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APPLICATION OF REGIONALIZED VARIABLE THEORY IN ANALYSIS OF MORPHOLOGICAL PHENOMENA OF THE HERZEGOVINA KARST

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Abstract: This paper presents an interpretation of results of a long-lasting scientific investigation of the Herzegovina karst using the methods of Regionalized Variable Theory, i.e. Geostatistics. Throughout the geological history of karst, its morphological phenomena (doline, polja, sinkholes, obodine) were filled by sedimentation processes and hence conserved only to some extent in their particular development phases, subsequently being subjected to further morphological development in such conditions. Data on these phenomena were carefully collected for twenty years. As the number of studied elements exceeded 100000, the collected database is very large and these data are all the more significant because these morphological elements were accessible for observation and measurement only for a short time before being filled again. A geostatistical model of soil was developed using the variographic analysis on soil samples taken in three characteristic glacial areas. Scientifically established relations between the geomechanical model and parameters of geological origin were defined.

Keywords: Regionalized Variable Theory, morphological phenomena of karst, database, geostatistical model of soil, glacial, grain shape.

1. Introduction

This paper gives a description of the part of results of scientific variographic studies of developed karst morphological phenomena and structural composition of glacial and fluvioglacial formations, based on examination of grain shape. Both studies are related to the Dinaric karst of Bosnia and Herzegovina (the region of Herzegovina, the glacial and fluvioglacial deposits of the Blidinje syncline, Fig. 1).

Fig. 1. Map of Herzegovina.

2. The problem of distribution of the variable "*depth*" of the karst morphological phenolmenon

Sets of data on a karst form, collected in regular exploration grid (Fig. 2), are significantly positively asymmetrical. This term means a „*tail that lags*“ behind the mean value in the depth histogram, on the right side. The left side of the histogram is naturally limited by the depth value 0, and these are *slashed distributions* (Marijanović, 2008).

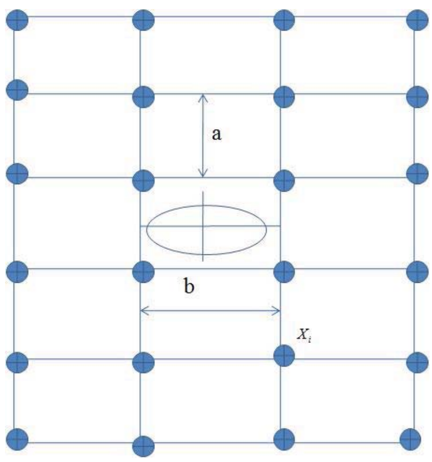

Fig. 2. Regular exploration grid.

The analysis will show that the *asymmetry of distribution* of depths within a karst form is the basis to understanding its development through a long geological time. In this connection, *lognormal two- and three-parametric distribution* will be very common in the analysis of karst morphological forms. The formula of the two-parametric lognormal distribution is:

$$f(x) = \frac{1}{X_i \cdot \beta \cdot \sqrt{2\pi}} e^{-\frac{(\ln(X_i)-\alpha)^2}{2\beta^2}} \qquad (1)$$

where X_i - i-th value of depth measured in the observed volume; β - standard deviation of logarithms of depth values measured in the observed volume, and β^2 respective variance; and α - mean value of logarithms of depth values measured in the observed volume.

Extensive research revealed that the lognormal three-parametric distribution of depths is also very common, according to:

$$f(x) = \frac{1}{(X_i + c) \cdot \beta \cdot \sqrt{2\pi}} e^{-\frac{(\ln(X_i+c)-\alpha)^2}{2\beta^2}} \qquad (2)$$

where c – constant.

Studies have also shown that in some cases values of depths complied with the law of normal distribution, according to the formula:

$$f(x) = \frac{1}{\sigma \cdot \sqrt{2\pi}} e^{-\frac{(X_i-m)^2}{2\sigma^2}} \qquad (3)$$

where σ - standard deviation and σ^2 variance of measured values of depths in the observed volume; m - mean value of measured depths.

2.1. The problem of distribution of the depth and volume of a karst form

The volume distribution analysis is based on the following assumptions: the entire volume of a karst morphological structure *V* is observed, and it consists of small volumes *v* in whose centers values of depths, X_i, are variable. Small volumes *v* are such that X_i are their mean depths (which is only the necessary assumption). Now the problem is reduced to defining the distribution of small volumes within the large volume. The analysis begins with the expression for the observed small volume *v* which comprises the value of depth X_i as its mean depth (Marijanović and Kovač, 1994).

All the analyses made on a very abundant technical documentation on these phenomena, derived from the civil engineering, geological and mining practices, have shown that consideration of these values is justified. It has been observed that the more developed a morphological phenomenon, the higher the said differences of *depth and volume* distribution functions in the interval from 0 to mean value *m*. Here, development of a karst phenomenon is descriptively called its *maturity*.

2.1.1. One example (the phenomenon called Gajine)

A total of 127 boreholes were made with the average depth of 6.89 m.

Based on the exploration work, these statistical values were calculated for it:
m = 6.89 m;
σ^2 = 42.80 m^2; and
coefficient of variation KV = 95 %.

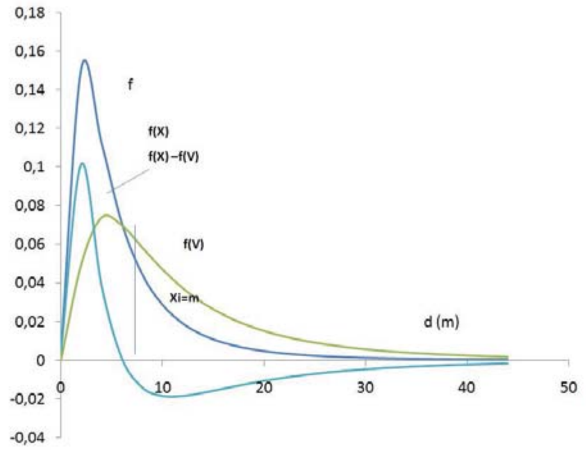

Fig. 3. Distribution of depths and volumes.

Comparing the histograms of depths and volumes within the observed karst form, mostly of lognormal, three-parametric type (Fig. 3), leads to an idea on the *maturity table*, which allows a very reliable assessment of the degree of its morphological complexity. Generally viewed, the distribution of depths and volumes transforms from a normal scheme (undeveloped systems, *immature* systems), through a lognormal or lognormal three-parametric one with moderate positive asymmetry (normally developed systems, *mature* systems) to lognormal or lognormal three-parametric distribution with very large positive asymmetry (developed systems, *mature* systems) (Marijanović at al., 2009). The idea of morphological development cycles of developed karst phenomena, based on the distribution of the variable "depth", collected in a regular or semi-regular grid, and on the proposed value of the coefficient of maturity, is shown in Figure 4. Figure 4 shows a fully developed (mature) morphological phenomenon partly filled with bauxite, in "fingers" of the morphological phenomenon (the site of Bojcica Bus, Čitluk).

grain size in narrow limits (10-20 mm). The coefficient of variation of grain size was about 50±10%, which means that sizes of grains were relatively uniform (Prskalo, 2008).

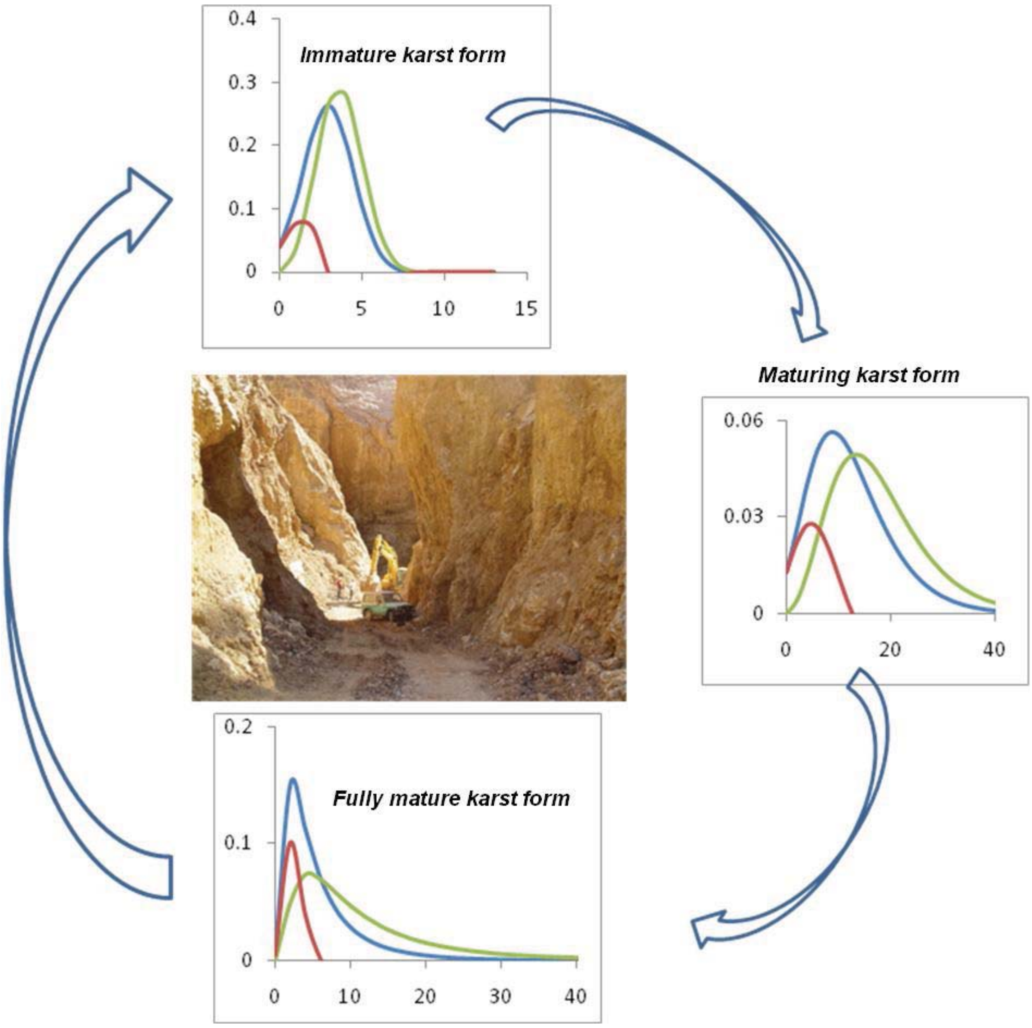

Fig. 4. The natural morphological cycles in karst.

3. Analysis of grain size distribution of the glacial and fluvioglacial soil

Statistical processing of grains of the glacial soil (samples of 100 grains) provided a conclusion on grain size intervals in which 95% of samples taken in the observed area would be found, and only 5% of them would deviate from these values. This means, if 100 samples (100 grains each) would be taken from the same location, 95 of them would have the results in the obtained intervals. The analysis of grain size distribution showed an asymmetric, lognormal distribution in all the examined samples, with the most common value of

3.1. Variogram as a result of spatial correlation of variables

Based on the obtained results of analysis of shapes and roundness of grains, a geostatistical model of soil was developed and relations between the geomechanical model and parameters of the geological origin of soil were defined and scientifically established. If variables on rock or soil are used, it is essential to know their properties in order to make a reliable geological/geotechnical model (Marijanović, 1996). Investigation results and conclusions arising from them are related by the reliability of assessment. The reliability of assessment is the evaluated measure of quality and quantity of performed investigation works, the purpose of which is to collect a statistically sufficient data set. Too few data means to take a risk of making a large error in judgment, while too large a set commonly requires high investment that exceeds the limit of cost-effectiveness. So, a statistically sufficient data set is required, but what is primarily required is the processing method that will produce the best conclusions with minimum error from this set. The connection of space and variables makes the specific quality of these information systems.

3.2. Variographic analysis of structure of glacial sediments

Attention in the research is devoted to defining the shape and roundness as significant properties of grains in geomechanical terms (sand, gravel, etc.). Analyzing the shape and roundness of glacial grains on samples taken from the field and from exploratory probes, it was concluded that the glacial sediment is *extremely heterogeneous*, and the glacial erosion (e.g. plucking, abrasion) resulted in formation of *clasts* of all sizes, from large calved blocks to fine particles of silt. From the formed database, grains were analyzed by reading the values of coefficient of grain size (kf). An input file was formed with values of parameters and relative coordinates in the exploratory probe column. The *geostatistic model of soil* was developed by applying variographic analysis, and scientifically established relations between the geomechanical model and parameters of geological origin were defined. The analysis of correlation between *depths and the mean value of longer dimensions of grains (d1)* proved that such a dependence does not exist (the correlation coefficient is -0.339). The obtained results indicate partial sorting that may be influenced by the way how the material was introduced into the sedimentation space (Fig. 5).

The variogram indicated an atypical structure of the fluvioglacial space with unsorted material. When the general shape of grain was chosen as the variable for variogram, the form of variogram in figure 3 was obtained. The overall explanation could be that the uniformity of grains continues up to the depth of 2 m on the average, and the identified form of grains from this zone continues over another two meters.

4. Conclusion

When working with a variogram, the fundamental principle should be a critical verification of the variogram function based on the known properties of the variable. Consequently, variogram is used to find new and previously unknown properties, but this function of variogram must be controlled by common sense. This approach to interpretation of a variogram ensures a constant presence of investigative and creative component in the work. Variogram has proved to be a generator of the investigation function and accumulator of acquired knowledge, but it also ensures a high-quality transmission of such knowledge to engineering practice, being the bearer of the modeling process. The idea on existence of cycles in morphological changes of karst phenomena is based on the established fact on gradual differences of basic statistical-geostati-stical parameters measured on the variable "depth", such that they illustrate some of the internal morphological "stresses" that "push" the development of morphological forms towards disintegration of the most developed form to a

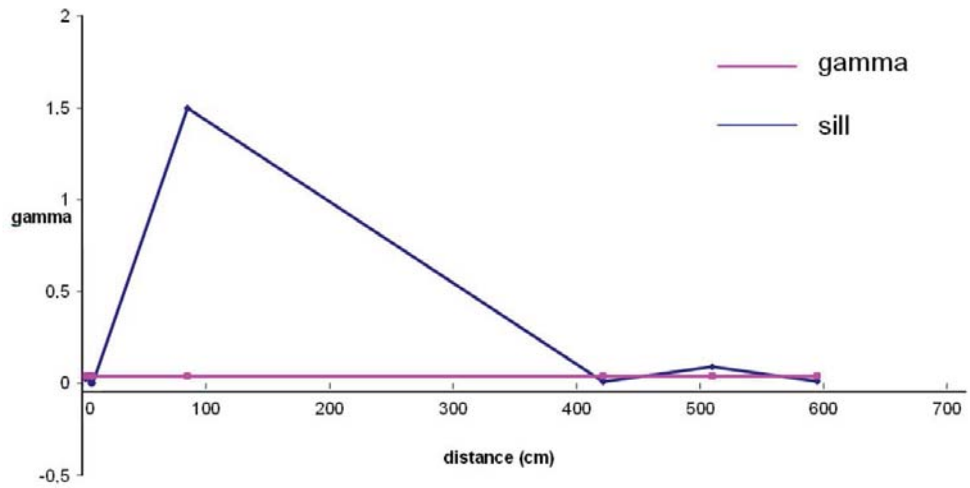

Fig. 5. Variogram in relation to coefficient of grain shape.

number of forms that correspond to its initial development phase. Application of variographic analysis in the case glacial and fluvioglacial deposits, based on the analysis of grain shape, reveals their specific structure as the basis of all geotechnical analyses and calculations. Preservation of the natural environment is possible only if the consciousness of those who inhabit it is at the level of such a task. Generally, the problem is not in the consciousness of people if they understand and accept the task. It means that people's perception is the most important. That is the goal of this paper in the first place. To tell more about results of long-lasting scientific investigations of karst in Herzegovina using methods of Regionalized Variable Theory (often called Geostatistics). In the course of twenty years, data were carefully collected on karst morphological phenomena that were filled by sedimentation through geological history, in that way only conserved to a certain extent in a development phase and left to further morphological development in such conditions. It was most often economic activities that lead to their cleaning from the sedimentary grounds (mining extraction of mineral raw materials, deep excavations in civil engineering for purposes of construction of larger structures, dams, hydro-electric power plants etc.) when they were carefully photographed and studied. A very large database was collected (the number of studied elements exceeded the figure of 100000), the value of which is also in the fact that such morphological elements were accessible to observation and measuring only for a short time, when they were filled again. Stress is placed on the description of morphological changes within long-lasting karstification processes. The answer is also reached to question why and how to protect that little known world of karst that surrounds us.

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