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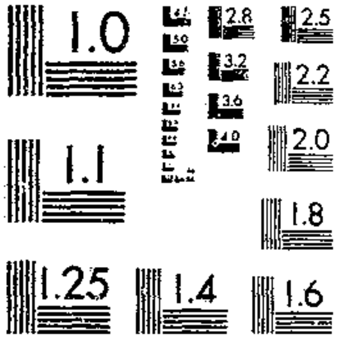

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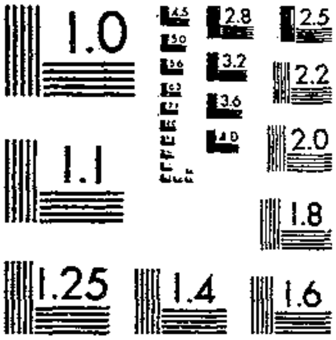

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Rock Weathering and Soil Profile Development in the Hawaiian Islands[1]

By G. J. Hough, *assistant chemist*, and P. L. Gile, *senior chemist, Division of Soil Chemistry and Physics*, and Z. C. Foster, *assistant soil surveyor, Division of Soil Survey, Bureau of Plant Industry*

CONTENTS

INTRODUCTION

In a previous bulletin (*7*)[2] dealing with Hawaiian soils, particular attention was given to the kinds of colloidal material developed under high and low rainfalls. The analytical data reported were obtained from seven profiles developed under rainfalls ranging from 20 to 104 inches annually. Fourteen more profiles have since been analyzed. These include examples of exceedingly young, young, and old profiles exposed to rainfalls of 18 to 273 inches. It is the purpose of this bulletin to show what the available data indicate as to the general course of soil weathering in the Hawaiian Islands and the chemical types of soil profiles developed.

It is realized that the deductions made here as to soil weathering and profile development in the Hawaiian Islands are not comprehensive or conclusive. But even if they should prove to be erroneous, they may help to develop the subject by directing inquiry or the acquisition of more data. An adequate treatment of such a subject is usually obtained only by growth.

A review of the literature dealing with the chemical composition of Hawaiian soils is given in the previous bulletin (*7*) and in the book on Hawaiian soils compiled by Moir et al. (*11*).

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[1] Submitted for publication June 5, 1940.
[2] Italic numbers in parentheses refer to Literature Cited, p. 42.

DESCRIPTION OF THE PROFILES

The analytical data pertaining to the seven profiles published previously are used in a recalculated form in many of the tables shown here. The profile numbers 15, 16, 17, 18, 19, 20, and 21 in this bulletin refer respectively to the profiles numbered 1, 3, 7, 6, 2, 4, and 5 in the previous bulletin (7).

The 14 new profiles selected for differences in their ages and in the rainfalls to which they are exposed were collected by L. R. Smith, formerly of the Division of Soil Survey, and by Z. C. Foster, of the Division of Soil Survey, Bureau of Plant Industry. Their descriptions of the profiles are given below.

EXCEEDINGLY YOUNG PROFILES

PROFILE 1, LABORATORY NOS. C1610 TO C1612.—Kilauea Special. Rainfall, 100 inches; elevation 3,800 feet; parent rock, volcanic cinders and clinkers from very young ejecta. Samples taken May 16, 1936, from a semivirgin roadside location, on a gently sloping spur of Kilauea Volcano in the Kilauea truck-farm region on the island of Hawaii.

C1610, 0 to 7 inches, friable or soft friable, dark grayish-brown light clay loam, with poorly defined crumb structure; when moist, pressing out into ⅛-inch layers. Easy augur twist and pull; large number of small roots and a few worm channels.

C1611, 7 to 18 inches, friable, brown light clay loam, with poorly defined crumb structure; when moist, pressing out into ⅛-inch layers. Easy augur twist and moderate pull. Moderate number of small roots and a few worm channels.

C1612, 18 to 27 inches, friable, dark reddish-brown loam, with poorly defined coarse-crumb structure. Easy augur twist and moderate pull. Moderate number of small roots below 27 inches. Cinders and clinkers.

PROFILE 2, LABORATORY NOS. C1613 AND C1614.—Oloa clay loam. Rainfall, 150 inches; elevation, 75 feet; parent rock, Aa lava rock, geologically recent. Vegetative cover consisted of guava and lantana. Sample taken May 14, 1936, on Kinoole Street extension, at Villa Franca, Hilo, island of Hawaii.

C1613, 0 to 9 inches, mellow, granular, dark grayish-brown clay loam mixed with rock fragments. Moderate number of small roots and a few worm channels.

C1614, 9 to 24 inches, soft, friable, granular, yellowish-brown clay mixed with fragmentary rock.

PROFILE 3, LABORATORY NOS. C1615 AND C1616.—Ohia special. Rainfall, 175 inches; elevation, 1,000 feet; parent rock, moderately dense pahoehoe lava rock. Sample taken May 14, 1936, from a gently sloping area on Oloa plantation, Ohia; on a side road 2,429 feet from highway between Ohia and Eleven-mile Homestead, Ohia, Olaa, island of Hawaii.

C1615, 0 to 7 inches, soft friable, dark brownish-gray light silty clay, with moderately well-defined, coarse-crumb structure, plastic upon crushing. Large number of small roots and a few root channels.

C1616, 7 to 15 inches, soft friable, dark yellowish-brown silty clay with slight reddish cast, moderately well-defined crumb structure. Small number of small roots. Moderately dense prehistoric pahoehoe lava rock below depth of 15 inches.

Young Profiles

Profile 4, Laboratory Nos. C1627 to C1629.—Waikiki. Rainfall, 20 inches; elevation, 2,630 feet; rock material, volcanic ash. Vegetative cover: Akia, unhaloa, tarweed, clover, rattail, Natal grass. Sample taken May 12, 1936, on moderately sloping land at edge of a shallow dry gulch, 4.4 miles towards Kona from Waikiki turn-off at prison camp on main road. South Kohala, island of Hawaii.

C1627, 0 to 10 inches, dark reddish-brown light sandy clay loam. Friable, moderately well-defined coarse-crumb structure. A large number of small roots.

C1628, 10 to 21 inches, dark reddish-brown light sandy clay loam. Friable, moderately well-defined, large crumb structure, breaking down to a mellow material. A moderate number of small roots.

C1629, 21 to 40 inches, dark brown with reddish cast, light loam. Mellow, moderately well-defined small nutlike structure. A few worm channels.

Profile 5, Laboratory Nos. C1617 to C1621.—Moaula light clay loam. Rainfall, 50 inches; elevation, 1,600 feet; parent rock, volcanic ash over lava. Taken May 18, 1936, 1 mile west of Pahala on slope of Mauna Loa, Pahala; Kau, island of Hawaii.

C1617, 0 to 6 inches, dark grayish-brown light clay loam.

C1618, 6 to 23 inches, yellowish-brown silty clay loam. Poorly defined fine-crumb structure, soft and friable.

C1619, 23 to 42 inches, strong yellow-brown silty clay loam. Poorly defined small-crumb structure, soft and friable. Contains remnants of scoria.

C1620, 42 to 75 inches, reddish-brown or reddish-yellow silty clay. Moderately well-defined coarse-crumb, breaking down to fine-crumb structure. Soft and friable, but sticky when wet.

C1621, 75 to 96 inches, strong reddish-yellow silty clay. Moderately well-defined crumb structure. Soft and friable; rolls to a sticky condition.

Profile 6, Laboratory Nos. C1607 to C1609.—Honokohau silty clay loam. Rainfall, 65 inches; elevation, 1,500 feet. Parent rock, at 25 inches moderately dense prehistoric pahoehoe lava. Vegetative cover: Crotalaria, honohonu, hilo grass, tarweed, guava, and coffee. Taken May 4, 1936, on slope of Mauna Loa, 317 feet north of entrance to Hall's hotel on main highway. Honokohau, Kona, island of Hawaii.

C1607, 0 to 9 inches, grayish-brown silty-clay loam, soft, friable, with moderately well-defined small nutlike structure; breaking down to poorly defined granular structure; when damp, pressing out into ⅛-inch layers. Large number of small roots, moderate number of medium-sized roots, and a few root channels.

C1608, 9 to 17 inches, yellowish, mellow to plastic, silty clay; with moderately well-defined fine nutlike structure; breaking down to poorly defined small-crumb structure; pressing into ⅛-inch layers when damp. Few roots and few root channels.

C1609, 17 to 25 inches, brown, mellow to plastic, silty clay; with poorly defined small-crumb structure; when moist, pressing into ¼-inch layers. A few small roots. Underlain by moderately dense pahoehoe lava.

Profile 7, Laboratory Nos. C1633 to C1636.—Kaieie heavy silty clay. Rainfall, 175 inches; elevation, 900 feet; parent rock, volcanic ash. Sample taken May 14, 1936, on gently sloping side of a small knoll, 1.96 miles from inland on main cane road, Pepeekeo plantation, 317 feet towards Hilo on a branch road; Pepeekeo, Hamakua, island of Hawaii.

C1633, 0 to 6 inches, pale yellowish-brown heavy silty clay; friable to plastic, granular.

C1634, 6 to 18 inches, dark yellowish-brown clay; soft, friable to plastic, with poorly defined crumb structure; when very wet, pressing into ⅛-inch layers.

C1635, 18 to 25 inches, brown clay, friable or plastic, poorly defined crumb structure; pressing into ⅛-inch layers when very wet.

C1636, 28 to 38 inches, reddish yellowish-brown clay. Soft, friable to plastic, poorly defined crumb structure; very wet, pressing into ⅛-inch layers.

PROFILE 8, LABORATORY NOS. C2271 TO C2277.—Hilo silty clay loam. Rainfall, 188 inches; elevation, 200 feet; volcanic ash over lava. Vegetative cover: Grass with guava shrubs. Sample taken October 9, 1936, from a pit opposite Kalooa garage on main road, 1 mile north of Papaikou, island of Hawaii.

C2271, 0 to 9 inches, pale medium-brown silty clay loam. The structure in places is a medium crumb, bound into soft lumps by the numerous grass roots. The lumps are easily friable under moderate pressure, but ribbon roughly under hard pressure. The material is slightly plastic. It is wet, but the wetness is not apparent until pressed. Roots are plentiful.

C2272, 9 to 28 inches, yellowish-brown silty clay tinged with red. Moderately well-defined, irregular nutlike structure that is very easily friable to well-defined firm flaky crumbs. These large crumbs may be crushed to a soft fine crumb under moderate pressure. Under strong pressure the material is slightly cohesive, and very slightly plastic. This layer is wetter than the surface layer, although the wetness is not apparent until pressure is applied. Roots are plentiful.

C2273, 28 to 31 inches, grayish-brown clay, containing numerous fragments of rotten rock. The rock varies in color from grayish brown at 28 inches to rusty red at 31 inches. The material digs out in moderately firm, irregular chunks that may be crushed to medium crumbs under moderate pressure. This horizon is moderately plastic and much more firm and cohesive than the layer above. Wetness is similar to the layer above. There are numerous roots.

C2274, 31 to 42 inches, yellowish-brown silty clay that digs out in irregular chunks easily friable to a well-defined, medium-crumb structure under moderate pressure. The crumbs may be broken down to very fine particles if care is taken. The material is slightly plastic and is not strongly cohesive. The apparent wetness is greater than that of any layer above. Roots are present in moderate amounts.

C2275, 42 to 72 inches, dull yellowish-brown heavy silty clay or clay. The material digs out in irregular chunks, the vertical cleavage planes of which have a glistening sheen and horizontal planes of which are dull. The mass is very slightly vesicular. The chunks are less easily friable than the horizon above, to a moderately well-defined, medium-sized crumb that may be crushed further if care is taken. The material is moderately plastic and more sticky than the layer above. It is similar in most physical characteristics except color and the presence of rotten rock to the material immediately above it. Roots are present.

C2276, 72 to 78 inches, reddish-brown (splotched with yellow and yellow brown) sandy clay. The material digs out in irregular, soft pieces that are very easily friable to gritty, slightly granular crumblike fragments. The material is saturated with water. It is not plastic. There are numerous rotten rock fragments that are the color of the soil. Roots are few to none.

C2277, 78 to 88 inches, yellowish-brown silty clay or clay with a reddish hue. The material digs out in irregular nutlike pieces that are moderately friable to slightly cohesive medium-sized crumbs. These crumbs cannot be broken down further under natural moisture conditions. The material is slightly plastic. It is very wet, but the wetness is not apparent as in the layer above. Roots are absent.

PROFILE 9, LABORATORY NOS. C2278 TO C2285.—Kaiwiki silty clay loam. Rainfall, 273 inches; elevation, 1,150 feet; parent rock, volcanic ash over lava. Samples taken from cane land with an average slope of 12 percent, 3.2 miles north of Hakalau, island of Hawaii.

C2278, 0 to 9 inches, grayish-brown silty clay loam having a rough nutlike structure that easily breaks down to crumbs. The immediate surface has a granular structure. Dehydrated particles are noticeable throughout. Very wet, slightly sticky, but not plastic. Some of next layer mixed in, due to deep plowing.

C2279, 9 to 14 inches, yellowish-brown silty clay with a reddish cast. Crumb structure that smooths out with pressure. Vesicular, friable. Apparently not as wet as surface soil. Low volume weight, numerous roots.

C2280, 14 to 26 inches, dark-brown plastic silty clay with an irregular nutlike structure that breaks to a crumb and finally smooths out with pressure. Vesicular. Slightly sticky. More cohesive than above layer. Plastic but not strongly cohesive. Sticky and slightly wetter than above layer.

C2281, 26 to 31 inches, dull-brown to dark-brown silty clay containing some fragments of a light, porous rocklike material, locally called scoria. Structure about same as layer above. Plastic but not strongly cohesive. Sticky and slightly wetter than above layer.

C2282, 31 to 36 inches, slight yellowish-brown or buff-colored silty clay with a large irregular nut structure breaking to a crumb, destroyed by slight pressure. Vesicular. Loosely friable but sticky with pressure.

C2283, 36 to 42 inches, yellowish-brown silty clay with same structure as above layer but more friable. Apparently not as wet. More vesicular.

C2284, 42 to 51 inches, brown silty clay splotched with light gray. Poor nutlike or poor crumb structure. Wetter, less friable, and less vesicular than above layer.

C2285, 51 to 66 inches, massive gray clay with light specks of undecomposed rocks and white specks resembling fungus growth. Plastic and stiff. This layer is underlain by lava.

OLD PROFILES

PROFILE 10, LABORATORY NOS. C1646 TO C1648.—Pulehu. Rainfall, 18 inches; elevation, 1,450 feet; parent rock, lava with probably some alluvium. Vegetative cover: Opuntias and several unidentified xerophytic plants. Sample taken May 18, 1936, on a gentle slope at break of roadside ditch, 2.58 miles down old Wailuku road from Pulehu, island of Maui.

C1646, 0 to 10 inches, dark yellowish-brown clay loam with slight reddish cast. Hard, friable, moderately well-defined large-crumb structure; breaking down into poorly defined granules. Large number of small roots, average number of medium-sized roots.

C1647, 10 to 45 inches, pale-brown silty clay, with a slight cast of red. Hard, friable, to hard moderately well-defined clod structure, breaking down successively to coarse nutlike and crumb structure; stiff upon moistening.

C1648, 45 to 60 inches, dark grayish-brown silty clay. Hard, friable, moderately well-defined coarse-crumb structure, plastic and sticky when moistened.

PROFILE 11, LABORATORY NOS. C1655 TO C1657.—Ewa. Rainfall, 22 inches; elevation, 97 feet; parent rock, alluvium from old residual materials. Sample taken May 20, 1936, where an alluvial terrace breaks into a gulch 317 feet upstream from road, just below and parallel to main highway to Waianae, island of Oahu.

C1655, 0 to 12 inches, light grayish-brown clay with slight reddish cast. Mellow, moderately well-defined fragmental structure, breaking down into poorly defined granules; moderate number of small roots.

C1656, 12 to 32 inches, hard, friable, moderately well-defined fragmental structure, breaking down into hard-crumb structure. Dark yellowish-brown with slight reddish cast silty clay. Small number of small roots.

C1657, 32 to 50 inches, dark yellowish-brown clay with slight reddish cast. Mellow, poorly defined fragmental structure; breaking into poorly defined granules.

PROFILE 12, LABORATORY NOS. C1652 TO C1654.—Kipapa. Rainfall, 36 inches; elevation, 540 feet; parent rock, basaltic lava. Sample taken May 20, 1936, on the break of a level plateau to a gulch located on north side of main Kipapa gulch, southwest of bridge on old abandoned road grade, Wahiawa, island of Oahu.

C1652, 0 to 14 inches, dark-brown clay with a slight reddish cast. Mellow, moderately well-defined fragmental structure, breaking down into poorly granular; dry, easy to smear, stiff plastic and tight rolling upon moistening. Moderate number of small roots.

C1653, 14 to 27 inches, yellowish, reddish-brown clay. Mellow, moderately well-defined fragmental structure; breaking down into poorly defined granules; stiff plastic when moist.

C1654, 27 to 50 inches, reddish-brown clay. Hard, friable, moderately well-defined fragmental structure; breaking down into hard moderately well-defined coarse-crumb structure.

PROFILE 13, LABORATORY NOS. C1643 TO C1645.—Lupi. Rainfall, 100 inches; elevation, 1,000 feet. Parent rock, lava. Sample taken May 18, 1936, on a moderate slope from a cut bank scraped back to natural moisture conditions, 0.5 mile south-southeast from triangulation point on Kauai O Kamelmeha about halfway between rain gages located on Puimalei and Lupi camp, island of Maui.

C1643, 0 to 10 inches, yellowish-brown clay; stiff, plastic, with moderately well-defined small nutlike structure; when very wet, pressing into ¼-inch layers. Large amount of small roots, and a moderate number of medium-sized roots.

C1644, 10 to 25 inches, strong yellowish-brown clay with slight reddish cast; stiff, plastic, with moderately well-defined small nutlike structure; when wet, pressing into ¼-inch layers. Moderate number of small roots.

C1645, 25 to 40 inches, pale yellowish-brown stiff, plastic clay with slightly reddish cast, with moderately well-defined fragmental structure; breaking down into moderately well-defined crumb structure; when wet, pressing into ¼-inch layers.

PROFILE 14, LABORATORY NOS. C1649 TO C1651.—Wahiawa Forest. Rainfall, 140 inches, elevation, 1,360 feet. Parent rock, basaltic lava. Vegetative cover: Nodding club fern, paperbark, species of *Paspalum*, hilo grass, guava, horsetail, and Koa. Sample taken May 20, 1936, on a moderate slope about 30 feet north of the road, 1,341 feet inland from the forest reserve gate, east of Wahiawa, island of Oahu.

C1649, 0 to 10 inches, grayish-brown, stiff clay, with moderately well-defined coarse-crumb structure, breaking down to poorly defined finer crumb structure; when very wet, pressing into ⅜-inch layers. Large amount of small roots, and moderate amount of medium-sized roots.

C1650, 10 to 25 inches, stiff, reddish-brown clay, with moderately well-defined coarse-crumb structure; breaking down into plastic poorly defined granules; when wet, pressing into ¼-inch layers. Small amount of small roots.

C1651, 25 to 40 inches, yellowish-brown, stiff clay, moderately well-defined fine nutlike structure; breaking down to moderately well-defined crumb structure; when wet, pressing out into ¼-inch layers.

THE ANALYTICAL DATA AND METHODS

Chemical analyses of the soil material in different layers of the 14 profiles are shown in table 1. This table also contains three analyses (C1610A, C1613A, and C1616A) of lava fragments that were too large to be part of the soil material analyzed. These were picked from profiles 1 to 3 and are presumed to represent the parent material of these profiles.

TABLE 1.—*Chemical analyses of soils*

EXCEEDINGLY YOUNG PROFILES

Profile No.	Nature of parent material	Rainfall	Sample No.	Depth	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	SO_3	P_2O_5	Ignition loss	Total	Organic matter	N	Se	Cr_2O_3	pH
		Inches		*Inches*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*P.p.m.*	*Percent*	
1	Cinders	100	C1610	0-7	44.71	12.09	12.72	10.48	9.03	0.32	1.35	2.58	0.16	0.18	0.22	6.37	100.31	5.72	0.22	------	0.10	6.12
			C1611	7-18	46.37	13.43	12.62	11.74	9.05	.35	1.32	2.41	.17	.12	.22	2.26	100.16	2.19	.09	------	.10	5.99
			C1612	18-27	46.20	13.27	13.80	9.74	9.50	.36	1.20	2.43	.14	.16	.22	3.10	100.33	2.58	.10	------	.12	6.45
			C1610A[1]	0-7	48.53	14.18	14.22	7.60	10.63	.42	1.97	2.28	.15	.12	.27	.00	100.44	------	------	------	.07	------
2	Aa lava	150	C1613	0-9	22.41	13.67	15.10	4.07	3.26	.03	.16	2.08	.17	.69	.71	38.00	100.45	30.53	1.39	------	.10	5.72
			C1614	9-24	29.87	11.77	23.73	5.91	5.17	.11	.18	2.04	.17	.33	.39	20.49	100.27	11.00	.46	------	.11	5.95
			C1613A[1]	0-9	46.83	14.35	14.03	8.37	9.47	.28	1.28	2.07	.16	.16	.37	2.87	100.36	------	------	------	.12	------
3	Pahoehoe lava	175	C1615	0-7	20.40	17.34	9.56	8.82	2.42	.15	.38	2.44	.18	.53	.38	37.41	100.27	32.00	1.10	------	.26	5.03
			C1616	7-15	16.89	26.10	15.50	12.00	1.14	.20	.18	2.75	.13	.55	.32	24.24	100.36	15.32	.50	------	.27	5.60
			C1616A[1]	7-15	38.93	16.65	13.46	22.80	4.31	.12	.45	.89	.18	.20	.11	2.01	100.44	------	------	------	.23	------

YOUNG PROFILES

Profile No.	Nature of parent material	Rainfall	Sample No.	Depth	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	SO_3	P_2O_5	Ignition loss	Total	Organic matter	N	Se	Cr_2O_3	pH
4	Volcanic ash	20	C1627	0-10	38.81	15.11	22.51	1.61	3.68	1.17	1.77	2.70	0.28	0.32	0.58	11.90	100.44	4.62	0.25	0.4	0.07	6.93
			C1628	10-21	53.44	9.02	19.87	1.43	2.13	2.34	2.67	1.68	.26	.16	.28	7.05	100.33	.59	.04	.4	------	7.40
			C1629	21-40	47.35	11.76	22.24	1.36	2.70	1.99	2.35	2.26	.28	.21	.17	7.71	100.38	1.24	.08	.1	------	7.27
5	do	50	C1617	0-6	35.93	15.98	16.40	4.73	4.77	.26	.89	4.22	.26	.34	.63	15.41	99.82	8.86	.44	------	------	5.35
			C1618	6-23	34.00	20.50	20.77	3.09	2.61	.09	.31	5.07	.27	.23	.28	13.19	100.44	3.47	.17	------	.15	6.09
			C1619	23-42	33.44	21.50	21.08	2.86	2.12	.08	.28	5.79	.28	.21	.32	12.41	100.37	2.15	.10	------	.10	6.42
			C1620	42-75	31.57	23.25	23.39	1.61	1.35	.13	.14	4.90	.25	.27	.42	13.14	100.42	2.48	.10	------		6.29
			C1621	75-96	35.51	22.15	20.85	1.86	1.52	.03	.15	6.01	.24	.14	.25	10.90	99.61	.83	.04	------	------	6.57
6	Pahoehoe lava	65	C1607	0-9	33.71	17.77	16.16	5.12	2.12	.68	.14	2.86	.36	.43	.95	20.37	100.67	10.19	.57	------	------	6.49
			C1608	9-17	32.74	18.79	17.09	4.02	1.74	.75	(²)	2.93	.44	.45	.90	20.32	100.17	9.56	.53	------	.11	6.40
			C1609	17-25	27.06	21.89	21.32	2.16	1.77	1.00	(²)	3.29	.39	.37	.57	20.76	100.58	8.27	.43	------	------	6.60
7	Volcanic ash	175	C1633	0-6	12.86	28.52	16.54	1.09	.82	.24	.30	7.06	.09	.56	.60	31.76	100.44	20.20	.76	------	------	5.17
			C1634	6-18	10.33	27.37	27.00	1.13	.17	.20	.17	5.25	.14	1.39	.48	26.72	100.35	10.70	.34	------	.20	5.17
			C1635	18-28	12.60	28.39	22.41	.84	.20	.33	.40	6.12	.18	1.25	.56	27.00	100.28	14.28	.50	------	.15	5.17
			C1636	28-38	12.73	28.27	24.34	.58	.12	.44	.14	5.64	.17	2.01	.38	25.69	100.55	10.02	.29	------	------	4.92
8	do	188	C2271	0-9	9.80	25.10	23.44	.78	.90	.25	.25	6.33	.23	.62	.62	31.45	99.93	17.16	.68	1.5	.07	5.04
			C2272	9-28	11.88	27.12	28.28	.39	.30	.41	.04	6.02	.31	1.17	.41	23.77	100.29	7.47	.20	6.0	.06	5.69
			C2273	28-31	10.93	23.48	32.61	.87	.64	.20	.10	6.00	.25	1.10	.36	23.66	100.32	6.75	.25	2.0	.08	5.97
			C2274	31-42	9.53	27.82	30.44	.31	1.11	.28	.11	6.06	.30	.76	.35	23.04	100.32	4.93	.20	4.0	.21	6.05
			C2275	42-72	13.27	28.52	25.79	.43	.48	.41	.68	6.56	.25	1.25	.43	22.42	100.04	7.30	.23	2.0	.17	6.10
			C2276	72-78	4.73	28.61	34.55	.40	.33	.06	.12	6.25	.13	.89	.35	23.69	100.30	2.56	.09	2.0	.05	6.10
			C2277	78-88	8.08	27.59	32.70	.15	.45	.40	(²)	5.85	.20	.89	.38	23.48	100.35	4.14	.13	2.0	.07	5.95

[1] Lava fragments from same layers as soil samples C1610, C1613, and C1616, respectively.

[2] Trace.

TABLE 1.—*Chemical analyses of soils*—Continued

YOUNG PROFILES—Continued

Profile No.	Nature of parent material	Rainfall	Sample No.	Depth	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	SO_3	P_2O_5	Ignition loss	Total	Organic matter	N	Se	Cr_2O_3	pH
		Inches		*Inches*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*P.p.m.*	*Percent*	
9	Volcanic sash	273	C2278	0-9	13.75	30.36	17.15	0.57	0.27	0.47	0.11	6.41	0 09	0 71	0.41	29.72	100.02	18.52	0 63	4.0	0.11	4.65
			C2279	9-14	12.81	31.79	20.43	.55	.23	.62	.18	5.56	.05	1.36	.30	26.64	100.52	13.90	.37	4.0	.16	5.42
			C2280	14-26	13.37	30.32	21.32	.79	.20	.70	.23	6.07	.09	1.50	.37	24.69	99.65	11.95	.31	2.0	.07	5.43
			C2281	26-31	10.79	26.92	27.76	.49	.12	.29	.02	5.90	.08	1.72	.30	25.94	100.33	10.35	.24	6.0	.08	5.52
			C2282	31-36	11.39	31.37	22.88	.47	.34	.50	.14	6.50	.08	1.48	.29	24.79	100.23	10.65	.25	2.0	.08	5.19
			C2283	36-42	9.85	36.20	19.06	.47	.50	.51	.16	6.44	.09	1.75	.25	24.45	99.73	10.68	.27	4.0	.04	5.42
			C2284	42-51	12.85	29.39	23.84	.52	.09	.77	.19	5.94	.09	1.42	.27	24.71	100.08	9.92	.25	2.0	.04	5.30
			C2285	51-66	29.41	28.12	19.30	.72	.14	1.65	.23	9.95	.08	.23	.07	10.60	100.50	3.14	.12	2.0	.08	5.13

OLD PROFILES

Profile No.	Nature of parent material	Rainfall	Sample No.	Depth	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	SO_3	P_2O_5	Ignition loss	Total	Organic matter	N	Se	Cr_2O_3	pH
10	Alluvial material	18	C1646	0-10	31.09	20.75	26.74	0.91	1.00	0.81	0.25	4.65	0.80	0.21	1.10	11.67	99.98	2.52	0.15	0.5	------	6.89
			C1647	10-45	30.31	21.97	27.97	.75	.84	.62	.19	4.71	.84	.19	1.31	10.34	100.04	.71	.05	.4	------	6.65
			C1648	45-60	30.97	21.04	28.74	.81	1.04	.47	.24	4.93	.39	.19	1.10	10.13	100.05	.50	.02	.4	------	6.19
11	do	22	C1655	0-12	33.54	22.57	23.38	1.18	.93	.35	.26	5.57	.26	.26	.43	10.75	99.53	1.38	.07	1.4	------	7.47
			C1656	12-32	31.87	22.66	25.20	1.13	.94	.27	.25	4.95	.18	.27	.27	11.92	99.91	2.43	.14	2.4	------	6.57
			C1657	32-50	30.63	24.42	25.02	1.05	.64	.20	.21	4.95	.18	.22	.31	12.20	100.03	2.78	.15	4.0	------	5.43
12	Basaltic lava	36	C1652	0-14	21.90	15.21	35.52	.57	.63	1.06	.21	2.11	3.80	.43	.29	18.72	100.45	3.95	.26	------	0.06	6.59
			C1653	14-27	23.42	15.85	36.59	.53	.51	1.03	.16	2.44	2.37	.30	.23	16.57	100.00	1.22	.10	------	------	6.79
			C1654	27-50	27.81	16.87	35.09	.43	.45	.85	.03	2.77	1.16	.31	.31	13.99	100.07	.64	.05	------	------	5.60
13	Middle-aged lava	100	C1643	0-10	16.90	37.18	13.48	.69	.21	.62	.34	10.01	.06	.33	.22	20.32	100.36	11.00	.45	14.0	.15	4.87
			C1644	10-25	6.16	41.73	23.30	.61	.21	.27	.06	5.97	.04	.30	.18	20.85	99.68	6.26	.13	------	.17	4.75
			C1645	25-40	12.06	33.87	28.74	.68	.32	.23	.15	5.87	.07	.28	.13	17.90	100.30	3.17	.06	12.0	------	5.10
14	do	140	C1649	0-10	21.41	37.54	7.45	.79	.42	.71	.29	19.60	.11	.42	.19	11.41	100.34	7.17	.32	------	.17	4.29
			C1650	10-25	11.79	48.35	18.04	.33	.51	.40	.08	4.76	.03	.44	.16	15.30	100.19	5.24	.11	------	.15	4.49
			C1651	25-40	19.85	36.36	24.22	.29	.29	.18	.06	4.51	.05	.44	.27	13.65	100.17	2.78	.05	14.0	.15	4.69

Analyses of the colloidal materials isolated from the soil materials are shown in table 2. In both tables the analyses are divided into three groups according to the ages of the profiles, and within each group the profiles are arranged in order of increasing rainfall. The age of a profile as exceedingly young, young, or old was estimated by the soil surveyor who collected the samples. The estimations were based largely on geological evidence and probably partly on observation of the soil profile itself.

TABLE 2.—*Chemical analyses of colloidal materials*

Profile No.	Nature of parent material	Rainfall	Sample No.	Depth	Quantity of colloid extracted	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	SO_3	P_2O_5	Ignition loss	Total	Organic matter	Cr_2O_3
EXCEEDINGLY YOUNG PROFILES																				
		Inches		*Inches*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	Cinders	100	C1610	0–7	0.5	21.10	10.37	14.00	3.03	3.08	0.52	0.38	0.94	0.14	1.06	0.98	44.61	100.21	37.06	-------
			C1611	7–18	1.0	27.50	12.67	17.45	6.59	3.54	.29	.35	1.81	.15	.56	.48	29.88	100.37	21.56	-------
			C1612	18–27	1.2	24.92	16.14	19.15	3.54	2.55	.19	.29	1.99	.16	.73	.42	29.96	100.04	20.23	-------
2	Aa lava	150	C1613	0–9	6.5	10.96	9.45	21.34	.72	1.67	.14	.11	1.17	.14	.96	1.29	51.58	99.53	37.67	-------
			C1614	9–24	1.7	20.08	4.51	36.87	.40	1.23	.12	.21	.90	.06	.61	.76	33.92	9.67	18.10	-------
3	Pahoehoe lava	175	C1615	0–7	4.3	10.85	17.54	17.78	.92	1.50	.27	.23	2.29	.17	1.01	.75	46.98	100.29	36.23	-------
			C1616	7–15	2.1	5.76	31.89	20.00	.59	.59	.15	(1)	2.93	.18	.56	.55	36.30	99.50	22.78	-------
YOUNG PROFILES																				
4	Volcanic ash	20	C1627	0–10	13.0	30.54	13.85	28.13	0.56	1.60	0.53	0.48	2.93	0.44	0.45	0.54	19.44	9.49	9.25	0.04
			C1628	10–21	6.6	45.90	10.61	24.33	1.10	1.13	.49	.46	1.45	.62	.16	.56	12.64	99.44	2.18	.02
			C1629	21–40	8.8	35.88	15.09	26.81	.86	1.68	.49	.23	2.35	.66	.27	.39	14.78	99.49	3.91	.03
5	do	50	C1617	0–6	5.9	26.67	16.37	22.01	.74	1.39	.35	.05	2.88	.37	.57	1.32	27.72	100.44	18.01	.06
			C1618	6–23	8.1	33.06	17.36	27.98	.93	1.09	.14	.02	3.18	.24	.22	.43	15.55	100.20	3.90	.06
			C1619	23–42	9.0	34.77	16.84	28.70	.68	.89	.12	.20	2.83	.22	.17	.42	14.41	100.25	2.70	.06
			C1620	42–75	14.0	34.02	16.51	29.31	.35	.85	.18	.02	2.68	.20	.15	.47	14.77	99.51	2.69	.02
			C1621	75–96	8.5	36.92	17.46	27.18	.50	.94	.07	.09	2.92	.19	.15	.38	12.70	99.50	1.43	.05
6	Pahoehoe lava	65	C1607	0–9	14.8	22.84	16.60	26.06	.81	1.39	.33	.12	2.06	.37	.62	1.47	27.74	100.41	14.70	-------
			C1608	9–17	12.2	23.26	17.37	26.46	.57	1.45	.30	.07	2.51	.40	.62	1.44	26.00	100.45	12.70	-------
			C1609	17–25	3.6	24.25	18.24	27.08	.75	1.14	.30	.01	2.55	.35	.51	.89	24.09	100.16	10.80	-------
7	Volcanic ash	175	C1633	0–6	8.4	10.75	25.28	18.96	.34	.48	.43	.13	5.08	.08	.56	2.28	35.59	99.96	22.90	.09
			C1634	6–18	5.4	9.23	30.64	24.34	.55	.24	.13	(1)	5.74	.18	.59	2.30	25.63	99.47	13.35	.10
			C1635	18–28	5.0	10.00	29.32	19.97	.40	.23	.37	.16	5.55	.15	.55	2.05	31.03	99.70	18.75	.08
			C1636	28–38	3.2	12.62	28.84	25.12	.54	.19	.38	.16	5.34	.20	.77	2.50	23.60	100.26	11.22	.09
8	do	188	C2271	0–9	7.1	8.39	30.52	17.93	.50	.57	.15	.23	4.25	.27	.73	1.10	35.69	100.33	21.71	-------
			C2272	9–28	42.1	10.86	33.66	23.51	.34	.39	.29	.11	4.97	.33	1.25	.63	23.87	100.21	9.75	-------
			C2273	28–31	42.3	11.75	29.27	27.67	.30	.38	.23	(1)	4.75	.27	1.10	.61	24.22	100.55	9.30	-------
			C2274	31–42	49.5	10.49	36.45	22.68	.32	.32	.24	1.14	6.10	.32	.89	.65	21.51	100.11	7.67	-------
			C2275	42–72	42.9	12.15	29.60	25.80	.35	.25	.27	.05	4.42	.27	1.25	.70	25.06	100.17	9.42	-------
			C2276	72–78	36.8	8.18	41.37	21.59	.40	.35	.04	(1)	7.17	.15	1.21	.71	19.08	100.25	4.72	-------
			C2277	78–88	50.9	9.89	37.12	25.37	.40	.14	.18	1.11	5.67	.21	1.02	.53	19.64	100.28	5.97	-------

[1] Trace.

9	do	273	C2278	0-9	7.1	10.49	29.04	20.02	.46	.23	.56	.18	4.88	.06	.69	.52	32.88	100.01	20.77	-------
			C2279	9-14	48.3	8.11	32.55	21.42	.42	.13	.43	.08	5.09	.04	1.42	.25	30.24	100.18	14.11	-------
			C2280	14-26	50.3	9.83	29.53	24.18	.34	.16	.32	.43	5.17	.07	1.41	.31	28.43	100.18	12.89	-------
			C2281	26-31	35.3	9.83	27.54	26.27	.24	.17	.25	.29	4.79	.07	1.72	.35	28.10	99.62	12.33	-------
			C2282	31-36	44.6	8.34	31.60	25.09	.26	.16	.30	.23	5.70	.05	1.44	.33	26.26	99.76	12.31	-------
			C2283	36-42	45.5	7.13	35.64	21.63	.27	.21	.32	.14	5.64	.08	1.79	.23	26.78	99.86	12.23	-------
			C2284	42-51	43.0	9.65	31.16	24.83	.30	.14	.46	.31	5.61	.07	1.39	.23	26.15	100.30	11.47	-------
			C2285	51-66	51-8	21.47	30.32	23.84	.49	.04	1.79	.25	6.12	.02	.25	.09	15.57	100.25	4.41	-------
OLD PROFILES																				
10	Alluvial material	18	C1646	0-10	35.5	33.78	13.27	32.78	0.55	0.96	0.76	0.05	2.77	0.25	0.22	1.41	13.51	100.31	2.06	0.03
			C1647	10-45	37.1	33.99	13.68	32.72	.48	.90	.72	.06	2.64	.32	.19	1.58	11.99	100.27	.96	.02
			C1648	45-60	39.6	35.73	10.98	34.72	.37	.81	.49	.16	2.43	.16	.17	1.17	13.16	100.35	.46	.02
11	do	22	C1655	0-12	38.5	39.60	13.75	28.96	.69	.86	.21	.25	2.00	.12	.17	.38	12.63	99.67	.88	.05
			C1656	12-32	25.6	37.56	13.19	30.09	.43	.96	.12	.44	1.99	.09	.20	.30	14.22	99.65	2.33	.06
			C1657	32-50	26.1	36.52	13.41	31.03	.36	.73	.14	.52	1.98	.08	.24	.27	14.47	99.80	2.75	.05
12	Basaltic lava	36	C1652	0-14	14.6	23.29	13.99	37.19	.42	1.13	.91	.43	1.62	.55	.37	.31	20.13	100.36	4.20	.02
			C1653	14-27	28.2	26.13	14.56	37.50	.26	.53	.74	.37	1.61	.27	.17	.20	17.94	100.30	1.45	.02
			C1654	27-50	42.2	28.55	15.91	35.95	.24	.49	.66	.36	1.95	.24	.14	.22	14.99	99.73	.92	.03
13	Middle-aged lava	100	C1643	0-10	26.4	14.59	35.18	19.57	.57	.21	1.11	.23	5.05	.03	.36	.33	22.22	99.45	10.80	.09
			C1644	10-25	52.1	7.55	36.25	28.06	.23	.19	.25	.19	3.80	.02	.18	.11	22.72	99.55	5.88	.13
			C1645	25-40	52.3	12.32	26.89	35.02	.23	.10	.22	.13	2.95	.03	.18	.12	21.34	99.53	3.70	.12
14	do	140	C1649	0-10	23.7	17.74	37.70	18.60	.38	.56	1.51	.44	4.97	.03	.26	.16	17.16	99.51	7.90	.14
			C1650	10-25	66.7	11.98	47.69	18.41	.12	.36	.51	.14	4.18	.03	.20	.13	15.85	99.60	4.97	.15
			C1651	25-40	57.8	22.70	32.48	25.12	.12	.33	.25	.23	3.08	.02	.15	.16	14.95	99.59	2.80	.12

No mechanical analyses of the samples are reported, as the results obtained by the usual analytical procedure were found to be quite erroneous in many instances. Modifications in the standard procedure needed to give accurate results in the case of these soils have not yet been developed, but that the standard procedure is inadequate for soils of this kind is shown by the following facts.

Most of the samples from profiles 8 and 9 seemed to contain less than 10 percent of clay or colloid and a high percentage of fine gravel when analyzed by the usual method. Yet nearly 50 percent of colloid was isolated from most soils for analysis, and the undispersed residue was found on microscopic examination to be made up chiefly of colloidal material.

There is no doubt but that these soils are made up almost entirely of colloidal material. Soil C1618, profile 5, contained about 4 percent of colloidal material according to the usual analytical method, whereas 8 percent of colloid was isolated for analysis. Mechanical analyses of the sample were then carried out with the standard procedure modified to include agitation in the Bouyoucos high speed rotary stirrer in addition to the customary shaking overnight in a reciprocating shaker. When agitated for 1 hour in the Bouyoucos machine the percentage of clay was 13 percent; when agitated for 8 and 10 hours the percentages of clay were 34 and 40 percent, respectively. The percentages of combined bases in the sample indicate that more than half of the sample is colloidal material. It seems evident that in the case of these soils an accurate estimation of ultimate particle size can only be obtained by employing a more effective dispersion means.

The methods followed in the chemical analysis of the samples, extraction of the colloid for analysis, and determination of the hydrogen-ion concentration were the same as those described in the previous publication (*7*). The selenium determinations were made by K. T. Williams according to the method described by Williams and Lakin (*12*). Chromium was determined as described below.

One gram of soil was fused with anhydrous sodium carbonate and a little potassium nitrate. The fused mass was extracted with hot water and allowed to stand on the steam bath until completely disintegrated. A few drops of alcohol were added, and, after warming on the steam bath to reduce manganese, the insoluble material was filtered off and washed well. The solution was acidulated strongly with hydrochloric acid and evaporated to about 100 cc. To the solution, now a pale-green color, ammonia was added in slight excess. The precipitate of chromium and silica formed was washed well and then transferred to a beaker with very little water. It was boiled with 10 cc. of 10-percent sodium hydroxide. About one-half of a cubic centimeter of 3-percent hydrogen peroxide was added and the solution was boiled to expel hydrogen peroxide. About 100 cc. of hot water was added and then 4 gm. of ammonium chloride crystals. The contents of the beaker were stirred, allowed to settle, and filtered. The filtrate was acidulated with 1 to 5 sulfuric acid, 1 cc. of 5-percent potassium iodide was added, then a starch solution. The solution was titrated with twentieth normal sodium thiosulphate, 1 cc. of which was equivalent to 0.0012 gm. of Cr_2O_3.

SPECIAL CHEMICAL CHARACTERISTICS OF THE SOIL SAMPLES

Before the analyses are considered for indications as to the effects of weathering, certain characteristics of the samples should be pointed out. These are chiefly characteristics imparted by the parent materials.

Like other Hawaiian soils the samples differ from most soils of the continental United States in being particularly low in silica and high in iron, alumina, and titanium. This is owing to the fact that the lavas and volcanic ashes, from which these soils were derived, contain practically no quartz and are usually high in titanium.

An outstanding feature of many of the soils is the quantity of organic matter present and the depth to which it has penetrated in the soil profile. Many of the soils contain more organic matter at 3 feet than well-drained soils of the mainland contain in the first 6 inches. Presumably the high rainfall is partly responsible for this, as the accumulation of organic matter deep in the soil increases with the rainfall to which the soil is exposed. It should be mentioned that profiles 2 and 3 do not contain so much organic matter in the whole mass of soil material as the analyses indicate. These profiles contain a large proportion of lava fragments too coarse to be included in the material subjected to analysis, and all the organic matter is concentrated in the fine material analyzed.

Some of the soils contain somewhat exceptional percentages of constituents that are usually present in small amounts. Profile 12 is high in manganese; profiles 7, 8, and 9 are unusually rich in sulfur; profiles 6 and 10 are exceptionally high in phosphoric acid; and 4 is higher than usual in soda and potash. These are presumably due to variations in the parent materials.

The exceptionally high contents of selenium in profiles 13 and 14 should be mentioned. These are among the highest yet encountered in soils that do not produce seleniferous vegetation. It is presumed that selenium in these soils is present as an insoluble ferric selenite (*8*).

In the course of the general analysis there were indications that some of the soils contained an appreciable amount of chromium. Determinations of chromium were subsequently carried out to gain an idea of its general distribution. It seems to be generally present.

Nickel is also probably present in somewhat greater amounts than in the average soil of the mainland United States. Sample C1634 contained 0.19 percent NiO, sample C1645 0.09 percent, and samples C1615 and C1616 both contained 0.07 percent.

WEATHERING OF HAWAIIAN ROCKS AND FORMATION OF HAWAIIAN SOILS, AS SHOWN BY ANALYSES OF THE WHOLE SOIL MATERIAL

Some idea of the formation of Hawaiian soils may be obtained from the foregoing chemical analyses of old and young soils developed under high and low rainfalls. If the compositions of soil materials of different degrees of weathering are compared with the compositions of the unweathered parent rocks the course of weathering should be apparent. The obvious uncertainties in this procedure lodge in determining the compositions of parent materials and in estimating the relative degrees the soils have been weathered.

The 14 soils cannot well be arranged in 1 series according to order of weathering, but after the soils have been divided into 3 age groups the relative weathering within the group should be roughly proportional to the annual rainfall that is well known. Estimations of the age groups to which the profiles belong were made in the field by soil surveyors on the basis of geological evidence. They should be reasonably certain and the analysis of the data which follows indicates that they are correct.

The chief uncertainty in determining the course of weathering from the soil analyses lies in the fact that it is necessary to assume a composition for the unweathered parent rocks of many profiles. In the case of the exceedingly young group of soils, compositions of the parent rocks are known from analyses made of lava fragments taken from within the profiles. These profiles were made up largely of lava fragments. Analyses of the lava fragments are shown in table 3, calculated to an ignition-loss-free basis.

TABLE 3.—*Composition of Hawaiian lavas*

Materials	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	Sum of bases (MgO, CaO, K_2O, and Na_2O)
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Highest percentage in any one of Cross's 43 samples (*4*)	62.19	22.03	18.87	5.35	30.89
Lowest percentage in any one of Cross's 43 samples (*4*)	35.96	4.55	7.60	.12	12.15
Average of Cross's 43 samples (*4*)	48.60	13.85	13.00	2.20	20.72
Standard deviation, σ, for samples averaged	5.27	3.84	2.00	1.15	4.90
Lava fragments from profile No. 1	48.53	14.18	14.22	2.28	20.62
Lava fragments from profile No. 2[1]	48.21	14.77	14.44	2.13	19.97
Lava fragments from profile No. 3[1]	39.73	16.90	13.74	.91	28.25

[1] The analysis is calculated to a basis free of ignition loss.

In the case of both the young and old soils, all the material within the profiles was more or less weathered. It was assumed for these soils that the parent rocks had the same composition as the average Hawaiian lava. This of course is probably more or less wide of the truth for all soils, but a fair estimate can be made of how much the assumed composition probably differs from the true composition in the majority of cases. In most cases differences between true and assumed values should not be more than the standard deviations of the constituents shown in table 3.

A composition for the average unweathered lava was obtained by calculating the average of the 43 analyses of Hawaiian lavas reported by Cross (*4*). In this calculation, minor constituents were omitted, the monovalent and divalent bases were lumped together, and ferrous oxide was converted to ferric oxide without recalculation of the percentages of other constituents for the slight difference this change involves. This average value is shown in table 3 together with the maximum and minimum percentages of the constituents found in any one sample. The standard deviations for the different constituents were calculated by the usual formula. If the standard deviations are compared with the average values, it will be seen that the 43 samples are least variable in silica, most variable in titanium, and about equally variable in iron, alumina, and sum of monovalent and divalent bases.

In order to follow the changes attending weathering, the analyses of whole soils shown in table 1 have been calculated to an ignition-loss-free basis. Organic matter and combined water, included in ignition loss, are lacking in the unweathered parent materials. It is therefore necessary to eliminate these constituents before comparing the soil analyses with analyses of the lava. The recalculated analyses are shown in table 4. Also, in order to facilitate comparisons, these analyses of separate horizons have been averaged to one analysis, shown in table 5, representing the average composition of all the material in a profile. In calculating the average analyses, the analysis of each horizon was weighted according to the thickness of the horizon. Weathering changes that might be peculiar to certain horizons in a profile have been obscured in this use of average analyses. In calculating the average analyses of the profiles, the 51- to 66-inch layer in profile 9 was omitted, as, according to the soil surveyor who collected the sample, it was presumed to be of different parent material from the rest of the profile. The 60+- and 31+-inch layers were also omitted from profiles 17 and 18, because it was impossible to weight these for depth.

TABLE 4.—*Chemical constituents of soils and of extracted colloidal materials calculated on an ignition-loss-free basis*

[Combined water calculated on material free of organic matter; organic matter and quantity of colloid extracted calculated on weight of whole soil]

EXCEEDINGLY YOUNG PROFILES

Profile No.	Rainfall	Sample No.	Depth	Analyses of whole soils									Analyses of extracted colloids						
				SiO_2	Fe_2O_3	Al_2O_3	TiO_2	Sum of bases (MgO, CaO, K_2O, Na_2O)	Combined water	Organic matter	C/N ratio	pH	Quantity colloid extracted	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	Sum of bases (MgO, CaO, K_2O, Na_2O)	Combined water
	Inches		*Inches*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*			*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	100	C1610	0-7	47.75	12.91	13.59	2.76	22.62	0.09	5.72	15	6.12	0.5	38.09	18.72	25.28	1.70	12.66	12.00
		C1611	7-18	47.44	13.74	12.91	2.47	22.98	.07	2.19	14	5.99	1.0	39.22	18.07	24.89	2.58	14.07	10.61
		C1612	18-27	47.68	13.69	14.24	2.51	21.56	.54	2.58	15	6.45	1.2	35.58	23.04	27.34	2.84	9.38	12.20
2	150	C1613	0-9	36.15	22.05	24.35	3.36	12.13	10.75	30.53	13	5.72	6.5	22.64	19.52	44.07	2.42	5.45	22.32
		C1614	9-24	37.57	14.80	29.85	2.57	14.30	10.66	11.00	14	5.95	1.7	30.39	6.83	55.80	1.36	2.97	19.32
3	175	C1615	0-7	32.59	27.70	15.27	3.90	18.80	7.96	32.00	17	5.03	4.3	20.46	33.08	33.53	4.32	5.51	16.85
		C1616	7-15	22.29	34.57	20.46	3.63	17.85	10.53	15.32	18	5.60	2.1	9.04	50.06	31.40	4.60	2.09	17.51
YOUNG PROFILES																			
4	20	C1627	0-10	44.05	17.15	25.55	3.06	9.23	7.63	4.62	11	6.93	13.0	37.91	17.19	34.92	3.64	3.93	11.23
		C1628	10-21	57.49	9.70	21.38	1.81	9.22	6.50	.59	9	7.40	6.6	52.54	12.15	27.85	1.66	3.64	10.69
		C1629	21-40	51.31	12.74	24.10	2.45	9.10	6.55	1.24	9	7.27	8.8	42.10	17.71	31.46	2.76	3.83	11.31
5	50	C1617	0-6	42.48	18.89	19.39	4.99	12.59	7.19	8.86	12	5.35	5.9	36.90	22.65	30.45	3.98	3.50	11.84
		C1618	6-23	39.17	23.61	23.93	5.84	7.06	10.07	3.47	12	6.09	8.1	39.15	20.56	33.13	3.77	2.58	12.12
		C1619	23-42	38.18	24.55	24.07	6.61	6.10	10.49	2.15	12	6.42	9.0	40.62	19.68	33.53	3.31	2.21	12.03
		C1620	42-75	36.35	26.77	26.93	5.64	3.72	10.93	2.48	14	6.20	14.0	39.92	19.37	34.39	3.14	1.64	12.41
		C1621	75-96	39.85	24.86	23.40	6.75	4.00	10.15	.83	12	6.57	8.5	42.29	20.00	31.13	3.34	1.83	11.43
6	65	C1607	0-9	42.33	22.31	20.29	3.59	10.12	11.34	10.19	10	6.49	14.8	31.61	22.97	36.06	2.85	3.67	15.29
		C1608	9-17	41.09	23.58	21.45	3.68	8.17	11.90	9.56	10	6.40	12.2	31.43	23.47	35.76	3.39	3.23	15.23
		C1609	17-25	34.15	27.62	26.91	4.15	6.22	13.62	8.27	11	6.60	3.6	31.95	24.03	35.67	3.36	2.90	14.90
7	175	C1633	0-6	18.85	41.87	24.24	10.35	3.58	14.49	20.20	15	5.17	8.4	17.69	39.25	29.44	7.89	2.14	16.46
		C1634	6-18	14.10	37.35	36.84	7.16	2.28	17.94	10.70	18	5.17	5.4	12.41	41.20	32.73	7.72	1.24	14.17
		C1635	18-28	17.26	38.89	30.70	8.38	2.42	14.84	14.28	17	5.17	5.0	14.50	42.51	28.95	8.05	1.68	15.11
		C1636	28-38	17.13	38.04	32.75	7.59	1.72	17.41	10.02	20	4.92	3.2	16.52	37.75	32.88	6.99	1.66	13.94
8	188	C2271	0-9	14.30	36.62	34.19	9.23	3.18	17.25	17.16	15	5.04	7.1	13.05	47.46	27.88	6.61	2.25	17.86
		C2272	9-28	15.58	35.58	37.10	7.90	1.50	17.62	7.47	15	5.69	42.1	14.27	44.21	30.88	6.53	1.48	15.65
		C2273	28-31	14.32	30.76	42.72	7.86	2.37	18.13	6.75	16	5.97	42.3	15.51	38.62	36.51	6.27	1.20	16.45
		C2274	31-42	12.38	36.15	39.55	7.87	2.35	19.05	4.93	14	6.05	49.5	13.36	46.44	28.90	7.77	1.30	14.99
		C2275	42-72	17.10	36.76	33.24	8.46	1.80	16.31	7.30	18	6.10	42.9	16.21	39.50	34.43	5.90	1.23	17.27
		C2276	72-78	6.20	37.48	45.28	8.19	1.19	21.69	2.56	16	6.10	36.8	10.11	51.12	26.68	8.86	.98	15.07
		C2277	78-88	10.56	36.06	42.73	7.65	1.39	20.18	4.14	18	5.95	50.9	12.31	46.19	31.57	7.06	1.03	14.54
9	273	C2278	0-9	19.56	43.20	24.40	9.12	2.02	13.75	18.52	17	4.65	7.1	15.63	43.27	29.83	7.27	2.13	15.28
		C2279	9-14	17.46	43.33	27.85	7.58	2.15	14.80	13.90	22	5.42	48.3	11.63	46.66	30.71	7.30	1.52	18.78
		C2280	14-26	17.75	40.26	28.31	8.06	2.55	14.47	11.95	22	5.43	50.3	13.73	41.26	33.79	7.22	1.75	17.84
		C2281	26-31	14.57	36.35	37.48	7.97	1.24	17.39	10.35	25	5.52	35.3	13.67	38.30	36.54	6.66	1.32	17.99
		C2282	31-36	15.14	41.71	30.42	8.64	1.93	15.83	10.65	25	5.19	44.6	11.31	42.85	34.02	7.73	1.29	15.91
		C2283	36-42	13.04	47.92	25.23	8.52	2.17	15.42	10.68	23	5.42	45.5	9.74	48.68	29.54	7.70	1.28	16.58
		C2284	42-51	17.07	39.04	31.66	7.89	2.09	16.42	9.92	23	5.30	43.0	13.07	42.19	33.62	7.60	1.64	16.58
		C2285	51-66	32.90	31.45	21.59	11.13	3.06	7.70	3.14	15	5.13	51.8	25.43	35.91	28.24	7.25	3.04	11.67

OLD PROFILES

10	18	C1646	0-10	35.20	23.49	30.27	5.26	3.36	9.39	2.52	10	6.89	35.5	39.06	15.34	37.90	3.20	2.68	11.69
		C1647	10-45	33.81	24.50	31.20	5.25	2.68	9.70	.71	8	6.65	37.1	38.62	15.54	37.18	3.00	2.45	11.14
		C1648	45-60	34.46	23.41	31.98	5.49	2.85	9.68	.50	15	6.19	39.6	41.14	12.64	39.98	2.80	2.11	12.75
11	22	C1655	0-12	37.58	25.29	26.29	6.24	3.10	9.50	1.38	11	7.47	38.5	45.32	15.74	33.15	2.29	2.30	11.85
		C1656	12-32	36.18	25.73	28.61	5.62	2.94	9.73	2.43	10	6.57	25.6	43.79	15.38	35.08	2.32	2.27	12.17
		C1657	32-50	34.89	27.81	28.50	5.64	2.39	9.69	2.78	11	5.43	26.1	42.70	15.68	30.28	2.31	2.05	12.05
12	36	C1652	0-14	26.94	18.71	43.70	2.60	3.04	15.38	3.95	9	6.59	14.6	29.16	17.52	46.56	2.03	3.62	16.63
		C1653	14-27	28.07	19.09	43.86	2.92	2.68	15.54	1.22	7	6.79	28.2	31.84	17.74	45.70	1.96	2.32	16.73
		C1654	27-50	32.33	19.61	40.80	3.22	2.05	13.44	.64	7	5.60	42.2	33.58	18.72	42.29	2.29	2.06	14.29
13	100	C1643	0-10	21.21	46.66	16.92	12.56	2.33	10.47	11.00	14	4.87	26.4	18.76	45.23	25.16	6.49	2.73	12.93
		C1644	10-25	7.78	52.72	29.44	7.54	1.45	15.56	6.26	28	4.75	52.1	9.77	46.91	36.31	4.92	1.11	17.89
		C1645	25-40	14.69	41.25	35.01	7.15	1.68	15.21	3.17	31	5.10	52.3	15.66	34.19	44.52	3.75	.86	18.32
14	140	C1649	0-10	24.17	42.37	8.41	22.12	2.49	4.57	7.17	13	4.29	23.7	21.41	45.51	22.53	6.00	3.49	10.05
		C1650	10-25	13.92	56.67	21.30	5.62	1.56	10.62	5.24	28	4.49	66.7	14.24	50.73	21.88	4.97	1.34	11.45
		C1651	25-40	22.99	42.11	28.05	5.22	.95	11.18	2.78	32	4.69	57.8	26.69	38.19	29.54	3.62	1.09	12.50

PRESUMABLY OLD PROFILES[1]

15	20	B3712	0-3	36.37	27.13	27.77	5.71	1.75	10.75	3.80	12	6.2	27.1	43.69	17.45	36.56	1.90	0.72	12.40
		B3713	3-15	36.70	27.28	27.05	6.58	1.39	10.74	1.60	10	6.2	31.8	43.83	17.53	36.98	1.77	.71	11.72
		B3714	15-35	36.62	26.48	28.12	6.57	1.45	11.03	.67	19	5.2	15.1	44.23	16.92	37.03	1.88	.63	12.36
		B3715	35-46	37.11	26.60	29.82	5.23	1.08	11.24	.63	9	4.9	22.5	44.17	16.97	36.07	1.87	.59	12.51
		B3716	46-60	45.50	19.90	28.56	4.17	1.63	10.17	.18	10								
16	20	B5791	0-2	35.52	26.18	29.71	4.93	3.32	9.18	6.27	12	6.7	27.4	41.25	18.52	35.36	2.07	1.67	12.09
		B5792	2-7	35.75	26.45	30.03	4.86	2.45	8.60	2.68	10	5.5	33.6	42.16	18.11	36.92	2.04	1.40	11.49
		B5793	7-28	35.46	25.52	31.25	4.95	2.24	10.19	2.13	9	6.0	33.9	41.99	18.01	37.03	1.85	1.46	11.41
		B5794	28-50	35.96	26.21	30.92	4.47	2.16	9.01	1.16	13	6.8	27.0	42.18	18.32	37.08	1.86	1.09	11.61
17	52	C946	0-9	28.98	33.73	24.86	7.56	3.38	10.66	7.60	13	5.1	9.9	38.18	22.07	35.04	2.63	2.00	12.25
		C947	9-13	30.68	31.03	30.03	5.45	2.62	10.67	3.90	15	4.0	29.2	37.94	20.66	37.00	2.35	1.29	12.54
		C948	13-25	30.29	31.65	28.84	6.76	2.28	10.92	2.67	16	4.8	23.7	39.84	19.78	37.14	2.23	1.03	12.27
		C949	25-41	29.62	33.03	27.76	6.65	2.29	10.41	1.58	15	4.6	20.0	40.27	19.06	37.28	2.22	.84	12.28
		C950	41-60	29.12	34.04	27.55	7.00	2.00	9.67	1.38	13	4.4	15.7	40.92	18.45	37.72	2.21	.99	12.05
		C951	60+	33.86	27.73	31.07	5.43	2.02	11.93	2.07	20	5.2	9.0	41.91	18.32	36.25	2.62	1.01	12.07
18	80	C942	0-7	23.74	48.57	13.64	10.41	3.11	8.02	6.88	18	4.0	9.3	23.93	42.63	26.35	4.42	3.18	10.30
		C943	7-10	20.48	46.45	22.05	7.45	2.68	11.12	5.67	23	4.9	13.0	18.39	48.00	27.71	4.13	1.87	11.13
		C944	10-31	18.56	46.61	27.06	4.92	2.62	16.01	5.58	27	4.9	14.5	16.91	47.09	29.83	4.02	1.65	12.77
		C945	31+	22.50	39.51	30.37	4.81	2.37	15.17	4.51	33	4.7	21.3	20.28	44.04	29.40	4.24	1.41	12.94
19	90	B3717	0-4	12.99	45.91	30.83	8.63	1.24	16.74	8.80	19	5.4	19.6	17.06	44.97	30.35	5.72	.95	14.48
		B3718	4-16	11.85	46.30	31.57	8.90	1.03	16.45	7.35	25	5.1	23.3	12.57	45.34	34.39	6.53	1.06	16.07
		B3719	16-33	12.23	49.72	28.84	8.01	.76	15.34	5.37	39	5.2	40.1	15.52	47.12	29.13	5.85	1.24	13.01
		B3720	33-180	12.29	44.01	36.00	6.90	.50	17.58	2.52	49	5.2	27.3	25.73	37.44	31.06	4.59	1.21	12.89
20	100	B5787	0-6	24.96	53.58	4.07	12.46	3.96	1.63	6.10	18	4.7	14.0	32.50	36.38	20.05	5.49	4.48	7.23
		B5788	6-9	22.45	53.95	8.84	10.05	3.51	4.95	6.61	20	4.5	24.9	23.91	49.27	17.72	5.13	3.28	11.18
		B5789	9-30	19.16	48.48	23.94	5.32	2.32	11.33	7.07	41	4.5	19.4	19.46	45.71	28.40	3.90	1.73	15.24
		B5790	30-40	24.62	27.44	39.45	3.55	3.48	14.52	8.52	45	5.0							
21	104	C938	0-7	31.78	43.70	6.58	14.21	2.73	4.11	7.88	19	4.0	5.3	27.94	40.33	21.55	6.83	3.25	10.06
		C939	7-15	19.23	53.97	16.08	7.90	1.80	10.82	6.71	35	4.3	6.3	15.84	54.81	22.68	4.53	1.40	13.71
		C940	15-22	39.54	16.33	40.69	2.27	1.19	13.86	1.73	33	4.9	9.0	36.53	15.27	46.02	1.56	.62	16.38
		C941	22-30	39.98	15.96	40.53	2.24	1.26	12.20	1.25	36	4.9	6.1	38.06	13.93	46.31	1.20	.46	16.71

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[1] In Technical Bulletin 584 the quantity of colloid extracted is expressed as percentage of the quantity of colloid indicated by the mechanical analysis. In this table the quantity is expressed as percentage of the whole soil.

TABLE 5.—*Average composition of the soil material in the whole profile*

[Constituents calculated on ignition-loss-free basis, except combined water calculated on organic-free basis and organic matter calculated on weight of whole soil]

Profile No.	Nature of parent material	Rainfall	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	Sum of bases, CaO, MgO, K_2O, and Na_2O	Combined water	Organic matter	SiO_2 lost [1]	Bases lost [1]	Loss of bases + loss SiO_2
	EXCEEDINGLY YOUNG PROFILES											
		Inches	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*			
1	Volcanic cinders	100	47.60	13.51	13.53	2.56	22.41	0.39	3.24	.....	.....	.....
2	Aa lava	150	37.04	17.52	27.70	2.87	13.49	10.69	18.32	0.60	0.65	1.08
3	Pahoehoe lava	175	27.10	31.36	18.04	3.76	18.29	9.33	23.10	.63	.65	1.03
	YOUNG PROFILES											
4	Volcanic ash	20	51.19	13.01	23.71	2.43	9.17	0.81	1.91	0.38	0.74	1.95
5	do	50	38.36	24.86	24.59	6.07	5.40	10.29	2.63	.50	.85	1.52
6	Pahoehoe lava	65	39.32	24.42	22.73	3.80	8.25	12.25	9.37	.54	.77	1.43
7	Volcanic ash	175	16.48	38.65	32.16	8.10	2.37	16.44	12.96	.88	.90	1.09
8	do	188	14.31	36.18	37.18	8.21	1.88	17.90	7.35	.89	.97	1.09
9	do	273	16.80	41.52	28.01	8.27	2.10	15.25	12.53	.68	.97	1.10
	OLD PROFILES											
10	Old alluvium	18	34.21	24.06	31.24	5.31	2.84	0.64	0.96	0.69	0.94	1.36
11	do	22	36.05	26.37	27.99	5.78	2.78	0.66	2.30	.63	.93	1.48
12	Basaltic lava	36	29.71	19.20	42.41	2.97	2.49	14.53	1.72	.80	.96	1.20
13	Middle-aged lava	100	13.73	46.91	28.40	8.65	1.76	14.16	6.29	.92	.97	1.05
14	do	140	19.87	47.64	20.61	9.60	1.57	9.32	4.80	.88	.98	1.11
	PRESUMABLY OLD PROFILES FROM T. B. 584											
15	Lava	20	38.79	25.16	28.30	5.72	1.43	10.80	0.59	0.61	0.97	1 59
16	do	20	35.71	25.64	30.02	4.73	2.27	9.47	1.92	.67	.95	1.42
17	do	52	29.57	33.05	27.63	6.84	2.38	10.33	2.80	.74	.95	1.28
18	do	80	20.47	46.99	22.09	7.14	2.75	12.31	5.91	.88	.96	1.09
19	do	90	12.27	44.74	34.91	7.18	.58	17.27	3.25	.92	.99	1.08
20	do	100	21.64	44.40	23.60	6.30	2.95	10.19	7.25	.86	96	1.12
21	do	104	32.43	32.66	26.13	6.55	1.75	10.33	4.37	.72	.96	1.33

[1] Calculated as a fraction of the quantity in the original lava.

Soil analyses reported in a previous bulletin (7) were also recalculated in the manner just described. These analyses are shown in tables 4 and 5 along with the present analyses. The profiles in this collection were not characterized as to age, but they are presumably all fairly old, because they are all made up almost exclusively of silt and clay particles. Arranged in order of rainfall they provide a series to compare with the old profiles.

No elaborate consideration of data is needed to show the general net results of weathering. All soils in table 5 except profiles 1 and 4 are higher in iron, alumina, and titanium and lower in silica and sum of monovalent and divalent bases than the average unweathered lava. This is plainly due to the fact that the losses, if any, of iron, alumina, and titanium by leaching are on the whole less than the losses of silica and sum of monovalent and divalent bases. A more detailed picture of weathering, especially with respect to the changes taking place at different stages of weathering, may be obtained from the data in table 5.

If the percentages of iron and alumina are compared it will be seen that in each age group the proportions of these two constituents show a regular variation with rainfall. In the exceedingly young group profile 1 should not be considered, because, according to its composition and its lack of combined water, this is practically unweathered, but in profile 2 the alumina is higher than iron; whereas in profile 3, of higher rainfall, iron exceeds alumina. In the young group of profiles, alumina exceeds iron in the profile receiving 20 inches of rainfall. Alumina and iron do not differ markedly in profiles receiving 50 to 188 inches of rainfall, and iron exceeds alumina where the rainfall is 273 inches. In the old group of profiles alumina exceeds iron in profiles receiving up to 36 inches of rainfall and iron exceeds alumina in profiles of 100 and 140 inches of rainfall. In the presumably old group of soils from Technical Bulletin 584 the pattern is similar; alumina exceeds iron in profiles receiving 20 inches of rainfall, and iron exceeds alumina in five profiles receiving 52 to 104 inches of rainfall.

These changes in the proportion of iron to alumina may, of course, be due to chance variations in the parent materials, but the odds are against this. Three of the 12 soils containing more iron than alumina have iron-alumina ratios of 1.88, 2.13, and 2.31. In the average lava, iron and alumina are about equal and no one of the 43 lavas reported by Cross contains iron and alumina in a ratio higher than 1.80. It is especially improbable that the correspondence between iron-alumina ratio and rainfall should be due to chance. In proceeding from profiles of low rainfall to those of high rainfall, the pattern of high alumina, approximately equal iron and alumina, and high iron, obtains for all four groups of soils, wholly or in part. Moreover, the pattern is more marked in the groups of old profiles than in the young group.

A more probable explanation of the data is that at some stage in the weathering of Hawaiian soils derived from lava, alumina becomes more soluble than iron. The point at which this takes place apparently corresponds to, or is dependent upon, the development of a certain hydrogen-ion concentration in the soil material. In profiles where alumina markedly exceeds iron most of the horizons have pH values of 6 or more; whereas in profiles where iron markedly exceeds alumina the horizons are in most cases more acid than pH 5.2. There is a fairly sharp line of demarcation between the two classes of soil at pH 5.0 to 5.2.

Titanium increases with rainfall in each age group almost as regularly as iron. The correspondence of titanium to rainfall should be somewhat poorer than that of iron, for titanium varies more widely than iron in Hawaiian lavas, as shown in table 3. It seems that titanium is fully as resistant as iron to leaching, or slightly more so, as the proportion of iron to titanium in the soil is about the same as in the lavas. The average percentages of iron and titanium in the 43 analyses of lava (*4*) are in the proportion of 6.4 to 1, and in the 21 soils of table 5 the average iron-titanium ratio is 5.5. There is no evidence in table 5 of titanium being more insoluble at one stage of weathering than at another, but other evidence on this point will be given later.

The percentages of silica are on the whole in good correspondence with the rainfall data in all four groups of soils. Although there are some discrepancies, these may reasonably be attributed to differences in parent material or to differences in the ages of soils in the same group.

There is also a reduction in the silica content with age. This is apparent in the low rainfall soils, but not in soils of high rainfall, if the exceedingly young group is excepted. Sufficient data are not available to tell whether depletion of the soil in silica reaches a minimum; i. e., a point where other constituents and silica are lost at the same rate. Some Hawaiian soils have been analyzed that contain less silica than any of those shown in table 5 (*11*), but it is not known whether their extreme composition is due to exceptional weathering or to a parent material of unusual composition.

The percentages of the combined monovalent and divalent bases agree with rainfall data fully as well as the silica percentages in the young and old groups of soils. But in the group of presumably old soils from Technical Bulletin 584 there is practically no correspondence between bases and rainfall. And in the old group where the bases stand in the same order as the rainfall, the percentages of bases are all so low that it seems that they might easily be put out of order by chance conditions. From the data available it seems that the silica content is a more reliable indicator of degree of weathering than the base content. Organic matter is presumably responsible for the slight or irregular variation of bases with rainfall. Part of the bases are associated with the organic matter and this generally increases with rainfall. If it were possible to subtract the bases held by organic matter from the total, the remaining bases would probably show a good correspondence with rainfall.

In Hawaiian soils the removal of bases evidently proceeds almost as far under low rainfall as under high rainfall, given sufficient age. Four old profiles (Nos. 10, 11, 15, and 16), developed under 18 to 22 inches of rainfall, are no higher or only slightly higher in bases than the soils developed under 100 or more inches in the young and old groups. Possibly silica likewise approaches the minimum under low rainfall in soils sufficiently old. More data bearing on this point are needed. It is evident, however, that the removal of silica proceeds at a slower rate than the removal of bases under low rainfall.

The comparative rates at which silica and the bases are removed is not shown so plainly by the percentage compositions of the soils as by calculations of the losses that have occurred during the development of the soil from the parent lava. In the case of soils 2 and 3 the losses of silica and bases can be calculated, because analyses of the actual parent lavas are available. The general method of calculating weathering losses is described by Merrill (*10*). In the case of soil 2 it was assumed that no alumina was lost in the transition from lava to soil and in the case of soil 3 iron was assumed to be the most insoluble constituent. For soil 2 the calculated losses of silica and the bases are 0.60 and 0.65 of the quantities present in the fresh lava and for soil 3 the losses are, respectively, 0.63 and 0.65. Thus the relation between the fraction of silica lost and the fraction of bases lost is almost identical for the two soils, although the parent lavas of the two soils contain silica and bases in different proportions, as shown in table 3. The lava of soil 2 contains 2.41 times as much silica as bases and the lava of soil 3 contains silica and bases in the proportion of 1.41 to 1. Considered simply as weight of material lost, the loss in silica is 2.23 times the loss in bases for soil 2 and 1.37 times the loss in bases for soil 3. The data on these two soils indicate that the absolute weights of silica and the bases lost are determined largely by the proportions in which these constituents are present in the parent lava.

It seems that the fractional loss of bases is always greater than the fractional loss of silica. This holds for soils 2 and 3 and for the remaining soils in table 5 and for lava boulders and their contiguous soil layers analyzed by Kelley (see Moir et al. *11*). The calculations made for soils 2 and 3 were also made for the remaining soils in table 5. Analyses of the actual parent lavas not being available, the data of reference in these cases was the assumed average lava. The fractional loss of bases calculated was in each case greater than the fractional loss in silica, the differences being much greater for the low rainfall soils than for the soils of high rainfall. The general trend of the values obtained is probably correct. They are in harmony with calculations made by Moir and his associates (*11*) from Kelley's data. Kelley's analyses were made of unweathered cores of lava boulders, and the weathered shells of adhering soil material found in the Wahiawa region, island of Oahu. Moir et al. calculate that in the development of the soil material from the fresh lava the loss of silica is 80 percent of that present in the fresh lava and the losses of lime, magnesia, soda, and potash average 94 percent of the quantities originally present. These losses are of the same order as those calculated for the high rainfall soils of the young and old groups and for soils of medium rainfall in the old groups; in other words, for soils 7 to 9, 12 to 14, and 17 to 21.

Further evidence on the course of weathering may be obtained from analysis of the extracted colloidal materials, but the conclusions drawn from the soil analyses may be briefly recapitulated. Alumina seems to be the least soluble constituent in soils that have not been markedly weathered or in soils exposed to low rainfall. In the more highly weathered soils iron is evidently less soluble than alumina; titanium is probably slightly less soluble than iron, but it varies considerably more than iron or alumina in the unaltered lavas. Silica and the sum of monovalent and divalent bases are by far the most soluble constituents in the soils and lavas. The bases seem to be lost more rapidly than silica, particularly in the early stages of weathering. Under high rainfall the loss of bases may be diminished somewhat by increased organic matter. The best index of degree of weathering seems to be the silica content of the material.

According to the preceding conclusions, a series of soils derived from the same parent lava but weathered to markedly different extents should show the following changes in composition when arranged in order of decreasing silica content. The base content should be high where the silica is high, but with a moderate drop in silica the bases should drop to a low level where they should fluctuate more or less with the organic matter. Alumina should increase markedly with the first small decrements in silica, remain fairly constant with further decrements in silica, and decrease when the silica content becomes low. Iron and titanium should increase with decreasing silica content, but the increases accompanying the first decrements in silica should be less than those accompanying subsequent decrements.

It seems as if it should be possible to test the preceding conclusions by an examination of existing data. However, few ultimate analyses have been made of Hawaiian soils. Moir et al. (*11*) report only 11 such analyses. These were made by Magistad and are of surface layers only. No information is given regarding the 11 soils except that they are from 6 different islands and are devoted to pineapple growing. These analyses are given in an abbreviated form in table 6, arranged in order of decreasing silica content. Only the major constituents are shown and these have been calculated to an ignition-loss-free basis, except water which is calculated on the material free of organic matter.

TABLE 6.—*Analyses by Magistad (11) of 11 Hawaiian pineapple soils*

[Calculated to an ignition-loss-free basis]

Laboratory No.	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	Sum of bases (CaO, MgO, K_2O, Na_2O)	Combined water H_2O[1]
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
620	40.64	31.64	12.26	4.17	8.57	12.05
913	38.25	24.82	25.15	4.30	5.72	10.88
917	36.86	28.73	23.64	4.12	4.71	10.13
636	36.19	28.57	21.39	8.49	3.12	10.40
919	33.52	33.23	22.33	6.53	3.84	17.43
918	30.59	37.70	20.39	6.98	2.29	12.71
621	30.16	35.68	22.99	5.65	3.94	14.83
631	18.00	58.21	7.75	12.92	3.11	8.86
626	6.48	62.12	17.60	9.42	4.51	16.60
920	6.45	60.40	7.79	16.58	2.32	3.20
625	5.18	58.60	17.46	10.04	8.34	26.50

[1] Calculated on organic-free basis.

It will be seen that this series of soils conforms fairly well to the pattern predicted for materials weathered to markedly different degrees but derived from the same parent material. Most of the deviations in iron, alumina, and titanium from the ideal trends are such as might reasonably be attributed to differences in parent lavas. The fact that the titanium percentages show more pronounced irregularities in their upward trend than the iron percentages show is in harmony with the idea that the irregularities are mostly due to differences in parent lavas, as titanium is a more variable constituent of Hawaiian lavas than iron.

WEATHERING OF HAWAIIAN ROCKS AND FORMATION OF HAWAIIAN SOILS, AS SHOWN BY ANALYSES OF THE COLLOIDAL MATERIAL

The preceding conclusions as to the effects of weathering were based on analyses of whole soil material. Because whole soils usually contain unweathered minerals together with the weathered residues of minerals, whereas the colloidal fractions of soils are made up chiefly of the weathered residues, it might be expected that analyses of the colloidal materials would give a clearer picture of weathering than the soil analyses.

Complete analyses of the colloidal materials extracted from the different horizons of the soil profiles are shown in table 2. The main constituents of these analyses calculated to a basis free from ignition loss are shown in table 4. These analyses are comparable with the analyses of whole soil also shown in table 4. In some cases, in order to facilitate comparisons of the colloidal materials in different profiles, a single analysis for each profile was obtained by averaging the analyses of all the horizons in a profile. These average analyses, shown in table 7, are comparable with the soil analyses of table 5. In calculating the average analysis for a profile, the analysis of each horizon was weighted according to the thickness of the horizon, but it was impossible to weight the analysis for the percentage of colloid present in a horizon, as this was uncertain.

If the data of table 4 are compared it will be seen that the extracted colloids and whole soils are for the most part much alike in composition. The most consistent differences between whole soils and colloids occur in the first 6 profiles. It seems that the first 6 profiles are made up of lava minerals and varying amounts of colloidal material, whereas the last 15 profiles are made up almost entirely of colloidal material. The evidence for these conclusions follows.

TABLE 7.—*Average composition of the colloidal materials extracted from profiles 1 to 6 and the compositions of the lavas from which they were formed*[1]

[All constituents except water calculated on material free of ignition loss. Water calculated on material free of organic matter only]

Material	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	Sum of bases (CaO, MgO, K_2O, Na_2O)	Combined water
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Average lava	*48.68*	*15.85*	*15.99*	*2.29*	*20.72*	--------
Colloid profile 4, 20-inch rainfall	43.92	16.05	31.33	2.68	3.80	11.12
Colloid profile 5, 50-inch rainfall	40.25	19.98	33.04	3.38	2.08	12.03
Colloid profile 6, 65-inch rainfall	31.68	23.47	35.84	3.19	3.28	15.15
Lava fragment, profile 1	*48.53*	*14.18*	*14.22*	*2.28*	*20.62*	*.00*
Colloid profile 1, 100-inch rainfall	37.71	19.90	25.81	2.44	12.15	11.50
Lava fragment, profile 2	*48.21*	*14.77*	*14.44*	*2.13*	*19.97*	*2.87*
Colloid profile 2, 150-inch rainfall	27.48	11.59	51.40	1.78	3.90	20.45
Lava fragment, profile 3	*39.73*	*16.89*	*13.74*	*.91*	*28.25*	*2.01*
Colloid profile 3, 175-inch rainfall	14.37	42.14	32.39	4.47	3.09	17.20

[1] Italics used to distinguish lava from colloid analyses.

In the 15 profiles following profile 6 the only consistent difference between whole soils and extracted colloids lies in the titanium contents. This constituent in almost every horizon is markedly higher in the whole soil than in the extracted colloid. In the lava titanium is frequently present as illmenite ($FeO.\ TiO_2$), a mineral very resistant to weathering. It may be that part of the titanium in the soil is present in the original illmenite particles larger than colloidal size, or it is possible that when minerals containing titanium break down the titanium does not become part of the clay minerals but forms an oxide not readily dispersable.

Except for the titanium contents many of the whole soils and extracted colloids in this group of 15 profiles are practically identical in composition. In some profiles differences occur, but they are not such as would be caused by the presence of unweathered minerals in the soils, as the calculated analyses of residues remaining after removal of the colloid samples do not correspond to unweathered lava minerals. Differences between soil and colloid that occur in this group of profiles are evidently due to the extracted colloidal material not being representative of all the colloid in the soil. The colloidal material that is difficult to disperse and is not extracted evidently differs in composition from the extracted colloid. Data bearing on this subject are given in two previous publications (*3*, *5*).

In profiles 10, 11, 15, 16, and 17, iron is considerably lower in the extracted colloids than in the whole soils and this difference accounts for the somewhat higher percentages of silica and alumina in the colloids. The profiles mentioned are all old profiles exposed to low rainfalls. Presumably here some of the iron has become dehydrated and consequently resistant to dispersion. In profiles 13, 14, 18, 20, and 21 the soil and colloid are nearly alike in the lower horizons, except for titanium, but in the surface horizons a condition obtains similar to that in the low rainfall profiles. Here the extracted colloid is much higher in alumina and combined water than the whole soil. In profiles 14 and 20 the surface horizons are so low in alumina and combined water that after the quantity of colloid actually extracted is removed the residue is made up almost entirely of silica, iron, and titanium with very little combined water. It seems that in these surface horizons the soil material is made up of two general classes of colloidal material—a dispersable part that is the usual hydrated alumino-silicate complex and a part that is difficult to disperse made up largely of partially dehydrated oxides of iron, silicon, and titanium. An X-ray examination of these soils and their extracted colloids would be of interest.

In the first 6 profiles the differences between soil and colloid are fairly consistent and are distinct from the differences obtaining in the last 14 profiles, except for titanium in profiles 5 and 6. As compared with the extracted colloids, the soils are, with few exceptions, higher in silica, lower in alumina and iron, higher in bases and lower in combined water. These are all characteristics that would be imparted by the presence of unweathered lava minerals. The differences are most pronounced in profile 1 and least pronounced in profile 6. Profile 1 is obviously made up almost exclusively of unweathered minerals. This is shown by the virtual absence of combined water in the soil material. The soil material of profile 6, on the other hand, is evidently made up largely of material colloidal in its degree of weathering with some unweathered minerals. In the other profiles the proportions of parent minerals and colloidal material are presumably intermediate between those obtaining in profiles 1 and 6.

It seems fairly certain from the preceding comparisons that the first 6 profiles contain some unweathered lava minerals in addition to colloidal material, whereas the last 15 profiles are made up almost exclusively of colloidal material. Colloidal material in this particular connection is taken as meaning the insoluble decomposition products resulting from the break-down of the parent lava minerals. Whether these products are readily dispersable or not probably depends in part upon changes that the colloidal complexes have undergone since they were formed. As shown in table 4, the last 15 profiles differ widely in composition and the differences are related to the ages of the profiles and the rainfalls to which they are exposed. Granting that these profiles consist largely of colloidal material, it seems evident that weathering has altered the colloidal material somewhat. However, there is considerable evidence that the composition of the colloid is determined largely at the time it is formed. Some light on these questions may be obtained from the analytical data reported here.

The analyses of the extracted colloids of profiles 1 to 6 are of particular interest, for it seems they represent, or are close to, the compositions of the freshly formed colloidal materials. These profiles are obviously less weathered than the others. Profiles 1 to 3 are especially young and only slightly weathered, as they contain a considerable proportion of large lava fragments that are practically unweathered. It required painstaking work to extract about 1 percent of colloidal material from the fine material of these three profiles. The fact that these profiles 1 to 6 apparently still contain minerals of the parent lavas indicates that the extracted colloids may be essentially as when first formed. The decomposition of these minerals with liberations of soluble constituents should tend to maintain the conditions that obtained when colloidal material was first formed.

Table 7 shows the average compositions of the colloidal materials extracted from profiles 1 to 6. Average analyses for a profile were calculated as described on page 22.

Granting that the analyses are those of freshly formed colloids, it appears that rainfall has considerable effect on the kind of colloidal materials formed when the parent minerals break down, as when the analyses are arranged in order of rainfall, the major differences in composition show a fairly definite trend if the analysis of profile 1 is omitted. This analysis may be excluded from the comparison as the base content of the colloid, the low combined water of the soil material from which it was extracted, and the small quantity of colloid that could be extracted suggest that this colloid may contain unweathered or partially weathered minerals. When profile 1 is excluded the series of analyses shows with increasing rainfall a regular decrease in silica, an almost regular increase in combined water, a regular increase in the sum of iron and alumina, a practically constant level of bases, and irregular amounts of titanium. There is no plain trend in the percentages of iron alone or alumina alone.

The constant percentage of bases in the colloid is doubtless a fallacy produced by calculating the constituents on a basis free of organic matter. Part of the bases must be associated with the organic matter rather than with the inorganic constituents, and the organic matter in the colloids increases with increasing rainfall from about 4 percent to nearly 30 percent. If a correction could be made for bases carried by the organic matter the bases of the inorganic constituents would doubtless show a regular decrease with increasing rainfall.

It is probable that the decrease in silica, the increases in combined water and in sum of iron and alumina, and the presumable decrease in bases are due to differences in rainfall. The irregular percentages of titanium are probably due to differences in the parent material, as titanium is one of the more variable constituents of unaltered lavas. Whether the irregular proportions between iron and alumina are due to differences in rainfall or to differences in parent materials is a question. Obviously much more data than those given in table 7 are needed to show with any degree of certainty the comparative effects of rainfall and parent material on the chemical composition of the colloids.

An examination of these colloids for the types of clay minerals present would be of considerable interest, as they contain widely varying proportions of silica, alumina, and combined water and yet are derived from parent rocks that are presumably much alike. In the colloid from the profile of 20 inches of rainfall the proportions of silica, alumina, and water plus bases are about what they should be if kaolinite is the chief constituent.

If the freshly formed colloids are compared with the parent lavas it can be seen that marked weathering changes accompany the formation of colloidal material under high rainfall. In table 7 the compositions of the colloids and of the parent lavas, either actual or assumed, are brought together. The lava analyses for profiles 1 to 3 are analyses of rock fragments found in these profiles, whereas the lava analyses for profiles 4 to 6 are those of the average lava which is assumed to be similar to the actual parent materials. It will be seen that the colloidal material formed under 20 inches of rainfall differs from the parent lava in containing twice as much alumina, much more water, and one-fifth as much total bases. In the colloids formed under 150 and 175 inches of rainfall these differences are accentuated and in addition the colloids contain much less silica than the parent lavas. The minimum weathering losses responsible for these differences in composition can be calculated assuming that either no iron or no alumina is lost, according to which has increased more in percentage. If this is done it appears that when the minerals decompose to colloidal material under low rainfall there is a marked gain in combined water, most of the monovalent and divalent bases are lost, and considerable silica is lost. When the minerals decompose under high rainfall the losses are practically the same except they are greatly accentuated. There is a suggestion, however, in the colloid of 175 inches of rainfall that more alumina may be lost than iron. This should be substantiated by more data.

Because the parent lava minerals have apparently disappeared in the last 15 profiles it may be assumed that the collodial materials in these profiles have been weathered more or less. If this is true, an idea of the effects of weathering on collodial material already formed may be obtained by comparing the colloids of the last 15 profiles with the freshly formed colloids in profiles 2 to 6. The colloid from profile 1 is excluded for the reasons given on page 24. As previously mentioned, the last 15 profiles seem to be made up almost entirely of colloidal material; hence the whole soil analyses of the last 15 profiles shown in table 5 may be compared with analyses of the extracted colloids shown in table 7. However, only colloids exposed to similar rainfalls should be compared, as the compositions of the freshly formed colloids vary with the rainfall. In order to facilitate the comparisons, analyses of the last 15 profiles in table 5 have been condensed to 5 by averaging the analyses of profiles exposed to similar rainfalls. These average analyses of weathered colloids are brought together with analyses of the freshly formed or unweathered colloids in table 8.

The weathered and unweathered colloids exposed to 175 inches or more of rainfall, shown in the last line of table 8, may be considered first. These colloids do not differ from each other appreciably in any constituent except titanium, which is considerably higher in the weathered colloid. The lower titanium of the unweathered colloid of profile 3 should probably be disregarded as a parent material difference, as the lava from which this colloid was derived contains only 0.91 percent titanium oxide. Had the lava contained the average amount of titanium (2.29 percent TiO_2) the unweathered colloid might have been similar to the weathered in titanium also. With the titanium content disregarded it appears that colloids formed under very high rainfall change little or very slowly under subsequent weathering. It is regrettable that more data are not available to support this important conclusion.

TABLE 8.—*Presumably unweathered and weathered colloidal materials compared*

[All constituents except water calculated on material free of ignition loss. Water calculated on material free of organic matter.]

Profiles [1] represented in analyses of—		Rainfall [1]		SiO_2		Fe_2O_3		Al_2O_3		TiO_2		Sum of bases CaO, MgO, K_2O, Na_2O		Combined water	
Unweathered colloid No.	Weathered colloid No.	Unweathered colloid	Weathered colloid	Unweathered colloid	Weathered colloid	Unweathered colloid	Weathered colloid	Unweathered colloid	Weathered colloid	Unweathered colloid	Weathered colloid	Unweathered colloid	Weathered colloid	Unweathered colloid	Weathered colloid
		In.	*In.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
4	10, 11, 15, 16	20	20	43.92	36.18	16.05	25.38	31.33	29.60	2.68	5.39	3.80	2.33	11.12	9.89
5	12, 17	50	44	40.25	29.04	19.98	26.13	33.04	35.02	3.38	4.91	2.08	2.44	12.03	12.43
6	13, 18, 19, 20, 21	66	95	31.00	20.17	23.47	43.14	35.84	27.03	3.19	7.10	3.28	1.05	15.15	12.85
2	14	150	140	27.48	19.87	11.59	47.64	51.40	20.61	1.76	9.00	3.90	1.57	20.45	9.32
3	7, 8, 9	175	212	14.37	15.86	42.14	38.78	32.39	32.75	4.47	8.10	3.69	2.12	17.20	16.53

[1] Where more than one profile is represented the analysis and rainfall are averaged.

In the four other comparisons of colloids exposed to less rainfall, the weathered colloid is considerably lower in silica, somewhat lower in alumina, and considerably higher in titanium and iron than the unweathered colloid. Considering the quantities present, the increase in titanium is greater than the increase in iron, hence titanium should be taken as the most insoluble constituent of the colloid. Translated into weathering losses, these changes in composition mean that as freshly formed colloids weather, silica, alumina, and iron are lost. More silica is lost than alumina and more alumina is lost than iron. There are evidently considerable losses of the monovalent and divalent bases also, although these cannot be calculated because of interfering organic matter.

The weathering of lava to colloidal material may now be compared with weathering of the colloid after it is formed. The most marked differences in the two stages of weathering evidently concern iron, alumina, and titanium. In the first stage of weathering alumina is the most insoluble constituent, except possibly under 175 inches or more of rainfall; some iron and titanium are evidently lost. In the second stage of weathering, however, iron and titanium are more insoluble than alumina, and titanium seems to be the most insoluble constituent. There are appreciable losses of silica and bases in both stages of weathering, but the proportions of silica lost in the two stages are somewhat different from the proportions of bases lost. Most of the bases disappear in the first stage of weathering under any rainfall whereas most of the silica disappears in the first stage only under high rainfall.

A rough estimate may be made of the minimum total losses that accompany the two stages of weathering in these particular soils. These estimates are shown in columns 3 and 6 of table 9. Losses accompanying formation of colloidal material from the parent lava are calculated from the alumina contents of the lavas and colloids shown in table 8. In the case of profile 3, however, the titanium contents are used as the basis of calculation, because in this profile titanium increases more in the colloid than alumina. Losses that accompany weathering of the colloid after it is formed are calculated from the titanium contents of the unweathered and weathered colloids. Data for this comparison are taken from table 8 where averages of several weathered colloids are compared with presumably unweathered colloids of similar rainfalls. The last figure in the last column of table 9 is probably far too high if the weathered colloids, 7, 8, and 9, were derived from lavas of average titanium contents, because, as mentioned on page 26, the unweathered colloid was derived from a lava low in titanium.

Probably the only conclusion that should be drawn from table 9 is that colloidal material after it is formed is subject to considerable losses by weathering and that these losses, given sufficient time, may be as great as the losses accompanying decomposition of the parent minerals to collodial material. Losses of the first stage of weathering vary markedly with rainfall and probably vary considerably with the nature of the parent minerals, and obviously losses of the second stage should vary with time. Much more data would be needed to estimate the effects of these variables.

TABLE 9.—*Total loss of constituents accompanying weathering of lava to colloidal material, and loss accompanying weathering of colloidal material*

Profile No. from which colloid was extracted	Rainfall	Total loss of constituents as percentages of weight of original lava	Profile No. represented in weathered colloid	Average rainfall	Total loss of constituents as percentages of weight of extracted colloid
	Inches	*Percent*		*Inches*	*Percent*
4	20	55	10, 11, 15, 16	20	50
5	50	68	12, 18	44	31
6	65	61	13, 18, 19, 20, 21	95	55
2	150	72	14	140	82
3	175	80	7, 8, 9	212	45

In the preceding discussion of the effects of weathering the combined water has not been considered. The presence of combined water in the soil material is an important feature of soil weathering, because it is associated with the colloidal material. The data in table 5 show that the combined water increases with rainfall to a maximum and then decreases under the highest rainfall in each age group. It follows a course similar to that taken by alumina. In fact, variations in combined water parallel variations in alumina fairly closely in most of the analyses reported in tables 4 and 5. This is satisfactorily explained by the fact that both alumina and water are constituents of the clay minerals. In the extracted colloids the ratio of the percentage of alumina to the percentage of water fluctuates around two values, 2.8 and 2.0. These are the proportions of the percentages of alumina and water in kaolinite and gibbsite, respectively. Kaolinite, or a closely related mineral, seems to be the most widely distributed of the colloidal minerals identified, but gibbsite has not yet been reported. It may be, however, that the two ratios are related to different constitutions of the colloids, because, with the exception of profile 2, the ratios close to 2.8 are found in profiles exposed to 52 inches of rainfall or less, whereas the ratios near 2.0 occur in profiles receiving 80 inches or more of rainfall. It is possible that in the colloids exposed to high rainfalls some of the water is associated with the ferric oxide. It seems evident from Magistad's analyses (*11*), the last four in table 6, that in some cases the iron oxide is highly hydrated and in other cases it must be practically dehydrated.

The conclusions drawn from the colloid analyses as to the net effects of weathering are the same as those drawn from analyses of the whole soils. The colloid analyses, however, have added some details to the picture. The limitations of the conclusions arrived at can be determined only by the accumulation of more data. It is to be expected that the weathering effects deduced apply to most well-drained Hawaiian soils derived from lavas but probably not to all such soils. Very little evidence has been obtained as to the effects of variations in the parent lava on the composition of the colloidal material and the weathered soil. Because most of the data considered have been average analyses of all the material in a profile, no indications have been obtained of weathering effects peculiar to any horizons.

THE HORIZONAL CHARACTERISTICS OF HAWAIIAN SOIL PROFILES

In the preceding discussion of weathering, the material of the whole soil profile was considered as a unit. No attention was paid to profile weathering; that is, to development of differences in the soil horizons.

In most soils the horizons are differentiated chiefly by the clay or colloid contents, but horizons in these Hawaiian soils cannot be distinguished in this way. As previously pointed out, a reliable determination of the colloid content of these soils is not obtained by the usual method of mechanical analysis. Also, in mature Hawaiian soils, the ultimate particles are probably nearly all colloidal, because in the parent lavas the mineral particles are all small and primary minerals as resistant to weathering as quartz are practically absent. Chemical composition, therefore, becomes the chief criterion of differences in the horizons.

The comparative compositions of the different horizons cannot be seen so well in the original analyses (table 1) as in the partial analyses calculated to a basis free of organic matter and combined water (table 4). In some profiles the ignition loss is so high and variable as to affect materially the percentages of other constituents. Horizonal differences are perhaps most plainly shown in the relative figures given in table 10. This table is based on the abbreviated, recalculated data of table 4. It shows for each constituent the comparative percentages in the different horizons of a profile. In the case of any constituent the highest percentage occurring in any of the horizons is taken as 100 and the percentages in other horizons of the profile are expressed relative to 100.

The 46- 60-inch layer in profile 15 was omitted from table 10, because it is apparent from the composition that this is partly in or near the parent material. This applies also to the 180- 240-inch layer of profile 19 and the 60+-inch layer of profile 17. The 51- 66-inch layer of profile 9 is omitted because, according to observations of the surveyor who collected this profile, the parent material of this layer is presumably different from that of the layers above, and the analytical data indicate this is the case. Profile 1 was omitted entirely. The analyses show that this profile contains such a small amount of weathered material that it is essentially a profile of parent material and as such is of no interest in this connection.

TABLE 10.—*The comparative percentages of constituents in different horizons of the profiles*

EXCEEDINGLY YOUNG PROFILES

Profile No.	Rainfall	Sample No.	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	Bases	Combined water	Organic matter
	Inches		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
2	150	C1613	96	100	82	100	85	100	100
		C1614	100	67	100	76	100	99	36
3	175	C1615	100	80	75	100	100	76	100
		C1616	98	100	100	93	95	100	48
YOUNG PROFILES									
4	20	C1627	77	100	100	100	100	100	100
		C1628	100	57	84	59	100	85	13
		C1629	89	74	94	80	99	90	27
5	50	C1617	100	71	72	74	100	66	100
		C1618	92	58	89	87	56	92	39
		C1619	90	92	89	98	48	96	24
		C1620	86	100	100	84	30	100	28
		C1621	94	93	87	100	32	93	9
6	65	C1607	100	81	75	87	100	83	100
		C1608	97	85	80	89	81	87	94
		C1609	81	100	100	100	61	100	81
7	175	C1633	100	100	96	100	100	81	100
		C1634	75	89	100	90	64	100	53
		C1635	92	93	83	81	68	83	71
		C1636	91	91	89	71	48	97	50
8	188	C2271	84	98	76	100	100	80	100
		C2272	91	95	82	86	47	81	44
		C2273	84	82	94	85	75	84	39
		C2274	72	98	87	85	74	88	29
		C2275	100	98	73	92	57	75	43
		C2276	36	100	100	89	37	100	15
		C2277	62	96	94	83	44	93	24
9	273	C2278	100	90	65	100	70	79	100
		C2279	89	90	74	83	84	85	75
		C2280	91	84	76	88	100	83	65
		C2281	74	76	100	87	49	100	56
		C2282	77	87	81	95	76	91	58
		C2283	67	100	67	93	85	89	58
		C2284	87	81	84	87	82	94	54
OLD PROFILES									
10	18	C1646	100	96	95	90	100	97	100
		C1647	96	100	98	96	80	100	28
		C1648	98	96	100	100	85	100	30
11	23	C1655	100	91	92	100	100	98	50
		C1656	96	93	100	90	95	100	87
		C1657	93	100	100	90	77	100	100
12	36	C1652	83	95	100	81	100	99	100
		C1653	87	97	100	91	88	100	31
		C1654	100	100	93	100	67	86	16
13	100	C1643	100	80	48	100	100	67	100
		C1644	37	100	84	60	62	100	57
		C1645	69	78	100	57	72	98	29
14	140	C1649	100	75	30	100	100	41	100
		C1650	58	100	76	25	63	95	73
		C1651	95	74	100	24	38	100	39

TABLE 10.—*The comparative percentages of constituents in different horizons of the profiles*—Continued

PRESUMABLY OLD PROFILES

Profile No.	Rainfall	Sample No.	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	Bases	Combined water	Organic matter
	Inches		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
15	20	B3712	98	99	93	87	100	96	100
		B3713	99	100	91	100	79	96	42
		B3714	99	97	94	100	83	98	18
		B3715	100	97	100	79	62	100	17
16	20	B5701	99	99	95	100	100	90	100
		B5702	99	100	96	98	74	84	43
		B5703	99	96	100	100	67	100	34
		B5704	100	99	99	90	65	88	19
17	52	C946	94	99	83	100	100	98	100
		C947	100	91	100	72	78	98	51
		C948	99	93	96	89	67	100	35
		C949	97	97	92	88	68	95	21
		C950	95	100	92	93	59	80	18
18	80	C942	100	100	45	100	100	50	100
		C943	86	96	73	72	86	69	82
		C944	78	96	89	47	84	100	81
		C945	95	81	100	40	70	95	60
19	90	B3717	100	92	86	97	100	95	100
		B3718	91	93	68	100	63	94	84
		B3719	94	100	80	90	61	87	61
		B3720	95	89	100	78	40	100	20
20	100	B5787	100	99	10	100	100	11	72
		B5788	90	100	22	81	89	34	78
		B5789	77	90	61	43	59	78	83
		B5890	99	51	100	28	98	100	100
21	104	C938	79	81	16	100	100	30	100
		C939	48	100	40	56	68	78	85
		C940	99	30	100	16	44	100	22
		C941	100	30	100	16	46	88	16

Certain features are common to nearly all profiles. The combined water varies with the alumina in all profiles except possibly profile 19. Here the combined-water determination is less exact than in the other profiles owing to the higher percentage of organic matter; hence it may not be an exception. In many profiles the parallelism between water and alumina is exact within probable limits of accuracy of the combined water determination. However, the ratio between water and alumina varies somewhat in different profiles according to the rainfall as previously mentioned (p. 28). The parallelism between variations of the two constituents in different horizons is obviously due to the fact that the combined water and alumina are both constituents of the same colloidal compounds. Owing to this parallelism it will be necessary to explain only the variations of alumina within the profiles.

A second feature common to nearly all profiles is the decrease of organic matter downward in the profile. This generality, of course, needs no explanation. The two exceptions to the rule, profiles 11 and 20, where the organic matter apparently increases downward, are not readily explained. These two anomalies in the distribution of organic matter are not connected with any anomalous features in the distribution of inorganic constituents in the profiles.

The sum of the monovalent and divalent bases, like the organic matter, decreases downward in the profile. The two exceptions to this generalization are profiles 2 and 9. The decreases are not strictly regular throughout the profiles for either organic matter or bases, but they are fairly regular. Because there is a parallelism between variations in these two constituents, it is far from being as close as that obtaining between combined water and alumina.

In some cases the approximate relation between decrease in bases and decrease in organic matter may be explained on the ground that part of the bases are combined with the organic matter. In other cases differences between horizons in organic matter are not sufficiently large to account for the difference in bases, as 1 gm. of soil organic matter would not be expected to combine with more than 0.05 to 0.10 gm. of bases. But in all cases the quantity of organic matter in the surface may be taken as an index of the bases brought to the surface by vegetation. A high content of organic matter in the surface means that the bases extracted from the lower horizons by plant roots and deposited at the surface by decay of the vegetative cover must have been large. As the vegetative cover increases with rainfall, the magnitude of this movement should increase with rainfall. However, the opposite effect, the leaching out of the bases, also increases with rainfall. Under excessive rainfall, 150 inches or more, the vegetative translocation of bases would not be expected to affect the distribution of bases in the profile. The marked decrease in bases downward in profiles 5 and 6, which will be discussed later, probably is not connected with the organic matter.

The parallelism between combined water and alumina and the decrease in bases and organic matter downward, which hold for practically all the profiles collected, may be considered characteristics of soil profiles in general. There are other relations between the compositions of the horizons that serve to distinguish one kind of soil profile from another.

It will be shown that among the old soils and the presumably old soils from Technical Bulletin 584, two distinct types of profile are represented. These are tentatively called the uniform and podzolic types of profile. The podzolic profile is considered a more mature or highly weathered type than the uniform, and, in some cases, it seems to be developed from the uniform type. Certain members of the group of old profiles are apparently in a stage transitional between the two types. The remaining profiles in this collection, which comprise the young and exceedingly young soils, seem to be in the process of developing into one or the other of these types. The evidence upon which these conclusions are based is discussed in the following pages.

THE UNIFORM PROFILE

Among the 12 old profiles there are four, Nos. 10, 11, 15, and 16, that are remarkably uniform in composition. The different horizons of these profiles do not vary from one another in silica, iron, alumina, and titanium by more than 5 percent of the quantities present in most cases. These profiles are considered to represent a fairly definite type of profile chemically. For convenience we shall call this the "uniform" type of profile, realizing that this term has no general significance in pedology.

These profiles were all classified as old by the soil surveyors who collected the samples and all are of considerable maturity with respect to weathering, because, as previously pointed out (p. 24), they seem to be made up almost exclusively of colloidal material; i. e., most of the primary minerals have been decomposed. The tendency of weathering in these cases, then, has evidently been to develop a profile with horizons of uniform chemical composition. Fortunately, in the case of these profiles the parent material cannot be invoked to explain the horizonal characteristics. If the parent materials were not uniform vertically, weathering has overcome the differences, and if the parent materials were uniform, weathering has maintained the uniformity.

The four uniform profiles were all developed under low rainfalls ranging from 18 to 22 inches, but this type of profile is obviously not developed only under low rainfall. Profile 19, developed under 90 inches of rainfall, is evidently of this same type, although a slightly less perfect example.

It is believed that the uniform type of profile is more or less transitional. But the development away from uniformity may be so slow or so long delayed under low rainfall that the type may be fairly permanent under these conditions. If this is so, the uniform profile should be characteristic for rainfalls of about 20 inches. This supposition can, of course, be tested by the examination of more samples of mature profiles from low rainfall regions. Under rainfalls of 150 inches or more, the uniform profile may be so short-lived that good examples of the type would be very rare in districts where such rainfalls prevail. This idea is suggested by the young profiles, Nos. 7, 8, and 9, developed under rainfalls of 175 to 273 inches.

Profile 7, of 175 inches rainfall, according to its acidity, seems to be slightly more weathered than profiles 8 and 9, and this profile, as will be shown later, seems to be in an incipient stage of development toward the podzolic profile, which is a more highly weathered type than the uniform. Profiles 8 and 9, which are of mixed composition, might be approaching the uniform type or developing from it. The latter supposition seems a little more probable. These two profiles possess some unusual features that will be discussed later.

A uniform soil profile as a fairly mature development is not in accord with the common idea that weathering of a soil profile should be more or less progressive from top to bottom. Inasmuch as the profile deepens from the bottom, the lower part of the profile is younger and seemingly, as a consequence, should be less leached. However, the four profiles, 10, 11, 15, and 16, are certain evidence that uniform profiles do develop. The immature profiles, 2 to 6, should give a clue as to the course of weathering leading to a uniform profile. These profiles, as pointed out on page 24, still contain a considerable part of the unweathered minerals and, according to the hypothesis, profiles 4 to 6, at least, should be on the way to becoming uniform.

Analyses of the whole soil, shown in table 4, indicate that profiles 5 and 6 are distinctly more weathered in the lower part of the profile than at the top. This is particularly evident in the bases, but the silica, iron, alumina, and titanium contents also indicate more weathering in the lower layers. The higher percentages of bases in the upper part of the profiles cannot in these cases be attributed to vegetative action. The different compositions of the horizons in the case of these immature soils are presumably associated with different proportions of primary minerals and colloidal material. It seems then that the lower layers contain more colloid than the surface layer. If this is partly due to illuviation of colloid from the surface layer, weathering is not necessarily more intense in the lower part of the profile, although the lower part is more highly weathered in its composition.

It will be noted that the colloidal material extracted from the horizons is somewhat more uniform than the whole soil. This is particularly evident in profile 6. Probably by the time the primary minerals have been decomposed in all the layers the colloidal material remaining will be quite uniform in composition. So long as readily decomposable primary minerals are present in a layer, the colloidal material in the profile is probably protected more or less from alteration by the decomposition products of the minerals. The effect seems to be most pronounced on the colloidal material in the same layer as the minerals, for in profiles 3 and 4 the compositions of the extracted colloids vary somewhat with the compositions of the whole soils.

It seems probable that the development of a fairly mature uniform profile is not necessarily preceded by a uniform weathering of all horizons or of a whole vertical section. Weathering in the beginning may be more intense in the top or bottom layers, depending on the moisture conditions of the layers as affected by drainage, rainfall, and evaporation. Profile 2 seems slightly more weathered in the first than in the second layer; in profile 3 the reverse is true; in profile 4, with only 20 inches of rainfall, the top and bottom layers are more weathered than the middle layer; and in profiles 5 and 6 the bottom layers are the most weathered. These differences may of course be partly due to illuviation of the colloidal material. The uniformity develops as the primary minerals disappear from the profile. When the minerals have been decomposed, the residual colloidal material making up the profile should be fairly uniform.

THE PODZOLIC PROFILE

Pronounced examples of the uniform profiles account for 4 of the 12 old profiles. Among the remaining 8 old profiles there are five, Nos. 13, 14, 18, 20, and 21, that have horizons of markedly different composition, and the horizontal variations in all 5 of these profiles conform to the same pattern.

The characteristics of this profile are as follows: Titanium decreases markedly downward whereas alumina increases downward in an equally marked manner. There is a close inverse relation between the decreases in titanium and the increases in alumina. Iron and silica are less variable in the profile than titanium and alumina. Iron is lowest at the bottom of the profile and in four cases out of five it is highest in the layer next to the top. The lowest silica content occurs in the layer above the maximum alumina content; in some cases this is coincident with the maximum iron content, in other cases it lies between the highest iron and the highest alumina content. The combined water increases markedly downward. As in the other profiles, it is closely related to the alumina content. The carbon-nitrogen ratio of the organic matter is similar to that of other profiles in the upper part of the profile, but in the lower part the ratios are exceptionally high. The pronounced change in this ratio occurs in the layer in which the silica content is lowest.

It seems wholly improbable that the variations obtaining within these 5 profiles could be due to differences in the parent materials from which the horizons were derived. Geological differences could hardly account for such an elaborate profile pattern being reproduced so perfectly in 5 profiles out of 20, especially when the 5 profiles were taken in four widely separated localities. Furthermore, the pattern distinctive of these 5 profiles is shown faintly and somewhat imperfectly by 2 other profiles of high rainfall (profiles 7 and 19). It seems certain that the pattern characteristic of these 5 profiles is the result of soil-forming processes and is not a geological coincidence.

There is a suggestion in Magistad's analyses (*11*) of surface soil that this type of profile is not unusual in the Hawaiian Islands. Two of the eleven analyses reported in table 6, Nos. 631 and 920, are obviously of the same character as the surface horizons of the five distinctive profiles in this collection. The combined water, titanium, alumina, and iron contents are very similar. Of course it is not certain that the deeper horizons of Magistad's soils have the same pattern as the profiles in this collection, but it seems probable.

The type of profile represented by profiles 13, 14, 18, 20, and 21 is evidently a more mature stage of development than the uniform type of profile represented by profiles 10, 11, 15, and 16. The members of this group of five are all old soils exposed to high rainfall. They are also more acid than the soils having uniform profiles. The two soils that seem to have this distinctive type of profile in an incipient stage of development (profiles 7 and 19) are also exposed to high rainfall. Probably at an earlier stage of development the five profiles under consideration were as nearly uniform in their horizons as the mature low rainfall soils are now.

The weathering changes that have brought about the markedly different compositions of the horizons need explanation. Of course, any such explanation is speculation until the subject is investigated further, but certain possibilities may be pointed out.

There is some suggestion in the horizon analyses of a movement of silica and iron upward in the profile. The lowest silica content is in the middle of the profile and the highest percentage in the top. In the case of iron the lowest percentage is in the lowest horizon and the highest percentage is near the top. An upward movement of silica and iron would be in harmony with the results of Harrison's (*6*) careful study of laterite profiles in British Guiana. The British Guiana profiles are exposed to about the same total annual rainfall as most of the Hawaiian profiles, which is about 100 inches. In the region of the British Guiana profiles there is a distinct dry period of about 3 months, during which a pronounced upward movement of salts would be possible. In the case of the Hawaiian profiles no such dry period obtains. The rainfall is quite uniformly distributed throughout the year and one of the pronounced examples of the Hawaiian profile is exposed to 140 inches annual rainfall. Under these Hawaiian conditions it does not seem reasonable to expect a movement of salts upward.

Also, a movement of silica and iron upward would explain only part of the profile pattern. If silica and iron did move upward, it would be necessary to assume a more pronounced upward movement of titanium and a leaching of alumina from the uppermost horizon.

An obvious idea is that differences in the horizons are due simply to different degrees of leaching; the surface horizons being older have been leached more than the younger, lower horizons; and the constituents showing the greater increases in percentage, as compared with the average lava, have been leached less than the others. This hypothesis is seemingly contradicted by the remaining uniform profiles. As previously pointed out, most of the other profiles are practically uniform in composition from top to bottom, indicating that leaching of constituents from the profile is not so much a progressive movement from horizon to horizon as it is a removal from the profile as a whole. In some of the uniform profiles the difference in age between the uppermost and lowest horizons of the profile must be fully as great as the difference in age between the first and second horizons of the distinctive type of profile; yet there is not the characteristic difference in composition. Also, some of the profiles with considerably more uniform horizons show fully as much leaching in their average composition (table 5) as the profiles with the distinctive pattern. Profiles 8 and 9, for instance, in their silica, base, iron, and titanium contents, seem to be at least as highly weathered as the five profiles under consideration. It is true, however, that in the case of profiles 8 and 9, developed under high rainfall, probably most of the constituents were lost in the weathering of the minerals to colloidal material.

The hypothesis that the different compositions of the horizons are due to different amounts of leaching, which are proportional to the ages of the horizons, does not satisfactorily explain some of the characteristic features of the profile pattern. The minimum percentage of silica in the second or third horizon and the maximum percentages of iron in the second horizon (in one profile the first horizon) are not explained by this hypothesis. In the first and second, or in the first, second, and third horizons, there are marked variations in titanium without corresponding variations in iron. It seems evident that if the different compositions of the horizons represent different degrees of the same kind of weathering, it is a different kind of weathering from that affecting the other profiles. The high titanium and low alumina percentages in the surface horizons indicate extreme weathering, but the silica percentage indicates only moderate weathering. In other words, silica has been removed less rapidly than alumina from the surface horizons. Also, in the weathering effects found to hold for profiles as a whole (table 5) iron and titanium increase together and silica decreases as weathering advances. These relations do not hold within this type of profile.

A third explanation of the pattern of profiles Nos. 13, 14, 18, 20, and 21 is based on the idea that there has been a transfer of certain constituents from the upper horizons to the lower. Calculations were made to see what translocation of constituents would explain the compositions of the horizons. The calculations are based on four assumptions; namely, first, that the titanium is the constituent most resistant to leaching; second, that titanium is the constituent least subject to movement in the profile; third, that prior to the translocation of constituents each horizon of a profile had a composition the same as the composition that is now the average of the whole profile; fourth, that no constituents have been lost from the profile during the translocation process. The last two assumptions are doubtless considerably wide of the truth, but they serve to simplify the calculations. The loss of constituents from the profile, which undoubtedly has taken place, would not affect the nature of the calculated translocations but would merely increase the calculated losses from certain horizons. It is also indirectly assumed that the profile does not change in depth during the translocation. As a matter of fact, each horizon is probably growing at the expense of the horizon below while movement from one horizon to another may be taking place, but this again would only affect the magnitude of the calculated figures, not the general trend of results.

The following is a description of the calculations. According to assumptions 1, 2, and 3, titanium originally was evenly distributed throughout the profile and has never moved except as the whole mass of soil has moved. Previous to translocation, all horizons had the same composition, which was the weighted average of the percentages now obtaining in the different horizons of the profile. A higher than average percentage of titanium in a horizon now is due to the removal of other constituents from the horizon, and a lower than average percentage in any horizon is due to the augmentation of other constituents. We assume that all horizons are of the same real and apparent specific gravity, now and before translocation. Then a percentage of titanium twice the average in a given layer means that this layer was originally twice as thick and that its thickness has been reduced one-half by the loss of other constituents. Likewise, a percentage of titanium one-half the average in a present layer means that this layer was once half as thick and that its thickness is now twice as great owing to the illuviation of other constituents. The titanium percentages (the average percentage in the profile, and the percentage in a given horizon) are used as the basis for calculating changes in the other constituents.

An example of the method of calculation is given for the movement of silica in the 0- to 10-inch horizon of profile 14. The losses or gains of other constituents are calculated in the same manner. The average percentages of titanium and silica in the whole profile are 9.60 percent of TiO_2 and 19.87 of SiO_2. The 0- to 10-inch horizon now contains 22.12 percent of TiO_2 and 24.17 of SiO_2. It is easier to visualize the movement in pounds, so we shall consider the movement in an area such that each inch of thickness weighs 100 pounds. The 0- to 10-inch horizon, which is now 10 inches thick, contains 1,000 pounds of material, of which 221.2 pounds is TiO_2. Originally 1,000 pounds of material would have contained only 96.0 pounds of TiO_2. Hence, the 0- to 10-inch horizon was originally $\frac{22.12}{9.60}$ or 2.31 times as thick as it is now, or 23.1 inches thick. The original layer, 23.1 inches thick, weighing 2,310 pounds, originally contained 19.87 percent of SiO_2 or 459.0 pounds of silica. The present 0- to 10-inch layer, weighing 1,000 pounds, now contains 24.17 percent of SiO_2 or 214.7 pounds of silica. There has thus been a loss of 217.3 pounds of silica (459.0–241.7) in the development of the present 0- to 10-inch horizon.

The calculated losses and gains of constituents from the different horizons are shown in table 11. These gains and losses superimposed on uniform profiles of the compositions assumed in the calculations would reproduce the actual compositions of the horizons. The data in general show a movement of silica, iron, and alumina from the upper horizon or horizons and a deposition in the lower. Alumina moves a little farther downward than iron. The movement of silica parallels that of alumina fairly well in that the losses and gains of silica are larger in the horizons where the losses and gains of alumina are larger. The relation between the quantities of these two constituents gained or lost is far from being exactly quantitative, but it suggests that alumina either moves downward as a silicate or that there is a precipitation of alumina and silica as an alumino-silicate in the lower horizon.

TABLE 11.—*Quantities of constituents gained or lost by different layers of soil in the development of the present soil profile*

Profile No.	Sample No.	Depth[1]	SiO_2	Fe_2O_3	Al_2O_3	Original depth of layer
		Inches	*Pounds*[2]	*Pounds*	*Pounds*	*Inches*
13	C1643	0-10	+13	−215	−243	14.52
	C1644	10-25	−63	+177	+70	13.08
	C1645	25-40	+50	+37	+173	12.40
14	C1649	0-10	−217	−650	−392	23.05
	C1650	10-25	+34	+431	+138	8.79
	C1651	25-40	+183	+243	+253	8.16
18	C942	0-7	−43	−140	−130	10.21
	C943	7-19	−11	−31	−12	12.52
	C944	19-31	+53	+171	+142	8.27
20	B5787	0-6	−107	−205	−256	11.86
	B5788	6-9	−36	−50	−86	4.78
	B5789	9-30	+19	+231	+85	17.72
	B5790	30-40	+124	+24	+202	5.63
21	C938	0-7	−270	−190	−351	15.19
	C939	7-15	−161	+117	−124	9.65
	C940	15-22	+109	+36	+222	2.40
	C941	22-30	+241	+38	+253	2.75

[1] The depths of the layers are those obtaining now. It is assumed that layers showing a net loss of constituents were originally thicker and layers showing a net gain of constituents were originally thinner.

[2] Pounds gained or lost per unit area such that 1 inch thick weighs 100 pounds. The assumed thicknesses of the unit areas are given in the last column.

There are general grounds for believing that the quite distinctive profile pattern is due to translocations of silica, iron, and alumina, probably not the exact quantities shown in table 11, which were calculated for an ideal case, but a movement of this general character. The fact that the gains and losses shown in table 11 explain all the peculiar variations in the percentages of constituents in different horizons of the profile is, of course, no proof that the explanation is correct, because these calculations were based on analyses of the horizons. But the fact that the translocation hypothesis should lead to a method of calculating a movement of constituents capable of explaining the profile pattern is in itself some evidence that the hypothesis is correct. Stronger evidence that the hypothesis is correct lies in the fact that the calculated movement of constituents turns out to be a general process of soil development.

The translocation of iron and alumina downward, the alumina slightly in advance of the iron, is not a new type of soil weathering; it is the typical podzolization process. This process accounts for the chief horizontal differences in a large part of the temperate region soils. Marbut (*9*) found evidences of podzolization throughout the Amazon Valley, and several Cuban soils discussed by Bennett and Allison (*2*) are markedly podzolized. It does not seem improbable that the process should be pronounced in some Hawaiian soils.

The translocation of silica indicated in table 11 may not be in accord with the general idea of the podzolization process, because in the A horizon of a typical podzol there is marked concentration of silica. It seems probable, however, that in the development of even a typical podzol some silica is translocated, although less of the silica would be moved than of the iron and alumina. Most podzol profiles are derived from rocks containing considerable quartz and it is probably the quartz residual from these rocks that accounts for most of the silica in the A horizon. Silica or silicates resulting from the decomposition of feldspars, micas, and other soil-forming minerals presumably is more subject to movement. Some of this doubtless is leached from the entire profile along with the bases while a podzol is being developed. Some may be removed from the A horizon and deposited in the B. Because alumina in the colloidal material seems to be present as a silicate, and because alumina is concentrated in the B horizon, it seems necessary to assume either that alumina carries some silica with it into the B horizon or that alumina fixes some silica in the B that would otherwise escape, both of which amount to a translocation of silica.

Quartz above colloidal size is practically lacking in the parent material of the Hawaiian soils. The parent lavas are made up of feldspars, augites, and olivines. On examining the soils petrographically, I. C. Brown found more quartz in the surface horizons than in the horizons below, but even in the surface horizons there is less than ½ of 1 percent quartz. If in the ordinary podzol, the silica of the A horizon is mainly residual quartz, the development of an ordinary siliceous podzol in Hawaii is obviously precluded by the nature of the parent material. What silica there is in Hawaiian soils is evidently derived from the mixed minerals and therefore has presumably been freer to move than quartz.

In the Hawaiian soils titanium seems to be the most insoluble constituent of the parent lavas. This may be regarded as taking the place of quartz. We then have a titaniferous podzol that looks similar to the ordinary siliceous podzol, except that the iron does not seem to increase from the surface downward (table 10) as it should in a typical podzol. But this is only an arithmetical vagary. When the silica, iron, and alumina percentages are expressed relative to the titanium percentages taken as unity (table 12) it can be seen that iron relative to titanium is markedly lower in the surface horizon than in the horizon below.

TABLE 12.—*The percentages of silica, iron, and alumina relative to titanium in different horizons of the podzolic profiles*

Profile No.	Sample No.	Depth	SiO_2	Fe_2O_3	Al_2O_3	TiO_2
		Inches	*Percent*	*Percent*	*Percent*	*Percent*
13	C1643	0–10	1.60	3.71	1.35	1
	C1644	10–25	1.03	6.90	3.90	1
	C1645	25–40	2.05	5.77	1.90	1
14	C1649	0–10	1.09	1.92	.38	1
	C1650	10–25	2.48	10.08	3.79	1
	C1651	25–40	4.40	8.07	5.37	1
18	C942	0–7	2.28	4.67	1.31	1
	C943	7–19	2.75	6.23	2.90	1
	C944	19–31	3.77	9.47	5.50	1
20	B5787	0–6	2.00	4.30	.83	1
	B5788	6–9	2.23	5.37	.88	1
	B5789	9–30	3.60	9.11	4.50	1
	B5790	30–40	6.94	7.73	11.11	1
21	C938	0–7	2.24	3.08	.16	1
	C939	7–15	2.43	6.83	2.01	1
	C940	15–22	17.42	7.49	17.93	1
	C941	22–30	17.85	7.13	18.09	1

It can be seen from table 11 that if the percentage composition assumed for the profiles prior to podzolization is correct, the quantities of iron removed from the first or first and second layers are on the whole about as great as the quantities of alumina removed, and if, prior to podzolization, the percentage of iron was less than the assumed percentage, the movement of iron would be less than that shown in table 11. Inasmuch as the calculations shown in table 11 are supposed to give only a qualitative idea of what has taken place, there is no certainty as to the relative amounts of iron and alumina removed from the upper horizons. It is evident, however, that an equal movement of iron and alumina is not incompatible with the analytical data, provided the translocation hypothesis is correct.

One pronounced feature of profiles 13, 14, 18, 20, and 21, not explained by the calculations shown in table 11, is the marked change of the carbon-nitrogen ratio in the lower part of the profile, shown in table 4. The organic matter of the second or third horizon has a carbon-nitrogen ratio about double that of the first horizon. This marked change in the character of the organic matter is not associated with any unusual change in the quantity of organic matter. The percentage of organic matter decreases regularly downward in all profiles except profile 20, just as in the uniform type of profile. The change does occur, however, at a definite place in the profile, i. e., in the horizon of lowest silica content. This is the upper part of the zone assumed to be illuviated according to the calculations shown in table 11.

A similar increase in the carbon-nitrogen ratio does not seem to be a characteristic of any of the profile types studied thus far. Of the many profiles tabulated by Anderson and Byers (*1*), only the Beckett loam from Massachusetts shows similar variations in the ratio. In this case the results are calculated from organic matter determined by hydrogen peroxide, and the data are at variance with those of five other podzol profiles.

In the case of the five Hawaiian soils this pronounced change in the organic matter is obviously a profile characteristic. As such it should be explained, for it may throw light on the mechanism by which the whole profile pattern is developed. But no explanation that could be called a hypothesis is at hand. The point in the profile at which the change in ratio occurs—the highly illuviated layer—suggests that organic matter low in nitrogen may be concerned with the fixation of iron and alumina into the lower horizons. Possibly organic compounds low in nitrogen form relatively insoluble iron and alumina "humates" in the lower horizons.

There are grounds for believing that this type of profile, which may be called "podzolic" for convenience, is a more mature development than the uniform type. In other words, it seems that in profiles 13, 14, 18, 20, and 21 the horizons were originally uniform and that they differentiated later. The two types of profile seem to be connected, for profiles 7 and 19 show the distinctive podzolic pattern faintly and profiles 8, 9, and 17 show the most pronounced features of the pattern imperfectly. In the latter three profiles titanium is highest in the surface horizon and decreases irregularly downward, and alumina is low in the surface horizon. Of course, if the two types of profile are connected, it does not necessarily follow that the podzolic developed from the uniform; it might be better the other way around. But it certainly seems more probable for a highly differentiated profile to develop from a uniform one than for a uniform profile to develop from a differentiated one.

More conclusive evidence of the podzolic profile being more mature than the uniform type lies in the field observations. The five pronounced examples of the podzolic type are all old profiles developed under high rainfall. The most pronounced examples of the uniform type are the young and old soils of 18 to 22 inches rainfall, and the soils showing some of the podzolic features are either young soils of very high rainfall or old ones of intermediate rainfall.

The hydrogen-ion concentration of the profile seems to indicate roughly when the podzolic type of profile should develop. The pH values of different horizons in some profiles vary considerably, but if these are averaged to give a single value for a profile, a rough comparison can be made. The 5 pronounced podzolic profiles have pH values of 4.9, 4.7, 4.9, 4.7, and 4.5. The 5 profiles having some podzolic features have pH values of 5.2, 5.6, 5.8, 5.3, and 4.9. The remaining 11 uniform or indeterminate profiles have pH values ranging from 5.3 to 6.9. Presumably the process producing the so-called podzolic profile starts when the soil becomes sufficiently leached to have a pH around 5.5, but a pronounced example will not be developed until the soil is leached below pH 5.0.

SUMMARY

This bulletin deals with the effects of weathering on Hawaiian soil material and on the chemical types of soil profiles that develop from Hawaiian lavas. The study is based on the chemical analyses of 21 soil profiles derived from exceedingly young, young, and old volcanic ejecta exposed to rainfalls ranging from 18 to 273 inches. The compositions of the soil materials are compared with those of the parent materials. In the case of three exceedingly young profiles, the compositions of the parent lavas are known, but in the case of 18 profiles the parent materials are assumed to have a composition the same as the average of Hawaiian lavas.

The comparisons indicate that alumina is the least soluble constituent in soils that have not been highly weathered. But in the highly weathered soils iron is evidently less soluble than alumina, and titanium is probably slightly less soluble than iron. Silica and the sum of the monovalent and divalent bases are by far the most soluble constituents of the lavas and derived soil materials. The combined bases seem to be lost more rapidly than silica, particularly in the early stages of weathering.

The kind of colloidal material formed by decomposition of the lava minerals (the first stage of weathering) varies with the rainfall. Colloidal material formed under high rainfall is lower in silica and higher in iron, alumina, and combined water than that formed under low rainfall. There is evidence that the parent material also affects the composition of the colloidal material somewhat. As the freshly formed colloids weather (the second stage of weathering), silica, alumina, and iron are lost. More silica is lost than alumina and more alumina than iron. Titanium seems to be the most insoluble constituent of the colloidal material. Under low to moderate rainfall, the losses accompanying the second stage of weathering may be as great as those accompanying the first stage, but under very high rainfall the greater losses probably take place in the first stage of weathering.

Certain features that are common to practically all the profiles are considered characteristics of soil profiles in general. These are: A

relation between combined water and alumina, and decreasing percentages of organic matter and of combined monovalent and divalent bases downward in the profile. Other variations in the compositions of the horizons serve to distinguish two distinct types of soil profiles. These types are tentatively called the "uniform" and "podzolic." Profiles that are not good examples of either the uniform or podzolic types appear to be developing toward one or the other of them.

Of the 12 old profiles in the collection, 4 are considered good examples of the uniform type. In these profiles, the horizons in most instances do not vary from one another in silica, alumina, iron, and titanium by more than 5 percent of the quantities present. They seem to be made up almost exclusively of colloidal material and were all developed under low rainfall. During the development of the uniform profile the different layers of the soil do not seem to be weathered uniformly. Probably uniformity is attained when all the primary minerals have been decomposed. It is believed that a uniform profile may be developed under a fairly high rainfall, but its life under these conditions is shorter than under a low rainfall.

Five of the twelve old profiles are pronounced examples of the so-called podzolic type. The features of this profile are a marked decrease in titanium and a proportionally marked increase in alumina downward in the profile. Iron is lower at the bottom of the profile than at the top. The silica content is lowest in a layer above that containing the maximum percentage of alumina. The carbon-nitrogen ratio is exceptionally high in the lower part of the profile. The five profiles were developed under 80 to 140 inches of annual rainfall, evenly distributed. The pattern of this profile seems to have been produced by a translocation of constituents from the upper to the lower part of the profile. Calculations indicate that some silica, iron, and alumina have been removed from the surface layers of the profile and deposited in the lower layers. Alumina moves farther downward than iron and the movement of silica parallels that of alumina. This is podzolization of a soil material lacking in quartz and high in titanium. It seems that this type of profile may be developed when the soil material has been leached to about pH 5.

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