MEDITERRANEAN SOILS

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Summary

Mediterranean soils are soils which form under a Mediterranean climate. They are variously called *Terra Rossa* (on hard limestone) and Red Mediterranean Soils. Not all soils in a Mediterranean environment are, however, qualified as such because normal pedogenetic development may be hampered by erosion (rejuvenation of the profile), lack of time, and lack of water or unfavorable parent material characteristics.

The impact of climate, topography, parent material (mineralogical composition, coherence and permeability), time and human influence as soil forming factors is discussed. Pedogenesis is reviewed and three phases in a color sequence are recognized,

with a major focus on soils developed over carbonaceous substrata. It is shown that the red phase corresponds to a climax development, but that as soon as environmental conditions are not optimal, this phase is not reached. The position of Mediterranean soils in the three major world classification systems is commented.

In terms of land use and production potential these soils are intensively used for both rain-fed and irrigated cropping. Under rain-fed conditions the choice of crops is limited to those that support a limited period of water supply in the year. Horticulture, citrus production and floriculture provide excellent cash returns, particularly because they can often be marketed as off-season crops.

1. Introduction

Mediterranean soils are soils which, by definition, form under Mediterranean climatic conditions. The main characteristic of the Mediterranean climate is that it has two well defined seasons in the year, with the rain period coinciding with low temperatures (winter) while summers are hot and almost completely dry.

In the world as a whole, Mediterranean soils are not very extensive. FAO (1991) estimates their extension at approximately 420 million ha. The main area is around the Mediterranean Sea, with smaller areas in California, Chile, The Western Cape Province of South Africa, and West and South Australia (Figure 1).

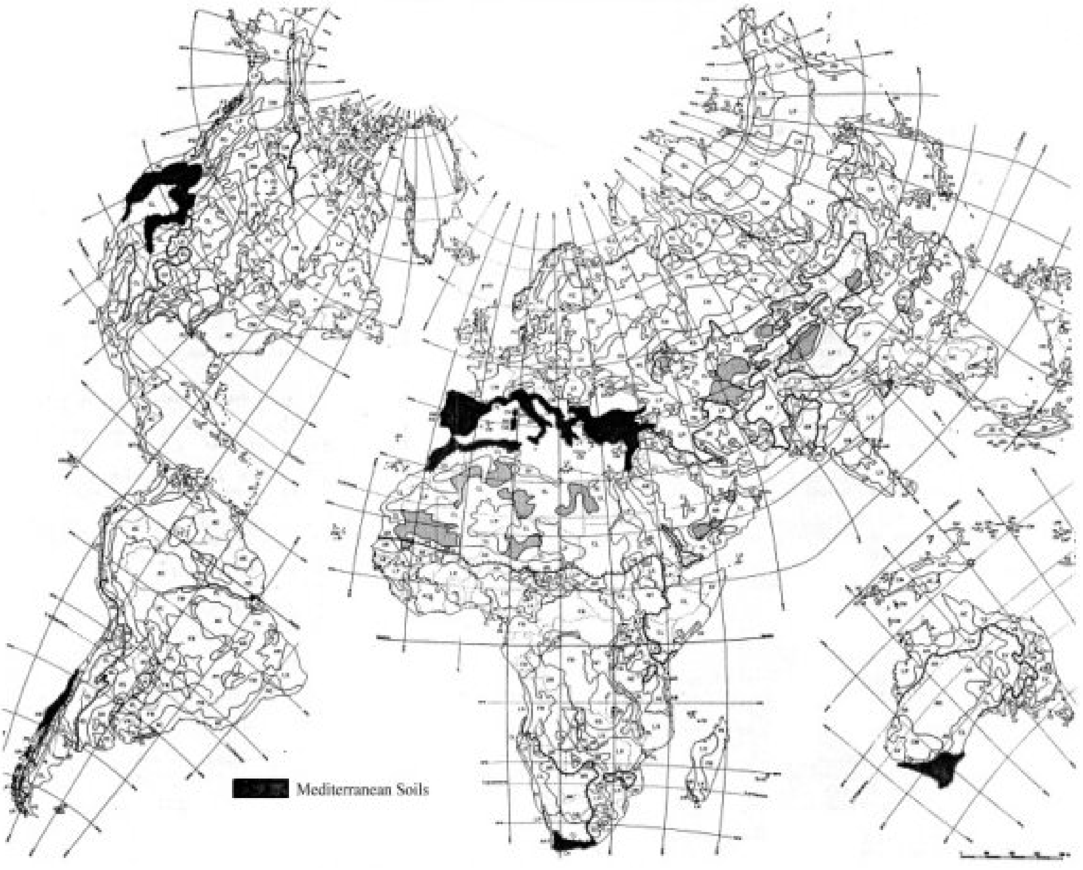

Figure 1: Extension of Mediterranean soils (adapted from FAO, 1991)

2. Soil Forming Factors

2.1 Climate

The main characteristic of the Mediterranean climate is the alternation of a moist cool winter and a hot dry summer exceeding generally 3 to 4 months. Expressed in terms of soil temperature and soil moisture regimes, *sensu* Soil Taxonomy (USDA, 1975) and updates (Soil Survey Staff, 2003), Mediterranean soils have:

- a *xeric* moisture regime, whereby most of the rainfall occurs immediately after the winter solstice, and is followed by a relatively important dry period after the summer solstice;
- a temperature regime which is *thermic* (mean annual soil temperature between 15° and 22°C) or occasionally *mesic* (8°-15°C), e.g. intermediate between temperate regions and the tropics.

Soil formation and weathering in Mediterranean soils is most active during the rainy winter when also evapo-transpiration is minimal. The conditions are then optimal for an effective dissolution and leaching of calcium carbonate and other easily soluble elements, as well as for the migration of clay. During the hot, dry summer the soil desiccates, causing the development of red dehydrated oxidized iron compounds (hematite, magnetite, etc.) within the profile.

Chemical soil processes related to available soil water refer in the first place to the decomposition, dissolution and leaching of easily soluble components. In soils developed over calcareous substrata this leads to a progressive decrease of the $CaCO_3$ content and ultimately, to its more or less complete elimination from the profile. This goes together with a decrease of soil pH from 8.0-8.2 to approximately 7.0-7.2 and a tendency towards a de-saturation of the cation exchange complex. On non-carbonaceous and acid substrata, like granites, gneiss or sandstones, natural leaching and plant acid exudation intensify the processes of acidification (soil pH between 6.0 and 7.0) and de-saturation during the winter period. Moreover, in a free draining soil environment clay particles in suspension in the percolating soil water migrate into the deeper layers of the profile. The relative importance of clay migration varies with the amount of rainwater that penetrates the soil, inherent soil permeability, clay dispersion, parent material and time.

During the dry summer period the pedo-climate is completely different, and dissolution, leaching and clay migration are temporarily stopped or even reversed, while the soil solution gets re-saturated. Hence, pH variations between summer and winter may in one and the same horizon be as high as one unit, especially in soil sections with high organic matter content. In addition, iron compounds become oxidized and a red matrix color develops.

The result is the development of what is commonly referred to as a Red Mediterranean Soil or *Terra Rossa* (on carbonaceous rocks)*;* though not all soils under this climatic regime reach this stage. The myth of Red Mediterranean Soil being dominant in this climatic area is therefore not substantiated in soil surveys, and the region is obviously more diverse in soils than any other climatic region, as shown by De la Rosa (1984) and Yaalon (1997). In this respect it should also be reminded that the connotation of *Terra Rossa*, as introduced by Reifenberg (1947) and Kubiena (1953) referred initially only to Mediterranean soils over hard limestone. In modern literature it has often been (erroneously) extended to all Red Mediterranean soils, including those over other types of rocks.

2.2 Parent Material

Parent material influences the formation of Mediterranean soils through its mineralogical composition, coherence, and permeability for water. Mineralogy influences the amount, particle size distribution and type of weathering products wherein the soil profile develops; coherence or hardness determines the resistance to weathering and speed of disintegration; permeability influences the intensity of physicochemical transformations within the original rock residue.

The variety of parent rocks in Mediterranean areas is quite large, though carbonaceous rocks seem to be the most extensive parent material. Around the Mediterranean Sea calcareous sedimentary rocks (limestone, dolomite, marl) with different behaviors in terms of mineralogical composition, hardness and permeability dominate. In South Africa and Australia, non-calcareous sedimentary rocks ranging from sandstone to mudstone and shale are well represented. Elsewhere, plutonic (granite), volcanic (basalt) and metamorphic rocks (quartzite, gneiss) are observed.

Mineralogy - Rocks have various compositions, and each of these components behave differently in terms of *solubility* when subject to weathering and disintegration. The mineralogical evolution on carbonaceous rocks in general starts with a chemical attack and dissolution of calcium carbonate by percolating rain water, especially when enriched by CO_2 and plant exudates:

$$\begin{array}{lll} CO_2 + H_20 \quad \Leftrightarrow & H_2CO_3 & \\ & \downarrow & \\ CaCO_3 + & H_2CO_3 & \Leftrightarrow \quad Ca(HCO_3)_2 \end{array}$$

whereby the less soluble $CaCO_3$ in the substratum first reacts with H_2CO_3 and is then transformed into easily soluble $Ca(HCO_3)_2$ and then evacuated by the drainage water. Whether the dissolution of the rock is complete or not, leaving behind a weathering product with a variable amount of free $CaCO_3$ depends on the nature and hardness of the substratum and on the amount and chemical aggressiveness of the water that percolates through the soil and rock.

Weathering of silicates or volcanic glass releases silica into solution, which can migrate and/or precipitate as opal, nodules or crusts (duripans). Mature soils developed on these materials have acid surface horizons, with pH and base saturation generally increasing with depth.

The mineralogical composition of the parent material determines also the *texture* of the weathering product. Granites containing large quartz grains and finer feldspars and micas, will decompose into a coarse sandy clay material, the coarser components being derived from the quartz fraction, and the finer fraction being linked to the weathering of feldspars and micas. The granite areas in South Africa weather into yellow-brown sands on the middle slopes and yield highly leached and acid white (albic) sands in the lower landforms. Basic igneous rocks like basalt will decompose into fine material. They form into red clayey soils on well-drained slopes (because they contain a lot of iron bearing minerals) and into Vertisols on lower flat slopes. For carbonaceous rocks the particle size distribution of the weathering material will mainly depend on the nature and composition of the acid insoluble residue, though in most cases it will hold a clayey texture.

Coherence and hardness - The coherence and hardness of the parent rock determines the type of weathering and affects the speed by which the bedrock decomposes into loose material. Soft substrata like chalky limestone or marl are easily broken down and their weathering material consists of coarse fragments that reflect closely the mineralogical composition of the parent rock. Moreover, the landscape on these rocks is severely eroded, soils are constantly rejuvenated and remain skeletal.

On more coherent carbonaceous substrata the physical disintegration of the rock is slower and, simultaneously with a mechanical breakdown, an initial chemical weathering of the soil material takes place. The harder and compacter the limestone the more difficult and slower is the physical rock weathering, but over this longer period also chemical processes can start. The volume of weathering material produced is small (to the point that it is often limited to a fine weathering cortex which is hard to observe with the naked eye), but it has already undergone a relatively important physicochemical and mineralogical transformation. In the field this is reflected in a clear-cut differentiation between the (white) rock and the partly or completely decalcified (red) soil.

Permeability and water infiltration - The permeability of the solum determines how much water and at what speed it can percolate through the profile and, therefore, affects the intensity of the chemical reactions and leaching.

A soft limestone and marl behave completely different in terms of permeability and water infiltration than a fractured hard limestone. The former is rapidly saturated after the first winter rains and remains almost impermeable for the rest of the season. Vertical water percolation and leaching in these soils is therefore seriously restricted, and enhances lateral runoff and surface erosion; in flat areas with no runoff, soils remain saturated with water for some time of the year and get hydromorphic properties.

On hard limestone the situation is different, in the sense that the rock, although rather impermeable by itself, is generally interwoven by many cleavages, joints and dissolution holes through which rainwater infiltrates (figure 2). Leaching is therefore activated, and easily soluble soil components (in this case mainly calcium- and magnesium carbonates) are evacuated from the profile. At the same time, pH decreases and the non-carbonate fraction undergoes further weathering as well. Soil formation on hard limestone yields therefore less weathering product but it is more intensely weathered than on less permeable carbonaceous substrata. The intensity by which leaching processes take place in the profile depends on the amount of water that passes through the soil (rainfall regime) and to the permeability of the substratum.

2.3 Time

Physical and chemical weathering processes are often slow and it takes time before their effects become visible. Time as a soil forming factor is, therefore, closely related to the combined effect of climate, parent material and human activity. The longer the time chemical weathering, leaching and clay migration can operate in a soil, and the less the soil is affected by erosion or by Man, the more advanced will be its development.

Figure 2: Hard limestone with numerous joints and dissolution holes, allowing the water to infiltrate into the soil substratum

The study of the time factor automatically implicates the evaluation of soil age, as well in the absolute as in the relative sense. In this respect, there exist two schools of thought, i.e. those who consider Mediterranean soils as a paleo-formation, and those who believe that they are the result of present-day environmental conditions.

Main promoters of the paleo-formation theory were Reifenberg (1947), Kubiena (1953) and Durand (1959). These authors believed that Mediterranean soils are mainly relict soils which have formed and developed under much moister tropical and subtropical climates of the late Tertiary and early Pleistocene periods. Although it may not be excluded that some of these soils have initially been formed at that period or at least under somewhat moister conditions than the present, studies by Lamouroux (1971) and Verheye (1973) in Lebanon have illustrated that their genesis is still active today, and that they can be considered as being in equilibrium with the present-day prevailing Mediterranean climate.

The question of the age of Red Mediterranean Soils is still unsolved, and most probably both theories hold a basis of truth. In this respect, Torrent (2004) refers to the intrinsic mosaic of Red Mediterranean soils observed in Spain and formed on both Pliocene *ranas* and Lower Pleistocene surfaces, represented by different pediments and river terraces,

2.4 Topography

In contrast with climate and parent material which exercise an active role in soil formation, topography is a passive element which refrains or orients profile development within the context determined by the former factors. Moreover, the exposure of slope with respect to rainfall and sunshine interception leads to different pedo-climates and weathering conditions on sun-exposed slopes (where evaporation is more intense and less soil moisture is available for weathering and leaching) as compared to slopes facing away from the sun.

In a steeply dissected landscape part of the rainfall runs along the slopes and creates erosion. Surface layers are removed, the deeper unaltered layers are brought nearer to the surface, and the profile is “rejuvenated”. The soil remains shallow and skeletal.

On more or less flat topography, lateral runoff is reduced and the rainwater will either percolate through the soil and underlying rock or it will stagnate on an impermeable deeper layer. In the first case it will stimulate weathering, deepen the profile and develop a better structure. Obviously, the soil which develops under those conditions will display physicochemical and mineralogical properties which differ from the underlying rock. In soils developed over carbonaceous substrata this is reflected in a more or less important decrease of the free $CaCO_3$ content in the upper layers, an initial clay migration into depth and the development of a good (sub)angular blocky structure in the subsurface horizons. In erosion-protected areas developed over hard permeable limestone soil development moves into a more or less de-calcified brown to reddish-brown soil (corresponding to Kubiena’s *Terra Fusca*, or to the *Inceptisol-intergrade-Alfisol* stage of Soil Taxonomy) or to a red completely de-calcified profile (corresponding to Kubiena’s *Terra Rossa* or Soil Taxonomy’s *Alfisol* stage).

In the second case, soil water will stagnate over an impermeable layer and profile development will be hampered under these temporary hydromorphic conditions. When the weathering product holds high amounts of swelling clays, vertic properties may develop.

Soil material eroded in the uplands accumulates in the lower parts of the landscape. Alluvial plains and their contiguous terraces extend over tens of kilometers in the major river valleys. River terrace soils provide an excellent soil chronosequence over long periods, extending sometimes until the Quaternary. Some of these terraces reach heights of more than 200m above the present river channel, as is the case in the Guadalquivir valley in southern Spain.

The role of topography in a Mediterranean environment is thus mainly to promote or inhibit normal soil development through its influence in the rejuvenation or protection of some landscape positions and in the accumulation of soil material and water in others.

2.5 Biological Activity and Man

The areas around the Mediterranean Sea have been densely populated and intensively exploited for long periods in history, and therefore human influence on soils and soil properties is immense. The most critical actions in this respect involve crop production, deforestation, grazing and related practices. In the New World, i.e. California, Chile, South Africa and Australia, this influence is obviously much less visible.

Massive *deforestation* in almost all the areas around the Mediterranean Sea is reported in many archives. Greece and Lebanon were major providers of timber for ship building and fuel wood in the eastern Mediterranean. Deforestation and *wildfires*, linked to traditional grazing practices, or modern land speculation are still an annual event in Italy, France, Spain and Portugal *(see also: Drylands and Desertification).*

The abrupt elimination of the vegetation leads to erosion of the surface layer and soil “rejuvenation”. The elimination of the natural surface cover through deforestation, overgrazing or burning also modifies soil microclimate and affects indirectly biological activity in the soil. Variations in microclimate, and particularly in the soil moisture status, affect the intensity of physicochemical weathering and mineralogical transformations. Field observations have shown that under a dense vegetative cover soil pH variations may exceed more than 1 unit between winters and summer periods as a result of the varying plant activity and CO_2 production.

An indirect effect of human activity is reflected in climate change, which is believed to result in an overall deterioration of soil quality in Mediterranean regions. A recent European study (EEA, 2003) has indicated that possible effects include salt accumulation, organic matter loss and increased wind and water erosion. Forest soils face already a loss of carbon through wildfires. As these are likely to increase, adapted policies should be developed to preserve soil quality and to promote a more sustainable use of land, for example through afforestation.

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Biographical Sketches

Willy Verheye is an Emeritus Research Director at the National Science Foundation, Flanders, and a former Professor in the Geography Department, University of Ghent, Belgium. He holds an MSc. in Physical Geography (1961), a PhD. in soil science [1970) and a Post-Doctoral Degree in soil science and land use planning (1980).

He has been active for more than thirty-five years, both in the academic world, as a professor/ research director in soil science, land evaluation, and land use planning, and as a technical and scientific advisor for rural development projects, especially in developing countries. His research has mainly focused on the field characterization of soils and soil potentials and on the integration of socio-economic and environmental aspects in rural land use planning. He was a technical and scientific advisor in more than 100 development projects for international [UNDP, FAO, World Bank, African and Asian Development Banks, etc] and national agencies, as well as for development companies and NGOs active in inter-tropical regions.

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