# Soils with Gypsic Horizons in Southern Sicily, Italy

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## Abstract

Information on the geographic distribution and abundance of gypsiferous soils, is required for better management of these soils in the semiarid Mediterranean basin. The aims of this study were to: (i) evaluate the occurrence of the gypsic horizon as influenced by soil-landscape relationships and (ii) classify them for better use and management. Seventeen sites (four soil pedons and thirteen soil augerings), spaced about 12 m apart were surveyed along a slope transect in a Mediterranean semiarid environment in Sicily, Italy. The gypsum content was determined by the thermogravimetric method. Results suggest that these soils, although they did not develop on gypsiferous substrata, are enriched with secondary gypsum received from a nearby overhanging gypsiferous geological formation. Spatial analysis of gypsum content showed that its presence in the soils exhibit an anisotropic behaviour, strongly depending on local soil morphology and relief. The pedons studied were classified as Gypsic Haploxerepts and Calcic Gypsisols according to the Soil Taxonomy and World Reference Base systems.

**Keywords**: Gypsisols, secondary gypsum, World Reference Base, Soil Taxonomy, Sicily

## Introduction

According to available data, the extent of soils affected by gypsum is more than 100 million hectares in the world, and they are found mainly in arid and semi-arid regions with less than 400 mm of annual rainfall (Boyadgiev and Verheye, 1996). Gypsic soils were well recognized in the early version of the FAO-UNESCO (1974) legend and in the USDA Soil Taxonomy (Soil Survey Staff, 1975). Because the definitions of the gypsic horizon were changed in both the updated editions of these two soil classification systems (FAO-ISRIC-ISSS 1998; Soil Survey Staff, 1999), the assessment of the extent of gypsiferous soils should be revised, to encompass semi-arid areas having more than 400 mm of annual rainfall, including the Mediterranean basin in which gypsic horizons can occur (Dazzi and Scalenghe, 2002).

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The goals of this study were to: (i) evaluate the occurrence and the spatial variability of the gypsic horizon in relation to the parent material and to morphology in a Mediterranean semiarid area of Sicily, (Italy) and (ii) classify these soils according to Soil Taxonomy and to World Reference Base (WRB).

*Classification of gypsiferous soils: State-of-the-art*

Soil affected by gypsum were first surveyed and classified as "sulphate soils", genus "gypsic soils" by Knop in 1871 (Dokuchaev, 1896). Much later Kulchitskii (1956), presented a note on the determination of gypsum in soils. Since then, surveys on such soils have become more frequent. According to Soil Survey Staff (1999), gypsic soils were recognized within five soil Orders (Table 1). The peculiarity of gypsiferous soils is due to the accumulation in the soil profile of enough gypsum to form a soil horizon which is called "gypsic". The definition of such horizon, which was modified with time, was made taking into consideration substantially the same parameters but in different ways (Table 2) (Soil Survey Staff, 1975, 1988, 1990, 1992, 1994, 1997, 1998, 1999; FAO-UNESCO-ISRIC, 1988; FAO-ISRIC-ISSS, 1998). Such differences are linked not only to the amount of the accumulation of secondary gypsum but, also, to its location with respect to the underlying horizon.

*Table 1: Soils with a gypsic horizon listed by the Soil Taxonomy at different levels (Soil Survey Staff, 1999).*

| ARIDISOLS | GELISOLS | INCEPTISOLS | MOLLISOLS | VERTISOLS |
|---|---|---|---|---|
| Gypsid | Gypsic Anhyturbels | Gypsic Calciustepts | Gypsic Calciustolls | Gypsitorrerts |
| Gypsiargids | Petrogypsic Anhyturbels | Gypsic Haploxerepts | | Gypsiusterts |
| Gypsicryids | Gypsic Anhyorthels | Gypsic Haplustepts | | Gypsic Haplusterts |
| Natrigypsids | Petrogypsic Anhyorthels | | | |
| Gypsid Aquisalids | | | | |
| Gypsid Haplosalids | | | | |
| Petrogypsic Petrocryids | | | | |
| Petrogypsic Petroargids | | | | |

The present parameters for defining the gypsic horizon, in those areas where the climatic features are not so strongly aridic but are typically xeric, or on the border between xeric and aridic, can have a strong influence on the formation of a gypsic horizon. Therefore, it is reasonable to extend the possibility of finding "Gypsisols" in areas with a semiarid climate of the Mediterranean basin with gypsiferous substrata (Dazzi and Monteleone, 2002).

*Table 2: Definitions of the "gypsic" horizon*

| Reference | Definition |
|---|---|
| Soil Survey Staff, 1975, 1988, 1990. | The gypsic horizon is a non-cemented or weakly cemented horizon of enrichment with secondary sulfates that is 15 cm or more thick, has at least 5 percent more gypsum than the C horizon or the underlying stratum, and in which the product of the thickness in centimetres and the percentage of gypsum is 150 or more. Cementation is weak enough that a dry fragment slakes in water. |
| Soil Survey Staff, 1992. | The gypsic horizon is a horizon of enrichment with secondary sulfates that is 15 cm or more thick and has the following properties:<br>1. it is noncemented (an air fragment slakes in water); and<br>2. its gypsum content is 5 percent or more (absolute) higher than that of an underlying 1C horizon; and<br>3. the product of its thickness in centimetres multiplied by its gypsum percentage is 150 or more. |
| Soil Survey Staff, 1994, 1997, 1998, 1999. | The gypsic horizon is an illuvial horizon in which secondary gypsum has accumulated to a significant extent.<br>A gypsic horizon has all of the following properties:<br>1. is 15 cm or more thick; and<br>2. is not cemented or indurated to such a degree that it meets the requirement of a petrogypsic horizon; and<br>3. is 5 percent or more gypsum and is 1 percent or more by volume secondary visible gypsum; and<br>4. has a product of thickness in centimetres multiplied by gypsum content percentage of 150 or more. |
| FAO-UNESCO, 1974. | The gypsic horizon is a horizon of secondary calcium sulfate enrichment that is more than 15 cm thick, has at least 5 percent more gypsum than the underlying C horizon, and in which the product of the thickness in centimetres and the percent of gypsum is 150 or more. |
| FAO-UNESCO-ISRIC, 1988. | The gypsic horizon is enriched with secondary calcium sulphate, is 15 cm or more thick, has at least 5 percent more gypsum than the underlying C horizon, and the product of the thickness in cm and the percent of gypsum is 150 or more. |
| FAO- ISRIC-ISSS, 1998. | The gypsic horizon is a non-cemented horizon containing secondary accumulation of gypsum ($CaSO_4 \bullet 2H_2O$) in various forms. It must have: 15% or more gypsum; thickness of at least 15 cm. |

## *The study area*

The study area is located in southern Sicily (Italy), near the Temple Valley of Agrigento (37°20'N 13°28'E) (Figure 1). It is a 1280-hectares area, in which the outcrops of gypsum formations were found (Bambina and Monteleone, 2002). A detailed soil survey was conducted by Laudicina et al. (2002).

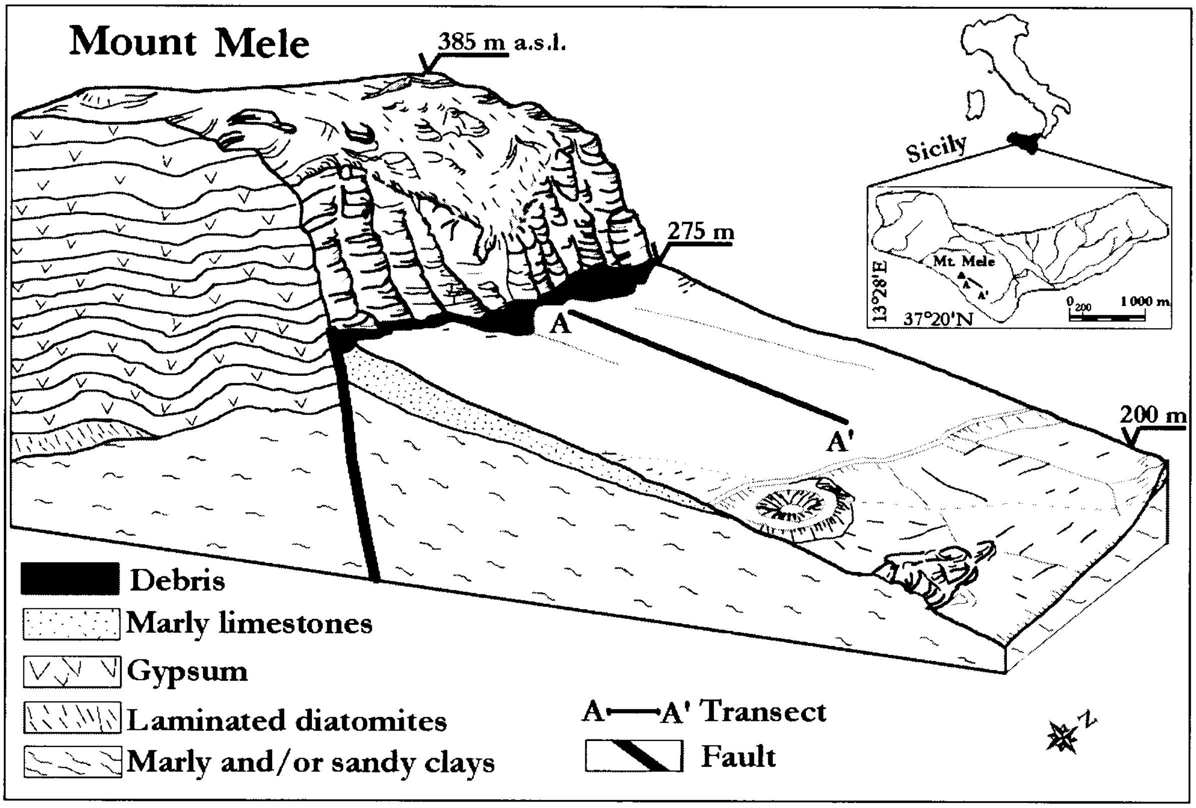


*Fig. 1: Location of the study area and the transect. Perspective of Mount Mele NW-SE slope and geological setting.*

According to data from the nearest weather station (Agrigento), the climate of this area can be defined as "Mediterranean semiarid". Average annual precipitation and annual temperature are 475 mm and 18°C, respectively. For the purpose of this survey, we investigated a 220 m long hillslope (Figure 1), with a 10% uniform slope, at the base of Mount Mele. This hill is a gypsiferous outcrop, formed through the first cycle of the evaporitic event above the marly limestone formation, on which a Sicanian necropolis (3000 BP) with many oven-type tombs is visible. Along the slope, land use consists of olive groves (Biancolilla) (8 × 8 m spacing). The yields of 900 kg $ha^{-1}$ (decadal averaged data) are very low considering the productive capacity of such a cultivar.

## *Geological and geomorphological setting*

The geological and geomorphological characteristics of the landscape of the study area are the result of endo- and eso-genetic processes that, acting in opposite ways, have determined its structure. The most important endogenetic events took place during the Miocene–Pliocene tectonic phase and to the more recent Pleistocene (Catalano, 1986). The latter, to the sub-vertical tectonic displacements identified along the eastern sector of the ridge bordering the Mount Mele, links lithotypes that are different both in age and in origin.

The physical continuity between the evaporitic deposits (first cycle gypsum) and the marly limestones, together with the stratigraphical relations among the outcropping lithotypes, are particularly evident (Figure 1).

Pre-evaporitic deposits (Upper Tortonian - Lower Messinian) are represented by clays and marly clays with sandy intercalations, locally disturbed by solifluction and, in some cases, even by landslides. Locally, at the top of such succession, are outcrop lenses of laminated diatomites ("Tripoli").

Evaporitic deposits (Messinian) outcrop extensively at the top of the slope. They are composed of well-stratified gypsum, whose strata are often separated by marly portions composed of selenitic crystals (swallowtail twin) subordinated by alabaster and tabular gypsum. At the top of such a sedimentary succession are arenitic gypsum outcrops. The described sequence is related to the so-called First Evaporitic Cycle.

Post-evaporitic deposits (Lower Pliocene) are composed of marly limestones containing Globigerinae, called "Trubi", and are generally transgressive on the lower deposits. They outcrop in the middle–high part of the area with ten m maximum thickness. From a geomorphological point of view, the horographic features are conditioned by the lithotechnic response of the outcrop either to the selective erosion or to the tectonic and neotectonic events. In particular, the geomorphological structure of the Mount Mele area is characterized not only by the described tectonic displacement but, also, by a series of steps (reaching a maximum height of 2 m) whose origin is related to the exso-genetic processes (morphoselection) acting in a lithologic context constituted by strata and interstrata with different rheologic characteristics.

## Materials and methods

A total of 17 observations (4 soil pedons and 13 soil augerings) spaced apart by about 12 m and with an average altimetric difference of about 3 m were surveyed along a slope. The four pedons were described and sampled according to the sequence of the horizons while the soil augerings were sampled every 15 cm. All samples were air dried and passed through a 2 mm sieve for laboratory analysis. Spatial data have been modeled using univariate and multivariate geostatistical techniques, adjusted to accommodate the Poisson-distributed nature of count data. Spatial distribution patterns of gypsum have been tested by analysis of variance of fitted semivariogram model parameters such as field observations and lab results, and by comparing interpolation maps.

### *Lab methods*

There is no standard way to estimate gypsum content as a percentage.(Porta, 1998). We evaluated the gypsum content from the fine-earth fraction by the thermogravimetric method (Nelson et al., 1978), which was recommended for Gypsisols with gypsum content more than 8% (Artieda, 1993). It is based on the fact that gypsum begins to lose water around 50°C (transformation of gypsum into bassanite), loses most of its water upon drying at 105°C for 24 hours while its total dehydratation into anhydrite is reached at about 200°C. This method commonly overestimates gypsum content, though comparisons with other analytical techniques showed no differences (Porta, 1998).

*Spatial distribution of gypsum*

We estimated the spatial distribution of gypsum in the soil sequence as a function of local topography, distance from Mount Mele, and slope. The quantitative methods developed for this analysis is based on 104 samples. Spatial data have been modeled using geostatistical techniques. Gypsum spatial distribution patterns were tested by analysis of variance of fitted semivariogram Gaussian model parameters, based on field observations, lab results, and comparing interpolation maps. In our study, punctual kriging was applied to extrapolate gypsum in the entire landscape. The accuracy of kriging was evaluated based on cross-validation technique. A contour map of estimated kriging data was obtained using the software SURFER 7.0 (Golden Software, 1999). This procedure allowed us to estimate the value of the regionalized variables at points that have not been sampled to estimate the trend of gypsum dynamics into the vertical soil profile and along the surveyed hillslope (bi-dimensional distribution).

Spatial structure of soil gypsum was determined through fitted variograms in a two-step procedure: (i) computation of experimental variograms, and (ii) fitting them to theoretical models validated by the cross-validation technique within soil depth (taxonomically targeted for the dislocation of the gypsic horizons in the Gypsisols, i.e. <100 cm soil depth).

For the calculation of the variograms each lag class contained an average of 150 data pairs with a minimum of 50 pairs. Variogram model fitting was selected on the statistical results obtained from cross-validation according to Vieira et al. (1983). Individual data were eliminated from the data set and then estimated using the surrounding points.

## Results and conclusion

Pedons surveyed show a very notable homogeneity regarding the soil texture and the reaction (Table 3). Texture of the soils were clayey, reaction was slightly alkaline. Electrical conductivity (EC) shows a wide variability in each pedon (except pedon 10), ranging from 0.9 dS $m^{-1}$ to 10.8 dS $m^{-1}$.

Studies on soil pattern on a large scale map in arid and semi-arid regions have rarely been conducted. However, some papers implicitly deal with the assumption that soil features are homogeneous in arid and semiarid systems (Rivas-Martínez and Costa, 1970). In our study, gypsum shows a large variability not only among the pedons (from 6.5 to 35.6%) but also inside each pedon. Such data are confirmed also by those obtained on the soil samples taken with the soil augering. In fact, the descriptive statistics for gypsum contents for all 104 samples (Table 4) show a high standard deviation (SD) and a positive skewness coefficient, indicating a remarkable variability with few extreme values.

*Table 3: Main chemical-physical features of the pedons studied.*

| Pedon n° | horizon | cm | [1]Texture | [2]pH $H_2O$ | [2]pH KCl | [3]OC g $kg^{-1}$ | [4]EC dS $m^{-1}$ | [5]TC g $kg^{-1}$ | [6]Gypsum % | [7]CEC $cmol_c^+ kg^{-1}$ | [8]$Na^+$ $cmol_c^+ kg^{-1}$ | [8]$K^+$ $cmol_c^+ kg^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | Ap | 0-12 | C | 7.4 | 7.3 | 24 | 3.7 | 23.9 | 25.2 | 19 | 2.8 | 5.8 |
| | $By_1$ | 12-35 | C | 7.8 | 7.1 | 4 | 2.7 | 24.8 | 35.6 | 13 | 1.5 | 1.7 |
| | $By_2$ | 35-60 | C | 7.7 | 7.3 | 7 | 2.7 | 24.8 | 30.8 | 15 | 1.4 | 2.0 |
| | Cy | > 60 | C | 7.8 | 7.3 | 1 | 2.7 | 51.6 | 19.2 | 8 | 1.5 | 1.3 |
| 11 | Ap | 0-15 | C | 7.4 | 7.1 | 19 | 3.6 | 24.9 | 9.8 | 22 | 2.3 | 4.7 |
| | By | 15-55 | C | 7.5 | 7.3 | 6 | 3.8 | 20.6 | 21.2 | 19 | 3.7 | 2.7 |
| | BCy | 55-100 | C | 8.1 | 7.5 | 2 | 9.5 | 13.8 | 14.1 | 17 | 1.7 | 3.8 |
| | Cy | > 100 | C | 8.1 | 7.1 | 2 | 10.8 | 7.5 | 11.9 | 14 | 2.2 | 4.6 |
| 12 | Ap | 0-15 | C | 7.4 | 7.1 | 18 | 6.1 | 21.4 | 8.2 | 27 | 2.0 | 5.8 |
| | $By_1$ | 15-55 | C | 7.4 | 7.2 | 4 | 3.0 | 15.4 | 20.1 | 22 | 2.3 | 2.4 |
| | $By_2$ | 55-80 | C | 8.0 | 7.6 | 2 | 3.3 | 9.9 | 18.2 | 22 | 2.4 | 1.9 |
| | BCy | > 80 | C | 8.0 | 7.8 | 2 | 8.0 | 9.1 | 11.9 | 14 | 1.1 | 1.7 |
| 13 | Ap | 0-15 | C | 8.1 | 7.2 | 14 | 0.9 | 26.9 | 6.5 | 25 | 1.8 | 5.8 |
| | Bk | 15-50 | C | 7.9 | 7.2 | 7 | 3.0 | 25.3 | 8.7 | 24 | 2.6 | 4.0 |
| | $By_1$ | 50-75 | C | 7.9 | 7.4 | 5 | 4.6 | 25.3 | 10.1 | 22 | 1.1 | 4.0 |
| | $By_2$ | 75-110 | C | 8.0 | 7.3 | 4 | 7.0 | 22.2 | 23.1 | 20 | 1.7 | 3.2 |
| | BCy | > 110 | C | 8.0 | 7.3 | 3 | 8.8 | 24.5 | 19.8 | 18 | 1.9 | 2.9 |

[1]Texture: C=clayey; [2]pH: 1:2.5; [3]OC: organic carbon; [4]EC: electrical conductivity of saturated paste; [5]TC: total carbonate (gas-volumetric method 1:1 w/v); [6]gypsum: $CaSO_4 \bullet 2H_2O$ (thermogravimetric method); [7]CEC: cation exchange capacity ($C_2H_3O_2NH_4$, pH 7); [8]exchangeable cations

| | | |
|---|---|---|
| Median | (g 100 $g^{-1}$) | 26 |
| Average | (g 100 g) | 27 |
| Minimum | (g 100 g) | 0 |
| Maximum | (g 100 g) | 52 |
| SD | (g 100 g) | 10 |
| Skewness | (g 100 g) | 0.32 |

*Table 4: Summary statistics for soil gypsum concentration.*

The variability of the overall values shows that the soil gypsum decreases gradually from Mount Mele down the hillslope (Figure 2). Nearest to Mount Mele the distribution pattern of the gypsum is more uniform along the soil profile; the contrary happens at the end of the transect where there is a remarkable increase with depth. We can reasonably assume that the gypsum distribution is a function of position along the slope, i.e. distance from the base of Mount Mele and slope morphology.

In Figure 2, the iso-lines of gypsum concentration in the pedosequence show two patterns: 1) on the left of the figure they show a vertical trend, 2) while on the right, they have an oblique trend. This means that in the first 40-50 meters of the slope, gypsum is uniformly deposited in the soil profile within the first meter (soil depth considered both in Soil Taxonomy and in the WRB for the presence of the gypsic horizon). In the second part of the slope, from 50 m to the end of the transect, gypsum accumulation shows a gradient of concentration that increases with the soil depth.

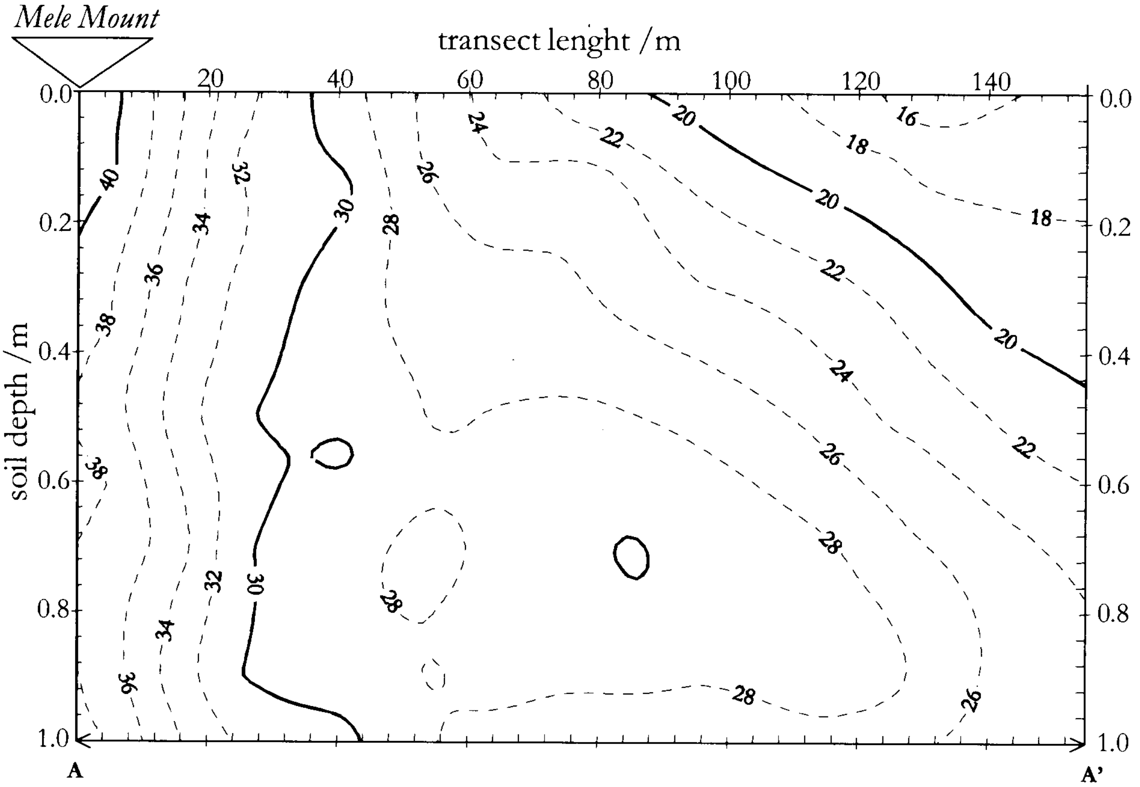


*Fig. 2: Transect AA', Contour map of the gypsum concentration (grams of gypsum 100 $g^{-1}$soil) within the taxonomically targeted soil depth.*

On the steep wall of Mount Mele, the rainfall that dissolves the gypsum runs toward the bottom of Mount Mele as a kind of "rock flow" that, together with the gentle slope in the first 50 m, is responsible for the homogeneous gypsum distribution in the soil. Beyond 50 meters distance from the base of the mountain, the slope increases, rain water tends to run as surface and sub surface flow and gypsum accumulation assumes a trend parallel to the surface increasing with soil depth.

The classification of the pedons along the slope take into consideration not only the above-mentioned processes but also the main physical-chemical and morphological properties (Tables 3 and 5). The longterm anthropic use of these soils is reflected by the Sicanian tombs on the Mount Mele wall.

The historic land use, which continues till today, is responsible for the presence of gypsum in the topsoil that, due to its unfavorable physico-chemical features and to the slope, is prone to erosion even with low intensity rainfalls. As a consequence the soils show an Ap-By-Cy profile, with a gypsic horizon. Another notable piece of evidence is the presence of gypsum crystals displaying, in many cases, a lenticular shape. From a taxonomic point of view, all the pedons surveyed can be classified as *Gypsic Haploxerepts* according to Soil Taxonomy, while according to the WRB they can be classified as *Calcic Gypsisols*.

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*Table 5: Main morphological features of the pedons studied.*

| Pedon n° | horizon | cm | [1]MC | [2]S | [3]C | [4]R | [5]RF | [6]$CaCO_3$ | [7]$CaSO_4$ | [8]B |
|---|---|---|---|---|---|---|---|---|---|---|
| **10** | Ap | 0-12 | 2.5Y6/2[d] | sb, f, m, c, 3/4 | sh | f, m | me, s | 3, a | 1 | ab, s |
| | $By_1$ | 12-35 | 2,5Y5/2[m] | sb/ab, m, 3 | f | f | f, s, r | 3, b | 2, a | gr, s |
| | $By_2$ | 35-60 | 2,5Y4/2[m] | ab, m, c, 3/4 | f/fi | a | f, me, r, a | 3, b | 3, a | gr, w |
| | Cy | > 60 | 5Y7/2[m] | ab/pr, m/c, 4 | fi | a | a | 3, b | 2, a | gr, ir |
| **11** | Ap | 0-15 | 2,5Y6/2[d] | ab, f, m, c, 4 | sh | f, fi | f, s, a | 1 | 1 | gr, s |
| | By | 15-55 | 2,5Y4/2[d] | ab/pr, m, 3/4 | sh | c, fi | c, me, s, a | 4, a, b | 4, b | gr, s |
| | BCy | 55-100 | 5Y4/1[m] | pr, m, 4 | fi | a | a | 4, b | 4, b | ab, s |
| | Cy | > 100 | 5Y5/1[m] | p, 4 | - | - | - | 1 | 4, b | - |
| **12** | Ap | 0-15 | 2Y6/2[d] | sb, f/m, 3 | sh | a | c, me, s | 2, a | 1 | ab, s |
| | $By_1$ | 15-55 | 2,5Y5/2[d] | sb, m, 3 | eh | a | f, s | 4, b | 4, b | gr, s |
| | $By_2$ | 55-80 | 2,5Y4/2[d] | ab/pr, m, 3 | eh | a | a | 4, b | 4, b | gr, s |
| | BCy | >80 | 5Y4/1[m] | pr, m/c, 4 | ef | a | a | 4, a | 4, a | gr, s |
| **13** | Ap | 0-15 | 2,5Y5/2[d] | sb, f, m, c, 3 | sh | c, fi | c, s | 1 | 1 | ab, s |
| | Bk | 15-50 | 2,5Y4/2[d] | ab/pr, m, 2 | eh | f, fi | s | 4, a | 1 | cl, s |
| | $By_1$ | 50-75 | 2,5Y4/2[m] | ab/pr, m, c, 2 | fi | a | f, s, fl, r | 3, a | 2, a | gr, s |
| | $By_2$ | 75-110 | 2,5Y4/2[m] | ab/pr, m, c, 2 | fi | a | f, s, fl, r | 3, a | 2, a | gr, s |
| | BCy | > 110 | 2,5Y5/4[m] | m | vf | a | c, s, r | 3, a | 2, a | cl, s |

[1]MC Munsell colo: d=dry, m=moist, [2]S structure: sb=subangular blocky, ab=angular blocky, pr=prismatic, p=platy, m=massive; f=fine, m=medium, c=coarse; 2=weak; 3=moderate; 4=strong; [3]C consistence: f= friable; sh= slightly hard, eh=extremely hard; fi=firm; vf=very firm; ef=extremely firm, [4]R roots: a=absent; f=few; c=common; fi=fine, [5]RF rock fragments: a=absent; f=few; c=common, me=medium; s=small; fl=flat, r=rounded, [6]$CaCO_3$ concretions: 1=absent, 2=few, 3=common, 4=abundant; a=fine, b=medium, [7]$CaSO_4 \cdot 2H_2O$ crystals: 1=absent, 2=few, 3=common, 4=abundant; a=fine, b=medium, [8]B boundary: ab=abrupt, cl=clear, gr=gradual; s=smooth, w=wavy, ir=irregular.

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