Genesis of the quartz in Spanish Mediterranean soils. An advance

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Abstract
The quartz grains of the light fine sand fraction of five Mediterranean soils from Granada province have been classified in 13 morphotypes with genetic associations, by means of a morphoscopic study with a scanning electron microscope (SEM) and image analysis (IA). A factorial analysis of the soil variables (physical, chemical, physico-chemical and mineralogical characters) and the morphoscopic characteristics of the quartz grains, has defined a system with six components (80.1% of the explained variance). This statistical analysis has allowed to distinguish morphotypes with neoformation traits from others that are without them.

Key Words
Quartz, Mediterranean soils, quartz grain morphotypes, SEM, multivariate statistical analysis.

Introduction

Quartz (SiO_2) is one of the most abundant constituent minerals of soils. The quartz is concentrated in the sand and silt fractions, both inherited from the parent rock by physical disintegration and/or dissolution, and by eolian contributions. It can be also neoformed. The low temperature polymorph of the quartz (α-quartz) is the most frequent in the superficial environments. Quartz is considered chemically stable, in Mediterranean soils (Delgado *et al.* 1990; Martin-García 1994; White *et al.* 1996). However, different papers (some of our Investigation Group; Delgado *et al.* 2003; Martin-García *et al.* 2004) have shown that the alteration, dissolution, transport and deposition processes, including regrowing, can impose marks in the surface of the quartz grains and changes in their chemical composition. The objective of this work is to elucidate the genesis of this mineral in the soil environment of five representative Mediterranean soils from the Granada province (south of Spain): Typic Calcixeroll *Sierra Elvira* (P1), Humic Distroxerept *Sierra Nevada* (P2), Inceptic Haploxeralf *Sierra Nevada* (SR-2), Typic Haploxeralf the *Llano de la Perdiz* (P3) and Fluventic Haploxeroll *Vega de Granada* (P4).

Methods

Description, analysis and soil classification

The macromorphologic field description of the soils and the analysis of the main physical, chemical, physico-chemical and mineralogical features of the soil horizons, granulometric fractions and soil solution samples (that have allowed to establish the soil classification – Soil Survey Staff 2006 –) have been carried out following the usual methods (Márquez 2010).

Quartz study

Morphoscopy of quartz grains of the light fine sand fraction (gravimetrically separated with bromoform – ρ = 2.82 g/cm^3 – in order to concentrate the quartz particles – ρ = 2.65 g/cm^3 –) has been studied by scanning electron microscopy (SEM) and energy dispersive X-ray analysis (EDX). The classification of quartz grains in morphotypes has been carried out with the application of a heuristic method (using morphologic, crystallographic, mineralogical and weathering features). The analysis of the SEM images (SEM-IA) has been carried out with the program Image'J (National Institutes of Health 2008).

Statistical study

A factorial analysis has been carried out using the obtained results by means of the statistical package SPSS 15.0. Previously, the test Kolmogorov–Smirnov was applied to the data population. Some variables were transformated.

Results

Site description of soils is shown in Table 1. The morphoscopic study of the quartz grains allowed classifying them in 13 morphotypes and 6 sub-morphotypes, with genetic sense, some of which are showed in the Figure 1. Thereby, morphotypes with quartz grains predominantly showing mechanical marks (Figure 1A, 1C), with some surface weathering marks (Figure 1B) or with some neoformation features can be distinguished. This classification has been confirmed by means of image analysis and statistical study (Márquez *et al.* 2009).

The adjustment of a factorial analysis to the variables of the studied soils and the morphologic variables of the analyzed quartz grains allowed to define the system for six components that explain 80,1% of the total variance (Table 2). The first component (28.4% of the variance) contains mainly the forming factors of the soil variables (climatic and topographic variables) and general chemical characters of soils (pH, exchangeable cations, i.e). The second component (18.0% of the variance) is a Mediterranean pedoevolution factor in which weathering variables are included (redness indexes, clay content, free forms, mineralogy of the clay fraction, phyllosilicate content, etc). The third component (10.9% of the variance) includes mainly the variables related with the silt granulometric fraction. The fourth component (8.7% of the variance) contains the variables related with the fine sand fraction and the morphotypes M2 and M6; these quartz grains haven’t neoformation features. The fifth component (7.8% of the variance) is mainly a factor related with the soil organic matter. Finally, the sixth component (6.3% of the variance) contains the variables related with the soil solution (mmol/L of Si^{4+}, i.e) and the morphotype M7; this morphotype contain quartz grains with certain traits of mineral neoformation.

Table 1. General information on the soil site.

Soil	Typic Calcixeroll	Humic Distroxerept	Inceptic Haploxeralf	Typic Haploxeralf	Fluventic Haploxeroll
Horizon sequence	Ah, Bw, BCk, 2CBk, 2Ck1, 2Ck2, 3Ck	Ah1, Ah2, Ah3, AC, C	Ap, AB, Bt, BCt1, BCt2	A, AB, Bt, Btg, BCtg	Ap, C, 2Cg, 3C1, 4C2
Parent material	Slope deposits from sandstone and marls	Slope deposits from mica-schits and quartzites	Slope deposits from mica-schits and quartzites	Formación Alhambra’s conglomerates	Aluvial sediments
Elevation (m)	760	2420	1410	1020	600
Physiographic location/Slope (%)	Lower slope/37	Upper slope/49	Middle slope/23	Upper slope/15	Flood plain/2
Vegetation	Holm oaks and scrubs (thymus)	Thyme field	Scrubs (thymus)	Scrub (thymus) and reforested pines	Poplar plantation
Moisture regime	Xeric	Xeric	Xeric	Xeric	Xeric
Temperature regime	Thermic	Cryic	Mesic	Thermic	Thermic

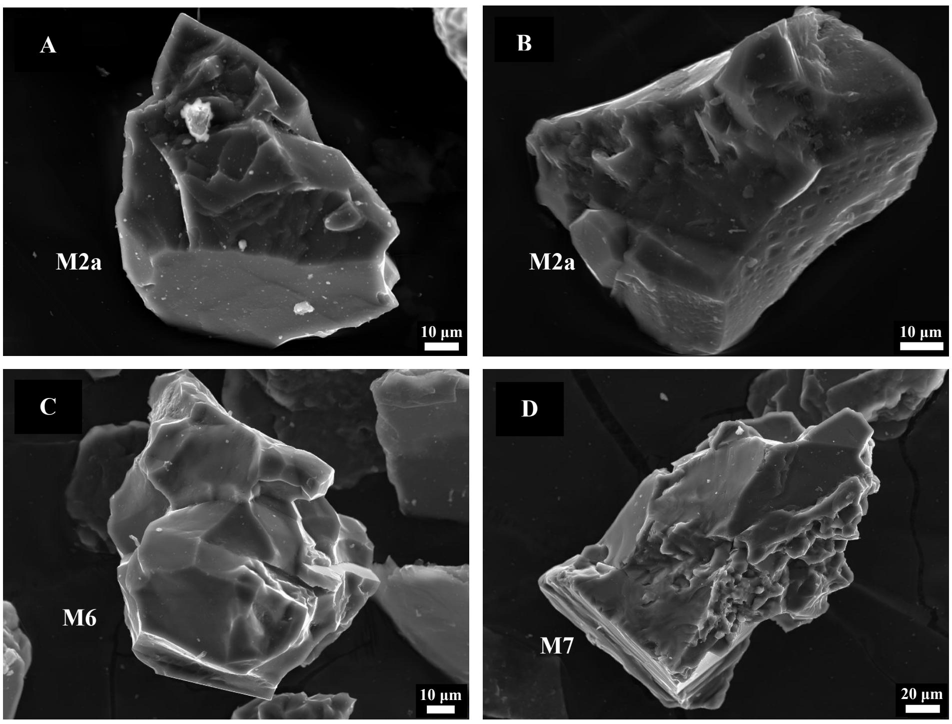

Figure 1. SEM images of some quartz grains morphotypes and submorphotypes. A: submorphotype M2a; B: submorphotype M2a with surface weathering marks (etch-pits); C: morphotype M6; D: morphotype M7.

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Table 2. Factorial analysis. Rotate component matrix.

Variables	Components 1	2	3	4	5	6
Elevation (m)	-xx					
Slope (m)					x	
RI (wet)		xxx				
RI (dry)		xxxx				
T (ºC)	xxxx					
[1]P (m)	xxxx					
ETP (m)	xxxx					
Ex (m)	-xxxx					
[1]Df (m)	-xx					
ETR (mm)	xxx					
Silt (%)			xx			
Clay (%)		xxx				
Coarse sand (%)	-x					
Fine sand (%)				xxx		
W (-33kPa) (%)			x			
W (-1500kPa) (%)		xx				
Available water (mm/cm)			xxx			
Organic carbon (%)					xxxx	
Nitrogen (%)					xxxx	
pH(H_2O)	xxxx					
pH(KCl)	xxxx					
Ca^{2+} (cmol(+)/kg)	xxx					
Mg^{2+} (cmol(+)/kg)		xxx				
Na^{+} (cmol(+)/kg)			xx			
Total bases (cmol(+)/kg)	xxx					
Saturation (%)	xxxx					
Fe_2O_3 (%)		xxx				
Al_2O_3 (%)	-xx					
SiO_2 (%)		xxx				
Total free forms (%)		xxx				
CS Quartz	-x					
CS Potassium feldspar	-xx					
CS Clay minerals	-xx					
[2]CS Chlorite	-xxx					
CS Goethite	-xx					
LFS Quartz				xx		
LFS Potassium feldspar				xx		
LFS Plagioclase				xx		
LFS Clay minerals	-xx					
S Quartz			xx			
S Plagioclase	x					
S Clay minerals			xxx			
S Chlorite			xxxx			
S Goethite			x			
S Haematite			x			
[2]C Quartz		xxxx				
C Clay minerals		xxxx				
[2]C Goethite		xxxx				
Chlorite		xxx				
Illite		xxx				
[2]Kaolinite		xxxx				
Smectite	xxx					
SS EC (mS/cm)	x					xx
SS pH	xxx					
SS K^{+} (mmol/L)						xx
SS Ca^{2+} (mmol/L)						xxx
[3]SS Mg^{2+} (mmol/L)						xxx
SS Si^{4+} (mmol/L)						xxx
SS Fe^{3+} (µmmol/L)					xxx	
[4]SS Al^{3+} (µmmol/L)					x	
[3] SS Li^{+} (µmmol/L)	xx					
[4] SS Mn^{2+} (µmmol/L)	-x					
SS Sr^{2+} (µmmol/L)						xxxx
SS Ba^{2+} (µmmol/L)						xxxx
Morphotype M2 (%)				x		
Submorphot. M2a (%)				xxx		
Morphotype M6 (%)				xxx		
Morphotype M7 (%)						x

RI, redness index; T, annual temperature; P, rainfall; ETP, evapotranspiration; Ex, water excess; Df, water deficit; ETR, real evapotranspiration; W, water content; CS, coarse sand; LFS, light fine sand; S, silt; C, clay; SS, soil solution; EC, electric conductivity.
Data transformated: [1]Opposite variable; [2]2*arcsen[√(variable/100)]; [3]√variable; [4]ln(variable+1).
Factorial analysis. Extraction method, principal components; Rotation method, Varimax with Kaiser.
Factor loadings. x, ≥0.6-<0.7; xx, ≥0.7-<0.8; xxx, ≥0.8-<0.9; xxxx, ≥0.9-1

Conclusion

In the Mediterranean soils studied, the quartz grains of the light fine sand have been classified in 13 morphotypes and 6 submorphotypes with genetic associations. Among others, morphotypes composed by quartz grains that only show surface mechanical marks, morphotypes with grains with surface weathering marks or morphotypes with quartz grains showing traits of neoformation, have been recognized. Morphotypes with neoformation traits (M7) have been distinguished from other that are without them (M2 y M6) by means factory analysis. The existence of these morphotypes in the studied soils questions the paradigm of quartz inalterability in Mediterranean environments, making necessary a bigger study of these problems.

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