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RELATIONSHIP BETWEEN MICROMORPHOLOGICAL CHARACTERISTICS AND ENGINEERING PARAMETERS OF CALICHE (CALCRETE)

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ABSTRACT: İ. Dinçer, A. Acar & D. Magaldi, *Relationship between micromorphological characteristics and engineering parameters of caliche (calcrete).* (IT ISSN 0394-3356, 2007).
Caliches are described as secondary carbonate formations and calcareous, semiconsolidated aragonite or early diagenetic calcite forming in loose materials such as pebble, sand, silt, and soil under semi-arid and arid climatic regimes.
The aim of this study is to identify and discuss effects of micro-morphological-mineralogical properties on engineering properties of caliche. Furthermore, correlations derived from mechanical, physical-index properties and micromorphological characteristics are evaluated and establish statistically predictable model for UCS. For this aim, samples were taken from different locations in caliche outcrops occurring in the southern part of Turkey.
Based on the statistical analyses, linear relationships were fitted between the Micromorphological index (MI) and each mechanical and physical-index properties. Based on these linear relationships among the engineering properties, uniaxial compressive strength, P-wave velocity, average Young's modulus and point load index there are significant correlations with the micromorphological index (MI). Results suggested that strength of the caliche is controlled by micromorphological properties. Four micromorphological parameters which are effective on engineering properties of caliche were identified: microstructure, voids, coarse materials and matrix. Microstructure is the most important parameter to assess engineering behaviour of caliche followed by voids, coarse materials and matrix. Statistically most reliable models, which allow the estimating of UCS, are discussed in this study. The empirical equation, $UCS = -7.137 + 3.06 \times 10^{-3} Vp + 0.38UW + 0.13MI$ where *Vp = P-wave velocity*; and *UW = Unit weight* is assumed to be the best and practical for engineering purposes.

RIASSUNTO: İ. Dinçer, A. Acar & D. Magaldi, *Relazioni tra caratteristiche micromorfologiche e proprietà geotecniche della crosta calcarea (calcrete).* (IT ISSN 0394-3356, 2007).
La costa calcarea (caliche o calcrete in inglese) è un accumulo carbonatico indurito semiindurito costituito da calcite e/o aragonite che si forma entro substrati geologici sciolti come le ghiaie, le sabbie e i limi oppure entro suoli di clima in genere arido o semiarido.
Questa ricerca ha avuto come scopo l'identificazione e l'analisi delle relazioni esistenti tra le caratteristiche micromorfologiche e mineralogiche e le proprietà geotecniche della crosta calcarea affiorante nella Turchia meridionale.Al riguardo sono stati considerati modelli statistici di previsione della resistenza a compressione uniassiale (UCS) a partire dalle caratteristiche micromorfologiche.Sono state inoltre trovate relazioni significative non soltanto per l'UCS ma anche per altri parametri geo-ingegneristici quali la velocità delle onde P entro i provini, il modulo di Young e il valore risultante dalla prova di carico puntuale (Point Load Test). Questi risultati suggeriscono che le caratteristiche micromorfologiche e mineralogiche così come evidenziate dall'analisi in sezione sottile ed espresse da un Indice micromorfologico (MI) , condizionano le proprietà meccaniche della crosta. Le caratteristiche micromorfologiche che maggiormente appaiono influenzate da quelle micromorfologiche sono, nell'ordine, la microstruttura (micromass, secondo Stoops, 2003), la tipologia dei vuoti, la tipologia dei costituenti grossolani, la matrice.
L'equazione empirica che appare maggiormente valida per stimare la resistenza a compressione uniassiale, principale indice delle proprietà meccaniche di una roccia,è la seguente: $UCS = -7.137 + 3.06 \times 10^{-3} Vp + 0.38UW + 0.13MI$, dove Vp = velocità delle onde P, UW= peso dell'unità di volume del materiale considerato e MI è il nuovo indice micromorfologico.

Keywords: caliche, micromorphological characteristics, mechanical properties, physical-index properties.

Parole chiave: caliche, caratteristiche micromorfologiche, proprietà meccaniche, proprietà geotecniche.

1. INTRODUCTION AND BACKGROUND

It is commonly accepted that engineering properties of the rocks are controlled by their petrographic characteristics. Zorlu *et al*. (2004) concluded that packing density and packing proximity are most influencing in mechanical characteristics for sandstone. Also they reported that texture is more important than mineralogy in this respect as far as sandstones were concerned. Tugrul and Zarif (1999) correlated the mechanical, physical-index properties with petrographical characteristics of granitic rocks. In the same way, they concluded that the influence of textural characteristics on the engineering properties appears to be more important than mineralogy. They also determined the types of contacts, grain (mineral) shape and size significantly influence the engineering properties of granitic rocks. Koncagül and Santi (1999) distinguished the factors affecting hardness, strength and durability in rocks in three different groups such as effective in grained rocks, argillaceous rocks and effective in both rock types. They concluded that packing density, degree of bonding, type of cement and bonding material, permeability, post-depositional factors, occurrence of soft/soluble minerals and microfractures affect both uniaxial compressive strength (UCS) and the slake durability test (SDT) in a similar fashion. These factors cause both UCS and SDT results to increase or to decrease. JENG *et al*. (2004) found that porosity has more influence on the UCS than grain and matrix content does. At the same time, few researchers established a statistical model to predict mechanical properties of rocks using their petrographic characteristics (BELL, 1978; FAHY and GUCCIONE, 1979; SHAKOOR and BONELLI, 1991; ULUSAY *et.al*., 1994).

Caliche adversely affects cut slope stability, earth fill material sensitivity, and ground stability at structure sites along the Motorway which is being constructed in the Southern 3 Turkey. About 90 % of active and potential slides in the region occur in the caliche deposits and colluvial deposits which have been derived mainly from caliche (YILMAZER and Smith, 1992). At the same time caliche widely formed foundations of buildings in the southern part of Turkey and it was also used in the historical buildings as a dimension stone due to the ability to easily shape it. Caliches are therefore very problematic materials for Turkey.

In this study, the relationship between micromorphological-mineralogical properties and rock index properties were examined for caliches. Correlations derived from mechanical, physical-index properties and micromorphological characteristics were evaluated to establish a statistical prediction of UCS.

2. MATERIALS

2.1 The caliche

Thirteen samples were taken from different locations of caliche outcrops in the southern part of Turkey (Fig 1). Caliche contains different levels for strength and deformability properties. However, only two levels were considered from a geotechnical point of view. The hardpan of the part shows rock properties whereas the soft pan at part below shows soil properties. Block samples (approx. 0.25x0.25x0.20 m) collected from hardpan (massive caliche) has low strength level. The caliche formation is widely distributed in the region on peneplain morphology occurring from east to west in the Adana Region.

Caliches are described as a secondary calcium carbonate accumulation forming in loose materials such as gravel, sand, silt, and soil under semi-arid and arid climatic regimes. The caliche term was firstly used for the gravel and similar calcium carbonate cemented materials in south-western United States. Some conditions which are required for the formation of caliche are country or basement rocks to be of a carbonate type, the occurrence of carbonate 4 in the soils, a semi-arid to arid climate and a widespread water percolation down the soil profile. In Turkey, caliche occurrences are commonly observed in Aegean, Mediterranean, and Central Anatolia in young rock formations (ATABEY, *et*

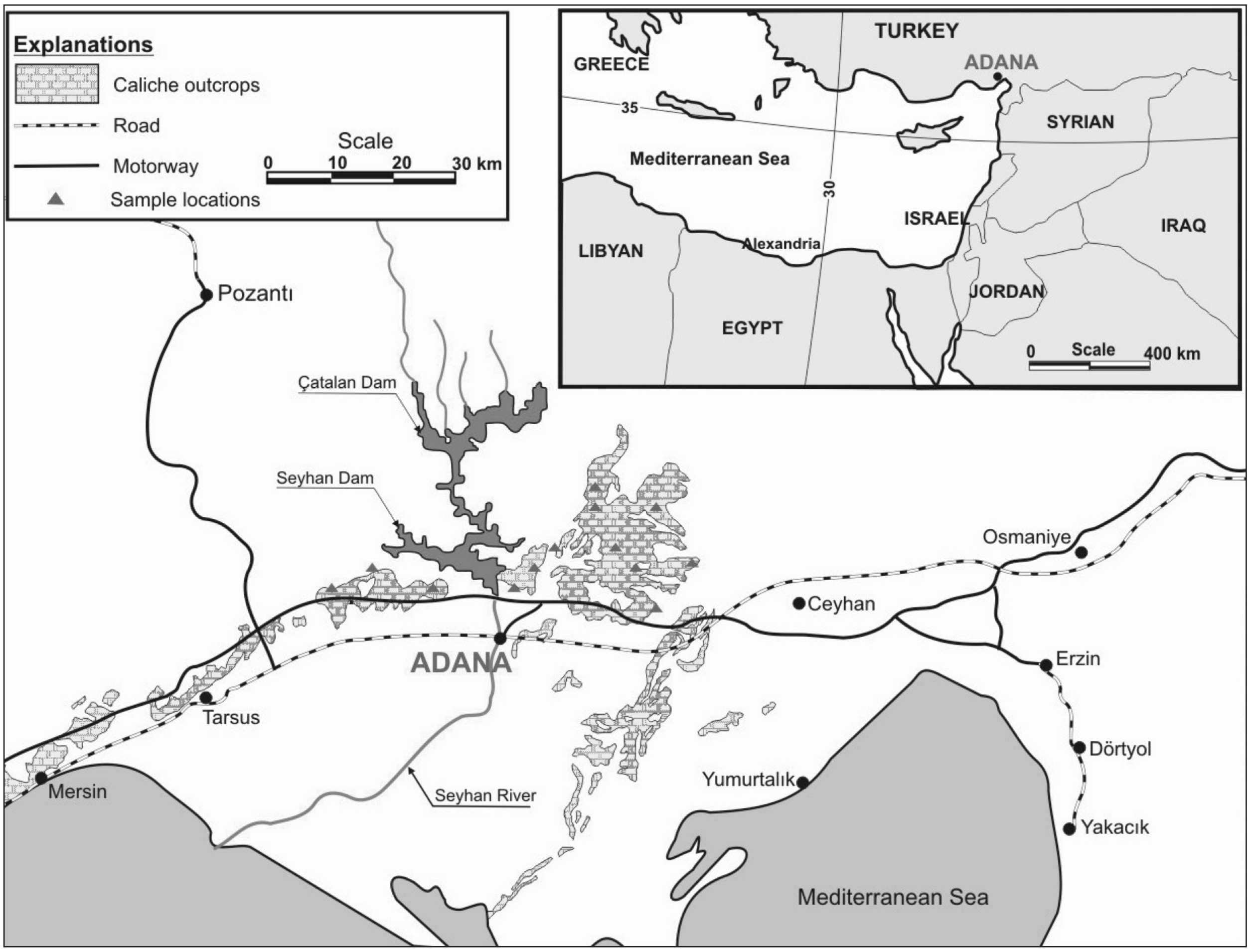

Figure 1 - Location map of the study area.
Localizzazione della zona studiata.

al., 1998). In southern of Turkey, formation of massive caliche was attributed to Pleistocene climatic fluctuations and a shallow lacustrine environment by KAPUR *et al*., (1993). The process is broadly similar to other sites around the Mediterranean.

2.2 Stratigraphic features of study area

Different Tertiary aged lithostratigraphic units are outcropped in the study area. The Tertiary stratigraphy was defined as Pre-transgressive, transgressive and regressive deposits in succession (KAPUR *et al*., 1993). At the base of this succession, Paleozoic and Mesozoic aged lithostratigraphic units are outcropped (Fig 2). Cenozoic succession is mainly represented by Tertiary and Quaternary units. Tertiary units unconformably overlap Paleozoic and Mesozoic rocks (YETIŞ,1988). The transgressive deposits comprise the terrestrial and lacustrine formations (Oligocene-Lower Miocene). The transgressive cycle of the Miocene Sea (Burdigaliyen-Serravallian) consists of shallow water beach clastics, the reef carbonates, the deep marine and turbiditic formations. The uppermost of the Tertiary unit comprises the Handere formation, which is consist of clay stone, sand stone and very rarely gravel stone. It was covered by pedostratigraphic units of the Quaternary, the Villafrankian to Late Pleistocene High and Low terraces, in the study area (ŞENOL *et al*, 1991) (Fig 3). This model is supported by DINÇ *et al*., (1991), for the Mediterranean coastal areas with pedo- geomorphological criteria. It consists of young deposits of study area, which are calichified glacis and glacis or river type conglomerates. Red Mediterranean and Reddish Brown to Brown soils and massive caliches (calcretes) occur with discordance in the Pliocene and between the Mid and Late Pleistocene periods (KAPUR *et al*., 1993).

3. METHODS

3.1 Rock Mechanics Test

Blocks samples (Fig 4 a and b) were taken from 13 different locations in the Adana Region. Using a core-drilling machine at the laboratory, NX and BX size core samples were prepared from caliche blocks (Fig 4 c and d). Unit weight (UW), apparent porosity (n), Schmidt rebound number (RN), shore hardness (SH), P-wave velocity (Vp), slake durability index (Id_2), point load index ($Is_{(50)}$), uniaxial compressive strength (UCS), Average Young's Modulus (E_{av}) values of the samples were all measured according to International Society for Rock Mechanics Standards (ISRM, 1981a).

Rock samples, having regular shapes, were used for unit weight and apparent porosity tests. Samples were sunk into water for 48 hours. Later, weight and dimensions of samples were measured with a scale having ±0.01 accuracy. After that, caliche samples were

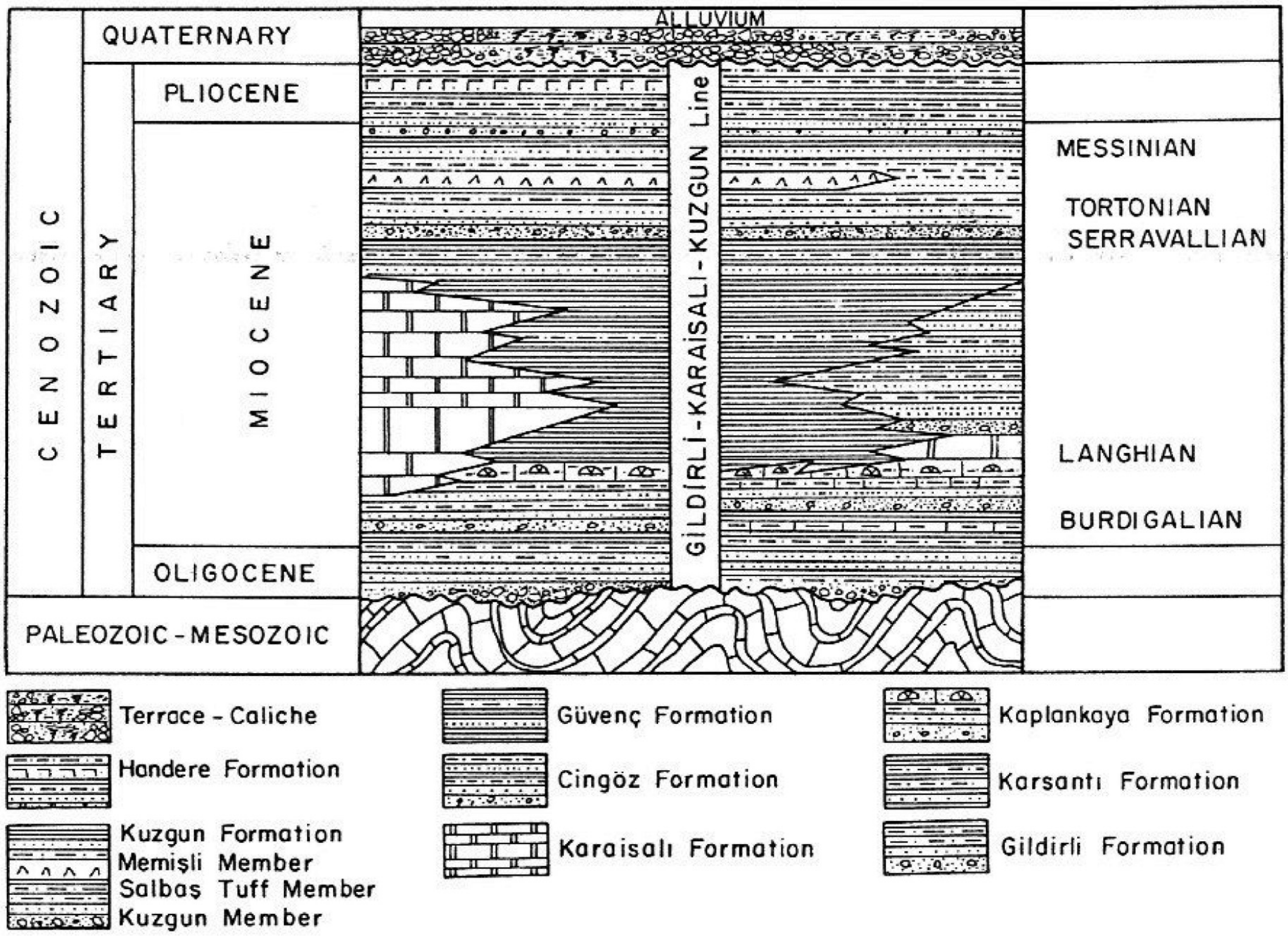

Figure 2 - Generalised lithostratigraphic sections of the study area (YETIŞ, 1988).
Sezioni lito-stratigrafiche della zona studiata (YETIS, 1988).

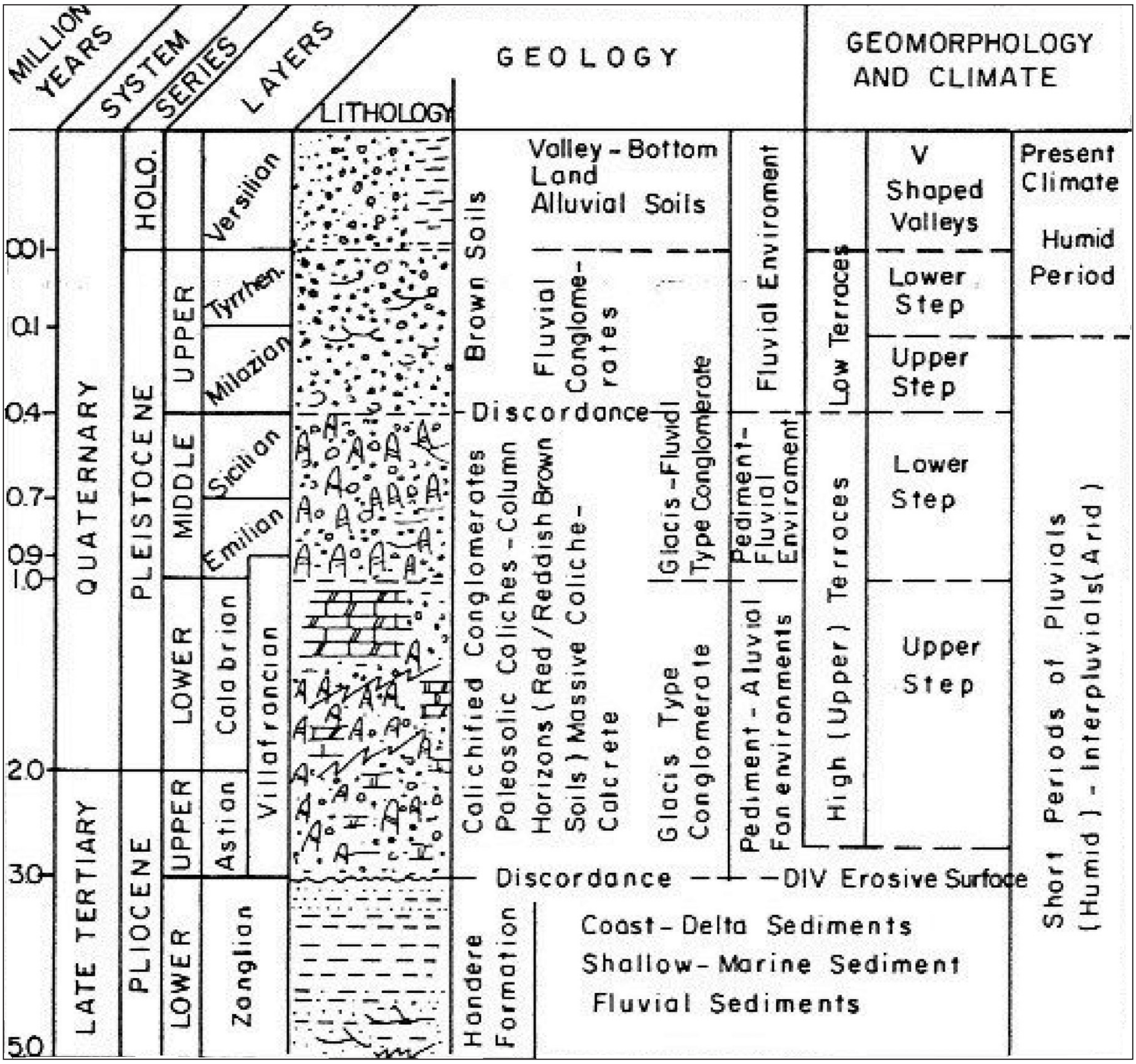

Figure 3 - Pedostratigraphic sections of the study area (ŞENOL *et al.*, 1991).
Sezioni pedo-stratigrafiche (ŞENOL et al., *1991).*

dried for 24 hours at 105 °C and weighted. Determination of apparent porosity and unit weight was achieved using volume, dry weight and saturated weight of the samples. The Schmidt Hammer tests were carried out in the field on large caliche blocks samples. All tests were performed by N type Schmidt Hammer following ISRM (1981b). The Schmidt Hammer tests were performed vertically on rock blocks with no discontinuity and cracks. Each time, twenty readings were taken and the upper ten values were averaged. Shore hardness values were determined using the C2 type shore schleroscope which was cleaned and calibrated using calibration block. Test procedures included 2.44 gr diamond tipped hammer drop freely on the caliche sample and carefully measuring and longing the rebounding height on the scale which ranged 0 to 140. Twenty readings were taken from each sample; and readings with the highest five and lowest five values were cancelled, and the remaining 10 readings were averaged according to ISRM (1978a). The pundit and two transducers (a transmitter and a receiver) were used in all tests. Three core samples were prepared (height/diameter 2-2.5) for each caliche samples. Both faces of drill cores were trimmed and smoothed so that the receiver and the transmitter could cover the faces tightly. The test was carried out according to ISRM (1978b). In the slake durability test, the apparatus combines the effects of both soaking and abrasion in order to evaluate the rate of weathering caused by water immersion. The test procedure was performed according to ISRM (1979) standards with ELE RM-310-2 test machine. Ten rock slumps with equal dimensions were prepared for the slake durability test. Rock slumps rotated in the steel mesh drum were partially immersed in water for ten minutes. Samples were subjected to three cycles and durability index (I_{d2}) in which each cycle was calculated as a percentage ratio of final to initial dry weight of rocks in the drum after drying and wetting cycles. In this study, the second cycle index (I_{d2}) was used for evaluation of slake durability index of caliches. The point load test is an index test to determine the strength of intact rocks. The system of this test consists of a hydraulic pump, a hydraulic jack, a pressure gauge and two steel points with standard dimensions. In the test, the rock sample is slowly loaded by activating the hand pump until failure of sample. The failure load is read from gauge. The test can be applied to irregular and regular rock samples in field or laboratory. There are three test methods, which are diametrical test, axial test and block test (ISRM, 1985). In this study diametrical and axial tests were used in laboratory. Caliche core samples were prepared with length/diameter ratio for 1/1. Failure of rock samples was achieved within 10-60 seconds. The point load strength index $I_{s(50)}$ was calculated using the correction factor.

The uniaxial compressive strength tests were performed according to the ISRM (1981c) standards. The test apparatus for the unconfined compressive tests consisted of a triaxial test machine (ELE ADR 2000) and a data acquisition system. NX and BX (length/diameter 2-2.5) size core samples were prepared for UCS. The loading rate was selected as 0.1 kN/s and failure of caliche samples was achieved within 5 – 10 minutes. At least five specimens were tested for each block samples. At the same time, ISRM (1981c) standard test procedure was used to determine the average Young's modulus (E_{av}).

3.2 Micromorphological Analyses

Thin sections (25 x 40 mm) of the samples were prepared for the microscopic observation. Some common micro morphological features (microstructure, voids, coarse materials and matrix) were selected to evaluate micromorphological characteristics of caliche according the results and assumptions after several papers (MAGALDI, 1983; BULLOCK *et al.*, 1985; STOOPS 1988; MAGALDI and TALLINI, 2000).

3.2.1 Microstructures

Same microstructures classification was used after MAGALDI, 1983 (Fig 5): Undifferentiated; size, shape and arrangement of matrix have a homogeneous crust. It contains few if any voids, rock fragments and organic materials;

Banded; laminated crust with different crystal size in individual laminae. Matrix and aggregates generally horizontally elongated and separated by planar voids.

Nodular; groundmass consisting of many nodules.

Brecciated; crust formed by irregular network of fractures and clasts.

3.2.2 Matrix

The matrix of caliche consists mainly of calcite which is the cementing medium. The calcite material is composed of more or less similar crystalline or cryptocrystalline particles. The calcite crystals are less than 2 μm to 15 μm in size. Three types of calcite cement

Figure 4 - Various views of the caliche outcrops and samples. (a) hardpan level of caliche, (b) morphological structures of caliches, (c) cored caliche blocks, (d) NX and BX size caliche core samples.

Immagini degli affioramenti e dei campioni di crosta calcarea: (a) livello di hardpan entro la crosta calcarea, (b) microstruttura della crosta calcarea, (c) microstruttura di crosta calcarea con il foro di carotaggio, (d) campioni di crosta calcarea con dimensioni NX e BX.

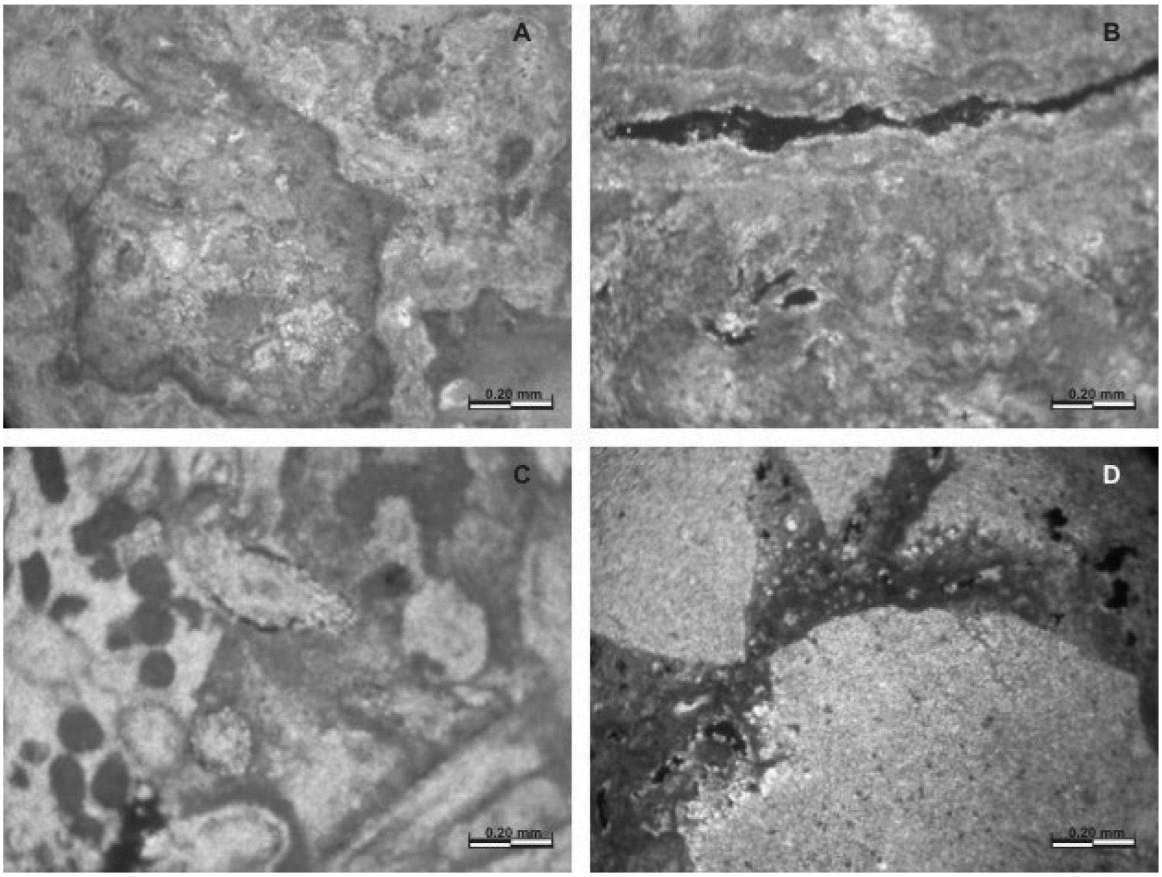

Figure 5 - Microstructure types of caliche samples. (a: Undifferentiated b: laminated c: Nodular d: Brecciated)
Tipo di microstruttura dei campioni di crosta calcarea. (a:Indifferenziata, b:Laminata, c: Nodulare, d: Brecciata).

occur in the matrix micrite, microsparite and sparite. Micrite (2 to 4 μm) occurs as cementing material between the skeletal grains and as a clear rim around the grains within the groundmass. Microsparite (4 to 10 μm) is formed by subhedral crystals. Microsparite occurs as drusy mosaic filling between the micritic rimmed grains and rock fragments. It is also observed in the following cases: a) hypo coatings around the voids and cavities; b) calcite crystals increasing away from the walls of the grain / channels or cavities; c) elongated crystals perpendicular to the wall of the cavity/ channel or grain boundary. Sparite (10 μm and above) generally occurs as infilling crystals within channels and voids. In some caliche samples, two or more different matrix types were observed at the same time. This matrix type was identified as mixed type.

3.2.3 Voids

Stoop's classification (1988) is used for classification of voids and spaces not occupied by solid material. Brewer (1964) classified voids according to their morphology, considering them as individuals. His classification was used by Bullock *et al*. (1985) with some small modifications.

3.2.4 Coarse Materials

Size, shape, frequency and internal characteristics are used as main criteria for description of the coarse materials. Three main groups of coarse particles can be determined according to their composition and origin; (1) mineral grains, (2) rock fragments, (3) some coarse pedo features and components (nodule, organic matter, etc).

4. MICROMORPHOLOGICAL INDEX AND CORRELATION WITH ROCK- INDEX PROPERTIES

Rock-Index properties of each sample were correlated with their selected micromorphological features. Microstructure, voids, coarse materials and matrix were considered and each feature was quantified by a simple rating qualitatively related to degree of presumable strength of the sample. Voids and coarse materials are rated according to both modal size and frequency. We used a rating 2 to 6 for one feature; 1 to 5 for four features; 1 to 3 for one feature (Table 1). Overall rating ranges from 7 to 29 increasing with the strength of material. This rating (MI) was obtained for each caliche sample. Table 2 shows the micromorphological (semi-quantitative data) and engineering properties of caliche samples.

Koncagül and Santi (1999) concluded that index properties of rocks are controlled by mineralogical composition, degree of cementation and re-crystallization. Well cemented and completely recrystallizated samples have higher strength and durability than other samples. In order to investigate the influence of micromorphological characteristics on mechanical and physical-index properties of caliche samples, a number of correlations based on simple regression and some graphs were made. At the same time multiple linear regression variable selection analysis can be performed with a forward selection process, a backward elimination process, or a stepwise selection process that is a combination of the forward and the backward methods. The stepwise selection method selects or eliminates the variables as per given user probability criteria. A dependent variable or response variable is related to predictor or independent variable(s). The objective was to construct a regression model relating the dependent variable, *y*, to independent variable(s). Stepwise forward selection procedure was used to select the best suitable regression model of the form to predict the uniaxial compressive strength (UCS) of caliches.

$$y = \beta_o + \beta_1 X_1 + \beta_2 X_2, + ... + \beta_k X_k + E_{n,} , \qquad (1)$$

β_o, β_1 .... β_k are the regression coefficients, and X_1, X_2 , X_k, are the selected independent variables. E_n is an error term representing the magnitude of y not accounted for by other terms in the equation.

5. RESULTS

5.1 Geomechanical Properties

Geomechanical properties of caliches are assumed to be controlled by mineralogical composition, degree of cementation and recrystallization. Well cemented and completely recrystallizated samples have higher strength and durability than other samples. Table 2 shows the laboratory test results of caliche samples. Obtained values of unit weight of the studied caliche blocks vary from 14.96 kN/m^3 to 22.00 kN/m^3. Apparent porosity (n) is fluctuated between %16 and %35. Schmidt rebound values (RN) of caliches range between 14.50 and 39.80. Shore hardness (SH) of caliches varies from 4.20 to 22.50. Highest P- wave velocity (V_p) was 1444 m/s, while the lowest was calculated as 375 m/s. The Slake durability test results (I_{d2}) of caliche blocks ranged from 65.36 to 97.53%. Point load index ($Is_{(50)}$) varies from 0.53 to 1.91 MPa. The unconfined compressive strength (UCS) of the samples ranges between 2.03 and 9.54 MPa. The value of average Young's modulus (E_{av}) varies from 0.16 to 1.29 GPa.

5.2 Micromorphology

Caliche has the following micromorphological features: undifferentiated, nodular and brecciated microstructures with 10YR 8/2, 5YR 5/6, 5YR 8/6, 10YR 7/4, 10 YR 8/6 and 10YR 5/4 colours; dark calcite matrix with micrite and rarely microsparite groundmass occurring in the voids and nodules; microsparite and sparite rarely occurring as drusy mosaic filling in the voids, serrate boundary between micrite and microsparite; very dense and irregularly shaped nodules, dark greyish and white in colour with microcrystalline ground mass. Edges of chambers, simple packing voids, vughs, channels and vesicles type voids are rough-undulating, completely unaccommodated. Voids frequency increases up to % 50 in some samples; c/f-related distribution pattern is close-single-open spaced porphyric; coarse materials consist of scattered angular grains of quartz, silica, tephra and limestone Their sizes range 5 µm to 1000 µm; large grains (>1000 µm) are rarely observed. Few orthic nodules and trace of plant root remains were observed. Some microscopic pictures under polarised light are given in Fig. 6.

5.3 Correlation of Micromorphological and Engineering Parameters of Caliche

Mean values of index properties of microstructures types which are identified for caliche samples, are given in fig 7. According to results undifferentiated microstructure has higher mean values than other types. But this type has similar mean values with brecciated with grain to grain contacts only for slake durability test. Microstructures types are probably the most important character controlling the mechanical behaviour of caliches.

In a uniaxial compressive test stresses are likely to concentrate along the

Table 1 - Micromorphological rating form.
Punteggio attribuito alle caratteristiche micromorfologiche.

Sample No :				
Description :				
Characteristic		**Type**	**Rating**	**Sample**
Microstructure		Undifferentiated	6	
		Banded	4	
		Nodular	2	
		Brecciated	2	
		Not: Brecciated with grain to grain contacts	6	
Voids	Size(µm)	<50	5	
		50-100	4	
		100-500	3	
		500-1000	2	
		>1000	1	
	Frequency (%)	<5	5	
		5-15	4	
		15-30	3	
		30-50	2	
		>50	1	
Coarse Materials	Size(µm)	<50	5	
		50-100	4	
		100-500	3	
		500-1000	2	
		>1000	1	
	Frequency (%)	<5 5		
		5-15	4	
		15-30	3	
		30-50	2	
		>50	1	
Matrix		Sparite	3	
		Mixed Type	3	
		Microsparite	2	
		Micrite	1	
Total rating				

Table 2 - Engineering and Micromorphological properties of samples.
Proprietà tecniche e caratteristiche micromorfologiche dei campioni.

Sample No	Engineering Parameters									Micromorphological Parameters						
	g (kN/m³)	(RN)	(SH)	Vp (m/sn)	n (%)	I_{d2} (%)	$Is_{(50)}$ (MPa)	UCS (MPa)	Eav (GPa)	Microstructure	Voids Size (µm)	Voids Frequency (%)	Coarse Materials Size (µm)	Coarse Materials Frequency (%)	Matrix	(MI)
BL-1	18.51	28.00	13.54	681	28.12	90.08	1.13	5.63	0.55	Undifferentiated	100-500	<5	50-100	5-15	Mixed Type	25
BL-2	17.93	24.60	8.58	491	28.44	94.29	0.97	3.37	0.19	Nodular	500-1000	15-30	<50	<5	M.Sparite	19
BL-3	21.55	27.80	12.13	1146	21.00	97.53	1.25	7.85	0.88	Undifferentiated	<50	15-30	<50	<5	Sparite	27
BL-4	14.96	14.50	4.20	375	34.79	65.36	0.53	2.03	0.16	Nodular	100-500	30-50	100-500	<5	Micrite	16
BL-5	19.17	31.40	12.04	509	23.98	92.76	0.96	4.52	0.52	Brecciated	500-1000	15-30	50-100	5-15	Micrite	16
BL-6	18.70	35.40	18.08	1085	26.36	96.92	1.69	6.28	0.68	Brecciated (grain to grain contacts)	50-100	<5	50-100	15-30	M.Sparite	24
BL-7	17.32	19.90	8.40	436	31.70	84.82	0.78	2.99	0.19	Brecciated	100-500	5-15	500-1000	30-50	Micrite	14
BL-9	20.33	26.90	11.00	758	24.15	90.52	1.03	6.50	0.82	Undifferentiated	500-1000	<5	<50	<5	Mixed Type	26
BL-11	19.84	26.00	11.80	727	23.75	93.52	0.97	4.90	0.63	Brecciated (grain to grain contacts)	100-500	5-15	500-1000	15-30	Micrite	19
BL-12	15.37	22.60	10.52	431	35.49	92.36	0.95	2.45	0.19	Nodular	50-100	30-50	<50	<5	Micrite	18
BL-14	22.00	39.80	22.50	1444	16.23	96.81	1.91	9.54	1.29	Undifferentiated	100-500	5-15	<50	<5	Mixed Type	26
BL-14A	18.87	22.00	9.60	713	26.73	90.15	0.79	4.32	0.59	Brecciated (grain to grain contacts)	100-500	15-30	>1000	30-50	Micrite	16
BL-15	18.26	27.50	11.46	477	26.23	91.90	0.86	2.65	0.18	Nodular	100-500	15-30	100-500	15-30	Micrite	15

γ: Unit weight, V_P : P-wave Velocity, RN: Schmidt Rebound Number, SH: Shore Hardness, n: apparent porosity, I_{d2} : Slake durability index (two cycle), $Is_{(50)}$: Point Load Index (MPa), UCS: Uniaxial Compressive Strength, E_{av} : Average Young's Modulus, MI: Micromorphological index.

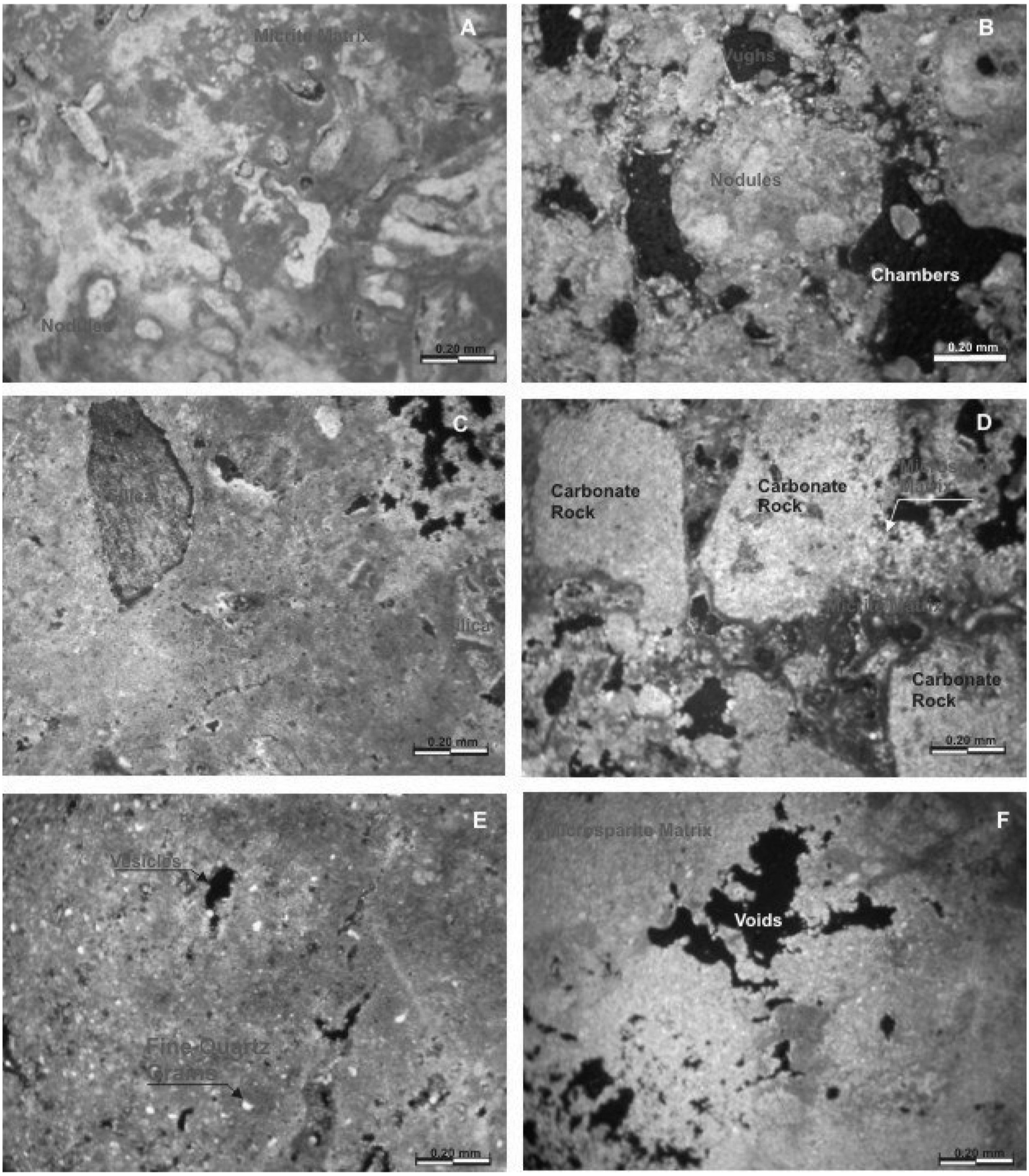

Figure 6 - Thin section views of samples.
Sezioni sottili dei campioni.

edges of cracks, voids and coarse materials. A rock with these features easily fails at low stress rate. Therefore, while undifferentiated microstructures can withstand higher uniaxial compressive loads, brecciated type is weaker than other types. Nevertheless some brecciated samples showed high strength because the number of grain to grain contacts is probably higher, so the applied external force is distributed over larger contact surface. Mineralogy of bonding or cementing material is an important property that controls strength, hardness and durability (KONCAGÜL and SANTI, 1999). Quartz provides the strongest binding followed by calcite and iron minerals. Clay binding material is the weakest.

Caliche consists of micrite, microsparite and sparite calcite matrix. Mean values of index properties are

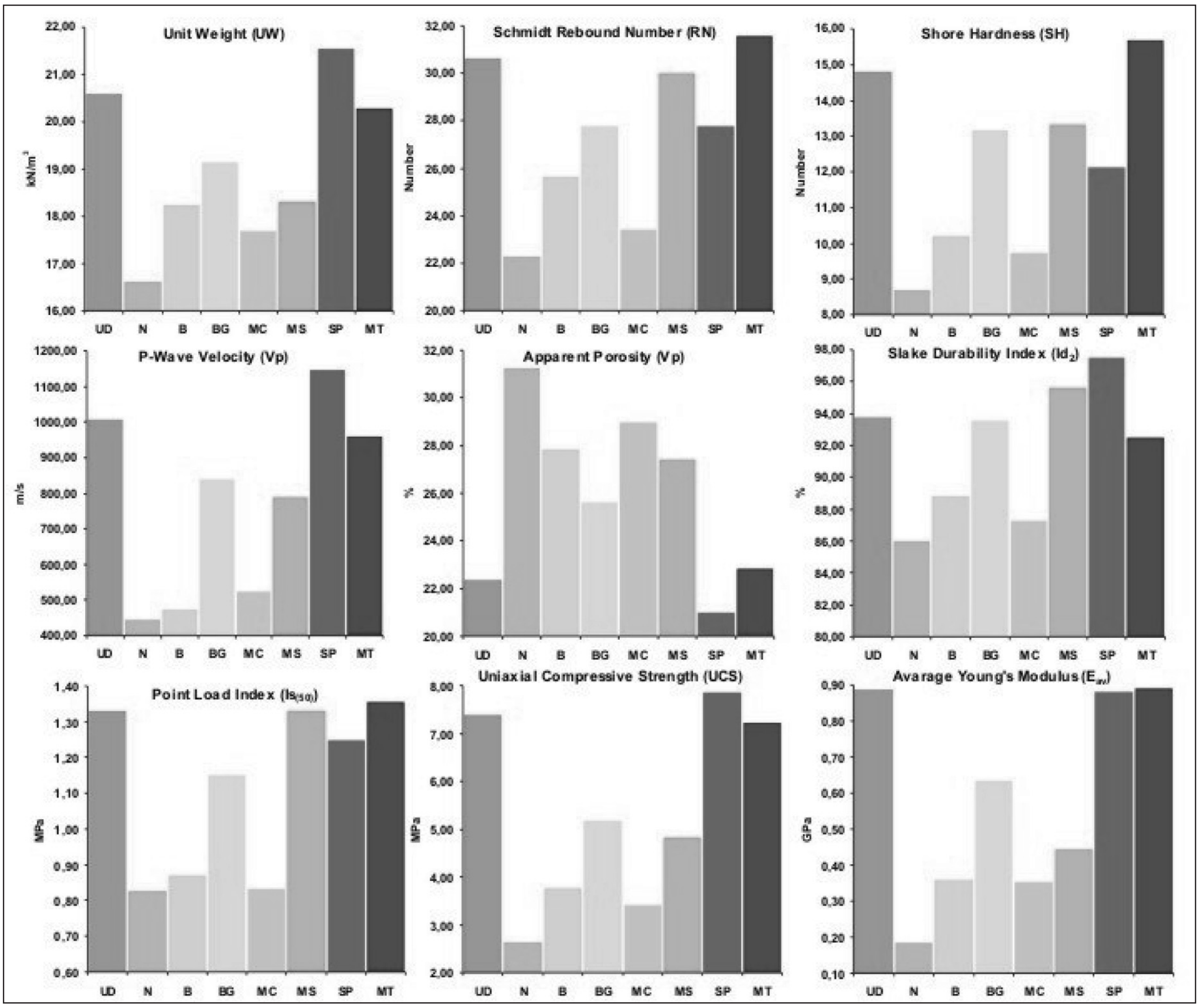

Figure 7 - Mean values of rock-index properties of microstructure and matrix types (UD: undifferentiated, N: nodular, B: brecciated, BG: brecciated with grain to grain contacts, MC: microsparite, SP: sparite and MT: mixed type).

Valori medi delle proprietà indici delle varie tipologie di microstruttura e matrice (UD: indifferenziate, N: nodulari, B: brecciate, BG: brecciate con contatti granulo-granulo, MC: microsparite, SP: sparite e MT: tipo misto).

given for matrix type of caliches in fig 5. Micrite values are normally lower than values of other types. Sparite matrix can withstand higher uniaxial compressive loads than micrite. Probably because micrite matrix occurs faster than sparite and micrite couldn't be cemented sufficiently.

Porosity has a significant effect on mechanical performance. PRICE (1960) and DUBE and SINGH (1972) reported that in sedimentary rocks all strength properties decrease with increasing porosity. This happens because high porosity allows the stress-induced microfractures to propagate (HOWARTH and ROWLANDS, 1986). The low uniaxial compressive strength in caliche samples is related to high frequency of voids.

Correlation matrices summarizing the determination coefficients of the index properties with significance levels are given in Table 3. The relationships between UCS *vs* UW, UCS *vs* Vp, and UCS *vs* MI yielded statistically significant correlations. Based on statistical analyses, linear relationships were fitted between the MI and some index property. Uniaxial compressive strength, P-wave velocity, average Young's modulus and point load index have significant correlations with micromorphological index (MI). Instead slake durability index, Schmidt hardness, shore hardness and unit weight have very weak correlation with MI. These findings suggested that micromorphological characteristics are controlling mechanical properties (as UCS) more than unit weight (UW) and durability (I_{d2}).

In order to determine how much the caliche strength is controlled by micromorphological properties MI was compared to Uniaxial Compressive Strength (UCS) which is the most widely used design parameter in rock engineering The correlations of thirteen samples is statistically significant with R^2 = 0.73 (Fig 8). According to Fig 8, UCS increases with the increasing of MI.

5.4 Prediction of the uniaxial compressive strengt h of caliche

UCS is the most important index property in rock mechanics. Testing procedure has been standardized by both The American Society for Testing and Materials

Table 3 - Correlation matrix of engineering and micromorphological index with significance level.
Correlazione di matrice dell'indice tecnico e micromorfologico con livello di significatività.

	UW	RN	SH	Vp	n	I_{d2}	$Is_{(50)}$	UCS	Eav
UW									
RN	,724(**)								
SH	,667(*)	,952(**)							
Vp	,805(**)	,771(**)	,839(**)						
n	-,971(**)	-,790(**)	-,722(**)	-,806(**)					
Id2	,669(*)	,747(**)	,680(*)	,553(*)	-,630(*)				
Is(50)	,648(*)	,910(**)	,956(**)	,894(**)	-,682(*)	,655(*)			
UCS	,889(**)	,779(**)	,800(**)	,947(**)	-,863(**)	,567(*)	,841(**)		
Eav	,882(**)	,742(**)	,777(**)	,927(**)	-,873(**)	,506	,782(**)	0.97(**)	
MI	,641(*)	,597(*)	,618(*)	,781(**)	-,569(*)	,451	,734(**)	,855(**)	,767(**)

*** Correlation is significant at the 0.01 level (2-tailed).*
** Correlation is significant at the 0.05 level (2-tailed).*

(ASTM) and The International Society for Rock Mechanics (ISRM). The tests are performed on well prepared core samples with a time consuming and expensive procedure. Preparing well core samples is rather difficult in soft rock like marl, caliches and others so many researchers employed simple models to estimate UCS by the rock index tests.

Then a multiple linear regression analyses were considered to obtain equations for estimating UCS from several index properties and MI. The data set is given in Table 2. Regression analyses were performed in two stage using SPSS for Windows statistical software. In the fist stage, only the quoted index properties (Table 4 and Table 5) were used as an independent variable to predict UCS:

$$UCS = - 5,742 + 4.5\text{x}10^{-3}\, Vp + 0.39UW \qquad (2)$$

In the second stage, all index properties and micromorphological index (MI) were used as independent variables and the stepwise forward technique for regression analyses are carried out to predict UCS. The best model for UCS was:

$$UCS = - 7.137+3.06\text{x}10^{-3}\, Vp+ 0.38UW+0.13MI \qquad (3)$$

The adjusted R^2 values indicate that the above multiple regression models explain 93.2% in equation (2) and 96.6 % in equation (3) of the total variation, respectively (Table 5).

Fig. 9 and Fig. 10 support the assumption of a linear relationship between the dependent variable UCS and the independent variables P- wave velocity (V_p), Unit Weight (UW) and micromorphological Index (MI). Regression equations have slopes equal to 1.0, high correlation coefficient and very low intercept values. The residual analyses confirmed that the assumption of a linear relationship is valid.

Table 4 - Statistics of some parameters used to estimate UCS.
Valori statistici di alcuni parametri usati per valutare la resistenza a compressione uniassiale(UCS).

Independent Variables	Un-standardised coefficients		t	Sig.
	β	Std. error		
Constant	-5.742	2.131	-2.694	0.023
Vp	0.0045	0.001	5.171	0.000
UW	0.394	0.139	2.834	0.018
Constant	-7.137	1.559	-4.578	0.001
Vp	0.003	0.001	4.025	0.003
UW	0.383	0.098	3.906	0.004
MI	0.133	0.040	3.336	0.009

Table 5 - Correlation and determination coefficients of the equations used to estimate UCS.
Coefficienti di correlazione e di determinazione delle equazioni usate per valutare l'UCS.

R	R^2	Adjusted R^2	Standard error of the estimate
0.971[a]	0.943	0.932	0.589
0.987[b]	0.975	0.966	0.415

a. Predictors: (Constant), Vp, UW
b. Predictors: (Constant), Vp, UW, MI

6. Conclusions

The caliche occurs from east to west in the southern part of Turkey. Caliche adversely affects cut slope stability, earth fill material sensitivity and ground stability at structure sites along the Motorway which is being constructed in the Southern Turkey. Caliches are very problematic materials for study.

Four micromorphological parameters which are significant on engineering behaviour of caliche were identified as follows: microstructure, voids, coarse

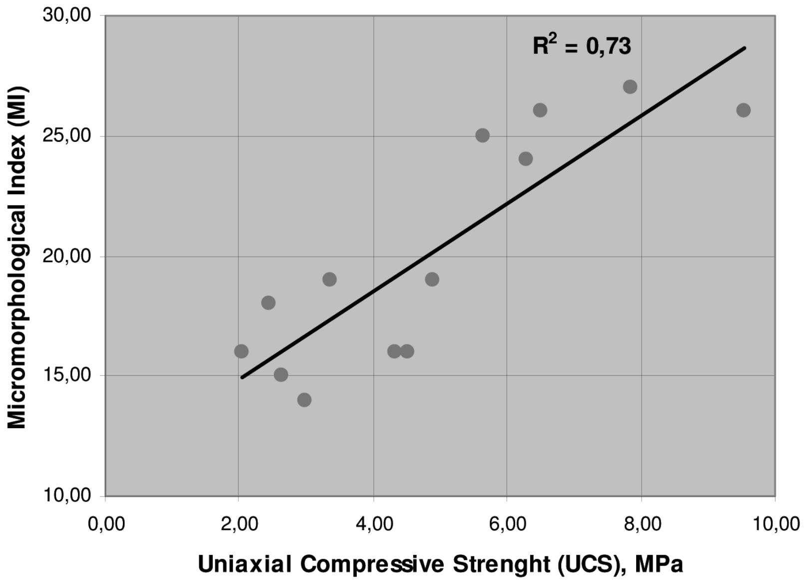

Figure 8 - Micromorphological index (MI) versus Uniaxial Compressive Strength (UCS) for thirteen samples.

Indice micromorfologico vs. Resistenza alla compressione uniassiale (UCS) per i tredici campioni di crosta calcarea.

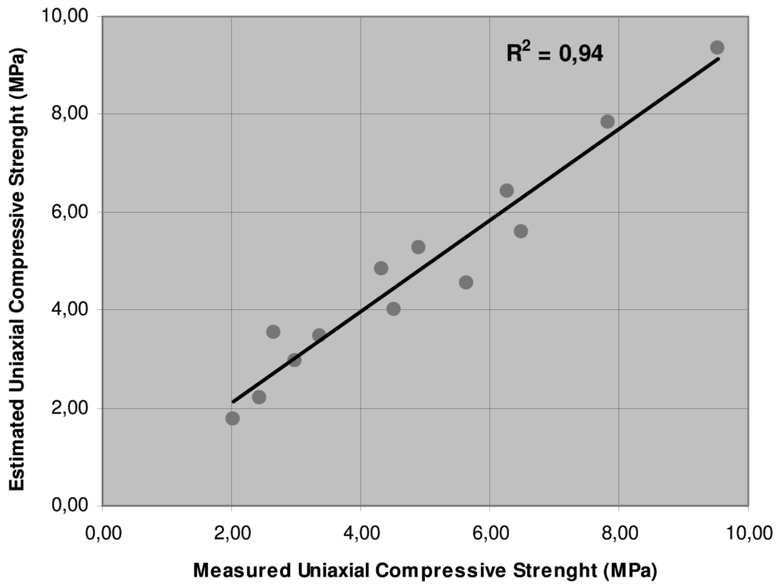

Figure 9 - Comparison of measured and the estimated UCS values for the model excluded MI.

Confronto tra i valori UCS misurati e quelli stimati con la relazione empirica, escludendo il parametro MI.

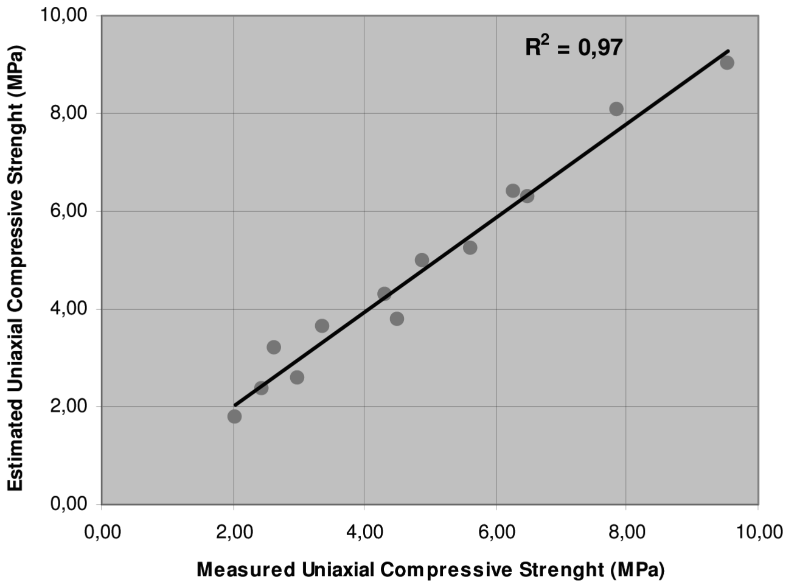

Figure 10 - Comparison of measured and the estimated UCS values for the model with MI.

Confronto tra i valori UCS misurati e quelli stimati con la relazione empirica, tenendo conto del parametro MI.

material and matrix. Microstructure is the most important parameter on engineering behaviour of caliche followed by voids, coarse materials and matrix. Micromorphological characteristics are more effective on mechanical properties than index properties and durability.

Results were obtained from a limited number of samples but the employed methodology seems to be promising for reaching indicative values of some rock index properties. Based on these linear relationships among the engineering properties, uniaxial compressive strength, P-wave velocity, average Young's modulus and point load index have significant correlations with a proposed micromorphological index (MI). The results suggested that strength of caliche is also controlled by micromorphological properties.

Then the statistically most reliable model as $UCS = -7.137 + 3.06 \times 10^{-3}\, Vp + 0.38UW + 0.13MI$ could be an accurate and less expensive estimation of UCS for engineering purposes based on micromorphogical as well geomechanic properties of the material. Lacking geomechanical properties UCS can be assessed with lesser precision by their simple relationship with MI.

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