A case of compatibility between quarrying of ornamental granite and forest exploitation

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A particular development is proposed to mine some good quality outcrops of granite found in a forest exploitation of eucalypts. The exploitation has been designed with a quarrying method, in which small open cast pits are opened and quarried sequentially, and later filled with the waste of the new open pit. Soil is finally used to cover this waste, so new growing tree areas are gained.

Key words*: ornamental granite, forest exploitation, reserves estimation, quarrying.*

Introduction

Mining projects may be compatible with other activities (Gomez-Marquez et al., 2011), as it is forest exploitation in the case proposed in this paper. This compatibility is especially positive if the projects involved take benefit of the synergies among them. However, compatibility of mining with other industries has not received much attention in the literature, possibly due to the fact that it is a highly multidisciplinary subject with a bearing on mine engineering, financial evaluation, legislation, the environment, and socioeconomic aspects (Gomez-Marquez, 2010). Moreover, many cases have been reported, historically, in which mining have caused environmental damage of different degrees, as it is well reflected in literature (Ponting, 1991; Sengupta, 1993; Ripley et al., 1996; Down, Stocks, 1997; Salomons, 1995; Dudka, Adriano, 1997).Nonetheless, mining has contributed economically to society, promoting wealth (Ghose, Roy, 2007).

Nowadays, as a result of being part of an increasing complex society in which the environmentally friendly and sustainable mining exploitation is demanded, mining companies are being forced and committed to develop new exploitation strategies, ensuring an ecological and sustainable approach to mining, apart from keeping reasonably good prices. This commitment has its evidence in the International Council on Mining and Metals (ICMM), which members have committed to the Sustainable Development Framework and the achievements that each member company is making are listed in a table on an annual basis (ICMM, 2011). Furthermore, Hilson and Murck (2000) provide some guidelines for mining companies seeking to operate more sustainably. Regarding this subject, a number of different authors, among which we can mention Humphreys (2001), Lambert (2001), Nooten (2007), Van Zyl et al. (2007) and Botin (2009), provide various and interesting views on mining sustainability.

On the other hand, although resource extraction fuels the global economy and the macroeconomic impact of the extractive sector is usually positive (Wise, Shtylla, 2007), mining industry has possibly caused more disputes over land use than any other industry (Gomez-Marquez et al., 2011). Mining companies have land use disputes mainly with forestry and agricultural operations (Hilson, 2002), which compete with mining companies for land. In fact, one of the critical problems facing the mining industry today is land acquisition for exploration and mining (Ramani, 2009). Additionally, conflict over the development of resources and the distribution of impacts and benefits can be significant in both political and economical terms (Solomon et al., 2008). Hence, governments also have a role to play in developing suitable legislation (Waye et al., 2009).

Also, there are signs of seriously diminishing public confidence in established expert-based analytic approaches to informing policy making (Commission of the European Communities, 2000). In this context, some authors have focused on the potential of public participation in resolving environmental conflicts (Stirling, 2006; Renn, 2006; Rauschmayer, Wittmer, 2006; Sybille van den Hove, 2006; Wittmer et al., 2006; Higgs, 2008). According to Stirling (2006), participation is the only robust way to validate the overall architecture and detailed framing of analysis. Although the different approaches to introduce public participation in social and environmental decision analysis is of great interest for the validation of compatibility projects, its study is not an aim of this paper. Alternatively, multinational mining firms have developed local legitimacy through contributions to community development in the vicinity of mines located in developing nations, (Gifford et al., 2010).

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In this paper, we give an example of compatibility of land use. The case-study presented is located in Galicia, a region in the northwest of Spain representative of many developed countries where communities are protected economically and legally. In consequence, conflicts between major companies and communities (Hilson, 2002; Howitt, 2001; Szablowski, 2002; McLeod, 2000; Esteves, 2008), although very important in developing nations, do not fall within the scope of this study. Gomez-Marquez et al. (2011) have briefly reviewed the disadvantages and benefits of seeking compatibility and have demonstrated how the benefits tend to overcome the drawbacks. These authors also recommend to seek sinergies among different activities, avoiding litigation to obtain prevalescence, which is often a waste of effort, time and money.

A case of compatibility

In Galicia, granite has been traditionally mined and carved in the last 50 centuries. As an example, we can see granite glyphs and a granite dolmen from around 2000 B.C. in Figure 1, and also various monuments, traditional constructions and sculptures performed using this noble rock in Figure 2. Even if classical ornamental rock quarries, as that showed in Figure 3, are typically more economically feasible, it is also true that as it is shown, the impact on the environment and especially on the landscape could be highly minimized by means of new strategies, as the one here suggested.

Fig. 1. Glyphs in granite rock in the upper part and a granite dolmen, showing the early representatives of a large history of quarrying and carving granite.

With that purpose, a particular development, consisting of scattered quarrying strategy is proposed, in which some good quality outcrops of granite found in a forestry exploitation of eucalypts will be mined (Fig. 4), trying to make this exploitation compatible with that for the wood. An aerial view of this same area is also illustrated in Figure 4. b. Figure 5 shows one of this interesting granite outcrops. To try to mine such deposits, initially, some interesting investigation techniques could be applied, showing the recovery estimate of the rock (Taboada et al., 1999). It is also convenient to study geology. Finally it is of great importance to study the quality of the rock. In our case, ornamental rock testing has been performed to show a good quality rock. (Carrilho et al., 1997). As a consequence, an exploitation strategy is designed and an economical analysis is carried out, showing that the scattering exploitations of the various granite outcrops are feasible. Finally, an environmental impact assessment is performed to find out that the ecological impact is slight, and can be considered as acceptable.

Fig. 2. A series of pictures showing classical, traditional and modern architecture and carving of granite in Galicia: a) The cathedral - plateresque style- in Saint Jacques of Compostela. b) traditional 'horreo', construction to keep corn in Galician villages c) Middle aged 'cruceiro' or sculptured cross for a crossroads (or milestone) d) modern sculptures based on traditional cromlech distribution of menhir forms in A Coruña. e) 'The wound' modern sculpture remembering the 'oil spill' of the oil tanker 'Prestige' in 2003 and f) in the first plane a modern sculpture representing 'Breogan', an old Celtic chieftain in the region, and at the bottom the so called Hercules tower in A Coruña, an old light house first built by the Romans and then rebuilt in various occasions, the last one in 1791 following neoclassic architecture.

Resources investigation

The investigated deposit is located in the province of A Coruña, Galicia (Spain), and it corresponds to an investigation permitted area named "Forno". The aim of the field campaign in research is the exploitation of ornamental granite and sub-products. This investigation permit covers 8 different mining zones. (Fig. 6). This ornamental granite is exploited for the production of blocks (B) and semi-blocks (Sb) for gang-sawing, but also for the production of another sub-products, like masonry-transverse stone (mt), and for smaller materials that can be used to obtain construction aggregates.

Fig. 3. View of the front of Faro quarry.

Fig. 4. Various pictures of the forest exploitation including an informative panel (left), an aerial view of the exploitation (upper right) and a general view of an area of eucalyptus (lower right).

Fig. 5. View of an outcrop.

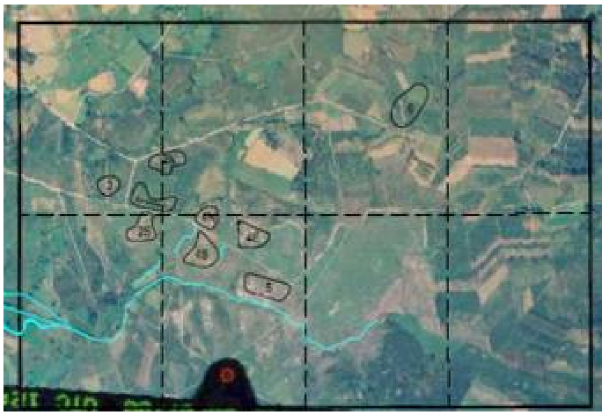

Fig. 6. Aerial view showing the granite outcrops finally selected for mining and the possible location of the waste dump.

In general terms, a block suitable for sawing in the gang-saw has the following characteristics: length 1.90-3.30 m, width 1.00-1.80 m and height 0.90-1.60 m. The slabs that are obtained after sawing will normally be 2-3 cm thick and surface area will be as large as possible so as to get the production of large pieces (Fig. 7). Next down the scale in terms of ideal quarry product size is the semi-block; although this may not have the ideal minimum block measurements indicated above, after sawing it will be of a size that is both commercially acceptable and economically viable. When the natural fracturing of the rock mass is such that it is impossible to obtain blocks or semi-blocks, then smaller sized particles can be extracted for sale. Those particles should be greater than 15 cm thick, 42 cm high and of variable length, as ashlar and rubble masonry. Finally, greater degrees of fracturing will mean that the rock mass will be exploited for smaller pieces suitable for cobbling or construction aggregates (Fig. 7).

For this reason, an economic analysis of this kind of exploitation must be taken into account, not only the physical and chemical characteristics of the rock, but also the degree and extent of fracturing of the rock mass. In order to estimate the availability of ornamental rock, a methodology already designed and used by the authors was tailored to the deposit (Taboada et al., 2005; Alejano et al., 2006). This methodology, based on that by Castaign & Rabu (1980), permits the estimate of the recovery percentage for each of the products, which can be obtained from ornamental granite quarry: block, semi-block, masonry-transverse stone, and smaller materials. This methodology ensures that quarry exploitation is exhaustive, thereby minimizing the production of spoils and the consequent negative impact on the environment.

Fig. 7. Different sizes of granite products.

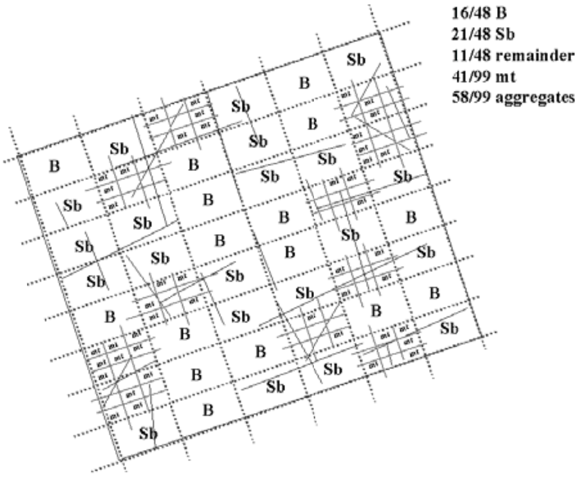

Fig. 8. Material percentage estimations.

The traditional analysis was based on a detailed compilation of discontinuity data from the research fronts (Brown, 1981), which are then interpreted statistically and projected over the three weakness planes that are a particular feature of ornamental granite deposits. Using this information, and bearing in mind the minimum commercially viable sizes for each kind of granite, the corresponding recovery rates are calculated for each material in each plane (Fig. 8). The results were then integrated using spatial techniques. This methodology was applied to a series of quarries in their initiating and operating phases in order to carry out assessments for the recovery of the different granite products and compare results to actual data. The obtained results showed a reasonable good level of agreement (plus or minus 5 %) for the recovery of blocks and semi-blocks.

In the case presented in this paper, due to the plane nature of the outcrops and due to the fact that a few joints were cut by the few drills performed, it was necessary to estimate from one single plane joint observation. This was done by estimating the recovery in the grain plane, and then comparing it to the total recovery for various areas of two quarries. A correlation was then established, and it was used to estimate the total recovery of granite blocks and semi-blocks in the different outcrops appearing in the investigated area.

Because the rock for ornamental use must have adequate physical and chemical properties, a number of lab essays have been carried out from rock cores taken from two drills performed (Fig. 9). The Spanish norms (UNE) of ornamental rock have been followed to obtain the results shown in table 1. We have obtained a recovery rate for blocks in each outcrop, which lets us decide whether to exploit or not each particular outcrop, depending on profits. Carrying out the process we obtain 8 particular outcrops favourable to exploit. An example is shown in Figure 10 for outcrop number 6.

Fig. 9. View of the excellent granite drill cores recovered in the investigation stage.

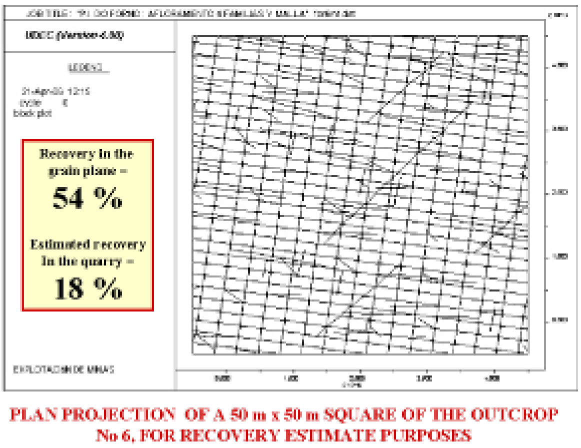

Fig. 10. Estimated recovery rate in an outcrop.

Tab. 1. Average property values for different classic tests on ornamental rock performed on rock samples from the quarry.

Test	Norm (Spanish norms)	Average Value
Apparent density	UNE-EN 1936: 1999	2606,2 kg/m^3
Open porosity	UNE-EN 1936: 1999	2.22 %
Unconfined compressive strength	UNE-EN 1926: 1999	71 MPa
Flexural strength under concentrated load	UNE-EN 12372: 1999	6.5 MPa
Impact resistance	UNE 22-179-85	78.33 cm
Frost resistance	UNE 22-174-85	0,00 %
Water absorption (under atmospheric pressure)	UNE-EN 13755	0.7 %
Water absorption coefficient by capillarity	UNE-EN 1925	4.09 $g/m^2.s^{1/2}$

In Table 2 the expected average recoveries in the selected outcrops, as considered by means of simple observation judgement and by means of the indicated methodology (Alejano et al., 2006) are presented. Outcrops number 1 and 7 were decided not to be mined.

Tab. 2. Expected average recoveries of granites blocks and semi-blocks in the selected outcrops, by means of simple observation judgement and by means of the indicated methodology (Alejano et al., 2006).

Outcrop	Judgement	**Methodology** (Alejano et al., 2006) [%]
1	Very bad	1
2-S	Bad	16
2-N	Bad-Very bad	18
3	Average	46
4-S	Average	39
4-N	Good	61
4-E	Average-Bad	28
5	Bad	16
6	Average	18
7	Very Bad	5

Exploitation design

Taken into account the ground morphology, the most adequate exploitation method is quarrying by means of a downward benching system. The extraction will advance three-dimensionally by downward benching from the highest elevations, by means of vertical deepening and horizontal benching advance. In benching exploitation methods, the exploitation is divided in horizontal slices, following parallel and equidistant surfaces. It is possible to have several exploitation benches maintaining adequate distances between benches between different levels (Fig. 11).

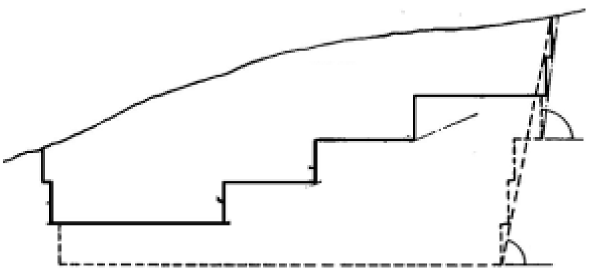

Fig. 11. Benched exploitation.

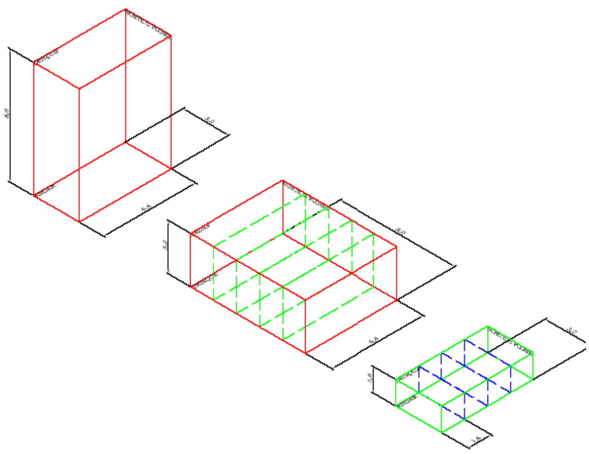

Fig. 12. Cycle of block cutting.

The production cycle consists of a number of elemental operations, carried out in a sequential manner. These operations basically consist of cutting and handling rock blocks. These blocks will have less volume as the cycle advances.

The cycle begins with the isolation of a big block of rock, with parallelepiped form and dimensions adequate to the task of cutting and loading equipment, with the aim of reaching the maximum productivity. This big block is divided in consecutive steps in order to reach easy-to-handle sizes, also taking into account commercial requirements (Fig. 12).

The disposal of wasted rock will be discontinuous, with mining by drilling and blasting, loading by means of a wheel loading shovel, and transport by an articulated haulage truck. This exploitation consists of quarrying sequentially the detected outcrops in such a way that the waste generated in the exploitation of the first outcrop will be stored in a waste dump, and once created the first exploitation void, the waste of the next exploited outcrop will be placed in it, and so on. Hence, the successive voids will be refilled, recovering the original morphology of the terrain (Fig. 13 and 14).

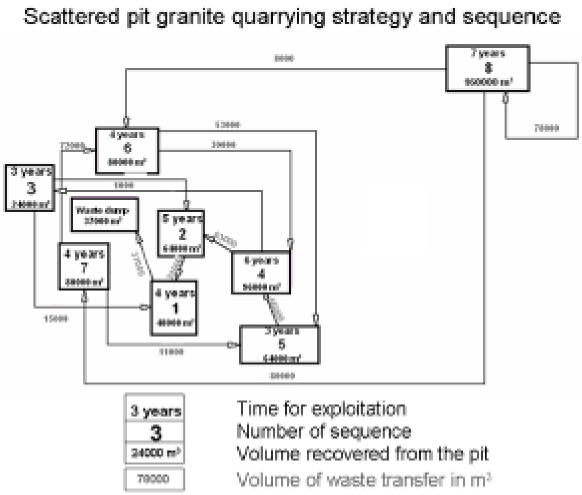

Fig. 13. Exploitation sequence.

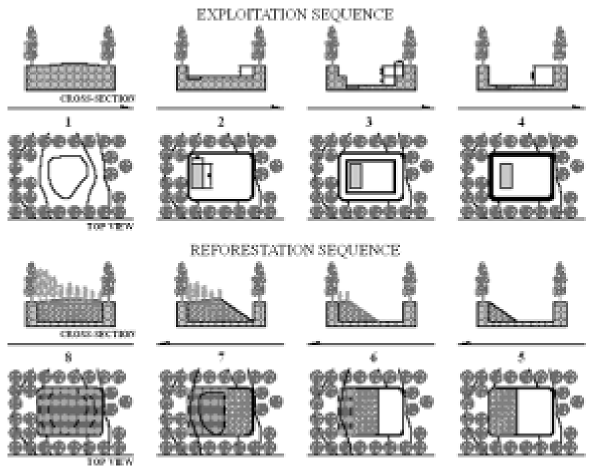

Fig. 14. Exploitation and reforestation sequence of a pit.

The sequence order must obey to the following criteria: a) Initially, because we have not any void to store the waste, we should begin the exploitation in an outcrop with little volume of waste. b) To guarantee the economic return of the quarry and the amortization of the initial investments, the exploitation should begin with an outcrop of great recovery, since there would be little waste to move, minimizing exploitation costs. c) The following outcrops to be exploited must generate a waste volume that fit into the previous exploitation voids, preventing the increase of the waste dump.

Taking these criteria into account, the needed calculations have been performed in order to obtain the ornamental rock recovered and the waste movement for the selected geometries as shown in tables 3, 4. In these tables the sequence in which the pits are quarried is shown in brackets together with the pit name. According to tables 3 4, 175,200 m^3 of ornamental granite can be obtained. An economic study has also been made, getting a investment return of 5 years, with an IRR of 26 % and a NPV (3 %) of 418,000 € in 10 years.

Tab. 3. Surface, depth and estimated recovery for the different pits to be quarried.

Pit (sequence)	**Surface** [m^2]	**H** [m]	**Recovery** **[%]**
2-S (7)	5,000	16	20
2-N (6)	5,000	16	20
3 (3)	3,000	8	50
4-S (1)	6,000	8	40
4-N (2)	4,000	16	60
4-E (4)	6,000	16	30
5 (5)	8,000	8	20
6 (8)	10,000	16	20

Tab. 4. *Based on the information in Table 3, volume of mineral, waste and swollen waste for every pit and for the total exploitation.*

Pit (sequence)	**V mineral** [m^3]	**V waste** [m^3]	**V swollen waste** [m^3]
2-S (7)	16,000	64,000	83,000
2-N (6)	16,000	64,000	83,000
3 (3)	12,000	12,000	16,000
4-S (1)	19,200	28,800	37,000
4-N (2)	38,400	25,600	33,000
4-E (4)	28,800	67,200	87,000
5 (5)	12,800	51,200	66,000
6 (8)	32,000	128,000	166,000
TOTAL	175,200	440,800	571,000

Ecological considerations

The main part of the surface belonging to the investigation permit is occupied by plots aimed at the reforestation of eucalyptus, so the exploitation of granite will only take place in those outcrops free of vegetation and fertile soil i.e. the areas exploited are outcrops, with no need of removing any vegetation or soil. However, it would be necessary to store topsoil borrowed from outside the exploitation in order to reforest. Therefore, mining and forestry exploitations became compatible, since granite exploitation will take place in areas where it is actually impossible to reforest, because of lack of soil.

Only a waste dump will be needed so as to store the waste produced in the first outcrop exploited. The waste of the successive outcrops exploited will be deposited in the voids left by previous exploitations, restoring its initial morphology. The waste dump is to be created with smooth slopes, to get a better integration in the environment, in such a way that it can also be used for increasing the forestry available surface.

An environmental impact assessment study was performed to find out that the environmental affections are low. They are null in what concerns geology, hydrogeology, climate topics, biological soil, and flora. The ecological affections are low in the regard of geomorphology and landscape (occurrence of eight pits in stages), surface hydrology (creek waters carrying solids), air quality (dust in the dry seasons of the year), fauna (some animals escaping the areas of mining) and socio-economy (noise). As a positive impact, the exploitation would hire 6 to 7 workers from the closer villages, the company is committed to developing new roads in the zone, and finally, the forest exploitation would be given around 25.000 square meters of planted forest in areas where nothing grew before mining.

Conclusions

Mining activities must be implemented where nature has placed mineral resources, but these activities may be compatible with others, like forest exploitation. In this paper, we try to show an example of land use compatibility between mining and forest exploitations. Compatibility generates wealth because two resources may be exploited, rather than foregoing one resource in favour of the other.

The case presented here is located in Galicia, where Spanish Constitution applies, and it states in article 45.2 that public authorities shall ensure rational use of all natural resources on the basis of essential collective solidarity, and in article 131.1 that the government shall plan general economic activities according to collective needs, and stimulate wealth growth and fair distribution thereof (Constitución Española, 1978).

The granite exploitation of Forno was designed with a quarrying method, similar to strip mining, in which small open cast pits are opened and quarried, and later filled with the waste of the new open pit. New soil, bought with the profits of mining, is used to cover this waste. In this way, at the end of the quarrying, new growing tree areas are gained in the filled pits and in a waste dump. The environmental impact, which has been painstakingly assessed, is almost positive. However, the economic impact is extremely positive for this rural area of Galicia (Spain).

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