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# Lime reactivity of loessic soils obtained by conductivity measurements

## Réactivité des sols loessic avec le chaux obtenus par des mesures de conductivité

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### ABSTRACT

In order to determine lime reactivity of loessic sediments, electrical conductivity measurements on a saturated solution of calcium hydroxide and soil were taken. Different curves were obtained that allowed the definition of values of immediate reactivity and time-dependent reactivity, related to the cationic change and pozzolanic reactions respectively. Three different zones were delimited in the time-conductivity curves, where special physical-chemical phenomena predominate. With the form of the curves and the calculation of the reactivity parameters, an appropriate scale of values for the characterization of the analysed materials was established. The use of this scale is suggested in addition of traditional tests - granulometry and plasticity- to measure the aptitude of soil to lime stabilization.

### RÉSUMÉ

A fin de déterminer la réactivité avec le chaux des sédiments loessic, des mesures de la conductivité sur une solution saturée du hydroxyde de calcium et du sol ont été pris. Les différentes courbes étaient qui a permis la définition des valeurs de la réactivité immédiate et de la réactivité temps-dépendante, être lié obtenu au changement cationique et les réactions pouzzolanique. Trois zones différentes ont été délimitées dans les courbes conductivité - temps, où les phénomènes physico-chimiques spéciaux prédominent. La forme des courbes et du calcul des paramètres de réactivité a laissé établir une balance appropriée des valeurs pour la caractérisation des matériaux analysés sur la base de sa réactivité. L'utilisation de cette balance est suggérée au lieu de des critères d'aptitude de stabilisation avec le chaux basés sur le courbe granulométrique et la plasticité des sols

## 1 INTRODUCTION

The sediments that conform the subsoil of the Argentine Pampean plain include a great variety of aeolian and fluvial deposits, with predominantly silty granulometry, accumulated during the end of Tertiary and the Quaternary (Döering, 1891; Frenquelli, 1955). In such geological periods winds with permanent southwestern - northeast circulation existed, that swept the great exposed rocky surfaces in the Patagonic and Andean regions, moving mineral particles and depositing them on the grassy steppes of the Argentine central plains. The winds also transferred and deposited volcanic ashes corresponding to the intense and explosive volcanic activity registered at the Andes Range in these same geological periods (Ricci, 1966; Iriondo and Kröhl, 1995). As a result two mineral populations can be distinguished in Pampean loessic sediments: one constitute by volcanic ashes and another one originated by crystalline minerals coming from the deflation of intrusive igneous and metamorphic rocks (Karlsson, 1993; Zarate and Blasi, 1991). The volcanic ashes jointly with weakly crystallized or amorphous minerals, constitute the denominated pozzolanic fraction, able to react with lime in the presence of water to form cementitious compounds.

The minerals originated by deflation of crystalline rocks due to its high degree of crystallization have inert behavior or show small chemical activity. (Quintana et al., 2000; Quintana and Redolfi, 2001; Quintana, 2001).

Lime stabilization of sediments has been mainly evaluated with procedures developed for clayey soils and based on the improvement of the soil by the reactions that happen immediately. Because of the slight plasticity that loessic pampean

sediments present, its reaction is pozzolanic and time-dependent, having to be measured with specific tests others than granulometric analysis and Atterberg limits.

The pozzolanic activity of mineral particles depends on the specific surface and the percentage of amorphous silica.

Different tests has been developed that measures the variations occurring in the electrical conductivity or resistivity of chemical solutions when a defined amount of the investigated material is mixed with them obtaining indirectly the soil reactivity (Raask and Bhaskar, 1975; Luxan et al., 1989; Tashiro et al., 1994; Mc Carter and Tran, 1996). Recently kinetic-diffusive models have been applied to the pozzolanic reaction in order to explain the phenomena that happen during the march of the conductivity tests (Villar-Cociña et al., 2003).

## 2 EXPERIMENTS

Pampean loessic sediments, located in the center, east and south of Córdoba Province were sampled and their behavior analyzed comparatively with material with well known pozzolanic behavior: volcanic ashes of the zone of Santa Elena and piroclastic rock samples of the Canary Islands (Spain),

Granites of Sierras Grandes (Córdoba Province) were used as a reference of inert behavior.

All the samples were dried, powdered and passed through 200 sieve. Table 1 shows the characteristics of plasticity and geotechnical classification (Unified Soil Classification –USC and Highway Research Board- HRB) of the samples.

Table 1: Characteristics of the analyzed samples.

Sample	LL	PL	PI	USC	HRB
Volcanic ash - C056	-	-	NP	ML	A4 (8)
Piroclastic rocks - 1059	-	-	NP	-	-
Granite	-	-	NP	-	-
Loess - M001	18,6	16,7	1,9	ML	A4 (6)
Loess - M002	30,9	25,6	5,3	ML	A4 (8)
Loess - M006	24,4	19,8	4,6	ML	A4 (8)
Loess - M007	24,9	23,8	1,1	ML	A4 (8)

The pozzolanic activity was determined in an indirect way that consists in determine the decrease in conductivity (measured in miliSiemens/cm) occurring in a saturated solution of calcium hydroxide, when a certain amount of pozzolane is added, keeping it under constant stirring and at a temperature of 40 degrees centigrade, during the measuring time.

Curves were obtained that show the variation of the conductivity with time. Time zero is taken at the moment the sample of sediment is added to the solution. The values of conductivity were standardized by the initial value in order of eliminate the influence of the initial conductivity of the solution and multiplied percent:

$$SC = Ct / C_0 * 100 \quad (1)$$

where SC = standardized conductivity; Ct = conductivity at time t; C<sub>0</sub> = initial conductivity at time t = 0

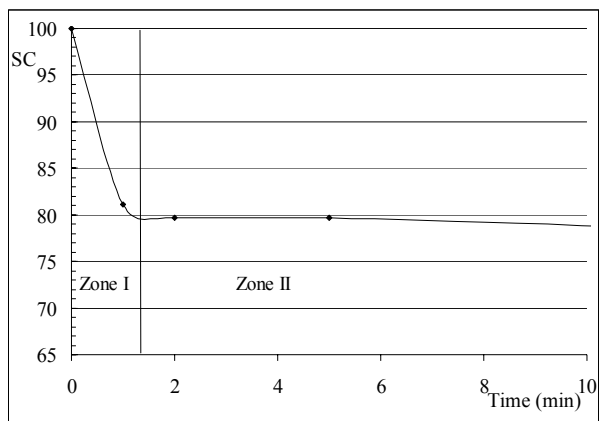


Figure 1: Standardized conductivity -time curve in the first minutes of reaction. Zone I and II.

### 3 RESULTS

There were three different zones in the conductivity - time graph: Zone I is developed almost instantaneously, when the sample is adding to the solution (Figure 1).

The phenomena of calcium ion adsorption by the surface of clay mineral particles, silica-aluminous colloids, etc., predominate with the consequent sudden diminution of the conductivity. Zone II is developed during a time T in which the speed of reaction is governed by the diffusion of ions calcium inside the particles and the chemical reaction of them with pozzolanes. This velocity will depend basically on the amount and the characteristics of reactive minerals attacked by calcium hydroxide. As a result insoluble hydrated calcium silicates and aluminates will precipitate. This ion diminution in solution generates interruptions in the lines of electric flux, consequently diminishing the conductivity (Tashiro et al., 1994). Zone III is characterized by a slow velocity of reaction, governed by the speeds of diffusion and chemical reaction of ions calcium inside minerals of greater crystallinity such as quartz, feldspars and micas (Figure 2).

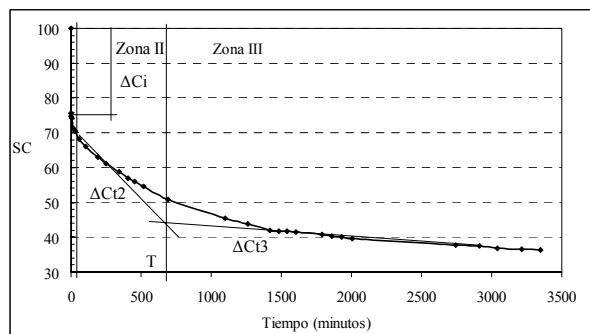


Figure 2: Time - conductivity curve at Zone II and III.

The reactivity of the materials can be determined with the instantaneous diminution of conductivity that happens in the first stage plus the time-dependent variation developed later.

This behavior can be described by mathematical expression compound of three parameters, that are obtained incorporating two regression lines in zones II and III, whose intersection defines time T (Figure 2). Such parameters are: ΔCi = intersection of L2 with the ordinate axe; ΔCt2 = variation of SC (%) with time (minutes) in zone II until time T; ΔCt3 = variation of SC (%) with time (minutes) in zone III.

The main cementing action is considered that happens in zone II (Mc Carter and Tran, 1996) so the parameter for zone III is misestimated for the calculation, being therefore:

$$SC = \Delta Ci - (\Delta Ct2 * T) \quad (2)$$

The total reactivity (TR) of the materials, defined as the sum of the instantaneous reactivity (Ri) and time-dependent reactivity (Rt) is:

$$Ri (\%) = 100 - \Delta Ci \quad (3)$$

$$Rt (\%) = \Delta Ct2 * T \quad (4)$$

$$TR(\%) = Ri + Rt \quad (5)$$

Also the total reactivity can be obtained from the standardized conductivity:

$$TR (\%) = 100 - SC (\%) \quad (6)$$

According to the results showed by the conductivity tests, three types of behavior can be differentiated: Type I: inert behavior, where the reaction of the material with the calcium hydroxide is extremely slow as a result of a mineralogy composed by crystalline silicates. The instantaneous reactivity is very low, denoting the absence of superficial cationic exchange. The time-dependent reactivity also is low. It does not exist important breaks of the curve at the end of Zone II (time T), (Figure 3). Type II: retarded pozzolanic behavior, characteristic of Santa Elena volcanic ashes, conformed mainly by inalterable glass. The absence of colloids or clays implies a minimum instantaneous reactivity, being the times of reaction governed by the speed of diffusion and chemical reaction of the solution inside the particles. The instantaneous reactivity is very small and the decrease of the SC in Zone II happens very slowly but it extends until a very high time T, producing a high pozzolanic reaction in the long term (Figure 4). Type III: typically pozzolanic behavior, where important instantaneous reactions occur and SC decrease in Zone II and in Zone III is very different. The time T of conclusion of Zone II is clearly defined. (Figure 5).

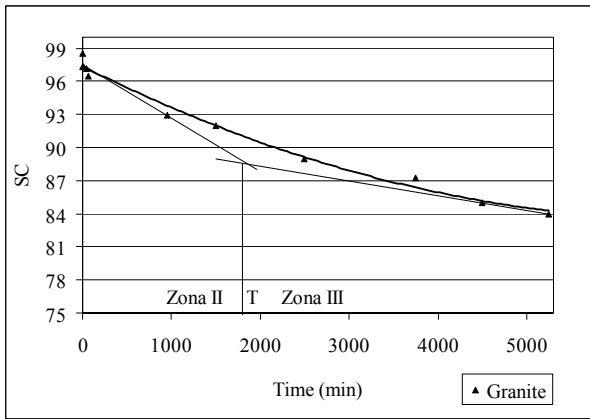


Figure 3: Time-conductivity curve. Granite. Inert behavior (Type I).

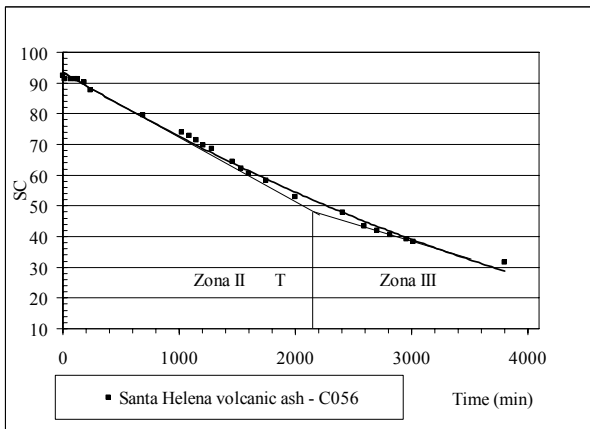


Figure 4: Time-conductivity curve. Santa Elena volcanic ash. Retarded pozzolanic behavior (Type II).

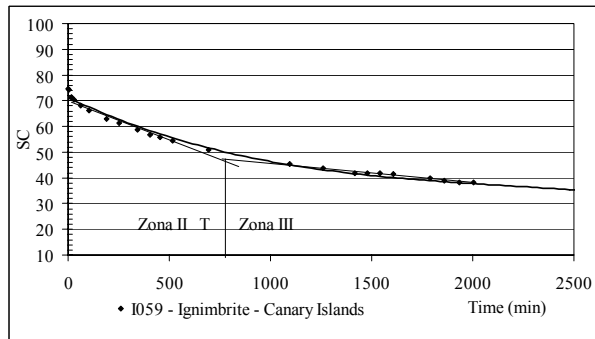


Figure 5: Time-conductivity curve. Ignimbrites of Canary Islands. Typically pozzolanic behavior (Type III).

The loessic sediments show a typically pozzolanic behavior, where the mineral variety and the percentage of clays and colloids produce accentuated answers in the instantaneous and time-dependent reactivity (Figure 6).

#### 4 ANALYSIS OF INSTANTANEOUS REACTIVITY

The instantaneous reactivity is related to the clay mineral and silica-aluminous colloids, with high capacity of superficial cationic adsorption. For clay minerals a logical correlation with Plasticity Index exists, but when the reactivity is product of other mineralogy-like volcanic ashes- there is no an evident relationship. As a result, during many years, the instantaneous reactivity of clay minerals, with important macroscopic effects,

has influenced in the use of lime for stabilization of these sediments, not happening the same with other reactive non-clayey minerals.

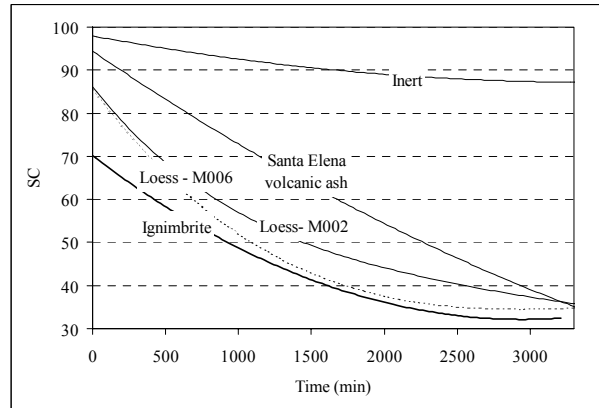


Figure 6: Time conductivity curve. Samples of Loess (M002 - M006). Typically pozzolanic behavior (Type III) Showed together with ignimbrite and granite curves.

#### 5 ANALYSIS OF TIME-DEPENDENT REACTIVITY

According to the physical models that explain the reactivity of the materials with lime -such as Decreasing Nucleus Model- the slope of the curve of reactivity in Zone II is related to diffusion's velocity of the calcium hydroxide inside pozzolanic particles and to the velocity of chemical reaction between both materials. In the case of inert mineralogy (quartz, feldspar, mica) these phenomena take place very slowly corresponding variations of the curve in Zone II of the order of 0.005 %/min. The volcanic ashes of Santa Elena show values of the order of 0.02 %/min, corresponding to the particular type of inalterable volcanic glass. In Pampean loessic sediments, where limited variations in the type of component minerals can be assumed, the influence of the amount of volcanic glass is noted. Beds with low amount of volcanic glass (around 15%) correspond to values between 0.02 to 0.026 %/min.; another one whose percentage of glass oscillates between 30 and 47% correspond with values around 0.03 %/min. Beds with high percentage of glass (over 50%) and evident pozzolanic cementation showed values from 0.037 to 0.057 %/min

#### 6 ANALYSIS OF TOTAL REACTIVITY

Total Reactivity take into account the complete answer of the sediment in their reaction with calcium hydroxide, being the direct sum of instantaneous reactivity and dependent-time reactivity. Consequently, the Total Reactivity means the answer of the amount and quality of pozzolanic minerals present in sediments, (volcanic glass, clayey minerals, etc.). Table 2 shows the parameters of conductivity obtained.

Table 2: Conductivity and Reactivity Parameters of analyzed sediments.

MATERIALES	Ci	$\Delta C_{I2}$	$\Delta C_{I3}$	T (min)	SC %	TR %
Cenizas- C056	93,36	0,021	0,0110	2200	47,16	52,84
Ignimbritas - I059	69,92	0,030	0,0070	750	47,42	52,58
Loess - M001	93,34	0,045	0,0070	760	59,14	40,86
Loess - M002	82,88	0,033	0,0050	1220	42,62	57,38
Loess - M006	82,06	0,027	0,0050	570	66,67	33,33
Loess - M007	82,94	0,060	0,0090	500	52,94	47,06
Granito	97,49	0,005	0,0013	1800	88,49	11,51

Considering that Total Reactivity are function of the methodology used in the test, a relative scale of values of reactivity for Pampean loessic sediments can be established: low TR < 30; intermediate TR 30 – 50; high TR > 50.

## 7 CONCLUSIONS

Mineralogical analysis of Pampean loessic sediments, reveals volcanic ash coming from the Andean volcanism constituted by volcanic glass, andesite particles, basalts, etc., of great pozzolanic activity and on the other hand mineral associations of the crystalline basement (quartz, feldspar, micas) with null or small participation in cementitious reactions. By the results of the electrical conductivity tests the Instantaneous Reactivity and Time-dependent Reactivity can be differentiated. The Total Reactivity (TR) is the sum of both, measuring the complete answer of the sediments mineralogy to calcium hydroxide and contemplating the clayey and pozzolanic mineral presence. Different curves of soil lime reactivity were obtained, corresponding to different types of behavior: inert, retarded pozzolanic and typically pozzolanic. These differences appears in materials that occupy the same geotechnical class, so the time-conductivity curves and parameters have to be taken into account as additional information in lime stabilization projects.

## ACKNOWLEDGMENTS

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