50 MPa Ménard PMTs Help Linking Soil and Rock Classifications.

Les essais pressiométriques à 50 MPa une aide pour relier les classifications des sols et des roches

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ABSTRACT: This paper is an update of previous contributions submitted to the 15th ECSMGE in Athens in September 2011 on Hard Soils and Weak Rocks. That Conference gave us the opportunity to submit a new concept of Ménard pressuremeter testing, permitting to apply pressure up to 25 MPa at the borehole wall through the HyperPAC 25 The development of this device lead to borehole expansion tests carried out up to 50 MPa through the HyperPAC 50. Some details are given on the methods used to keep the convenient accuracy on pressure and deformation readings for these high pressures. The first tests, submitted here, were carried out in massive rock without any beginning of failure under 50 MPa, particularly in a silica cemented silicate sandstone. The most recent ones made it possible to analyze the behavior in cylindrical expansion of rock in various conditions of jointing and weathering. The paper also indicates some new developments of the pressuremeter-based classification for soils and rocks, submitted as a multiple axes diagram called Pressiorama®, which can be used for a global determination of the Ménard ground rheological factor α from a set of tests in soil or rock.

RÉSUMÉ : L'article est une mise à jour de deux précédentes contributions au 15ème Congrès Européen de Mécanique des sols et Géotechnique (Athènes, Septembre 2011) consacrée aux sols indurés et roches tendres. Ce congrès fut l'occasion de présenter une nouvelle conception du pressiomètre Ménard (HyperPAC25) permettant d'atteindre une pression de 25 MPa. Cette nouvelle communication expose la montée en puissance de l'appareil (HyperPAC50), et donne quelques détails sur les méthodes permettant de conserver une précision suffisante des mesures de déformation à de telles pressions. Les premiers essais sont présentés, dans des roches massives ne présentant pas d'amorce de rupture sous 50 MPa, notamment le grès de Fontainebleau. Les plus récents essais réalisés ont permis d'explorer aussi le comportement en expansion cylindrique de roches dans différents états de fracturation et altération .Egalement, on rend compte de l'extension du diagramme Pressiorama® qui en résulte pour une classification unifiée des sols et des roches basée sur les résultats pressiométriques, incluant désormais le coefficient rhéologique α.

KEYWORDS: Pressuremeter, flexible dilatometer, rock moduli, rock limit pressure, hard soils, weak rocks, weathered rocks.

MOTS-CLES: Pressiomètre, dilatomètre, modules des roches, pression limite des roches, sols raides, roches tendres, roches altérées.

1 TOWARDS A CONTINUUM FROM SOIL MECHANICS TO ROCK MECHANICS

The Athens 15th ECSSMGE in 2011 offered us the opportunity to submit the first step of development for high pressure Ménard pressuremeter tests in a small size borehole using the brand new 25 MPa HyperPac control unit (Arsonnet et al. 2011, 2013). The simultaneous thought was to build a ground classification diagram able to take into consideration the transition between soil analyzed by geotechnical Engineers and rock studied by tectonic Geologists under a "geomechanical" viewpoint.

Since the publication of this paper, research by these authors and their co-workers went on, in the line of the Louis Ménard target to progressively reach a 100 MPa pressuremeter, the "Pressiomètre 1000 bars" (Ménard 1974), envisioned as soon as the last years of the 1950 decade, that is immediately after the development of the now conventional pressuremeter.

history of both general geology and engineering geology, described in several papers (Ellenberger 1981, 1984). A question still pending is the precise date of its cementation, between Oligocene and the Quaternary era. Stampian sandstone is an exception in the usual cycle followed by mineral material, as shown on the first figure in a previous reference (Baud and Gambin 2011), since this rock creates a short-cut between sedimentation, cementation, crystallization and weathering, by practically staying at the surface of the earth, by-passing the internal geodynamic process. This rock is ideal to develop equipment for very high pressure expansion testing in boreholes without fearing early failure. Furthermore, sandstone beds can be reached at shallow depth and they are free of any joints.

Consequently, technological and metrological problems faced by the researchers involved in these very high pressure tests can be successfully solved. It appears that E-moduli in the order of magnitude of 10 Gigapascal (107 KN/m²) shall be measured with an acceptable precision.

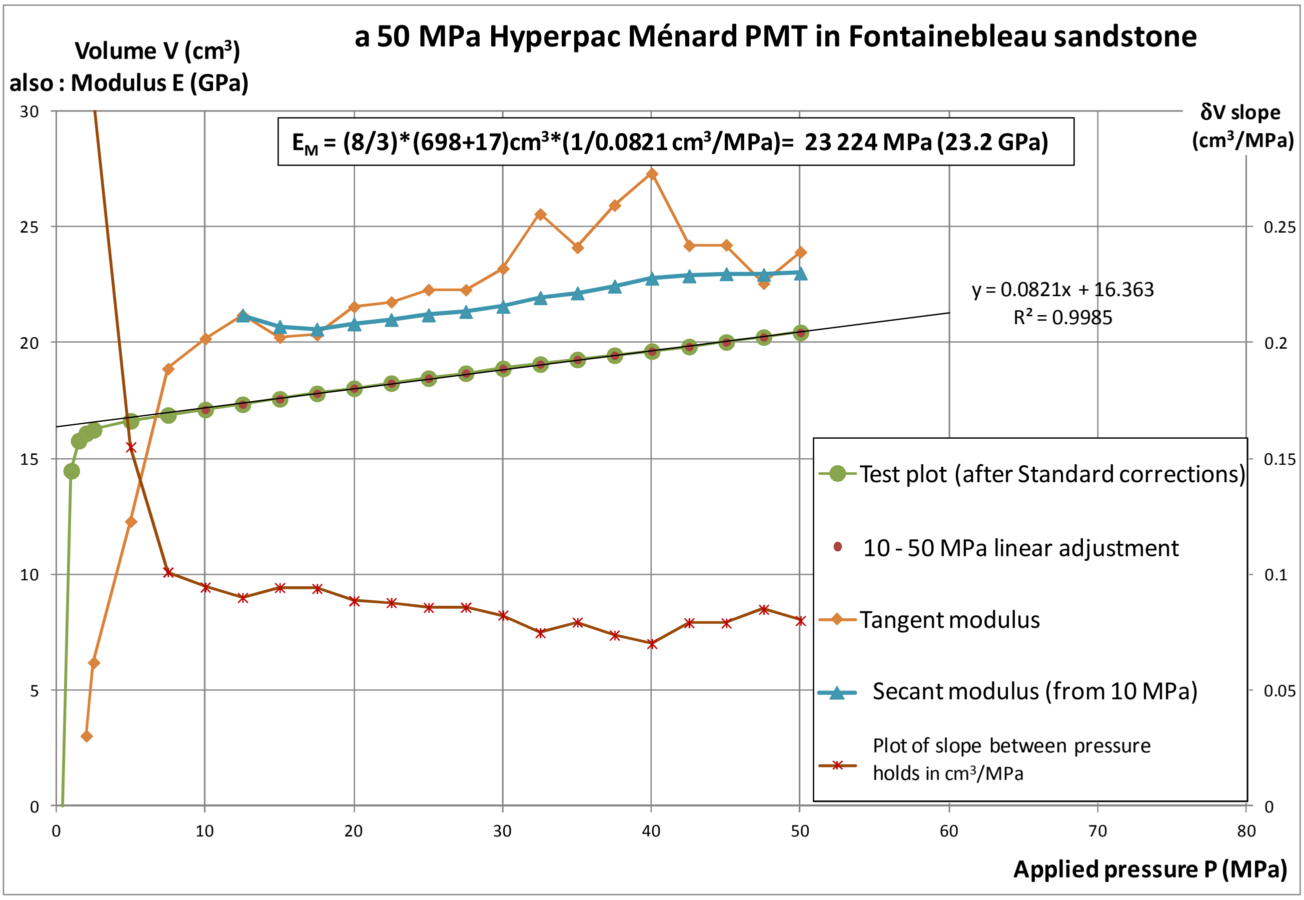


Figure 1. HyperPac. Plotted readings after data reduction in sandstone using 50 MPa pressuremeter.

We herewith submit (Figure 1) the example of a test carried out up to 50 MPa, without failure, in a bed of Stampian∗ sandstone - often called Fontainebleau sandstone in the Parisian Basin. This "perfect" rock is very close to the Euclid solid on a geomechanical stand-point, 99% of the silica sand particles being cemented by cement made of silica, and the silica being re-crystallized. It is a recent rock, which crystallized near the surface, in a continental surrounding, consisting of sand dunes in the Parisian Basin during the Oligocene epoch. Its genesis has been the subject of many geological research works in the

In the same time, obtaining pLM limit pressures up to 50 MPa (5x104 KN/m2) shall be possible. Although this value is quite above those looked after in conventional soils (Gambin 2005), this target is very moderate compared to pressure of several hundreds of GPa - and temperatures of several thousands of Kelvin degrees - experienced by material of the Earth's crust (Sanloup 2012).

∗ Stampian (from Etampes town) is the local name of Rupelian stage for International Stratigraphic Chart (33.9 to 28.4 Ma).

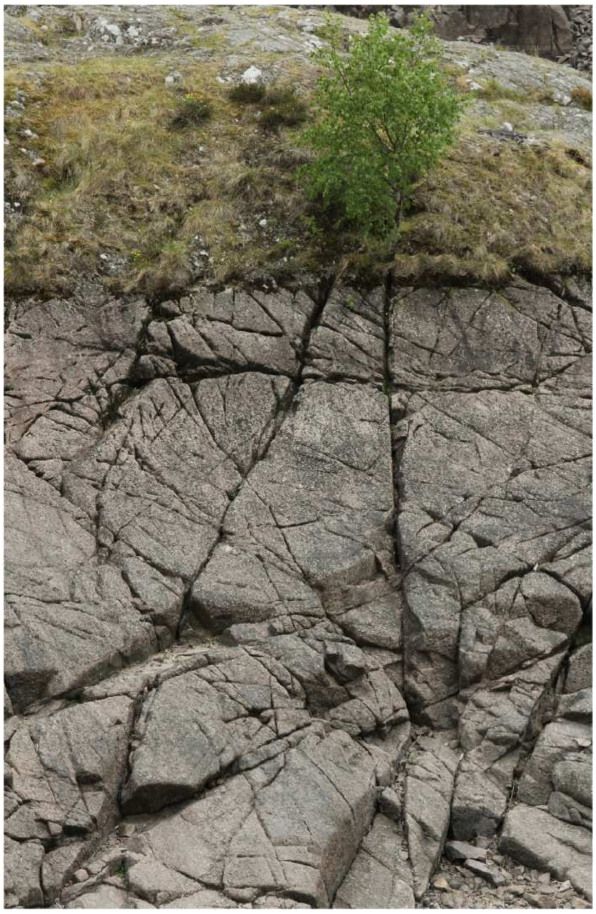


Figure 2. A typical vue of superficial fracturation in a microgranite. Taken at the Alfeld Dam right bank abutment in Upper Rhine District, France.

2 CIVIL ENGINEERING APPLICATIONS

This progress leads to new opportunities in Civil Engineering, such as in the design of piles and anchor tendons in rock which require high friction resistance of the embedment material (Bustamante et al. 2009), or also in the measurement of in situ EM moduli showing the effect of joints in large rock masses.

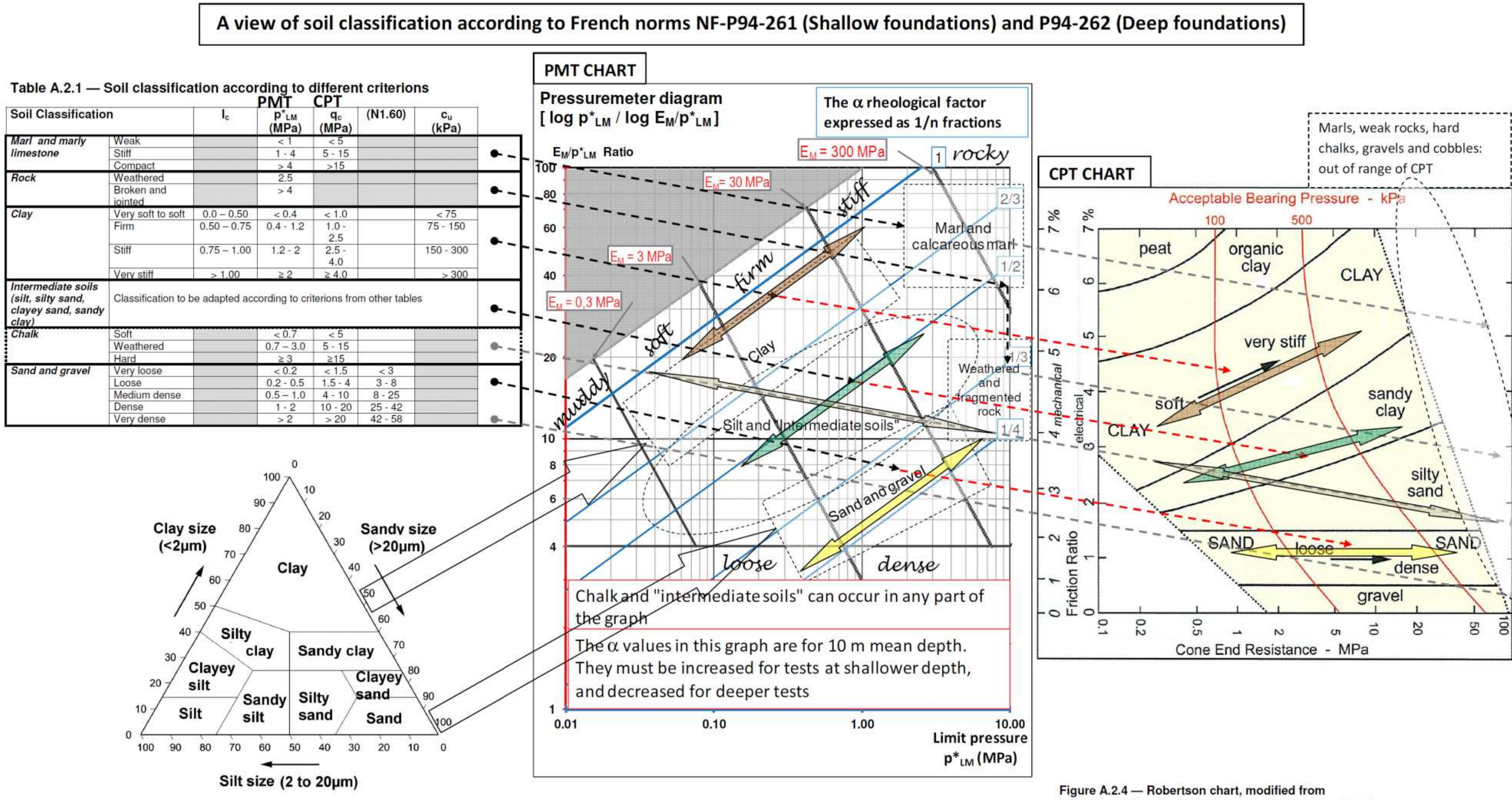
At another level, the opportunity to obtain pressuremeter test data involving pressures up to 4 to 5 times those looked after in typical geotechnical surveys, usually limited to 5 MPa, helps and considerably enlarge the limits of our “Pressiorama” diagram, originally submitted for conventional pressuremeter tests at the ISP5 Symposium (Baud 2005).

Due to this very recent tuning of the pressuremeter equipment up to 50 MPa, the number of representative sites remains limited. But from now on, Ménard PMT can be carried out in any type of rocks with different levels of density in the fractures and joints structure, opening and filling (Fig. 2). We expect many lessons from progressive increase in the practice of cylindrical shear stressing in the great variety of natural rock masses (see as first example in this ISP6 session the Tezel & al. paper for jointed sandstones and mudstones).

This diagram can be used as a basis for a “Unified soil and rock classification” which may satisfy the diverging points of view of soil geotechnical engineers specialized either in soil or in rock. This Pressiorama® which permits to visualize the soil structural (or rheological) factor α defined by Louis Ménard, is now included in the latest French Standards written as Eurocode-7 National Applications for shallow and deep foundations (AFNOR 2012, 2013).

The direct link between pressuremeter properties of soils and rocks, and soil classification as used in these Standards is shown in Figure 3 (next page). CPT diagram (Robertson, 2009), usable only in soils up to CPT refusal, is presented in front of PMT Pressiorama®.

Accuracy between soil classification used in these Standards and in the Pressiorama diagram is under a validation process by an outside team (Reiffsteck et al., 2013). This classification is nothing more than a huge simplification of the general USCS soil classification, and in this respect, applications of USCS classes to Pressiorama would become convergent, as shown by another group of geotechnical engineers in this ISP6 session (Ritsos & al. 2013).



A view of soil classification according to French norms NF-P94-261 (Shallow foundations) and P94-262 (Deep foundations)

Table A.2.1 — Soil classification according to different criterions

Soil Classification		I_c	PMT p^*_{LM} (MPa)	CPT q_c (MPa)	(N1.60)	c_u (kPa)
Marl and marly limestone	Weak		< 1	< 5		
	Stiff		1 - 4	5 - 15		
	Compact		> 4	>15		
Rock	Weathered		2.5			
	Broken and jointed		> 4			
Clay	Very soft to soft	0.0 – 0.50	< 0.4	< 1.0		< 75
	Firm	0.50 – 0.75	0.4 - 1.2	1.0 - 2.5		75 - 150
	Stiff	0.75 – 1.00	1.2 - 2	2.5 - 4.0		150 - 300
	Very stiff	> 1.00	≥ 2	≥ 4.0		> 300
Intermediate soils (silt, silty sand, clayey sand, sandy clay)	Classification to be adapted according to criterions from other tables					
Chalk	Soft		< 0.7	< 5		
	Weathered		0.7 – 3.0	5 - 15		
	Hard		≥ 3	≥15		
Sand and gravel	Very loose		< 0.2	< 1.5	< 3	
	Loose		0.2 - 0.5	1.5 - 4	3 - 8	
	Medium dense		0.5 – 1.0	4 - 10	8 - 25	
	Dense		1 - 2	10 - 20	25 - 42	
	Very dense		> 2	> 20	42 - 58	

Figure A.2.1 - Triangular diagram for soil classification (after Demolon, 1948)

Figure A.2.4 — Pressiorama chart, Baud (2005, 2011)

Figure A.2.4 — Robertson chart, modified from T. Waltham, Foundations of engineering geology (2009)

Figure 3. Soil and weak rock classification suggested in recent French norms NF-P-64-261for shallow foundation and NF-P-94-262 for deep foundation.

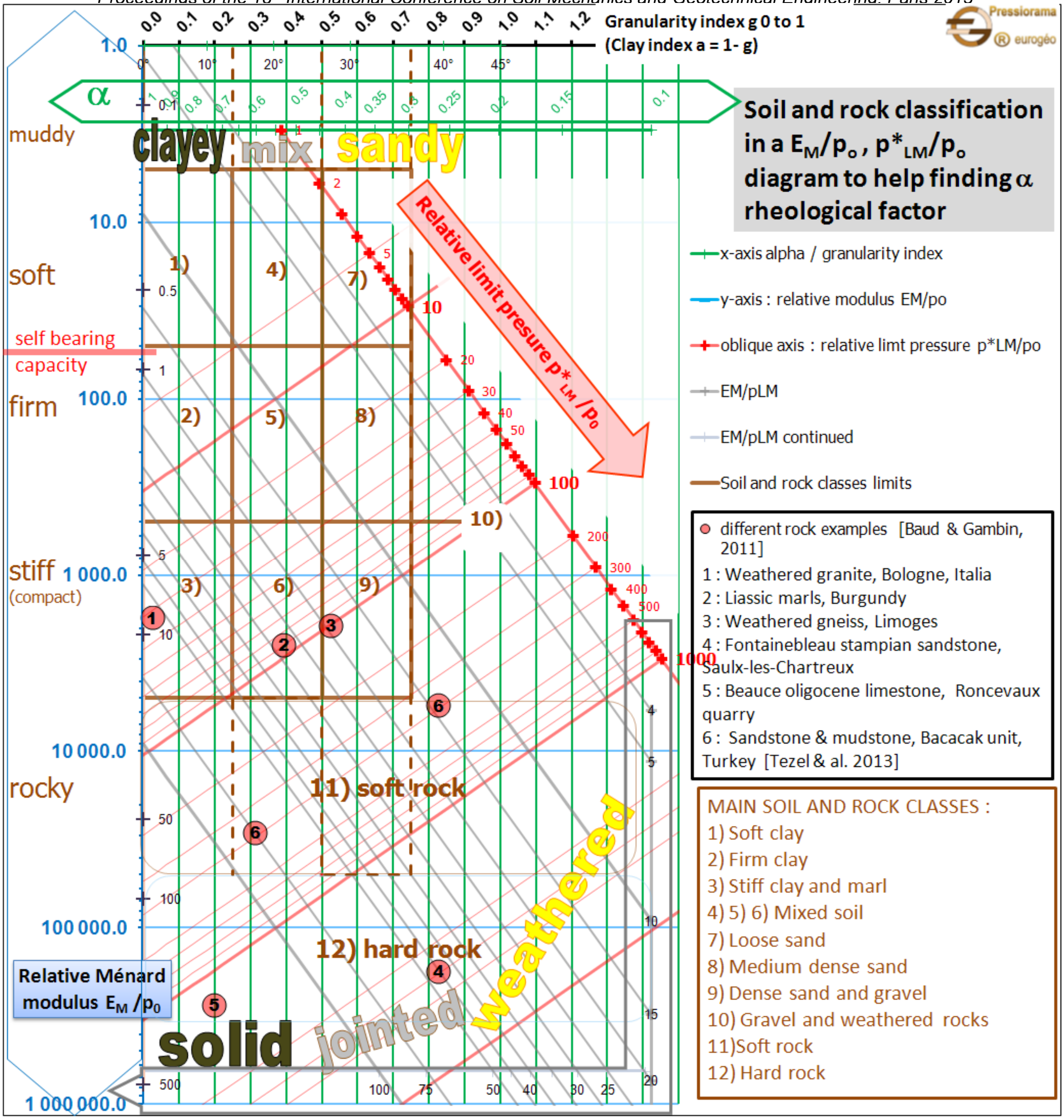


Figure 4 Pressiorama diagram based on PMT relative modulus E_M / p0 and relative limit pressure p^*_{LM}/p0. Examples of PMT results (1 to 5) for different rocks are to be found in ref. [Baud & Gambin, 2011].

3. SOILS AND ROCKS COMMON BEHAVIOUR

Nowadays, the present co-authors are working on the development of a proposition to compute the pressiometric α factor from tests results obtained either in soil or in rock (Baud & Gambin 2013). Here α is the rheological soil factor as defined much earlier (Ménard & Rousseau 1962).

The relationship shall simultaneously link α of the ground to its EM modulus, its pLM limit pressure and po, the initial horizontal virgin soil or rock pressure at rest, either measured with pressuremeter techniques, or estimated, under the form:

$$\alpha = \frac{\left(\frac{E_M}{p^*_{LM}}\right)^{\frac{1}{n}}}{k_E \cdot \left(\frac{p^*_{LM}}{p_0}\right)^{\frac{m}{n}}} \qquad (1)$$

A first tentative is given here using $k_E = 4$, $m = 0.5$ and $n = 2$ (Figure 4).

4 THE FUTURE

We expect to build up a large database of PMT results from either soil or rock site investigations and to improve the above-mentioned coefficients, essentially kE, but also *m* and *n*.

During the same time, we expect to find more significance to the relationship between these parameters.

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