



## Soils of Hawai'i

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**S**oil, like water and air, is crucial to life on earth. Soil has five key functions in supporting life:

- Soils provide physical support to anchor plant roots.
- Soils store water, air, and plant nutrients and mediate their supply to plants.
- Soils recycle plant organic matter to form humus, thus playing a key role in the earth's geochemical cycle.
- Soils are habitat for a myriad of organisms, from microscopic bacteria to the ubiquitous earthworm.
- Soils are an engineering medium and vary dramatically in physical properties and stability.

Given these crucial functions, an understanding of soil contributes to actions that help maintain a healthy planet.

Soils are not uniform across the earth's surface. They vary depending upon the factors that contribute to their formation: time, parent material, climate, living organisms, and topography. For example, the deep, dark, fertile soils developed from prairie grasses are different from the acid, infertile soils that develop under coniferous forests, which are in turn different from the highly weathered, clayey, oxide-rich, infertile soils formed in the hot, humid climates of the tropics.

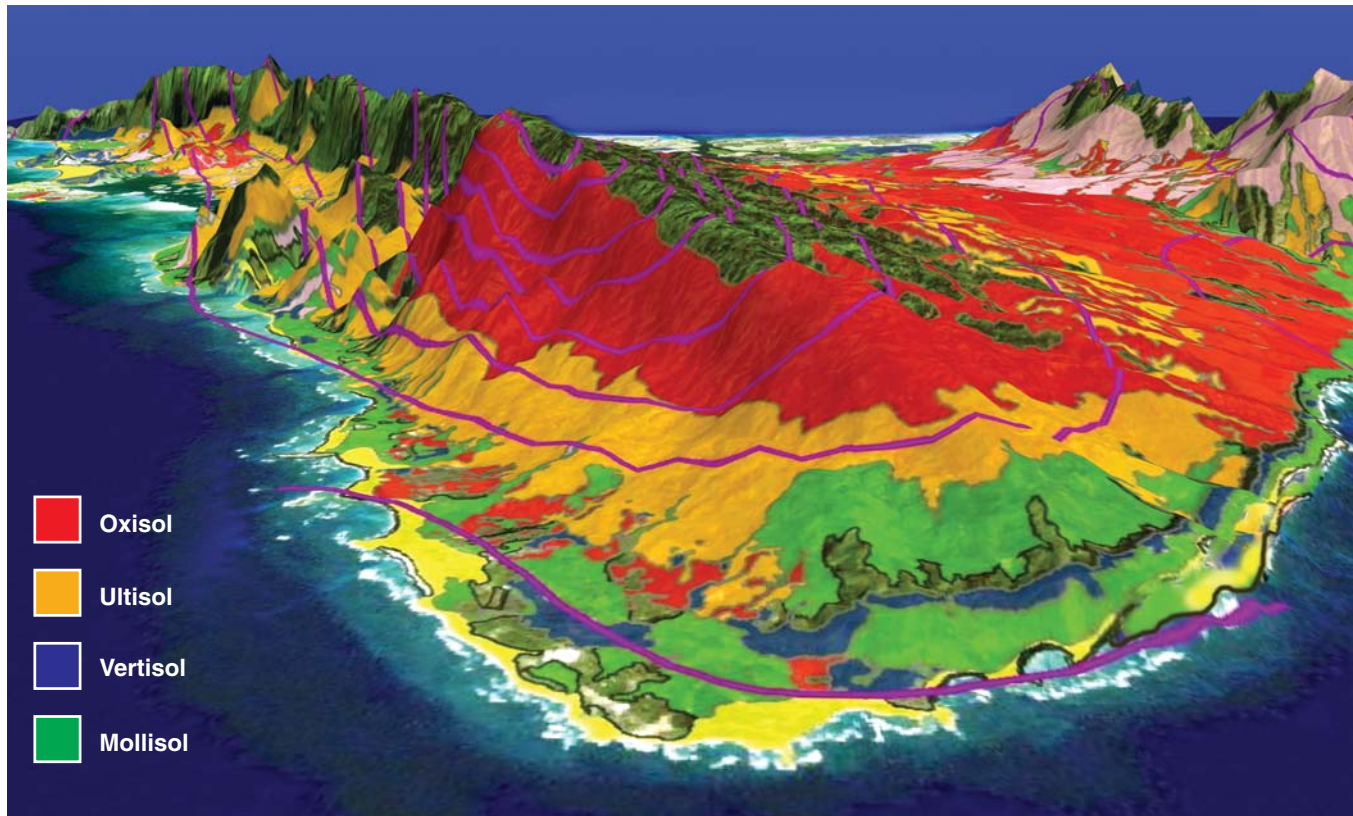
The eight main Hawaiian Islands show a tremendous diversity in soil types, despite their small total land area (approximately 6420 square miles). Soils vary dramatically over small distances in Hawai'i because the factors that contribute to their formation also vary dramatically. The soils of Kaua'i are very different from those found on the island of Hawai'i because the former have been exposed to weathering for a much longer time. Likewise, the effect of rainfall on soil differentiation is clearly exhibited as you move from the dry coastal low-

lands to the moist ridges of most islands. This is well illustrated in Figure 1 with a view of the northeast shore of O'ahu. On the coastal plains of Kahuku, where annual rainfall is around 40 inches, the soils are mostly fertile Mollisols. Further up the mountain, as rainfall increases to above 59 inches, the soils have weathered to become acidic, infertile Ultisols, which eventually change into highly weathered, infertile Oxisols under conditions where rainfall is above 120 inches.

To make sense of this diversity, soil scientists have developed a hierarchical classification system that places soils with similar measurable properties into the same broad groups. Soils formed by similar factors are grouped into the same category, and they respond and behave similarly. In other words, a soil formed at low elevation on the dry leeward side of Kaua'i will be similar to a soil that formed in the same environment on O'ahu.

At the highest and most general classification level are twelve soil orders, all ending with the suffix "sol"; these orders comprise all of the soils found on earth. Five lower categories within each order each carry increasing amounts of detail and information. In this publication we will discuss only the soil orders found in Hawai'i, highlighting the main features of each soil order with an emphasis on its fertility and potential for agriculture, and including maps for each island depicting the spatial distribution of the orders.

Ten of the twelve soil orders are represented in the Hawaiian Islands, exemplifying Hawai'i's tremendous biodiversity (Table 1). The effect of time on soil diversity is evident when we compare the soils on Kaua'i with the soils on the island of Hawai'i. Kaua'i is the oldest island (about 5 million years) and it shows the



**Figure 1.** A view of the windward coast of O'ahu (Kahuku in the foreground, looking toward Kāne'ohe to the left) depicting the change in soil orders as rainfall increases along an elevation gradient. The illustration was created by draping a soil order map over a Landsat satellite image and a digital elevation model; map created by Kyle Barber.

greatest diversity, with ten soil orders, whereas Hawai'i is the youngest (about 500,000 years) and the least diverse, with six soil orders present.

### Andisols

An Andisol is a soil developed from volcanic ejecta such as ash, pumice, and cinder. The clay minerals that weather from the ash (i.e., allophane and imogolite) are poorly crystallized and thus amorphous in structure and have an extremely large amount of surface area per unit of volume. These soils contain very large amounts of organic matter in the surface "horizon" (soil layer); 13–28 percent total organic matter is a common range. As andisols become more weathered, they have a tremendous water-holding capacity. They are considered light soils because they have a low bulk density (0.4–0.8 g/cm<sup>3</sup>), and therefore they are generally easy to cultivate. The combination of good physical properties (low bulk density, stable soil aggregates, high water holding ca-

capacity, and good drainage) coupled with their naturally high organic matter content makes Andisols generally highly productive soils. However, the aluminum and iron clay minerals in Andisols have a very strong capacity to adsorb phosphorus (P, one of the essential plant nutrients) and make it unavailable for plants; this process is especially pronounced in the Andisols that occur in wet environments (>60 inches of rainfall).

Andisols is the most extensive soil order in Hawai'i, with large areas on Hawai'i and Maui (Table 1). These soils are found in areas where volcanic vents were once active. On O'ahu, for example, we find Andisols weathered from ash ejected from the once active cinder cones of Diamond Head and Koko Head (p. 11). The Andisols are also extensive on the slopes of Haleakalā on Maui (p. 9) and Mauna Kea on Hawai'i (p. 6).

Andisols that are found in areas receiving less than 60 inches of annual rainfall are some of the most fertile and productive soils of Hawai'i. These are moderately

**Table 1. The areas (in acres) of soil orders on the six main Hawaiian Islands.**

<i>Soil order</i>	<i>Kaua'i</i>	<i>O'ahu</i>	<i>Moloka'i</i>	<i>Lāna'i</i>	<i>Maui</i>	<i>Hawai'i</i>	<i>Total</i>
Andisol	14,499	3794	5555	0	99,245 <sup>a</sup>	695,381	818,474
Aridisol	4,616	7431	1588	0	14,204	41,126	68,965
Entisol	4,093	5438	4545	1247	8352	14,998	38,673
Histosol	6095	172	0	0	5762	527,890	539,919
Inceptisol	21,307	16,791	12,227	53	21,805	51,046	122,513
Mollisol	24,867	38,466	8794	11,791	66,917	13,018	163,853
Oxisol	76,638	83,079	27,941	16,703	12,156	0	216,517
Spodosol	4105	0	1892	0	0	0	5997
Ultisol	14,381	45,861 <sup>b</sup>	6387	1129	21,854	0	89,612
Vertisol	3,069	25,096	2283	3650	0	0	34,098

<sup>a</sup> This acreage of Andisols on Maui includes 45,836 acres mapped to a mixture of Andisols and Histosols and 12,351 acres mapped to a mixture of Andisols and Spodosols.

<sup>b</sup> This acreage of Ultisols on O'ahu includes 13,442 acres mapped to a mixture of Ultisols and Inceptisols.

weathered loamy soils high in organic matter and plant nutrients such as calcium (Ca) and potassium (K). Good examples of these soils are found in the Kula (Maui) and Waimea (Hawai'i) areas, where they support extensive vegetable production. Where rainfall exceeds 60 inches per year, the Andisols are more weathered and less fertile (e.g., the Hāmākua Coast of Hawai'i and the Hana District on Maui). The higher amount of rainfall has leached much of the plant nutrient content (i.e., Ca and K) from the surface horizons, and the remaining aluminum and iron minerals have a tremendous capacity to bind soil P. With proper fertilization, however, these soils can be made productive for a wide range of food crops.

### Histosols

Histosols are soils that develop from organic materials and consist of more than 50 percent organic matter in the surface horizons. They are typically found in cool, moist environments that are so wet that they have anaerobic conditions in the soil profile. Like Andisols, Histosols have low bulk density and high water-holding capacity.

Histosols are the dominant soil type in the Alakai Swamp at the top of Mt. Wai'ale'ale on Kaua'i, but they are most extensive on Hawai'i (Table 1) where they cover large areas south of Hilo and throughout the Ka'ū and Kona Districts (p. 6). They have formed on recent lava flows where organic matter from decaying vegetation

has accumulated. If they have formed on 'a'ā lava, the organic matter is mixed with the 'a'ā fragments, making these soils very stony (as much as 80 percent rock fragments). When they form on pāhoehoe lava flows, the organic matter accumulates above the pāhoehoe bedrock. The Histosols that exist in areas of moderate rainfall (40–60 inches) are often slightly acid to neutral in reaction (there are exceptions) and generally well supplied with Ca and K. On the other hand, when they occur in higher rainfall areas (90 to >150 inches) they are usually very acidic (pH 4.5–5.0) and depleted of Ca and K due to extensive leaching. Soil acidity is a problem for many plants under this condition, because acidity increases the solubility of toxic elements such as aluminum (Al). In Histosols, however, the presence of dissolved organic substances neutralizes aluminum toxicity by binding aluminum ions into organic molecules that are no longer toxic to plant roots.

The natural vegetation of these Histosols is often dominated by 'ōhi'a trees and various native fern species. These soils have frequently been cleared and planted to macadamia, papaya, and coffee. Because of the rapid drainage, leaching of plant nutrients such as nitrogen (N) and K can be a problem, so adding fertilizers in small, frequent doses is a good practice. Histosols in high-rainfall areas often require additions of Ca to maintain good crop growth.



## Oxisols

Oxisols are highly weathered soils, low in fertility, that form under year-round hot tropical climates. In Hawai'i, these soils have formed from material weathered from basaltic lava and are found, for example, in both low-elevation, dry areas on Lāna'i and Moloka'i (25–30 inches rainfall) and in mountainous, very wet areas on Kaua'i (100–200 inches rainfall). Oxisols cover large areas on the older islands of Kaua'i and O'ahu, but only small areas of West Maui, and they are not found on Hawai'i, the youngest island (Table 1).

Oxisols are infertile because they have experienced intensive weathering, which has removed most of the weatherable minerals (i.e., silicate clays), leaving behind the insoluble oxides of iron and aluminum. Iron and aluminum oxides have very low cation exchange capacity (CEC) and, therefore, they do not readily retain important plant nutrients like Ca, magnesium (Mg), and K. In addition, because oxides have such a strong adsorption capacity for P, Oxisols usually require substantial amounts of P fertilizer to produce good crop yields.

Although by definition Oxisols are generally infertile, the amount of rainfall determines the degree of infertility. The least fertile examples occur in areas of high rainfall (>100 inches), on the windward coasts of O'ahu and Kaua'i, for example, and are characterized by very low CEC, trace amounts of Ca and K, and very high capacity to adsorb P. The Kaneohe series on O'ahu and the Kapaa series on Kaua'i are examples of very infertile Oxisols. Oxisols found at low elevations (<1000 feet) in areas with rainfall less than 25 inches per year tend to be more fertile, with slightly acid to neutral pH, higher CEC, moderate levels of Ca and K, and a relatively low P adsorption capacity. The Molokai series, which is found between sea level and 1000 feet on Moloka'i, Lāna'i, Maui, and O'ahu, is a good example of a more fertile Oxisol. It is classified as an Oxisol because it probably formed under a wetter environment in the geologic past.

Despite their low fertility, Oxisols have excellent physical properties. The oxide clay minerals form exceptionally strong aggregates that behave like sand particles, allowing the soils to drain water well and also support heavy loads even when they are wet. With the addition of lime to raise pH and increase the Ca level, and application of sufficient amounts of fertilizer, Oxisols can be transformed into very productive agricultural soils.

## Mollisols

Mollisols are deep, dark-colored, nutrient-rich soils, typically found on grasslands. They are extensive on the plains of North and South America, Europe, and Asia. Because of their high iron content, Mollisols in Hawai'i are often reddish in color, as opposed to the typically darker-colored Mollisols of temperate grasslands. In Hawai'i they are mostly found on coastal plains and gently sloping lands from sea level up to 1500 feet with annual rainfall ranging from 25 to 50 inches. These soils tend to be well drained but can be sticky and difficult to cultivate when they are wet; when they dry, they form hard, difficult-to-manage clods.

Mollisols in Hawai'i are very fertile, productive soils that were extensively planted to sugarcane in the past and are currently used for vegetable production and other diversified crops. They are generally neutral to slightly alkaline in pH and naturally rich in essential plant nutrients such as Ca, Mg, and K. The clay minerals in these soils do not adsorb much P, and therefore P deficiency is easily corrected with soluble P fertilizers.

## Inceptisols

Inceptisols are young soils that show poor profile development. They often occur on relatively active landscapes, such as mountain slopes where newly exposed, unweathered materials are actively exposed by erosional processes, or river valleys where sediment deposition readily occurs. On the island of Kaua'i (map, p. 7), for example, we see that Inceptisols are dominant on the steep slopes and flood plains in and around Hanalei on the north shore of the island.

Inceptisols show tremendous diversity, depending upon where they formed. Inceptisols that developed from alluvium in the river valleys of the islands are generally fertile soils with poor drainage and, therefore, are well suited to wetland agriculture. The Hawaiians recognized these properties and planted taro in these soils (Hanalei series). Ancient lo'i are still cultivated on the Inceptisols found in Waipi'o Valley (Hawai'i), Ke'anae (Maui), Hālawā Valley (Moloka'i), Wai'ahole (O'ahu), and Hanalei (Kaua'i). On the other hand, the Inceptisols found on older and/or wetter landscapes (i.e., Kahana and Haliimaile series on Maui) are strongly acid, depleted in plant nutrients, and often contain toxic levels of Al and manganese (Mn). These soils are well suited for acid-loving crops such as pineapple, but they must be limed and fertilized to support crops intolerant of soil acidity.

Liming increases soil pH and detoxifies the soil by removing free Al and Mn ions from the soil solution.

### Ultisols

Ultisols are weathered soils, usually rich in kaolinite (a silicate clay), that generally form in warm, humid climates with distinct wet and dry seasons. In Hawai'i, Ultisols are found in mountainous areas in close proximity to Oxisols on the windward side of the islands where rainfall is moderate to high (50–90 inches). They are typically forest soils with good physical properties (i.e., good tilth and drainage,) and a humus-rich surface horizon. They are less weathered than Oxisols but are often acidic to strongly acidic, deficient in essential plant nutrients including Ca, K, and P, and have a high concentration of exchangeable aluminum that is toxic to many crops. Like Oxisols, they have a high capacity to fix P.

Although Ultisols are relatively infertile in their natural state, they are highly productive agricultural soils given appropriate management. Liming to increase soil pH, detoxify Al, increase Ca levels, and reduce P adsorption capacity are critical first steps in ameliorating these soils. With good fertilizer application programs, these soils can support a wide variety of agriculture, including sugarcane, pineapple, vegetables, orchard crops, and pasture.

### Aridisols

Aridisols are desert soils, where lack of moisture limits growth of most plants. These soils typically are found in coastal areas of the leeward sides of the islands, where rainfall is low and dry periods are prolonged. The lack of moisture limits weathering reactions, and these soils tend to be shallow and show minimal profile development (i.e., no distinct soil horizon sequences). In addition to being dry, these soils tend to accumulate salts because there is insufficient water to leach them through the profile.

With adequate irrigation, Aridisols in Hawai'i can be very productive agricultural soils, because they are usually rich in plant nutrients. The Keahua series on the lower slopes of Hāleakala in central Maui is a good example of a highly productive Aridisol. These soils were planted extensively to sugarcane and pineapple in the past and are now planted to a wide range of vegetable crops.

### Entisols

Entisols are poorly developed mineral soils with no distinct subsurface soil horizons. They are either recent soils in the early stages of soil formation, or possibly old soils where the parent materials have not been transformed by soil-forming influences. In Hawai'i, Entisols are commonly either sandy soils developed from coral limestone, found in low-lying coastal areas, with a surface horizon rich in organic matter, or soils developed from alluvium in dry areas. The Jaucas series is a common Entisol found near the shoreline of most of the islands. It is a sandy soil with an organic-rich surface horizon, usually alkaline in pH, and excessively drained.

Entisols show great diversity in physical and chemical properties, depending on where they were formed. The Jaucas series, formed close to the shoreline, is sandy, alkaline, and typically deficient in nutrients such as P and K. The Kamakoa series, an Entisol found near intermittent streams in the South Kohala area of Hawai'i, is an organic, rich, sandy soil developed from alluvial volcanic ash. Entisols are neutral to slightly alkaline and well supplied with Ca, K, and Mg. Careful management of fertilizers to reduce leaching is essential to maintain good crop growth on these sandy soils.

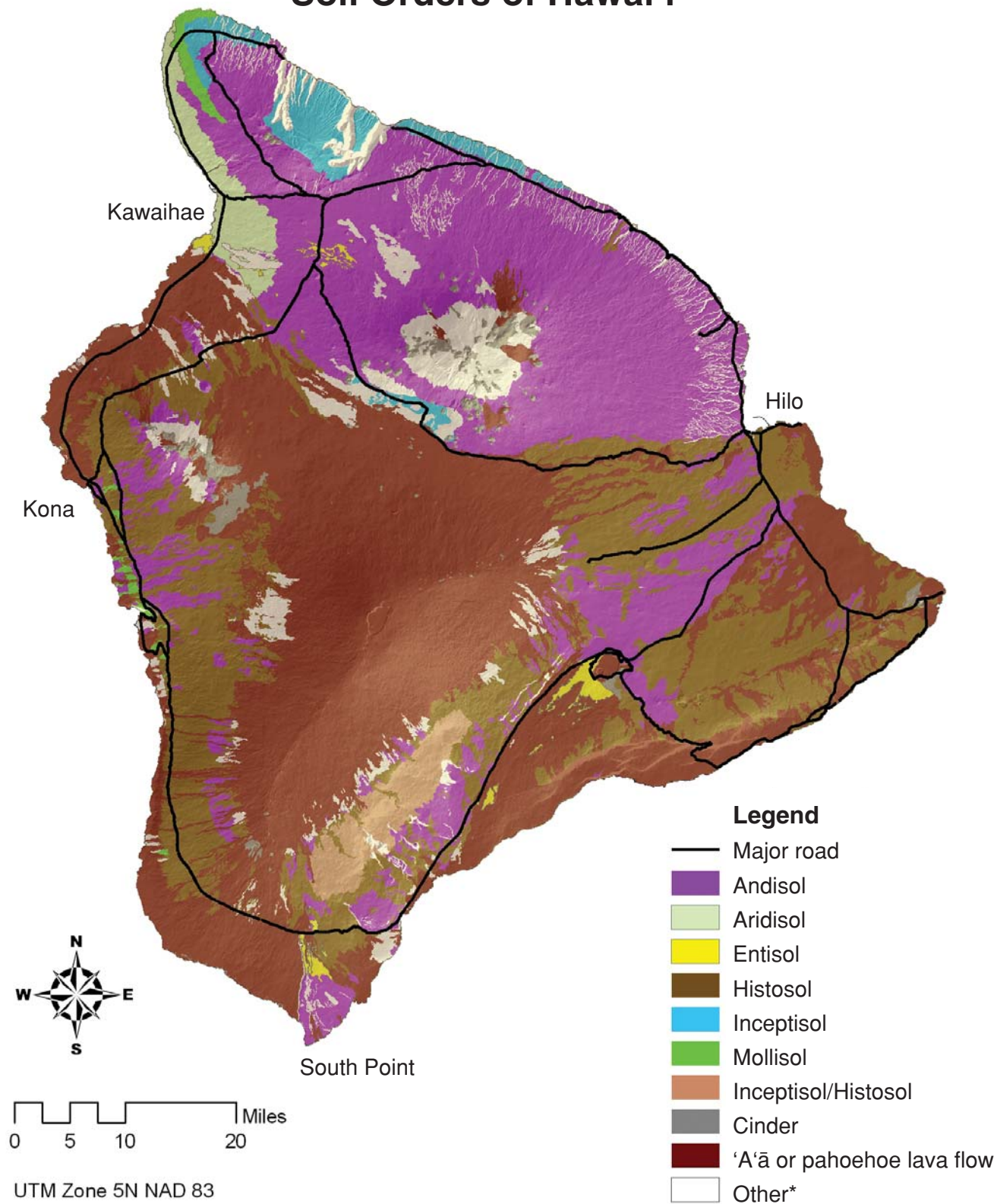
### Vertisols

Vertisols are dark soils, rich in clays that shrink when dry and swell when wet. They generally occur in relatively dry environments in lowland regions. During dry periods the clay shrinks, creating deep, wide cracks, but when the rains return the clay rehydrates and swells, closing the cracks. The high shrink-swell potential of Vertisols make them very unstable soils not suitable for construction of buildings or roadways. These soils are also difficult to cultivate because when they are dry they form large, hard clods that are difficult to break apart, and when they are wet they are excessively sticky. The Lualualei series, found on flat valley floors of leeward Kaua'i and O'ahu, is a good example of a Vertisol.

Despite their poor physical properties, Vertisols are very fertile, neutral to alkaline soils capable of supporting good crop growth. Cultivation is possible in conjunction with proper water management to control soil moisture. Their physical properties can be improved by adding organic matter.

(continued on p. 12)

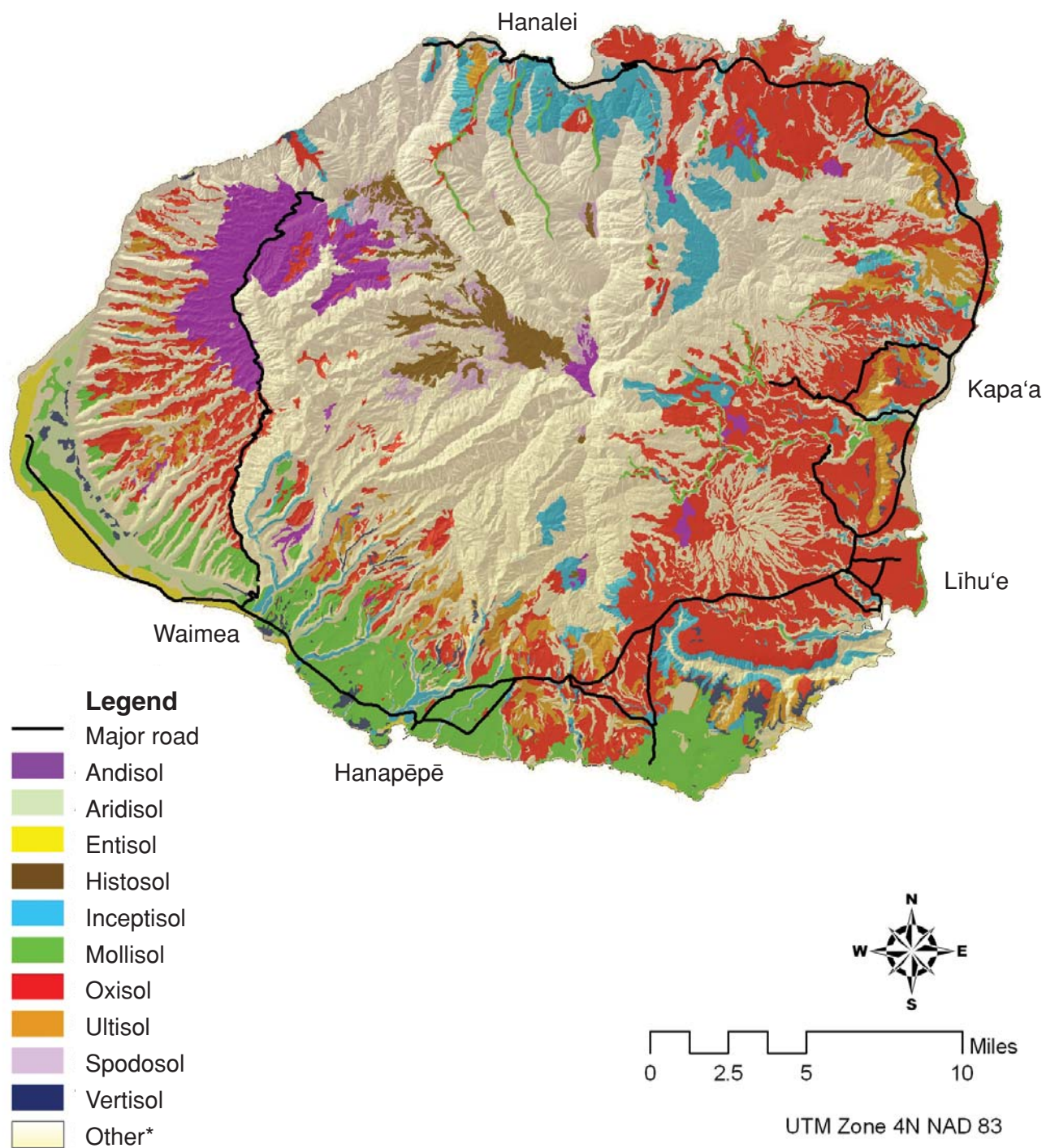
## Soil Orders of Hawai'i



\*Beaches, fill land, alluvial land, broken land, rocky land, and stony land

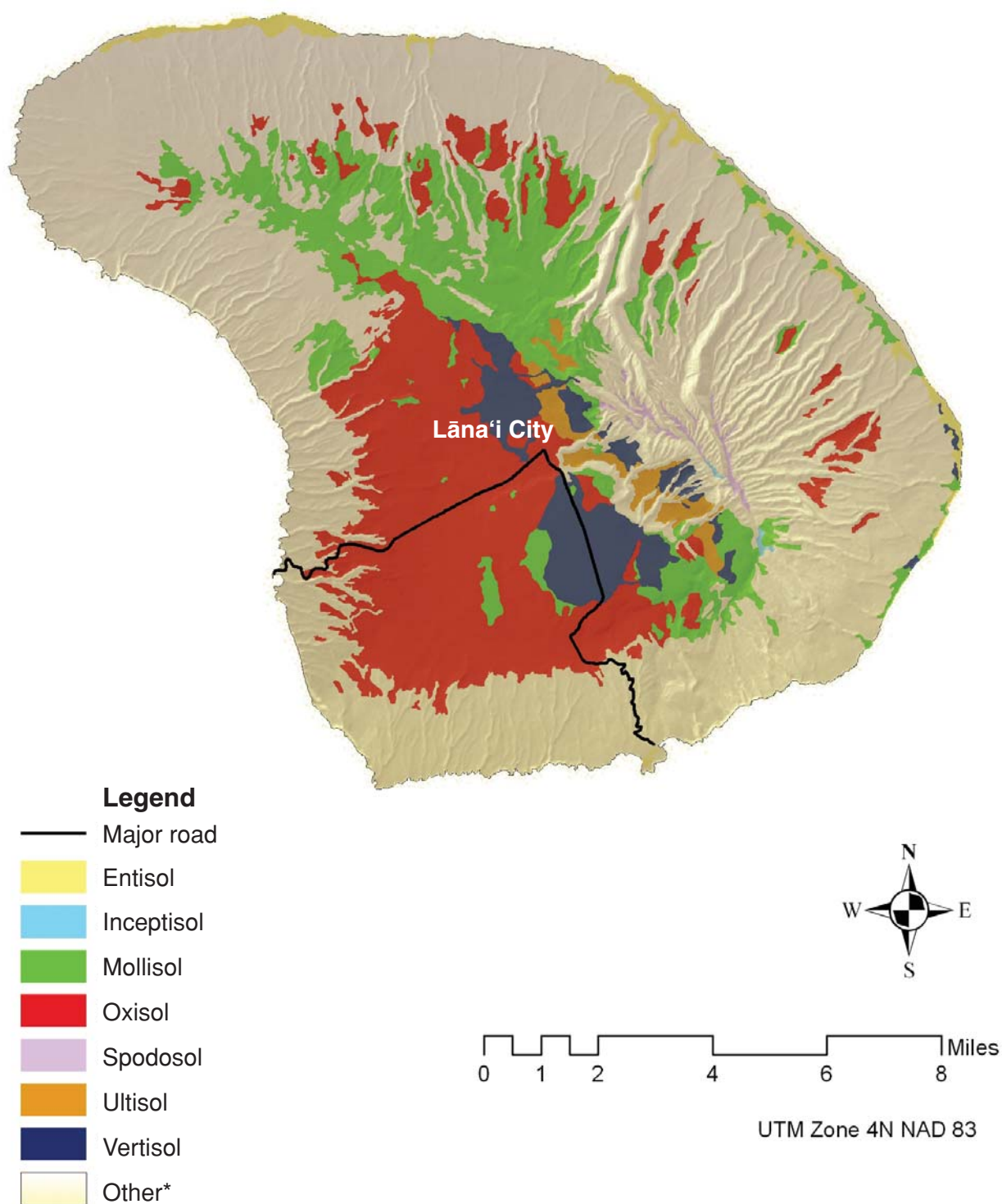


## Soil Orders of Kaua'i



\*Beaches, dunes, fill land, marsh land, rocky land, and outcrop

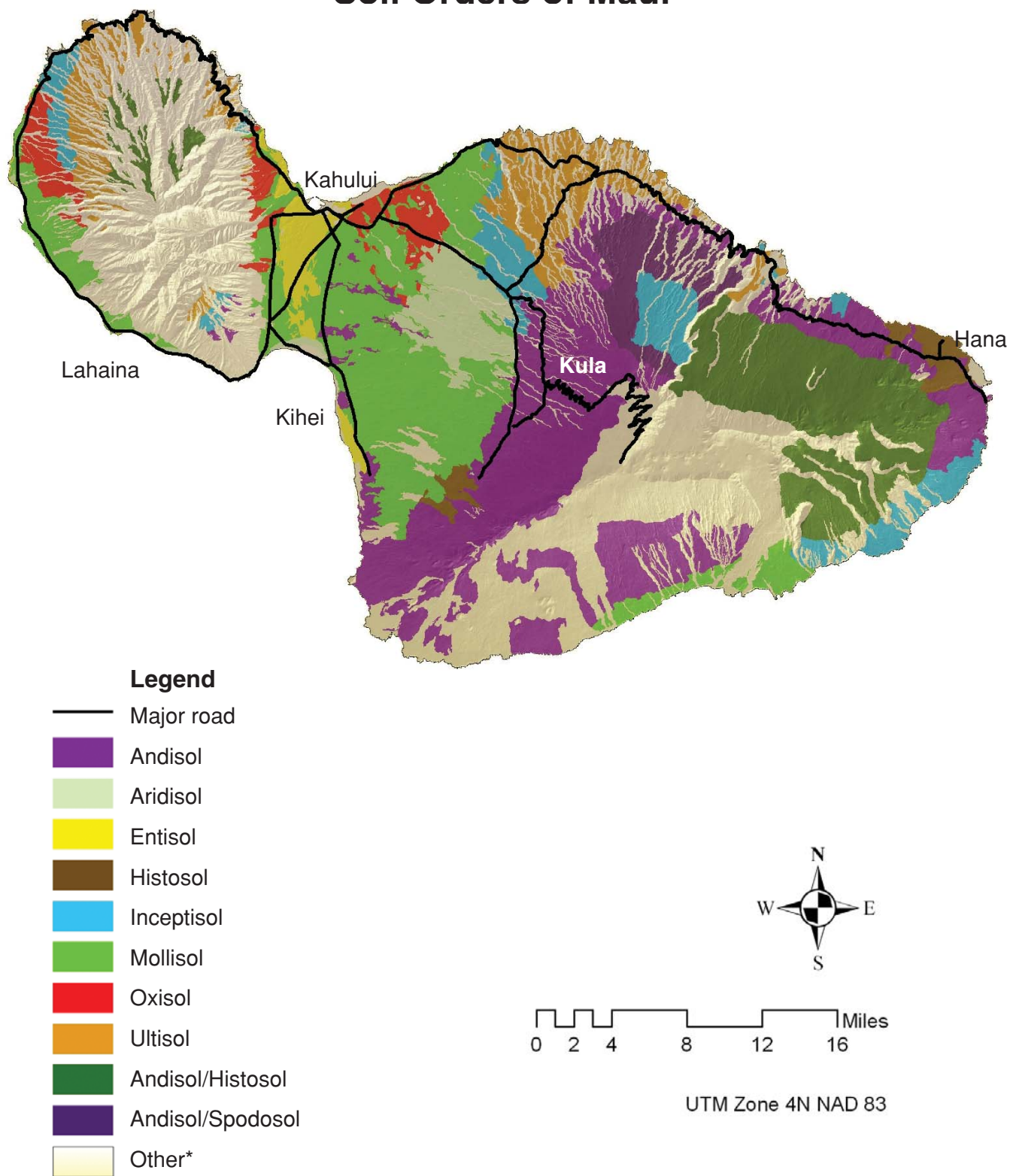
## Soil Orders of Lānaʻi



\*Beaches, blown-out land, coral land, rocky land and outcrop, alluvial land, rough broken land, rocky land, stony land, and rough mountainous land

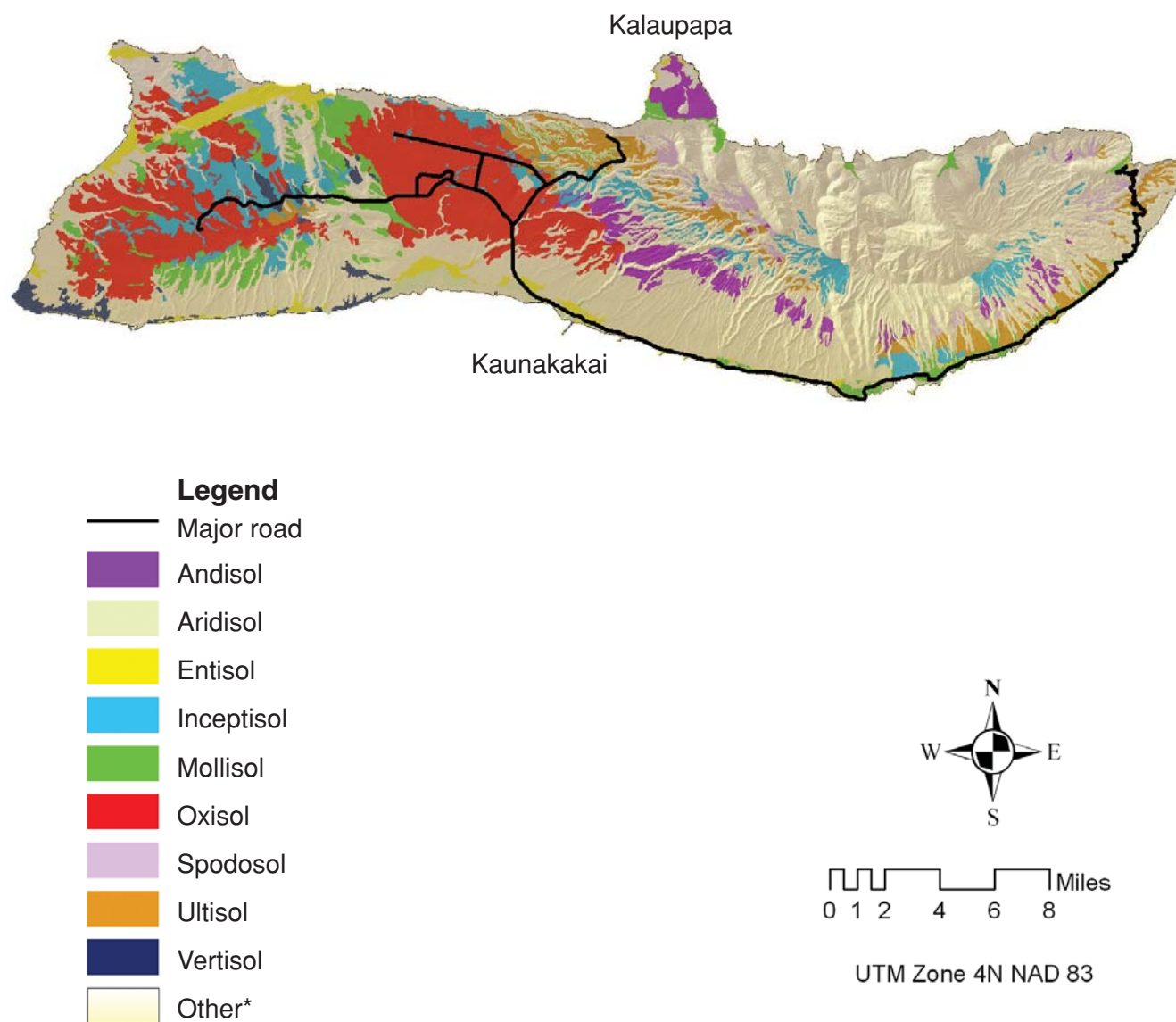


## Soil Orders of Maui



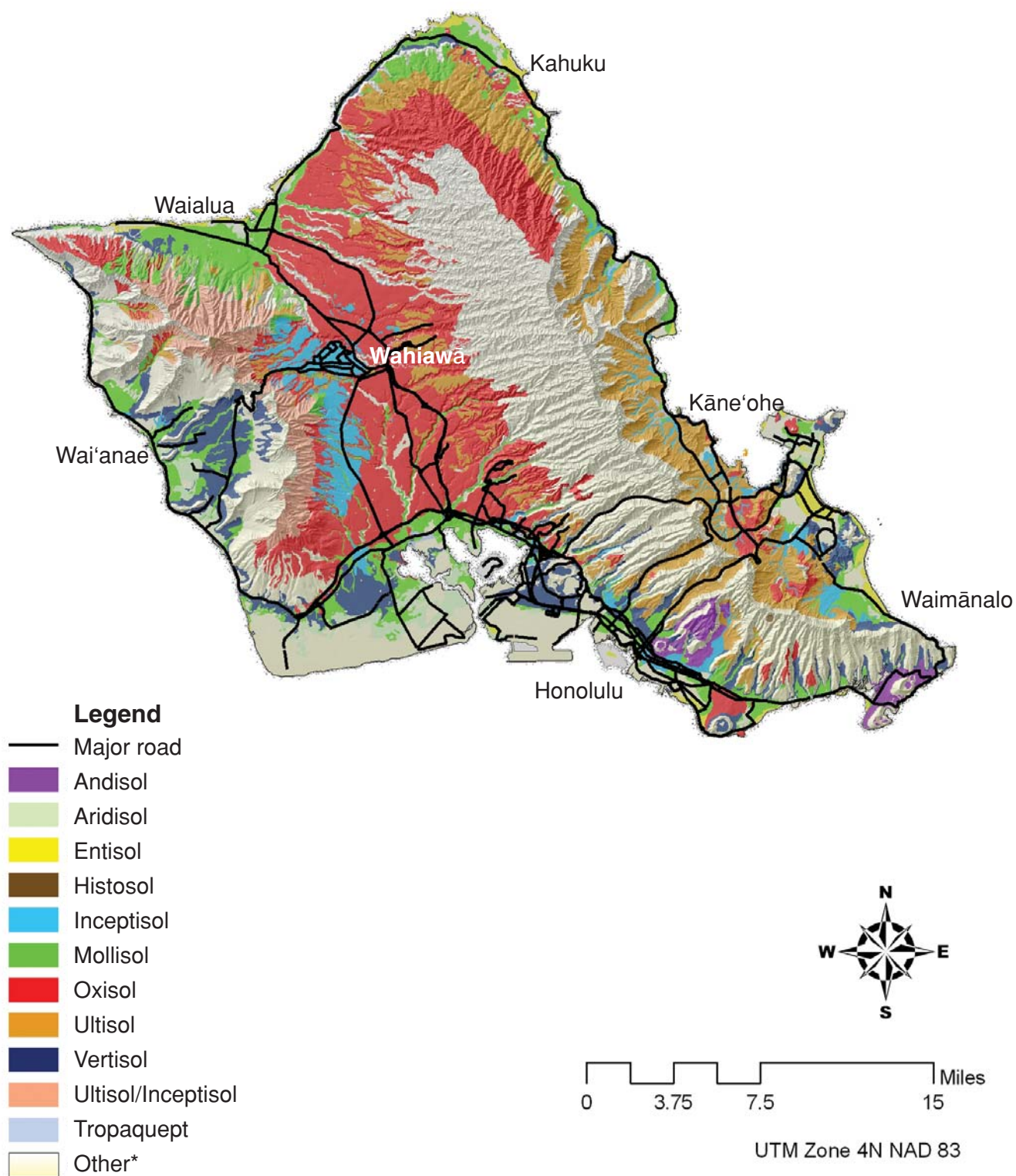
\*Beaches, dune land, Koele rocky complex, Naiwa silty clay loam, Puuone sand, cinder land, 'a'ā lava flow, rocky land and outcrop, rough terrain, stony land, and Uma coarse sand

## Soil Orders of Moloka'i



\*Beaches, colluvial land, gullied land, rocky land and outcrop, stony land, and broken land

## Soil Orders of O'ahu



\*Beaches, coral, fill land, marsh land, and rocky land



## Spodosols

Spodosols are soils that form under forest vegetation in moist to wet areas. They cover extensive areas in the cool, moist coniferous forests of northern temperate regions. These generally acidic, infertile soils are characterized by a light-colored, leached subsurface horizon overlying a dark horizon rich in leached organic matter and oxides of aluminum and iron. In Hawai'i, Spodosols are limited to the cool, wet, upland forests of Moloka'i and Kaua'i, with small areas found on Lāna'i. These soils are not used for agriculture.

## Other soil orders

Gellisols, the soils of arctic regions, and Alfisols, soils of deciduous forests, are not found in the Hawaiian Islands.

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## Glossary

Acid, acidic—pH less than 7.0.

Aggregate (soil)—Many soil particles (sand, silt, clay) held in a single mass or cluster, such as a clod, crumb, block, or prism.

Alkaline—pH greater than 7.0.

Allophane—A poorly crystalline aluminosilicate clay mineral prevalent in volcanic ash materials.

Alluvial—Pertaining to material deposited by streams or rivers.

Bulk density—The mass of dry soil per unit of bulk volume, including air space.

Cation exchange capacity (CEC)—The sum total of exchangeable cations (positively charged ions of minerals such as calcium, potassium, and magnesium) that a soil can adsorb.

Imogolite—A poorly crystalline aluminosilicate clay mineral prevalent in volcanic ash materials.

Leaching—The removal of materials in solution from the soil by percolating waters.

Weathering—All physical and chemical changes produced in rocks and minerals, at or near the earth's surface, by atmospheric agents.