SEDIMENTOLOGY IN THE SERVICE OF ENGINEERING GEOLOGY: STUDY OF SOME RESULTS OF THE EXPLORATIONS FOR HIGHWAY CONSTRUCTION AND TUNNELING IN CROATIA

D. Pollak
Institute of Geology, Zagreb, Croatia

K. Braun
Institute of Geology, Zagreb, Croatia

ABSTRACT: Exploration for highway construction and tunneling in Croatia besides normal field investigations, involved sedimentological survey. This paper presents results of laboratory and field investigations which can improve our conclusions about rock mass quality. The authors encourage the application of sedimentology in engineering geology, particularly in karstic regions, for more appropriate understanding of the rock mass and intact rock. Introduction of sedimentological modelling into this project indicates a great influence of sedimentology into engineering geology and it certainly enhanced our engineering-geological model.

RESUMÉ: Dans le cadre de la construction des routes et tunnels en Croatie, en plus des travaux de reconnaissance usuels, ont été effectués aussi les essais sédimentologiques. L'article présente les résultats des essais en laboratoire et sur le terrain ayant amélioré sensiblement l'évaluation de la masse rocheuse. L'adoption des modèles sédimentologiques dans les projects de reconnaissance géotechnique, a démontré, spécialement dans la région karstique de la Croatie, une grande influence de la sédimentologie sur l'aspect et sur la qualité du modèle d'ingéniérie géologique définitif.

INTRODUCTION

Sedimentary rocks are of considerable importance in Croatia since they compose more than 90% of its territory. At the central and southern part of the country, most are carbonate rocks.

Increased planning, designing and constructing of the highways in our country demanded thorough investigations of certain areas. Since most investigated areas are sedimentary rocks, mostly carbonates, the investigations have been reconciled to demand of nature. The authors idea was to cover the investigated area with sedimentological mapping, in addition to the usual complex field investigations: photogeology, geological and engineering-geological mapping, structural measurements, refraction seismic, geoelectrics, analytical research and data processing.

Therefore all of the sedimentological exploration in the paper were directed towards limestone and dolomite rock masses.

Since numerous sedimentation factors have a great impact on geotechnical characteristics of rocks (structure and texture, shape of the sediment body, thickness of layers, mineral composition, diagenesis, roughness of the bedding surfaces etc.), depositional conditions and models should have an important place in creating of engineering-geological models.

MODELS

To determine the properties of the intact rock and rock mass, it is very important to know as much as possible about its history. Its formation, genesis, structure, texture and later transformation, alteration and destruction are the basic processes which determine properties of the rocks. The engineering geologist should pay particular attention to this when developing the model.

Classification of the intact rock

A very simplified classifications was used in the course of basic geotechnical (engineering-geological) description of rocks and rock masses. Considering carbonate rocks, a more detailed description was based on classification systems given by Carozzi (1960) and Folk (1959). Both of

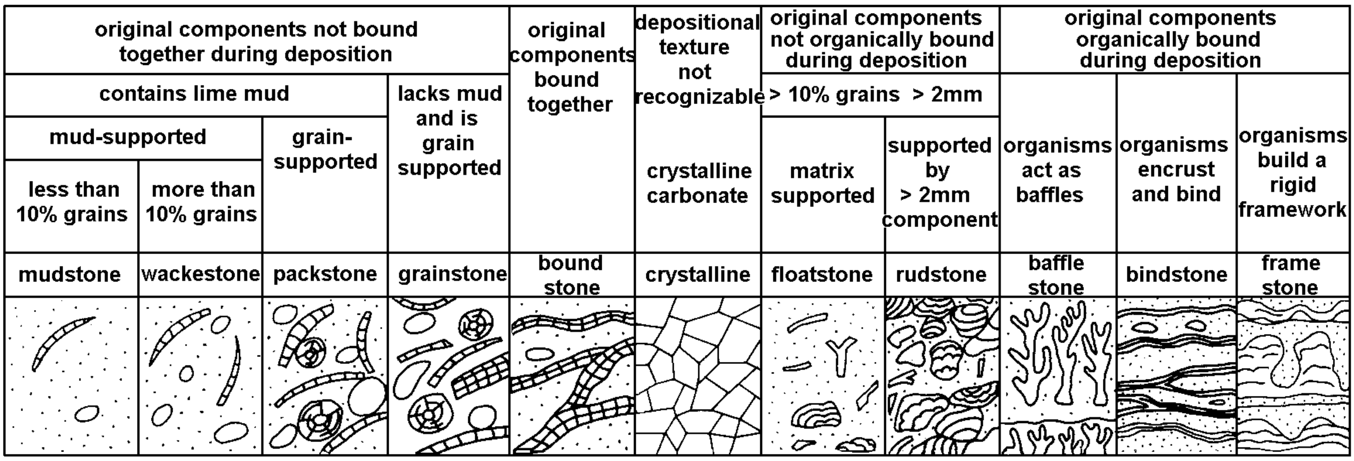


Figure 1. Classification of limestones based on depositional texture. After Dunham (1962) with modifications of Embry & Klovan. From Tucker (1991).

classifications require microscopic determination of the rock type. For engineering-geological practice, following up the approach in sedimentological investigations, classification proposed by Dunham (1962) (Fig. 1) seems to be more convenient, because it enables description of intact carbonate rocks according to their depositional texture directly in the field. Depositional textures, furthermore, make it possible to recognize the depositional environment defining facies transitions, disposal, scale and persistence of certain rock types. Importance of these factors in engineering-geological modelling is paramount, since they define diversity, appearance, shape, dimensions and persistence of single lithological unit (Fig. 2) and consequently, members of the engineering-geological model.

STAGE	TYPE OF LIMESTONE	SPECIES DIVERSITY	SHAPE OF REEF BUILDERS
DOMINATION	bindstone to framestone	low to moderate	laminate encrusting
DIVERSIFICATION	framestone (bindstone) mudstone to wackestone matrix	high	domal massive lamellar branching encrusting
COLONIZATION	bafflestone to floatstone (bindstone) with a mudstone to wackestone matrix	low	branching lamellar encrusting
STABILIZATION	grainstone to rudstone (packstone to wackestone)	low	skeletal debris

Figure 2. Stages of reef growth. A sketch of the four divisions of the reef-core facies with a tabulation of the most common types of limestone, relative species diversity and shape of reef-builders found in each stage. After Walker (1984).

Facies modelling in defining the engineering-geological properties of rock masses is particularly important, acting as a framework and guide in prediction of rock mass engineering-geological and geotechnical behavior, in certain circumstances (e.g. in tunneling).

Sedimentological studies offer the possibility of defining the regularities in deposition of important or reference geotechnical members in the lithostratigraphical sequences. In carbonate rocks, belonging to the carbonate platform, low energy intertidal sequences are very common, including a transition from typical muddy to typical grainy ones (Fig. 3).

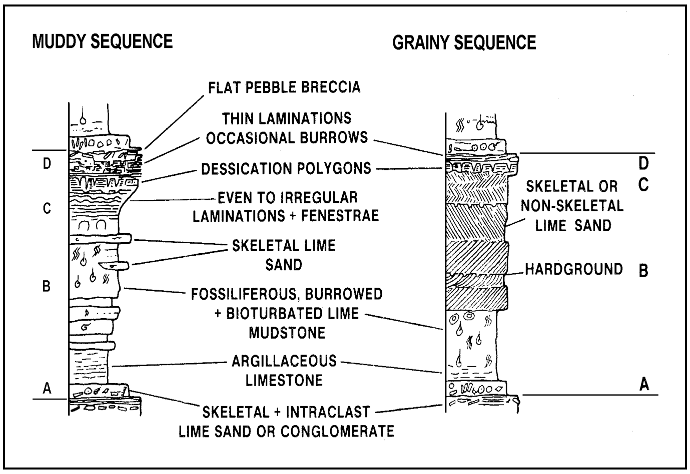


Figure 3. Low energy intertidal. Two hypothetical sequences with a low energy tidal flat unit developed on a low energy subtidal unit (left) and high energy lime sand unit (right). After Walker (1984).

Regularities of facies variations can be a considerable aid in engineering and geotechnical modelling and defining prognostic profiles, for example in tunnel designing.

Sedimentological modelling was, recently, very successfully applied in designing the tunnels (“Cicarija”, 12.7 km and “Velebit”, 5.7 km) and highway (Rijeka-Karlovac, 100 km) in Croatia. For example, the “Velebit” tunnel area is of carbonate rocks of the Adriatic Carbonate Platform ranging from Middle Triassic, to the late Cretaceous.

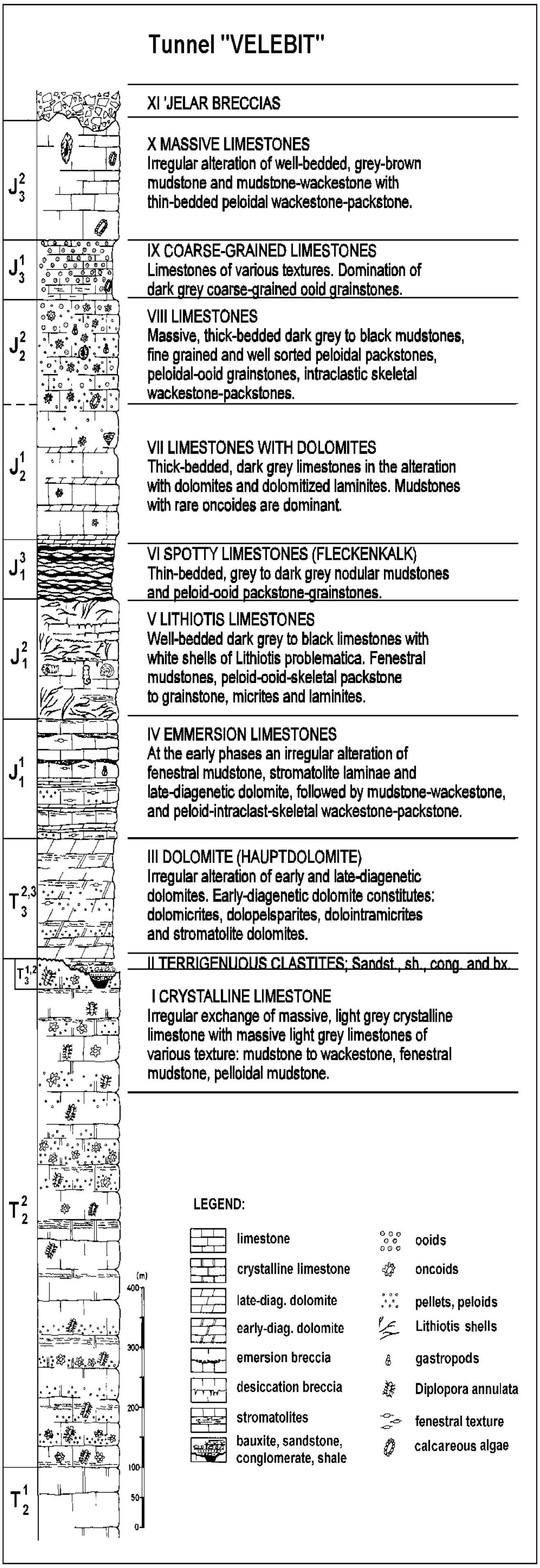


Figure 4. Schematic geological column of the "Velebit" tunnel area. After Maticec at al. (1997).

Main depositional environments are represented by peritidal carbonate sediments (subtidal, intertidal and less supratidal sedimentary deposits) (Fig. 4). In that case detailed sedimentological classification of the sedimentary rocks clearly shows correlation with their engineering-geological properties. Exploration enabled designing a very reliable geotechnical profile which was checked while the excavation is in progress.

Facies models, bedding and engineering geology

A layer is a geologic body separated from its surrounding rock mass by a primary discontinuity. It represents the consequence of changes of granulometry, mineralogy, lithology, orientation or pattern of particles or simply the termination of sedimentation. In most cases it is external bedding, represented with the upper and lower discontinuity separating the layer from the next one.

Internal bedding is a textural or structural property of the layer itself, and can be laminated, crossed, parallel, undulated, graded etc.

Thickness and persistence of the layers can vary vertically and laterally, and often depends on the mechanism of the deposition and conditions of the sedimentation.

The roughness of the bedding surfaces directly influences engineering-geological properties of the rock mass and can be influenced by rain drops, ripple marks, turbiditic traces, rolling marks, sliding marks etc.

There are also some chemical, biochemical and diagenetic processes which can influence geotechnical rock mass properties, like stylolitization, bioturbation, recrystallization, dolomitization, silicification, selective dissolution and cataclasis.

For example, stylolitization can improve roughness of certain discontinuity, but on the other hand, it also very often contain clay mineral fill, and rock with the a lot of stylolites separate easily.

If mica flakes are oriented parallel to the layer itself, the discontinuities becomes slickenslided and a separation of interlayers is much more likely. If coarse-grained particles constitute the base of the layer, they usually erode the fine grained top of the lower bed, creating irregular bedding surfaces.

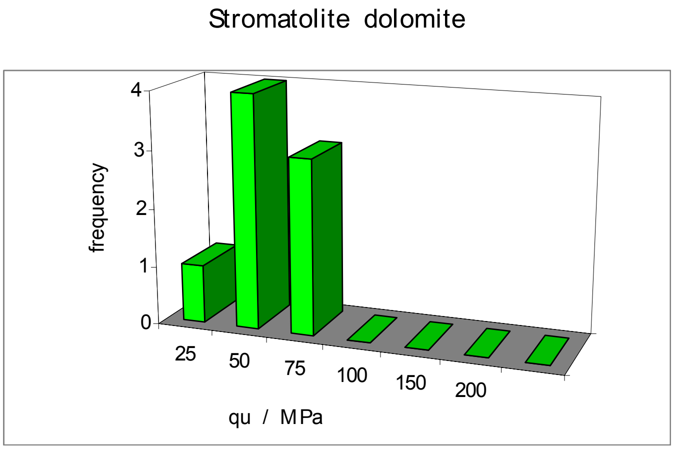
Sedimentological investigations, divide the carbonate deposits into sedimentary sequences, using appropriate knowledge to predict, for example, the density of slickenslided primary discontinuities. Obviously, higher density of such discontinuities occurs in muddy parts of sequences (mudstones, wackestones) of the intertidal or shallow subtidal marine depositional environments.

Lithological type and strength of the intact rock

In clastic sedimentary rocks, physical properties of the intact rock can be determined by strength of the grains and their matrix. It is even possible to calculate the theoretical strength of some rocks, but they are far from being ideal materials, with many irregularities in texture and structure. Our aim is not to predict the exact value of some physical property of the rock, but to place the rock mass on its right group. Here it should be noted that the index of the rock texture (m_i), an important factor of the Hoek-Brown failure criterion, depends generally on grain size, but also on: particle texture (detrital, muddy or skeletal); their fabric or ratio between the content of particles and matrix (wackestone or packstone); kind of matrix (micritic or sparitic); and degree of recrystallization of the intact rock.

Strength of most of the sedimentary rocks depends on characteristic of the matrix between the particles, kind of particles and their bonds. For example analysis of the uniaxial strength of limestone indicated a higher strength of packstone and grainstone than mudstone and wackestone.

A good example of this situation is the Upper Triassic dolomite in the “Gorski kotar” region, Croatia, covering more than 5 km of Zagreb to Rijeka highway (and expected to be excavated in the “Velebit” tunnel) (Fig. 5).



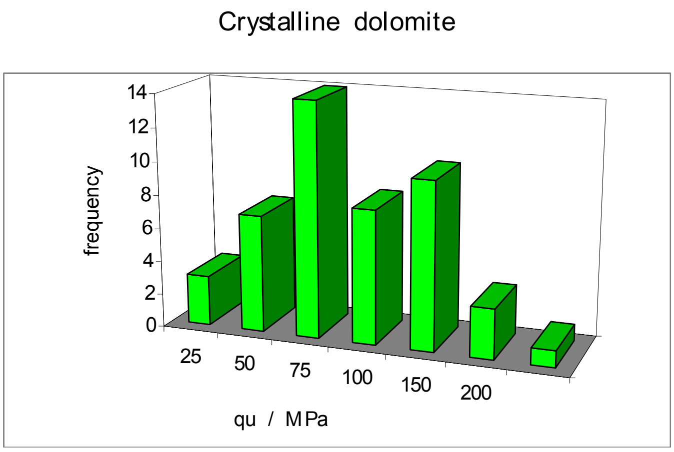


Figure 5. Uniaxial strength of stromatolite and crystalline dolomite at the core samples.

The dolomite is represented by coarse crystalline dolomite and interlayers of stromatolitic dolomite. Stromatolite dolomite represents about 10-20% of the dolomite mass. With a lower uniaxial strength and laminated texture it interrupted the homogeneity of the rest of the rock having higher uniaxial strength. Distinction between crystalline and stromatolite dolomite was simple, so the homogeneity and anisotropy could be established by measurements of visible bed thickness.

Different textural rock types which occurred in investigated highway and tunnels in Croatia, have variable uniaxial strength. The differences, related to the different varieties of limestones, can be seen in the following tables (Table 1 and Table 2).

Table 1.

LIMESTONES	uniaxial strength / MPa		ultrasonic waves mean / (m/s)	
texture (num. of samples)	mean	range	v_p	v_s
MUDSTONE (163)	119	70-169	5800	2584
PACKSTONE (16)	136	89-183	6129	2862
INTRABAS.BRECC.(13)	117	57-177	5217	2382

Table 2.

DOLOMITES	uniaxial strength / MPa		ultrasonic waves mean / (m/s)	
texture (num. of samples)	mean	range	v_p	v_s
CRYSTALLINE (46)	85	39-131	3853	2002
STROMATOLITE (8)	43	26-60	3977	2194

Facies model and sampling

In creation of an engineering-geological model it is vital to have valid quantification of the data. It is often a challenging problem to evaluate the impact of different factors to the rock mass. Consequently, the most important is that the sample taken for analysis have to be representative of the rock mass.

As carbonate rocks are product of sedimentation under various conditions, each textural type should be recognized in the field and placed in correlation with sedimentary sequences or their parts. The establishment of the sedimentological model that includes a determination of depositional environment of the investigated area, dimension, shape and persistence of rock types with equal or similar mechanical and geotechnical characteristics, allows establishment of a reliable engineering-geological model. Only reliable engineering-geological models can act as an appropriate input for successful geotechnical modelling and designing, particularly in tunneling and highway construction.

Therefore, more detailed classification of the sediment type and determination of depositional conditions, seems to be fundamental and effective in engineering-geological modelling.

CONCLUSION

Sedimentological modelling was recently and successfully applied in designing the tunnels ("Cicarija" and "Velebit") and highway (Rijeka-Karlovac), in Croatia.

Basic properties of sedimentary rocks normally determine engineering-geological properties of the rocks. Impact of these factors on geotechnical properties of the rocks should be evaluated by the engineering geologist.

In engineering-geological practice, following the approach in sedimentological investigations, the Dunham (1962) classification of limestone modified by Embry and Clovan was used. It enables description of intact carbonate rocks according to their depositional texture directly in the field. Depositional textures, furthermore, enable recognition of the depositional environment, defining facies transitions, disposal, scale and persistence of certain rock types.

Facies models furthermore act as a framework and guide in the prediction of rock mass engineering-geological and geotechnical behavior.

Geometry of sedimentary bodies, thickness and persistence of the layers, roughness and other characteristics of primary discontinuities, directly influence engineering properties of rock masses, and depend on condition of depositional environment.

The strength and rock texture index (m_i) in most of the sedimentary rocks is the consequence of grain size, particle varieties and fabric, matrix between the particles and their bonds. Analysis of uniaxial strength of limestone indicated higher strength of packstone and grainstone than mudstone, wackestone and rudstone. Also crystalline dolomite is stronger than stromatolite ones.

Prompt establishment of the sedimentological model, linking rock types with the equal or similar mechanical and geotechnical characteristics (using Dunham's classification of carbonate rocks), allows the establishment of the appropriate and reliable engineering-geological model. It enables also the appropriate sampling according to the diversity, mode of appearance, shape, dimensions and persistence, defined in the frame of facies model. Therefore, more detailed classification of the sediment type and determination of sedimentation conditions already in the field, seems to be fundamental and effective in engineering-geological modelling.

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