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THE APPLICATION OF THE CATENA CONCEPT IN STUDIES OF PEDOGENESIS IN MEDITERRANEAN AND DESERT FRINGE REGIONS

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INTRODUCTION

The soils of Israel exhibit considerable variability within a limited morphogenetic zone. Detailed field and laboratory studies of several hillslope sequences on various parent materials established the significance of the relief factor in soil differentiation. Following the study of all members of the continuous hillslope sequence, detailed mapping (1 :5,000 and 1 :10,000) of selected areas demonstrated the variability and typology of the catena in the landscape.

Two main types of catenas are widely distributed. Under conditions of sufficient relief difference the complete sequence is found, and the scarp face of the pediment backslope (Ruhe, 1960), which is covered by shallow lithomorphic soils, gains prominence. Under conditions of moderate relief the free face is altogether missing, and the slopes are covered with deeper and more developed soils. Combinations of forms between these two main catena types are found depending on the nature of the parent material, rate of erosion and other morphogenetic processes.

In the present paper a brief description of the catenary soil development in three landscapes is given and discussed. The soil classification of Dan, Koyumdjisky and Yaalon (1962) is used throughout. Some geographic aspects of soil distribution in Israel have been recently published (Dan and Koyumdjisky, 1963). In addition to the main factors responsible for the catenary development which were listed briefly by Milne (1936), the modifying effect of aeolian deposition and accelerated erosion will be discussed. The implications of the spatial soil differentitation as viewed by the concept of dynamic equilibrium and adjustment will be examined.

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CATENARY SOIL DEVELOPMENT IN THE MOUNTAINOUS REGIONS

In mountainous regions unstable retreating catenas characterize bare steep slopes on soft calcareous rocks. Soils of the pediment backslope are lithomorphic while on the footslope young colluvial-alluvial soil material accumulates. On hard carbonate rock, including the caliche which may develop due to slope stabilization into chalky and marly areas, shallow developed soils occur. In the Mediterranean climatic zone mainly fine textured terra-rossa and brown rendzina soils are formed, and in arid areas shallow silty light brown soils. Colluvial-alluvial and alluvial soil material accumulates on the footslope and toeslope. Soils of these slope elements exhibit only slight profile differentiation.

On moderate slopes other catenas prevail. The moderately sloping upland is slowly covered by deep medium to fine textured orthogenic soils including grumusols in the Mediterranean climatic zone, dark brown grumusolic soils in the semi-arid areas loessial brown soils and loessial serozems in the arid part of the country. The pediment backslope is less evident and may even disappear altogether. Deep soils similar to those of the upland are found on the footslope and toeslope. The typical footslope, covered with stony and gravelly soils, disappears altogether with the pediment backslope.

The process of changing a steep catena into a moderate one is fairly rapid in the semiarid and moist parts of the arid zone. In these areas deepsoils cover moderate to steep slopes, while in the Mediterranean and the ex- tremely arid zones such soils are restricted to completely level uplands and toeslopes.

CATENARY SOIL DEVELOPMENT IN THE COASTAL PLAIN

The Coastal Plain of Israel is characterized by a series of ridges running parallel to the Mediterranean coastline. The ridges are derived from coastal sands accumulated during the Pleistocene. They decrease in age from east to west (Itzhaki, 1961). A number of different soils covers this area, whose properties vary according to climate, slope position and age of sand accumulation (fig. 1).

Recent sand dunes characterize the area adjacent to the coast. Behind the dunes sandy and regosols further on sandy hamra are formed on young sandy deposits. The typical catena on still older dunes (Middle to Late Pleistocene) in the Mediterranean climatic zone consists of sandy clay loam hamra on moderate slopes, sandy hamra on steep slopes, nazaz on footslopes, and hydromorphic grumusols in the swampy bottomlands. Nazaz and grumusols become more widespread towards the hills in the east, and leached residual dark brown clay loam is found there on moderate slopes. At the eastern edge of this part of the Coastal Plain grumusols cover the whole area.

Going southward into the semiarid climatic zone the older ridges are covered mainly by residual dark brown clay loam, while on the footslopes accumulative dark brown clay loam soils occur. Pararendzinas develop on steep hilly slopes. Dark brown grumusolic soils characterize most of the moderately sloping hills in the eastern part of this area. The fine textured sedi-

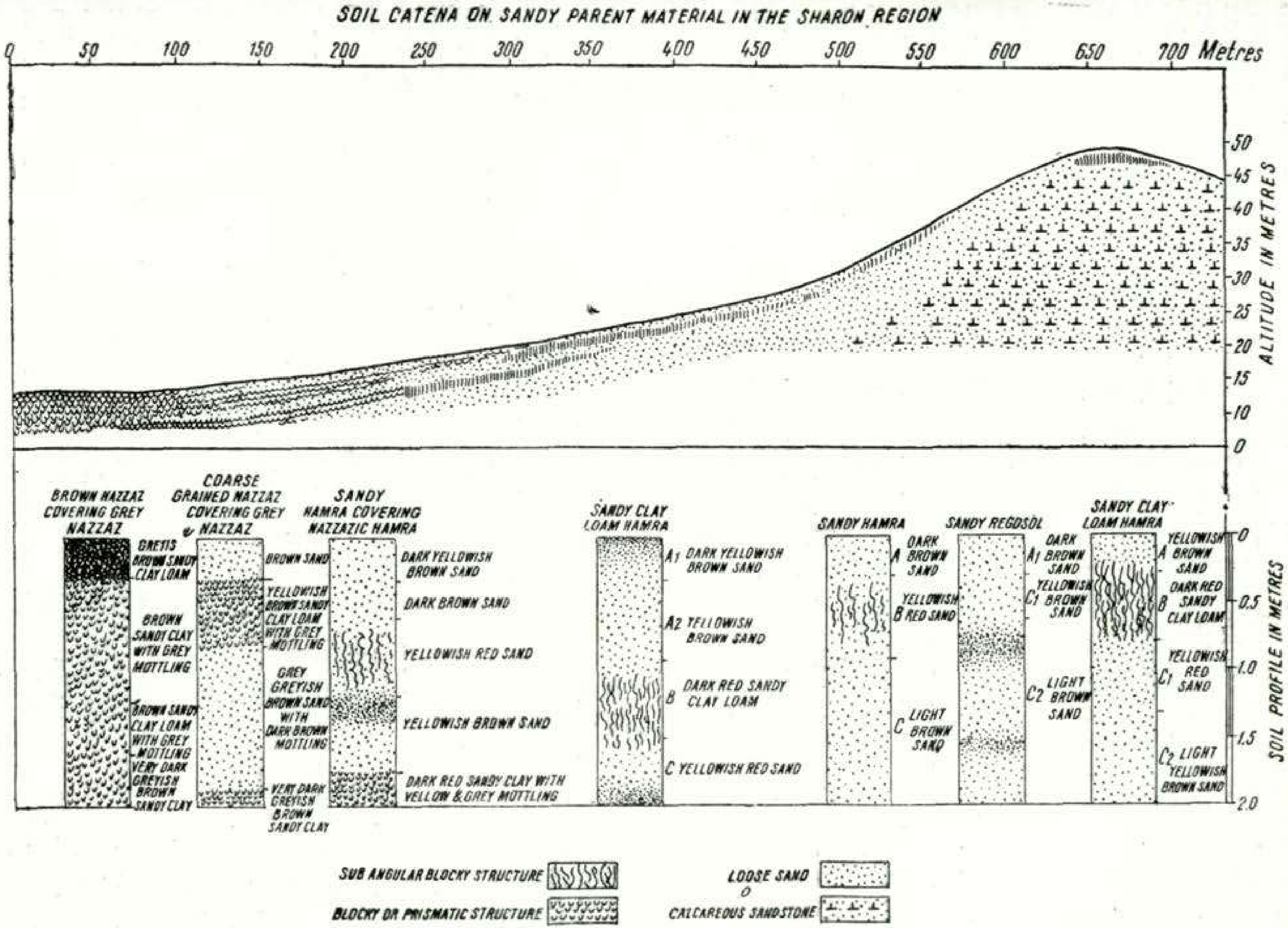

Fig. 1. Catena in the Mediterranean Coastal Plain of Israel showing relationships of landscape elements and soil type.

ments covering the sand or sandstone get thicker towards the east and south, reaching a thickness of up to 20 m.

In the arid southern part of the Coastal Plain brown loessial clay loam characterize most of the moderate slopes, while young redeposited loessial soils occupy the valleys and depressions (fig. 2). These soils are underlain, like the dark brown grumusolic soils, by clay and clayey paleosols. Sandy soils and soils which originated from sandy parent material are restricted to steep slopes in the western part of this area.

CATENARY SOIL DEVELOPMENT IN THE NEGEV DESERT

Psammic soils and various lithosols are widespread in the Negev. Going southward they appear first only on the southern and steep northern slopes, while loessial serozems cover the plateaux and moderate northern slopes. Still further to the south the loess-derive soils are confined to depressions only,

In the extremely arid zone loessial soils disappear altogether. Stony regs characterize the plains and plateaux, while stony and gravelly desert alluvium covers the valleys, depressions and alluvial fans. Steep slopes are bare and devoid of soil; moderate slopes are rare or even non-existent. Fine textured silty soils are confined to terminal drainage basins (fig. 3).

MODIFYING EFFECT OF AEOLIAN DEPOSITION

Most of the silt and often also the clay material in the soils of Israel originated from aeolian dust, which accumulates to the present day. Dust accumulation is slow in the Mediterranean climatic zone which is far away from the desert source, whereas it is most rapid in the southern semiarid and arid desert fringe regions. In the extremely arid parts it is again restricted, because of the sparse vegetation and confined to moister sites of northern slopes and depressions. The nature of the dust varies according to the distance from the desert source. Farthest away it is fine textured and the deposited material weathers to form clayey soils. On the fringe of the desert, typical silt texture prevails forming silty or even very fine sandy soils.

The age and nature of the landscape has a pronunced effect on the amount of dust accumulation. Accumulation is more extensive on the older coastal ridges, and gently sloping landscapes may be completely covered by a thick aeolian blanket. In dissected mountainous areas dust accumulation and soils formed from it is mainly restricted to some level uplands and depressions.

Much of the primary dust is eroded by runoff water and redeposited in valleys and depressions. Many of the soils in such depressions are immature and receive continuous accretion. On plains and moderate slopes the redeposited material is incorporated into the well differentiated soil profiles. On steep unstable slopes or on young sandy sediments the dust accumulation is slow or non-existent.

Airborne salt accumulation is another active modifying factor in the development of the soils (Yaalon, 1963).

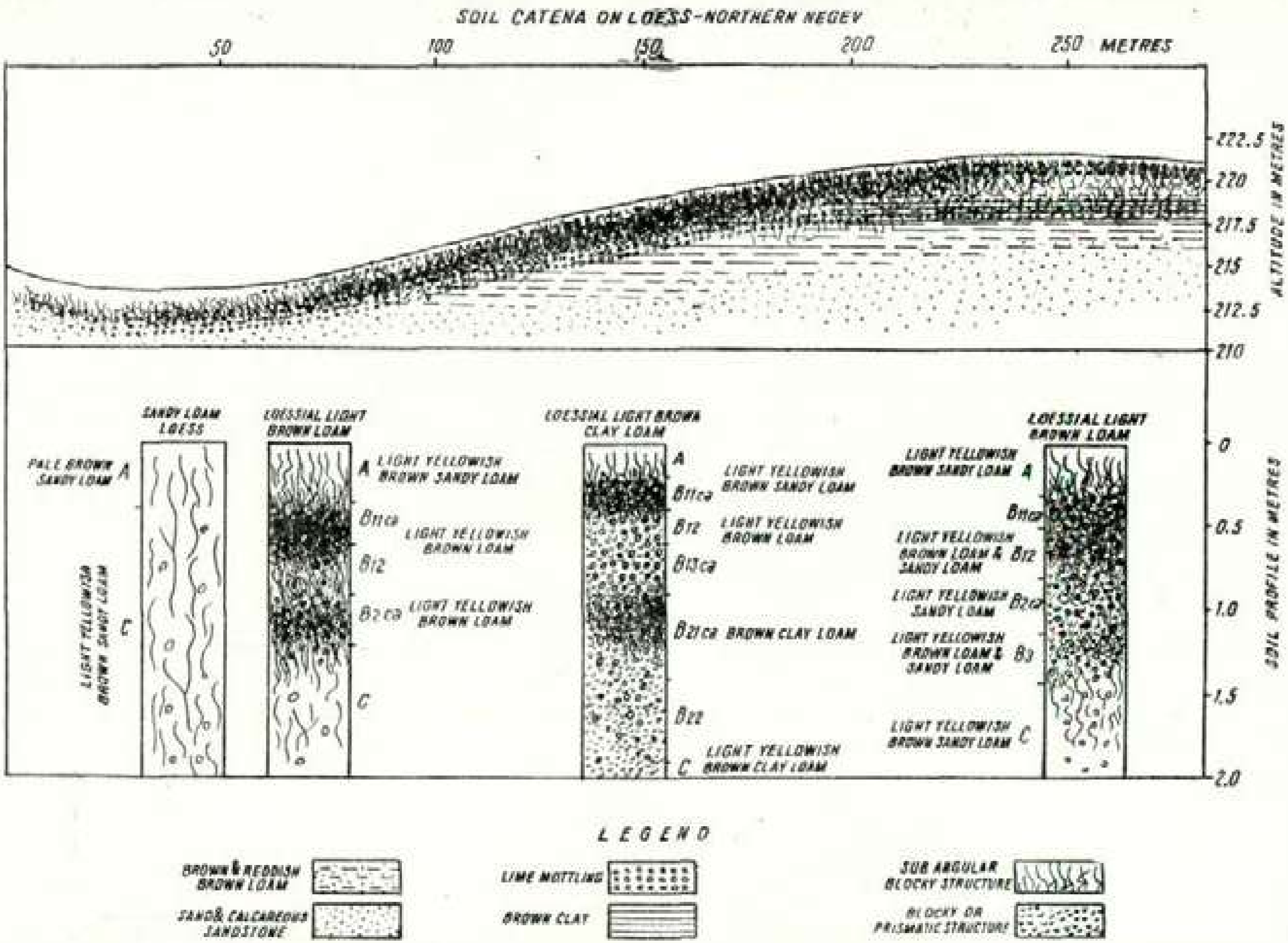

Fig. 2. Soils of a typical catena developed on loess material in the semiarid Northern Negev. Drawn to scale.

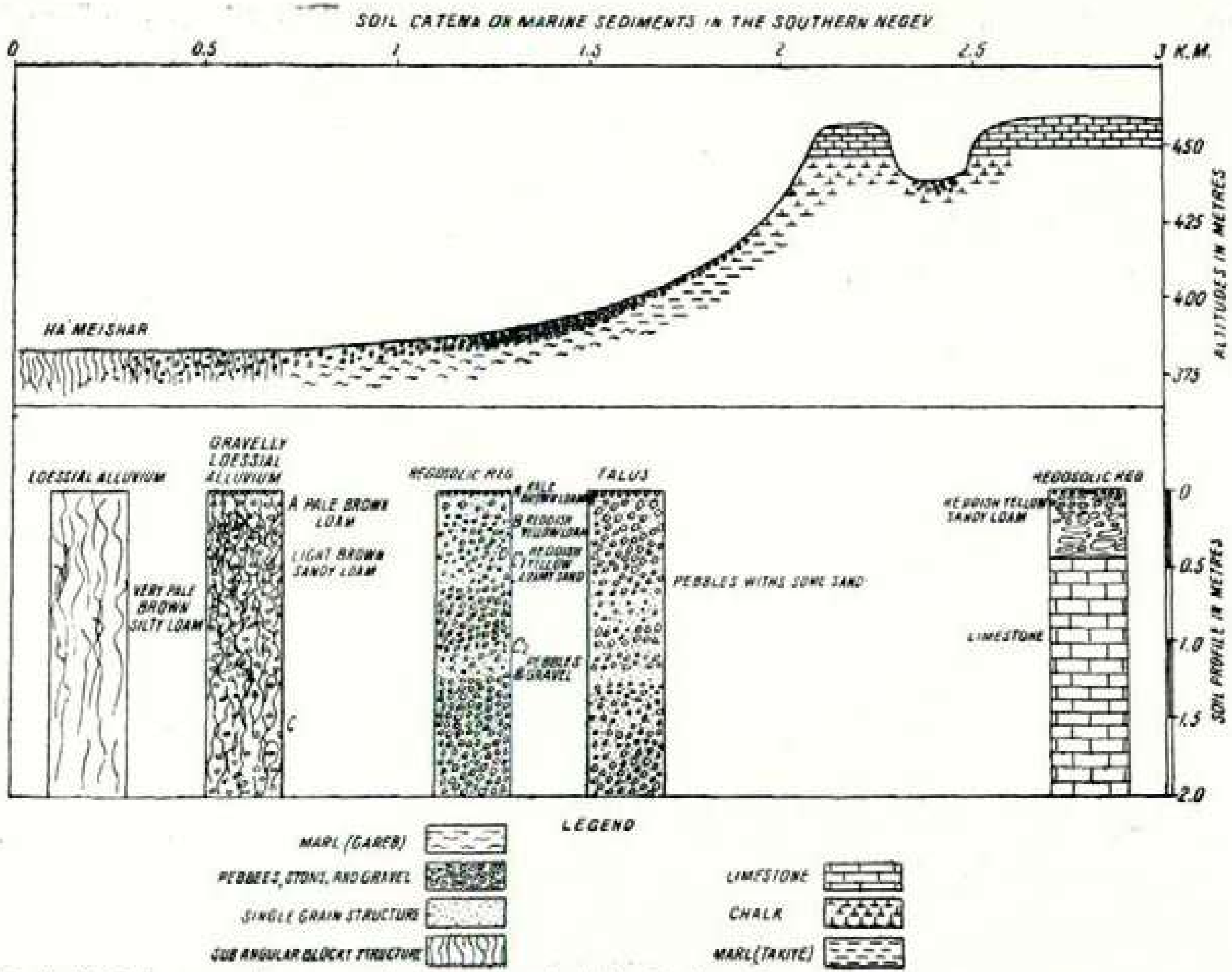

Fig. 3. Typical cross-section on carbonate sediments in the Southern Negev desert showing relationship between nature of bedrock, landscape element and soil type.

MODIFYING EFFECT OF ACCELERATED EROSION

Many catenas are altered as a result of accelerated erosion. Erosion has cut into moderate slopes so that new steep free faces were exposed, often revealing several paleosols formed on various Quaternary sediments. The effect is most evident in the undulating to hilly Coastal Plain.

The accelerated erosion began as result of the destruction of the natural vegetation and improper land use (Reifenberg, 1955). The disturbance of the natural equilibrium increased and locally concentrated surface runoff and the slopes acquired the properties of a derivation slope (Holmes, 1955). Erosion stoopped when hard rock was exposed which imparted to some slope sections again the character of a wash slope. Similar erosion cycles are common on sandy sediments (Rim, 1955). It is possible to compare this situation with the normal erosion process that characterizes the extremely arid zone. In all these cases erosion and mass movement is unhindered because of sparse vegetation. Moderate slopes are rejuvenated and the free scarp face retreats rapidly until a new adjustment is attained.

THE CATENA CONCEPT AS A FRAMEWORK FOR PEDOGENETIC INTERPRETATION

The habitual formula of soil formation describes it essentially as a differentiation of genetic horizons in the vertical plane. It largely ignores that soil formation involves also a spatial differentiation along hillslopes and a steady flux of airborne components. Since the spatial differentiation of soils is congruent with landscape development, the members of a catena must not be identified with successive stages of soil development. The catena as a whole is developing in response to the action of the environmental factors acting on the particular parent material. The pattern represents a series of mutually adjusted members, whose different properties are brought about by drainage conditions, differential transport of eroded material of mobile chemical constituents.

Applying the dynamic equilibrium concept of landscape evolution (Hack, 1960) to the soil catena, it follows that the morphology of each member is determined by its position in the landscape and related to its adjoining members. Each catenary member is continuously adjusting to the given dynamic conditions (Yaalon, 1960) and the catena as a whole is subject to readjustment to any change in the environmental factors.

Acknowledgements.

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SUMMARY

Soil catena relationships in the Mediterranean and desert fringe regions of Israel were investigated. Soil properties were related to the processes responsible for landscape and slope development. Aeolian dust accumulation and its redeposition by erosional agencies is the major modifying factor. The rate of dust accumulation is most rapid in the semi-arid and mildly arid desert fringe areas, slow in the Mediterranean climatic zone and practically non-existent in the extremely arid desert. The interrelationship between aeolian accumulation, the nature of the underlying parent material, relief and age of the landscape is responsible for the development of a whole spectrum of soil catenas. The spatial differentiation of soil properties along a hillslope was related to the respective landscape elements and was used in the interpretation of the processes acting in soil morphology development. It is concluded that the catena as a whole interacts with the environmental agents and is subject to continuous readjustment with time and changing conditions.

RÉSUMÉ

On a fait des recherches sur les rapports des catenae de sol dans les régions de la Méditerranée et au bord du désert d'Israel. Les propriétés du sol ont été rapportées aux processus qui entraînent le développement du paysage et des pentes. Le facteur modifiant majeur en est l'accumulation éolienne de la poussière et sa redéposition par des agents d'érosion. La proportion d'accumulation de la poussière est plus rapide dans les contrées semi ou modérément arides des bords du désert, lente dans la zone climatique méditerranéenne et pratiquement inexistante dans le désert extrêmement aride. La différentiation spatiale des propriétés du sol le long d'un versant a été rapportée aux éléments du paysage et a été employée à interpréter les processus qui se déroulent dans le développement de la morphologie du sol. On a conclu que la caténa dans son entier et les agents du milieu s'influencent réciproquement et la caténa est sujette à de continuels réajustements avec le temps et les conditions changeantes.

ZUSAMMENFASSUNG

Bodenkatenenbeziehungen in den Mittelmeer- und Wüstenrandgebieten von Israel wurden untersucht. Die Bodeneigenschaften wurden zu den für Landschaft und Hängeentwicklung bestimmenden Vorgängen in Beziehung gebracht. Die äolische Sandanreicherung und ihre Wiederablage durch Erosionselemente ist der hauptsächlich verändernde Faktor. Die Geschwindigkeit der Staubakkumulierung ist am höchsten in den halb- und semiariden Wüstensaumgebieten, langsam in der Mittelmeerklima-Zone, und in der äussersten ariden Wüste praktisch überhaupt nicht vorhanden. Die Wechselbeziehungen zwischen äolischer Anhäufung, der Natur des unterliegenden Ausgangsgesteins, dem Relief und dem Alter der Landschaft bedingt die Entwicklung mannigfaltiger Bodenkatenen. Es wird die Schlußfolgerung gezogen, dass die Katena — als Gesamtheit — mit den Umgebungsfaktoren zusammenwirkt und fortwährenden Wie dergestaltungen, die durch Zeit und veränderliche Verhältnisse bedingt sind, ausgesetzt ist.