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9. ABSTRACT

The soils examined in this study were subsoil samples collected in Hawaii. The soils classified as Oxisols and Ultisols contain varying amounts of kaolin clays and hydrous oxides of iron and aluminum. The great group, Eutrandepts of the order Inceptisols, consists of slightly to moderately weathered volcanic ash, while the great group Hydrandepts consists of highly weathered volcanic ash with decidedly more amorphous oxides of iron and aluminum, and is highly hydrated. The Vertisols are composed predominantly of montmorillonitic clays. The higher water-holding capacity of Oxisols and Ultisols, compared to that of the Vertisols and Inceptisols at 15 bars of suction, is attributed to the presence of intra-aggregate void spaces. The existence of such voids was verified with the aid of a scanning electron microscope. These voids are obvious in soils with kaolinitic and oxidic mineralogy, but are not evident in soils of montmorillonitic or amorphous oxide composition.

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Influence of Soil Microstructure on Water Characteristics of Selected Hawaiian Soils

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Influence of Soil Microstructure on Water Characteristics of Selected Hawaiian Soils[1]

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ABSTRACT

The higher water-holding capacity of Oxisols and Ultisols compared to that of the Vertisols and Inceptisols at 15 bars of suction is attributed to the presence of intra-aggregate void spaces. Existence of such voids was verified with the aid of a scanning electron microscope. These voids are obvious in soils with kaolinitic and oxidic mineralogy but are not evident in soils of montmorillonitic or amorphous oxide composition.

Additional Index Words: **soil water characteristics, intra-aggregate voids.**

SOIL COMPOSITION, pore-size distribution and temperature govern the retention of water in soil. Amounts of inorganic and organic constituents determine differences in soil composition. The influence of inorganic constituents on water retention can be established by studying soils of different mineralogical composition.

The pore-size distribution of a soil, in most instances, can be predicted from particle-size distribution or soil texture. However, for some Hawaiian soils, the laboratory determination of particle-size distribution does not always correspond to the apparent field texture. This is particularly true for the Oxisols and Ultisols. For example, particle-size analyses by Kawano and Holmes (1958) showed some Latosols (Oxisols and Ultisols) to be clays, but their water-release characteristics were similar to material of coarser texture at low suctions (Sharma and Uehara, 1968). Hence reliance must be placed on physical properties other than on texture if we are to predict the water characteristics of these soils.

Methods of Kawano and Holmes (1958), Uehara et al. (1962), and Cagauan and Uehara (1965) have been used to study the soil macrostructure or the inter-aggregate arrangement of solids and voids. The existence of inter-aggregate voids in Hawaiian soils was first reported by Cagauan and Uehara (1965). Later, Sharma and Uehara (1968) demonstrated how influential both inter- and intra-aggregate voids were on the water characteristics of two Hawaiian Oxisols. The rapid release of water at low suctions and the high water content at higher suctions were attributed to the presence of inter-aggregate and intra-aggregate voids, respectively. However, no observable evidence has been presented to substantiate the size, shape and arrangement of such intra-aggregate voids.

In this work, the soil microstructure or intra-aggregate arrangement of solids and voids was studied with the scanning electon microscope (SEM). Differences, if any, in the microstructure between soils were recorded on photomicrographs and were related to differences in the water characteristics of each soil. Soils classified as Oxisols, Ultisols, Vertisols, and Inceptisols were used in this study.

MATERIALS AND METHODS

Soils

The soils of this study, listed in Table 1, were collected from the islands of Oahu and Hawaii. All of the samples were subsoils. Selection of these soils were based on (i) their differences in chemical, physical, and mineralogical composition and (ii) their agricultural importance to the State of Hawaii.

Soils classified as Oxisols and Ultisols contain varying amounts of kaolin clays and hydrous oxides of iron and aluminum. The great group, Eutrandepts of the order Inceptisols, consists of slightly to moderately weathered volcanic ash, while the great group, Hydrandepts, consists of highly weathered volcanic ash with decidedly more amorphous oxides of iron and aluminum than the former, and is highly hydrated. The Vertisols are composed predominantly of montmorillonitic clays.

Scanning Electron Microscope

A Cambridge Stereoscan S-4 scanning electron microscope (SEM) permitted examination of surface features of individual, intact soil aggregates at magnifications above the upper limit of light microscopes. Lynn and Grossman (1970) and Eswaran (1972) have used the scanning electron microscope to study different features and types of soil fabrics.

For scanning electron microscopy, air-dried aggregates were attached to aluminum support stubs using silver conducting paint and gold-coated by vacuum evaporation with a Denton DV-502 Vacuum Evaporator. The samples were photographed on Polaroid 55P/M film.

Outflow Measurements

The water content-suction relationships for the various soils were determined by employing two types of commercially available pressure plate outflow apparatus: (1) Tempe pressure cell and (2) 15-bar ceramic plate extractor. The Tempe pressure cells were used exclusively in the suction range of 0 to 1 bar. The ceramic plate extractor was used for suctions between 1 and 15 bars.

Except for the Akaka soil, which dries irreversibly, air dried soil samples were crushed and passed through a 2-mm sieve. The soil samples were placed on saturated porous ceramic plates and allowed to wet by capillarity for at least 24 hours. Mercury manometers and air pressure gauges were used to measure the imposed suction. Equilibrium between soil water and imposed suction was attained when water outflow from the soil sample ceased. In the case of the 15-bar ceramic plate extractor, the soil samples were removed and oven-dried at 105C.

Table 1—Classification of the selected soil samples. (Foote et al., 1972; Sato, et al., 197.)

Series	Depth	Order	Subgroup	Family
	cm			
Wahiawa	20-40	Oxisols	Tropeptic Eutrustox	clayey, kaolinitic, isothermic
Molokai	20-40	Oxisols	Typic Torrox	clayey, kaolinitic, isohyperthermic
Manana	53-86	Ultisols	Orthoxic Tropohumult	clayey oxidic, isothermic
Paalua	66+	Ultisols	Humoxic Tropohumult	clayey, oxidic, isothermic
Lualualei	3-38	Vertisols	Typic Chromusterts	very fine, montmorillonitic, isohyperthermic
Akaka	8-18	Inceptisols	Typic Hydrandepts	thixotropic, isomesic
Waimea	59-94	Inceptisols	Typic Eutrandepts	medial, isothermic

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[2] Assistant Soil Scientist, Assistant Specialist in Soil Science, and Assistant Soil Scientist, respectively, Univ. of Hawaii.

to determine their water content. For the Tempe pressure cells, the entire cell with soil and water was weighed after each equilibrium step (Reginato and van Bavel, 1962). The net difference between the initial and equilibrium weights was used as a measure of water content at a given suction. The final water content at 1 bar was obtained by oven-drying the soil sample at 105C.

RESULTS AND DISCUSSION

Oxisols and Ultisols

The rapid release of water at low suctions and the relatively high water-holding capacity of Hawaiian Oxisols is evident when the water characteristic curves for these soils are examined (Fig. 1). Except for small differences in bulk density, field cores and laboratory-packed cores had similar water release curves (G. Y. Tsuji, 1967 Measurement and evaluation of soil water transmission coefficients in some Hawaiian latosols. M.S. thesis. University of Hawaii, Honolulu). Sharma and Uehara (1968) concluded that water released at low suctions was associated with inter-aggregate void spaces while that retained by the soil at higher suctions was held in intra-aggregate void spaces. The inter-aggregate arrangement of solids and voids in the Molokai and Wahiawa soils was previously shown with soil thin sections by means of a polarizing microscope by Cagauan and Uehara (1965) and Sharma and Uehara (1968). However, the intra-aggregate arrangement of solids and voids was not immediately obvious.

Figures 2A and 2B are scanning electron micrographs of the Wahiawa and Molokai soil aggregates, respectively. The microstructure or intra-aggregate arrangement of void spaces between soils is distinctly different. An array of voids of different sizes is more clearly evident in the Wahiawa than in the Molokai soil. This result is not unexpected since earlier results have shown that the Molokai had a higher bulk density than the Wahiawa (Kawano and Holmes, 1958). Furthermore, a bimodal distribution of void sizes indicating soil aggregation becomes apparent when the method of Childs and Collis-George (1950) is applied to the water characteristic data of Sharma and Uehara (1968). From Fig. 3 it is evident that the Wahiawa has a decidedly higher frequency of intra-aggregate voids than the Molokai. If the capillary-rise equation is assumed to be applicable to the present soil-water system, then it can be used to calculate approximate suction values at which water is released from voids such as those in Fig. 2. Hence, the greater water-holding capacity for the Wahiawa over that for the Molokai for suctions > 0.2 bars indicates the influence of the intra-aggregate voids on water retention.

The presence of distinct intra-aggregate voids in the Wahiawa was attributed to the degree of its structural development or soil anisotropy. According to Cagauan and Uehara (1965), Oxisols with strongly developed structure (Wahiawa) are found in high rainfall areas whereas those with weakly developed structure (Molokai) are found under low rainfall conditions. Such structural developments would suggest that soils of similar mineralogical composition, as these Oxisols, but developed under higher rainfall may exhibit stronger microstructural development.

To test the above hypothesis, two soils classified as Ultisols were examined. These soils, Manana and Paaloa, were

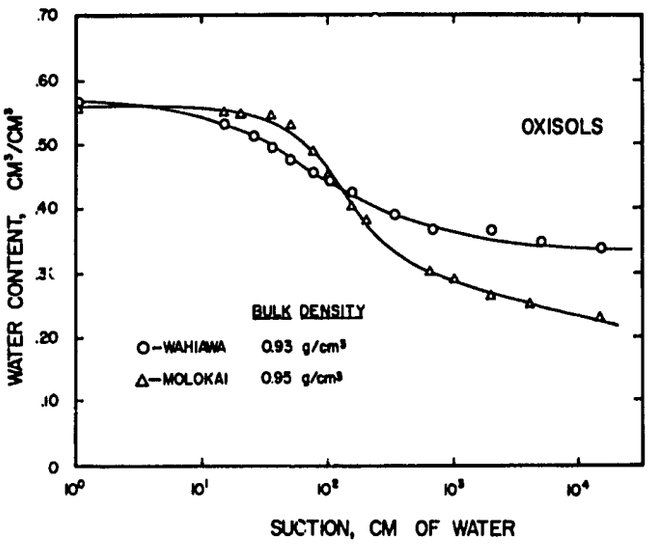

Fig. 1—Soil water characteristic curves for Wahiawa (Tropeptic Eutrustox) and Molokai (Typic Torrox) soils.

formed under higher and more uniformly distributed rainfall than the Wahiawa. Water characteristic curves of these soils, shown in Fig. 4, are remarkably similar to that for the Wahiawa. Water held in the inter-aggregate voids are released at suctions of approximately 200 cm of water. As in the Oxisols, soil water contents of > 0.20 to 0.30 at 15 bars and beyond can most likely be attributed to the microstructure or intra-aggregate voids. Examination of individual aggregates under the SEM (Fig. 2C and 2D) revealed a much more porous body with regularly shaped intra-aggregate voids of more uniform size than those observed in the Oxisols. These intra-aggregate voids are of such radial dimensions that water contents of > 0.30 at suctions > 15 bars is not unreasonable.

The mineralogical composition appears to be the most obvious common denominator between the Oxisols and Ultisols. At the family category (Soil Survey Staff, 1970), the Wahiawa and Molokai soils are classified as clayey, kaolinitic, isothermic and clayey, kaolinitic, isohyperthermic, respectively. The Paaloa and Manana are both classified as clayey, oxidic, isothermic (Foote et al., 1972). Mineralogically, the Ultisols have more oxides of iron and aluminum and less kaolin clays than the Oxisols. However, the clay texture appears to be misleading when the pore size distribution is evaluated from measured water characteristic curves such as those in Fig. 1 and 4. In fact, the Oxisols and Ultisols behave like material of coarse texture

Table 2—Soil texture data of the selected soil series

Soil series	Sand (0.05-2 mm)	Silt (0.002-.05 mm)	Clay (0.002 mm)
Wahiawa*	0.3	5.5	94.2
Molokai*	1.6	15.7	82.7
Manana	0.1	7.2	92.7
Paaloa	10.2	28.5	61.3
Lualuaiei*	2.6	32.9	65.2
Akaka†	4.6	11.1	10.0
Wairea‡	3.0	21.0	24.0

* A. A. Briones, 1969. Physics of drained paddy soils. Ph. D. diss. University of Hawaii, Honolulu. Diss. Abstr. no. 70-43060.
† H. H. Tenma, 1965. Some characteristics of non-crystalline constituents in Hawaiian soils. M.S. thesis. University of Hawaii, Honolulu.
‡ K. H. Houng, 1964. A study on the soils containing amorphous materials on the Island of Hawaii. Ph. D. diss. University of Hawaii, Honolulu. Diss. Abstr. no. 64-119120.

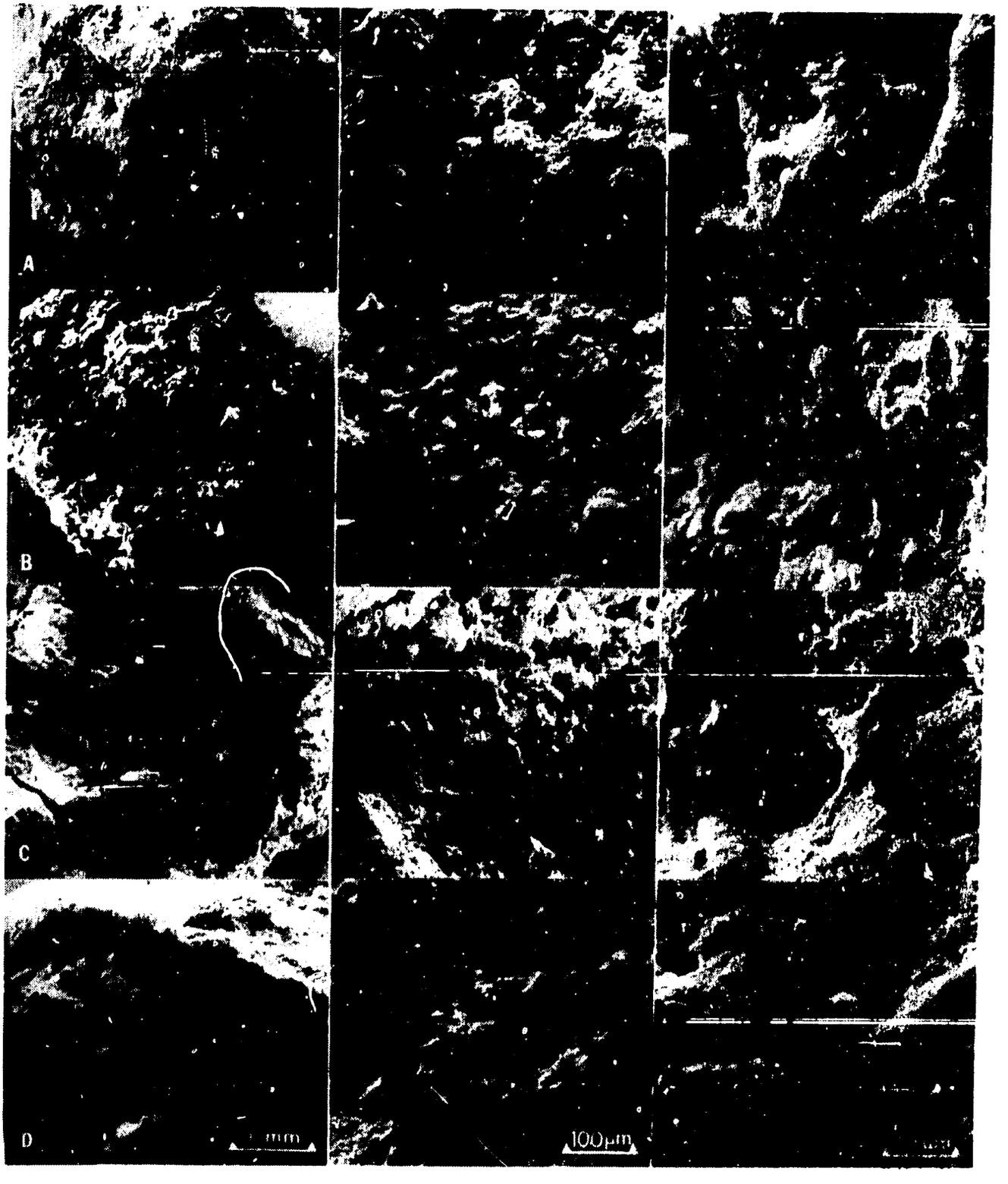

Fig. 2—Scanning electron micrographs of the (*A*) Wahiawa, (*B*) Molokai, (*C*) Paaloa, and (*D*) Manana soil aggregates.

at low suctions and retain water in a similar fashion to clay soils at high suctions. Field determination of soil texture appears to be more indicative of the pore-size distribution. Field descriptions of these soils place them in the silty clay or silty clay loam class. Textural data, listed in Table 2, were obtained from soils out of the same sample container as those used in the present study.

Hence, it is apparent that mineralogical composition and soil structure, in relation to the development of inter- and intra-aggregate void spaces, rather than texture would be

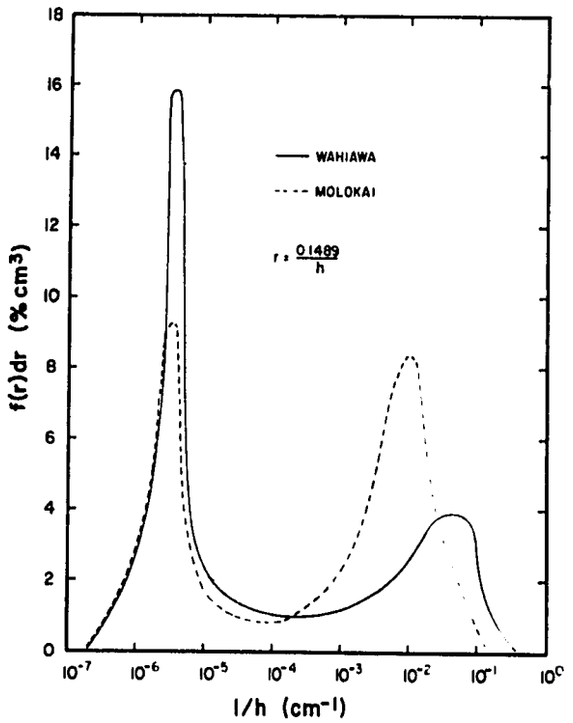

Fig. 3—Frequency distribution of inter- and intra-aggregate void sizes in the Wahiawa and Molokai soils.

better predictive parameters of the water-holding characteristic of these soils.

Vertisols and Inceptisols

The influence of mineralogical composition and soil structure on soil water release characteristics can be examined further by considering soils in Orders where mineralogical composition is distinctly different from those of the Oxisols and Ultisols. Vertisols and Inceptisols are in that category.

Water release characteristics of two Inceptisols (Akaka and Waimea) and a Vertisol (Lualualei) are shown in Fig. 5 and 6. The water content value is based on the initial volume of soil and water at zero suction. At suctions > 300 cm of water, the water release curves of both the Laulualei and Akaka soils are influenced by the effect of shrinkage. This is especially true for the Akaka, a Typic Hydrandept, which shrank by as much as 50% in volume. On the other hand, shrinkage in the Waimea soil, a Typic Eutrandept, was negligible and its water release curve strongly resembled that of a sand of uniform particle size.

SEM micrographs of both the Akaka and Waimea soils (Fig. 7A and 7B) reveal differences in their matrix. At the family category, the texture of the Akaka soil is classified as being thixotropic while that of the Waimea is medial. Because of its thixotropic nature, the structural arrangement of air-dried particles in Fig. 7A should not be construed to be representative of the Akaka. Unconsolidated porous fragments appear to predominate in the Waimea

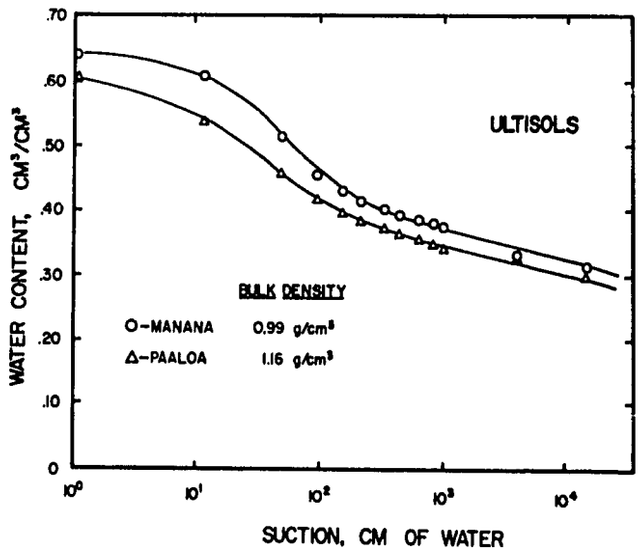

Fig. 4—Soil water characteristic curves for Manana (Orthoxic Tropohumult) and Paaloa (Humoxic Tropohumult) soils.

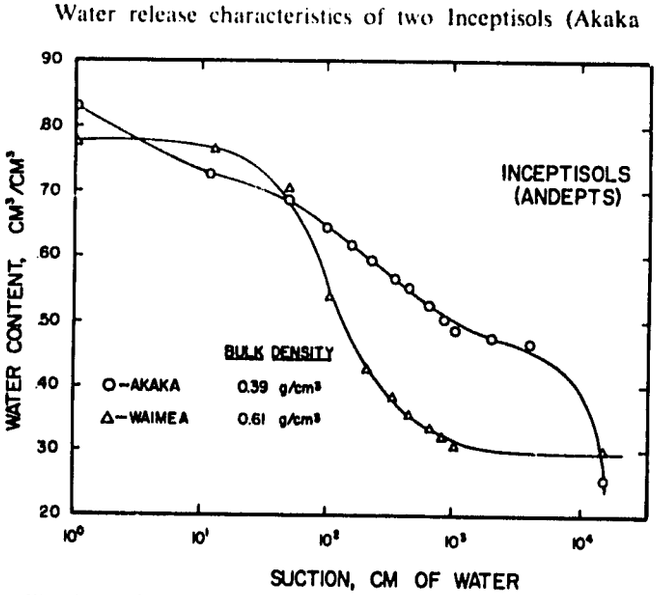

Fig. 5—Soil water characteristic curves for Akaka (Typic Hydrandept) and Waimea (Typic Eutrandept) soils.

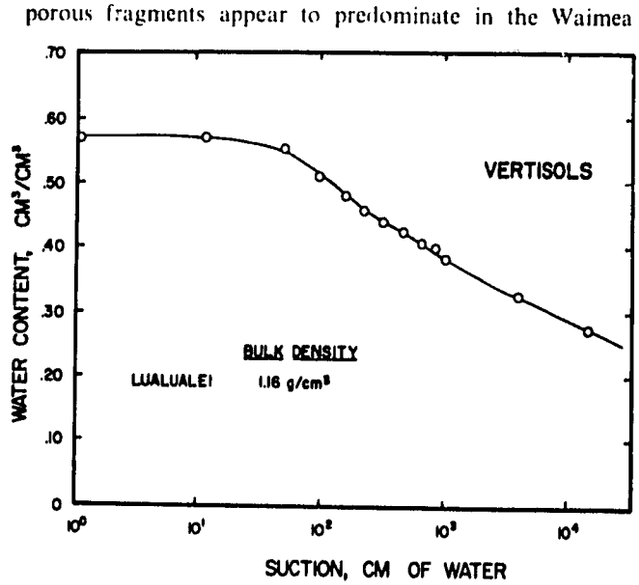

Fig. 6—Soil water characteristic curves for Lualualei (Typic Chromusterts) soil.

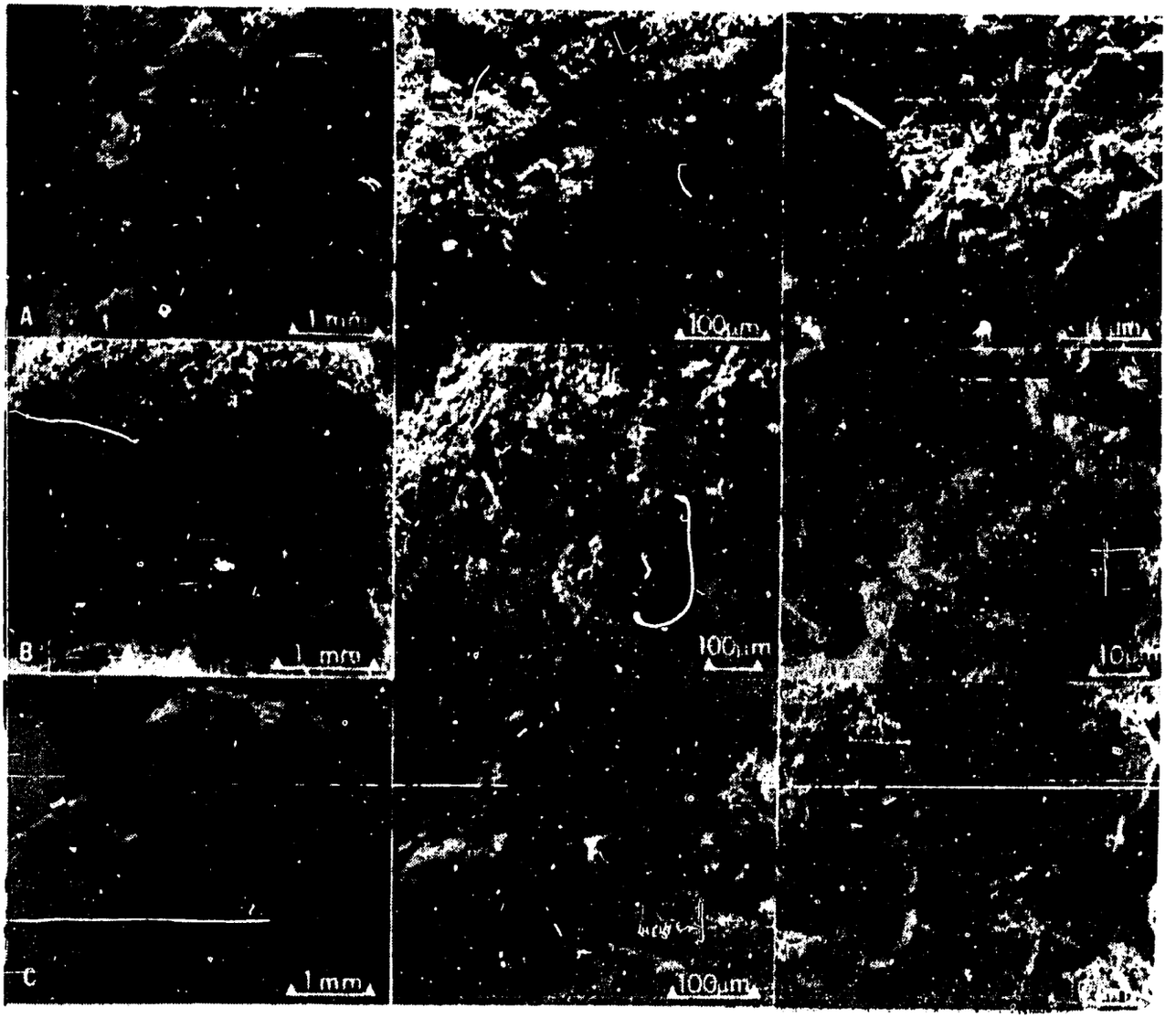

Fig. 7—Scanning electron micrographs of the (*A*) Akaka, (*B*) Waimea, and (*C*) Lualualei soil aggregates.

soil. For these two Inceptisols, textural differences rather than mineralogical composition determined their water-retention capacity. The sum total of both organic matter and free iron oxide contents amounted to 35.7% and 12.7% for the Akaka and Waimea soils, respectively. Addition of both values to the total separates content yielded a value of < 100%. The difference was attributed primarily to the loss of water of hydration associated with oxides of iron and aluminum (H. H. Tenma, 1965. Some characteristics of non-crystalline constituents in Hawaiian soils. M.S. thesis. Univ. of Hawaii, Honolulu).

The influence of montomorillonitic mineralogy should have an overriding effect on the water-holding characteristics of the Lualualei. The water release curve of the Lualualei (Fig. 6) is not typical of most Vertisols which generally show smaller changes in slope with increasing suction. The reason for this behavior may be explained, in part, by the accumulation of stable clay granules or aggregates in the upper horizons of the Lualualei due to the excessive shrinkage of clay by the sun's heat in the arid climate of the sample source. SEM photomicrographs (Fig. 7C) do not show any obvious intra-aggregate voids as those found in the Oxisols and Ultisols.

It may be surmised that the water-holding capacity of the Oxisols and Ultisols at 15 bars of suction can be attributed to the presence of intra-aggregate voids. These voids were obvious in soils with kaolinitic and oxidic mineralogy but were not evident in soils with montmorillonitic or amorphous oxide mineralogy. It appears then that mineralogical composition plays an influential role in the development of soil microstructure. Furthermore, because of this type of structural development, soil texture data alone are not sufficient to predict the pore-size distribution of the Oxisols and Ultisols considered in this study. Similarly, the use of 15-bar water content data to predict clay content for these soils would most likely be erroneous. For example, if the estimate of clay content were computed according to the relationship of 2.5 times the 15-bar water content, as used

by the Soil Conservation Service (1972), clay contents of 84.3%, 57.5%, 75.0%, and 77.5% would be obtained for the Wahiawa, Molokai, Paaloa and Manana, respectively. These values are very different from those listed in Table 2. The influence of these intra-aggregate voids on water infiltration in Oxisols and Ultisols presents an interesting problem that will be a subject of further investigation.

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