Estimation of the local recovery of a slate massif by merging drill hole and quarry face information

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1. Abstract

The rational exploitation planning of slate quarries was focused in a previous work by calculating two indices based on drill holes – one for 'quality' and the other for 'recovery' (Pereira *et al.*, 1995). Those indices relate the observable geological/technological attributes in drill hole cuttings to the quality of the slate plates to be produced and to the expected recovery in the quarry development.

In this paper, the available information in the exposed faces of the quarry is employed to enhance the quality index, which is used as an ancillary variable to carry on the co-kriging of the local recovery in the entire massif.

A case study, referring to the Valdeorras slate quarry, is presented for the purpose of illustrating the proposed methodology. The estimated values of the local recovery in exploitation units are arranged in a 3D model of the entire massif, which is the basis for further planning.

2. Introduction

When planning the exploitation of slate quarries, it is crucial to forecast the recovery in the exploitation units designed for the future development of the quarry. If an *ex ante* 3D model of recovery is created, the mine workings may conducted in accordance to local recovery zoning. It is by this bias possible to avoid the exploitation of low recovery zones, where the rejected material would cause environmental problems.

The recovery depends on a set of attributes that can be measured/observed in drill hole cuttings, *e.g.* density of discontinuities and kink bands, RQD values, etc. Since the number of drill holes is always exiguous to estimate a reliable 'recovery index' as a combination of those attributes, it is useful to dispose of some ancillary variable, available both in drill holes and in the exposed faces of the quarry, where image sampling is feasible at will. This new variable, which correlates with the former, is the 'quality index', calculated by combining a new set of characteristics, like presence/absence of ultra-metamorphism, quartz veins, sand laminations, oxidation, carbonates, crenulation.

Now, to construct this quality index in the exposed faces of the quarry, it is required to capture pertinent data in the available faces image in a way that simulates the drilling procedure, in order to merge these data with the analogous set drawn from drill holes.

Once obtained a file of attributes captured both in the face images and in drill holes, those are combined by a methodology relying on Correspondence Analysis as a discriminant procedure (Pereira, 1988, Pereira *et al*., 1993) that produces a single continuous synthetic variable – the quality index – referring to a more significant set of samples (drill hole cuttings + pieces of face image that simulate drilling). Using this new index as an ancillary variable for enhancing the recovery index estimation by co-kriging, a more reliable 3D model of the later index can be produced to support exploitation planning.

3. Geological Setting

In order to illustrate the proposed methodology, it was selected the slate quarry of Valdeorras, located in Galicia, Spain, in an Ordovician massif (Figure 1)

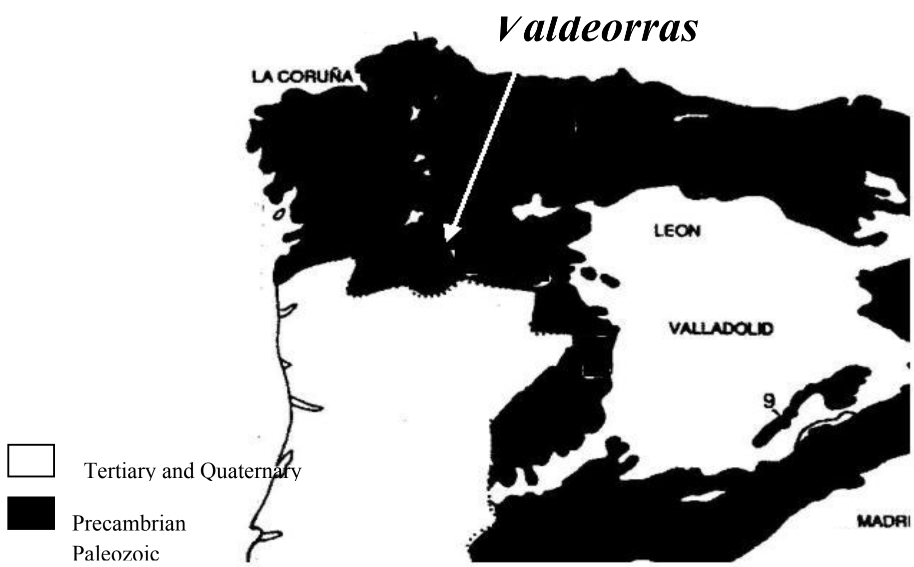

Figure 1. Location Map of Valdeorras quarry

The geological factors that are believed to affect the exploitation of this quarry were scrutinized (Taboada, 1993), for the purpose of guiding the selection of pertinent attributes linked with recovery and/or quality.

Among the scrutinized geological factors, those that can be observed in the faces of the quarry and/or in the drill hole cuttings are the following:

- Ultra-metamorphism – this factor jeopardizes the quality of the rock, since it "melts" the schist plans, avoiding slab separation.

- Presence of quartz veins, kink bands and other discontinuities – these 'accidents' influence both quality and recovery.

- Presence of carbonate inclusions – this secondary precipitation has an effect on quality, since it produces white nodules by weathering.

- Presence of sand laminations and oxidized material – this occurrence leads to low recoveries, given that it disaggregates the material to be exploited

- Presence of crenulation - this factor, which applies to all type of discontinuities, refers to the 'multiplying effect' of intersections.

4. Data Capture

The first step of this procedure is to select, in drill hole cuttings, an appropriate set of attributes that are expected to drive recovery. In this case, those attributes, indicated by the quarry management, are the following: number of fractures/m, number of kink bands/m, presence of weathered material, results of RQD tests. Hence, this set of attributes were captured in the available 13 drill holes, giving rise to a file of 261 entities (one for each of the 5m drill hole cuttings) to feed the recovery index algorithm.

In addition to this set of attributes, geological information indicates that other factors affecting quality can be observed both in drill hole cutting and in the exposed faces of the quarry. The attributes reflecting those factors, if properly merged, could be combined in a new index – denoted quality index -, which is to be used as an ancillary variable to enhance recovery estimation.

In order to obtain a comprehensive set of attributes that are shared by drill holes and quarry exposed faces, it is required to somehow simulate the drilling procedure on the digitized image of the available exposed faces of the quarry. For this purpose, the photographs of the quarry faces were digitized and a number of lines were superimposed to the image by a regular pattern of 5m interval, as shown in Figure 2.

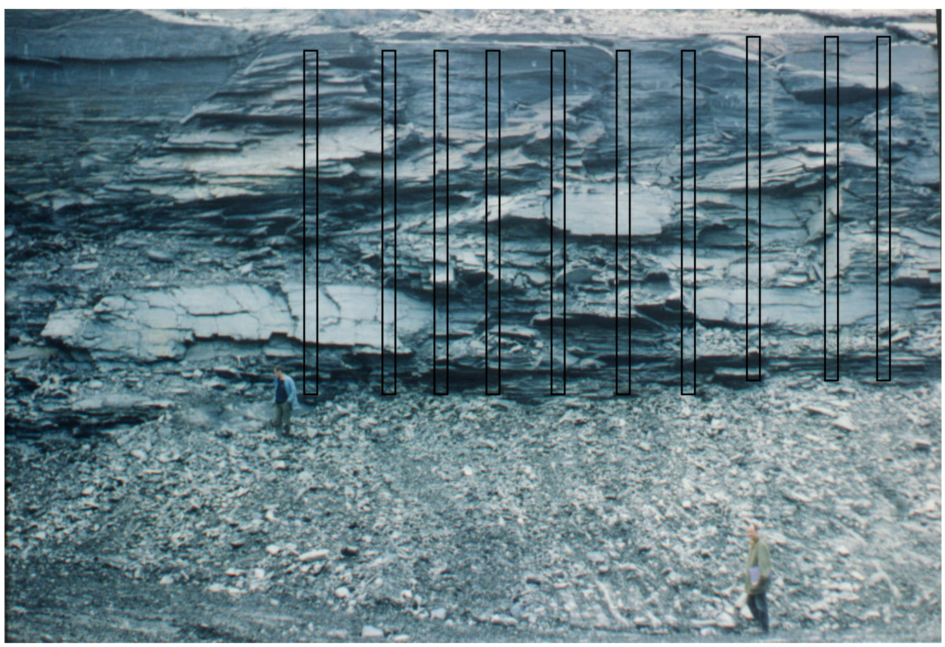

Figure 2. Simulated drill holes in a face of the quarry

Using the appropriate support, which corresponds to the dimension of the real drill-hole cuttings, the image of each available face was wiped along the simulated drill-holes, in order to extract the relevant attributes (those that are common to real drill-holes), using the procedure given in Sousa, 1997. For this case, the relevant attributes linked to ‘quality’, as indicated by the quarry management, are Boolean variables codifying the presence/absence of ultra-metamorphism, quartz veins, sand laminations, oxidation, carbonates, crenulation.

By merging the same information from drill-holes with this new set of attributes captured in the face images, a file of 605 entities was created to feed the quality index algorithm.

5. Data Treatment

Given the two files, one for recovery attributes and the other for the quality attributes, those were submitted to the Correspondence Analysis algorithm proposed in Pereira et al., 1993, that gives as an output two continuous variables – the recovery and the quality indices.

These indices are viewed as Regionalized Variables that fit the co-kriging paradigm, as described in Pereira *et. al*., 1995, provided that experimental variograms and cross-variograms are modelded by authorized functions guarantying that the correlation matrices are definite positive.

In fact, as it can be seen in Figure 3, the spatial auto- and cross-correlation between the two indices are modeled by an anisotropic spherical scheme, whose parameters obey to the general linear model of corregionalizations.

In the cross-variograms depicted in Figure 3, it is worth noting the negative correlation between variables. In fact, when recovery increases, quality decreases, indicating that the environmental gain in producing less waste should be balanced with the loss in selectivity, which entails the fabrication of less valuable slabs. This is a point to be addressed in exploitation planning.

Based on the parameters given in Figure 3 for the corregionalization model, the estimation of the recovery index in the 10x10x5 m exploitation units was performed, using the GSLIB software for co-kriging (Deutsch & Journel, 1992). The resulting 3D model of the massif is depicted in Figure 4 (A), being the recovery index split in three classes, corresponding to the practice of the quarry. In order to visualize the gain in detail provided by the co-kriging procedure, it was also included in Figure 4(B) the analogous map of kriged blocks, based only on recovery information collected in drill-holes. As expected, in the vicinity of the exposed faces, an earnest enhancement of the kriged map is observed, when applying the co-kriging algorithm that conveys information on quality to the recovery map.

6. Conclusions

The proposed methodology was able to provide an accurate 3D model of the local recovery index based on the co-kriging of the target variable, using as ancillary information a set attributes capture on the exposed faces of the quarry. These attributes were drawn from the face images by simulated drill holes in a given pattern.

When used for exploitation planning proposes, the model provided by this methodology is the basis for a trade-off between the gain in recovery and the loss in quality, entailed by exploiting only the “good recovery” zones of the quarry.

7. References

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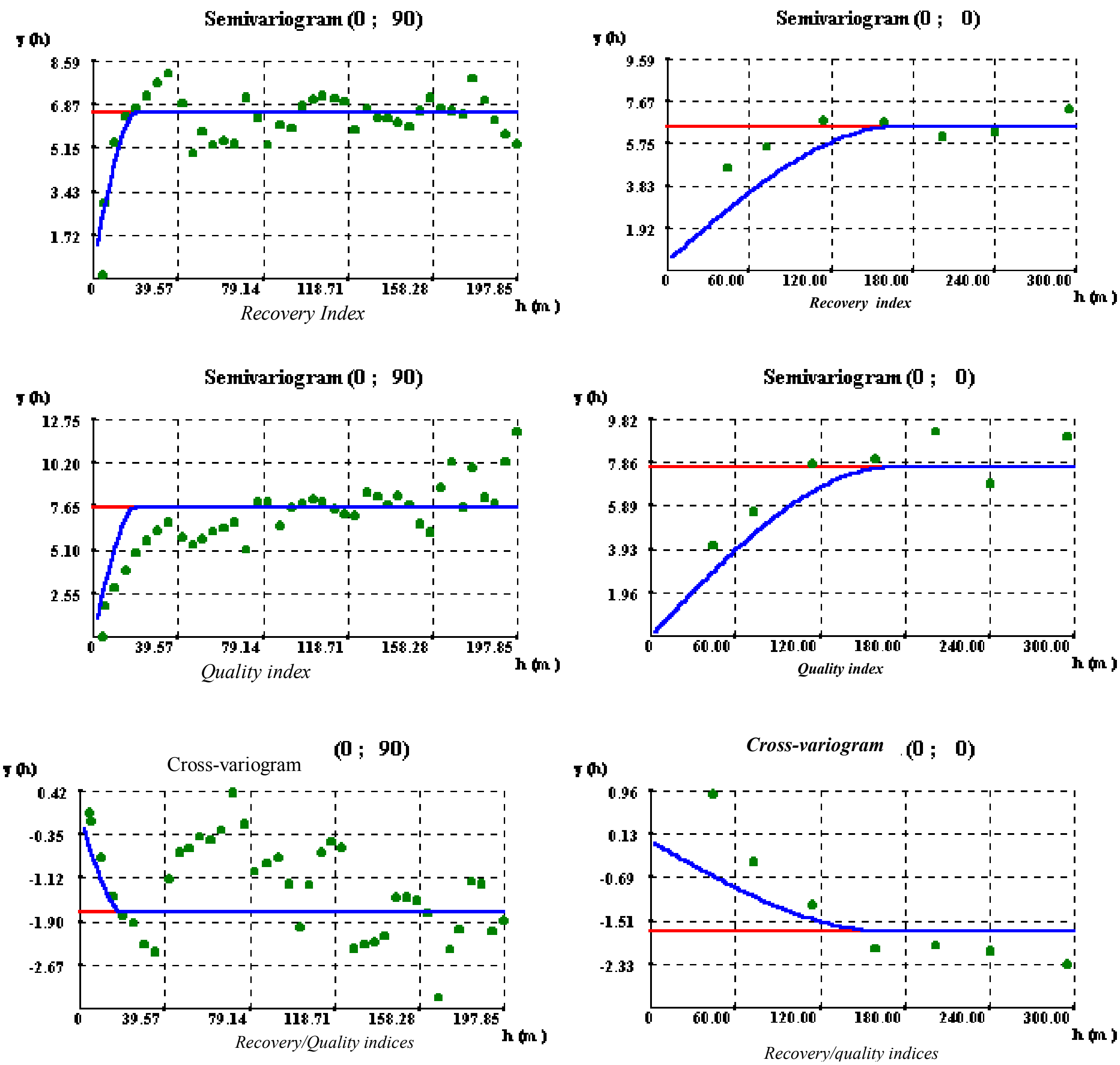
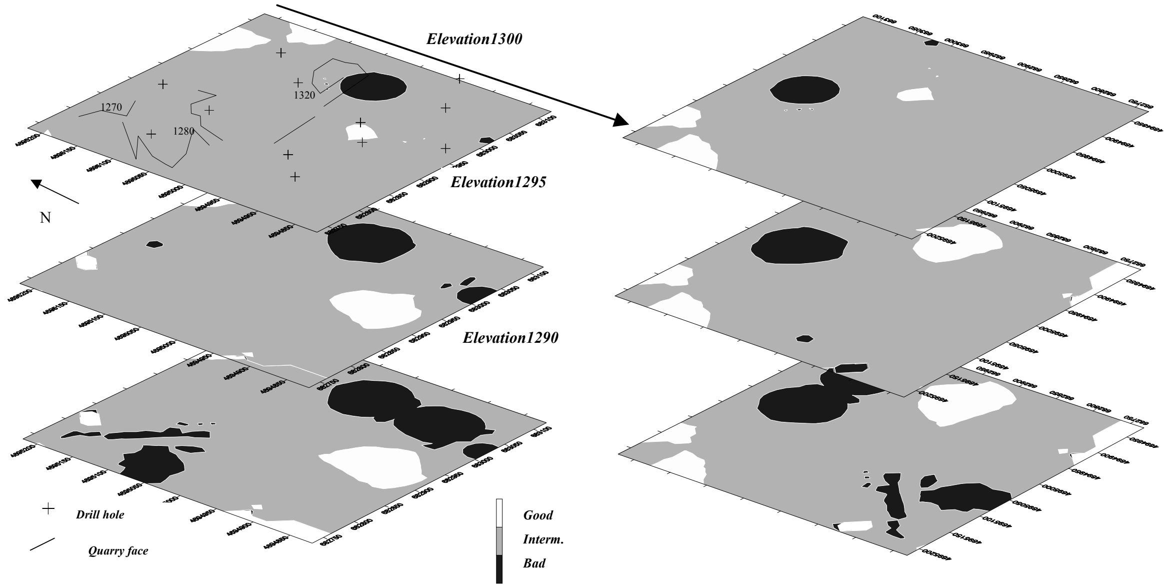


	Nugget effect	Sill	Horizontal Range (m)	Vertical Range (m)
Recovery	0.42	6.123	120	35
Quality	0.00	7.632	120	35
Recovery/Quality	0.00	-1.710	120	35

Figure 3. Experimental variograms and cross-variogram of recovery and quality indices and parameters of the fitted model

A



B

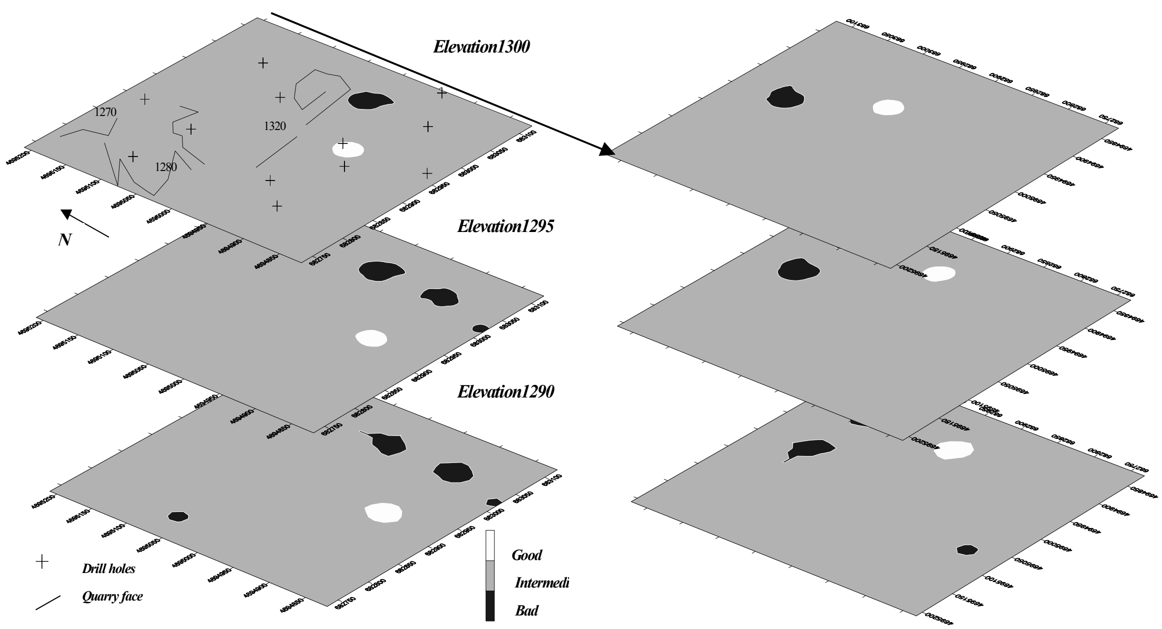


Figure 4. Estimated values of the recovery index for the entire massif based on co-kriging (A) and kriging (B).