

**CHROMIUM DISTRIBUTION IN THE LATOSOLS
OF THE HAWAIIAN ISLANDS**

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Martha Nakamura and G. Donald Sherman

INTRODUCTION

The Hawaiian Islands were formed from basaltic lavas, some of which have high concentrations of pyroxene and olivine. Since chromium is associated with the foregoing minerals, it is reasonable to assume that the element is present in the soils of Hawaii. Hough *et al.* (8) in their work in 1941 on rock weathering have affirmed this assumption. The present study was designed to determine the presence and the distribution of the element in the various great soil groups formed through the process of laterization. Other objectives were to determine the correlation, if any, between chromium concentration and the intensity of weathering in the soils and the influence of the parent material on the accumulation of the element. This study will attempt to show that both these factors play important roles in the concentration of chromium in the Hawaiian soils which were analyzed.

REVIEW OF LITERATURE

The work carried out thus far on the problem of the chromium content of soils is limited. Very little is known of the role of chromium in soil, although there is a general agreement as to its toxic effect upon plants. Therefore, much of the investigation has been limited to studies of infertile soils containing large quantities of chromium. In addition to the above-mentioned studies of infertile soils there are general studies in trace element distribution. Data on chromium content of soils may also be obtained from chemical analysis tables in soil survey reports and soil analysis tables.

The available literature can be divided into two general categories for the purposes of this investigation. In one group of publications the parent material and the resultant chromium concentrations are noted. In the other category, the investigations are of Pacific island soils where parent material differences are omitted and correlation between weathering and accumulation of the element was found.

Parent material studies

Among the earlier soil survey reports where chromium contents are reported is that of Bennett and Allison (1), which covered Cuban soils. The Nipe clay

described in the survey has since become the modal profile for comparative purposes for writers dealing with the problem of infertile soils high in chromium.

Robinson *et al.* (11) conducted their investigation of infertile soils of Maryland, Pennsylvania, Virginia, Oregon, California, Cuba, and Puerto Rico. These soils were derived from serpentine or chlorite, and they all showed in common a comparatively high chromium and nickel content. Chromium was found to range from 510–38,360 ppm, with the average being 8350 ppm. Birrell *et al.* (2) studied lateritic soils of Western Samoa and Niue Island. These soils were derived from limestone and serpentine. The chromium content was high throughout, but the soils of serpentine origin contained much higher amounts of chromium. The work of Birrell and Wright (3) was done on a New Caledonia soil of serpentine origin, where chromium was found to be from 20,900–33,800 ppm. The soils of South African Transvaal were discovered to be toxic to citrus plants by van der Merwe and Anderssen (21). These infertile soils were high in chromium and were derived from chromiferous rocks.

Both Robinson (10) and Slater *et al.* (17) have investigated trace elements in agriculturally important American soils. These soils were derived from loess, granite, gneiss, schist, shales, and limestone; and chromium was found to be present in the soil profiles in small amounts, usually from a trace to 170 ppm. Swaine (20) studied trace element distribution in some Scottish soils. He investigated soils formed from different parent materials and found chromium to range from 15–500 ppm in soils with parent materials ranging from acidic to basic rocks. In soils derived from serpentine till, concentrations of 3000–3500 ppm were found.

The literature tends to indicate that the concentration of chromium is partially dependent upon the parent material from which the soil is derived. The literature further indicates that soils developed on ultra basic rocks such as serpentine and chlorite contain chromium in amounts likely to be toxic to plants. Soils developed from basic rocks do not contain chromium in amounts as high as the above-mentioned soils. When the soils have been developed from acidic rocks and their derivatives, the chromium content has been uniformly low.

Weathering studies

Seelye's survey of the soils of Western Samoa (14) and the survey by Grange *et al.* (6) of the soils of the Lower Cook Island Group, give the chromium content of the soil profiles in their tables of chemical analyses. No discussion is found on chromium in either of these soil surveys. An observation of the chemical analysis tables indicated that there was an appreciable amount of chromium in the soils and that the content increased with the weathering of the soil.

What is available on this topic as far as the Hawaiian Islands are concerned is limited to the publication of Hough and his associates in 1941 (8). The subject of the study was rock weathering and incidental thereto the investigators analyzed the chromium content of the soils. In the course of the general analysis, Hough and his associates found indications that chromium was present in Hawaiian soils, with certain soils containing appreciable amounts of the element

EXPERIMENTAL PROCEDURES

Method of analysis

The analytical method used was a composite of the methods outlined in Sandell (12, 13) and Hillebrand *et al.* (7).

A half gram of oven-dried sample was fused with 5–6 grams of sodium peroxide in a nickel crucible. This melt was leached with water, and eight drops of ethyl alcohol were added to reduce any manganate manganese present to the hydrated manganese oxide. The resulting solution was digested over a water bath for an hour, then filtered through filter paper and made to volume.

The aliquot to be taken from the leachate solution in order to be used in the subsequent analysis for hexivalent chromium should not contain more than 1.0 microgram of chromium in the final 25 ml. solution. The appropriate aliquot obtained from the solution above was neutralized with 0.4 N sulfuric acid. A half ml. of a 1:3 nitric acid solution was added to this neutralized solution which was then boiled to decompose the peroxide. One ml. of 1 percent silver nitrate and 2 ml. of 10 percent ammonium persulfate were then added to the boiling solution and boiled for about 10 minutes to expel the excess ammonium persulfate. This step was taken to reoxidize any chromium that might be in the trivalent state into hexivalent chromium. Sandell states that vanadium will interfere with the determination of chromium by the diphenylcarbazide method, if vanadium is in excess of chromium in the solution. However, the vanadium content of Hawaiian soils does not exceed that of chromium; therefore, this separation was not necessary.

The diphenylcarbazide color was developed according to Sandell's method (13). The intensity of the color of the solution was then read in the Klett-Summerson photoelectric colorimeter using a filter having a maximum transmission at the 540 millimicron wave length.

Description of samples

The appended tables contain the lists of soils, rock samples, and concretionary materials analyzed during the course of the experiment. Representative samples from the families of the latosol groups of the Hawaiian Islands were analyzed for chromium. General descriptions of the typical modal profiles of the soils have been given by Cline *et al.* (4) in the soil survey of the Hawaiian Islands. There are a number of publications on the Humic Ferruginous Latosol soils with detailed profile descriptions and chemical analyses of the soils that were analyzed in this study (5, 15, 16).

Also analyzed for chromium were some rock samples representing the parent materials of the Hawaiian Islands. Samples of concretionary products of soil weathering were also analyzed. Although it would have been desirable for the purpose of this study to have these samples sifted from the analyzed soils, this was possible only in the case of a few samples. Where other concretionary materials were concerned, it was necessary to collect them from soils in the same family group, but not from the exact locations where the soil samples were dug.

EXPERIMENTAL RESULTS AND DISCUSSION

Distribution of chromium in the great soil groups

Hough and his associates (8) in their study found chromium to be generally present in Hawaiian soils with appreciable amounts in certain soils. Their tables, however, omit reference to the element in several instances. This could probably indicate that the quantity present was not great enough to be detected by the analytical procedures followed. The method of analysis followed in this study, on the other hand, was a micro-analysis and probably more sensitive to chromium analysis than that followed by Hough *et al.* Every soil sample analyzed in this investigation contained chromium. These results are included in table 1.

The most significant fact uncovered during the analyses of the soils was the finding that the highest as well as the lowest concentrations occurred in the same family of the Humic Ferruginous Latosol group. The sample of the Naiwa soil taken from Kokee, Kauai, showed the highest amount of any of the samples with 9000 ppm of chromium present. The lowest occurred in the Naiwa soil from Meyer Lake, Molokai, where there was an average of 225 ppm of chromium.

The group which generally contained the lowest concentration of chromium was the Low Humic Latosol group. The soils of the Molokai, Lahaina, and Wahiawa families were found to have an average content of 550 ppm. The two Kahana family soils analyzed averaged a chromium content of 900 ppm. The Kohala family soil, the most weathered soil in this group, averaged 1200 ppm. The soils of the Humic Latosol group and the Hydrol Humic Latosol soils roughly averaged 1000 ppm of chromium.

The samples from the Humic Ferruginous Latosol group generally averaged the highest content of chromium among the great soil groups. However, as stated previously, unexpected variations were discovered in the results of the analysis of certain families within this group; namely, in the Naiwa soils and in the Haiku soils. The samples dug on the island of Kauai all manifested the highest concentration; whereas, the samples from Maui and Molokai, although from the same family, contained much lower amounts of the element.

Relation of parent material to chromium distribution

The unexpected variations found within the same families led the writers to consider factors other than weathering in the investigation. The geological maps of all the islands showed that the volcanic flows underlying the areas where the samples were taken differed even though the soil profiles indicated that the weathering processes that occurred were approximately the same. Representative rock samples of these flows were obtained and analyzed for the element in question. The results are compiled in table 2.

The volcanic flow underlying the area where the sample of Meyer Lake soil was dug is listed as being from the East Molokai volcanic series (19). This is predominantly andesite and is trachyte only in rare instances. According to Wager and Mitchell (22) andesite contains less than 2 ppm of chromium. The parent material of the Naiwa sample from Wailuku, Maui, was a trachyte, which upon analysis

was discovered to have 40 ppm of chromium. The flow underlying the Kokee area where the Naiwa sample was obtained is the Waimea Canyon volcanic series which is predominantly olivine basalt and picrite basalt of the oceanite type (9). The average amount of chromium in olivine basalts analyzed was 450 ppm, while picrite basalts averaged 1300 ppm of chromium.

Basaltic andesite was predominant in the flow underlying the Maui Haiku soil analyzed (18). A volcanic rock sample of basaltic andesite was found to have 56 ppm of chromium. The Haiku family soil from Lihue was taken from an area where the parent material is a melilite nepheline basalt with a chromium content of about 610 ppm. The area where the Haiku soil of Waipahi, Kauai, was obtained was covered by the flow from the Koloa volcanic series, which contains olivine basalt, picrite basalt of the ankaramite type, and nepheline basalt (9). The chromium content of these basalts ranges from 450 ppm to 1300 ppm.

A definite correlation between the parent material and the accumulation of chromium was seen when the parent materials were compared in the instances above.

Relation of weathering to chromium accumulation

Among the elements analyzed and listed by Grange *et al.* (6) in their tables accompanying their soil survey report of the Lower Cook Island Group was chromium. They list the element as being present in most of their soils. The chemical analysis of the soil profiles compiled by Grange *et al.* indicates that the concentrations of chromium are correlated to the degree of weathering the soils have undergone. Since the islands of the Lower Cook Group were formed from basaltic flows in essentially the manner that the Hawaiian Islands were formed, an attempt was made to discover a possible correlation between chromium accumulation and weathering in Hawaii and the Cook Islands. Since Grange *et al.* state that the soils of the Cook Islands were formed through laterization, particular attention was directed toward studying the latosols of Hawaii to note any correlation between chromium in the Cook soils and the Hawaiian latosols.

The soil samples in the Low Humic Latosol group were found to generally contain the lowest concentrations of chromium among the great soil groups. Cline *et al.* (4) in their analysis have considered that the clay minerals in this group are kaolinitic and therefore have not been subjected to as intensive weathering as the other latosol group soils. However, the lower three horizons of the Kahana soil samples from Anahola, Kauai, were discovered to average approximately 1900 ppm of chromium. This may partially be accounted for by the fact that the lower layers were buried soils. Chromium was present in a higher concentration in the Kohala family soil from Lawai, Kauai, than in the other Low Humic Latosol soils. Cline *et al.* describe the Kohala family as being subjected to certain conditions such as higher rainfall which tend to make it lapse into the Humic Latosol group in certain respects such as the accumulation of oxides.

The Humic Latosol group is described by Cline *et al.* as having been subjected to greater weathering than the Low Humic Latosols. The accumulation of chromium in this group of soils, when compared with the accumulation of the element in the

Low Humic Latosols, falls into the general pattern suggested by the tables compiled by Grange *et al.* (6).

Although the Hydrol Humic Latosol soil is probably the most highly weathered soil in a continuously wet area, the chromium content approximated 1000 ppm, slightly higher than that of the soils in the Humic Latosol group. When the degrees of weathering in the two soil groups are considered, the Hydrol Humic soils showed a relatively lower total of chromium accumulation. Although it is possible that the intensive weathering process in the Hydrol Humic Latosols could have leached some of the element out of the soil profile, this possibility has not been established yet. Another explanation may lie in the fact that the parent material of the Hydrol Humic soils which were analyzed was andesitic ash, which is low in chromium; whereas, olivine basalt predominated as the parent material of the Humic Latosol soils analyzed.

Cline *et al.* (4) have described the Humic Ferruginous Latosol as being a highly weathered soil group concentrating oxides of iron and titanium. As noted previously, the highest concentrations were found in some of these soils. The chromium concentrations in the soil profiles of this group have also shown strong horizon differentiation coinciding with the stratification of the iron and titanium oxides.

The unexpected variations in the Naiwa family would appear to cast much doubt upon the consideration of weathering as an important factor in chromium accumulation. However, when the initial chromium content of the parent material is taken into account, there is no doubt that the weathering factor plays an important role. For example, in the Meyer Lake soil, the parent rock contained less than 2 ppm of chromium, but the highest horizon of concentration in the soil indicated 230 ppm of the element, an increase of 100 times the initial concentration. The Naiwa soil from Wailuku shows an increased concentration of 12 times the original, while the increase in the Kokee soil is 1 to 10.

Distribution of chromium in concretionary material

The concretionary materials analyzed were either bauxitic or ferruginous concretions. These samples were obtained in only two instances from the soil profiles that were analyzed, both of which were Kokee soil. In these instances it was found that the concretionary samples which were ferruginous, contained 2140 and 1860 ppm of chromium, respectively. The horizons where the concretions were found showed an accumulation of approximately 9000 ppm in both cases.

In the case where a ferruginous sample was obtained from the iron pan layers of a Haiku soil found at Lihue, Kauai, the chromium content was discovered to be lowest in the iron pan layer with only 465 ppm. The layers directly above and below the pan both contained approximately 900 ppm. The soil below the second iron pan registered the highest concentration, with 1110 ppm.

A bauxitic concretionary sample obtained by dehydrating a Hilo soil upon analysis showed 380 ppm of chromium, while the remaining fraction of dark soil material indicated double the chromium content of the gibbsitic aggregate, with a reading of 740 ppm.

In the other instances where the samples were obtained from related soils in locations other than where the soil samples themselves were dug, the relationship between the chromium found in the concretionary samples and in the soils approximated the ratio found in the Kokee soil. This held true whether the samples were ferruginous or bauxitic.

With a few exceptions, chromium distribution throughout the profiles of the soil samples was found to be fairly constant in the Low Humic Latosols, the Humic Latosols, and the Hydrol Humic Latosols. In these exceptional profiles the highest concentrations occurred in the A horizons. In the Humic Ferruginous profiles, the horizons where the heavy minerals were accumulated showed the highest concentrations of chromium. The foregoing pattern of trace element distribution tends to indicate chromium to be a residual element where weathering is concerned. In the analysis of the concretionary materials, it was learned that the concretions themselves contained lower amounts of chromium than the surrounding soils, furnishing further proof of the residual property found above. When the mobile aluminum or iron precipitates into concretionary materials, the relatively immobile chromium present in the soil probably is entrapped in the concretions. If chromium possessed the same mobile qualities of iron and aluminum, the concretions would in all probability contain higher concentrations of the element than the surrounding soil.

SUMMARY

The Hawaiian soils of the latosol groups, rocks representing the parent material of the soils, and concretionary weathering products were analyzed for chromium. The presence of the element was indicated in all of the analyzed samples. The chromium content of the soils ranged from 230 ppm to 9000 ppm. The analyzed parent materials contained from 40 to 1400 ppm and the concretionary products ranged in content from 380 to 2140 ppm of chromium.

The chemical analysis table in Grange's soil survey of the Lower Cook Island Group (6) showed the chromium content to be higher in the more highly weathered soils. The soil samples analyzed in the course of this investigation generally followed the pattern of correlation between chromium concentration and intensity of weathering found by Grange. However, there were several samples with unexpectedly low amounts of chromium in view of the fact that the soils were considered to be intensely weathered. The unusually low concentrations, unaccountable through weathering alone, were in part explained by the extremely small amounts of the element that were present in the parent materials. A definite correlation between the parent material and the concentration of chromium in the soil was noted.

The correlation between weathering and the accumulation of chromium was definitely affirmed by the analyses of the latosols of the Hawaiian Islands. Weathering in itself, however, cannot account for the amount of the element present in the soil since parent material and the physico-chemical properties of the element are responsible to a certain degree for accumulation. Chromium possesses properties which make it a residual weathering element and allow its accumulation in the soil.

APPENDIX

TABLE 1. The chromium content of typical soil profiles of the latosols of the Hawaiian Islands

GREAT SOIL GROUP	SOIL FAMILY	LOCATION	AVERAGE RAINFALL, inches	DEPTH, inches	CR (VI) PPM		
Low Humic Latosol	Molokai	Kunia, Oahu	24	0-8	560		
				8-24	560		
				24-36	660		
	Lahaina	Waialua, Oahu	35	0-6	620		
				6-11	550		
				11-18	600		
	Wahiawa	Poamoho, Oahu	40	18-22	620		
				0-10	380		
				10-21	500		
	Kahana	Waimea, Oahu	40	21-42	470		
				42+	500		
				0-1	800		
				1-6	955		
				6-10	410		
				10-24	480		
				24+	535		
				Anahola, Kauai	50	0-9	965
						9-18	960
18-21						920	
21-28						990	
28-34						1515	
34-52	2125						
Kohala	Lawai, Kauai	65	52+	1700			
			0-10	1490			
			10-15	1085			
			15-20	1175			
			20-26	1210			
Humeic Latosol	Kaneohe	Kaneohe, Oahu	65	26-44	1180		
				0-8	1015		
Honolua	Helemano, Oahu	80	8-24	985			
			24-34	1065			
			0-6	725			
Hydrol Humic Latosol	Hilo	Hilo, Hawaii	145	18+	760		
				0-8	1135		
	Akaka	Akaka Falls, Hawaii	225	8-40	1000		
				28-32*	495		
				0-12	980		
				12-24	880		
				24-32	1015		
32-38*	460						
38-56	1175						
Humic Ferruginous Latosol	Mahana	Windward Lanai, Lanai	34	0-6	1145		
				6-15	1470		
				15-21	1405		
				21-40	1425		
				40-48	1135		
				48+	935		

*Dark organic layer.

(continued)

TABLE 1. The chromium content of typical soil profiles of the latosols of the Hawaiian Islands
(continued)

GREAT SOIL GROUP	SOIL FAMILY	LOCATION	AVERAGE RAINFALL, inches	DEPTH, inches	CR (VI) PPM
Humic Ferruginous Latosol (continued)	Naiwa	Kokee, Kauai	35	0-3	3180
				3-5	8840
				5-11	9290
				11-13	5050
				13-27	1906
	Wailuku, Maui	50		27+	4260
				0-8	340
				8-14	500
				14-20	400
				20-40	400
				40	175
				rock core	100
				0-12	230
				12-20	215
				20-34	130
	Haiku	Haiku, Maui	70	34+	155
				0-8	690
				8-14	745
				14-17	560
				17-26	495
Lihue, Kauai		65		26-42	490
				42+	325
				0-8	1880
				8-14	1200
				14-22	1170
Waipahi, Kauai	150		22-34	1385	
			34+	1375	
			0-4	2320	
			4-20	5040	
			20-30	1880	
			30+	1950	

TABLE 2. The chromium content of some rocks of the Hawaiian Islands

ROCK	LOCATION	CR (VI) PPM
Picrite basalt, ankaramite type	Waikolu valley, Molokai	815
Picrite basalt, oceanite type	Kunia Road, Oahu	1455
	Kunia Road, Oahu	1300
Picrite basalt	Mauna Loa, Hawaii flow of 1852	1100
Olivine basalt	Mauna Loa, Hawaii flow of 1950	400
Basalt	Kapoho, Hawaii flow of 1955	125
Andesitic basalt	Haleakala, Maui	55
Trachyte	West Maui	40
Latite	West Maui	50
Melilite nepheline basalt	Hanalei, Kauai	610
	Moiliili quarry, Oahu	360

TABLE 3. Concretionary products of some of the soils of the Hawaiian Islands

DESCRIPTION	LOCATION	SOIL FAMILY	CR (VI) PPM
Magnetic iron oxide aggregates	Kokee, Kauai	Naiwa	2140
Iron oxide aggregates	Kokee, Kauai	Naiwa	1860
	Kilauea, Kauai	Haiku	1400
Iron pan layers	Lihue, Kauai	Haiku	
A. layer above 1st Fe pan			910
B. Fe pans			465
C. layer just below Fe pans			940
D. soil between Fe pans			800
E. soil below 2nd Fe pan			1110
Gibbsitic aggregates	Hilo, Hawaii	Hilo	380
Dark soil material	Hilo, Hawaii	Hilo	740
Bauxitic aggregates	Hanalei, Kauai	Haiku	1100
	Lihue, Kauai	Haiku	250

LITERATURE CITED

- BENNETT, H. H. AND R. V. ALLISON.
1928. THE SOILS OF CUBA. Tropical Plant Research Foundation. Washington, D. C.
- BIRRELL, K. S., F. T. SEELYE, AND L. I. GRANGE.
1939. CHROMIUM IN SOILS OF WESTERN SAMOA AND NIUE ISLAND. N. Z. J. Sci. and Tech. 21: 2A, 91A-95A.
- AND A. C. S. WRIGHT.
1945. A SERPENTINE SOIL IN NEW CALEDONIA. N. Z. J. Sci. and Tech. 27: 72-76.
- CLINE, M. G., *et al.*
1955. SOIL SURVEY OF THE TERRITORY OF HAWAII. U.S.D.A. Series 1939, No. 25.
- FUJIMOTO, G., G. DONALD SHERMAN, AND A. E. CHANG.
1948. THE CHEMICAL COMPOSITION OF THE SEPARATED MINERAL FRACTIONS OF A FERRUGINOUS HUMIC LATOSOL PROFILE. Soil Sci. Soc. Amer. Proc. 13: 166-169.
- GRANGE, L. I., J. P. FOX, F. T. SEELYE, R. H. ARBUCKLE, AND A. VALK.
1953. SOILS OF THE LOWER COOK GROUP. New Zealand Dept. of Sci. & Industrial Res. Soil Bureau Bul. 8.
- HILLEBRAND, W. F., G. E. F. LUNDELL, H. A. BRIGHT, AND J. I. HOFFMAN.
1953. APPLIED INORGANIC ANALYSIS. Second Edition. John Wiley and Sons, Inc., New York.
- HOUGH, J., Z. C. FOSTER, AND P. L. GILE.
1941. ROCK WEATHERING AND SOIL PROFILE DEVELOPMENT IN THE HAWAIIAN ISLANDS. U.S.D.A. Tech. Bul. 752.

9. MACDONALD, G. A.
1949. HAWAIIAN PETROGRAPHIC PROVINCE. *Bul. Geol. Soc. Amer.* 60: 1541-1596.
10. ROBINSON, W. O.
1914. THE INORGANIC COMPOSITION OF SOME IMPORTANT AMERICAN SOILS. U.S.D.A. Bul. 122.
11. ———, G. EDINGTON, AND H. G. BYERS.
1935. CHEMICAL STUDIES OF INFERTILE SOILS DERIVED FROM ROCKS HIGH IN MAGNESIUM AND GENERALLY HIGH IN CHROMIUM AND NICKEL. U.S.D.A. Tech. Bul. 471.
12. SANDELL, E. B.
1936. DETERMINATION OF CHROMIUM, VANADIUM AND MOLYBDENUM IN SILICATE ROCKS. *Ind. Eng. Chem., Anal. Ed.* 8: 336-341.
13. ———.
1950. COLORIMETRIC DETERMINATION OF TRACES OF METALS. Second Edition. Interscience Publishers Inc., New York.
14. SEELYE, F. T., L. I. GRANGE, AND L. H. DAVIS.
1938. THE LATERITES OF WESTERN SAMOA. *Soil Sci.* 46: 23-31.
15. SHERMAN, G. DONALD, Z. C. FOSTER, AND C. K. FUJIMOTO.
1948. SOME OF THE PROPERTIES OF THE FERRUGINOUS HUMIC LATOSOLS OF THE HAWAIIAN ISLANDS. *Soil Sci. Soc. Amer. Proc.* 13: 471-476.
16. ———, J. FUJIOKA, AND G. FUJIMOTO.
1955. TITANIFEROUS FERRUGINOUS LATERITE OF MEYER LAKE, MOLOKAI, HAWAII. *Pac. Sci.* 9: 49-55.
17. SLATER, C. S., R. S. HOLMES, AND H. G. BYERS.
1937. TRACE ELEMENTS IN THE SOILS FROM THE EROSION EXPERIMENT STATION WITH SUPPLEMENTARY DATA ON OTHER SOILS. U.S.D.A. Tech. Bul. 552.
18. STEARNS, H. T. AND G. A. MACDONALD.
1942. GEOLOGY AND GROUND-WATER RESOURCES OF THE ISLAND OF MAUI, HAWAII. *Div. Hydrog. Bul.* 7.
19. ——— AND ———.
1947. GEOLOGY AND GROUND-WATER RESOURCES OF THE ISLAND OF MOLOKAI, HAWAII. *Div. Hydrog. Bul.* 11.
20. SWAINE, D. J.
1955. THE TRACE-ELEMENT CONTENT OF SOILS. Commonwealth Bur. of Soil Sci. Tech. Communication No. 48.
21. VAN DER MERWE, A. J. AND F. G. ANDERSEN.
1937. CHROMIUM AND MANGANESE TOXICITY. Is it important in Transvaal citrus growing? *Fmg. in S. Afr.* 12: 439-440.
22. WAGER, L. R. AND R. L. MITCHELL.
1953. TRACE ELEMENTS IN A SUITE OF HAWAIIAN LAVAS. *Geochim. et Cosmochim. Acta* 3: 217-223.

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