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Red Mediterranean soils in some karstic regions of Taurus mountains, Turkey

I. Atalay

Dokuz Eylül University, Buca Faculty of Education, Department of Geography, 35150 Buca, Izmir, Turkey

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Abstract

Red soils are found along fractures and between bedding surfaces in karstic regions of both Mediterranean and Aegean regions of Turkey. These soils are very unique and information on pedogenesis in karstic regions are rather limited. Detailed field works were carried out at 17 locations, soil profiles were examined at 14 sites, and 7 of these were reported here. Soil samples from the A and B horizons of these soils are used to detailed characterization analyses in the laboratory. Occurrence of normal soil profiles were unusual in the study regions. The fractured structure of limestone leads to unusual water and air circulation. When water penetrates into rock fissures and holes and diffuses into sedimentary layers, in situ weathering processes take place. Rock fissures and holes may also be filled in by the transport of soil materials from higher elevations.

Sedimentary petrology and mineralogy of limestones are the factors that control the course of the pedogenesis. Oxidation of Fe, especially sulfides (pyrite) accelerates the soil formation in limestones. Soils are not present on massive and fractured or fissured limestones, and thin and stony red soils are common only at the bottom parts of "V" shaped dolines. However, soils are thick and common within the materials that have alternating marl and sandy–silty layers. Vertical movement of soil particles towards the deeper parts of the limestone takes place, as a result of the widening of the lapiés which are mostly formed along the fractures.

Most of the red soils in the studied karstic regions were likely developed during the Tertiary and hot and humid periods of the Quaternary epochs. Large body of soils which are found in deep limestones suggest their formation under paleoclimatic environments.

Keywords: karstification; soil formation; Red Mediterranean soils

1. Introduction

Taurus mountains rise up to 3000 m abruptly from the Mediterranean coast. A major part of the mountains is composed of limestones of different geological times and

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lithology. During the Mesozoic era, the area was occupied by Tethys geosyncline and magma erupted in the ocean floor produced ultrabasic rocks composed of peridotite–serpentine on which carbonates were accumulated continuously (Ilhan, 1976).

Toward the upper Mesozoic, a regression occurred by the early Alpine tectonic movement. During Eocene, areas of the Mesozoic terrains were occupied by a sea in which carbonates accumulated, especially in the western part of the Taurus mountains. The middle part of the Taurus was occupied by a shallow sea during the lower Miocene and carbonates containing more silicate clays were accumulated. Taurus mountains were subjected to vertical tectonic movements in Pliocene and early Quaternary epochs. Consequently, the western part of the mountains were collapsed and the present day tectonic basins were formed (Fig. 1), some of these have been occupied by lakes, such as Beysehir and Egridir (Atalay, 1987a,b).

The study area has the typical Mediterranean climate (xeric moisture regime). More than half of the annual precipitation falls during the winter period, totaling over 1000 mm. This amount increases on the slopes facing south and southwest. Climax vegetation is *Pinus brutia* forest; destroyed areas were covered with maquis vegetation which mainly associated with *Quercus coccifera*, *Arbutus andrachne*, *Arbutus unedo*, *Laurus nobilis*, *Pistacia terebinthus*, *Mrytus communis*, *Olea europea*, *Styrax officinalis* and *Ceratonia siliqua* (Van Zeist and Bottema, 1991; Atalay, 1994).

Red soils formed under the Mediterranean climate are recognized in early soil classification system by Baldwin et al. (1938). These soils are frequently referred to as Terra Rossa or Red Mediterranean soils (Robinson, 1949) and defined by their specific pedogenic processes, properties and qualities. In geomorphological textbooks (Thornbury, 1969) and even recent studies these red soils are recognized as the red clayey residue from dissolution of limestones (Bronger and Bruhn-Lobin, 1996).

Addition of aeolian sediments (dusts) from Sahara is emphasized by Yaalon and Ganor (1973), Yaalon (1987), Stahr et al. (1989), and Jahn et al. (1991). Several authors have explained the genesis of Red Mediterranean soil by addition of allochthonous material — for the real Mediterranean area (Kubiëna, 1970) and for southern Indiana, USA (Olson et al., 1980).

The regular Red Mediterranean soils are not found on the steep slopes of the karstic lands which are widespread in the Taurus mountains, in Turkey. But these land surfaces are covered with forest and maquis vegetation, under the natural conditions. There are two major points we need to address here:

(1) Although the land surface is very steep there may be thin soil cover under the forest canopy. The presence of thin and stony soils are attributed to natural and especially accelerated erosion by anthropogenic activities. One can hypothesize that bare karstic lands were exposed due to soil erosion and thus transported soil materials were accumulated within wide fractures and in the karstic depressions. But, this explanation is not sufficient, because of the fact that all rainfalls infiltrate along the fractures and can cause the soil formation in situ (Atalay, 1988; Atalay, 1991; Atalay et al., 1990). There is no runoff, even under a heavy rainfall. Indeed, although the amount of mean annual precipitation is over 1500 mm on the upper slopes, there is no evidence for runoff, in the Taurus mountains facing south.

(2) Sedimentary petrology and mineralogy of the karstic limestone appear to be very

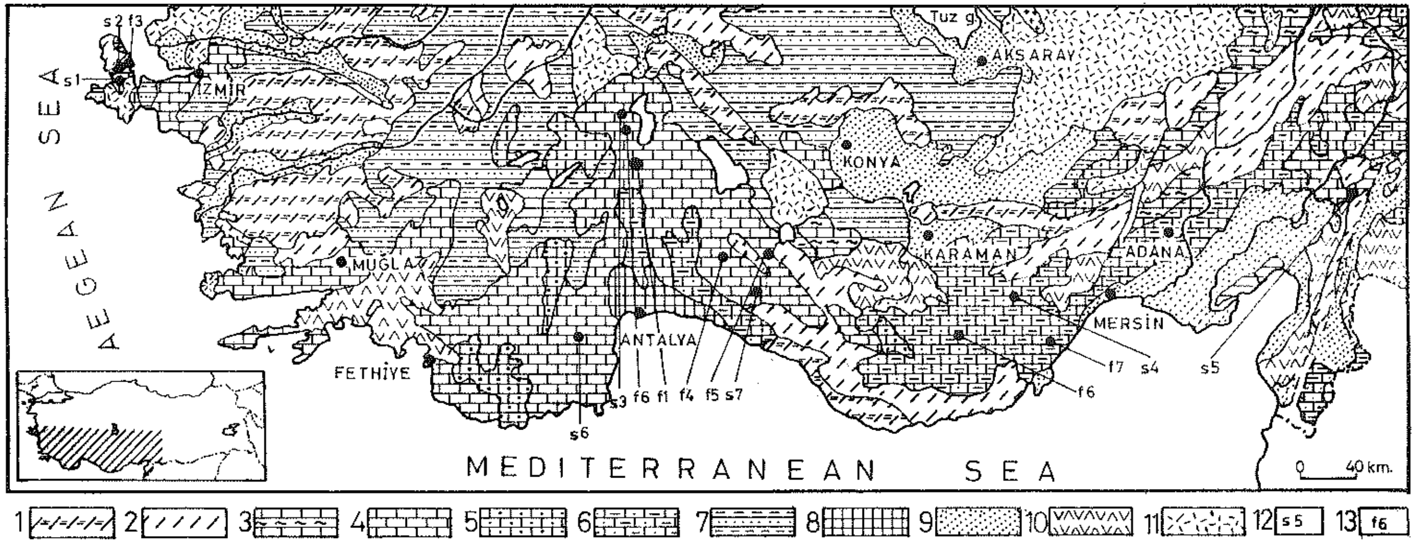

Fig. 1. Geological map, location of soil samples and figures. 1 — Paleozoic metamorphic schists (gneiss, quartzite, mica schists), 2 — epimetamorphic schists, 3 — Paleozoic hard and bluish limestones, 4 — Mesozoic limestones (mostly comprehensive series), 5 — Tertiary (lower Miocene) clayey limestones, 6 — Tertiary (Neogene) clayey and sandy limestones, 7— Neogene marl and soft limestones, 8 — Quaternary travertine deposits, 9 — alluvions, 10 — ophiolites (serpentine and peridotite), 11 — volcanic rocks, mostly andesites, 12 — soil sample sites, 13 — figure sites.

significant in soil formation. It is known that water easily infiltrates along the fractures. Therefore, soil formation does not proceeds on steep slopes, because of the fact that water is not detained on the bare surfaces and also weathered materials are transported along the slopes by gravity and water transport. Soil develops along the fractures and between the layers, as water remains in thin fractures and between the surfaces of sedimentary layers. Silicate clay minerals which are the minor constituents in the limestone and the other primary minerals, such as quartz, remain in place when limestone is dissolved (Atalay, 1989b; Bronger and Bruhn-Lobin, 1996; Gerrard, 1981; Jenning, 1985; Kapur et al., 1979; Olson et al., 1980; Özbek et al., 1976; Robert, 1993). The limestone residue is generally clayey and soils derived from this material are also clayey in texture.

The objective of this work is to provide further explanation regarding the pedogenesis of Red Mediterranean soils in the karstic Mediterranean regions of Turkey.

2. Materials and method

Detailed field studies were conducted at 17 locations of the karstic regions of south and southwestern Turkey and soil profiles were examined only at 14 sites (Fig. 1), by considering stratigraphical and lithological properties of the study regions. Samples were collected from 14 different locations. However, 7 soils are reported here (Table 1). Soil pH (1 : 1 H_2O), and cation exchange capacity of only clay size particles (< 2 μm) were determined according to Thomas (1982), $CaCO_3$ content by Nelson (1982), and mechanical analysis by Day (1965). These analyses were carried out at the Forest Soil Research Laboratory in Eskisehir.

Clay mineral composition from selected soil horizons were determined using a Philips X-ray diffractometer in the Laboratory of Soil Science Department, Faculty of Agriculture, Çukurova University, using the method described by Jackson et al. (1981). Diffraction patterns of oriented clays were obtained using a Cu-K_α radiation. Estimation of the clay minerals was semi-quantitative and based on the relevant major peak heights.

3. Results and discussion

Based on our field work and laboratory analyses, we concluded that there are several factors affecting pedogenesis in the Turkish karstic landscapes. These are described in the following.

3.1. Physical and chemical properties of the karstic soils

As can be seen in Table 1, the examined soils were clayey in texture ($>$ 40% clay), but some soils were clay loam and silty clay (sites 2 and 4), and contained no or little carbonates in the horizons that were designated as A and B. The soil pHs were near neutral (pH 6.1 to 7.7). Under the same climatic regime, the soils which have been developed from marl are alkaline in reaction. But soils may have alkaline reaction in the

Table 1
Physical and chemical properties of the selected seven karstic Red Mediterranean soils in Mediterranean and Aegean regions of Turkey

Site, parent material, and elevation above sea level (m)	Horizon	Texture [a]	pH	$CaCO_3$ (%)	CEC [b] ($cmol_c\ kg^{-1}$)
(1) İzmir–Çesme road, limestone, 400 m	A	c	8.0	1.5	36.2
	A	c	7.8	–	34.2
(2) Karaburun peninsula, W of Aegean region, limestone cracks, bedding surfaces, top soils, 20 m					
	A	cl	7.0	1.5	31.5
	A	c	8.2	1.5	31.3
	A	cl	7.6	–	40.7
(3) Davras mountain, W of Taurus in doline areas, Middle Taurus, 1600 m					
	A	cl	7.0	0.4	–
(4) Dumbelek düzü, Middle Taurus, 2300 m	A	sic	6.6	0.0	43.5
	B	c	7.5	3.0	46.0
(5) Baskonus dagi, E of Taurus, 1300 m near doline	A	lc	7.7	2.8	41.3
	AB	c	6.5	2.4	47.7
	Bl	c	7.5	0.8	45.5
	B3	c	7.3	0.2	53.1
(6) Beydagi (W. of Taurus), Çiglikara, 1600 m	A	c	7.4	1.6	52.1
	B	c	7.1	1.2	50.2
(7) Gazipasa (Middle of Taurus), Karatepe, 1700 m	A	c	7.2	0.8	48.5
	B	c	7.2	0.8	53.2

[a] c: clay, si: silty, cl: clay loam, sic: silty clay.
[b] < 2 μm size particles.

Table 2
Physical, chemical and clay types of Red Mediterranean soils in Karaburun Peninsula, western part of Turkey (locations of soil samples are shown in Fig. 4Fig. 6)

Soil sample No.	Texture			pH [a]	$CaCO_3$ (%)	Clay types [b]		
	Clay < 2 μm	Silt 50–2 μm	Sand > 50 μm			Smectite	Palygorskite	Kaolinite
1	41	28	31	7.8	0.2	* * *	* *	* *
2	46	33	21	8.3	0.2	* * *	* *	* *
3	49	27	24	8.5	0.2	* * *	* *	* *
4	59	34	7	8.1	0.2	* *	* *	* *
5	67	27	6	8.4	0.2	* * *	* *	* *

[a] 1/1 soil/water.
[b] * * * high, * * medium.

deeper level of the wide fractures. Cation exchange capacity of soil clay fractions (< 2 μm) were high (25–40 $cmol_c$ kg^{-1}) (Tables 1 and 2). This was due to high amounts of smectite (major component of the clay minerals) in the clay sized fractions.

Detailed clay mineral analyses were carried out on soils from the Karaburun Peninsula of Izmir province (western Aegean region of Turkey). Other components of the silicate clay minerals were palygorskite and kaolinite (Table 2). Özbek et al. (1976) have also found similar clay mineral composition for Red soils developed on karstic limestones. Some primary minerals such as quartz were present as minor components in the clay fraction. The soils studied were typically red in color, but no attempt was made to measure the free Fe content of the soils.

The clay content of the B horizon is, in general, more than the A horizon. This is likely due to clay illuviation process (Tables 1 and 2) (Fedoroff, 1993). This is also the case for the soils which are found in the narrow fractures. In contrast, the amount of the silt size particles in the A horizon is generally more than the B horizon. This may be due to the aeolian influence, as discussed by several authors (Yaalon and Ganor, 1973, 1979; Mermut et al., 1976; Yaalon, 1987; Atalay, 1991; Kapur et al., 1993; Kubilay et al., 1993).

Under the humid Mediterranean climate, carbonates are completely leached out from the solum of the mature Mediterranean soils. But the secondary carbonates may be found in the lower landscapes.

3.2. Crack structure of limestone

Soils examined at site 2 (the Karaburun Peninsula of Izmir province, western Aegean region of Turkey) and site 6 (Beydagi region; western Taurus mountain) (see Fig. 1 and Table 1) showed the evidence of weathering through the dissolution process, along the thin fractures. Also some kind of lapiés develops along the vertical fractures which were more clear at site 6 (Fig. 2; Fig. 1 f1). The tree roots easily penetrate into deeper part of the fractured rocks. This suggests the presence of favorable ecological conditions for soil

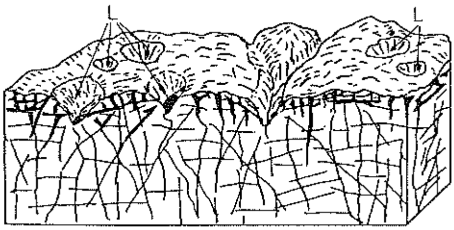

Fig. 2. Soil accumulation along the cracks. This figure represents the Mesozoik hard limestones at sites 2 and 6 in Table 1, in the western part of Taurus Mountains (L indicates lapiés).

formation. Root residues, producing organic acids, may also be effective in chemical weathering.

The size and depth of the fractures mainly depend on the chemical composition and age of limestones. The hard limestones, observed at sites 2 and 6, which were subject to tectonic movements, were dissected by very frequent fractures (Fig. 2) and the amount of fractures were much more than those observed in the clayey limestone or marl observed on Izmir Çesme road (site 1) (Fig. 3).

Atalay (1987a) noticed that almost all Paleozoic and Mesozoic limestones (non bedded and > 1000 m thick) in the study region, which were deposited in the deep part of the Tethys ocean, contain abundant fractures than that of the clayey or marly limestones of the Tertiary sediments in Karaburun Peninsula of Izmir province (western part of the Aegean region) (Fig. 3). In general, clayey or marly limestones produce a rather regular soil profile, most of them are classified as Mollisols (Soil Survey Staff, 1994) or Rendzina (Baldwin et al., 1938).

It is interesting to note that, the limestones which were dissected with the fractures are richer in terms of Red Mediterranean soil content within the rock system than the one with less frequent fractures (Fig. 2; Fig. 1 f1) (also see, Atalay, 1973; Jenning, 1985; Sari et al., 1986; Atalay, 1987a, 1988, 1989a,b, 1991).

The Red Mediterranean soils, which are found only in fractures without any connection to the rock surface, have a clay texture with little evidence of clay coatings but, with clear sign of secondary calcite formation (Fig. 1 f1, f6) (Fig. 4). In addition, thin and stony red soils are common only at the bottom parts of the "V" shaped dolines. In some areas dolines may have a frying-pan shape. The flat bottom of these dolines also contains clayey Red Mediterranean soil; reddish colluvial soils occur as a narrow belt along the edge of these dolines.

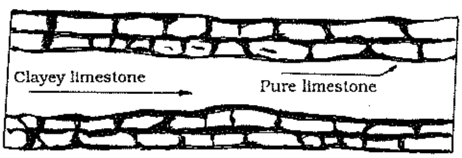

Fig. 3. Difference between marl and fractured limestones. Black signs show Red soils. This figure is prepared from the Karaburun Peninsula, western part of Aegean region.

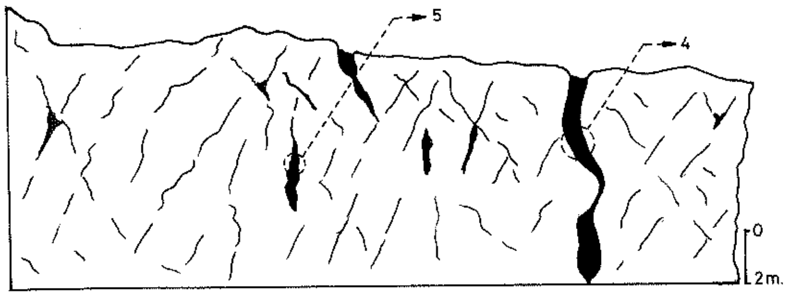

Fig. 4. Red Mediterranean soils which have formed along fractures in the hard Paleozoic–Mesozoic limestone in the Karaburun Peninsula. The clay content is higher than that of other limestones. Numbers 4 and 5 show soil samples indicated in Table 2.

3.3. Composition of limestone

Generally Paleozoic and Mesozoic limestones formed in the deep sea are rich in $CaCO_3$ content. But shallow marine limestones belonging to lower Miocene and/or Neogene contain sand and marl materials. As can be seen in Fig. 4, when limestone has been completely dissolved, the clay sized residues are left behind. Although the residual clay content of the limestone is less, however, rich soils are found on this type of limestone (site 2 from Table 1, and Fig. 4 from Karaburun peninsula, Fig. 1 f3). Sandy limestones produces sandy soils which are widespread on the Taseli plateau, Middle Taurus mountain.

Red Mediterranean soils and Mollisols may be found in the same area. While, Rendolls or Rendzina soils are found on the marly deposits with no or very little Fe, the Red soils appear on the hard limestones with some Fe containing minerals, such as pyrite. Fig. 5 clearly explains the importance of parent materials in the formation of Red soils in Mediterranean regions.

The thick and regular soils are found on plateaus (level or nearly level) of rather pure limestones of Paleozoic and Mesozoic epoch which are common in both the eastern and western parts of the Taurus Mountains (especially Davras and Dedegöl mountains).

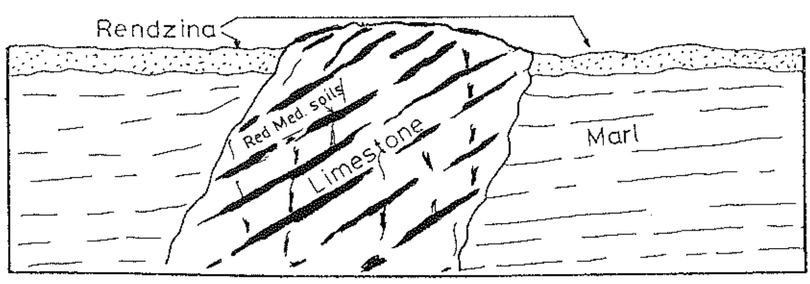

Fig. 5. Soil accumulation between marl and fractured limestone. Black signs show Red Mediterranean soils. This figure is prepared from the Karaburun Peninsula in the vicinity of Balikliova Town, the western part of Aegean region.

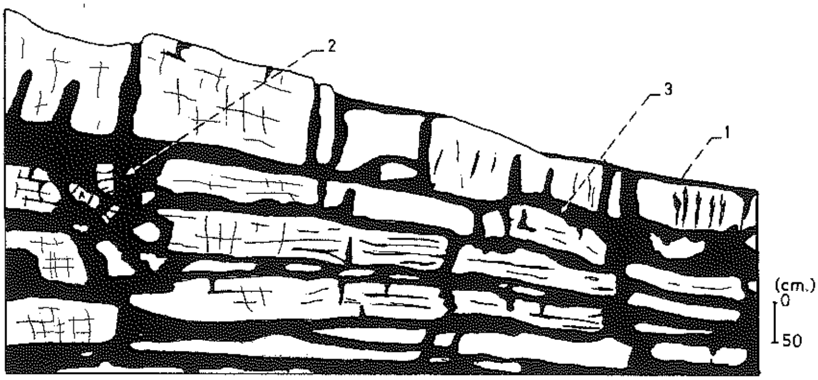

Fig. 6. Relationships between soil formation and stratification. Black signs show Red Mediterranean soils. This figure is taken from the northern part of Balikliova Town, Karaburun Peninsula, western part of Aegean region. Numbers (1, 2, 3) show soil samples indicated in Table 2.

3.4. Mode of stratification and age of limestones

When the limestone consists of alternating clayey, marly and sandy layers of stratigraphic sequence, the water is held along the bedding and/or weak surfaces. Therefore, soil formation is initiated between the bedding surfaces (Figs. 6 and 7). A Red soil examined at site 2, developed from stratified limestones (Fig. 1, Table 1, Fig. 6) from Balikliova town (Karaburun peninsula, Izmir province) has a clay loam texture as a whole, however, soil materials attached to the surfaces of original clay layers can be clayey in texture. The thick bedded limestone, may be more widespread. At this site, the Red soil has smectite as the dominant clay minerals and palygorskite and kaolinite are the other two constituents in the clay size fractions (Table 2).

The thin bedded limestones appeared to provide condition for more active soil formation. It appears that they quickly weather and produce soil. Fig. 6 shows a profile, observed in Elmali (Fig. 1, f6), developed from the Eocene limestone. At this site, about half of the material consists of Red soil materials. Soil layers resemble a wall built by bricks. This type of soil formation was also observed earlier by Atalay (1988, 1989b) in the other parts of Taurus Mountains.

The Red soil materials become much less when the bedded limestones is thick. Such

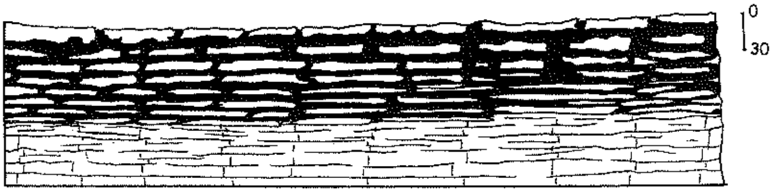

Fig. 7. Thin stratified limestone. Soil forming process is rapid and more advanced than in the thick layered limestones. This figure is prepared from the Elmali Eocene limestone, western part of Taurus mountains.

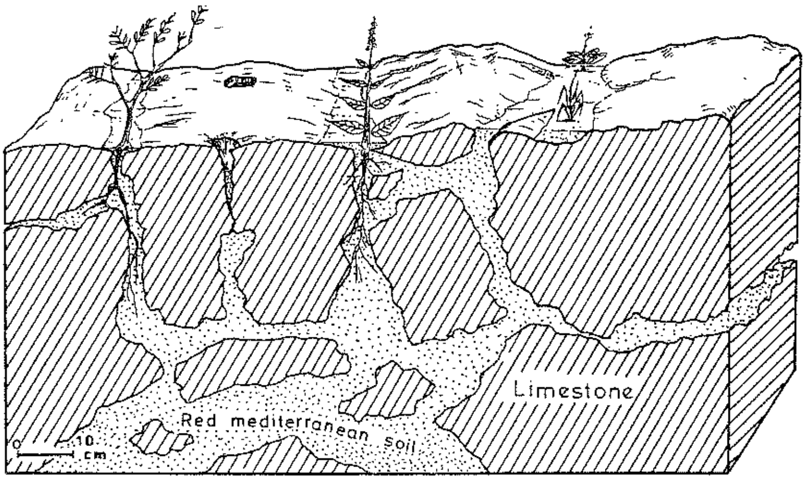

Fig. 8. Soil formation in compact limestones. Red Mediterranean soil has formed along fractures. This figure is prepared from a site in the vicinity of Akseki Town, western part of Taurus mountains.

a situation is observed in Akseki town (Fig. 8; Fig. 1 f7). There is almost no soil at the surface and the Red soils are found along the fractures. The bluish and compacted limestones representing Mesozoic in the western part of the Taurus mountains, and Karaburun peninsulas in Aegean region, produce similar soils. This suggests that when the sediments are more hardened the only possible site for soil formation is the crack surfaces.

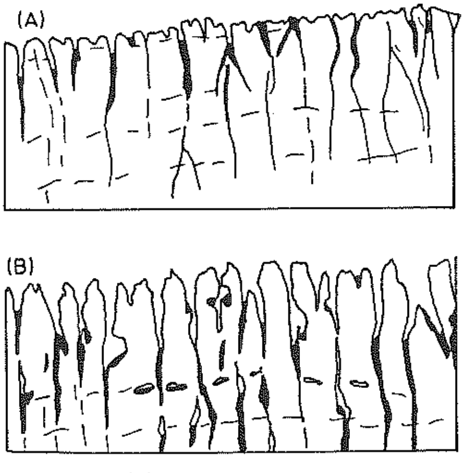

Fig. 9. Soil development along the cracks (A), and vertical transport of the soil within the widening of cracks (B). This figure represents Gidengelmez mountains, made up of Mesozoic limestone and extending between Seydisehir and Manavgat towns, western part of the middle Taurus mountains (f4, Fig. 1).

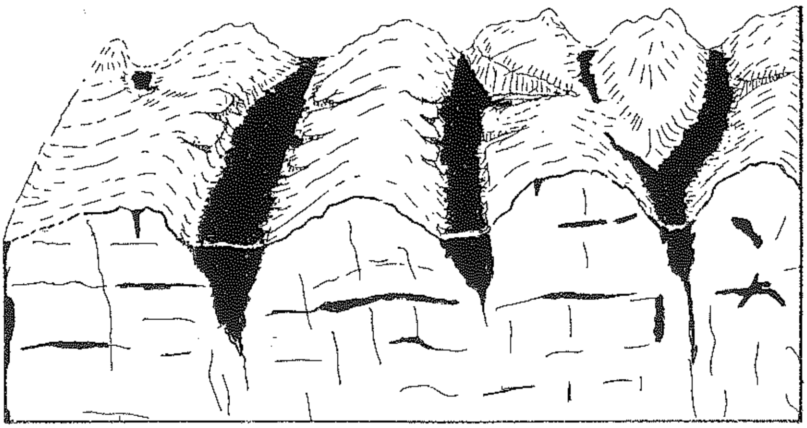

Fig. 10. A general view of the Red Mediterranean soils formed along the weak zones of limestones. This figure represents Red soil appearance in the southern part of the middle Taurus mountains.

It is suggested that karstification in the Taurus mountains has started during the upper Mesozoic (Atalay, 1987a,b). Indeed, the bauxite deposits had formed in the lower level of the Mesozoic limestones in the Gidengelmez mountain. Therefore, it can be said that most of the Red Mediterranean soils can be considered as paleosol (Atalay, 1989a,1994; Kapur et al., 1993; Bronger and Bruhn-Lobin, 1996; Brückner et al., 1996; Frenzel, 1992). It is interesting to note that, the Red Mediterranean soils are found in the much deeper part of Paleozoic limestone than that of the Mesozoic and Tertiary limestones (Fig. 4). We therefore, postulated that, there is a close relationship between soil formation and karstification events.

The dissolution of limestone along the vertical fractures leads to the widening of

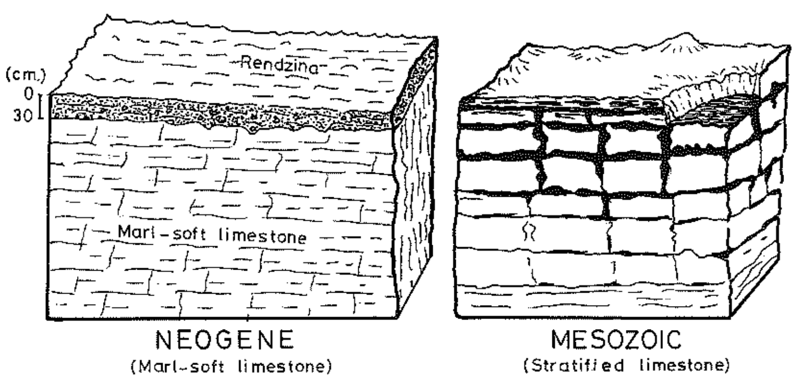

Fig. 11. Retardation of soil forming processes in the marl layer (left). But soil formation has occurred (black signs) when the limestone layer is exposed in the karstic plain (right). This figure represents Taseli Plateau composed of clayey and limestone layers horizontally bedded.

fractures, a process which is very well expressed in the Mesozoic limestones such as Gidengelmez mountains in the western part of the middle Taurus mountains (Fig. 1, f4; Fig. 9). As mentioned above, dissolution may become faster if the rock contains sulfides (pyrite). Upon oxidation, pyrite will produce sulfuric acid and this process will accelerate the soil formation.

Soils which have been developed along the fractures transported vertically by widening of the fracture. Thus, the soils mass may be moved from the near surface to much deeper zones with time. Such soils are red and completely decalcified. This explains why soils are found in the deeper section of karstic lands. As can be seen in Fig. 10, regular soil may be found as a narrow band along the weak zones as we have seen in the rocky Taseli plateau, middle part of Taurus mountains. In this case, we may suggest that there is a short distance lateral transport, in addition to in situ soil development.

While the presence of clayey layers may prevent the karstification activities, soil formation may be rapid in this type of parent material. As can be seen in Fig. 11, the bottom of the karstic depressions such as dolines and poljes is generally composed of clay and/or clayey layer on which a thick soil can be found. Atalay (1989a) found soils also in the poljes of the middle and eastern parts of Taurus mountains, especially on the Taseli plateau.

4. Conclusions

Our studies have shown that geomorphic properties and evolution of the karstic area are very important, in terms of the Red soil formation, in the Mediterranean coasts of Turkey. Soils are not found on the steep slopes of the karstic lands, except along the fractures and bedding surfaces or between the layers.

Soils have developed along thin fractures and between the layers. Thin fractures and bedding surfaces are favorable sites for the water holding. Therefore, weathering or soil formation takes place in locations where there is a water. Vertical transportation of soil particles occur in widened fractures lapiès. Thus, in the karstic areas which are deeply dissected by the lapiès, soils are not found on the surfaces, but they are present in the deeper section of the rock system. The tree oots easily penetrate into the deeper part of the rocks through the fractures and accelerate the soil formation.

Soil erosion activities generally do not occur on surfaces of the karstic lands because of the fact that the run-off is very low and rocks have high infiltration capacity.

Clay is the main impurity within the hard limestone with some iron containing minerals, such as pyrite, and this is the reason why the soils in the karstic lands often have clay texture and red in color. The fractures in the limestones provides a favorable conditions for oxidation so that through Fe oxidation soils attain reddish color.

Rich and thick soils are common in the places where thin bedded stratigraphic sequence are present. Because, pure limestones contain much more fractures than the clayey limestones, soil formation takes a long time, and most of the soils do occur in widened fractures, even a few meters below the rock surface, therefore, most of them are paleosols.

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