

PROCEEDINGS OF THE FOURTH INTERNATIONAL SYMPOSIUM ON MINE PLANNING
AND EQUIPMENT SELECTION/CALGARY/CANADA/31 OCTOBER-3 NOVEMBER 1995

Mine Planning and Equipment Selection 1995

Edited by

RAJ K. SINGHAL

Université Laval, Québec / Federal Government of Canada

International Journal of Surface Mining, Reclamation and Environment, Canada

ANIL K. MEHROTRA

The University of Calgary, Alberta, Canada

JOHN HADJIGEORGIOU

Université Laval, Québec, Canada

RICHARD POULIN

The University of British Columbia, Vancouver, B.C., Canada

Associate editors

KOSTAS FYTAS & JEAN-LUC COLLINS

Université Laval, Québec, Canada

E. M. DE SOUZA

Queen's University, Kingston, Canada

OFFPRINT



A. A. BALKEMA / ROTTERDAM / BROOKFIELD / 1995

Exploitation planning in slate quarries by merging the recovery and quality indices

H.G.Pereira, A.J.Sousa, T.Albuquerque & J.Ribeiro
 IST/CVRM, Lisbon, Portugal

J.Taboada
 Universidad de Vigo, Spain

ABSTRACT: The rational exploitation planning of slate quarries requires to forecast the *in situ* value of the material to be extracted, in order to include this value in the detailed production scheduling programme of the venture. Two components that relate the observable geological/technological attributes to the above considered *in situ* value are considered in this paper: the quality index of the plate and the recovery index of the exploitation. Once established these two indices by Correspondence Analysis and detected their spatial continuity by variography (auto and cross correlation), they are estimated in the exploitation volumes by Co-kriging. The estimated value of the combined index is the basis for further planning.

A case study, referring to the Valdeorras slate quarry, is presented for the purpose of illustrating the methodology. The estimated values are validated by using real data supplied by the exploitation experts of the quarry.

Key words: Slate quarry; Regionalised variable; Recovery index; Quality index; Correspondence Analysis; Variography; Co-kriging.

1- INTRODUCTION

When planning the exploitation of slate quarries, two components of the objective function should be taken into account: the costs of exploitation and the value of the material to be extracted. The first component, apart from other factors, depends on the exploitation recovery; the second component is related to the quality of the material to be extracted, for a given market situation. These two components - recovery and quality - are summarised by the methodology given in Pereira *et al.*, 92 and two indices are produced, each one of which reflecting a specific feature of the evaluation problem. In order to combine these two indices, conveying information from recovery to quality and conversely, a new step was added to the original methodology. This step consists of calculating the cross-variogram of the two indices by:

$$\gamma_{I_1 I_2}(h) = \frac{1}{2} E \{ [I_1(x+h) - I_1(x)] [I_2(x+h) - I_2(x)] \} \quad [1]$$

I_1 - Quality index
 I_2 - Recovery index
 x - co-ordinates
 h - lag

and estimating the two indices in the exploitation units by Co-kriging (Journel & Hujbreghts, 1978), applying the system [2], where n is the number of samples and λ_{ij} are the Co-kriging weights

$$\left\{ \begin{array}{l} \sum_j \lambda_{ij} \gamma_{j'j'}(x_i, x_{j'}) + \mu_{j'} = \gamma_{j'j_0}(x_i, x_0), \\ \forall i' = 1, \dots, n; \forall j', j = I_1, I_2 \\ \sum \lambda_{ij_0} = 1 \quad [2] \\ \sum_i \lambda_{ij} = 0 \quad \forall j = I_1, I_2; \forall j \neq j^0 \end{array} \right.$$

The proposed methodology, generalised to cope with the problems arising from the exploitation planning of slate quarries, was applied to the

Valdeorras quarry, located in Spain. The geological and geotechnical factors that influence the slate quality and exploitation conditions are of stratigraphic, structural and metamorphic nature.

2 - DATA CAPTURE

The basic attributes on which the recovery and quality depend were scrutinised as given in table I:

Table I - Recovery and quality attributes to a slate exploitation

RECOVERY INDEX (I ₁)	QUALITY INDEX (I ₂)
n° fractures/m	Ultrametamorphised slate
n° Kink bands/m	Kink-bands
Alteration	Quartz - veins
RQD	Sand - laminations
	Oxidation
	Carbonates
	Multicrenulated slate
	Crenulation

These two sets of attributes were captured in 9 drill-holes, by counting the occurrence of their categories in 5m supports.

The classification was made by direct observation of the selected attributes on the core samples using video images and pericial information.

3-INDEX CALCULATION

By applying the equation (Pereira *et al.*, 1992),

$$f(i) = \frac{1}{\sqrt{\lambda} \cdot q} \cdot \sum_{k=1}^a W(k) \cdot \sum_{l=nc(k)+1}^{nc(k)} x(i,l) \cdot p(l) \quad [3]$$

where

$f(i)$ is the index of support i

λ is the eigenvalue associated with the discriminant axis

q is the number of attributes k

$W(k)$ is the weight given to attribute k

$nc(k)$ is the number of categories of attribute k

$x(i,l)$ is the grade of membership of support i to category l

$p(l)$ is the projection of category l onto the discriminant axis

The two indices were calculated on the basis of the attributes given in Table I. The system of weights $W(K)$ and the attribute classes were modified

interactively until a validation was reached against the expert opinion of the quarry management. Also, the archetypes of the poles of discrimination for both indices were established according to the experience of what is considered the extremes of recovery and quality by the quarry management.

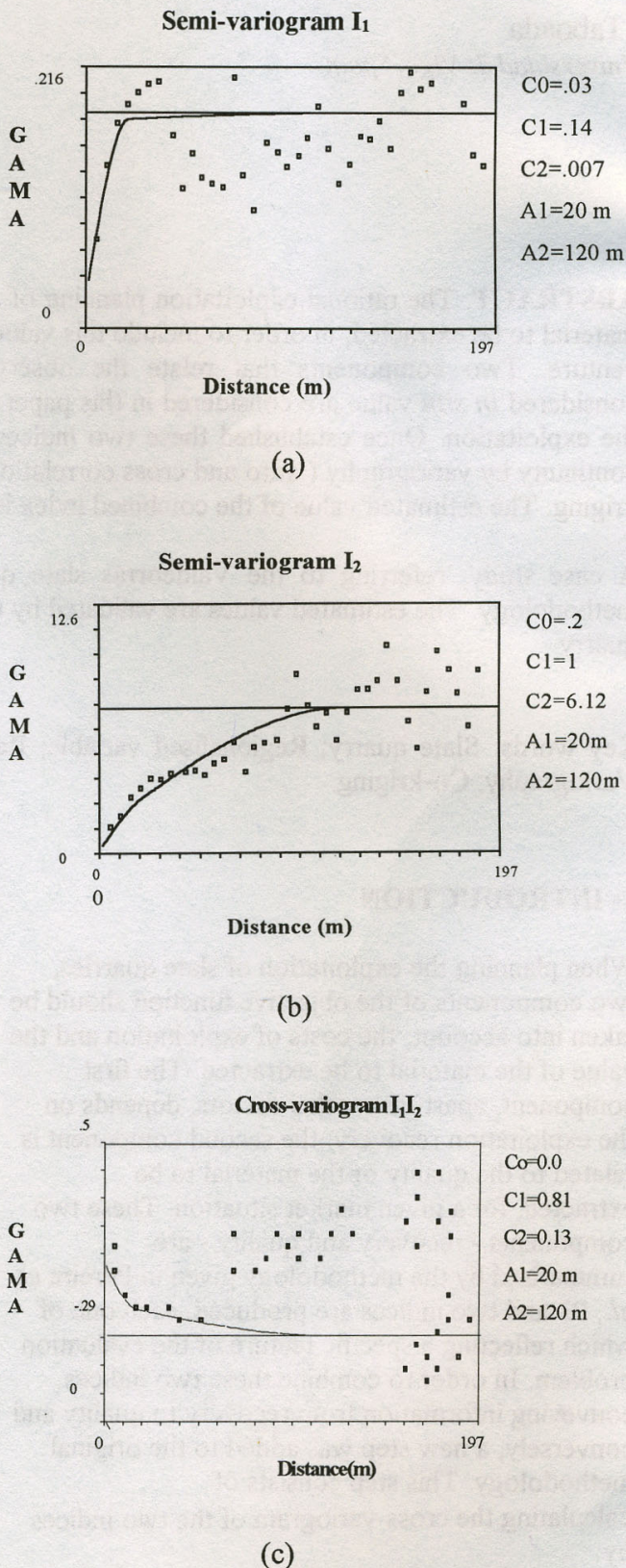


Fig.1 - (a) and(b) Semi-variograms for I₁ and I₂.
(c) Cross-variogram of I₁I₂.

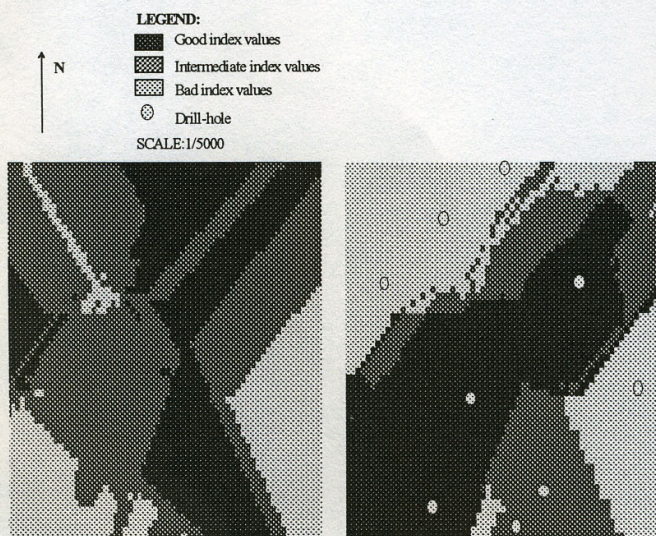
4 - ESTIMATION OF THE INDICES IN EXPLOITATION UNITS

The omnidirectional variograms and cross-variogram of the two indices were calculated as shown in Fig. 1:

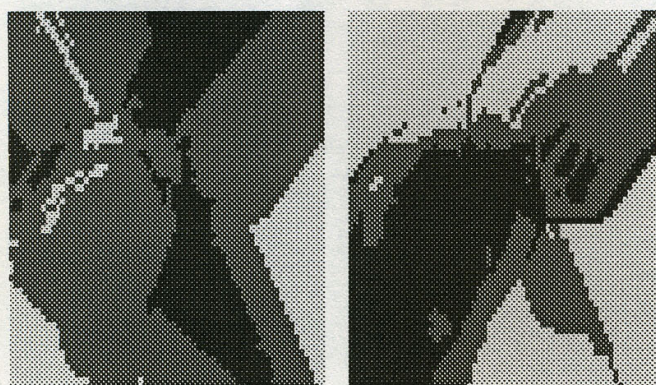
Hence, the variogram parameters are summarised in Table II:

Table II - Theoretical spherical models parameters

	C_0	C_1	A_1	C_2	A_2
I_1	0.20	1.00	20m	6.120	120
I_2	0.03	0.14	20m	0.007	120
I_1I_2	0.00	0.18	20m	0.130	120



(a) I_1 and I_2 at level 1360m



(b) I_1 and I_2 at level 1315m

Fig.2 - Representation of the estimated values:

- (a) Level at 1360m
- (b) Level at 1315m

CONCLUSIONS

The proposed methodology allows the construction of two indices in slate quarries, each one of which reflects features of the material to be extracted: the recovery index is linked to the exploitation costs and the quality index summarises the value of the slate.

The two indices were calculated in the available drill-holes and their estimation in the production zone was performed by Co-kriging.

When the image of a working face is available, the recovery index can be calculate in the same support as drill-holes and the recovery index for that face can be inferred by the Co-kriging estimation procedures, permitting to guide the short term exploitation planning. This is the main advantage conveyed by the proposed Co-kriging method, since it is most possible to capture, in the face, the attribute in which the quality index is based.

ACKNOWLEDGEMENTS

We are thankful to JNICT for granting the research conducted.

REFERENCES

- Journel , A. G. and Hujbregts, A., (1978) - Mining geostatistics - Academic Press, New York
- Pereira H.G., Brito M. G., Albuquerque T., Ribeiro J., (1993) - Geostatistical Estimation of a summary recovery index for marble quarries - Geostatistics Troia '92 - Kluwer Academic Publishers, vol II, pp. 1029-1040.

Hoek, E., P.K.Kaiser & W.F.Bawden 90 5410 186 5
Support of underground excavations in hard rock
 1995, 28 cm, 232 pp., Hfl.95 / \$45.00 / £35 (No rights India)
 (Student edn., 90 5410 187 3, Hfl.45 / \$19.50 / £16)
 A comprehensive volume dealing with the design of rockbolts, dowels, cable bolts and shotcrete for underground excavations in hard rock. Many practical examples are given and extensive use is made of user-friendly software developed specifically for this application (available separate). Topics covered include rock mass classification systems, shear strength of discontinuities, analysis of structurally controlled failures, in situ and included stresses, estimating rock mass strength, support design for overstressed rock as well as discussions on different types of underground support.

Demirel, Harnil & Salih Ersayin (eds.) 90 5410 513 5
Progress in mineral processing technology – Proceedings of the 5th international mineral processing symposium, Cappadocia, Turkey, 6-8 September 1994
 1994, 25 cm, 596 pp., Hfl.195 / \$110.00 / £72
 Recent progress in mineral processing, with special emphasis on processing of industrial minerals both fundamentally & technologically. Includes papers on the application of mineral processing techniques to environment related problems. *Topics:* Comminution; Gravity, Magnetic & electrostatic separation; Flotation fundamentals; Flotation technology; Industrial minerals; Coal processing; Hydrometallurgy; Gold & silver; Agglomeration; Dewatering; Novel techniques; Modelling, simulation & control. 80 papers.

Jeremic, M.L. 90 5410 113 X
Rock mechanics in salt mining
 1994, 25 cm, 544 pp., Hfl.175 / \$99.00 / £65
 (Student edn., 90 5410 103 2, Hfl.95 / \$55.00 / £35)
 5 chapters consider general geology, folding & faulting structures composition of salt & form of salt bodies with the simplifications. 3 chapters deal with the exploration & opening of salt deposits with the aspect of design of safe & stable mine structures, and risk of water inflow into the mine. 3 chapters analyse deformation & failure of the salt due to elasto-plastic, creep & outbursts loading conditions. 5 chapters discuss strata mechanics & control for different mining systems of flat, inclined & massive salt bodies, as well as solution mining & excavation for storage. The last chapter presents the stability analyses to the mine structures in regard to salt mining subsidence. Author: Laurentian Univ., Sudbury, Canada.

Bawden, W.F. & J.F.Archibald (eds.) 90 5410 325 6
Innovative mine design for the 21st century – Proceedings of the international congress on mine design, Kingston, 23-26 August 1993
 1993, 25 cm, 1054 pp., Hfl.230 / \$130.00 / £85
 A state-of-the-art on technology, innovative mining practices, & anticipated evolutionary trends in the various fields of mining engineering. *Topics:* Slope stability & rock mechanics; Underground support & backfill; Grade estimation & mine feasibility; Open pit planning & design; Underground planning & design; Machinery, materials handling & mine maintenance; Mine environment; Mine management; Research & development.

Pasamehmetoglu, A.G., C.Karpuz, S.Eskikaya & T.Hizal (eds.)
Mine planning and equipment selection 1994 – Proceedings of the third international symposium, Istanbul, 18-20 October 1994
 1994, 25 cm, 964 pp., Hfl.210 / \$125.00 / £79 90 5410 327 2
 The latest technological developments have proved an increase in both the types and the capacities of equipments used in mining activities. As a result of these improvements mine planning and equipment selection are of crucial importance. The proceedings include valuable contributions on topics such as design and planning of surface and underground mines; mine simulation and mine plan generation; mine evaluation, financial and management planning; production scheduling; surface and underground mine monitoring; geotechnical stability; planning and equipment selection for difficult mining conditions; innovative mining systems and equipment; drilling and blasting operations; equipment selection procedures; equipment performance monitoring; equipment maintenance management; expert systems; mine and equipment information systems.

Almgren, G., U.Kumar & N.Vagenas (eds.) 90 5410 314 0
Mine mechanization and automation – Proceedings of the second international symposium, Luleå, Sweden, 7-10 June 1993
 1993, 25 cm, 827 pp., Hfl. 250 / \$140.00 / £93
 Innovative mining systems: Non energy minerals (metals), industrial minerals; Innovative mining systems: Solid fuel minerals; coal, etc.; Mechanization & automation of drilling operations; Mechanized rock fragmentation; Material handling & data communication; Machine automation & control; Computer applications; Human factors and safety, miscellaneous; Reliability and maintenance of mining systems. Editors: Luleå Univ. of Technology.

Hustrulid, W. & M.Kuchta (eds.) 90 5410 173 3
Fundamentals of open pit mine planning and design
 May 1995, 25 cm, c.850 pp., 2 vols, Hfl.245 / \$125.00 / £90
 (Student edn., 90 5410 183 0, 2 vols, Hfl.125 / \$65.00 / £46)
 The book is divided into two parts. Part 1 consists of six chapters in which the basic planning & design principles are presented: Mine planning; Mine revenues & costs; Orebody description; Geometrical considerations; Pit limits; Production planning. Much of the actual calculation involved in the design of an open pit mine is done by computer. Two professional computer programs CSMine & VarioC have been specifically developed with the university undergraduate learning environment in mind. These programs, their related tutorials & user manuals, together with a data set for the CSMine Property, are subject of part 2 of this book. Six chapters involved are: Introduction; CSMine property description; CSMine tutorial; CSMine user's manual; VarioC tutorial & user's guide; VarioC reference manual.

Szwedzicki, T. (ed.) 90 5410 321 3
Geotechnical instrumentation and monitoring in open pit and underground mining – Proceedings of the Australian conference, Kalgoorlie, 21-23.06.1993
 1993, 25 cm, 562 pp., Hfl.210 / \$125.00 / £79
 Displacement monitoring; Stress measurement & monitoring; Groundwater monitoring; Blast monitoring; Seismic activity monitoring; Environmental monitoring & Instrumentation as tool for numerical modelling. Editor: W.A.School of Mines, Kalgoorlie.