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Clay distribution over the landscape of Israel: From the hyper-arid to the Mediterranean climate regimes

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ABSTRACT

The current study evaluates clay distribution in modern surface sediments, mainly soils, to which desert dust is a major contributor. The mineralogical composition of the clay fraction of seventy seven samples was analyzed by X-ray diffraction. Twenty nine soil and dust samples were also analyzed for their bulk chemical composition. The samples are settled dust, soils developed on various sedimentary rocks, stream and lake sediments. They were collected along a climate gradient from hyper-arid to Mediterranean regimes in Israel. The purpose of the study is to decipher the main factors that control variable clay distribution along this gradient including annual precipitation, substrate type and topography. The common clay composition for most samples, of all sources, is illite–smectite (IS) > kaolinite > illite. Trace amounts of chlorite, palygorskite, goethite and quartz might be present. Pedogenic processes are recognized even under arid climate where loessial soils display kaolinite depletion and more illitic IS phases than dust. Two main processes shape clay composition under a Mediterranean climate regime, regardless of the parent material. A smectitization process occurs in leached, low-permeable clayey soils, and reaches optimum evolution with ~90% smectite, or smectitic IS. This evolutionary trend is also recognized in poorly-drained soils of catenary chains that are related to other soil types like terra rossa, hamra and pale rendzina. Kaolinitization and apparently illite pedogenic formation occur in well-drained red Mediterranean soils of the terra rossa and hamra types to the detriment of smectitic IS phases of parent materials. In the most evolved terra rossa and hamra soils kaolinite becomes the principal mineral and illite is significantly enriched. Pedogenic evolution of the clay fraction mineralogical composition affects bulk chemical composition of most soil types. Clay inheritance from the bedrock is rather limited in leached soils. It is widely recognized in pale rendzina soils by the presence of smectite, or smectite and palygorskite, derived from late Cretaceous or Eocene chalks, respectively. Streams' clay composition, like that of dust, is fairly uniform, as streams average various sources across their drainage basins. However, composition variations can be attributed to local contribution from certain sources.

1. Introduction

Soils are an essential component of the critical zone (Brantley et al., 2007) where they continuously respond to changing atmospheric and hydrological conditions and biological activity (Jenny, 1961). As such they are sensitive to environmental fluctuations, to changing global conditions, and to the impact of man-made interventions (Cambardella and Elliot, 1994; Rasmussen et al., 1998; Singer and Warkentin, 1996). From a sedimentological point of view soils provide a historical record of the influences of climate and biological activity upon the parent material from which the soil is formed. Hence soils are a key tool for reconstructing past paleoenvironments recorded in young sedimentary successions (e.g. Huang et al., 2012; Hugget, 1998).

Furthermore, soil erosion transports clays and other fine material into rivers and streams, and finally into aquatic basins, like lakes and seas, or into land sinks, like alluvial fans and river banks (e.g. Weaver, 1989). The latter environments may often turn, under preferable conditions, into newly formed soils. Hence, the recognition, identification and distribution of clays in soil types and associated surface materials such as dust and stream sediments are essential for studying critical zone processes, environmental issues and the near past sedimentological history of a region.

Clay minerals generally form from aqueous solutions interacting with other, pre-existing silicate species by dissolution–recrystallization processes (Velde and Meunier, 2008). In the framework of soil formation this process has been traditionally described for crystalline bedrocks and occasionally for sedimentary rocks. Recently, the contribution of airborne fine particles, namely dust, to soils has received greater attention (Cattle et al., 2002; Dreise et al., 2003; Erel and Torrent, 2010; Huang et al., 2011; Muhs et al., 1990). In regions subjected to substantial dust accumulation, such as the Middle East,

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dust may become a major parent material of soils (Yaalon, 1997; Yaalon and Ganor, 1973). Yet, there are hardly any regional studies that are dedicated to the mineralogical variability of the clay fraction composition and soil-forming processes where the major parent material is settled dust, or recycled settled dust. Nor there is a published study which examines such variability, and especially that of illite–smectite composition, along a climatic transect. The soils of Israel extend along a strip that starts in the sub-Saharan desert belt in the south and ends in the wet Mediterranean climate regime in the northern mountainous summits. The fate of clays incorporated in soils can be, therefore, evaluated on a variety of substrate rocks, landscapes and climatic regimes.

The current paper summarizes and interprets data on the mineralogical composition of clay fraction in soils and additional modern surface sediments as streams and lakes. The chemical composition of selected soils is discussed with relation to the pedogenic processes that shape mineralogical composition of the clay fraction. The Israeli nomenclature (Dan and Koyumdjiski., 1979; Dan et al., 1976) is used to refer to the soil types. All data were analyzed and interpreted by the author; most of it is new and some are quoted from former publications.

The aim of this study is to provide a basic framework, which utilizes current clay terminology, for interpreting sources and processes that shape the abundance and distribution of clays in soils and other surface sediments along a climatic transect. The study outlines new basic concepts for evaluating composition variability within the same soil types and among different soil types residing in limited geographic units. These concepts may also serve as reference guidelines for further research on clay composition of Quaternary sediments and buried soils in Israel and the Middle East.

2. Climatic, geologic and pedologic background

Israel extends along several climatic zones from latitude 29°30′ in the south to 33°15′ in the north (Fig. 1). The annual mean precipitation increases from nil in the south to 950–1000 mm on the Galilee summits in the north (the Hermon Mt. was not included in this study). The rainy season extends from September to May, whereas maximum monthly rainfall usually occurs from December to February (Goldreich, 1995). Dust storms that bring desert dust to the east Mediterranean occur in three major synoptic systems in the spring, fall and winter: the Red Sea trough, the Sharav cyclone, and the cold depression, respectively (Dayan, 1986; Formenti et al., 2001). Eolian desert dust is derived from North African and Arabian deserts (Ganor and Foner, 2001; Israelevich et al., 2003). Most of the atmospheric dust is deflated from topographical lows or lands adjacent to topographical highs (Maher et al., 2010; Prospero et al., 2002; Yaalon and Ganor, 1979).

The annual flux of settling atmospheric dust to Israel was estimated to be 30–200 g m^{-2} y^{-1}, decreasing northward (Ganor and Foner, 2001). The coarse-grain fraction of dust is usually dominated by quartz, carbonates and feldspars, whereas the fine-grain fraction is dominated by clay minerals (Crouvi et al., 2008; Ganor, 1991; Ganor and Foner, 2001; Singer et al., 2003). Dust is settled upon the landscape surface, incorporates into existing soils and sediments, and accumulates on hard rocks (e.g. Dan, 1990; Danin et al., 1983). Most of the clay and silt fractions of red sandy soils along the coastal plain are of eolian origin (Dan et al., 1969) and so is the origin of brown soils developed on calcrete at the upper catenary position (Dan et al., 1972). In other Mediterranean soil types the insoluble residue from substrate also contributes to the fine material. Based on clay-to-silt ratios in dust, in the insoluble fraction of limestone and in soils, dust contribution to terra rossa soils was estimated to vary from one-third to two-fifths (Yaalon and Ganor, 1973). By comparing rates of dust accretion to hard limestone dissolution it was estimated that eolian material makes up to 50% of the fine fraction in soils on hard limestone rocks (Yaalon, 1997).

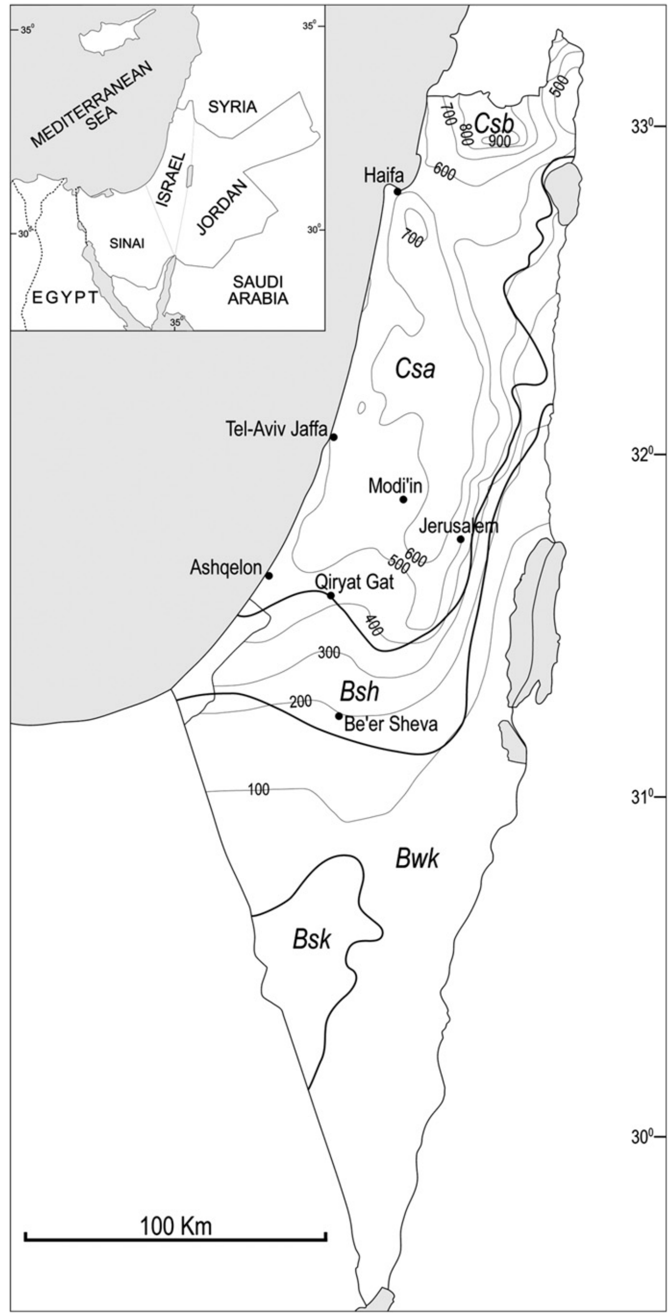

Fig. 1. Map of climatic zones and average precipitation of Israel. The climatic zones are according to the Köppen classification (modified after Goldreich, 2003). Csa = Mediterranean climate a, Csb = Mediterranean climate b, BSh, semi-arid hot climate, BSk = semi-arid cold climate, BWh = arid hot climate. The 100 mm isohyets are annual averages for 1981–2010 (modified after Israel Meteorological Service http://www.ims.gov.il/IMS/CLIMATE/ClimaticAtlas/RainMaps.htm).

The central backbone of Israel (the Negev and Judea anticlines, Mt. Carmel and the Galilee Mts.) exposes mainly Cretaceous to Eocene rocks. Quaternary colluvial–alluvial sediments are accumulated along the western foothills and fill the mountain valleys. The Mediterranean coastal plain consists mainly of sand, calcareous sandstone and sandy soils (Fig. 3). Thick loess deposits (the loess belt) were deposited at central Israel due to the conversion from semi-arid to semi-humid climates (Fig. 3). There, well-differentiated soil profiles characterize the primary eolian loess, whereas poorly differentiated profiles characterize the re-deposited fluvial loess (Crouvi et al., 2008, 2009; Yaalon and Dan, 1974). Toward the south, loess deposits decrease in thickness