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F. H. BEINROTH, G. UEHARA & H. IKAWA

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Geomorphic Relationships of Oxisols and Ultisols on Kauai, Hawaii[1]

F. H. BEINROTH, G. UEHARA, AND H. IKAWA[2]

ABSTRACT

A succession of Eutrustox-Eutrorthox-Gibbsiorthox-Gibbsihumox occurring in northeastern Kauai, Hawaii, is shown to be a climosequence. These soils developed synchronously on basic lavas forming one geomorphic surface of Pleistocene age. Ultisols found along the knickpoint of this surface to recent erosion surfaces are the result of soil creep. The mechanisms of clay mobilization by soil shear caused by creep are discussed.

Additional Index Words: **soil-geomorphology, Oxisols, Ultisols, soil creep.**

KAUAI, the northernmost of the main islands of the Hawaiian chain, consists of two major geologic units: the Waimea volcanic series of Pliocene age which forms most of western Kauai, and the Koloa volcanic series of Pleistocene age which predominates on eastern Kauai (Fig. 1). There is a marked unconformity and hiatus between these formations. Koloa lavas unconformably overlie both the dissected Waimea formations and old sediments derived from these rocks which form pediment-like surfaces graded to a former base level (2).

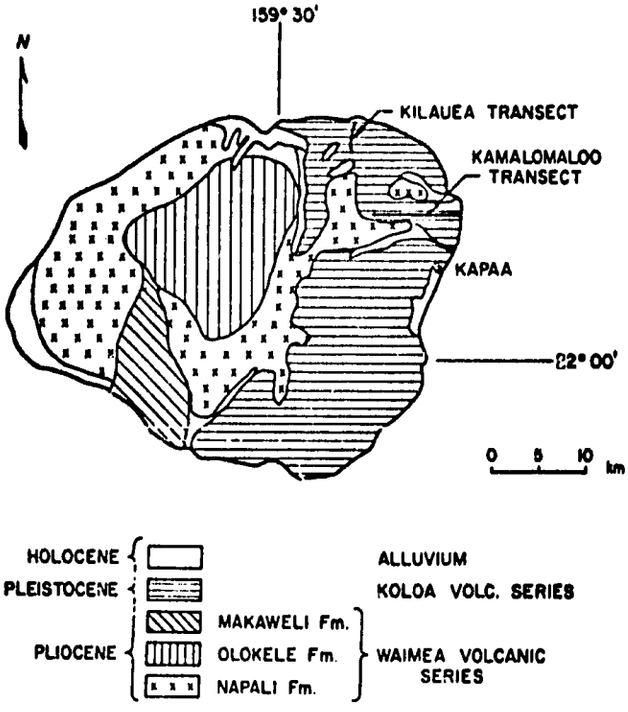

Fig. 1—Generalized geologic map of Kauai, Hawaii, after Macdonald et al. (2), and location of transects.

The rainfall in northeastern Kauai is essentially of orographic nature and conditioned by the prevailing northeasterly tradewinds and by elevation. It is, therefore, lowest along the coast and highest on the windward side of the interior mountains. On account of this rainfall pattern, the flows of Koloa lava have been more actively eroded near the mountain ridges while dissection has been less intense towards the coast. This resulted in amphitheater-headed valleys segmenting the gently sloping Koloa lava flows in wedge-shaped landscape elements.

One such landform is found in the Kamalomaloo area between the Kapaa and Anahola streams some 6 km north of Kapaa (Fig. 2). This area was selected to study soil distribution and soil-geomorphic relationships. In addition, a physiographically similar area near the hamlet of Kilauea was investigated with the same objective. (For location of study areas, see Fig. 1).

RESULTS

Kamalomaloo Transect

Figure 2 depicts the general geomorphic aspect of this area and its soil pattern. A longitudinal cross-section is given in Fig. 3. The triangular interfluve bordered by escarpments caused by the Anahola and Kapaa streams and extending from the Kaneha reservoir to Kumukumu village on the coast is considered one geomorphic surface tentatively named Kumukumu surface.

The soil pattern along the central part of this surface is logical and largely controlled by the amount of rainfall. The sequence Eutrustox-Eutrorthox-Gibbsiorthox-Gibbsihumox corresponds with a continuous increase in precipi-

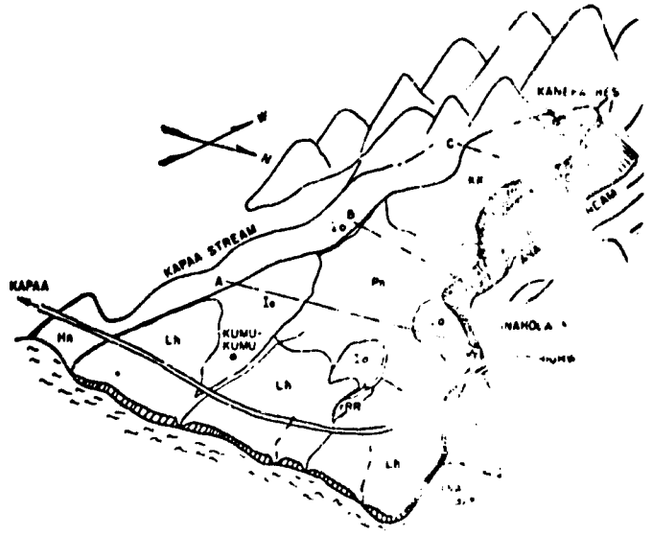

Fig. 2—Generalized soil-geomorphic pattern on [illegible] surface, Kamalomaloo area, NE Kauai, Hawaii [illegible] (Gibbsihumox); Hn = Hanalei (Fluvaquents), [illegible] (Tropohumults); Kk = Kapaa (Gibbsiorthox), [illegible] (Eutrorthox); Pn = Puhi (Eutrorthox) and rhy[illegible] broken land.

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[2] Associate Professor, Dep. of Agronomy, Univ. of Puerto Rico, Mayaguez Campus; Professor and Associate Professor, Dep. of Agronomy and Soil Science, Univ. of Hawaii, respectively.

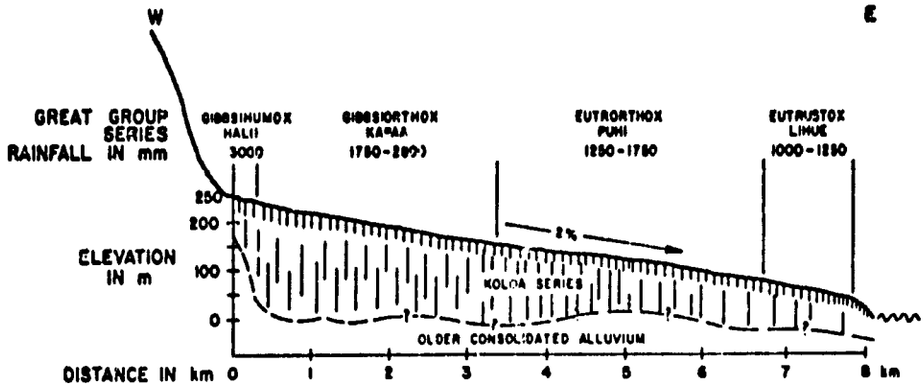

Fig. 3—Kamalomaloo transect. Generalized longitudinal cross-section in central part of Kumukumu surface.

tation from 1,100 to 3,000 mm (45 to 120") annually (Fig. 3).

Figure 4 shows three cross-sections perpendicular to the long axis. The sections indicate that Tropohumults are typically encountered on the knickpoint of the Kumukumu surface to the upper backslope of the recent erosion surfaces associated with the Anahola and Kapaa streams (Fig. 4, sections a-a' and b-b'). Where these backslopes are steeper than 20% "rough broken land" (rRR) replaces the Ultisols (Fig. 4, section c-c').

On the lower part of the Kumukumu surface the soil pattern is somewhat more complicated because erosion encroaching onto the surface from the coast caused some dissection. In general, however, Ultisols are again mapped on the more sloping sites whereas only Oxisols are found on the smooth parts of the landscape (Fig. 4, section a-a').

Kilauea Transect

This transect is located in a similar geomorphic position as the Kamalomaloo transect. In fact, the geomorphic surface at Kilauea is considered part of the Kumukumu surface. The soil pattern follows an identical trend and the sequence Eutrustox-Eutrorthox-Gibbsiorthox-Gibbsihumox correlates with annual rainfall increasing from 1,250 to 2,500 mm (50–100") (Fig. 5).

DISCUSSION

The occurrence and distribution of different Oxisols on the central part of the Kumukumu surface is a logical consequence of the pedogenetic conditions prevailing in this area. The Kumukumu surface is less than 1 million years old and thus much younger than most surfaces where insitu Oxisols are customarily encountered. However, it should be noted that the process of formation of oxic horizons is significantly accelerated by readily weatherable basic rocks such as the olivine basalts and melilite basalts of the Koloa volcanic series. The central part of the wedge-shape landscape elements (Fig. 2) that have been affected neither by parallel slope retreat nor by sheet erosion under natural vegetation, constitutes a stable surface. It is considered one geomorphic surface because it originated in all parts during the same volcanic activity and because no escarpments or knickpoints could be detected. Thus, time zero for soil formation is equal everywhere on the surface. While no precise figure can be given for the age of the Kumukumu surface, it must be between 0.5 and 1 million years, because Koloa volcanism began probably in late Pliocene time and extended through midPleistocene (2).

The climate during the period since soil formation started on the Kumukumu surface until today has not been constant. Climatic changes concurrent with glacial and interglacial epochs during Pleistocene caused fluctuations in

Table 1—Classification of soils of the study area according to US Soil Taxonomy

Order	Subgroup	Family	Series
Oxisols	Tropeptic Eutrustox	clayey, kaolinitic, isohyperthermic	Lihue
	Tropeptic Eutrorthox	clayey, oxidic, isohyperthermic	Puhi
	Typic Gibbsiorthox	clayey, oxidic, isohyperthermic	Kapaa
	Typic Gibbsihumox	clayey, ferritic, isothermic	Halii
Ultisols	Orthoxic Tropohumults	clayey, oxidic, isohyperthermic	Koloa

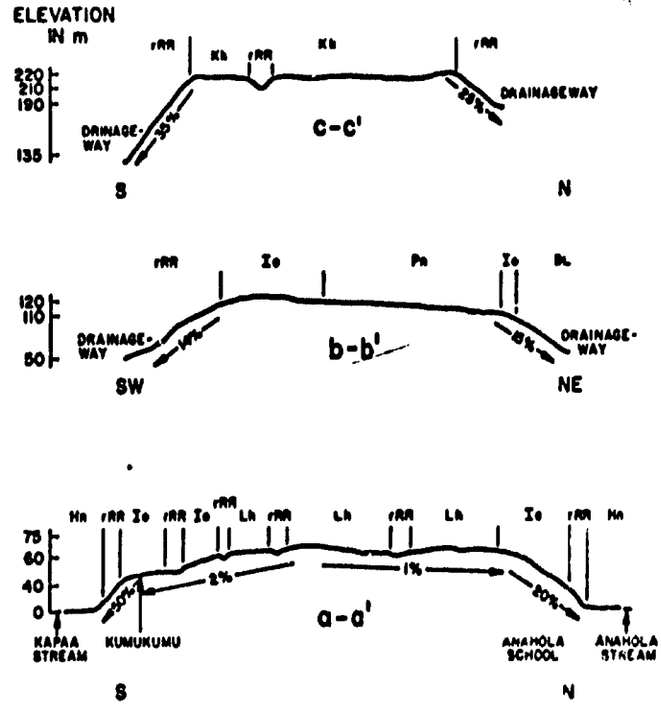

Fig. 4—Kamalomaloo transect. Cross-sections of Kumukumu surface perpendicular to long axis. See Fig. 2 for legend.

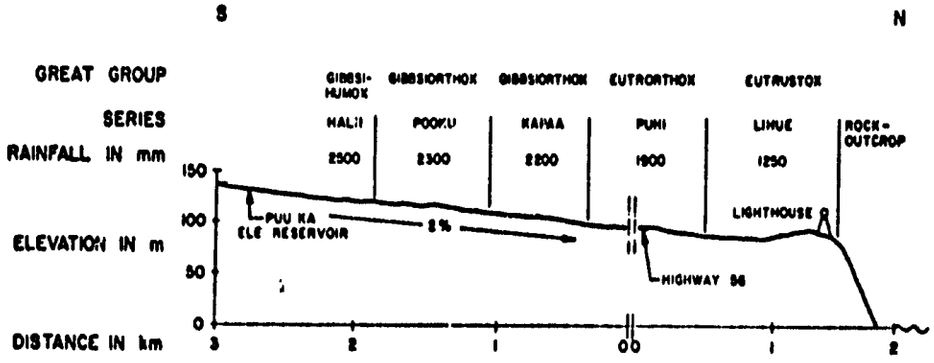

Fig. 5—Kilauea transect, longitudinal cross-section.

both rainfall and temperatures. These changes affected rainfall and temperatures intensities but not the pattern (3). Relative weathering intensities on the Kumukumu surface were, therefore, identical to those of today.

Table 1 shows the classification of typical soils of the study area. The listing indicates a sequence in soil mineralogy from kaolinitic to oxidic to ferritic when going from ustic to udic soil moisture regimes. Because all soils on the central undissected part of the Kumukumu surface are developed in situ, occur on one geomorphic surface, and there is no appreciable difference in lithology on this surface, the formation of different Oxisols must be controlled by the amount of rainfall, both past and present. The succession Eutrustox-Eutrorthox-Gibbsiorthox-Gibbsihumox is therefore clearly a climosequence. The genesis of the Gibbsihumox has been studied in detail by Sherman et al. (4). The formation of the Eutrustox is likely related to a paleoclimate with higher rainfall than today. The relatively high base saturation status of the Eutrustox and Eutrorthox may be partially caused by splash carried inland by the prevailing easterly winds from the ocean.

The Oxisols-Ultisols relationships on northeastern Kauai are intriguing. As shown on Fig. 4, Ultisols generally occur on steeper slopes than Oxisols on surfaces related to the present dissection of the Kumukumu surface. These steeper surfaces appear to be less stable than the almost level surfaces where Oxisols occur. An indication of the instability are shear planes that were observed in the upper solum of the Ultisols. Figure 6 shows such shear planes which are accentuated by roots growing along the plane. These shear

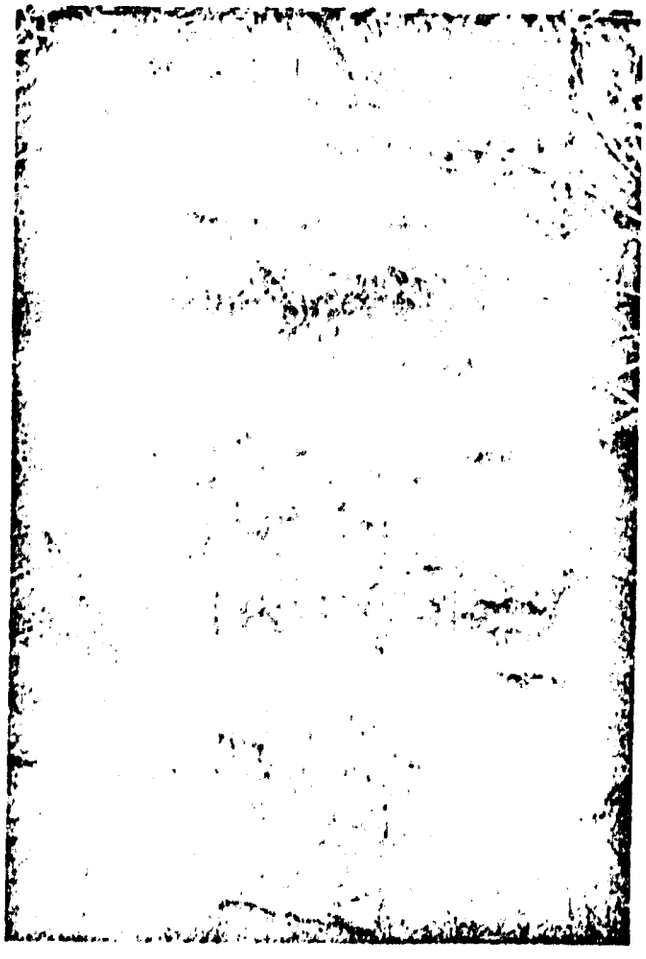

Fig. 6—Shear planes in Ioleau soil. Note root mats along several slope-parallel shear planes.

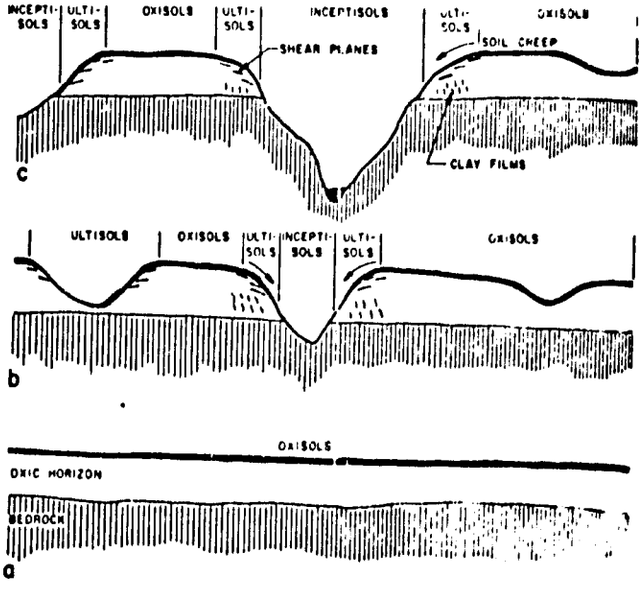

Fig. 7—Sketch illustrating different stages of dissection of an Oxisol-surface and the resulting Inceptisol-Ultisol-Oxisol pattern. a . . . undissected; b . . . moderately dissected; and c . . . strongly dissected.

planes result from soil creep along and below the knickpoint of the Kumukumu surface to the recent erosion surface. This shear process causes a breakdown of the structural skeleton of the clay and a disruption of the interparticle bonds of the stable fabric (1). The clay which is apparently immobile in Oxisols is reactivated in this manner, can be translocated and thus form the clay films that give rise to an argillic horizon. This model which was developed for the geomorphic relationships between Lihue, Puhi, and Ioleau soils on Kauai could also explain the Wahiawa-Manana (Futrustox-Tropohumults) on Oahu, Hawaii, and Niu-Puu Opae (Haplustox-Tropohumults) associations on Kauai, Hawaii. Figure 7 shows a schematic sketch of an Oxisol-surface in different stages of dissection and the ensuing soil pattern. This pattern is consistent with and explains the detailed soil maps prepared by the Soil Conservation Service, USDA (5).

An interesting case presents itself when Oxisols essentially devoid of silicate clay are subjected to soil creep. No clay skins can be generated in this case and Oxisols should, therefore, juxtapose Inceptisols. A situation substantiating this point was actually encountered on a steeper surface next to a Puhi soil. In this case Oxisols are found on rather steep slopes, but it must be stressed that they did not form there.

From the discussion above, it is evident that the adjoining Oxisols and Ultisols must be essentially identical in their chemical and mineralogical properties. This is reflected in the classification of the Puhi and Ioleau soils: Tropeptic Eutrorthox; clayey, oxidic, isohyperthermic vs. Orthoxic Tropohumults; clayey, oxidic, isohyperthermic. In a logical application of the concepts presented above, it must be concluded that the soils adjacent to the Lihue soils on steeper slopes should be classified as Oxic Haplustalfs, clayey, kaolinitic, isohyperthermic.

The concepts and models outlined above are speculative at this point and are based on limited field observations. However, they appear substantial enough to warrant their testing through more extensive geomorphic and micromorphologic studies in Hawaii and elsewhere. This should contribute to a better understanding of the intricate Oxisols/Ultisols relationships in the tropics.

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