# Pressiorama – Application of Ménard Pressuremeter to Classify Several Geological Formations Encountered in Greece

## Pressiorama – Application du Pressiomètre Ménard pour classifier diverses formations géologiques rencontrées en Grèce

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ABSTRACT : Pressuremeter tests carried out within several geological formations that can be found in Greece, are presented and commented basically by using the graphical display named Pressiorama© (Baud 2005, Baud and Gambin, 2013). With this graphical display the evaluation of the pressuremeter results and the pressuremeter parameters, in accordance with laboratory tests for the determination mainly of the physical properties in characteristic samples, is much more accurate and gives the possibility to determine more precisely the ground strength, several geotechnical engineering parameters and mathematical expressions needed for design purposes. Four typical case studies are presented using this graphical display, showing that this is an adequate process to provide useful information for the structure of several ground formations in relation to their strength.

RÉSUMÉ : Des série d'essais pressiométriques réalisés dans des formations géologiques diverses qui existent en Grèce, sont présentés et commentés notamment en utilisant le diagramme nommé Pressiorama© (Baud 2005, Baud et Gambin, 2013). Ce diagramme, permet que l'évaluation des résultats et des paramètres pressiométriques, en accord avec les essais de laboratoire pour la détermination surtout des propriétés physiques des échantillons caractéristiques, soit plus exacte, et donne la possibilité de déterminer plus précisément la résistance de sol, plusieurs paramètres géotechniques et expressions mathématiques nécessaires au niveau des études. Quatre études de cas caractéristiques, utilisant Pressiorama sont présentées, indiquant que c'est une procédure adéquate pour fournir des informations utile quant à la structure des formations diverses du sol par rapport à leur résistance.

KEYWORDS : Greece, pressiorama, parameters, soft soils, hard soils, weak rocks, tests, offshore tests, case studies.

MOTS CLES : Grèce, pressiorama, caractéristiques des sols, sols mous, sols raides, rocher altéré, essais en mer, études de cas.

## 1 INTRODUCTION

Ménard Pressuremeter Test (MPM) has been widely used during the last years in Greece, for the investigation of the ground conditions, and the determination of the ground strength parameters in several geotechnical projects (e.g. buildings, underground structures). The pressuremeter tests are usually performed in parallel with sampling boreholes, and other in situ and laboratory tests. The evaluation of the measured parameters is critical for the geotechnical design in any case.

'Pressiorama©' which has been introduced by J. P. Baud (Baud 2005, Baud and Gambin, 2013), is a spectral diagram where the graphical display of the main pressuremeter parameters, such as $E_M$, $P^*_{LM}$, and ratio $E_M/P^*_{LM}$, can be presented for several ground formations, for an overall classification, ranging from loose soils to hard soils and to weak rocks. This diagram is essential for the further evaluation of the test results, the principal qualitative characterization of the tested ground materials and the facilitation of the choice of a suitable value of the rheological factor '$\alpha$', used in the geotechnical design. The chosen values of '$\alpha$' takes the values of 1/4, 1/3, 1/2, 2/3, or 1, as initially proposed by Ménard and Rousseau (1962). The pressuremeter modulus $E_M$ is related to the oedometer modulus Es, under the same pressure and strain conditions, by using the formula $Es = E_M/\alpha$ .

In the 'Pressiorama©' graphical display used hereby, $\log(P^*_{LM})$ given in the horizontal axis has an upper value of 10MPa, the ratio of $\log(E_M/P^*_{LM})$ in the vertical axis ranges between 4 and 100, and the third diagonal axis presenting $\log(E_M)$ takes values 0.30-3-30-300MPa. Ratio $E_M/P^*_{LM}$ is characteristic of the ground structure, with higher values corresponding to well cemented or over consolidated material, and lower values indicating disturbed material during insufficient drilling or alluvial soils. $E_M/P^*_{LM}$ values between 4 and 7 may correspond to saturated very loose material and sometimes are neglected during evaluation, when the drilling process is questionable.

The results of the pressuremeter tests, presented in this study, indicate that the pressuremeter curves are suitable. Also, the behavior of several geological formations tested varies significantly, classifying them from soft-even liquid ground material with water present or without, to hard soil and weak rock. The pressuremeter tests were performed on different soil materials, with varying weathering degree, from liquid to stiff and cemented. The permeability and porosity of these formations vary predominantly as well, depending on the depth, thickness, nature and sequence of stratigraphy.

The majority of the pressuremeter tests were performed during 2000 to 2012, at depth intervals of 2m and 3m, in several depths up to a maximum of about 50 m.

The maximum applied pressure to the ground was 10MPa.

Several characteristic diagrams resulting from the tests are presented here, emphasizing on the 'Pressiorama©', where characteristic pressuremeter values for each classified formation are commented.

Four characteristic cases in several locations in Greece are concisely presented:

1. *Case 1: Athens* – Hard Soil and weak rock of Quaternary, Neogene, Alpine age, with emphasis to the Red Loam Clay that was used to make ceramic during ancient time.

2. *Case 2: Thessaloniki* – Quaternary to Neogene deposits underlying the archeological layer.
3. *Case 3: offshore tests* – Tests performed at relatively shallow sea depths using a stable temporary platform, in an almost liquid soft lean sandy to silty clay, where the CPT was not sufficient for measuring the ground strength.
4. *Case 4: Santorini,Thira* – Volcanic materials in Akrotiri area, where a 'Bronze age Pompeii' was found in the Ancient Aegean Sea, in the island described also in Jules Verne books.

The pressuremeter test results are discussed and in addition compared to data resulting from a series of sampling boreholes drilled in many cases next to the pressuremeter boreholes. The variation of ground geological structures as well as the strength and other geotechnical properties were also defined through laboratory testing, and other in situ tests (CPT, SPT) as well as using empirical correlations for similar formations based on literature. Based on the results of the current report, it may be concluded that the display of the pressuremeter test results on the 'Pressiorama©', is a useful graphical approach for the estimation of the expected range of critical geotechnical design parameters, for different ground formations.

## 2 CASE 1 : ATHENS

Athens is located in a basin surrounded by three mountains and the sea in the southern direction.

The geological formations tested refer generally to semi-cohesive to cohesive soils, hard soils and soft rocks. Most of the tests were carried out within Neogene and Quaternary clastic formations, of variable granulometry, as well as within the weathered mantle of the bedrock and the bedrock known as 'Athenian Schists', which constitutes an important part of the stratigraphy of the basin. The lower parts of these formations are mainly coarse and poorly graded while the upper parts are fine and well graded. The geological formations from the youngest to the oldest are:

- *Quaternary formations*. Appear mainly in the south east part of the basin and are cemented or loose materials, with clay, sand, gravels, etc. These formations are more permeable, having periodically and locally a free aquifer. Their Pressiorama© is given in diagram 1, where the orientation of the non cemented and cemented material is distinct.
- *Neogene formations*. They have a semi-cohesive to cohesive nature, and include clastic sediments of variable grain size. The different materials are classified as Red Loams, Marls (clayey or calcitic), Mudstones, Siltstones, Sandstones, Marly Limestones. Their Pressiorama© is given in diagram 3, where the trend to the more compact and rocky behavior is distinct. The red loams are more homogenous materials.
- *Alpine formations*. The basin bedrock consists mainly of 'Athenian Schists'. This is a clastic formation of a specific flysch type character consisting of alternations of slightly dynamometamorphosed clayschists, black clayschists and sandstones, named meta-clayschist, meta-siltstones, meta-sandstones, with intercalations of marly to sandy crystalline limestones, conglomerates and locally ophiolitic olisthostromes or olistholites. Their Pressiorama© is given in diagram 4, where the trend to the well cemented and rocky behavior is clear.

Unfortunately, the performed tests for this time period couldn't exceed P*max=10MPa, due to the probe's capacity.

The *'Athenian schist'* presents variable mechanical properties which reflect directly to the mineral composition and the grade of weathering. The uppermost parts of the schist formations are locally totally weathered and refer to cohesive soil (elouvial mantle) of different thickness. The schists are generally not permeable, with certain permeability into the sandy-carbonate members. In certain cases, where hard rocky parts were encountered, the tests were not applicable (Pmax 10MPa).

The *Red Loams (Ng) are* homogenous materials, investigated down to 33m depth. Historically, such material was used in ceramics and pottery, using the flowing water from the closest mountain. Borrow pits were found in the ancient location called 'Athmonon', an area close to the Olympic stadium of Athens. In diagrams 2 and 3 the measured values are presented, in which the homogenous behavior can be seen in a sorted relatively similar behavior with depth. This material is classified as silty clay material, CL, ML (USCS), and as A-4, A-6, A-7-6 (AASHTO). UCSmax=135-600KPa. $N_{SPT}$=35 to refusal. $P^*_{LM}$=1.7-6.8MPa - $E_M$=7.4-166MPa - $E_M/P^*_{LM}$=5-25.

In the Athens basin urban area, (37) pressuremeter boreholes were evaluated, performed in 15 test locations, drilled during several stages usually next to sampling boreholes. A total number of about (518) pressuremeter tests were performed, in 2 to 3m intervals, up to maximum investigation depth of 40m. In (216) tests the pressuremeter parameters could be determined directly from the test diagrams.

The majority of the formations tested may be classified as cohesive, cemented, hard soils or soft rocks, with cohesive or granular composition with fines, with a varying percentage of clayey particles, in a progressive phase of weathering process.

From a total number of 518 performed tests, the 6% indicated that the ratio $E_M/P^*_{LM}$, that is indicative of the material structure, was $E_M/P^*_{LM} < 7$, the 42% had a value of 7-16, while for the rest 52% the ratio was higher than 16 with a maximum value of 75. A minimal value of $E_M$=1MPa was evaluated for the weathered clayey marl and a maximum value of $E_M$=2500MPa for the weathered Athenian schist.

In general, for all fine formations containing clayey particles, classified from soft, to cohesive, and up to stiff material, an accurate correlation between $E_S$ (oedometer modulus) and $P^*_{LM}$, especially for values of $P^*_{LM}$ between 1.0 to 6.5 MPa, is:

$$E_S = (16 \text{ to } 21)\, P^*_{LM} \quad (1)$$

An average proposed equation (Ritsos et al, 2005) is:

$$E_S = 18.5\, P^*_{LM} \quad (2)$$

## 3 CASE 2 : THESSALONIKI

Thessaloniki is located in an area with an amphitheatric relief, from hills and small mountains in the north, to sea in the south. Several rivers are crossing this plateau, and therefore the superficial ground material is mainly river deposits and lake or lagoon sediments. The bedrock of the area is mainly gneiss and schist formations of the Mesozoic period. The overburden ground material is upper Miocene to lower Pliocene Neogene deposits, consisting of stiff to hard red clays to silty clays with variable appearance of coarse material and Quaternary formations with sands, clays, gravels and locally conglomerates.

Historically, the city was founded in 315 BC, and that is why consecutive archeological layers of several historical periods can be found in the ground usually at an average depth of 7 to 10m. That archeological layer contains locally recent and manmade deposits consisting of coarse to fine material.

The Neogene and the Quaternary deposits consist of lacustrine, brackish and terrestrial phases which lithologically are dominated by clays of varying percentages of coarse fractions. These deposits cover the alpine background (geo tectonic unity of Paeonia) and more specifically the metamorphic rocks of the Hortiati magmatic series. The geological formations in the area include the following formations from the youngest to the oldest:

- *Recent deposits & 'Archaeological layer'.* Silt to clay with local interlayer of gravels and sands, with presence of artificial materials such as bricks, bones, wood (etc) and weathering products. There may be loose deposits and voids which usually include materials mixed with ashes from historical fires that burnt the city.
- *Recent Quaternary deposits.* Alluvial and loose clastic deposits consisting mainly of silty clayey materials, including sands and gravels deposits from the ravines.
- *Old Quaternary deposits.* Clastic heterogeneous mixtures of clay and silts, locally including gravels to cobbles that present hard calcareous and manganese oxide phases.
- *Pliocene deposits, 'Sandstone and Marl series'.* Sea and lagoon phases of fine sand with local presence of hard calcareous phases which locally cause cementation.
- *Pontius deposits, such as 'red clays series'.* Lagoon to lake deposits with sequence of greenish, reddish to red brownish, stiff to very stiff and hard, silty clay to clayey silt with local presence of sands intercalations.
- *Alpine background.* Includes the metamorphic rocks of Hortiati magmatic series (Grs) with gneiss schists, green schists and sandstone schists.

The ground water level along the coast line is at the sea level. In the main land the ground water appears electively to the coarser sandy gravelly interlayer, at an average depth of 2 to 6m, which is unloaded when the continuation of this layer is interrupted by a finer clayey layer. Depending on the hydrologic conditions during the year, ground water appears periodically at the ravines and also free runoff water.

In the study area (22) pressuremeter boreholes were evaluated, drilled in several stages usually next to the sampling boreholes. A total number of about (300) pressuremeter tests were performed, of 2 to 3m intervals, up to an investigated maximum drilling depth varying from 22m to 50m. In all cases pressuremeter parameters could be determined directly from the test diagrams.

The pressuremeter values were correlated based on the nature of the ground material, classified according to the USCS as *fine grained soils* - such as clay (C) and silt (M) with at least 50% passing through No200 sieve – and *coarse grained soils* – such as gravel (G) and sand (S) with less than 50% passing through the No200 sieve. The ratio $E_M/P^*_{LM}$ ranges between 5 and 40. The 'rheological factor' α is estimated based on the nature of the tested ground material.

For the fine grained material, the proposed relation (1) between $E_S$ and $P^*_{LM}$, that is $E_S$=(16 to 21)$P^*_{LM}$, is also valid, most effectively in the range of $P^*_{LM}$ =1.0 to 6.5 MPa. In all the examined values the average ratio was equal to $E_S/P^*_{LM}$ =19.40 which is within the proposed range of 16 to 21.

In diagrams 5 and 6, the 'Pressiorama©' of the fine grained, or coarse grained materials are presented. Silty and sandy to gravelly material have greater compact strength, progressively increasing towards the direction of the cemented material. Fine clayey material gives higher ratio of $E_M/P^*_{LM}$ which is also evidence of good drilling technique.

In diagrams 7 and 8 (log$P^*_{LM}$ vs log$E_s$) the proposed linear relationship (2) is presented, which is valid mainly for the fine grained and the clayey material, along their average distribution. For the coarse grained material this relationship (2) can be used only as a lower limit, while their measured strength is 2 to 3 times higher than the fine grained material.

The classification of the material based on their nature and the sieve used is not always feasible and direct, while that is possible based only on their strength, progressively classifying them from compact and cohesive, to stiff and cemented.

The measured parameters for each sieve classification are summarized in table 1.

Table 1. Thessaloniki – Range of pressuremeter parameters (USCS).

| USCS | $E_M/P^*_{LM}$ | $E_M$ (MPa) | $P^*_{LM}$ (MPa) | α | $E_s$ (MPa) |
|---|---|---|---|---|---|
| CH | 7 - 26 | 16 - 62.5 | 0.8 - 4.6 | 1/2 - 1 | 21 - 93 |
| CL | 5 - 6 | 3 - 30 | 0.5 - 5.4 | 1/3 | 9 - 91 |
| | 7 - 8 | 2.5 - 57 | 0.4 - 7.8 | 1/2 | 5 - 114 |
| | 9 - 15 | 1.3 - 37 | 0.1 - 4.2 | 2/3 | 2 - 56 |
| | 16 - 40 | 11 - 157 | 0.5 - 6.8 | 1 | 10 - 157 |
| MH | <8 | 16 | 2.3 | 1/2 | 32 |
| | 8 - 14 | 33 - 55 | 2.7 - 6.2 | 1/2 | 66 - 110 |
| | 15 - 22 | 33 - 120 | 1.6 - 7.9 | 2/3 | 50 - 180 |
| ML | <8 | 4 - 21 | 1.0 - 3.4 | 1/2 | 9 - 43 |
| | 8 - 14 | 4 - 65 | 0.5 - 6.7 | 1/2 | 9 - 130 |
| | 15 - 30 | 14 - 88 | 0.7 - 4.0 | 2/3 | 21 - 130 |
| SC | <7 | 3 - 8 | 0.5 - 1.7 | 1/3 | 8 - 25 |
| | 7 - 11 | 3 - 75 | 0.4 - 8.0 | 1/3 | 8 - 219 |
| | 12 - 31 | 9 - 180 | 0.6 - 8.3 | 1/2 | 18 - 360 |
| SM | <7 | 2 - 20 | 0.3 - 3.6 | 1/3 | 6 - 60 |
| | 7 - 11 | 4 - 88 | 0.5 - 8.3 | 1/3 | 12 - 266 |
| | 12 - 38 | 8 - 160 | 0.5 - 6.9 | 1/2 | 15 - 323 |
| GC | 5 - 9 | 4 - 60 | 0.8 - 8.0 | 1/4 | 18 - 240 |
| | 10 - 37 | 19 - 100 | 0.7 - 7.0 | 1/3 | 55 - 300 |
| GM | 5 - 9 | 4 - 45 | 0.9 - 4.8 | 1/4 | 16 - 180 |
| | 10 - 33 | 6 - 213 | 0.3 - 7.6 | 1/3 | 19 - 650 |
| GP | 11 | 8 | 0.7 | 1/3 | 24 |
| GW | 35 | 70 | 2.0 | 1/3 | 210 |
| BRECCIA | 8 - 32 | 70 - 246 | 7.5 - 8.5 | 1/2 - 2/3 | 138 - 367 |

## 4 CASE 3 : OFFSHORE TESTS

Offshore geotechnical investigations were performed, either from a floating platform, or from a temporary installed stable platform. The bottom of the sea was inclined with a maximum depth of 20m, measured from the sea level.

The carried out ground investigations comprise a number of sampling boreholes, SPT tests, CPT tests, laboratory tests and pressuremeter boreholes. In those boreholes a total number of (23) pressuremeter tests performed, from the ground of the bottom of the sea, down to 40m depth (25m inside the ground).

The bearing layer in the ground was weathered and fractured schist. The above layered ground material comprises an alternation of fine to coarse, silty clayey to sandy, soft to lose material, with seaweeds and some gravels locally, down to a variable depth where the schist formation is encountered.

The SPT values in the soft ground range from 1 to 3 blows, indicating no strength in the ground for several meters. During the performance of the pressuremeter tests the following steps were adopted:

- Casing of the borehole up to one meter above the test depth.
- Slow drilling without casing up to the test depth. In several cases drilling wasn't necessary to reach the test depth. The probe was carefully self pressed into the ground.

The ground stratigraphy is the following:

- *Layer A-1 : Clay to Sand with some gravel*

Encountered in some of the boreholes, consisting of fines, sand (30%), gravels (38%) and shells, dark grey to grey in color, of low plasticity and maximum thickness 2.5m. Ground material classified as GM, GC, GP, SM (USCS).

- *Layer A-2 : Very soft lean sandy* Clay

Encountered in all boreholes, consisting of dark grey very soft lean clay with sand to soft lean clay (85%) of low to medium plasticity, with a few gravels (5%). Ground material classified as CL (USCS). Organic<2.5%. UCS=26KPa. $N_{SPT}$=1-8blows. Average: $P^*_{LM}$=0.30MPa - $E_M$=2.40MPa - $E_M/P^*_{LM}$=7-10.

*- Layer A-3 : Silty Sand to sandy Silt*
Appeared in all boreholes, consisting of very loose, non plastic silty sand (60%), sandy silt (20%) and interlayers of soft lean clay. Ground material classified as SM, SW, ML (USCS).
$N_{SPT}$=1-12blows. $P^*_{LM}$=0.37MPa - $E_M$=4.60MPa - $E_M/P^*_{LM}$=13

*- Layer B : Fractured Schist with stiff sandy Clay*
Fractured ground material of very stiff sandy clay (60%) with gravel (15%). Material classified as GM, GC, CL (USCS).
UCSmax=150-300KPa. $N_{SPT}$=17 to refusal.
$P^*_{LM}$=0.4-1.10MPa - $E_M$=9.10MPa - $E_M/P^*_{LM}$=7-9

*- Layer C : Weathered Schist*
Locally weathered to slightly fractured, with veins of Quartz.
$P^*_{LM}$=1.50MPa - $E_M$=18.0MPa - $E_M/P^*_{LM}$=10-12

- *Layer D : Schist.* Pressuremeter tests weren't performed.

The performance of the CPT tests was not regarded adequate for such lose and soft formation. In diagram 9, the classification of the ground material based on CPT test results (Robertson et al 1986, 2010) is given. The ground material that corresponds to Layer B is classified as silty clay, silt to silty clayey mixture. The ground material that corresponds to Layer C is classified as sand mixtures to silty sand. For Layer A (mainly for layers A-2 and A-3) the friction ratio was very low or zero, that corresponds to sensitive, soft to lose material.

The pressuremeter tests were adequate for all ground Layers A, B, C, and the measured values were used for the design. In diagram 10 the 'Pressiorama©' of the sedimentary soft materials down to the schist formation, are presented. The progressive increase of the strength of the sediments with depth, by their self weight, is characteristic.

## 5 CASE 4 : SANTORINI ISLAND

The island of Santorini is located in the volcanic arc of Aegean Sea. The volcano located there is responsible for the current landscape of the island, with a volcanic activity known for at least 2 million years. The last catastrophic eruption was about 3600 years ago.

The investigations were performed at 'Akrotiri', where a prehistoric settlement was found under a layer of pumice of pozzolana in 1866. The French volcanologist Ferdinand Fouqué was one of the scientists who visited that time the island (1867). The settlement was destroyed during the volcanic eruption at about 1600 BC and was buried under the volcanic tuff and volcanic ash. Archeological excavations in the area were carried out the last years by Prof. S. Marinatos and by Prof. Ch. G. Doumas.

The biggest part of the island is covered by volcanic rocks with several volcanic series. In the broader area of Akrotiri the volcanic rocks include mainly the following units:

- *Upper Pumice Series.* The formation age is 3600 years old and comprises the Minoan IA time eruption. It is of white color and the magma is rhyodacite. At the base pumice is found and at the upper part chaotic volcanic ash deposits. The formation thickness is around 10 to 15 m.
- *Various volcanic Pyroclastic Series.* Formations average cemented, grey to yellow and reddish in color, products of various volcanic eruptions, including ash, lapilli, pumice and ignimbrites. According to literature the formation's thickness in the ground is about 200 m.
- *Lavas, tuffs and scorias.* Products of historical eruptions, aged about 1 million years old, found in the broader area of Akrotiri and mainly at the closest cape. The formation grey to reddish in color, is sufficiently cemented.

The old settlement was founded on the Pyroclastic Series, where the upper part consists of friable volcanic breccia and volcanic tuffs with lapilli and local intercalations or lenses of loose volcanic ash. The lower part consists of well cemented volcanic breccia with greater lapilli over imposed to lose volcanic tuffs and ash. Locally in the pyroclastic bedrock some discontinuities were found, with an average vertical length 150cm and locally 500cm, slightly open filled with sandy material (M. Ch. Alexiadou 2000).

Above the archeological findings and the Pyroclastic rock, based on the results of the geotechnical investigations, the main geotechnical formations are:

*- Layer I : Surface Deposits*
*- Layer II : Weathered Pumice Deposits*
*- Layer III : Volcanic ash*
*- Layer IV : Volcanic tuffs*
*- Layer V : Altereted Pyroclastic*
*- Layer VI : Archeological Layer*

The geotechnical design of special foundations with shaft piles, hand excavated in volcanic material of different ages was done by using the results of the geological supervision, the ground investigations and the pressuremeter tests. The need of almost dry sampling in the boreholes, and the performance of laboratory tests was a very difficult issue for such materials. For that reason the results of the pressuremeter tests were significant for the engineering purposes.

A total number of (17) pressuremeter tests were performed, in (2) pressuremeter boreholes next to the sampling boreholes, up to a maximum depth of about 25m. The tests were performed mainly inside layers III, IV, that are sandy to silty at layer V. Based on the tests, the Pyroclastic rock was sub-divided in two categories, the upper $V_\alpha$ formation, which is fractured and weathered, and the lower $V_\beta$ formation, which is almost a weak rock. That classification was established from the pressuremeter strength measurements and was endorsed during the hand excavation of the shafts and the geological supervision of the pit.

The 'Pressiorama©' of the volcanic materials are displayed in diagram 11, where the progressive natural compaction, by the self weight of the volcanic material is visible. The proposed geotechnical parameters are summarized in table 2.

Table 2. Volcanic material geotechnical parameters

| geotechnical | Volcanic – ash, tuffs, Pyroclastic rock | | | |
|---|---|---|---|---|
| parameters | III | IV | Va | Vb |
| $P^*_{LM}$ (MPa) | 3.90 | 1.76 | 4.06 | 4.15 |
| $E_M$ (MPa) | 45.50 | 19.50 | 44.44 | 83.61 |
| $E_M/P^*_{LM}$ | 10 | 10 | 10 | 17 |
| φ (degrees) | 36 | 31 | 39 | 39 |
| c (KPa) | 19 | 0 | 0 | 14.5 |

## 6 CONCLUSIONS

- Pressiorama© is a valuable tool in order to evaluate the pressuremeter results and hence the ground nature and response.
- Pressuremeter tests can be performed in all types of ground material from soft to hard soil and in weak rock.
- The increase of the probe loading capacity from 10MPa, to 25 and 50 MPa will increase the usefulness of the test.
- Useful data concerning the strength of the ground materials were withdrawn especially related to the transition from cohesive to coarser and cemented materials.
- The drilling technique is critical, in order to avoid disturbance and change in the cementation especially of coarse ground particles.
- The ground water conditions are critical, since the selective water circulation, pending water strata and the resulting variable weathering processes affect significantly the strength response.
- The use of the pressuremeter is sufficient for cases when other in situ and laboratory tests are not valid, such as in loose, in soft material and in coarse grained material.

- The numerical relations (1) and (2) between the oedometer modulus $E_S$ and the $P^*_{LM}$ are proposed, which are most valid for materials containing an important percentage of clay into their structure (classified as fine in USCS), from soft, to cohesive, and up to stiff material. These correlations are more accurate for values of $P^*_{LM}$ between 1.0 to 6.5 MPa.
- The Geotechnical Engineering judgment is critical.

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***CASE 1 : ATHENS***

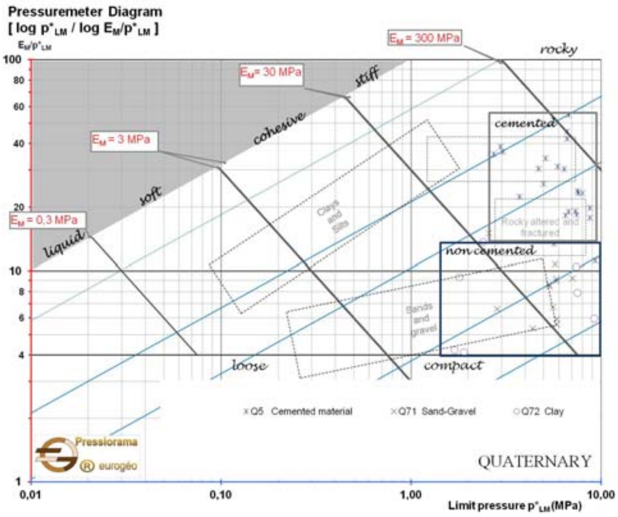


Figure 1. Pressiorama© - Quaternary, non cemented & cemented.

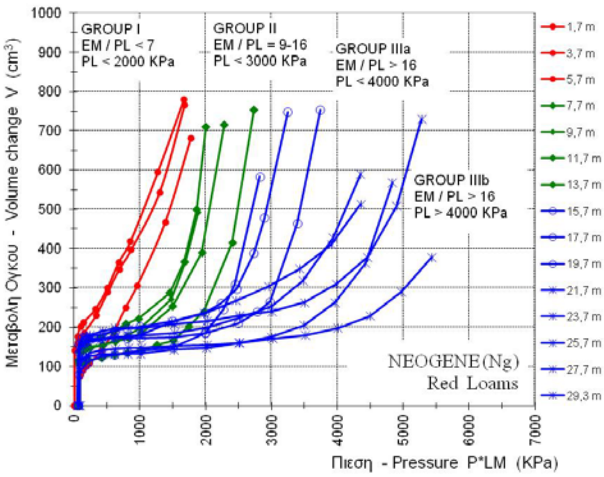


Figure 2. Red Loams (Ng) – Pressuremeter borehole 'Athmonon'.

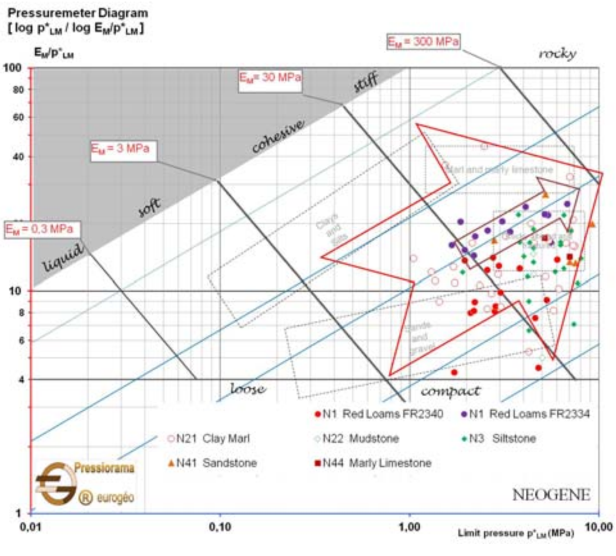


Figure 3. Pressiorama© - Neogene material (Ng)

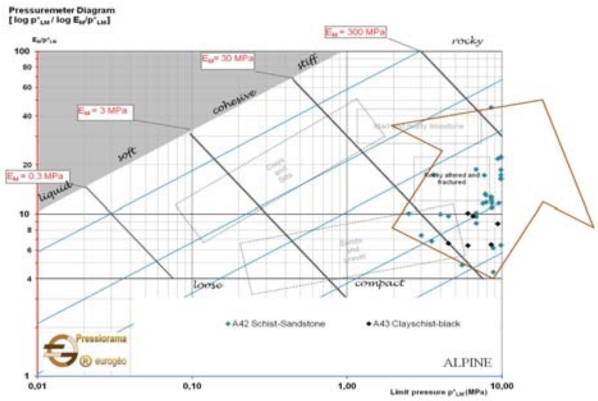


Figure 4. Pressiorama© - Alpine material.

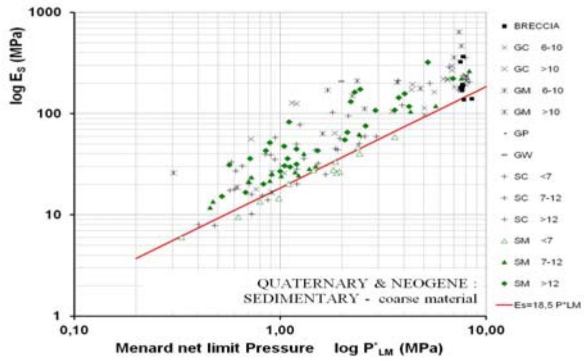


Figure 8. COARSE material - log$P^*_{LM}$ vs log$E_S$ [in MPa]

## *CASE 2 : THESSALONIKI*

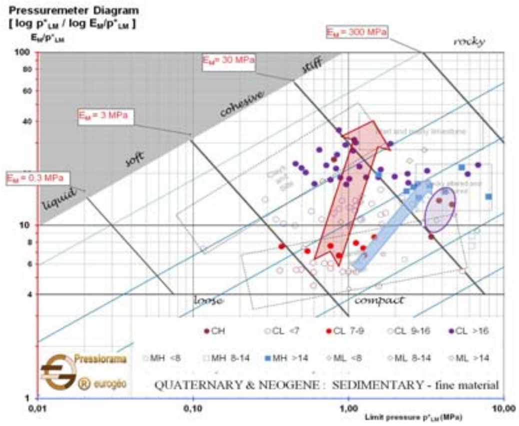


Figure 5. Pressiorama© - FINE material.

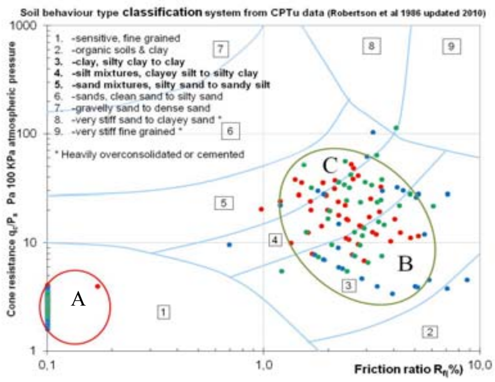


Figure 6. Pressiorama© - COARSE material.

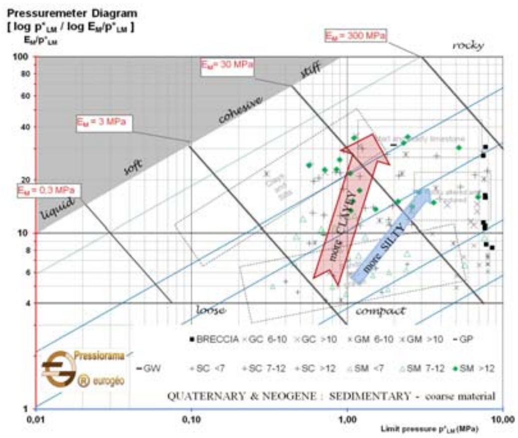


Figure 7. FINE material - log$P^*_{LM}$ vs log$E_S$ [in MPa]

## *CASE 3 : OFFSHORE TESTS*

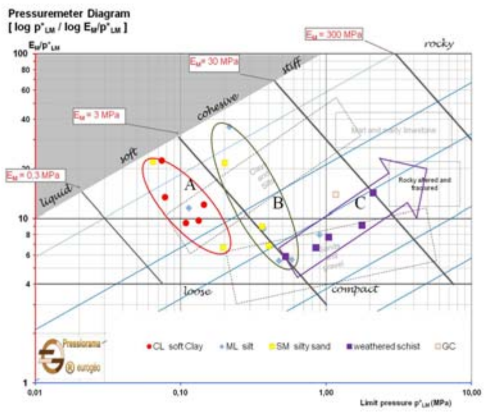


Figure 9. CPT - Offshore tests.

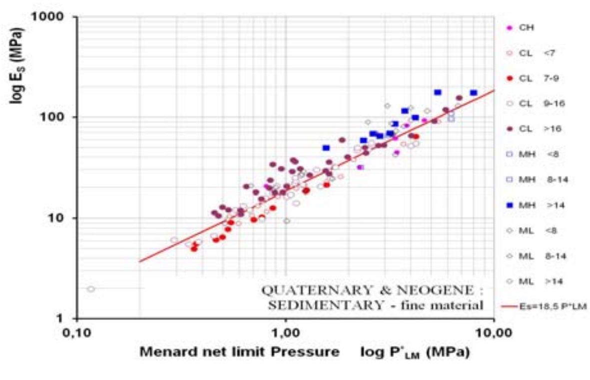


Figure 10. Pressiorama© - Offshore tests.

## *CASE 4 : SANTORINI ISLAND*

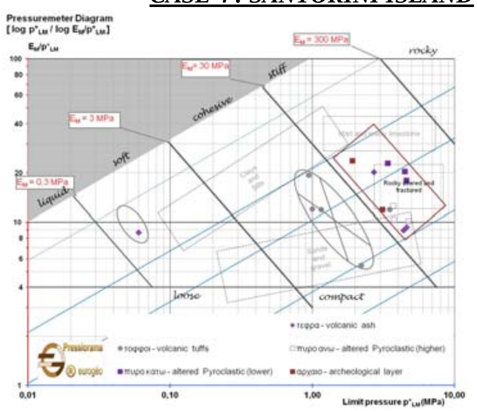


Figure 11. Pressiorama© - Volcanic material.