SOILS OF ARID AND SEMI-ARID AREAS

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Summary

Arid or desert soils are soils which have no water available to mesophytic plants for long periods. They have often weakly developed, shallow and skeletal A-C or A-R profiles except in the lowlands where soils are deeper due to colluviation and alluviation. The main factors that affect their formation and development are: lack of water, important daily temperature variations, deflation by wind, and microorganisms living on dew. Physical weathering is prominent in the hyper-arid and arid zones, but is gradually replaced by chemical weathering and solution-precipitation processes in the

semi-arid zone.

The soils of arid areas display a number of characteristic features such as: desert pavement, desert patina, vesicular layer and a prominent $CaCO_3$ redistribution in the profile; the latter is expressed by the accumulation of secondary calcium carbonate under the form of individual nodules or of a continuous crust (*caliche)*. When present, salts go into solution, redistribute and accumulate in the profile.

In Soil Taxonomy arid soils belong mostly to the order of Aridisols. In the World Reference Base and in the French CPCS classification they belong to different hierarchical units depending on their intrinsic profile properties. Arid and semi-arid soils are difficult to manage and require irrigation for sustainable economic agricultural production. Under rain fed conditions their use is mostly limited to cereals and extensive grazing.

1. Introduction

Desert soils are, by definition, soils which have almost no water available for soil formation (pedogenesis) and for the growth of mesophytic plants for long periods. Such soils cover approximately one third of the earth's surface, and there are indications that desertification is still spreading (see *Desertification in China)*. Arid and semi-arid soils are mainly found in Africa (Sahara, Namibian and Kalahari deserts), the Middle East (Arabian desert, Iran, Afghanistan, Rajasthan, etc.), North and South America (Mohave desert, Chile, etc.) and Australia (Fig. 1).

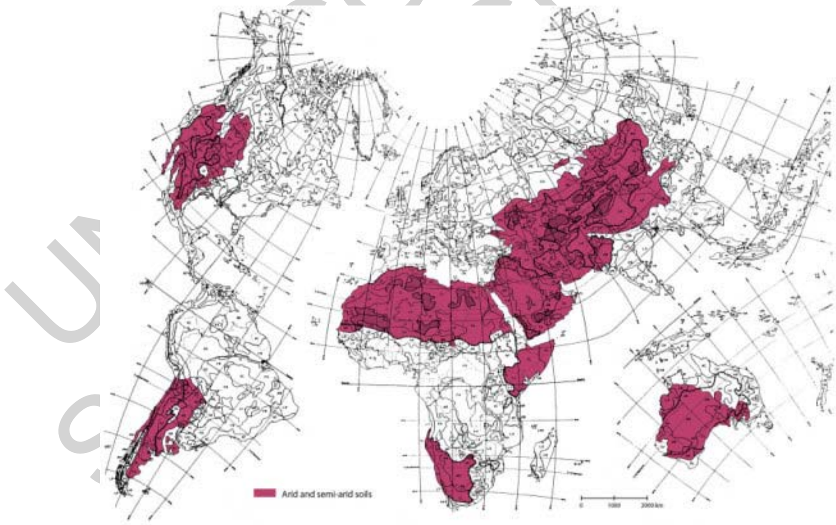

Figure 1. Extension of arid and semi-arid soils in the world (after FAO, 1991).

The characteristics of aridity have been discussed *in extenso* in *Drylands and Desertification*, whereby a distinction can be made between hyper-arid (less than 100 mm annual rainfall), arid (rainfall between 100 and 200-250 mm) and semi-arid areas (rainfall between 200-250 and 500 mm); however, most of these boundaries are set rather arbitrarily. Other definitions and criteria are used as well. The non-availability or near absence of water in these soils can have two reasons:

- a climatic reason linked to low precipitation and high evaporation, whereby little moisture is left for soil processes like dissolution and leaching;
- the presence of salts which absorb and retain water with such a strength that it is no more freely available in the soil, causing then an increase of soil solution osmotic pressure.

2. Factors of Soil Formation

Among the 5 standard soil forming factors, three of them act in no way different in arid and semi-arid environments than in other parts of the world. Climate, vegetation and biological activity are, however, major differentiating factors and need therefore a particular attention (*see Drylands and Desertification)*. Landform, in particular slope exposition, may indirectly play a local role because they influence the soil moisture balance. The main climatic parameters are: precipitation, evaporation, and wind action. Dew as a secondary factor is important in the way it may enhance microbiological activity and volumetric expansion of salts.

2.1. Rainfall and Moisture Supply

The rainfall regime in desert areas is characterized by low, irregular and unpredictable precipitation, often concentrated in few rainstorms. They bring moisture in the soil for a short period and over a limited area; several years may elapse between successive rainfalls. In semi-arid areas this irregularity and unpredictability gradually disappears.

The moisture supplied to the soil from rain is offset by evaporation; the latter is enhanced by low air humidity, high solar radiation and high air temperature. The result is a limited dissolution of soluble primary minerals, and the development of only a shallow, skeletal soil with a weak profile differentiation.

Because of the irregular rainfall distribution mean precipitation values have little meaning in the (semi)-arid zone, if not also the range of variation is indicated. This variability refers to both temporal and spatial variability.

Temporal variability affects not only the onset and duration of the rains in the year, but plays also a role in year-by-year differences. The variability is highest in the hyper-arid zone, where the mean precipitation value is made up of hardly 2-3 important storms in several years. **Spatial variability** is even more spectacular, as in arid areas most precipitation occurs as isolated showers over relatively short distances. Table 1 displays the annual rainfall in 2 stations in Algeria located at the same latitude and hardly 130 km away from each other. It illustrates that while in some years the precipitation is rather equal (1932, 1945, 1946, and 1947) it varies in most other years by more than 100% between the two locations (1936, 1938, and 1939).

Year	**Mean annual rainfall (mm)**	
	Beni Abbès	**Tabelbala**
1934	33.9	35.0
1935	17.2	20.0

1936	42.9	8.0
1937	27.2	12.0
1938	52.8	12.0
1939	29.5	8.5
1940	5.3	22.7
1941	33.5	19.0
1942	40.0	30.0
1943	58.5	40.0
1944	5.8	27.0
1945	15.8	13.3
1946	20.9	20.0
1947	7.0	<1

Table 1. Rainfall variability in two locations in Algeria located 130 km from each other

The very local character of arid zone rainfall has been measured *in situ* by Evenari *et al.* (1971) in Israel, whereby 20 pluviometers installed over a 10 ha plot registered variations in rainfall up to 3.5 times for one single rainstorm. A similar micro-scale study in the ICRISAT Sahel Center of Sadore in Niger using 18 rain gauges over a 2.5 km^2 area showed for one single rainstorm in 1989 variations from 1.7 mm to 25.7 mm. This spatial variation has an obvious impact on local differences in soil properties and soil processes in arid soils.

Short intensive rainstorms - A third characteristic of desert rainfall is its occurrence under the form of short intensive rainstorms. When these fall on a heated barren surface – as is often the case in the arid zone – a part of it is immediately evaporated and does not participate in soil formation processes. High rainfall intensity results on the other hand in a rapid saturation of the surface layers and creates lateral runoff and erosion, in particular on sloping land. Many arid and semi-arid soils show therefore features of gully and sheet erosion.

Field studies in Australia and Africa have shown that the first 5-6 mm of rain falling on a hot desert surface evaporate almost immediately, whilst single storms with an intensity of more than 20 mm loose a major part by lateral runoff (see *Drylands and Desertification*). Hence, it is estimated that from the already low rainfall in the arid zone an important part is lost and, thus, does not participate in weathering and soil formation processes. The importance of this runoff depends on a number of site-specific factors such as rainfall intensity, slope, surface sealing, soil texture and vegetation.

What is the effect of rainfall on soil formation and weathering? Low amounts of rain penetrate the soil over a small depth, the latter being determined by the amount of rain and by the permeability of the soil, itself being affected by texture and the occurrence of surface sealing. This moisture inhibits a very weak chemical weathering and dissolution of calcium carbonate according to Eqs. (1) and (2) or of salts according to Eqs. (3) and (4):

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \tag{1}$$

$$CaCO_3 + H_2CO_3 \leftrightarrow Ca + 2HCO_3 \leftrightarrow Ca(HCO_3)_2 \quad (2)$$

$$2NaX + CaSO_4 \leftrightarrow CaX + Na_2SO_4 \quad (3)$$

$$Na_2SO_4 + 10H_2O \leftrightarrow Na_2SO_4.10H_2O \quad (4)$$

Because the wetting front is limited to the upper part of the soil, horizon differentiation is restricted to the surface layers, and the soils take the form of a shallow A-C-R or A-R profile, occasionally A-Cca-R profile. In semi-arid soils affected by a relatively higher rainfall the infiltrating water reaches a greater depth, and the profile takes an A-(B)-Ca or A-Bca-C form.

Due to the spatial irregularity of the rains and the occurrence of lateral runoff concentrating additional water in (micro)depressions, soil profile development may vary quite consistently from one location to another in arid zones. This phenomenon might to some extent explain the occurrence of A-Bt-C profiles with clear clay illuviation in some isolated locations in desert zones.

2.2. Temperature

Air temperatures in arid zones are generally high and show important variations between day and night which, under certain conditions, may attend 40° C or more. Because of the absence of a protective vegetative cover and specific thermal absorption and desorption effects at the rock surface, air temperatures of 35-45° C may reach peaks up to 50-60° C or more on the soil or rock surface.

Air temperature variations are reasonably well reflected at the soil surface but disappear rapidly in depth. At 50 cm depth daily variations are almost completely waved away, and only seasonal fluctuations can be observed. Almost similar situations occur in hard consolidated rocks. Those, although having a somewhat higher thermal conductivity than loose materials, do not allow for a high thermal penetration. In rocks, thermal gradients are in the order of 5° to 10° C per 10 cm.

These high temperature gradients over short distance create important internal pressures because of the variable expansion of the different components inside the rock or the soil. This results in a frequent breakdown and mechanical splitting of the larger stones and cobbles on the desert surface (Photo 1). This physical weathering is most important in rocks with a heterogeneous composition because of the uneven volumetric expansion of minerals. Even in the same mineral the linear expansion can widely vary depending on the direction within the crystal lattice. In calcite for example the linear expansion is approximately 5 times higher parallel to the L3 axis (25.6×10^{-6}) as compared to the direction perpendicular to that same axis (5.5×10^{-6}).

2.3. Dew

Atmospheric dew is a much less important moisture source than rainfall. Although there are examples known of improved germination and early plant growth as a result of dewfall, the major effect of this moisture source is linked to the development of microbiological activity and to the effects of salt hydration (see Sections 2.5 and 2.6).

Dew observations are rare, mainly because of the low quantities registered per dew night (in the order of 0.2-1 mm water per night) and the difficulty to measure them. Observations in the Negev Desert, Israel, indicated dewfall of 25-35 mm per year over 4 to 6 months. Figures from elsewhere range between 12-15 mm/year in Amman, Jordan, and 40 mm/year in Pretoria, South Africa. Dew deposition is obviously influenced by site conditions, in particular topography and surface roughness. It is not necessarily limited to coastal areas.

Dew, in contrast to rainfall, concentrates in a slow process on the soil surface during the night and early morning when evaporation is reduced to a minimum. Its action is strictly limited to the upper few mm to maximum 1 cm of the soil or rock surface, but because dew condenses and remains on the surface for some time it plays a major role in the activation and impact of microorganisms.

2.4. Wind

On a desert surface with little or no protection from vegetation the effects of wind action may be important. Because of variations in atmospheric pressure winds are often very strong, especially during the day. Some of these winds occur at more or less fixed periods in the year and get special names: *harmattan* (south of the Sahara), *sirocco* (North Africa and the Western Mediterranean), *chamsin* or *khamasin* (the Middle East), etc.

Wind action refers to 4 major processes which, in one way or another, affect soil formation: (1) deflation, (2) abrasion and erosion, (3) transport and (4) accumulation.

Deflation is the process whereby soil particles are taken up by the wind and displaced to another location. The process is affected by wind speed, nature of the soil surface, and particle-size or aggregation status of the surface.

The net result in terms of soil formation is loss of soil. In desert areas covered by physically weathered shallow soils, deflation, removes mainly the fine and medium-sized particles–clay and silt first, the somewhat coarser sand afterwards– and leaves behind a desert pavement, variously called *reg* (Sahara), *serir* (Libya) or *gibber plains* (Australia).

In semi-arid areas deflation is comparatively less important, except in places where vegetation is sparse, or is removed by man, or is overgrazed. The intensification of deflation processes in this part of the world can therefore be attributed to a large extent to man. The best known example of this is the famous Dust Bowl in Kansas and North West Carolina where, as a result of the introduction of mechanized agriculture in the 1930s, approximately 20-25 cm of fertile topsoil has been blown away in less than 20 years time. Along the same line it has been estimated that between 20 and 50 % of the soils in Iraq are impoverished in fine elements by wind action. Wang and Otsubo (in

Desertification in China) indicate that in North China wind deflation has tremendously increased between 1975 and 1985.

Abrasion and erosion: The dust-loaded wind has an erosive action and contributes to a physical disintegration of rock surfaces and monuments (see *Drylands and Desertification*) or to polishing of the components of the desert pavement, giving them a characteristic patina (*desert varnish*) and shape *(ventifacts*).

Wind transport: Wind-blown components are carried away over a more or less important distance as a function of wind velocity and particle size of the material. Wind speeds up till 6.5 m/sec transport dust and fine sand with a diameter of less than 0.25 mm; sand grains up to 1 mm diameter are uplifted at wind speeds of 10 m/sec. At 20 m/sec also particles of 4-5 mm may be removed. Based on these physical laws the transportation of coarse fragments, *in casu* the sand fraction, occurs over relatively short distances from the deflation zones by a process known as *saltation*. These sand grains settle then in more or less continuous layers and either become progressively mixed with the underlying soil layers, or accumulate in dune formations.

Medium-coarse particles are transported over relatively important distances of the order of a few 100 meters to more than 1000 km. Hence, aeolian deposits of silt-size material settle into a loess belt along desert fringes. This transported material may affect the chemical composition of the original product that has accumulated on top of the underlying rocks. Some anomalies referring to the relatively high base saturation (and high exchangeable Ca^{2+} content) in the surface layers of soils south of the Sahara may be due to the addition of Ca-saturated aerosol brought along with the *harmattan*.

The finest particles composed of fine silt and clay are carried over much larger distances. Using oxygen isotopes of aeolian quartz it has been shown that a non-negligible quantity of dust with an average diameter of 1-10 microns is transported by jet streams from desert zones over the rest of the world. Aeolian admixtures have been referred to explain the presence of SiO_2 in soils developed in non-quartz-containing volcanic rocks in Hawaii, Israel and southern Australia.

The issue of aeolian dust at higher altitudes has received renewed attention since it has been shown that it may bind radioactive elements like ^{137}Cs or ^{90}Sr after atomic explosion tests. This might implicate that such tests, even in as remote areas as the Nevada Desert or Pacific Ocean, may still have an impact on human health worldwide.

Accumulation: Though the process of wind action and transport of material is clearly recognized, it is difficult to measure its impact in the accumulation zones. Such measurements are most successful in the immediate neighborhood of the deflation zones where the thickness and volume of sand or loess deposits can easily be calculated. In the northern periphery of the Negev aeolian deposits range from a few cm to several meters which correspond to an average accumulation of 10 to 100 mm/millennium since the Lower Pleistocene (Dan and Yaalon, 1971).

2.5. Biological Activity

The main role of vegetation and biological activity as a soil forming factor is that their impact is comparatively small, though somewhat particular. The higher vegetation is composed of ephemeral grasses which can survive after a long dormancy period and then germinate after a local rainstorm to complete their growth cycle in a few weeks. These plants and the sclerophytes that survive aridity provide little organic material to the surface and almost do not play a role in soil weathering and horizon differentiation. Besides, there exist some salt-tolerant plants like *Atriplex* and a number of others (see: *The Use of Shrubs in Livestock Feeding in Low Rainfall Areas*) that accumulate salts in their above-ground system and thus modify the salt profile.

Biological activity from insects, lizards, snakes and rodents is limited as well, and mainly concentrates in the deeper soil layers where moisture remains relatively high and temperature fluctuations are reduced. Earthworms have by some researchers been considered as interfering in the development of gypsum accumulation layers in the profile.

The most important and most particular biological activity is, however, by microorganisms which concentrate by preference on surface stones and rocks, where they are called *lithophytes*. The number of these micro-biota in various deserts throughout the world is in the order of 10^3 to 10^6 per gram of soil (see: *Drylands and Desertification*), and in the Sahara alone French microbiologists have described more than 45 types of cyanophyceae, 70 types of chlorophyceae, 90 types of lichens and more than 300 of diatoms. Hence, deserts cannot be considered an a-biotic environment.

The first colonizers of a bare rock are often bacteria and green-blue algae. They dissolve some of the more soluble components in the rock through an exchange reaction between the acids they secrete and the nutrients they absorb (K from feldspars; P from apatite). Some bacteria are even capable of taking up Si from alumino-silicate clays. Diatoms are known to absorb amorphous silica and to store it in their structures.

Algae, in particular green-blue algae, and lichens form the bulk of the microflora in desert environments. Many of them can stand long periods of drought, but can also rapidly re-hydrate with a minimal amount of moisture, e.g. dew. They are less affected by temperature or light intensity for their photosynthesis. Algae form dense populations on the surface of arid soils and rocks, and they influence in many ways the soil properties. They can absorb and concentrate N from the air and make it available to plants. They can largely modify the soil pH, and can disintegrate organo-mineral compounds, silicate clays and even silica.

Algae, on the other hand, are also influenced in their development and activities by environmental conditions. Green-blue algae *Microleus* and *Nostoc* are predominant colonizers of a number of arid areas in the American South West, India and New South Wales (Australia), but are almost absent in many other parts of the world. *Azotobacter* is observed in many arid soils in Arizona, but disappears once the concentration of soluble Na in the soil exceeds 3000 mg/kg. Algae populations may also vary as a function of the season, as is the case in *takyr* soils where green-blue algae colonize the surface after the floodwaters have retreated. They are, however, rapidly replaced by a reddish variant at the moment the profile starts to dry out. Some algae, whether or not in association with lichens, form a soil crust and protect the soil from further drying out and from wind and water erosion.

Research from German microbiologists in the Negev, Israel, and reported in *Drylands and Desertification* has highlighted the role of algae and lichens, in particular the lichen *Verrucaria*, in the microbiological weathering and disintegration of rocks, and the formation of a desert patina on them. At the surface of a (siliceous) limestone the calcite is dissolved, but the quartz and silicate components are left undisturbed. The contact zone is colonized by a high amount of algae, lichens and actinomycetes and is enriched in Fe_2O_3 and MnO – two elements which do not occur in the underlying rock, and the presence of which can only be attributed to dust-fall. The latter observations seem to make the link between microbiological activity and the development of a dark-colored desert patina (see below).

2.6. Effect of Salts

All soils contain soluble salts, but their concentration is often no more than 0.4g/l of the saturated soil extract. The salt content of most arid soils is, however, much higher because, once present in the profile, they are difficultly removed under conditions where soil leaching is minimal.

Salts from desert soils originate usually from three main sources: (1) deposition of wind-blown salt spray or dust; (2) *in situ* weathering of salt-containing rocks or sediments, and (3) upward movement with the capillary flow from a shallow salty groundwater. Along the coastline some salt accumulation may occur through intrusion and flooding of seawater.

Saline soils vary considerably in their salt content, type of salt, structure and ease to be reclaimed. Dominant anions are chlorides, sulfates and carbonates, sometimes nitrates and bicarbonates. Sodium salts occur most frequently, but calcium and magnesium compounds are common as well, while mixtures of various salts and complex minerals are not exceptional. The non-salt solution contains mainly calcium salts (50-80 %); magnesium (15-35 %), potassium (2-5 %) and sodium (1-5 %) make up the remaining cations. In saline soils however the percentage of Ca^{2+} is lower, and the values of K^+, Mg^{2+} and Na^+ are higher.

Saline soils are often recognized in the field by the presence of a white surface crust, by damp oily-looking surfaces devoid of vegetation, stunted plant growth, and sometimes by tip-burn and firing of leaf margins. Soil analysis rather than visual observations are nevertheless needed to properly assess salinity.

Saline soils are characterized by their Electrical Conductivity (as an expression of salt content) and Exchangeable Sodium Percentage (ESP), and they are variously called saline or sodic (formerly alkaline soils in older literature) soils. The nature and properties of these soils have been discussed in full detail in *The Salinity and Alkalinity Status of Arid and Semi-Arid Lands.*

Besides their effect on plant growth and production, the presence of salts in the profile influences consistently soil properties and soil processes, in particular with respect to the water retention. Because of their capacity to absorb moisture from the soil they reduce the water available for weathering. They also affect the soil pH and, if Na^+ is the dominant cation, they adversely influence the soil physical condition, its infiltration capacity and aeration. Moreover, due to the volumetric expansion with variable temperature and moisture conditions, they interfere also in the physical disintegration of stones and rocks on the desert surface (see above and *Drylands and Desertification*).

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Bibliography

Arnon, I. (1973). *Crop Production in Dry Regions. Vol.1: Background and Principles*. Leonard Hill, London, 650p. [A good monograph on the desert environment and land use potential, and though it has been published more than 30 years ago, it is still an actual work].

CSSA (2004). *Challenges and Strategies for Dry Land Agriculture*. Special Publ. 32, Crop Science Society of America, Inc. American Society of Agronomy, Inc. 677 South Segoe Road, Madison Wisconsin 53711, USA. [Gives an excellent state-of-the-art on present land use options in drylands].

Dan, Y. (1973). *Arid Zone Soils.* In: Yaron, B., Danfors, E. and Baadia, Y., eds.: Arid Zone Irrigation. Chapman and Hall Ltd, London, and Springer Verlag, Berlin, pp. 11-28. [An excellent concise overview of soil genesis and soil distribution in arid areas].

Dan, Y. and Yaalon, D.H. (1971). *On the Origin and Nature of Paleopedological Formations in the Coastal Desert Fringe of Israel.* In: Yaalon, D.H., ed.: Paleopedology, Origin, Nature and Dating of Paleosols, Israel University Press, Jerusalem, pp. 245-260 [Report on eolian dust-fall in the Negev, and its interpretation in a paleo-historical context].

Evenari, M., Shanan, L. and Tadmor, N. (1971). *The Negev: The Challenge of a Desert.* Harvard University Press, Cambridge, Mass. [An excellent monograph on arid environments, with details of field research trials and measurements].

FAO (1989). *FAO-UNESCO Soil Map of the World at 1: 5,000,000: Revised Legend.* FAO World Soil Report 60, FAO, Rome, 119p. [Updated legend of the world soil map, with a definition of diagnostic criteria and a description of the main soil groupings].

FAO (1991). *World Soil Resources: An Explanatory Note on the FAO World Soil Resources Map at Scale 1: 25,000,000.* FAO World Soil Resources Report 66, FAO, Rome, 58p. [Interpretation of the FAO soil map units with reference to their production potential].

FAO-UNESCO (1974). *FAO-UNESCO Soil Map of the World. Vol. 1: Legend.* UNESCO, Paris, 73p. [First version of the FAO system of soil classification, conceived as the legend for the UNESCO soil map].

FAO-ISSS-ISRIC (1998). *World Reference Base for Soil Resources.* FAO World Soil Resources Report

84, FAO, Rome. [Technical manual containing definitions and criteria for classifying soil reference groups; the system has been continuously updated; for the latest version see: http://www.fao.org/landandwater/agll/wrb/wrbdocs.stm].

Figueira, H.L. (1982). *Study of Vesicular Structure in Arid Soils, North Patagonia, Argentina.* MSc. Thesis, International Training Centre for Post-Graduate Soil Scientists, Gent, Belgium, 76 [Report on a literature review and experimental study of the vesicular layer in arid soils, with application to Argentina].

Goudie, A. (2002). *Great Warm Deserts of the World: Landscape and Evolution*. Oxford University Press. [An overview of arid land geomorphology and landforms].

Kramer, R.A., Steiner, R.L. and Monger, H.C. (2005). *Mineralogical Distinctions of Carbonates in Desert Soils.* SSSAJ, 69:6 p 1773-1781 [A good overview of carbonate chemistry in desert soils].

Mabbutt, J.A. and Floret, C., eds. (1983). *Etudes de Cas sur la Désertification.* UNESCO Series: Recherches sur les Ressources Naturelles XVIII, UNESCO-PNUD, Paris, 291p. [Detailed description of the environmental conditions in deserts located in Tunisia, Chili, Niger, Rajasthan, Iraq, Pakistan, China, Australia, Israel and the USA].

McFadden, L.D., Eppes, M.C., Gillespie, A.R. and Hallet, B. (2005). *Physical Weathering in Arid Landscapes due to Diurnal Variation in the Direction of Solar Heating*. Geological Society of America Bulletin, 117: 161-173.[Describes physical weathering processes in desert environments].

Simmers, I. (2003). *Understanding Water in a Dry Environment: Hydrological Processes in Arid and Semi-Arid Zones.* International Association of Hydrogeologists/A.A. Balkema Publishers, Lisse, The Netherlands, 341p. [A reference book on the effect of rainfall, runoff and water flow processes on soil properties and soil management in arid and semi-arid zones].

USDA (1975). *Soil Taxonomy. A Basic System of Soil Classification for Making and Interpreting Soil Surveys.* US Department of Agriculture, Soil Conservation Service, Agricultural Handbook 436, Washington DC, 754p. [Background document explaining the concept and structure of Soil Taxonomy; the system has undergone several updates and modifications; see: http://soils.usda.gov/technical/classification/taxonomy].

Biographical Sketch

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