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CHARACTERISTICS OF THE VANUATU ANDOSOLS

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SUMMARY

The andosols of the Vanuatu Archipelago are deriving from recent volcanic ashes and lapilli, under a tropical climate. There are four main groups of andosols: vitric (Vitrandepts), base-saturated (Eutrandepts), base-unaturated (Dystrandepts) and perhydrated (Hydrandepts).

This paper summarizes the main characteristics of each group and it emphasizes their diagnostic criteria. These are: for the first two groups, the richness in silica of the weathering products and a rather weak or moderate water and phosphorus retention-capacity: for the last two groups, the richness in alumina of the weathering products and a high water and phosphorus retention-capacity. Other diagnostic criteria have been selected, like: the dehydration-irreversibility and △ CEC ratios, the bulk density, the Al-oxalate content and the base-saturation ratio. Among them the first two are the most note-worthy.

RESUME

Les andosols de l'Archipel du Vanuatu sont dérivés de cendres et lapilli volcaniques récents, en climat tropical. Il y en a quatre groupes principaux: vitriques (Vitrandepts), saturés en bases (Eutrandepts), désaturés en bases (Dystrandepts) et perhydratés (Hydrandepts).

Cet article résume les caractéristiques majeures de chaque groupe et il met en relief leurs critères diagnostics. Ce sont: pour les deux premiers, la richesse en silice des produits d'altération et une capacité de rétention pour l'eau et le phosphore plutôt faible ou modérée; pour les deux autres groupes, la richesse en alumine des produits d'altération et une capacité élevée de rétention pour l'eau et le phosphore. D'autres critères diagnostics ont été sélectionnés, tels que: les taux de déshydratation irréversible et de △ CEC, la densité apparente, l'extrait d'Al-oxalate et le taux de saturation en bases, parmi lesquels les deux premiers sont les plus remarquables.

RESUMEN

Los andosols del Archipiélago de Vanuatu provienen de cenizas y escorias volcánicas recientes, en un ambiente tropical. Se distinguen cuatro groupos principales: vítricos (Vitrandepts), saturados en bases cambiables (Eutrandepts), desaturados en bases cambiables (Distrandepts) y perihidratados (Hidrandepts).

En este papel se compendian las caracteristicas mayores de cada grupo y se hacen resaltar los criterios de diagnóstico de esos. Conviene destacar: en los dos primeros grupos, la riqueza en sílice de los productos de la meteorozación y una capacidad bastante debil o moderada de retención del agua y del fósforo; en los dos otros grupos, la riqueza en alumína de los productos de la mateorización y una fuerte capacidad de retención del agua y del fósforo. Otros criterios de diagnóstico han sido seleccionados, tal como: los porcentajes de deshidratación irreversibile, de △ CEC y de saturación en bases cambiables, la densidad aparente y el extracto de Al-oxalato, siendo más relevantes los dos primeros criterios.

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1. INTRODUCTION

The andosols of the Vanuatu are located in a tropical country, between 13° and 20° S Latitude, in the S.W. Pacific. They are found under a warm and wet climate. These soils have been deriving from recent (< 5,000 years) volcaniclastic materials, such as ash and lapilli. These materials are mainly basic and of basalt and andesite composition. We have observed the following four main groups of Andosols: 1. undifferentiated and vitric (Vitrandepts); 2. well differentiated and base-saturated (Eutrandepts); well differentiated, base-unsaturated and unperhydrated (Dystrandepts); well differenciated, base-unsaturated and perhydrated (Hydrandepts).

2. CHARACTERISTICS

The main characteristics of the four groups of Andosols have been summarized in the tables 1a, 1b, 1c.

Tab. 1a: MAIN CHARACTERISTICS OF THE 4 GROUPS OF ANDOSOLS (IN THE B HORIZON FOR THE GROUPS II, III AND IV).

Andosol-group	I Vitric	II eutric	III perhydric	IV dystric
Age of material / Years	< 1,000	1,000 - 2,000	2,000 - 5,000	2,000 - 5,000
Rainfall mm/y	> 2,000	1,800 - 4,000	> 4,000	2,500 - 4,000
Presence of (B) horizon	No	Yes	Yes	Yes
Bulk density g/cc	1.2 - 0.9	0.9 - 0.7	0.3	0.5 - 0.4
Primary minerals %	> 60	30 - 60	10 - 50	10 - 50
Organic matter A_1 %	> 1 / < 10	5 - 10	> 20	10 - 20
(B) %	–	1 - 5	2 - 4	1 - 4
< 2 μ fraction %	< 10	10 - 30	20 - 60	> 20

Tab. 1b: MAIN CHARACTERISTICS OF THE 4 GROUPS OF ANDOSOLS (IN THE B HORIZON FOR THE GROUPS II, III AND IV).

Andosol-group		I Vitric	II eutric	III perhydric	IV dystric
Secondary minerals		opal Si-allophane	Fe-allophane	Imogolite Gibbsite	Al-allophane
Amorphous products	Seg. %	< 15	11 - 24	25 - 55	> 20
(Al, Fe, Si) amount*	Oxal. %	< 8	6 - 13	15 - 39	> 15
	HCl %	< 5	5 - 10	18 - 31	> 10
Al_2O_3 oxalate** %		0.4 - 2.8	a: 1 - 5 b: 0.2 - 1	6 - 19	> 5
Allophanic clays %		< 5	5 - 10	15 - 30	> 10
SiO_2/Al_2O_3 mol. of < 2 μ fraction		> 3	> 2	⩽ 1	1 - 2
Specific surface area m^2/g of < 2 μ fraction		100 - 200	100 - 200	300 - 700	300 - 400

* Sum of amorphous Al, Fe and Si oxides extracted by Seg = Segalen method, Oxal = Tam reagent with U.V., HCl = 2 N HCl reagent.

** Al_2O_3 extracted by NH_4-oxalate pH 3.5 with U.V., infered from cumulative curve of 6 extracts. a: chromic subgroup; b: melanic subgroup.

Tab. 1c: MAIN CHARACTERISTICS OF THE 4 GROUPS OF ANDOSOLS (IN THE B HORIZON FOR THE GROUPS II, III and IV).

Andosol-group	I Vitric	II eutric	III perhydric	IV dystric
pH (H_2O)	~ 7	~ 7	~ 6	~ 6
ΔpH (H_2O - KCl)	–0.9 to –0.5	–1.0 to –0.5	–0.4 to + 0.2	–0.5 to –0.3
CEC (pH 7) me/100 g	< 15	20 - 40	10 - 30	15 - 25
ΔCEC (pH 9 - pH 4) ratio***	> 40	40 - 60	70 - 80	60 - 70
Base-Saturation ratio %	> 50	> 50	⩽ 10	20 - 50
Water-retention-capacity % ⅓b	< 45	40 - 85	100 - 300	80 - 130
(wet soil) 15b	< 25	20 - 60	80 - 240	50 - 100
Dehydration-irreversibility ratio**** %	> 40	40 - 60	75 - 90	50 - 73
P retention-capacity %	a: 0 - 8 b: 25 - 55	c: 65 - 85 d: 40 - 50	97 - 99	98 - 99
available P (Truog) ppm	⩾ 15	⩾ 50	0	0

*** $\frac{\Delta CEC\ (pH\ 9 - pH\ 4)}{CEC\ (pH\ 9)} \times 100$

**** $\frac{\Delta H_2O\ (⅓\ b)\ wet - air\ dried\ sample}{H_2O\ (⅓\ b)\ wet\ sample} \times 100$

2.1. VITRIC ANDOSOLS

The "vitric andosols" are very young soils which derive from less 1,000 years old volcaniclastic material. The weathering is slightly advanced and the soil profile is rather undifferentiated, although several layers of ash and lapilli are often superimposed. These soils consist essentially of one or several shallow humic horizons, containing 1-8% organic matter and 1-10% of $< 2\ \mu$ fraction.

The vitric andosols contain more than 60% of unweathered pyroclastic material, such as glass and microlites. Their weathering products are not made of clay minerals, except some eventual traces of halloysite and smectite, but only of amorphous or paracrystalline constituents, like allophane and opal. These products are very rich in silica, but very poor in alumina (mol. SiO_2/Al_2O_3 ratio > 3). Then, the silica and iron-rich form of allophane seems similar to hisingerite. The amount of estimated amorphous products is at most: 15 % by Segalen's method, 8% by oxalate extraction, or 5% by 2N HCl dissolution. In fact, the allophane content does not exceed 5% of whole soil.

The vitric andosols have the following main characteristics: a bulk density ~ 0.9 - 1.2; a light or even null reaction to the NaF test; a water-retention capacity (undried soil) < 45% at ⅓ bar and < 25% at 15 bars; a rate of dehydration-irreversibility after air-drying > 50%; a pH weakly acid in the topsoil (except in case of sulfuric fumaroles or very heavy rainfall), neutral or slightly alkaline in the depth; a CEC value < 25 me in A_1 horizon, or < 15 me/100 g in C horizons, but CEC/ $< 2\ \mu$ fraction $> >$ 1 me/1 g; a rate of Δ CEC 40%; a base-saturation ratio > 50% (except the soils under a perhumid climate or to windward of sulfuric fumaroles); available phosphorus (Truog's method) values fairly high $> >$ 15 ppm, which means a weak P-retention (25-55%).

These soils can be classified as Vitrandepts in the Soil Taxonomy (1975), or diverse vitric great groups or subgroups of Andisol Proposal (1978).

2.2. SATURATED ANDOSOLS

The "saturated andosols" are young soils. Their parent-material dates from the recent past, ~ 1,000 to 2,000 years ago. Its chemical composition is rather basic and rich in iron. These andosols are forming under a wet tropical climate, which comprises or not a short dry season, but is never perhumid (rainfall < 3,000 mm/y). Their profile is fairly well differentiated in A_1, (B) or B-C, and C horizons. But the (B) horizon is at an early stage of development (1-2 m) and the weathering is weakly advanced. Often, the soil is multiphase and made of a serie of successive (often 2 or 3, sometimes as many as 7) eruption deposits.

The upper humic horizon is 10-25 cm thick and very dark in colour; it contains 5-10% organic matter and 10-30% of < 2 μ fraction. The (B) horizon is brown or reddish-brown coloured; it contains 1-5% organic matter and 5-30% of < 2 μ fraction.

The mineral soil is still rich in weatherable primary minerals, the amount of which approximates 30-40 %. The weathering products are largely amorphous or paracrystalline, at least in the upper part of soil profile; although small quantities of clay minerals, such as halloysite in the wettest regions or beidellite in the driest zones, appear increasing toward the deeper part of soil or toward the drier climatic zone. The weathering products are very rich in silica, iron and basic cations, but rather poor in alumina (mol. SiO_2/Al_2O_3 ratio generally > 2). These products are rich in opal, such as diatom skeletons, phytoliths and micro-discs. In addition they contain an iron-rich allophane which is similar to hiseringite. But they have few iron oxy-hydroxides and no free alumina. The amount of amorphous products in the (B) horizon approximates: 11-24% (as Al, Fe and Si oxides) by Segalen's method, 6-13% by oxalate extraction or 5-10% by 2N HCl dissolution. In fact, the allophane content does not exceed 10% of whole soil.

The saturated andosols have the following main properties in the (B) horizon: a bulk density ~ 0.7 - 0.9; a fairly good reaction to the NaF test; a water-retention capacity (undried soil) ~ 40-85 % at ⅓ bar and ~ 20-60 % at 15 bars; a rate of dehydration-irreversibility ~ 40-60 %; a pH near 7 and Δ pH ~ 0.5 to 1.0; a CEC value ~ 20-40 me/100 g and CEC/ < 2 μ fraction > > 1 me/1 g; a rate of Δ CEC ~ 40-60 %; a base-saturation ratio > 50 %; available phosphorus (Truog's method) > 50 ppm, meaning a weak or moderate P-retention, < 85 %).

These soils can be classified as Eutrandepts in the Soil Taxonomy (1975). But, their taxonomic position in the Andisol Proposal (1978 or 1983) is not very clear; a mollic subgroup should be proposed for the Haplotropands (1978) or Tropudands and Haplustands (1983) great groups. We proposed in our classification proposal (Groupe de Travail Andosol, 1972) to subdivide the saturated andosols in: a chromic subgroup for the reddish-brown ones of the wetter zone and a melanic subgroup for the dark epipedon type of the drier zone. This latter type has a tendency to form beidellite clay minerals and then to have smaller values of both Δ CEC and dehydration-irreversibility rates.

2.3. PERHYDRATED ANDOSOLS

The "perhydrated andosols" are unsaturated and very hydrated soils. They are still

young soils, but at a more advanced stage of weathering than the vitric or saturated andosols. Their parent-material dates several thousand years; but it is generally less 5,000 years old and often rejuvenated by recent ash-falls in the topsoil. Moreover, the climate is perhumid (rainfall > 4000 mm/y). The soil profile is well differentiated in A_1 (B) and C horizons; it is often multiphase and shows a more weathered IIB horizon; its depth can exceed 2 m.

The upper humic horizon is 10-30 cm thick, very dark in colour, and contains often > 20 % of organic matter. The transition to B horizon is gradual, the organic matter decreasing to 15-10 % in the A-(B) horizon until 40-80 cm, and then 4-2 % in the B horizons between 1-2 m in depth. The B horizon has a fine loamy texture and shows a massive but microporous structure and some thixotropic properties.

The perhydrated andosols have undergone a very strong weathering, at least in the (B) or II B horizons, where the residue of primary minerals can approximate 30 to 10 %. The weathering products are almost amorphous or paracrystalline, even in the lower and older part of the soil. These nearly amorphous minerals are very abundant, approximating 15-30 % in the A and 30-60 % in the B horizons. Nevertheless, these can contain some traces of clay minerals (halloysite, kaolinite and even smectite), Fe-oxyhydroxides (goethite, lepidocrocite) and moreover a few gibbsite, which increases often toward te bottom, in the older part of soil. These weathering products are very rich in alumina; their molar SiO_2/Al_2O_3 ratio approximates 1 and it is often lesser. They are mainly constituted by imogolite (20 - 25 % of soil), with some allophane and Al-Fe hydroxide gels. In the top-soil the allophane increases and few opal appears, due to the enrichment of soil in fresh minerals and silica by new ash-falls. These products have a very large specific surface area: ~ 300 - 700 m^2/g.

The perhydrated andosols show the following main properties in the B horizons: a bulk density ~ 0.3; a very strong reaction to the NaF test; a water-retention capacity (undried soil) generally much more than 100 %, ~ 100 - 300 % at ⅓ bar, ~ 80-240 % at 15 bars, and moreover a rate of dehydration-irreversibility ~ 75-90%; a pH ~ 6 and ΔpH ~ −0.4 to + 0.2; a CEC value ~ 10-30 me/100 g, CEC / < 2 μ fraction generally near 1 (~ 0.3-1.4) me/1 g; moreover a rate of Δ CEC ~ 70 - 80 %; a base-saturation ratio often < 10 %; available phosphorus (Truog's method) ~ 0 ppm, meaning a very high P-retention (> 95 %).

Most of these soils could be classified as Hydrandepts in the Soil Taxonomy (1975), or Hydrudands for Andisol Proposal (1978).

2.4. UNSATURATED ANDOSOLS

The "unsaturated andosols" are the more common andosols of lowlands, which are under a wett but non-perhumid climate (rainfall ~ 2500-4000 mm). They form an intergrade between the both preceding groups of andosols. Like the perhydrated ones, they are young soils, dating several thousand years, showing a well differentiated profile and having a low base-saturation in the B horizon. But according to less heavy rainfall conditions, they are not at a so advanced stage of weathering and their base-saturation ratio is higher, ~ 20-50 %. In addition, the B horizon has a more granular, although very friable, structure, and doesn't show any thixotropic property.

The upper humic horizon is more reddish and contains only 10-20 % organic matter, while the B horizon keeps still 1-4 % of it. But, the amount of < 2 μ fraction and the residue of weatherable minerals don't differ greatly. Nevertheless the content in amorphous or paracrystalline products is lesser than in perhydrated andosols and moreover, these products

are richer in silica, the molar SiO_2/Al_2O_3 ratio being ~ 1-2. There is a mixture of sphaeroidal allophane and fibrous imogolite. But in the depth, the oldest part of soils shows often a few quantity of halloysite, goethite and gibbsite. However, the specific surface area of $< 2\,\mu$ fraction from the B horizon remains high: ~ 300 - 400 m^2/g.

The unsaturated (non-perhydrated) andosols present the following main properties in the B horizon: a bulk density ~ 0.4-0.5; a quite good reaction to the NaF test; a water retention capacity (undried soil) ~ 80-130 % at ⅓ bar and 50-100 % at 15 bars; a rate of dehydration irreversibility ~ 50-73 %; a pH near 6 (5.7 - 6.7) and Δ pH ~ 0.5 to 0.3; a CEC value ~ 15-25 me/100 g and CEC/ $< 2\,\mu$ fraction often < 1 (~ 0.4 to 1.4); a rate of Δ CEC ~ 60-70 %; a base-saturation ratio ~ 20-50 %; available phosphorus (Truog's method) ~ 0 ppm and a high P-retention (> 95 %).

These soils can be classified as Dystrandepts in the Soil Taxonomy (1975), and Haplotropands or Tropudands for Andisol Proposal (1978, 1983).

3. CONCLUSION

We have seen that the Vanuatu andosols can be subdivided in four main groups. These andosols derive from recent and basic volcaniclastic materials. Both main factors of differentiation are the age of ashfall parent material and the rainfall distribution.

The "vitric" ones are the less 1,000 years old andosols, without B horizon. These soils show a very weak grade of weathering, and have the following properties: unweathered primary material > 60 %; bulk-density ~ 1.2 - 0.9; silica-rich weathering products, made of opal and iron-rich allophane; molar SiO_2/Al_2O_3 ratio of $< 2\,\mu$ fraction > 3; water-retention > 3; water-retention capacity* at ⅓ bar < 40 %, at 15 bars < 20 % and rate of dehydration-irreversibility** > 40 %; CEC < 15 me100 g, rate of Δ CEC*** > 40 % and base-saturation ratio**** generally > 50 %; low P-retention (< 55 %).

The "saturated" andosols date around 1,000 - 2,000 years and show a beginning of (B) horizon, although they are still weakly weathered. They don't appear under a perhumid climate. There are their main properties in the (B) horizon: unweathered primary material < 60%; bulk density ~ 0.9-0.7; silica and iron-rich weathering products, made of hisingerite-like allophane and few opal; molar SiO_2/Al_2O_3 ratio of $< 2\,\mu$ fraction > 2; water-retention capacity * at ⅓ bar ~ 40-80 %, at 15 bars ~ 20-60 %, and dehydration-irreversibility rate** ~ 40-60 %; CEC ~ 20-40 me/100 g, rate of Δ CEC*** ~ 40-60 % and base-saturation ratio**** > 50 %; low P-retention (< 85 %).

The "perhydrated" andosols date several thousand years and show a well developed B horizon and the most advanced grade of weathering. They form only under a perhumid climate (> 4000 mm/y rainfall). The upper A_1 horizon contains at least 20 % organic matter. The B horizons show the following properties: unweathered primary material < 50 %; bulk-density ~ 0.3; > 30 % of alumina-rich weathering products, made of imogolite, ± allophane and few gibbsite; molar SiO_2/Al_2O_3 of $< 2\,\mu$ fraction < 1; water-retention capacity* at ⅓ bar ~ 100-300 %, at 15 bars ~ 80-240 %, and dehydration-irreversibility rate** ~ 75-90 %; rate of Δ CEC*** ~ 70-80 %; base-saturation ratio**** ~ 10 % or less; very high P-retention (> 95 %).

* on undried soil
** W.R.C. at ⅓ bar
*** rate of pH dependant CEC between pH 9 and 4
**** base-saturation of CEC at pH 7

The "unsaturated" andosols are close the perhydrated ones, but they are not formed under a perhumid climate (rainfall ~ 2500-4000 mm). The A_1 horizon contains only 10-20 % organic matter. In the B horizons their properties differ by the following ranges of value: bulk-density ~ 0.5-0.4; molar SiO_2/Al_2O_3 ratio of < 2 μ fraction ~ 1-2; paracrystalline clay richer in allophane than in imogolite; water-retention capacity* at ⅓ bar ~ 80-130 %, at 15 bars ~ 50-100 % and moreover a rate of dehydration irreversibility** ~ 50-73 %; rate of △ CEC*** ~ 60-70 %; base-saturation ratio**** ~ 20-50 %. The P-retention remains high (> 95 %).

In conclusion we can outline these following criteria as diagnostic for the four group of Vanuatu andosols: presence or not of B horizon and several ranges of bulk density; silica richness of weathering products, marked by the molar SiO_2/Al_2O_3 ratio of < 2 μ fraction; water-retention capacity at 15 bars (on undried soil) and rate of dehydration irreversibility at ⅓ bar; CEC and moreover the rate of △ CEC; base-saturation ratio; and P-retention capacity. These criteria have been summarized in the table 2.

Tab. 2: DIAGNOSTIC CRITERIA OF THE FOUR GROUPS OF ANDOSOLS (IN THE B HORIZON FOR THE GROUPS II, III AND IV).

Andosol group	I Vitric	II eutric	III perhydric	IV dystric
Age y.	< 1,000	1,000 - 2,000	> 2,000	> 2,000
Rainfall mm/y	~	< 4,000	> 4,000	2,500 - 4,000
(B) horizon	No	+	+	+
Bulk-density	1.2 - 0.9	0.9 - 0.7	0.3	0.5 - 0.4
SiO_2/Al_2O_3 mol. of < 2 μ fraction	> 3	> 2	⩽ 1	1 - 2
H_2O 15 b. (wet soil) %	< 20	20 - 60	80 - 240	50 - 100
Dehydration-irreversibility-ratio %	> 40	40 - 60	75 - 90	50 - 75
△ CEC ratio %	> 40	40 - 60	70 - 80	60 - 70
Base-saturation %	> 50	⩾ 50	⩽ 10	20 - 50
P retention-capacity %	< 60	40 - 85	> 95	> 95
Al_2O_3-oxalate %	< 2	< 5	> 5	> 5

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