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Two lowland tropical spodosols from the Fiji Islands: first report from small islands

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Two Lowland Tropical Spodosols from the Fiji Islands: First Report from Small Islands¹

D. M. Leslie,² Philomena Gangaiya,³ and R. J. Morrison^{3,4}

Abstract: Spodosols, one of the major orders of soils in the U.S. Department of Agriculture Soil Taxonomy, are believed to be formed by down-profile movement of colloidal humic materials complexed with aluminum and iron. Conditions favoring formation of these soils are normally cool and humid climates, but some tropical Spodosols have been observed in continental and island situations, mainly at higher elevations. Here we report on observation of two Spodosols at low elevations in Fiji, the first such report for the South Pacific islands. Soil field descriptions and associated laboratory data are presented, along with interpretation of data in terms of soil genesis, classification, and land use. Soils are classified as an Aquic Haplorthod, coarse-loamy, siliceous, isohyperthermic (from Drekeiwaila, Viti Levu) and an Oxyaquic Ultic Haplorthod, sandy over clayey, siliceous, isohyperthermic (from Lovonivia, Vanua Levu).

SPodosols, soils that exhibit features of pedogenetic movement of colloidal humus, aluminum, and iron, are usually found in cool, humid climates (Soil Survey Staff 1999). Soils having “spodic” or “podzol” features were first described by Dokuchaiev in 1879, and there has been some debate about the origin of the podzol terminology (McKeague et al. 1983). The original descriptions highlighted the presence of an ashy light-colored eluvial horizon, with less emphasis on the now more important illuvial horizons. Spodosols are naturally infertile (acidic with serious phosphorus deficiencies) but can be responsive to good management.

Spodosols are widely distributed in northern North America, Europe, and Asia, with an estimated global area of 3,354,000 km², about 4% of the earth’s ice-free land surface (Wilding 2000). Less than 1% of Spodosols occur in tropical areas (Wilding 2000), where they are usually located in two situations: in humid lowlands (generally on sandy parent materials) and on mountains (Young 1976). Tropical Spodosols have been found in Africa (Van der Merwe 1940, Ahn 1993), Australia (Murtha 1986), Asia (Richards 1941, Whitmore and Burnham 1969), and South America (e.g., Klinge 1965, Horbe et al. 2004). They have also been reported from island locations such as Borneo (Askew 1964), Madagascar (S.W. Buol, North Carolina State University, pers. comm., 2014), Sumatra (Tan et al. 1970), and Sri Lanka (Joachim 1935), but most island examples are at high (>500 m) elevation.

In the Pacific islands, Spodosols have been reported from Hawai’i (two series at elevations of 380–1,500 m [Hue et al. 2007]), Solomon Islands (two sites at elevations of 1,070 and 1,690 m [Lee 1969]), and New Guinea (West Papua at about 2,000 m [Hardon 1936 as reported in Richards 1941], Reijnders 1964). One soil likely to qualify as a Spodosol has also been reported from New Caledonia, but no site elevation was provided (Latham et al. 1978). Thus, low-elevation tropical

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Spodosols are not common, and in the small (<~12,000 km²) Pacific islands no confirmed examples have been reported. In this paper we provide descriptions and data for two soils that qualify as Spodosols and discuss their possible genesis and classification.

MATERIALS AND METHODS

Two locations for possible Spodosols were identified from the literature and local informants. In a preliminary report, Fox (1954) described a “ground water podzol” at Koronivia in southeastern Viti Levu, providing a limited description without supporting laboratory information. Fox (1954:28) and Twyford and Wright (1965) interpreted the “ground water podzol” as the remnant of an older land surface where soil processes saw “progressive removal in groundwater of bases, clays and oxides of iron and aluminum, with the iron pan formed at 1.5 m depth.” A soil in Wainikoro, eastern Vanua Levu, originally described in Twyford and Wright (1965) also showed profile features that could indicate the presence of a Spodosol. The Wainikoro site was of particular interest because it was in a location having a strong dry season, and Spodosols are usually associated with humid conditions. These two sites were examined in detail, profiles described, and soil samples taken for laboratory analysis. The Lovonivia series at Wainikoro are separately mapped, but the Drekeiwaila soils on Viti Levu, even though identified and described by Fox (1954) and Twyford and Wright (1965), are not mapped separately because of their limited areal extent; they are recognized as an inclusion within the Koronivia (Typic Kandihumult) series (Leslie and Seru 1988).

A preliminary auger survey was made of each area to determine the extent of soil variability, and to confirm the identity of the “Spodic” soils. In both locations, pits were dug in each of soils of interest (July 1984), and the profiles were described according to Taylor and Pohlen (1979), except that the term “nut structure” was replaced by “subangular blocky structure.” Horizon designations are according to Milne et al. (1995), which follows closely the FAO/UNESCO Legend

(1974). The soils were sampled and analyzed according to the methods of Blakemore et al. (1987) or the Soil Conservation Service of the U.S. Department of Agriculture (SCS-USDA 1984). Mineralogical studies were made on whole soil samples (<200 mesh) and on the clay (<2 µm) fraction using X-ray diffraction (Morrison 1991). The soils were classified according to methods of the USDA (Soil Survey Staff 1975, 1999, 2014).

RESULTS

Using the available literature, profiles were located at Nasinu, southeastern Viti Levu, 8 km north of Suva, Drekeiwaila (DRW) (18° 03' 36" S, 178° 31' 10" E), and at Wainikoro, eastern Vanua Levu, Lovonivia (LOV) (16° 18' 11" S, 179° 33' 30" E), Fiji. Site and profile descriptions are given in full in the Appendix, and the supporting laboratory data are given in Tables 1 and 2 (for DRW and LOV, respectively).

Soil and Site Features

DREKEIWAILA PEATY SAND (DRW): DRW 1 soils are located in small areas adjacent to the Koronivia Research Station near Nasinu. They occur in a dissected plateau, in areas of flat and flat to gently undulating (3°–5°) slopes, with an elevation of 10–20 m above mean sea level. The parent material is silica sand, outwashed from rhyolitic rocks. The mean annual rainfall is 3,189 mm (Fiji Meteorological Service 1981) with no dry season; the average annual temperature is 24.7°C with less than 5°C difference between the warmest and coolest months, giving a perudic soil moisture regime and an isohyperthermic soil temperature regime (Soil Survey Staff 1999). The vegetation at the time of initial fieldwork in 1984 was mainly disturbed wet broadleaf forest (*Calophyllum* spp., *Intsia bijuga*, *Aleurites moluccana* with *Dacrydium* spp.) with no specific land use (disturbed natural state). As can be seen in the Appendix, the profile consists of a thin (5 cm) dark reddish-brown fine sandy loam topsoil of weak fine granular structure overlying 56 cm of gray, loose, single sand grains, over 44 cm of gray,

TABLE 1
 Soil Data Sheet for DRW
 Pedon: Drekeiwaila [DRW]; Location: Nasinu; Classification: Aquic Haplothod, Coarse-Loamy, Siliceous,
 Isohyperthermic

Particle Size Information and Particle Diameter (mm)							
Depth (cm)	Horizon	Sand % (2–0.05)	Silt %	Clay % (<0.002)	Coarse Fragments (>2 mm)		
0–5	Ah	84	0	16			
5–23	Eg1	98	1	1			
23–61	Eg2	95	4	1			
61–105	Eg3	94	5	1			
105–118	Er	78	20	2			
118–128	B(m)	96	2	2			
128–158	Bfm	79	11	10			
158–168	C	92	2	6			
128–140	Bt	46	15	39			

							KCl H + Al	
Depth (cm)	pH (H ₂ O)	pH (KCl)	IoA	Org C %	Org N %	Pretn %	H	Al
0–5	4.5	3.1		3.60	0.27	0	0.82	0
5–23	5.3	3.8		0.57	0.05	0	0.16	0
23–61	4.8	4.1		0.06	0.02	0	0.18	0
61–105	6.2	4.5		0.06	<0.01	0	0.15	0
105–118	6.9	4.4		0.04	0.01	0	0.14	0
118–128	5.8	4.4		0.08	0.01	0	0.18	0
128–158	4.4	3.7	84	3.97	0.09	<1	0.02	1.34
158–168	0.3	4.2		1.96	0.05	<1	0.32	0.42
128–140	4.6	3.8		2.24	0.06	4	0.41	4.76

Ion Exchange Exchangeable Bases (cmol/kg)							
Depth (cm)	Ca	Mg	K	Na	TEB	CEC pH 7	BS % NH ₄ OAc
0–5	1.50	0.70	0.08	0.04	2.32	10.84	22
5–23	0.21	0.04	0.01	0.05	0.31	2.05	15
23–61	0.11	0.02	<0.01	0.04	0.17	0.63	27
61–105	0.13	0.02	<0.01	0.05	0.20	0.63	31
105–118	0.12	0.02	<0.01	0.04	0.18	0.89	20
118–128	0.09	0.02	<0.01	0.04	0.15	0.76	20
128–158	0.20	0.07	<0.01	0.05	0.37	7.83	5
158–168	0.18	0.04	0.01	0.01	0.24	2.81	9
128–140	0.28	0.10	0.02	0.12	0.52	15.07	3

Depth (cm)	Al _{ox} (%)	Fe _{ox} (%)	Al _{py} (%)	Fe _{py} (%)	Al _{dc} (%)	Fe _{dc} (%)	ODOE
0–5	0.02	0.20	0.00	0.02	0.02	0.20	0.02
5–23	0.00	0.05	0.00	0.00	0.00	0.05	0.01
23–61	0.00	0.11	0.00	0.00	0.00	0.11	0.00
61–105	0.00	0.19	0.00	0.00	0.01	0.19	0.00
105–118	0.00	0.05	0.00	0.00	0.01	0.05	0.00
118–128	0.00	0.31	0.00	0.00	0.01	0.31	0.00
128–158	0.32	0.01	0.14	0.00	0.21	0.01	0.36
158–168	0.14	0.01	0.12	0.05	.17	0.28	0.14
128–140	0.34	0.05	0.34	0.26	0.71	2.00	0.35

TABLE 2

Soil Data Sheet for LOV
Pedon: Lovonivia (LOV); Location: Wainikoro, Vanua Levu; Classification: Oxyaquic Ultic Haplorthod, Sandy over Clayey, Siliceous, Isohyperthermic

Particle Size Information and Particle Diameter (mm)							
Depth (cm)	Horizon	Sand % (2–0.05)	Silt %	Clay % (<0.002)	Coarse Fragments (>2 mm)		
0–22	Ap1	46	44	10			
22–31	Ea1	49	45	6			
31–64	Ea2	52	42	6			
64–76	Bs1	37	31	32			
76–92	Bs2	25	24	51			
92–111	Bt	30	32	38			
111–141	Bw	33	32	35			

						KCl ext	
Depth (cm)	pH (H ₂ O)	pH (KCl)	Org C %	Org N %	Pret _n %	H	Al
0–22	4.5	3.5	1.16	0.09	0	0.22	1.66
22–31	4.7	4.2	0.22	0.02	0	0.26	0
31–64	5.4	4.5	0.04	0.01	0	0.14	0
64–76	4.6	4.0	0.30	0.03	11	0.16	3.30
76–92	4.6	4.2	1.34	0.06	79	0.20	1.83
92–111	4.4	4.0	0.20	0.02	27	0.09	3.61
111–141	4.4	3.8	0.12	0.02	11	0.40	4.25

Ion Exchange Exchangeable Bases (cmol/kg)							
Depth (cm)	Ca	Mg	K	Na	TEB	CEC pH 7	BS % NH ₄ OAc
0–22	0.16	0.04	0.03	0.14	0.37	4.58	8
22–31	0.06	0.01	<0.01	0.11	0.18	0.83	22
31–64	0.02	0.02	<0.01	0.12	0.16	0.72	22
64–76	0.12	0.05	0.03	0.11	0.31	5.43	6
76–92	0.10	0.03	0.03	0.14	0.30	14.01	2
92–111	0.14	0.06	0.04	0.13	0.31	9.12	3
111–141	0.56	0.14	0.05	0.16	0.91	7.10	13

Depth (cm)	Al _{ox} (%)	Fe _{ox} (%)	Al _{py} (%)	Fe _{py} (%)	Al _{dc} (%)	Fe _{dc} (%)	ODOE
0–22	0.03	0.17	0.00	0.13	0.06	0.32	0.06
22–31	0.01	0.05	0.00	0.05	0.01	0.08	0.02
31–64	0.00	0.02	0.00	0.02	0.01	0.03	0.00
64–76	0.11	0.01	0.07	0.01	0.11	0.03	0.03
76–92	1.10	0.72	0.94	0.62	1.40	3.33	0.36
92–111	0.07	0.04	0.04	0.01	0.33	1.10	0.00
111–141	0.17	0.11	0.1	0.05	0.26	0.74	0.02

loose, coarse sand, with common large iron concretions. This in turn lies on 13 cm of pinkish-gray, very firm medium sand, massive breaking with difficulty to single grain; this rests, through a sharp wavy boundary, on a 10 cm discontinuous yellowish-red iron pan over a thin yellowish-brown clayey firm and sticky horizon with many distinct humus cutans overlying a dark reddish-brown very firm massive continuous iron pan. The profile

is excessively well drained to a depth of 105 cm but poorly drained below that depth.

LOVONIVIA SANDY LOAM (LOV): LOV 1 soils, forming part of the Wainikoro set (Twyford and Wright 1965), cover a limited area in Vanua Levu adjacent to the Wainikoro River. They are located on flattish quartzose outwash fans and terraces supporting local scrub vegetation and formed in a zone with a strong dry season. The average annual rainfall is 1,800–2,400 mm (Fiji Meteorological Service 1981) with a strong dry season from May to November, and the average annual temperature is 26°C; the soils thus have an ustic soil moisture regime and an isohyperthermic soil temperature regime (Soil Survey Staff 1999). They are formed in flat to gently undulating and undulating areas with an elevation range of 6–20 m. As can be seen in the Appendix, the profile consists of 20 cm of dark grayish-brown very friable sandy loam topsoil, with a weak subangular blocky and crumb structure overlying 9 cm of massive, firm, and weakly cemented light brownish-gray loamy sand with dark yellowish-brown mottles (5%). This in turn overlies 33 cm of light grayish-brown extremely firm and massive loamy silt, which rests on 12 cm of dark grayish-brown friable clay loam with a weak coarse block structure, and 16 cm of brownish-yellow firm loamy clay with a weakly medium platy structure, and a weakly cemented iron/manganese humus pan with organic coatings. Below this lies 19 cm of brownish-yellow friable loamy clay, massive breaking to a weak blocky structure with distinct strong brown clay cutans, on a pale yellow very friable clay loam, massive breaking to weak blocky structure, with profuse coarse yellow mottles and yellowish-brown organic cutans. These soils are poorly drained due to a firm consistency and weak cementation in the 22–64 cm layer and low soil permeability below 64 cm.

Laboratory Information

As can be seen in Tables 1 and 2, these soils exhibit many features common to Spodosols. The upper sections of the profiles are dominated by sand, with appreciable clay contents found only in or close to the spodic horizons

(discussed further in the next section). The soils are acidic, with low overall contents of organic carbon and nitrogen. There is a notable increase in organic carbon in the spodic layers. Cation exchange capacities are generally low (highest value 14 cmol/kg), and contents of exchangeable bases are very low, with only the DRW topsoil having a total exchangeable bases (TEB) > 1 cmol/kg. KCl extractable aluminum values are relatively low except in horizons near the “spodic zone.” P retention values are near zero except in the LOV horizons with clay contents above 30%. Extractable Al, C, Fe, and Si data used in identifying spodic materials often show very low values except, as discussed in the next section, in zones where spodic features occur.

Classification

Classification of Spodosols has focused on the “spodic” horizon/materials rather than the “bleached” horizon often used in earlier times (Buol et al. 2011). As noted earlier, spodic materials arise from the transport of aluminum and iron with carbon and deposition in the lower parts of profiles. Evidence of such eluviation/illuviation is provided by a combination of field and laboratory observations. The field characteristics include the presence of orstein or cracked coatings on mineral grains and specific color requirements in the spodic horizon. The laboratory characterization involves the use of optical identification of amorphous material in the spodic horizon, pH, organic carbon content, and extractable aluminum and iron data. There have also been some changes in the parameters used since the publication of *Soil Taxonomy* in 1975 (Soil Survey Staff 1975). These changes include the nature of the extractants used for aluminum and iron, with the 1999 *Soil Taxonomy* (Soil Survey Staff 1999, 2014) using acid oxalate instead of pyrophosphate and dithionite-citrate. These changes have been developed to facilitate better separation of Spodosols from other soil orders, such as Andisols and Inceptisols.

The dominant profile characteristics of the Drekeiwaila and Lovonivia soils have, respectively, reddish-brown and grayish-brown

subsoil spodic horizons representing the accumulation of translocated organic matter complexed with aluminum and iron. Both soils have albic horizons, but for Drekeiwaila it is not directly above the spodic horizon. These soils are very acid throughout the profile (Tables 1 and 2). As with other Spodosols, other diagnostic features are recognized below the spodic horizon, such as an embryonic placic horizon in the Drekeiwaila and an argillic horizon in the Lovonivia soils.

The Drekeiwaila soil meets the Spodosol criteria (Soil Survey Staff 1999), with the DRW 1 pedon having an ochric epipedon (0–5 cm) and albic and spodic diagnostic subsurface horizons. The eluvial horizon (5–61 cm) has a gray 5YR hue with a chroma of 2 or less and a moist value of 4 or more and so meets the requirements for an albic horizon. The spodic horizon does not immediately underlie the albic; rather, it is recognized at 128–158 cm depth. This C horizon satisfies the criteria for spodic, having very firm consistence with the pH less than 5.9 (4.4), organic carbon content greater than 0.6% (3.97%), and the optical density of oxalate extract (ODOE) value is greater than 0.25 (0.36). Incidentally, the sum of oxalate extractable aluminum + $\frac{1}{2}$ iron is less than 0.50 (0.30), but this attribute can be waived because Drekeiwaila meets all the foregoing criteria.

The Drekeiwaila soil qualifies as a Spodosol with a spodic horizon greater than 10 cm thick within a depth of 200 cm (because it is of sandy texture above the spodic) but does not meet criteria described for four of the five suborders (two occur in cold climates); a seasonally high water table is not recognized (Aquods), and organic carbon values are less than 6% in the spodic horizon (Humods); it is an Orthod at the suborder level. The absence of other key features places this in the Haplorthod great group, and because redoximorphic features are observed in one or more horizons within 75 cm of the surface with aquic conditions occurring for some time in normal years this meets the criteria for the Aquic suborder. The full classification for Drekeiwaila soils is Aquic Haplorthod, coarse-loamy, siliceous, isohyperthermic.

The Lovonivia soil has an ochric epipedon (0–22 cm) and albic and spodic diagnostic horizons. The light-colored leached horizons (22–64 cm) satisfy the criteria for albic, having color hues of brownish-gray (2.5Y) with chromas of 2 or less and values (dry) of 6 or more. The Bs2 horizon at 76–92 cm meets the requirements for spodic, with pH less than 5.9 (4.6), organic carbon greater than 0.6% (1.34%); the horizon has firm consistence, an ODOE value greater than 0.25 (0.36), and the sum of acid oxalate extractable aluminum + $\frac{1}{2}$ iron is greater than 0.50 (1.46) and two times more than the layer above.

The Lovonivia soil also has a spodic horizon greater than 10 cm thick within a depth of 200 cm and, for the same reasons as outlined earlier for the Drekeiwaila soils, is in the Orthods suborder and Haplorthods great group. The Lovonivia soils have an argillic horizon within 200 cm of the surface and so satisfy Ultic criteria, and because profiles are saturated with water in one or more layers within 100 cm of the surface in normal years for 20 or more cumulative days, they also meet the Oxyaquic subgroup requirements. The Lovonivia soil, therefore, classifies as an Oxyaquic Ultic Haplorthod, sandy over clayey, siliceous isohyperthermic.

DISCUSSION

Soil Genesis

In an overview of Fiji soils, Twyford and Wright (1965) stated that climate was the most important factor influencing soil formation in the country. This is not the case for the genesis of the Spodosols, where it appears that parent material is of primary importance, with time, climate, vegetation, and hydrology as other factors of significance.

In their assessment of the genesis of Fiji soils, Twyford and Wright (1965) outlined two parallel paths of soil development, one for basic rocks and one for acidic parent materials. In the acidic materials pathway of particular relevance here, they proposed that initially A/C profiles were predominantly developed with a relatively dark A horizon, with possibly a weakly developed B horizon;

they referred to these as nigrescent soils. These acid rock nigrescents were thought to weather into brownish to reddish-yellow sandy clays (red-yellow podzolic soils). In high rainfall zones, these red-yellow podzolic soils have a “pronounced yellow color,” but in regions with a marked dry season, the subsoils tend to be more compact and heavier than the topsoils. If the parent materials are very quartz rich, the highly weathered and leached soils tend to be characterized by light grayish colors with bleached quartz grains in the upper soil profile, which could in some places lead to humid tropical Spodosol formation.

The probable origin of the DRW and LOV soils is the presence of permeable quartz-rich sands under high rainfall that leads to strong leaching of bases. This could occur only in locations where the quartzitic materials were stable for sufficient time to allow the soil-forming processes to develop the Spodosol features. There would also have to be present an original type of forest that produced raw humus, intensifying the leaching and assisting in the removal of aluminum and iron oxyhydroxides released during weathering. Although little of the existing forest remains at the study sites, the vegetation history of the country suggests that there was a wet broadleaf forest (*Calophyllum* spp., *Intsia bijuga*, *Aleurites moluccana* with *Dacrydium* spp.) at DRW and *Casuarina* spp., *Elaeocarpus* spp., *Syzygium* spp., and *Intsia bijuga* at LOV (Parhum 1972, Smith 1979). Both vegetation communities could produce acidic humus (Stevenson 1994), facilitating the downward movement of organic-complexed Al and Fe.

Over time the relatively high leaching together with the humus-derived organic material weather any primary and secondary aluminosilicate minerals, Al and Fe oxyhydroxide materials, and transport the weathering products along with solubilized silica down until they reach the groundwater (DRW) or a secondary textural change layer of limiting permeability (LOV) where the opportunity arises for deposition and reaction of the mobile components to create the spodic materials. Some aluminosilicate materials formed (ka-

TABLE 3
Mineralogical Information on DRW and LOV Soils

Profile/Horizon/Depth	Mineralogy
DRW 25–100 cm	Quartz 87% Heavy minerals 13% (comprising ilmenite 90%, magnetite ~8%, clinopyroxene 2%)
LOV 22–64 cm	Quartz > 90%
LOV 64–114 cm clay fraction	Kaolinite > 50%

olinite and possibly allophane), and the Al and Fe formed oxyhydroxides such as goethite, gibbsite, and ferrihydrite. The mineralogical interpretations are supported by the limited mineralogy data in Table 3 and the extractable Al and Fe data (Si_{ox} data not presented because most values were less than the detection limit) in Tables 1 and 2 using the links established by Parfitt and Childs (1988). In addition, it is likely that some organic particles and complexed mineral material would have been precipitated. Based on the comments by Buol et al. (2011), the parent materials of the Fiji Spodosols would have been low in Al, Fe, and clay.

Podzolization involves simultaneous production, transport, precipitation, redissolution, and breakdown of substances at different parts of the soil profile (McKeague et al. 1983, Mokma and Evans 2000, Buol et al. 2011). The process changes over time, because pH of the soil tends to decrease with continuing depletion of weatherable minerals. As noted earlier, the conditions favoring these processes are usually cool, wet climates, favoring vegetation that produces an acid humus, and these are not often found in tropical areas other than at high elevation. In Fiji, most areas are relatively wet (rainfall < 1,500 mm/yr is very unusual), but cool temperatures are unusual, with the highland areas (elevation > 1,000 m) having temperatures down to <5°C on some nights, but the annual mean is seldom < 15°C. Consequently, in Fiji climate is not, as indicated earlier, the dominant soil-forming factor for Spodosols; parent material is more important in this case.

As noted earlier the differences between the DRW and LOV pedons are as follows: (1) the thickness and particle size of the albic/eluvial horizon, (2) the occurrence of a placic horizon in DRW and an argillic horizon in LOV, and (3) the influence of groundwater for DRW. Apparently the final thickness of the E horizon and the expression of the B horizon depend on many factors, such as composition of the parent material, nutrient status of subsoil (affecting decomposition of organic matter), and composition of the organic fraction itself. The nature of the parent material will influence considerably the thickness and dominant particle size of the E horizon, and the features of the two pedons studied indicate that although the parent materials may have some characteristics in common they would have had different particle size feature and slightly different composition. The LOV parent material is likely to have had more fine sandy materials and a higher content of aluminum (to enable kaolinite to form). The groundwater influence in DRW will have limited opportunities for kaolinite development by removing any soluble silica. The groundwater movement may also have facilitated solubilization and subsequent deposition of iron in the placic horizon of DRW.

Classification

Lovonivia and Drekeiwaila soils conform with other Spodosols described in the literature that show that spodic horizons of Orthods are dominated by silt loams and fine sandy loams, whereas those of Aquods are sandy textured, and structures are weak or absent in all suborders of Spodosols but are frequently present in Orthods. Lowland tropical podzols are classed as albic arenosols in the FAO system (FAO-UNESCO 1974), only meeting the Orthic or Humic Podzol classes if there is a “sesquioxide” B horizon within 125 cm.

Current and Potential Uses of These Soils

As indicated earlier, these soils are of low fertility. The acid nature, low water-holding

capacity in the upper horizons, low organic matter, and low base contents are all indicative of problems. The restricted areas of Drekeiwaila soils are not used for any major agricultural activities and are likely to be utilized in the rapidly expanding housing developments in the area. The Lovonivia soils have been utilized in limited areas for pasture and rice and vegetable (cassava) production, but any intensive use has required substantial fertilizer inputs and regular watering in the dry season. The infertile nature of the soils and the availability of more fertile soils of greater extent in the surrounding areas (Leslie and Seru 1988) mean that they are unlikely to be developed for any substantial agricultural use; the inputs required would make any such activities uneconomic in the current situation in Fiji.

Significance of Locating These Soils

Tropical Spodosols are of limited extent, especially those found at low elevations. The identification of such soils in small Pacific islands was most unexpected, with few of the “normal” soil-forming features associated with such soils being present (Mokma and Evans 2000). The occurrence of cool and humid zones with acid compost-producing vegetation in mainly sandy parent materials is unusual in tropical islands based mainly on basalt and andesitic rocks and their sedimentary and metamorphic derivatives and coral reef limestone. There is evidence of rainfall and temperature changes in the region over the last 2 million years (e.g., Southern 1986), but conditions such as those associated with continental Spodosols are unlikely to have occurred. A possible scenario is that geological conditions in limited areas are such that only nutritionally poor vegetation could develop, giving rise to acidic compost, which under wet climatic conditions would give rise to an acidic chelating leachate and the production of spodic materials at depth. Although these two low-elevation Spodosols have been identified in Fiji, they occupy small land areas and have limited agricultural potential, as they exhibit the low fertility status shown by many Spodosols worldwide.

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Appendix

Site and Profile Descriptions

Pedon DRW

- Classification: Typic Tropohumod, sandy, siliceous, isohyperthermic
- Location: Nasinu cemetery, SE Viti Levu, Fiji
- Physiography: Planar backslope in “plateau-like” topography (marine planated) with evidence of saltation; altitude 10 m above mean sea level
- Topography: 2° E-facing smooth slope
- Drainage: Excessively drained to 105 cm, poorly drained below 105 cm
- Vegetation: Open disturbed forest
- Parent material: Strongly leached rhyolytic outwash
- Climate: Average annual temperature 26°C; rainfall approximately 3,000 mm annually with very weak dry season June–October

Profile Description (by D. M. Leslie and R. J. Morrison)

- Ap 0–5 cm: slightly moist; dark reddish-brown (5 YR 2/2) fine sandy loam; weakly developed fine granular and crumb structure; loose; nonsticky; nonplastic; abundant fine, medium, and coarse roots; distinct smooth boundary,
- Eg1 5–23: slightly moist; gray (5 YR 6/1) sand; single grain; loose; nonsticky; nonplastic; abundant fine, medium, and coarse roots; distinct smooth boundary,
- Eg2 23–61: slightly moist; gray (5 YR 5/1) medium sand; single grain; loose; nonsticky; nonplastic; many fine and medium roots along boundary only; indistinct smooth boundary,
- Eg3 61–105: slightly moist; gray (5 YR 6/1) coarse sand; common large yellowish-red (5 YR 5/8), red (2.5 YR 4/6), and dusky red (2.5 YR 3/2) iron concretions; single grain; loose; nonsticky; nonplastic; indistinct smooth boundary,
- Er 105–118: slightly moist; 80% pinkish-gray (7.5 YR 6/2), 20% gray (5 YR 6/1) medium sand; massive breaking with difficulty to single grain; very firm; nonsticky; nonplastic; distinct wavy boundary,
- B(m) 118–128: wet; gray (5 YR 5/1) very coarse sand; single grain; loose; nonsticky; nonplastic; discontinuous yellowish-red (5 YR 5/6) iron pan; sharp wavy boundary,
- Bfm 128–158: wet; dark reddish-brown (5 YR 3/2) coarse gritty coarse sand; massive breaking to single grain; very firm; nonsticky; nonplastic; discontinu-

	ous humus pan; distinct smooth boundary,		
C1 158–168:	wet; reddish-brown (2.5 YR 4/4) fine sand; single grain; loose; non-sticky; nonplastic,	Ea2 31–64:	yellowish-brown (10 YR 4/4) fine reticulate mottling; massive; very weakly cemented; firm; indistinct wavy boundary,
Note: Within pedon and in equivalent position to horizon 7, the profile shows:			
Bt 128–140:	wet; yellowish-brown (10 YR 5/6) clay; many medium distinct strong brown (7.5 YR 5/6) mottles; weakly developed medium blocky structure; firm; sticky; slightly plastic; many distinct dark brown (10 YR 3/3) organic cutans; many fine and medium roots; upper and lower boundaries sharp wavy,	Bs1 64–76:	moist; 80% dark grayish-brown (10 YR 4/2) and 20% light brownish-gray (2.5 Y 6/2) loamy very fine sand; weakly developed coarse blocky structure breaking to single grain; friable; slightly sticky; common distinct dark grayish-brown (10 YR 4/2) organic cutans; sharp smooth boundary,
on	the iron humus pan as described earlier.	Bs2 76–92:	moist; brownish-yellow (10 YR 6/8) gritty clay; many medium and coarse dark yellowish-brown (10 YR 4/4) mottles (layered horizontally); weakly developed medium platy structure breaking to single grain; firm; slightly sticky; slightly plastic; very weakly cemented; discontinuous reddish-brown (5 YR 4/4) embryonic iron/manganese humus pan; few distinct dark yellowish-brown (10 YR 4/4) organic coatings; distinct smooth boundary,
Pedon LOV			
Classification:	Oxiaquic Ultic Haplorthod, sandy over clayey, siliceous. isohyperthermic		
Location:	Near mouth of Wainikoro River, Vanua Levu, Fiji		
Physiography:	High terrace remnant adjacent to Wainikoro River; altitude 10 m above mean sea level		
Topography:	2° SW-facing smooth slope approximately 100 m long	Bt 92–111:	moist; brownish-yellow (10 YR 6/6) gritty clay; few fine and medium faint strong brown (7.5 YR 5/8) mottles; massive breaking to weakly developed coarse blocky structure; friable; slightly sticky; slightly plastic; common faint brownish-yellow (10 YR 6/8) and common distinct strong brown (7.5 YR 5/8) clay cutans; few distinct light olive brown organic cutans; distinct smooth boundary,
Drainage:	Poorly drained		
Vegetation:	Ground cover of carpet grass with scattered shrubs, <i>Hibiscus</i> sp.		
Parent material:	Strongly weathered riverine alluvia of acidic composition		
Climate:	Average annual temperature 26°C; rainfall approximately 2,200 mm annually with strong dry season June–October		
Profile Description (by D. M. Leslie and R. J. Morrison)			
Ap 0–22 cm:	dry; dark grayish-brown (2.5 Y 4/2) fine sandy loam; weakly developed fine subangular blocky structure with fine crumb; very friable; few fine and very fine roots; sharp smooth boundary,	Bw 111–141:	moist; 50% pale yellow (5 Y 8/3) clay; 50% profuse medium and coarse prominent yellow (10 YR 7/8) mottles; massive breaking to weakly developed medium blocky structure; very friable; slightly sticky; slightly plastic; few faint brownish-yellow (10 YR 6/8) clay cutans; few distinct yellowish brown (10 YR 5/4) organic cutans.
Ea1 22–31:	dry; 95% light brownish-gray (2.5 Y 6/2) and 5% dark grayish-brown (2.5 Y 4/2) loamy very fine sand; common fine distinct dark		