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Cluster analysis applied to engineering geological mapping

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ABSTRACT

Cluster analysis of morphometric variable is reported in this paper to support characterization of rock masses and deposits. The first technique is related to fast mechanical characterization of bedrock and the second one on the mapping of the depth of superficial deposits. In order to extrapolate site-specific information to the whole study area two techniques are applied to morphometric space: supervised and unsupervised classifications through the algorithms maximum likelihood and ISODATA, respectively. The analysis of morphometric space with these techniques has provided significant results in order to discriminate bedrocks with different mechanical characteristics and the depth of superficial deposits.

KEY WORDS: cluster analysis, lithotechnical mapping, morphometric analysis, superficial deposits.

INTRODUCTION

The engineering geology mapping is a valuable tool to support the urban planning and the evaluation of hydrogeological hazard. The collection of engineering geological data for such mapping requires, in general, field survey activities which are expensive and time consuming. The development of techniques for analyzing digital data helps not only to reduce costs, but also to direct the search for predisposing conditions of certain hazardous events such as landslides over large areas. Digital Terrain Models (DTM) with high spatial resolution allowed us to estimate morphometric parameters (e.g., slope and curvature) descriptive of the territory.

The engineering geological variables are mainly related to factors such as geology, climate and morphometry of the study area (fig. 1). One of the major problems in the implementation of these studies was to identify the relationships among the factors to extend the site-specific information to the entire study area

In this paper the techniques of cluster analysis are applied to the morphometric variables as a method of extrapolation of site-specific information to the entire study area. Two examples of different classification techniques are: expert analysis on the basis of morphometric patterns (supervised analysis) and an automatic distribution of morphometric units (unsupervised analysis). Two different techniques were chosen since from field survey two different models of interpretation of relationship between data and morphometric variable were supposed. The supervised classification was used for the Engineering geological map project because during field activities was possible identify the relation between specific morphometric patterns and specific engineering geological properties of rock masses. Instead, an unsupervised classification was used for Surficial Deposits depth mapping because in the field survey, relationships between the depth of Surficial Deposits (SD) and morphometric patterns weren't fully clear.

The two classification techniques were carried out on study areas located in northern Tuscany, Italy (fig. 1): the Area 1 was located on the Tuscan side of the northern Apennines roughly between the relief watershed and the Serchio River near the town of Barga, the Area 2 was located within the mountains near the city of Pistoia. From the geological point of view all analyzes carried out in this paper regard only areas where the substrate was composed of sandstones belonging to the Formation of Macigno.

DATA AND ANALISIS

Based on field evidences, in this work, we chose to use the follow morphometric variables: longitudinal and transverse curvature, slope and flow accumulation (Wilson & Gallant 2000, Wood 2009). These variables were obtained from a DEM with a spatial resolution of 10 m that it was derived from topographic map. For each variable a descriptive statistical analysis was performed and for longitudinal and transverse curvature, extreme values (± 4.5 standard deviation) were deleted in order to strengthen the significance of the core values. The flow accumulation data were normalized by a lognormal transformation. The data thus obtained were standardized reporting each variable to the range of variation of slope variable.

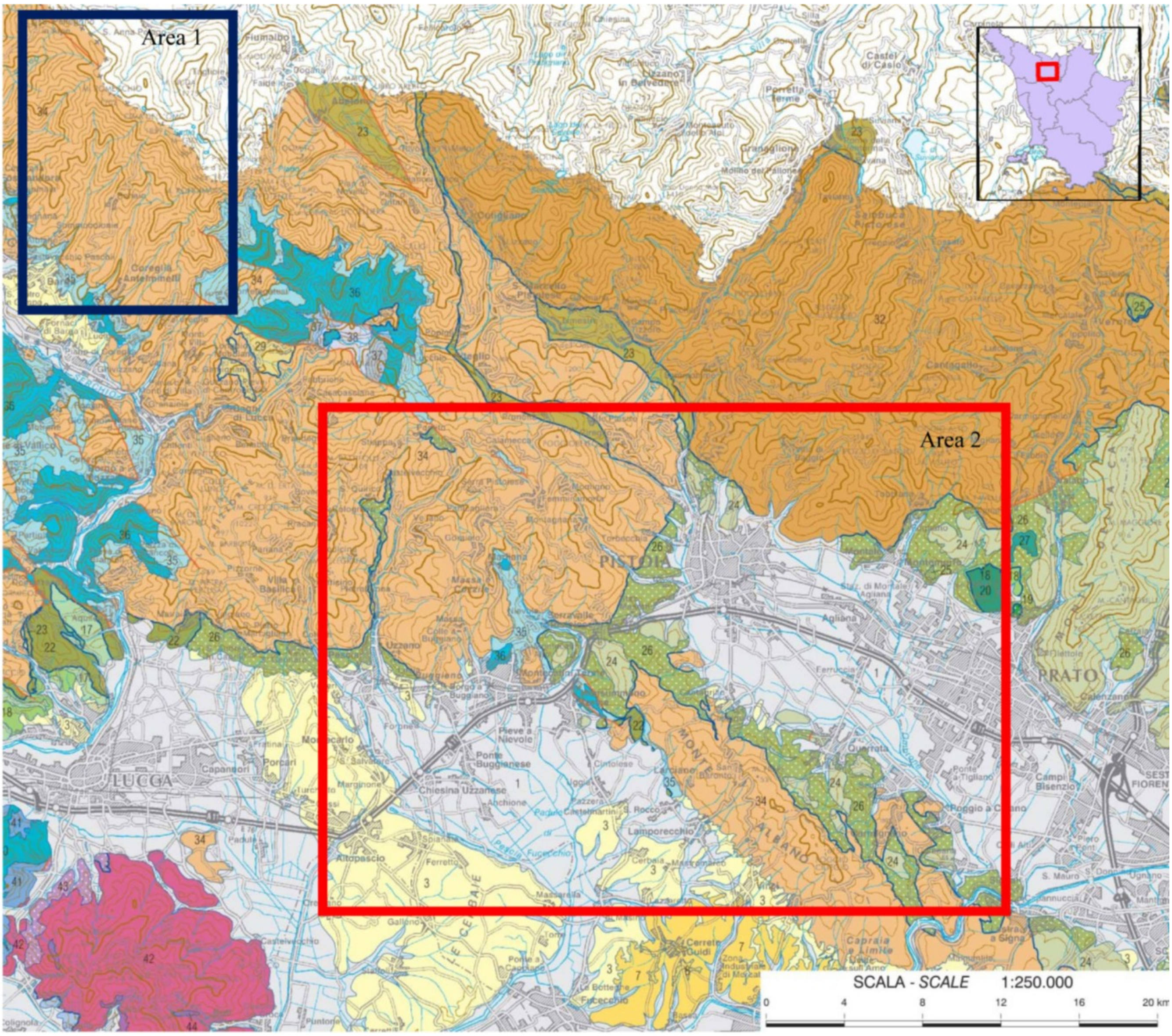

Fig. 1 – Geology map of the study area (modified from Carmignani and Lazzarotto, 2004). Legend: Pliocene –Quaternary continental and costal deposits, 1 and 3; Pliocene –Quaternary marine deposits, 7 and 8; Internal Ligurian Domain, (17) arenaceous flysh (18) shales silston and limestons (20) ophiolites; External Ligurian Domine, (22) Helmintoind flysh (23) sandstones (24) shales and sandstone (25) breccias and polygenic conglomerates; Subligurian domain, (26) sandstone and conglomerates (27) shales limestones and siltstones; Non Metamorphic Succession (32) external sandstone flysh (34) internal sandstone fiysh (35) shales and marls (36) marls shales and limestone

SUPERVISED CLASSIFICATION FOR ENGINEERING GEOLOGY MAPPING

Based mainly on the use of RQI (1), the classification process for lithotechnical mapping allows us to split the outcropping rock masses in: hard rock (RQI > 25), weak rock and soil (RQI <25) (Disperati et al. 2012, Disperati et al. 2013) RQI parameter was estimated using the equation (1) derived from Deer and Miller (Deere 1963):

$$RQI = \frac{1}{n}\sum_{J=1}^{J=n} 10^{\left(0.00088\bar{r}_J \cdot \gamma + 1.01\right)} \qquad (1)$$

where: $\bar{r}_J$ is the mean of at least 20 rebound measurements collected at the sampling grid node J; n (≥20) is the number of nodes of the sampling grid; γ is the unit weight of rock samples determined in laboratory.

The survey has identified different morphotypes characterized by different values of RQI. In particular, the areas of high elevation and generally flat (Morfo1) are dominated by rock masses with low value of RQI, while areas of steep slopes (Morfo2) are dominated by rock masses with high value of RQI. For the remaining areas with non-steep slopes (Morfo3) the data are not sufficient to allow a clear interpretation.

A supervised classification of the morphometric space was performed in order to extrapolate such interpretive model on a statistical basis. Training sets (about 2% of the analyzed area) were identified at the first from well-known areas or test site areas and, subsequently, morphotypes were recognized using topographic map. The automatic classification process was performed using a maximum likelihood algorithm implemented in the software ArcGis 9.3. On tab. 1 is reported the accuracy of classification process.

Subsequently, through the use of software R the distribution of RQI values (99 test sites) within the three morphometric classes was analyzed: the results are shown in fig. 2. Based on this result, the morphometric classes morfo 1 and morfo 3 have been bounded as weak rock mass, and the class morfo3 has been classified as hard rock masses. On fig. 3 the outcome of this analysis is showed.

		Output raster		
		1	2	3
Training set	1	96.6	0.3	3.1
	2	0.0	98.2	1.8
	3	2.9	5.4	91.7

Tab. 1. Accuracy of the supervised classification process. In the table are reported, on percentage, the distribution of pixel of training set into the output raster.

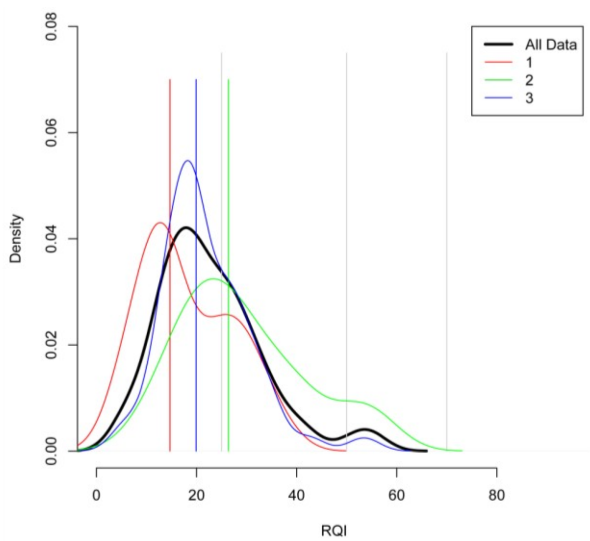

Fig. 2 – RQI PDF of test sites on Area 2. Color legend: red for sites test on morfo 1, green for morfo 2, blue for morfo 3 and black for all data. With vertical lines are represented median value of each population (colored) and the RQI threshold (grey). Note that median and mode of 1 and 3 dataset are less than 25 RQI value (weak rock mass). The PDF of population 1 show bimodal but the sample isn't ought big to split it into two separate populations.

UNSUPERVISED CLASSIFICATION FOR SUPERFICIAL DEPOSIT DEPTH MAPPING

An analysis of morphometric patterns through unsupervised clustering techniques was performed in order to carry out a map of the depth of superficial deposits (SD). Based on a

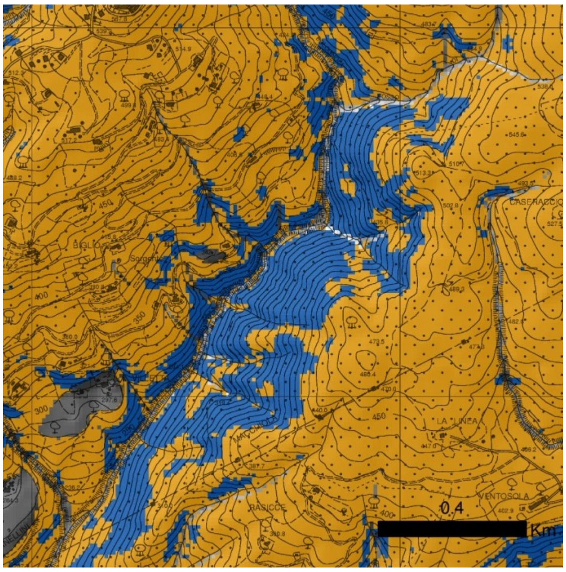

Fig. 3. The outcome of supervised classification process. Weak masses are showed on brown and hard rock masses on blue.

review of wide literature (Scott Eaton et al. 2003, Lorz et al. 2011, Arno and Birgit 2013), for the aim of this work, a Surficial Deposits (or Hillslope Deposits) was a deposit of geological material that come from the weathering and physics in situ breaking up of bedrock and/or the transport of material along the hillslope by water and/or gravity, independently from the age and the degree of cementation or consolidation of deposit.

The depth of SD was investigated by 174 test sites performing manual inspection of profiles or boreholes with drill manual.

Given the methods of investigation, the scale of the work and the high variability of the depth found in the countryside, the depth of the SD is divided in 8 classes. The classes of depth are arranged into two groups (tab 2): the SD with depth "thin" (≤ 0.3 m) are attributed to the classes A, those with depth "significant" (> 0.3 m) to the class B.

The survey activities allowed us to identify that, even over the same lithotype, more types of superficial deposits were superimposed and characterized by different engineering geological parameters and different relationships with the morphometry of the study areas. For example around the Apennines watershed SD were identified mainly consisting of coarse material with the thickness from zero up to several meters. On the other hand, the SD outside of this area showed a complex relationship with the morphometry of the slopes whose investigation was the subject of this work.

The morphometric space has been segmented into 30 classes using ISODATA algorithm implemented within the software Leica Erdas. We chose to use 30 classes to reduce the effect of initial conditions on final outcome. One depth class was assigned to each morphometric class using field data, starting from the most sampled classes. The class of depth was assigned for classes not sampled or for those with statistically unrepresentative sampling by basing on the experience of the survey and assuming that neighbouring entities in morphometric space likely to have similar depth. In the assignment of depth classes was also taken into account the uncertainties related to input parameters, such as the quality of the DEM and for the B depth classes of objective difficulties of investigation (e.g., underestimated depth). On fig. 4 the outcome of this analysis is shown.

Surficial deposit depth classification	
Depth class	**Description**
A1	The area of outcrop is prevalent to the SD area and the depth of SD is generally lower than 30 cm.
A1B	A1 area where are present significant but not mappable B depth classes of SD.
A2	The area of SD is prevalent to the outcrop area and the depth of SD is generally lower than 30 cm.
A2B	A2 area where are present significant but not mappable B depth classes of SD.
B1	The depth of SD is generally from 30 cm. to 100 cm.
B2	The depth of SD is generally from 100 cm. to 200 cm.
B3	The depth of SD is generally over 200 cm.

Tab. 2. Description of the SD depth classes.

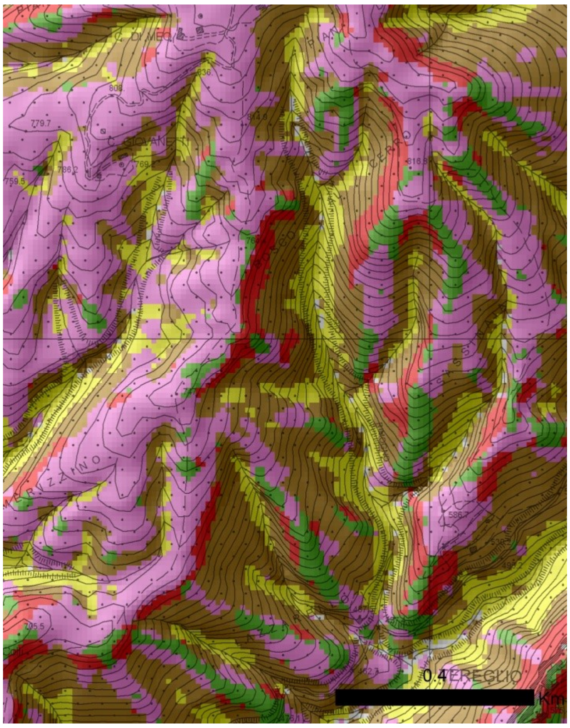

Fig. 4. Outcome of the unsupervised classification process. SD depth legend: A2 green, A2B red, B1 pink, B2 brown and B3 yellow.

CONCLUSIONS

Morphometric analysis techniques have provided significant results in order to discriminate bedrocks with different mechanical characteristics and the depth of superficial deposits. Classification techniques of the morphometric space may help users to address the survey in areas with similar characteristic patterns and morphotypes.

The low distribution of samples and the limits of investigation scheme in situ reduce mapping interpretation. Uncertainties related to input parameters may be reduced in order to improve the lithotechnical mapping of outcropping rock masses and depth of superficial deposits. These techniques might require the collection of elevation data with high spatial resolution and different sampling approaches.

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