EVALUATION OF MUDSTONE FORMATIONS FROM CRETE AND THEIR SUITABILITY FOR RAMMED EARTH AND ADOBE PRODUCTION

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ABSTRACT

Mudstone formation samples from Crete, GREECE are investigated, in respect to their suitability as raw materials for rammed earth and adobe production. The investigation concerns the determination of the mineralogical composition, the soil particle size distribution of the studied samples, as well as the analysis of sample consistency and compressive strength of rammed earth cube samples. Quartz and clay minerals are the major mineralogical constituents, whereas micas, chlorites, iron-oxides and hydroxides, carbonates and feldspars were detected in various amounts, follow. The samples are evaluated, concerning their suitability for rammed earth and adobe production, on the basis of their soil particle size distribution and the mineralogical composition. All samples have suitable compressive strengths to satisfy the minimum requirement of 2.0 MPa outlined in European Standards. Most of the studied materials, which have sand contents smaller than 60% are suitable for stabilisation as rammed earth and adobe.

Key words: mudstone, silt, clays, rammed earth, compressive strength

INTRODUCTION

1.Terminology - Mudstone, Silt, Clays

Although the terms clay, mud and shale are widely recognized, their technical definitions and usage have long been troublesome and not fully agreed upon. There are at least two reasons for this – the term"*clay*" is used both as a size and a mineral term, plus many clays, muds and shales are rich in silt-sized particles and thus span the clay-silt boundary. First consider clay as a size term. The upper limit of clay has been set at 2, 4 and even 20 μm so there is not a universal limit with respect to size. As a sediment, clay has been defined as an unconsolidated deposit that has 50% or more clay minerals by weight and is plastic when wet. A related but broader term is *mud*, a field term for a fine-grained deposit of any composition. It can consist dominantly of clay minerals, carbonate, volcanic ash, or contain much fine silt or even diatoms – as long as any of these form 50% or more by weight of a deposit, which is plastic when wet.
Here we emphasize the terrigenous components of this broad spectrum and use the term mud as defined above for unconsolidated deposits and the term *mudstone* for their lithified equivalents(Potter, P. E, et al.2005).
Terrigenous clay-sized material, less than 4microns, is derived mostly from the chemical weathering of rocks at the Earth's surface, with some contribution from volcanic ash and glacial rock flour. The origin of the silt component of mudstones is more controversial. Terrigenous silt, 4 to 64 microns in size, has been thought by many to be largely the product of physical processes – fracture or chipping in transport,

freezing and thawing, thermal expansion, exfoliation, release of confining pressure – all processes that favor size reduction. Some terrigenous silt may also be "born and not made", when mudstones are deeply buried or become low-grade metamorphic rocks. Silt may also be formed biologically by the action of plants or animals to break up larger grains or to precipitate new silt-sized grains. Mudstones, especially from the Mesozoic and younger, contain clay- and silt-sized carbonate and fine siliceous debris of biogenic origin. These physical and biological processes are enhanced by the chemical transformation of parent materials, which releases both mineral particles and solutes from a rock. The flow diagram of Fig.1 incorporates many of these possibilities.

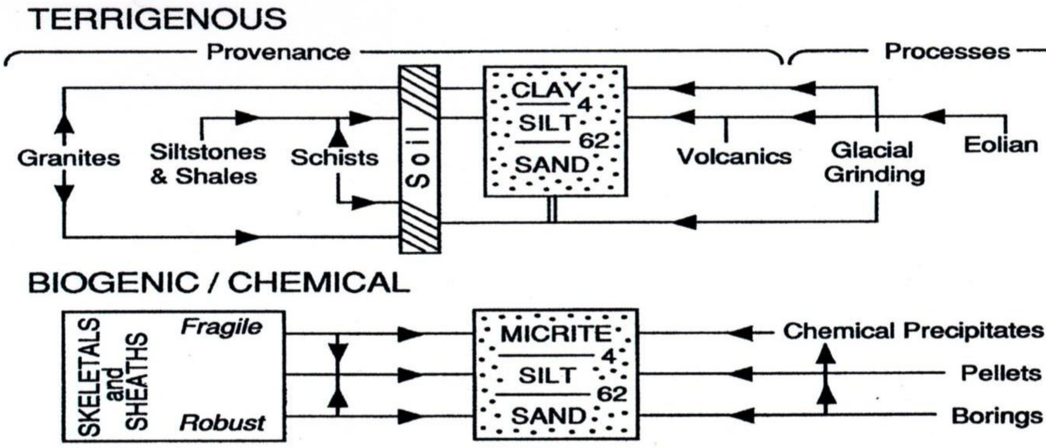

Fig. 1. Flow chart for the production of clay- and silt-sized terrigenous and biogenic/chemical debris(Chamley 1989)

The chemical processes that reduce mineral grains in size and transform primary minerals formed at depth into stable clay minerals are better understood, both qualitatively and quantitatively than are the diverse physical and biological processes that produce silt-sized terrigenous debris. Sources of terrigenous mud and silt include soils; erosion of unconsolidated clays and silts by slope wash on interfluves; gully and stream bank collapse; volcanic ash, especially on convergent margins; the deflation of arid and semi-arid regions by wind, which deposits loess on land or silt and clay directly into a lake or ocean (Potter, P. E.et al.2005).

2.1. Sedimentary Differentiation

Sedimentary differentiation starts in the profile of weathering in humid climates (more than 50 cm of rainfall per year) and follows the sequence below (Chamley 1989).

Parent rock + Cation deficient rainwater → Secondary clay minerals plus quartz,

Fe and Mn oxides + Export of solutions rich in cations and dissolved silica. The processes represented by this equation transform large primary minerals formed at high P-T conditions into fine-grained secondary clay minerals stable at low P-T conditions so that finally insoluble minerals such as quartz, kaolinite, and aluminum and iron oxides accumulate at the Earth's surface. Virtually all these transformations occur in soils or in alluvium as it sits in flood plains in transit to the sea. Although not explicit in the above equation, the *residence time* that the primary mineral spends in the zone of weathering is all-important – the longer this time, the greater the likelihood of mineralogical transformation between a mountain range and a distant basin. There are also two other outcomes – weathering in semi-arid (10 to 50 cm rainfall) and arid (less than 10 cm) climates, where the above pattern does not apply. In semi-arid regions Na+ and K+ are both mainly in solution, but Ca++, Mg++, and H4SiO4 only partially. Consequently, mineralogical transformation is less complete.

A general equation could describe the formation of clay minerals as follow:

Clay mineral = f(time, parent rock, climate, vegetation and topography relief)

2.2. Clay Minerals and Weathering

Clay minerals chiefly form via the weathering of primary minerals in soils in the following way (Chamley 1989):

H^+ +primary mineral→intermediate clay mineral+solutions→gibbsite+solutions .Three examples of the above general equation are,

H^+ + K-feldspar→illite→smectite→kaolinite→gibbsite ,

H^+ + muscovite→illite→smectite→kaolinite→gibbsite ,

H^+ + glass→gels (allophanes)→smectite→halloysite→kaolinite→gibbsite .

The needed H^+ comes via release from water, which is facilitated by excess CO2

H2O, H^+,+OH^- ,

CO2, + H2O, H2CO3 H^+,+ HCO^-_3

carbonic acid, bicarbonate ion

Thus the more CO2 dissolved in the water (supplied by bacterial respiration), the faster the weathering process. Another factor, and probably more important, is the total flux of water through the soil system; the larger the flux, the greater the tendency for these reactions to move to the right, a process that always converts complex crystal structures into simpler ones. Conversely, with minimal H+ all these reactions are sluggish or stall. This H+ or its proxy, rainfall, with pH around 5,5, is a key underlying driving force in weathering and the production of clay minerals.

Two other factors are time – with enough time even slow reactions go to completion – and, of course, starting materials in the source rocks. Hence, clay mineral compositions depend on residence time, rainfall, and source rocks. The above reactions tend to be reversed during burial, for example illite and quartz form at the expense of smectite, silica leached from uplands are added back to the clay mineral lattices.

3.1 Soil Specification

3.1.1 Colour

Natural soil is available in a very wide range of colours, including reds, yellows, browns, greys, greens, blues, white, and black. Red colour soils are often preferred. Variation in aggregate colour can lead to non-uniform finishes. Though other parameters, such as strength and erosion resistance, are more likely to govern soil selection, colour is an important aesthetic consideration for the client and designer. Natural colours can be varied by using additives, such as lime and cement, or by blending different soils (Kapfinger, 2001).

The colour of a soil can be a useful indicator of its composition. Materials such as iron, for instance, impart a vivid red or dull rust hue. Soils with high organic content have a black to dark grey colour. Alkali and gypsum give the surrounding terrain a white, chalky appearance. Soils of the latter type absorb a great deal of water and acquire a jelly-like consistency during stabilisation. None of these soils are suited to stabilisation; hence, rusty, black, or white soils should be avoided. Favourable soils tend to be buff coloured, indicating areas of loam, sandy loam, silt loam, or clay loam.

3.1.2 Particle Size Distribution

Particle size distribution testing by sieving and sedimentation testing has become acceptable practice for appraisal of soil for rammed earth. However, influence of variation in grading on physical characteristics of rammed earth, including both strength and durability, remains unclear (Keable, 1994). Organic matter content should be avoided, as this may lead to high shrinkage and possible biodeterioration as well as increasing susceptibility to insect attack. Organic material also interferes with action of stabilizers such as cement. In order to increase the mechanical strength and weathering resistance of soil it is advantageous to minimise the voids ratio in order to increase the contact between soil particles. Theoretically soils with no voids can be achieved if the soil particles are entirely spherical and their distribution follows the Fuller Formula. Engineering soils may be classified based on the relative size proportion of their main elements, namely gravel, sand, silt and clay. The British Standard grading limits used in this report are:

- Gravel, 60 mm to 2 mm
- Sand, 2.00mm to 0.06mm
- Silt, 0.06mm to 0.002mm
- Clay, less than 0.002mm

More generally care is required when reviewing international literature as particle size definition limits do vary (ACI Materials Journal, 1990; Alley, 1948; Jaggard, 1921; Middleton, 1995).

3.1.3 Selection criteria for Natural Rammed Earth

A wide variety of sub-soils have been used for natural rammed earth buildings, with the exception of uniform coarse sands and gravels with no fines or cementing agents (Hughes, 1983). For earth wall construction, the soil should contain all four elements (McHenry, 1984). Ideally the soil should have a high sand/gravel content, with some silt and just enough clay to act as a binder and assist soil compaction (Keable, 1996). According to Norton (1997) any material coarser than 5-10mm should be sieved out. Proposals tend to converge towards a 30%-70% balance between clay/silt and sand proportions (Berglund, 1986; Dayton, 1991; Easton, 1996). The recommendations for soil selection for rammed earth applications following IETcc (M. Carmen Jiménez Delgado and Ignacio Cañas Guerrero, 2006) are showed in Table 1.
Nevertheless no soil is likely to be ideal with regards to all of the aspects considered (Saxton, 1995) and therefore researchers around the world usually publish upper and lower limits for each of the main soil elements. In general the percentages are ‘by mass’, though in some cases (McHenry, 1986) it is not clear whether the percentages stated by the author were ‘by volume’ or ‘by mass’(Alley, 1948) (Houben & Guillaud,1994). Rammed earth buildings are extremely durable and can last for centuries. Experts claim that rammed-earth walls continue to harden - or cure, in their parlance - during the first year after construction. Although finished walls are somewhat water resistant, they can be stuccoed, plastered painted or left natural and sealed to better waterproofing them. Like adobe, rammed earth buildings have the advantage of having very thick walls that retain heat. Their thickness, or thermal mass, helps to even out temperature fluctuations between day and night, making them easy to heat and cool.

Table 1. Recommendations for soil selection for rammed earth following IETcc (Jiménez Delgado, M. C.and Cañas Guerrero, I. 2006).

Classes of rammed-earth	**Soil grading**[a]	**Plasticity**
Mud rammed earth	Clay + silt[b] 30–60%	–
Strengthened rammed earth	Fine gravel: 10–20%	–
	Sand: 10–40%	
	Silt: 20–40%	
	Clay: 10–40%	
	Clay + silt[b] < 45%	
Stabilised rammed-earth		LL < 40%
	Sand > 33%	10 < LP < 25
	Clay + silt[b] < 30%	Better
		12 < LP < 20
		IP = 6–22%

[a] Particle sizes are: clay $d < 0.002$ mm; silt $0.002 < d < 0.5$ mm; sand $0.5 < d < 5$ mm; fine gravel $5 < d < 20$ mm.

3.1.4 Adobe

Until recently, the techniques of building with adobe changed little from the mud brick homes built during the Neolithic period, around 7100 BCE. Since the mixture of mud is created by human power and the bricks are fired by the sun, adobe requires a very minimal manufacturing process. Because skilled labour is not necessary, it offers a viable solution to low-cost housing. Made from available soil, adobe is abundant, inexpensive and energy-efficient. A sustainable material, it has little impact on the environment and uses little or none of the planet's finite resources like fossil fuels. Adobe has many environmental benefits, including low energy costs. Because of its high thermal mass, it works well in hot climates with cool night time temperatures. Adobe bricks are made by blending together soil and water into a goopy mix. Traditionally straw is added to the mixture to provide strength and to prevent cracking. The adobe is then shaped in a mould or by hand and dried by the sun. The resulting bricks can be almost any shape or size and are laid with a mortar made of the same material - soil and water. In the summer, it takes about a week of hot, dry weather for the bricks to cure adequately before they can be handled and used. Adobe buildings can last hundreds of years, providing their walls are protected from moisture. Adobe can be effectively sealed and waterproofed by applying a cement stucco to the exterior. Recent variations to the adobe mix - adding small amounts of liquid asphalt emulsion stabilizers or Portland cement - make it less crumbly and more resistant to moisture (Easton, D., 1996).

CRETE GEOLOGICAL SETTINGS

The island of Crete is a prominent horst structure in the central fore-arc of the Hellenic subduction zone, which is governed by rollback of the African slab. The geology of Crete provides a nearly complete record of the evolution of the plate boundary between Eurasia and Africa during the last 35 Myr.

The internal structure of the forearc exposed on Crete is characterized by a pile of nappes derived from different paleogeographic zones. The nappes are subdivided into the upper tectonic units, lacking a Cenozoic metamorphism, and the lower tectonic units with a late Oligocene to early Miocene high-pressure/low-temperature (HP-LT) metamorphism (Fig. 2). The upper units are separated from the lower units (comprising the Phyllite–Quartzite Unit, Plattenkalk Unit) by a low-angle normal detachment fault (Seidel and Theye, 1993; Fassoulas et al., 1994; Jolivet et al., 1994, 1996; Kilias et al., 1994), recently referred to as the Cretan detachment (e.g. Ring et al., 2001a,b; Ring and Reischmann, 2002). The lower tectonic units were rapidly exhumed by displacement along the low-angle normal detachment fault from a depth of over 30 km within a few million years in the mid-Miocene (Thomson et al., 1998, 1999; Brix et al., 2002) and had reached a position in the upper crust at less than about 10 km depth by c. 19 Ma. The rate of exhumation requires rollback of the subducting slab (e.g. Thomson et al., 1998, 1999). Both lower and upper tectonic units are exposed in western Crete, predominantly bound by late normal faults, and partly covered by Neogene sediments deposited between c. 9 and 5 Ma (e.g. Keupp and Bellas, 2000).Underneath these marine sediments, huge masses of mainly breccias and conglomerates are exposed in two areas of western Crete (Fig. 1), which must be older than 9 Myr. Tortonian (c. 9 Ma) marine sediments (Frydas and Keupp, 1996; Frydas et al., 1999; Keupp and Bellas, 2000) in north-western Crete, which transgressively overly the breccio-conglomerates.

These marine Tortonian sediments contain clasts from all units of the Cretan nappe pile, including the HP-LT metamorphic lower tectonic units, and are in turn underlain by coarse terrestrial sediments (Creutzburg,1963; Freudenthal,1969) consisting predominantly of detritus derived from the HP-LT metamorphic Phyllite–Quartzite Unit (Seidel et al 2000).

SAMPLING AND MATERIALS

Mudstones occur on Crete within the Neogene basins. Mudstone and soil samples of different colouring from Western Crete, in an area of 10 to 20 km far from the city of Chania have been collected and investigated, in respect to their suitability as raw materials for rammed earth and adobe production. 10 Samples of mudstones and soils taken from the local sites of Agia (AG), Alikianos (AL), Patelari (PAT), Spilia (SP), Gerani (GER), Platanos (PL), Souda (SOU), Kampanos (KAM) were studied in order to evaluate their properties as raw materials. The samples were taken from ground rungs in respect of half a meter depth under the ground surface so as to avoid any organic content.

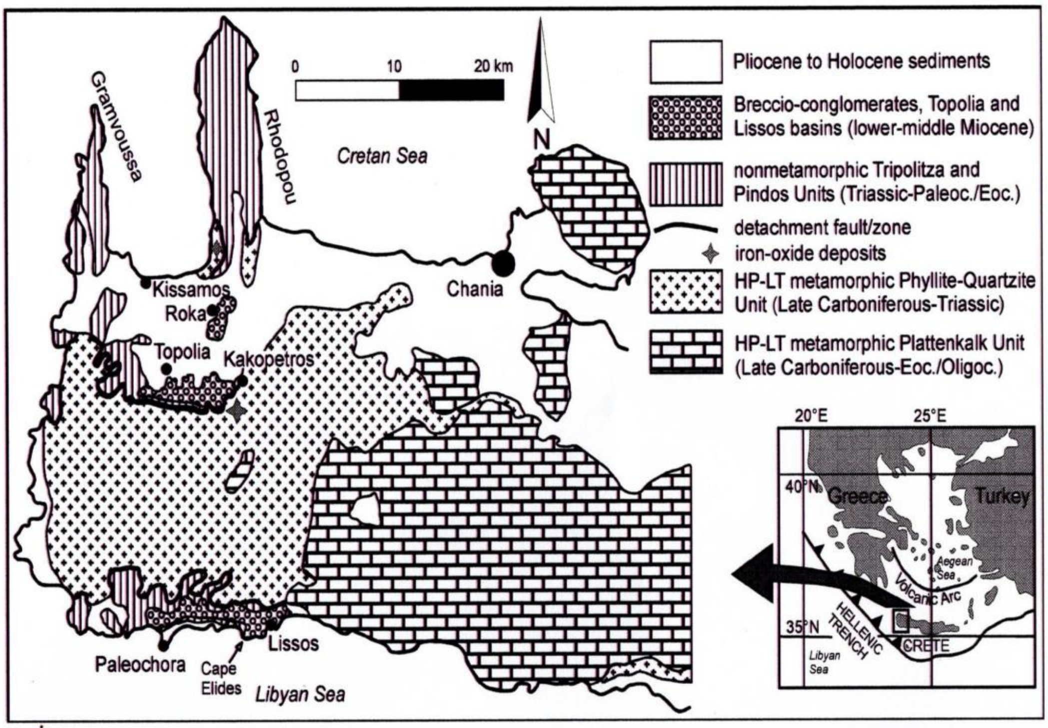

Fig. 2. Generalized geological map of western Crete (modified from Creutzburg et al., 1977; Trypali Unit included in the Plattenkalk Unit), west of the Lefka Ori, showing the Neogene basins, the underlying tectono-stratigraphic units, and the detachment fault (Seidel et al. 2000).

EXPERIMENTAL – RESULTS

The investigated raw samples show a very wide range of colours, including reds, yellows, browns, greys, greens and blues and their natural moisture content was measured up to 10-15 %. Their mineralogical characteristics were identified by using X-ray diffraction (XRD) and calcimetry analyses. In order to determine their physical technical characteristics laboratory measurements of soil particle size distribution and plasticity were undertaken for each soil. Also a number of cube specimens 5x5x5 cm of the samples were produced, compacted, and cured for 28 days under laboratory conditions for the necessary compressive strength measurements (Fig. 3). A quantitative mineral phases analysis by XRD was performed using the Siroquant V2.5 Quantitative XRD software (Table 2).

The raw materials are mainly composed of quartz, illite, muscovite, chlorite and calcite, with some Fe-minerals, feldspars and traces of gypsum, halite and anhydrite. The amount of clay minerals varies between 30 to 50%. The high percentage of Quartz and mica is due to the presence of the Phyllite-Quartzite Unit in the surrounding area. Furthermore the presence of Gypsum, anhydrite and halite is connected with the deposition of marine sediments (Frydas and Keupp, 1996; Frydas et al., 1999) between c. 9 and 5 Ma (e.g. Keupp and Bellas, 2000).

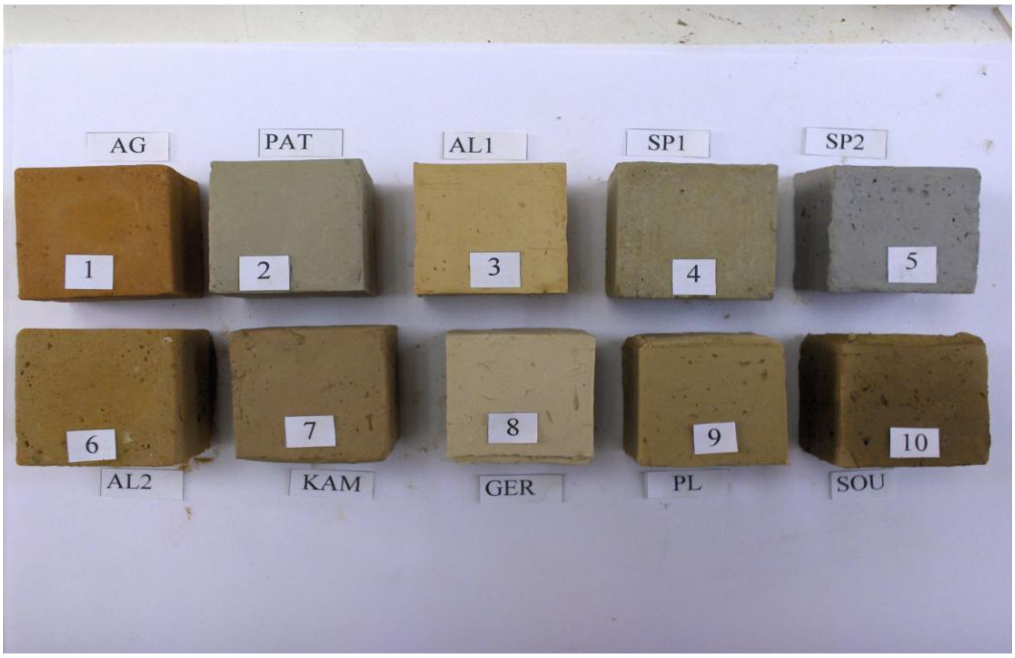

Fig. 4. Soil cube specimens (5x5x5cm) from the 10 samples

Table 2: Quantitative XRD analyses

Mineral Phases	Samples									
	AL 1	SP1	GER	AL2	PAT	AG	SP2	PL	KAM	SOU
Illite	34.0	27.1	11.2	31.0	45.7	31.5	49.3	40.6	42.8	34.7
Quartz	33.3	29.7	15.5	64.7	8.6	50.0	7.4	2.8	24.4	32.2
Orthoclase	7.4	7.1								
Muscovite	25.4		9.5	3.0	9.3	5.2	13.3	2.3	11.1	1.4
Calcite		20.1	63.8	1.4	20.4	1.6	4.7	35.0	1.6	2.0
Chamosite		2.3								
Hematite						1.6				
Halloysite		5.0								
Sodium Chlorite		4.4					1.4	0.6	1.2	1.0
Albite		0.7								7.9
Montmorilonite		3.1								
Biotite					3.2	1.2				
Chlorite		0.4			7.6	3.6	10.5	4.1	6.0	4.2
Dolomite					5.3	2.3	3.8	1.5	2.0	2.2
Goethite						3.0	2.4	3.0	3.6	4.9
Smectite-chlorite							3.6	5.7	4.1	4.6
Anhydrite							0.8	1.3	1.1	1.9
Gypsum							2.7	3.2	2.2	3.0

Shrinkage or swelling properties of the soils concerning the final appearance of the cube specimens when dried can be associated with the relationship between mineralogy and swelling potential of soil samples as shown in Table 3 (Bain, D. 2007).

Table 3: Summary of characteristics of common soil clays (Bain, D. 2007).

Secondary mineral	Type	Interlayer condition / Bonding	CEC [cmol/kg]	Swelling potential	Specific surface area [m2/g]	Basal spacing [nm]
Kaolinite	1 : 1 (non-expanding)	lack of interlayer surface, strong bonding	3 - 15	almost none	5 - 20	0.72
Montmorillonite	2 : 1 (expanding)	very weak bonding, great expansion	80 - 150	high	700 - 800	0.98 - 1.8 +
Vermiculite	2 : 1 (expanding)	weak bonding, great expansion	100 -150	high	500 - 700	1.0 - 1.5 +
Hydrous Mica	2 : 1 (non-expanding)	partial loss of K, strong bonding	10 - 40	low	50 - 200	1.0
Chlorite	2 : 1 : 1 (non-expanding)	moderate to strong bonding, non-expanding	10 - 40	none		1.4
Allophane	-	-	10 - 50	-		-

The granulometry of the samples was investigated in the soil fraction <2 mm using a sedimentation test, the Bouyoucous soil particle size analysis (Table 4). The results are also exhibited in a particle size chart (Fig.5).

Table 4. Classification of the soil and mud samples

Sampling sites	Num	Sample	Sand %	Silt %	Clay %
AGIA	**1**	**AG**	79	8	13
ALIKIANOS	**2**	**AL1**	23	32	45
ALIKIANOS	**3**	**AL2**	63	32	5
PATELARI	**4**	**PAT**	9	64	27
SPILIA	**5**	**SP1**	35	58	7
SPILIA	**6**	**SP2**	5	58	37
GERANI	**7**	**GER**	21	42	37
PLATANOS	**8**	**PL**	19	47	34
SOUDA	**9**	**SOU**	57	26	17
KAMPANOS	**10**	**KAM**	59	20	21

The investigated samples could be classified as silty clays(2, 6,7,8), clay sand(10), silty sand(1,3), clay silt(4) and sandy silt(5) thus covering a wide area of differentiated consistency, but the more fine ones (silty clays and clay silts) could be used as soil plasters.

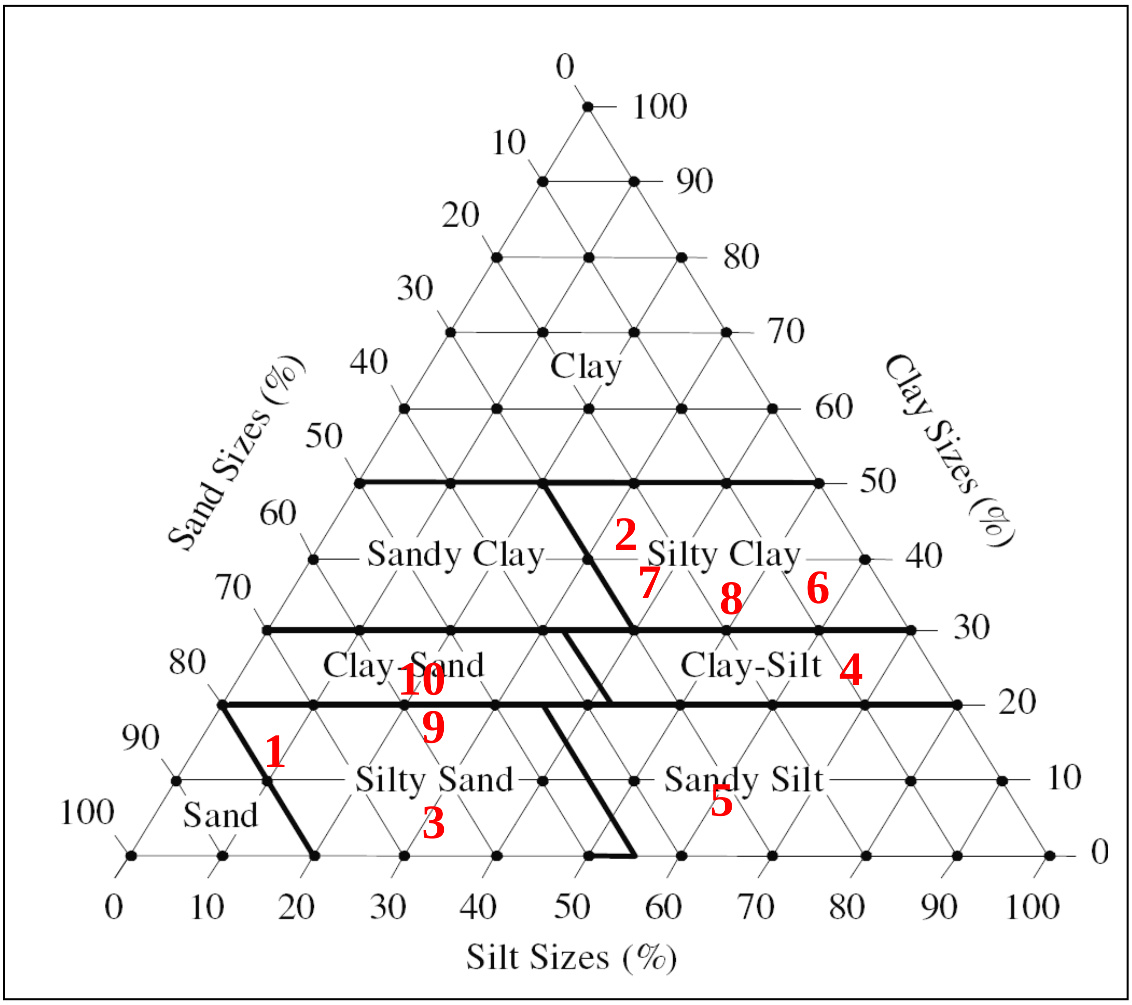

Fig.5 Cretan mudstone and soil particle-size distribution (sample1 –10)

The Atterberg limits (liquid limit LL, plastic limit PL) as well as the plasticity index (PI= LL-PL) were determined using both the Casagrande method in comparison with the Cone Penetration Test(ASTM D2487-00) and they are exhibited in Table 5.
Particularly, acording to the IETcc recommendations (Table 1) for soil selection for rammed earth, the main important properties for the suitability of a soil are soil grading and plasticity. The investigated soils show an appropriate soil grading (Fig.5) and satisfactory plasticity, due to the presence of adequate amounts of clays in all samples, except the samples AG (1) and AL2 (2) (Fig.5, Tab.4), with PI-values between 9-20, which are within the IETcc recommendations.

The mechanical strength of a soil is very much dependent on the voids ratio of the soil after ramming, cohesive strength of fines content, aggregate strength and moisture condition during testing. Density of the soil is a very important factor for the strength of the soil. Therefore, in the same way that it is difficult to give a specific value for the density, it is impossible to predict an exact value for the mechanical strength of a soil based on any kind of description with no prior testing (Table 6).

Table 5. Atterberg limits

Sample	Apparent density (gr/cm^3)	Liquid Limit (LL) Casagrande	Liquid Limit (LL) Cone test	Plastic Limit (PL)	Plasticity Index (PI=LL-PL)
SOU	2.39	25.45	29.09	13.58	11.87
PAT	2.56	33.57	37.69	13.58	19.99
AL1	2.04	26.86	31.33	15.39	11.47
AG	2.28	22.63	26.76	18.13	4.5
SP2	4.06	41.22	56.39	32.03	9.19
GER	2.39	44.75	45.73	26.04	18.71
AL2	2.67	19.95	28.45	18.18	1.77
PL	2.14	43.88	45.99	20.05	23.83
SP1	3.41	31.13	32.75	19.7	11.43
KAM	6.28	31.45	34.89	24.8	6.65

Table 6. Compressive crushing strengths following MOPT (1992)

Kind of stabilisation		Rammed earth (N/mm^2)	Adobe (N/mm^2)
Unstabilised	Low strength	0.6	0.75
	Medium strength	1.2	1.5
	High strength	1.8	2.25

Concerning their mechanical characteristics only the compressive strength has been measured so far. The compression test results are shown in Table 7. Except for the natural soil tested, cube specimens containing straw, following a volumetric ratio 1:1 soil to straw, were also produced for some samples as well as an experimental adobe specimen for investigative purposes.

Table 7. Compression strength of the samples

	COMPRESSION	STRENGTH
SAMPLE	**Stress σ (MPa)**	**Young's Modulus E (Mpa)**
AG	1.79	116
AGs	0.83	41
AL1	2.01	170
AL1s	0.80	18
AL2	0.37	48
PAT	1.00	77
PATs	0.48	18
SP1	0.52	41
SP2	1.10	48
GER	2.00	120
GERs	0.52	13
PL	2.55	105

SOU	3.69	232
KAM	1.08	71
PATadobe	1.18	81

Some of the soil and mud samples such as AL1, GER, PL, SOU exhibit high natural compressive strength from 2 to almost 4 Mpa.

CONCLUSIONS – DISCUSSION

This study examines the relationships between soil properties, mineralogy and stabilised strength for 10 mudstone and soil samples taken from sites in the area of Chania, W. Crete (Greece).

The raw material are mainly composed of quartz, illite, muscovite, chlorite and calcite, with some Fe-minerals, feldspars and traces of gypsum, halite and anhydrite. The amount of clay minerals varies between 30 to 50% ,corresponding to mudstones that contains much more alumino-silicates than expanding clays such as montmorillonite (ie. SP1). All the other clays are of non expanding type. The investigated soils show an appropriate soil grading and satisfactory plasticity, due to the presence of adequate amounts of clays in all samples, except sample AG (Fig.3, Tab.4) with PI-values between 9-20, wich are within the IETcc recommendations except sample AG The investigated samples could be classified as silty clays (samples 2,6,7,8), clay sand (sample10), silty sand(samples 1,3), clay silt (sample 4) and sandy silt(sample 5).

The samples showed different stabilised strengths ranging from 0.37-3.69 MPa and this strength variation is due to variation in soil properties. The most important soil properties explaining stabilised strength are mineralogical composition, grading and plasticity index.

The sand content and the silt/clay ratio seems to be very important factors affecting the final mechanical strengrth of the raw materials. According to the classification of Burroughs, V. S. (2001) concerning the granulometric analysis, three categories can be distinguished:
a)Favourable category: clay/silt 21-35 %; or sand 30-65 %; or gravel 3-5 %.
b)Unfavourable category: clay/silt < 21 or > 45 %; or sand > 75 %; or gravel<3%.
c)Satisfactory category: clay/silt 36-45 %; or sand 66-75 %; or gravel 3-12 %.

The samples from Agia and Alikianos 2 containing sand >60 % exhibit low PI and low compression strength.
The mechanical strength of the compressed sample from Patelari becomes higher values due to compression.
The samples from Alikianos 1 and Gerani, when mixed with straw, show lower strength values but, by the time they reach maximum strength, they become more flexible keeping their consistency and do not break down fast, during testing.
Another important factor affecting the mechanical strength is the clay content itself. A low clay amount, lower than 10% such as found in the samples Alikianos 2 and Spilia1 is responsible for low compression strength values.
A medium to low sand content, the plasticity index and the mechanical strength of the soils are strictly associated with an adequate silt/clay ratio, an optimal grain size distribution and an appropriate clay amount such as found in the samples Gerani with

21% sand, clay/silt 37/42%, PI 18.7, compressive strength of 2 MPa and Platanos with 19% sand clay/silt 34/47%, PI 23.8 and compressive strength of 2.55 Mpa.
Concerning also the results of their corresponding mineralogical analysis the Gerani and Platanos samples are marls, containing mainly calcite and different amounts of quartz, 15% and 2.8% respectively, combined with different amounts of illite. Thus the presence of the phylosilicates in accordance to the quartz amounts seems to be responsible for a similar behaviour among the sample properties.
Similar soil characteristics are also found in the samples Alikianos 1 with 23% sand, clay/silt 45/32%, PI. 11.47, compressive strength of 2.01 Mpa and Souda with 57% sand clay/silt 17-26%, PI 11.87 and compressive strength of 3.69 Mpa.
The samples Alikianos 1 and Souda exhibit similar physical characteristics and mineralogical contents of quartz and illite.

Following the IETcc recommendations (Table 1), the raw materials Alikianos 1, Patelari, Spilia, Gerani, Platanos, except those from Agia and Alikianos 2, are proposed for rammed earth applications.
Also the raw materials Patelari and Spilia 2 with a low percentage of sand could be used as natural soil plasters obtaining different colourings.

Furthermore, we are starting to investigate also other properties of the soils such as shear strength, bending strength, linear shrinkage, thermal conductivity, freeze and thaw testings, which are important characteristics for a soil suitability concerning to rammed earth and adobe production.

The use of all those materials in our time with a continuous climate change is recommended because they are environmental friendly, sustainable, exist in many regions of the world, effective and of low cost for 'green' architectural constructions.-

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