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Amorphous Clay Coatings in A Lowland Oxisol and Other Andesitic Soils of West Java, Indonesia

Selaput Liat Amorf pada Oxisol Dataran Rendah dan Tanah-tanah Andesitik Lainnya di Jawa Barat, Indonesia

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ABSTRACT

Isotropic allophanic coatings were found in a West Java Oxisol on andesitic volcanic products. These coatings recrystallize toward birefringent, probably halloysitic coatings that are easily confused with illuviation argillans. The allophane is probably due to weathering of airborne ash additions. Both amorphous and (partly) crystalline coatings appear to be common in the three andesitic catenas investigated except for the perhumid part of the catenas. Crystallization and abundance of the coatings tend to increase in soils wich suffer a distinct dry season, but in some soils it is not possible to unequivocally distinguish recrystallized coatings from illuviation argillans. Amorphous and recrystallized coatings are thought to occur in many ash-influenced soils throughout Indonesia.

Index words: *allophane, argillans, allophanans, oxisol, clay illuviation, volcanic ash, andesite, andosols.*

ABSTRAK

Selaput allofan isotropik ditemukan pada *Oxisol* dan tanah andesitik lainnya di Jawa Barat. Selaput-selaput ini mengkristal ke arah *birefringent*, kemungkinan besar selaput berhalloisit yang mirip dengan illuviasi *argillans*. Allofan ini kemungkinan hasil pelapukan abu volkanik yang terbawa angin. Kedua selaput yang amorf dan terkristal sebagian tampaknya lumayan pada tiga *catena* berandesit yang diteliti, kecuali pada bagian dengan curah hujan paling tinggi. Pengkristalan dan jumlah selaput cenderung bertambah pada tanah-tanah yang mengalami musim kering yang jelas. Tetapi pada beberapa tanah terlalu sulit untuk membedakan antara selaput mengkristal dan illuviasi *argillan*. Selaput amorf dan terkristal diperkirakan terjadi pada tanah-tanah yang berbahan abu volkanik di seluruh Indonesia.

INTRODUCTION

A major part of the soils of Java is formed in volcanic products of mainly andesitic character. Depending on rainfall, temperature, and age of the deposit, these soils develop into Ultisols, Alfisols, Oxisols, Inceptisols or Vertisols. In East Java, with a monsoon climate that features a distinct dry season, soils are classified as Oxisols, Ultisols, Alfisols, Vertisols, and Inceptisols. In West Java, without a clearly defined dry season, Vertisols and Alfisols are not found.

Because micromorphological analyses of Indonesian soils are still scarce, recognition of the argillic horizon is mainly based on textural discontinuities and, consequently, the classification of many soils, especially those on stratified volcanic deposits, is still open to discussion.

The exploratory soil map of West Java (Lembaga Penelitian Tanah, 1974) indicates, in the area between Bogor and Jakarta, an association of Red Latosols and Reddish Brown Latosols. Subardja and Buurman (1980) classified these soils as Eutrorthox and Dystropepts, and this classification was corroborated by investigations of Nanere *et al.* (1982).

In 1980, several profiles of the catena described by Subardja and Buurman (1980) were collected for display in the International Soil Museum (now International Soil Reference and Information Centre = ISRIC) at Wageningen, the Netherlands. These soils were resampled and thin sections of various horizons were prepared. Micromorphological analysis was first carried out by Astiana (1982), who described argillans in the lowland member of the catena. This would have required a reconsideration of the classification of this profile. Upon reexamination, these coatings were completely different from the classic illuviation argillans of layer lattice clays that are prerequisite to the argillic horizon. Part of the clay coatings was isotropic, and this is very unusual for tropical lowland soils.

These findings merited further elaboration. The profile was restudied completely, and its micromorphology is reported here. Amorphous coatings and related features that occur in this profile were also encountered in other Indonesian catenas on andesitic rocks. To put the findings of the West Java profile in its proper context, the relevant information on these catenas is presented as well.

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MATERIAL

The profile

The profile investigated is Profile P2 of Subardja and Buurman (1980), and is registered as INS 1 at the ISRIC. The abbreviated profile description is as follows:

Profile number	: P2 (Subardja and Buurman, 1980); INS 1 (ISRIC, Wageningen monolith)
Location	: Parung, West Java, Indonesia; 6°23'10" S and 106°32' 15" E
Morphology	: Dissected alluvial fan
Parent material	: Andesitic volcanic tuff
Elevation	: 140 m
Mean annual temperature	: 26°C
Mean annual precipitation	: 2600 mm
Landuse	: Former irrigated rice field, now cultivated with bananas
Drainage class	: Well drained
Short description	:
Apl 0-23 cm	: Brown to dark brown (7.5 YR 4/4, moist) clay; strong very fine granular structure; many pores, friable to firm when moist; slightly sticky and slightly plastic when wet; common fine roots; abrupt and smooth to:
Apg 23-51 cm	: Brown to dark brown (7.5 YR 4/4, moist) clay; weak angular blocky structure; common to many fine and very fine pores; firm when moist, slightly sticky and slightly plastic when wet; many distinct fine iron mottles (7.5 YR 5/8) and common fine black manganese mottles. At contact with Ap1 manganese and iron segregations along root channels; clear and smooth to:
Bwg 51-78 cm	: Yellowish red (5 YR 4/6, moist), clay; weak subangular blocky structure; many fine and very fine pores; friable when moist; many prominent medium irregular black manganese mottles along pores and peds; gradual and smooth to:
Bw 78-150 cm	: Yellowish red and yellowish brown (5 YR 4/6 and 10 YR 5/6, moist) clay; weak subangular blocky structure; many fine and very fine pores; very friable when moist; few faint fine manganese mottles, decreasing with depth (sampled 78-100 and 100-150 cm).
Classification	: (USDA; Soil Survey Staff, 1975): Typic Eutrorthox, very fine clayey, halloysitic, isohyperthermic (FAO, 1974): Orthic Ferralsol (Indonesia; Suhardjo and Soepraptohardjo, 1981): Oksisol Eutrik.

RESULTS

Chemical and mineralogical properties

Chemical and mineralogical data of Profile INS 1 are provided in Tables 1 and 2. Because the soil was formerly used for irrigated rice cultivation, it has a distinct iron manganese pan at the bottom of the puddled zone. Organic matter content in the topsoil is low, while clay content is extremely high. On the other hand water dispersible clay which is characteristic for Oxisols, is very low. Cation exchange capacity (CEC)-clay in the subsoil is low enough to qualify for an oxic horizon, and so are other exchange properties of the Bw horizon. The sand fraction of these horizons amounts to only 1% and therefore its considerable content of weatherable minerals should not interfere with the denomination *oxic*. Soil reaction (pH) in NaF indicates an increasing reactivity with depth, but oxalate-extractable Al and Si indicate that the total amount of amorphous matter is fairly low. (In Andosols of the same catena, the sum of oxalate-extractable matter may amount to more than 9%). The plowpan is clearly indicated by a high amount of extractable Mn.

Table 1. Chemical characteristics of profile INS 1

Soil characteristics	Ap	Apg	Bwg	Bw1	Bw2
pH					
H_2O	5.1	5.0	5.3	5.3	5.4
KCl	4.0	4.2	4.4	4.4	4.5
NaF 1	8.5	9.1	9.4	9.5	9.6
NaF 60	9.6	9.8	10.1	10.1	10.2
Texture					
sand (%)	1.0	1.2	1.2	1.1	1.0
clay (%)	85.7	91.2	88.4	89.8	89.3
WDC (%)	10	2	2	2	0
Exchangeable					
bases (me/100 g soil)	6.0	6.2	6.2	6.2	6.8
Al (me/100 g soil)	0.8	0.2	0.1	0.1	0.0
H (me/100 g soil)	1.4	0.6	0.1	0.1	0.3
CEC soil					
PC (me/100 g soil)	6.8	6.4	6.3	6.5	6.8
NH_4Cl (me/100 g soil)	9.3	8.8	10.3	8.2	9.0
CEC7 (me/100 g soil)	18.1	15.6	16.0	13.6	14.0
CECS (me/100 g soil)	22.8	20.6	20.6	19.8	19.0
CEC clay					
PC (me/100 g clay)	8	7	7	7	8
pH7 (me/100 g clay)	21	17	18	15	16
Base saturation					
CEC7 (%)	33	40	39	47	49
PC (%)	88	97	99	99	99
Dithionite and oxalate extractable matter					
Fe_d (%)	6.06	5.76	6.29	6.31	6.69
Al_d (%)	0.80	0.77	0.86	0.80	0.75
Si_d (%)	0.18	0.21	0.21	0.19	0.24
Mn_d (%)	0.33	1.14	0.23	0.21	0.21
Fe_o (%)	0.54	0.46	0.38	0.39	0.39
Al_o (%)	0.33	0.31	0.31	0.32	0.28
Sio (%)	0.02	0.11	0.21	0.13	0.15
Bulk density					
dry (g/cm^3)	0.95	0.93	–	0.86	–
1/3 bar (g/cm^3)	1.23	1.27	–	1.17	–
Organic C (kg/m^3)	8.3				

WDC = water dispersible clay; PC = permanent charge (bases + Al); CEC7 = CEC in NH_4OAc at pH7;
CECS = CEC by sum of cations ($BaCl_2$, pH 8.2); Al and H in 1*M* KCl.
d = dithionite; o = oxalate.

The mineralogical analysis of the sand fraction (Table 2) indicates that the parent material is almost purely andesitic, but consists of several strata. The clay fraction is dominated by halloysite, but the diffractograms show a distinct reflection at 1.2 nm, which can be attributed to stacking in allophane (Van der Gaast, *et al.*, 1985).

Micromorphology

Micromorphological features have been summarized in Table 3.

Skeleton grains: are mainly quartz and volcanic glass. Quartz is angular, 50-100 microns; volcanic glass is spherical or irregular, sometimes vesicular, 20-200 microns, and most abundant in upper horizons. Other primary minerals are augite, hypersthene, and plagioclase, all strongly weathered and angular, 50-200 microns. Some basaltic fragments, consisting of glass with small plagioclase phenocrysts are encountered. Of secondary origin are subrounded sharply bounded gibbsite nodules (20-200 microns).

Plasma: mainly consists of clay, with fair amounts of organic matter in the topsoil and high contents of iron in the lower parts of the profile. The plasmic fabric is undulic, but sepic fabrics are regularly encountered throughout the profile (lattiseptic, glaesepic, omnisepic).

Voids: are mainly biogenic and of sizes between 50 microns and several millimeters: compound packing voids, interconnected vughs and channels. In the plowpan, craze and skew planes are a common feature.

Special features:

A. Oriented clay:

Type *a*. Yellow, birefringent clay coatings with a continuous orientation pattern, but without stratification (Figure 1 c-f), are common in sections 1808 and 1807. They occur in recent biogenic voids and have a thickness of 20-50 microns. Papules derived from these cutans are extremely rare but occur in section 1806.

Type *b*. Yellow, partially birefringent, partially isotropic clay coatings without stratification (Figure 1 a, b), are common in section 1808. Birefringent parts of these coatings have a continuous orientation pattern and are fully comparable to type *a* cutans. Type *b* cutans, 20-50 microns thick also occur in recent biogenic voids; derived papules were not encountered.

Type *c*. Clay papules up to 200 microns in diameter, shaped like the volcanic glass fragments. Such papules are birefringent, yellow, and have a strong continuous orientation pattern. They are

Table 2. Mineralogical composition of the sand and clay fractions of profile INS 1

Horizon	Sand fraction: Total fraction										Heavy fraction				Light fraction			Clay fraction			
	opaque	quartz	iron concr	min. fragm.	rockfragm.	volcanic glass	plagioclase	augite	hypersthene	others	opaque	augite	hypersthene	zircon	quartz	volcanic glass	labradorite	halloysite	allophane 1.2 nm	goethite	quartz
Ap	20	15	18	7	3	15	4	1	16	1	12	16	72	–	57	17	26	+ + +	+ +	+	(+)
Apg	16	15	29	7	5	10	6	–	12	–	29	6	65	–	63	18	19	+ + +	+ +	+	(+)
Bwg	33	11	27	8	3	7	1	1	8	1	45	15	40	–	65	18	17	+ + +	+ +	+	(+)
Bwl	58	12	21	4	2	–	–	–	1	2	80	2	17	1	76	14	10	+ + +	+ +	+	(+)
Bw2	36	11	39	9	3	–	–	–	1	1	78	1	15	6	90	6	4	+ + +	+ +	+	(+)

+ + + abundant
+ + common
+ present
(+) traces

Table 3. Some micromorphological observations of profile P2 (INS 1)

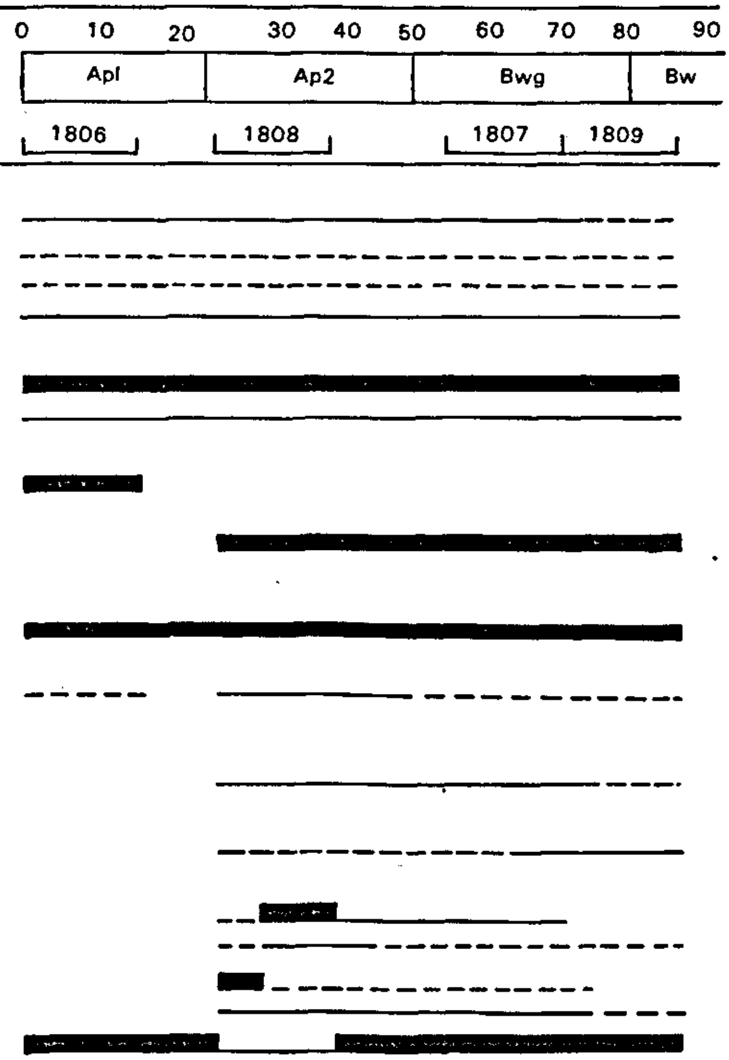
Depth (cm)
Horizon
Sample

Skeleton grains
- volcanic glass
- hypersthene/augite
- plagioclase
- quartz

Plasma
- undulic plasmic fabric
- in- latti- glae- omni sepic plasmic fabric
- clay minerals, iron and org. matter
- clay minerals and much iron

Voids
- biogenic: (compound packing voids interconnected vughs)
- physiogenic: (craze/skew planes, vughs)

Special features
- yellow strongly birefringent clay coatings
- yellow, partially birefringent partly isotropic clay coatings
- normal void neo mangans
- manganiferous nodules, irregular
- normal void neo ferrans
- ferric nodules, irregular
- matric faecal pellets



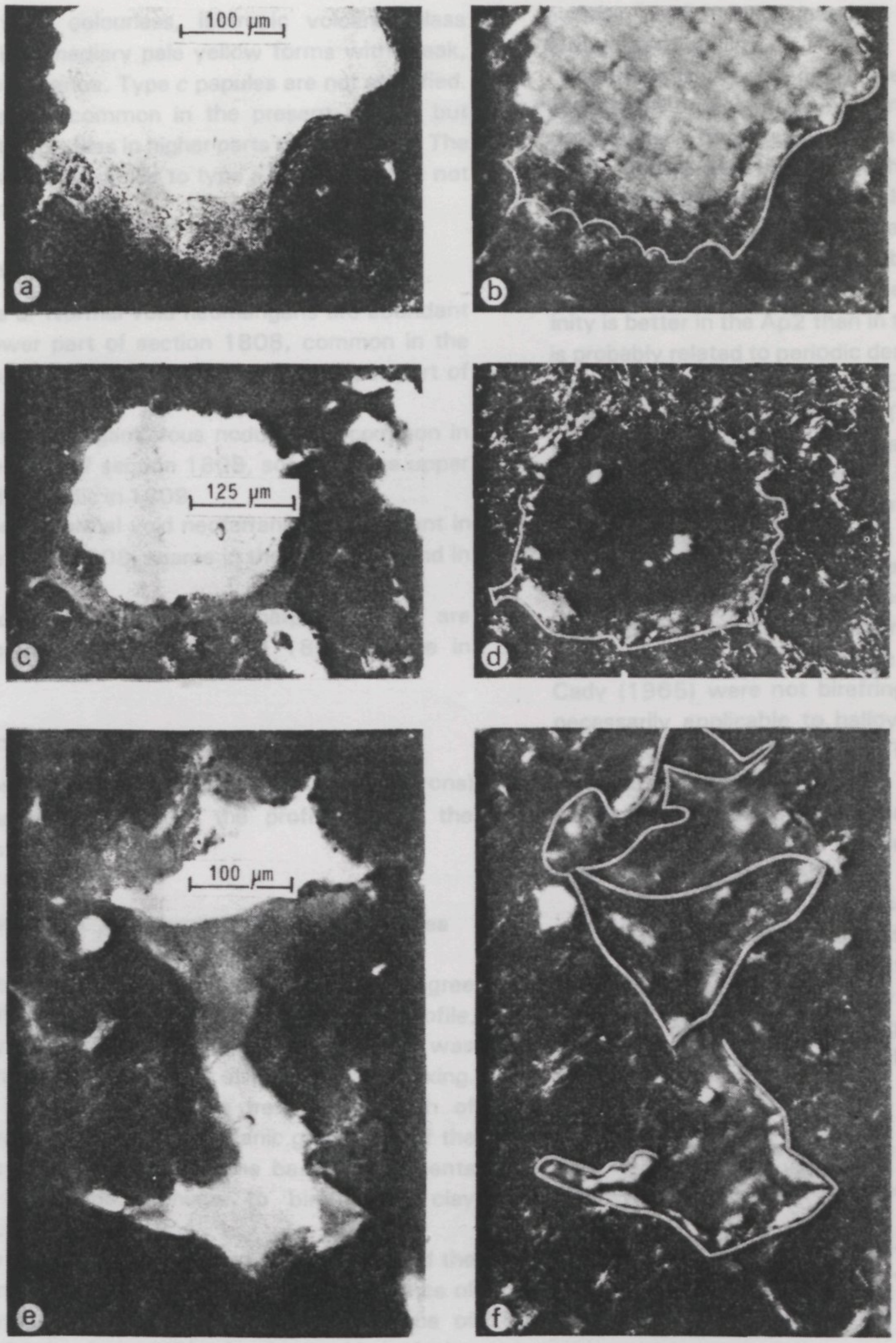


Figure 1. Thin sections of isotropic and birefringent coatings.
a/b : nearly amorphous coating. Section 1807, plain light/crossed polarizers.
c/d : yellow birefringent type *a* coating with discontinuous orientation pattern. Section 1808, plain light/crossed polarizers.
e/f : yellow birefringent type *a* coating with continuous orientation pattern. Section 1807, plain light/crossed polarizers.

derived from colourless, isotropic volcanic glass through intermediary pale yellow forms with weak, local birefringence. Type *c* papules are not stratified. They are not common in the present profile, but abundant in profiles in higher parts of the catena. The papules are very similar to type *a* cutans but are not at all related.

B. Iron and manganese segregations:

Type *d*. Normal void neomangans are abundant in the lower part of section 1808, common in the upper part of 1807, and scarce in the upper part of 1809.

Type *e*. Manganiferous nodules are common in the lower part of section 1808, scarce in the upper part, and sporadic in 1809.

Type *f*. Normal void neoferrans are abundant in the upper part 1808, scarce in the lower part and in 1807.

Type *g*. Ferric nodules (sharp, irregular) are common in sections 1807 and 1808, scarce in 1809.

C. Structures related to biological activity:

Type *h*. Matric faecal pellets (20-200 microns) are abundant throughout the profile except the plowpan.

Interpretation of micromorphological features

Distribution of skeleton grains and their degree of weathering indicate rejuvenation of the profile, probably with airborne volcanic material which was incorporated in the profile by strong biological mixing. This is corroborated by the trend with depth of weatherable minerals and volcanic glass. Part of the volcanic glass fraction and the basaltic fragments shows a pseudomorphosis to birefringent clay papules.

The amount of clay plasma is very large and the occurrence of sepic fabrics points to a dominance of crystalline clay minerals. The overall presence of undulic fabrics is probably due to masking of clay birefringence by the fairly large amount of iron compounds (Brewer, 1964). Shape of voids and abundance of matric faecal pellets point to a high biological activity, which is somewhat suppressed in the former plowpan.

Cutans of types *a* and *b* are genetically similar, because in type *b* isotropic parts and strongly and continuously birefringent parts occur within one cutan. In one-way polarized light, the two types of cutans are completely similar. Isotropism points to amorphous material, while birefringence points to crystallinity and orientation. Obviously, crystallization occurs after formation of the cutans. As crystallinity is better in the Ap2 than in the lower horizons, it is probably related to periodic desiccation and slightly more elevated temperatures. Electron microscopic (EDAX) analyses of the cutans (Table 4) corroborate the chemical similarity of type *a* and *b* coatings and indicate that their composition is within the normal range for allophane. Similar coatings are common in higher members of the catena (Buurman *et al.*, in preparation). Because the allophane tends to crystallize into halloysite in these soils on andesitic material, the crystalline, birefringent coatings are probably halloysitic. Halloysite coatings found by Cady (1965) were not birefringent, but this is not necessarily applicable to halloysite formed through crystallization of allophane. The formation of allophanic coatings and their recrystallization are clearly recent processes: the coatings occur in recent voids, and the absence of papules indicates that very little reworking has taken place.

The iron and manganese segregations are typically related to former use of the land for irrigated rice cultivation. The typical distribution of iron with respect to manganese points to pseudogley (artificial ponding), and manganese segregations are found deeper in the oxidized subsoil than are iron segregations.

Table 4. EDAX analyses of isotropic and birefringent coatings (7-10 analyses per sample)

Sample	Al_2O_3	SiO_2	Fe_2O_3	Al/Si (atomic)
	%			
A	33.0 ± 1.7	52.7 ± 2.7	14.2 ± 1.9	0.91
B	36.8 ± 1.4	50.6 ± 1.1	12.4 ± 2.4	0.86
C	38.1 ± 1.2	52.7 ± 0.7	9.0 ± 0.8	0.85

A = isotropic coating similar to Fig. 1. a/b.
B = birefringent coating similar to Fig. 1. c/d.
C = birefringent coating similar to Fig. 1. e/f.

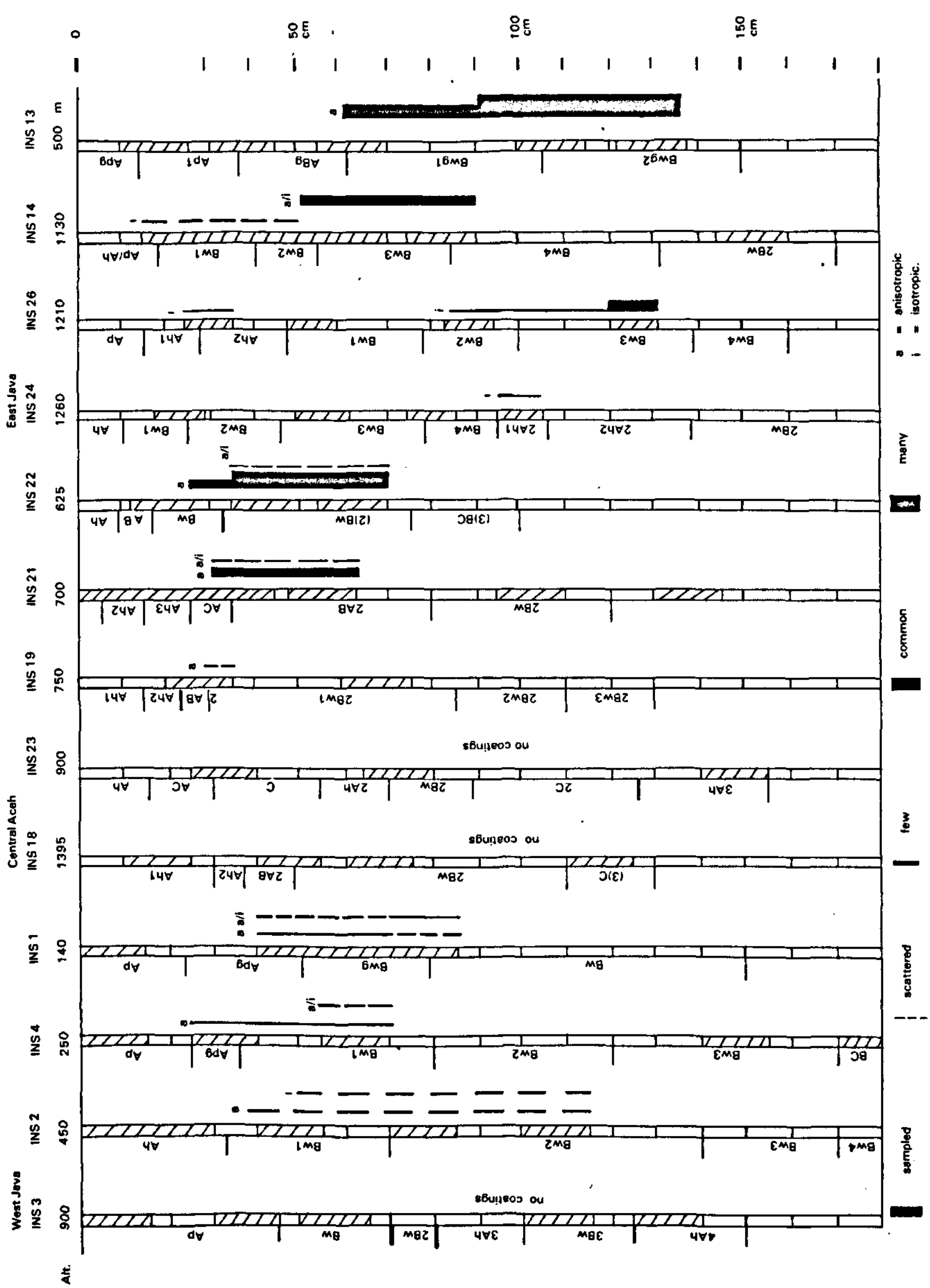


Figure 2. Distribution of isotropic and anisotropic coatings in profiles of three catenas

Data from other catenas

The profiles investigated are given in Table 5. The Central Aceh profiles are from the Geureudong volcanic complex; the West Java profiles from the Gede/Pangrango system; and the East Java profiles from the surroundings of Malang. Details on stratification and horizon sequence can be deducted from Figure 2. The profiles INS 1 through 3 are equivalent to the numbers P2, P5, and P8 of Subardja and Buurman (1980). Complete descriptions and analyses of all these profiles will appear in a complete publication on the three catenas, (Buurman *et al.* in preparation). They are not necessary for the present purpose.

Table 5. Profiles of the West Java, Central Aceh and East Java catenas

Profile	Altitude	Annual rainfall	Classification	Area
	m	mm		
INS 1	140	2600	Typic Eutrorthox	West Java
INS 2	450	4400	Typic Humitropept	West Java
INS 3	900	3350	Andic Humitropept	West Java
INS 4	250	3800	Oxic Dystropept	West Java
INS 18	1395	1800	Typic Hydrandept	Central Aceh
INS 19	750	2200	(Andic) Oxic Humitropept	Central Aceh
INS 21	700	2600	Typic Hydrandept	Central Aceh
INS 22	625	2200	Oxic Dystropept or Orthoxic Tropudult	Central Aceh
INS 23	900	2600	Typic Hydrandept	Central Aceh
INS 13	500	1700	Anthraquic Hapludoll or Typic Argiudoll	East Java
INS 14	1130	2350	(Cumulic) Andic Eutropept	East Java
INS 24	1260	2300	Hydric Dystrandept	East Java
INS 25	50	1125	Vertisol	East Java
INS 26	1210	2200	Andic Humitropept	East Java

In these soils, the amorphous coatings and (partly) birefringent coatings occur in varying amounts, depths and altitudes. A compilation is given in Figure 2.

Due to partial sampling for micromorphology, information on all these soils is incomplete . However, some trends are obvious:

1. Cutans are more common in the Aceh and East Java catenas than in the West Java catena;
2. Isotropic cutans are more common in the deeper part of the profiles;
3. In the Aceh catena, the coatings are nearly restricted to buried soil horizons, but are also found in overlying nearly fresh ash (Bw of INS 22);
4. Anisotropic coatings are most abundant in the East Java catena; the isotropic coatings here are found above the anisotropic ones;
5. In all catenas, there is a tendency for coatings to become more abundant at lower altitudes, although there are strong differences between catenas. Coatings are lacking altogether in some of the higher members of the West Java and Aceh catenas.

An additional observation is that amorphous coatings are frequent in pores (vesicles) in fragments of weathered volcanic glass, both in the saprolite and in other parts of profiles.

In profiles INS 13 and INS 14 of the East Java catena, organomatri-ferriargillans are common to abundant. These coatings, are due to instability of surface structure (slaking). Slaking may occur when strongly dried-out soils are suddenly wetted, e.g. by rain or irrigation water.

DISCUSSION

The crystallized parts of the clay coatings found in these soils (type *a*) are easily confused with argillans that are due to layer lattice clay illuviation, and are distinguished mainly by their lack of stratification. As far as they are associated with (partly) isotropic coatings, they are certainly not due to illuviation of crystalline clay and should therefore not be regarded as argillans.

The coatings have probably formed by precipitation of allophanic material from the soil solution and the precipitation of allophane in these soils is probably comparable to that of allophanic coatings in andosols and that of (proto) imogolite and allophane in brown soils and podzols (e.g. Farmer *et al.*, 1985). Similar isotropic coatings were described by Dalrymple (1964, 1967) in fossil andosols of New Zealand; birefringent coatings were described by Pain (1971) and by Chartres *et al.*, 1985) from volcanic soils in Papua New Guinea. None of these authors, however, attributed the coatings to allophane and its crystallization products.

Formation of isotropic coatings is clearly an actual process, as these coatings may be found close to the surface as well as in deeper parts of the profile. The extent of crystallization will depend on a number of external factors which cannot be properly asserted as yet. Desiccation may play an important role.

Climates are rather different for the three catenas and for profiles within one catena and, therefore, part of the differences should probably be attributed to this factor. In the lower part of the East Java catena, evaporation exceeds precipitation even on a yearly basis, which implies a very distinct dry season. On the contrary, the higher soils of the West Java catena are under a perhumid moisture regime and the soil does not dry out in normal years. The Central Aceh catena is in an intermediate position, with its upper members probably perhumid. Thixotropy in this catena clearly illustrates that the soils, except at lesser altitudes, do not normally dry out completely.

Coatings are not found in the highest members of the West Java and Central Aceh catenas, which might be due to the strong leaching and perhumid moisture regime of these profiles.

Figure 2 suggests that coatings become more abundant in soils which suffer a more pronounced dry season and that crystallinity increases with the severity of this season.

In INS 1 and other strongly weathered profiles, weathering of volcanic glass and other airborne volcanic material is the probable source for sufficiently high concentrations of silica and aluminum. The total amount of oxalate-extractable material in these soils is low and almost constant with depth, but its crystallization towards the top of the profile is accompanied by a decrease of pH in NaF.

In the soils that have high amounts of volcanic glass and feldspars, the source of allophanic matter is obviously this primary material.

Because isotropic coatings are very scarce in profiles of the East Java catena, attribution of the birefringent coatings in INS 13 and 14 of this catena to crystallization of amorphous material cannot be proven. Nevertheless, this possibility deserves serious consideration.

It is remarkable that in INS 1, the horizon with oxic properties has the highest pH in NaF and the lowest bulk density. Nevertheless, the amount of amorphous material is not sufficient to seriously influence soil properties or change its classification.

CONCLUSION

The formation of amorphous coatings is apparently an active process. It can be expected, therefore, that many lowland soils, in and outside Java, that have recent additions of volcanic ash, will show amorphous and recrystallized coatings as described above. This once more emphasizes the problem of identifying the argillic horizon in soils influenced by volcanic material.

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