wastes (CER code 010413; see points 12.3 and 12.4 of directive 72 published on the April 16, 1998 Official Gazette, DM February 5, 1998 and DMA. n. 350/98) on the base of D.Lgs 22/97 (Ronchi Law Directive). It is possible to obtain permits to dispose of sludge as inert waste by means of article 27 and 28 from D.Lgs 22/97 and in accordance with 13 March 2003 Directive "*Critera for waste disposal in landfill*". This directive contains a table (table. 2 art. 5) reporting the limits for elemental concentrations (3 August 2005 Directive "*Definitions about the criteria for the wastes admissibility in landfill"*).

Unfortunately the bioremediation process to produce loam is not listed in the treatment processes or authorised uses of sludge included in D.Lgs 22/97 and DM dated 5th February 1998.

Therefore we have applied assessment criteria in accordance with:

- DM 471/1999 (for polluted soil), for assessment criteria for heavy metals and TPH;
- L. 748/84 (for fertilizer), for a specification for Loam.

SLUDGE "BIOREMEDIATON PROCESS" TO PRODUCE LOAM

A specific directive for loam, and in particular from loam obtained from a residual sludge bioremediation process has not been published. However, the conversion of the contaminated sludge, from dimensional stone quarries and beneficiation plants into valuable soil for re-naturalisation and fertile substrata obtainment, is possible by means of bioremediation process.

It is not feasible to use residual sludge on farmland due to their particle size distribution, their physio-chemical state, as well as their probable contamination by petroleum hydrocarbons (e.g. TPH C10-C40) and their heavy metal content.

The process described in this paper is based on mixing specific formulations (weight by weight) of residual sludge, shredded green material, compost, natural loam and proprietary nutrients and bio-stimulants (patent Envirorem n.1299265). The bioremediation process accelerates and stimulates the growth of autochthonous aerobic bacteria. The process takes 12 weeks (from March to June 2005). Agricultural loam, normally contains 10^5 – 10^7 CFU (Colony Forming Units) per gram. Sterile material like residual sludge typically contains 10^2-10^4 CFU/g. During the bioremediation process the CFU quantity rises to 10^8-10^{10} CFU per loam gram, and as a consequence the material is more able to mineralise organic elements, carbon and energy sources for agricultural use. The bioremediation technique, however, only accelerates reactions which would happen naturally over a longer time period.

Bioremediation process is periodically monitored by reference to a number different physical parameters which include temperature, loam humidity, O_2/CO_2 ratio in biopiles, CFU content and overall appearance.

Table 4. Trial "Mix" Formulations

Material	Mix A		Mix B		Mix C		Mix D	
	Weight (t)	% dry material	Weight (t)	% dry material	Weight (t)	% dry material	Weight (t)	% dry material
Sludge from diamond frame-saw	30.5	58,84	41.8	59.43	-	-	-	-
Sludge from gangsaw (with abrasive shot)	-	-	-	-	38.0	61.69	-	-
Mixed sludge	-	-	-	-	-	-	37.0	61.06
Green material	22.0	22,64	18.0	13.65	23.0	19.91	23.0	20.24
Compost	12.0	18,52	12.0	13.65	6.0	7.79	6.0	7.92
Rejected fruit and vegetables	-	-	7.0	2.65	-	-	-	-
Natural loam	-	-	8.0	10.62	7.0	10.61	7.0	10.78
Total	64.5	100,00	86.8	100.00	74.0	100.00	73.0	100.00

Figure 2 depicts a flow diagram outlining the bioremediation process. The process consists of four stages (Corio, 2005):

1. Sludge selling off.
2. Mixing of ingredients. (This was conducted under a under cover as it is important to control the moisture content and the sludge/(green material, compost, loam) ratio.
3. Adding activating reagents.
4. Quick maturation: the four mixes were placed undercover in a "closed" loft building arranged in 4 biopiles, each with a volume of approximately 70 m^3). Air ventilation channels below the piles enabled air injection to increase the oxygen available for the bioremediation process. The "quick maturation" lasted 28 days during which periodic monitoring was undertaken. The piles were mechanically turned at intervals. The quick maturation building is under negative pressure in order to ensure pollution control.

Following these four stages the material is moved to an "open" loft building for 8 weeks for the "slow maturation" stage. During this stage the piles are turned twice and after 12 weeks the material obtained is ready to be used for quarry remediation.

Periodic monitoring on the 4 mixes was an important element of the research project. This included;

- Process control: punctual periodic evaluation on the biopiles to obtain data for the process control, over the 12 weeks duration of the bioremediation process;
- Laboratory analysis on the samples to characterise the tranformation process.

The following testing was undertaken;

- Chemical analysis: TPH, dry substance at 105°C, pH, heavy metals (Zn, Cd, Pb, Ni, total Cr, Cu, Hg, As, Fe, Co), CFU;
- Particle size distribution using wet and dry methods;
- Analysis on the mix ingredients (compost and shredded green materials) pH, dry substance at 105°C, pH, powders (600°C), humidity, total organic substance, total organic carbon, total nitrogen, C/N ratio, heavy metals (Zn, Cd, Pb, Ni, total Cr, Cu, Hg, As, Fe, Co);
- Bio-evaluation analysis on the resultant loam. These involved the growing of three different plant species (lentils, corn and wheat) in loam in a controlled agricultural environment. Controls were grown in agricultural soil. Germination time, phyto-toxic resistance and plant (biomass) growth were evaluated.
- Agronomic and phyto-toxic parameters: dry substance, pH, organic fraction, salinity, nutrients elements (P2O5 , K2O, Mg, CaO, total nitrogen, NO3—N, NH4+-N, NO3-N / NH4-N ratio, C/N ratio), toxic elements (TPH: C10-C40);
- Leaching tests (DM February 5, 1998)

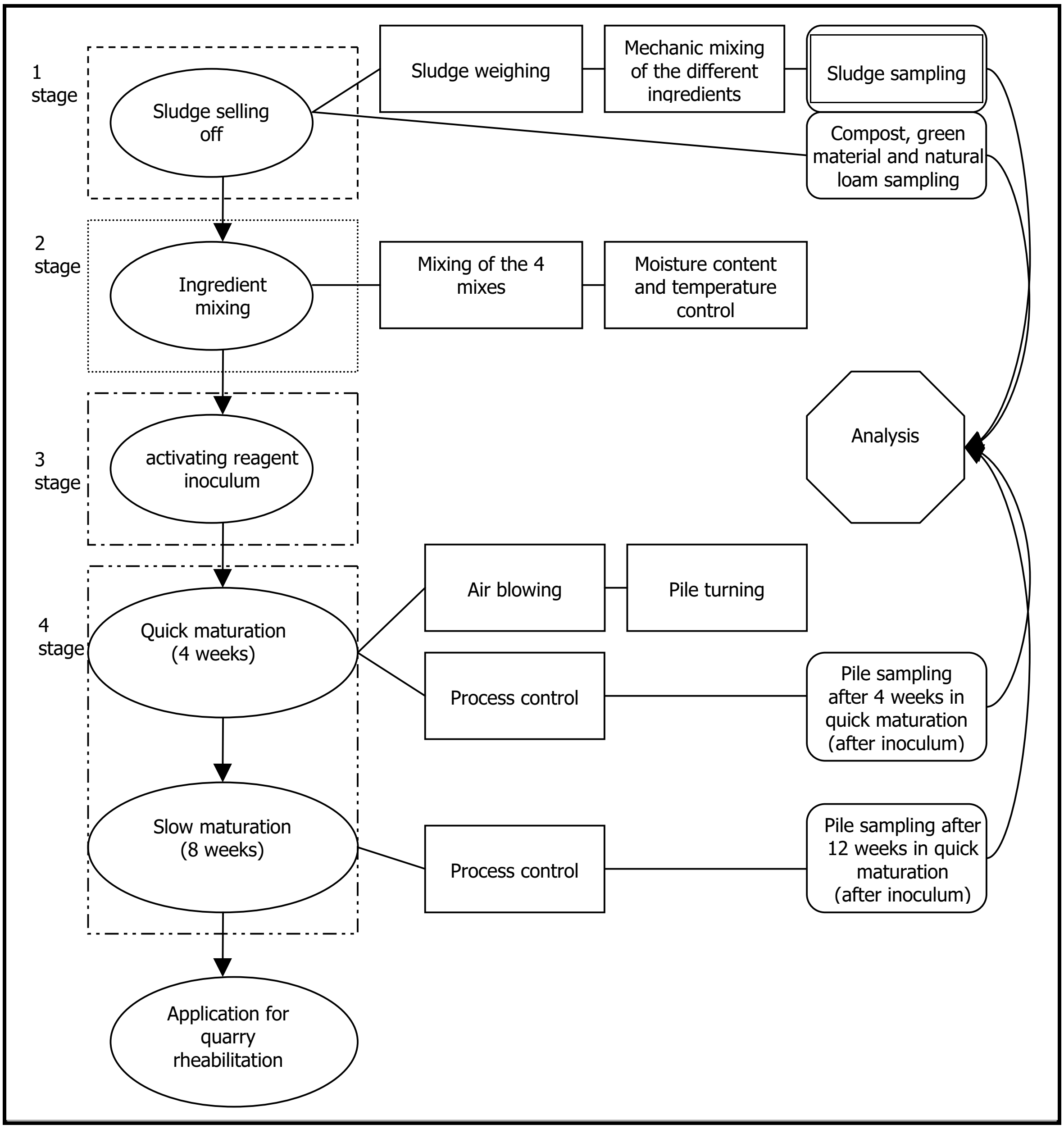

Figure 2. Process flow chart (Corio 2005)

RESULTS

With reference to the results presented in Tables 5 and 6 it is evident that some parameters (eg. TPH) exhibit a marked decrease following composting compared to the initial concentrations in the mix ingredients and now do not exceed criteria published in DM 471/99. Other parameters however, for example Co in mixes A and B, Cr and Cu in mix C and Cu in mix D still exceed DM 471/99 criteria. Attempts to separate abrasive shot in residual sludge from the gangsaw (PIC Interreg III A project "Residual sludge valorisation". Partners: Ossola Valley (IT) and Canton Ticino (CH)has provided promising results with a significant reduction in heavy metal content.

Comparison of the heavy metal content of the four composted loam mixes indicates that assessment criteria published in Law 748/84 (Table 7) and modified by the 27[th] March 1998 Directive are not exceeded. The materials contain low organic carbon, humic and fulvic acids (% dry substance) as would be expected for such materials with high mineral contents. However the resultant loam appears suitable for use in quarry remediation

Table 5. Chemical analysis of original ingredients, mixes A and B, compared with assessment criteria published in DM 471/99.

Elements	Metric units	Compost	org. CAAT	Green material	Sludge from diamond frame-saw	Mix A 08/06/05	Mix B 08/06/05	471/99 tab. A limits
As	mg/kg ds	3.90	< 0.5	2.00	14.20	11.20	13.50	20.00
Cd	mg/kg ds	< 0.5	<0.5	<0.5	0.58	0.50	0.50	2.00
Cr Tot.	mg/kg ds	**154.00**	14.90	76.50	24.50	40.80	35.60	150.00
Hg	mg/kg ds	0.50	0.09	0.10	0.13	1.00	1.00	1.00
Ni	mg/kg ds	97.60	7.90	47.30	10.10	30.70	30.50	120.00
Pb	mg/kg ds	82.30	6.90	18.60	8.20	21.90	14.00	100.00
Cu	mg/kg ds	**142.00**	20.70	34.10	49.90	72.40	63.30	120.00
Se	mg/kg ds	Nd	< 0.5	<0.5	Nd	Nd	Nd	
Zn	mg/kg ds	**330.00**	67.60	104.00	98.80	116.40	91.10	150.00
Mn	mg/kg ds	Nd	Nd	Nd	Nd	406.00	591.70	
Co	mg/kg ds	Nd	Nd	3.60	**89.40**	**49.10**	**62.00**	20.00
Cr VI	mg/kg ds	Nd	Nd	Nd	Nd	0.50	0.50	2.00
TPH	mg/kg ds	Nd	Nd	**889.00**	**411.00**	**10.00**	**11.30**	50.00

Table 6. Chemical analysis of original ingredients, mixes C and D, compared with assessment criteria published in DM 471/99.

Elements	Metric Units	Compost	org. CAAT	Verde SGM	Sludge from gangsaw	Mix C 08/06/05	Mixed sludge	Mix D 08/06/05	L 471/99 tab A Limits
As	mg/kg ds	3.90	< 0.5	2.00	9.8	10.80	12.90	9.70	20.00
Cd	mg/kg ds	< 0.5	<0.5	<0.5	1.8	0.50	3.10	0.50	2.00
Cr Tot.	mg/kg ds	**154.00**	14.90	76.50	166.0	189.80	189.00	**122.50**	150.00
Hg	mg/kg ds	0.50	0.09	0.10	0.9	1.00	0.43	1.00	1.00
Ni	mg/kg ds	97.60	7.90	47.30	95.3	115.50	**132.00**	90.40	120.00
Pb	mg/kg ds	82.30	6.90	18.60	12.6	25.90	14.90	23.20	100.00
Cu	mg/kg ds	**142.00**	20.70	34.10	**188.0**	**206.90**	**291.00**	**168.20**	120.00
Se	mg/kg ds	Nd	< 0.5	<0.5	Nd	Nd	Nd	Nd	
Zn	mg/kg ds	**330.00**	67.60	104.00	75.7	99.10	38.80	93.30	150.00
Mn	mg/kg ds	Nd	Nd	Nd	Nd	1420.00	Nd	1976.90	
Co	mg/kg ds	Nd	Nd	3.60	14.4	13.30	18.70	14.00	20.00
Cr VI	mg/kg ds	Nd	Nd	Nd	Nd	0.50	Nd	0.50	2.00
TPH	mg/kg ds	Nd	Nd	**889.00**	**746.0**	10.00	**165.00**	10.00	50.00

Table 7. Chemical analysis of mixes A, B, C and D compared with assessment criteria published in L. 748/84 modified DM 27/03/1998

	Metric Units	Mix A 08/06/05	Mix B 08/06/05	Mix C 08/06/05	Mix D 08/06/05	Directive 748/84 mod. DM 27/3/98 Limits
As	mg/kg ds	11.20	13.50	10.80	9.70	
Cd	mg/kg ds	0.50	0.50	0.50	0.50	1.50
Cr Tot.	mg/kg ds	40.80	35.60	189.80	122.50	
Hg	mg/kg ds	1.00	1.00	1.00	1.00	1.50
Ni	mg/kg ds	30.70	30.50	**115.50**	90.40	100.00
Pb	mg/kg ds	21.90	14.00	25.90	23.20	140.00
Cu	mg/kg ds	72.40	63.30	206.90	168.20	230.00
Se	mg/kg ds					
Zn	mg/kg ds	116.40	91.10	99.10	93.30	500.00
Mn	mg/kg ds	406.00	591.70	1420.00	1976.90	
Co	mg/kg ds	49.10	62.00	13.30	14.00	
Cr VI	mg/kg ds	0.50	0.50	0.50	0.50	0.50
TPH	mg/kg ds	10.00	11.30	10.00	10.00	
pH		7.61	7.60	7.97	8.09	6-8.5
Dry substance 105°C	% w/w					
humidity	% w/w	20.76	22.71	13.34	25.23	< 50
Organic carbon	% w/s d.s..	**13.30**	**3.30**	**7.60**	**2.70**	> 25
Humic and fulvic acids	% d.s.	**5.60**	**2.30**	**4.10**	**1.90**	> 7
Organic nitrogen	% N d.s.	0.26	0.17	0.23	0.28	
Nitric nitrogen	mg/kg d.s.	128.32	9.32	2.80	8.14	
Ammoniacal nitrogen	% N d.s.	0.01	0.01	0.01	0.01	
N tot	% N d.s.	<0.50	< 0.5	0.50	0.50	
P tot	% d.s.	0.30	< 0.2	0.20	0.20	
Conductibility	mS/cm	0.53	339.00	0.53	0.53	
C/N		**49.20**	18.33	**31.67**	10.38	< 25
Ca	mg/kg s.s.	23.482.00	21.206.00	29.099.00	38.263.00	
K tot	% s.s.	0.90	1.20	0.50	0.50	

USE OF PRODUCTS FOR QUARRY REMEDIATION

Laboratory controlled growth trials of corn, wheat and lentils in the four composted mixes and a natural peaty soil used as a control medium indicate that, in general, the composted loams are not phyto-toxic. Monitored parameters, included germination time, biomass growth, plant height and, in addition, a qualitative assessment of plant pathology caused by dangerous micro-bacteria was made.

Figure 3. Product obtained by residual sludge bioremediation process

Figure 4. Corn growth after 40 days. 1: mix A, 2: mix B, 3: mix C, 4: mix D, T: natural soil

Approximately 60 m^3 of the each mix was subsequently used for quarry remediation in Luserna Stone Basin. The material was spread, with an approximate thickness of 8-10 cm on a slope in "Cava del Tiglio", Pra del Torno, in Rorà Village (TO). The remainder (ca. 90 m^3) will eventually be used for quarry remediation in Ortiolo, Montoso Village (CN).

Figures 5 and 6 show the results of a previous experiment (Lodrino – CH, 2003) were loam produced in a similar way to the methods presented in this present research has been used in quarry remediation.

Figure 5. Lodrino (Canton Ticino). Recently seeded "Artificial loam" obtained from a similar bioremediation process (Fornaro et al. 2003).

Figure 6. Lodrino (Canton Ticino), "Artificial loam" obtained from a similar bioremediation process a number of months after seeding (Fornaro et al. 2003).

CONCLUSIONS

The classification of residual sludge as waste (D.Lgs. 22/97 and DM 05/02/98) is restrictive this study has shown that through appropriate treatment, residual sludge can be transformed into loam for use in environmental engineering.

The aim of the research was to demonstrate the effectiveness of a sludge management process as an alternative to landfill. Systematic treatment of residual sludge results in a "secondary raw material" which can be used to produce loam we consider and that this process should be exploited by public bodies and private companies.

The authors intend to replicate this experiment in other geological and environmental contexts, to test the validity of the results.

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