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EVIDENCE OF MOBILITY AND INPUT OF Al, Fe, Ti AND TRACE ELEMENTS IN ALTERED VOLCANIC ROCKS FROM KALIMANTAN, INDONESIA

Gaston SIEFFERMANN* and Suharto TJOJUDO**

ABSTRACT – This study concerns thick layers of isovolumetric transformations products developed from Miocene phonolite, in the uplands of Central Kalimantan Province (Borneo). The study of this unusual alteration material is carried out by means of chemical and thermal analysis, of X-ray diffraction and of electron microscopy. The wax-like isovolumetric alteration material shows a density close to **2.4** and a very low porosity ranging from 10 to 10 %. There are no more remains of minerals of the original rock, but the initial volume seems to be **perfectly** preserved. The clay material of these alterations is mainly composed of well-ordered kaolinite mixed with a small amount of 2:1 clay minerals.

Mass-balance calculation shows that the alteration material contains 40 to 60 % **more** Al_2O_3 **than the same volume of the initial rock.** This increase in Al_2O_3 is on a par with a similar increase in Fe_2O_3 and TiO_2. For trace elements, this increase varies according to each element, ranging from 15 to 30 %.

INTRODUCTION

Since 1979, Indonesian and ORSTOM scientists, within the framework of scientific cooperation between Indonesia and France, have produced soil maps covering large parts of Central Kalimantan Province (BRABANT and MULLER, 1981; ORSTOM and DEPT. TRANSMIGRASI, 1981; SIEFFERMANN and LEVANG, 1982; SIEFFERMANN and MICHONNET, 1984).

Numerous maps, observations and analyses are available for the soils and rocks of the Central Kalimantan Province (SOIL RESEARCH INSTITUTE BOGOR, 1972, 1973; SUMARTADIPURA, 1976). All references concerning the soils show that the uplands of Central Kalimantan Province are a vast Oxisol landscape developed on metamorphic, sedimentary and volcanic rocks.

The pedogenesis depends mainly on the present humid equatorial climate, with a well distributed annual rainfall of more than 4,000 mm and a mean annual temperature of 27°C. This climate results in an extreme weathering of most minerals of the bedrocks with formation of disordered kaolinites, metahalloysite, goethite, hematite, gibbsite and anatase.

The transformation of the rock into weathering material mostly occurs without a volume change. In the deep part of the soils, in contact with the parent rock in the weathered material, one can frequently see the shape of former crystals. That is what MILLOT and BONIFAS (1955) called "*weathering with preserved volume*" or "*isovolumetric weathering*".

Besides these well-known weathering products resulting from the present climate, we have observed another type of *isovolumetric alteration material* presenting important differences with common weathering material. This paper describes this material and its analytical data and outlines the implications on the mobility of Al, Fe, Ti and trace elements during its formation process.

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PRESENTATION

A - DESCRIPTION OF THE OUTCROPS

The most conspicuous outcrops of the unusual *alteration material* are located some 130 km north of Palangka Raya, the provincial capital of Central Kalimantan, north-east of the town of Tewah, between the upper Kahayan River and the upper Kapuas River (fig. 1).

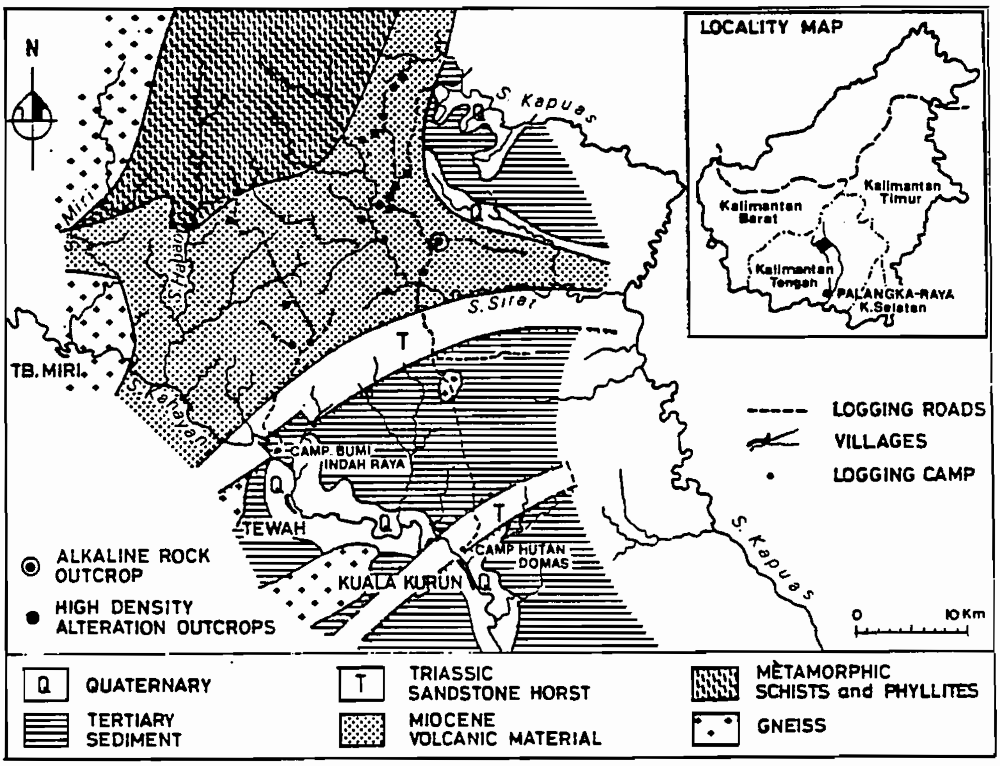

Figure 1. *Geological formations*

More than 15 outcrops were studied, all are located between 150 and 300 m above sea level and consist of erosion resistant soft rock layers of more than 15 m in thickness. Sometimes the material appears in outcrops even under primary forest, but mostly it is covered by shallow, less than 50 cm deep soil (Pl. I., Ph. a). This is a surprising fact in an environment where the soils are usually about 10 m thick.

B - GEOLOGICAL ENVIRONMENT

All observed outcrops are located inside a large, south-west, north-east oriented volcanic range of *Miocene* age (fig. 1). The main part of this volcanic range shows lavas, pyroclastic rocks, scoria, tuffs and ashes of andesite composition. The parent rocks from which the high density alteration seems to derive are close to phonolites forming occasional outcrops; they show a lower iron content than andesites and a high sodium content resulting from nepheline (Tab. 1a, b and d). They could correspond to early volcanic activity in this region during the final stages of the *Oligocene*.

Table 1. *Chemical distribution of the elements*

	SiO_2	Al_2O_3	MgO	CaO	Fe_2O_3	Mn_3O_4	TiO_2	Na_2O	K_2O	$H_2O(+)$	
a)	60.3	18.8	1.2	2.9	5.8	0.15	0.74	6.75	2.09	0.96	%
b)	53.0	17.6	4.4	8.7	9.9	0.19	1.0	3.0	0.9	0.4	%
c)	41.2	32.7	0.06	<0.2	10.8	0.05	1.9	<0.05	0.05	12.9	%

	Sr	Ba	V	Ni	Co	Cr	Zn	Cu	Sc	Y	Zr	
d)	356	504	112	5	15	5	75	34	15	22	159	ppm
e)	31	40	245	10	19	13	118	48	24	14	231	ppm

a) Average of 12 Phonolites
b) Average of 8 TEWAH area Andesites
c) Average of 9 high density alteration products
d) Average of minor elements of 12 Phonolites
e) Average of minor elements of 9 high density alteration products

C - CHARACTERISTICS OF THE MATERIAL

The colour of the material, from the Munsell chart, is pinkish-grey, pinkish-red, dark brownish red or dark yellowish-brown (Pl. I, b). Mostly the material is of isovolumetric type; most samples show well-defined white rectangular or rounded clay phantoms of former crystals, and usually also the **perfectly well preserved structure** of the initial rock (Pl. I, b). The material never contains unaltered primary minerals. Field observations show that the material can result from the transformation of compact lavas as well as from pyroclastic products of various sizes and from volcanic conglomerates.

The materials differ from those of common weathering, principally by their physical characteristics:

- They are heavy and very compact, their density ranges from 2.3 to 2.6 and this means that 1 dm^3 of this material weighs 1 kg more than the usual weathering product.

- Contrary to common weathering products, they show a very low porosity, by visual as well as microscopic observation, ranging from 10 to 18%.

D - MINERALOGICAL COMPOSITION

The study of the mineralogical composition was carried out by means of X-ray diffraction, chemical and thermal analysis and electron microscopy.

1. *X-ray diffraction data*

More than 30 samples analyzed show that this material is mainly composed of kaolinites, hematite and goethite, mixed with about 10% of 2 : 1 clay minerals. Figure 2 (a and b) represents two of the most characteristic diffractometer patterns of this material; the first (2a) corresponds to a pinkish-red sample with a 12% Fe_2O_3 content; the second (2b) is a nearly white sample with a low iron content.

This X-ray powder diffraction patterns reveal a well-ordered kaolinite with prominent basal reflections at 7.12 and 3.56 Å. The sequence os 02*l*, 11*l* reflections in the range of 20°-33° (2Θ) are sharp and intense (4.17, 3.85 and 3.75 Å); even reflections of low intensity like 021, 112 and 112 are sharp and clear. The reflections with indices 13*l*, 20*l*, in the range of 35°-40° (2Θ) form, together with the 003 basal reflection, two groups of sharp and intense triplets as reported by BRINDLEY and BROWN (1980) for well-ordered kaolinite.

After a treatment with hydrazine (RANGE, RANGE and WEISS, 1969), the 7.2 spacing in pattern 2(a) and 2(b) splits into two reflections : 7.2 and 10.2; there are obviously two types of kaolinite group minerals present,
a well-ordered and a less-ordered one. To emphasize the **strong** difference between the kaolinite group minerals of this material with those of the *present weathering* products, we have represented in 2 (c), the diffractometer pattern of a common andesite weathering crust located in the field, only some hundred metres from 2(a) and 2(b).

The present andesite weathering shows a very different clay mineral suite with gibbsite, metahalloysite, halloysite and a small amount of quartz.

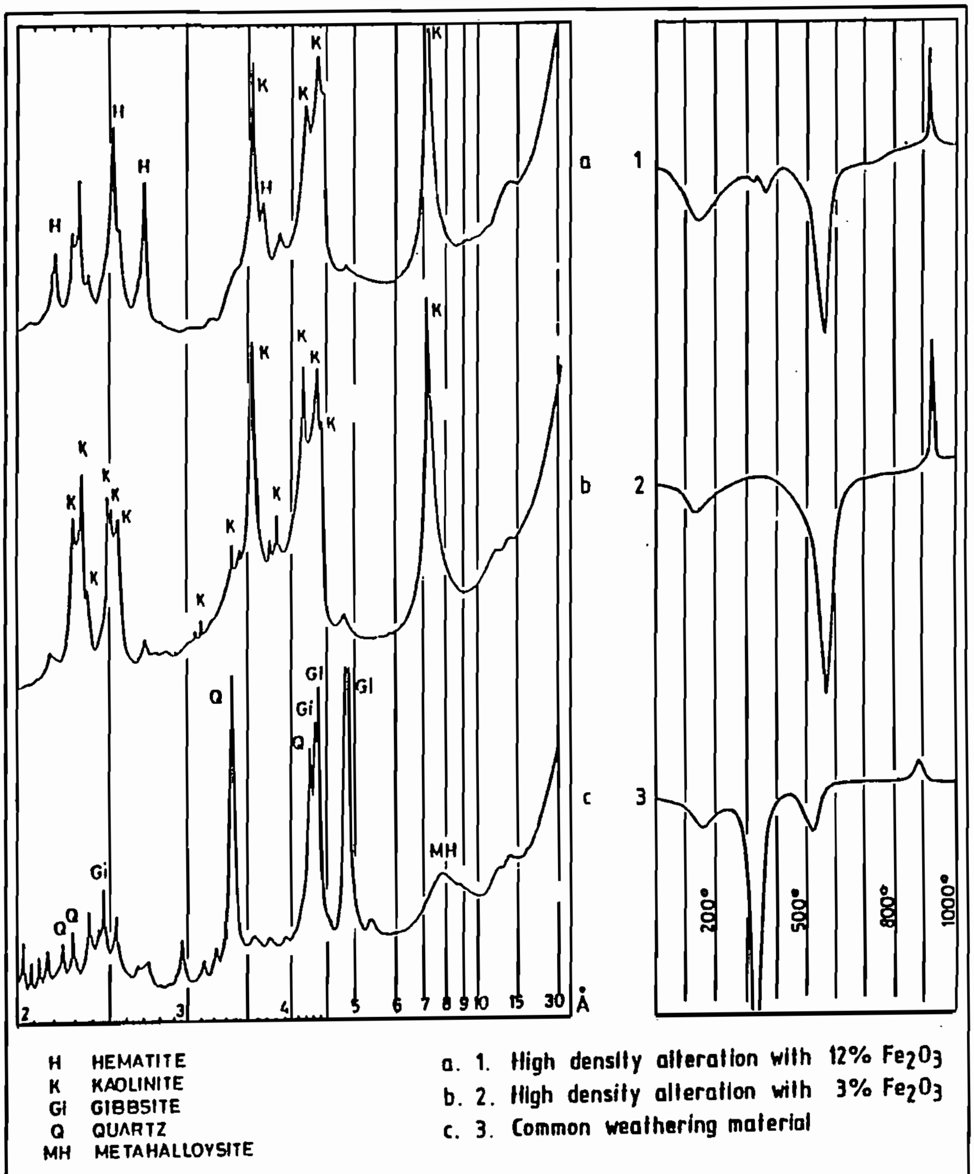

Figure 2. *Comparisons of X-ray diffraction and DTA patterns of high density and common weathering material*

2. *Thermal analysis*

More than 20 samples analyzed confirm the X-ray results and show that the high density material is very different from the usual weathering product. Figure 2(1), (2) and (3) represents the DTA patterns corresponding to the X-ray diffractometer patterns (a, b, c) of the same figure.

3. *Chemical analysis*

Table 1 (c and e) represents the chemical distribution of major and minor elements of the most representative of the analyzed high density samples.

4. *Electron microscopy*

Electron micrographs (Pl. I, c) of more than 25 samples were studied. The characteristics of this clay material are the following :

- The largest part of the material consists of small platelets of kaolinite.
- The size of most of these platelets is from 0.1 to 0.01 μm.
- Well-shaped hexagonal platelets do not represent more than 10% of the clay; mostly the platelets show rounded edges and are of irregular polyhedral shape. Platelets with curved edges, and tubular forms of halloysite are extremely rare.
- The iron-minerals are mostly spindle shaped and of about the same size as the platelets of kaolinite; or in the form of fine grains less than to 0.01 μm.

E. MASS-BALANCE CALCULATION

The method of studying element mobility through mass-balance calculation was established 34 years ago by MILLOT and BONIFAS (1955). Since then, element mobility during weathering processes has been extensively studied in this way (BONIFAS, 1959; TARDY, 1969; SIEFFERMANN, 1973; LELONG and SOUCHIER, 1979; LEPRUN, 1979; PION, 1979, GARDNER, 1980; COLMAN, 1982; CRAMER and NESBITT, 1983). These authors have reported that, during hydrolysis processes, nearly two-thirds of the weathered rock is removed in soluble ionic form, and that aluminium is usually one of the most immobile major elements. When an increase in aluminium was observed in a pH 4 to 5 environment, it was attributed to imperfect isovolumetric conditions, analytical errors or remained unexplained. In our case, the content of aluminium is so huge and the isovolumetry so perfect, that neither analytical errors nor small distortions in isovolumetry or fluctuation in the initial rock composition can be raised to challenge the results.

The mass-balance calculation represented in Table 2, which compares the content of each element in the same volume of alteration material and fresh rock, shows that :

- Sodium, calcium, magnesium, potassium, strontium and barium are almost completely removed, as usual, in the equatorial humid environment.
- Only 40% of the silica is removed; which is **significantly less than in a normal hydrolysis process** under an equatorial humid climate, where usually more than 65% of the silica is lost.
- Aluminium, iron and titanium have increased. The increase in aluminium of 51% is considerable if we take into account the fact that the aluminium content in the parent rock is high.

From the interpretation of the above (D) mentioned data and the mass-balance calculation, this ***isovolumetric alteration material*, with density ranging from 2.2 to 2.6**, has the following composition :

- 65 to 87% of kaolinites
- 5 to 20% of 2 : 1 clay minerals with an SiO_2/Al_2O_3 ratio near 3.3.
- 6 to 15% of hematite and goethite

A volume of 1 litre of this material contains approximately 2 kg of clay minerals, mainly kaolinites, and 300 g of iron and titanium oxides and hydroxides. **Half of the clays of this isovolumetric material contains aluminium coming from elsewhere than the parent rock.** We want to point out that we have not been able yet to find or to receive from clay specialists, any reference concerning *isovolumetric* material with such characteristics.

Table 2. *Mass balance calculation*

		%	CONTENT in g./dcm^3	LOSS in g./dcm^3	INCREASE in g./dcm^3	LOSS %	INCREASE %
HIGH DENSITY ISOVOLUME ALTERATION MATERIAL DENSITY: 2,3	H_2O	12.9	296.7		261.3		738
	SiO_2	40.5	931.5	633.7		40.5	
	Al_2O_3	31.9	733.7		247.5		50.9
	MgO	0.078	1.8	21.6		92	
	CaO	< 0.2	< 4.6	> 70.8		> 94	
	Fe_2O_3	11.4	262.2		111.4		73.9
	Mn_3O_4	0.07	1.6	2.3		59	
	TiO_2	1.47	33.8		14.6		76.0
	BaO	0.004	0.09	1.2		92	
	SrO	0.003	0.07	0.7		87	
	Na_2O	< 0.05	< 1.2	> 174.0		> 99	
	K_2O	0.06	1.4	45.0		97	
	Σ	98.4	2268.7	-949	+635		
PHONOLITIC PARENT ROCK DENSITY: 2,6	H_2O	1.36	35.4				
	SiO_2	60.2	1565.2				
	Al_2O_3	18.7	486.2				
	MgO	0.9	23.4				
	CaO	2.9	75.4				
	Fe_2O_3	5.8	150.8				
	Mn_3O_4	0.15	3.9				
	TiO_2	0.74	19.2				
	BaO	0.05	1.3				
	SrO	0.03	0.8				
	Na_2O	6.75	175.5				
	K_2O	1.79	46.5				
	Σ	99.4	2584.0				

MAJOR ELEMENT MOBILITY IN THE GENESIS OF HIGH DENSITY MATERIAL

F. TRACE ELEMENTS

Trace element mobility has been studied by mass-balance calculation with the methodology described by MOSSER (1980) for more than 15 samples. The results are represented in Table 3 and show that chromium, vanadium, nickel, scandium, zirconium, zinc, copper and cobalt increase. The increase varies from 135 to 15% according to the element.

Mass-balance calculation data for trace elements is less reliable than for major elements. Variations in the content of the rock are frequent, due to the sample size, and may explain some results like the 42% loss in yttrium.

Table 3. *Trace element mobility in the genesis of high density material*

	Sr	Ba	V	Ni	Co	Cr	Zn	Cu	Sc	Y	Zr
Increase %			98	81	15	135	43	28	45		45
Loss %	92	93								42	

DISCUSSION

In Central Kalimantan, on volcanic rocks, two different isovolumetric alteration materials can be discerned :

The first material is typical of weathering in an equatorial humid environment and has been extensively reported during the last 40 years by TAMURA, JACKSON and SHERMAN (1953); BIRRELL, FIELDES and WILLIAMSON (1955); NAKAMURA and SHERMAN (1965); SIEFFERMANN (1973). This type of weathering material contains the same amount of aluminium or less than the initial volume of the rock and the clay minerals are metahalloysite and halloysite (SIEFFERMANN, BESNUS and MILLOT, 1968; COLMAN, 1982).

The second isovolume material described in this paper is very different; it contains much more aluminium, iron and titanium than the initial volume of rock and the clay minerals are **well-ordered kaolinite** which never occur in weathering of basic rocks. There are no references available concerning similar material.

The problems to explain this material concern mainly the mobility and origin of the aluminium excess. All observed outcrops are more than 10 m thick implying that a huge amount of aluminium has been brought in from elsewhere. Under the present climate, the soils on basic rocks do not show any tendency either to clay dispersion or to clay accumulation in the deep horizons. Placed under arid conditions, Oxisols can become saturated in bases, and then their clay minerals can easily disperse in water and move. Nevertheless, in this case, this material should contain at least 40% of metahalloysite, the *normal type of weathering clay*, and it does not.

A hydrothermal mechanism could have brought the aluminium in soluble ionic form, through acid hydrothermal fluids, but we have no clear field evidence of hydrothermal influence in the outcrops; and this would imply hydrothermal activity over a very large area; the described outcrops are spread on a surface of more than 300 square kilometers.

The **well-ordered kaolinite** of this material suggests a hydrothermal origin; even though there is little information available about simultaneous transport of aluminium, iron and titanium by hydrothermal fluids. More laboratory investigations have to be undertaken in order to understand the genesis of this material.

CONCLUSION

We have shown through mass-balance calculations, with constant volume as a reference frame, that the abnormally dense alteration material of Kalimantan results from a huge input of aluminium, iron, titanium and trace elements.

The clay mineral nature suggests more a hydrothermal than a weathering origin.

Under the present climatic conditions, there is no evidence in actual weathering horizons of accumulation of translocated clays. However, we cannot fully exclude a formation in the past under very different climatic conditions.

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Plate I.

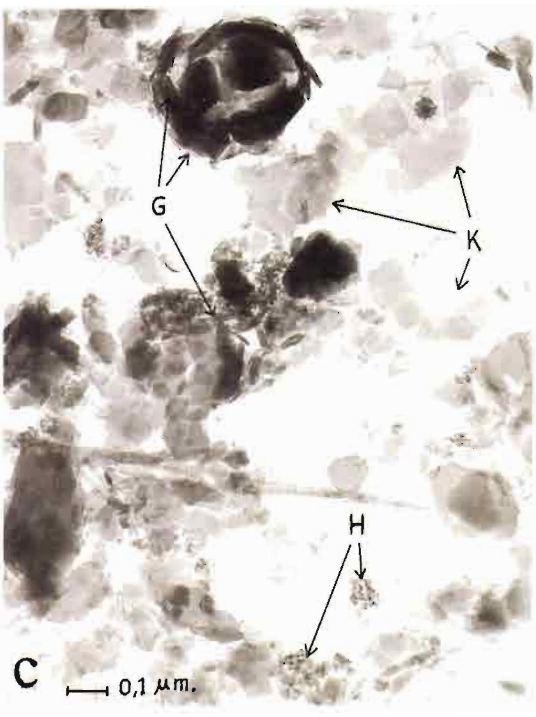
a. Alteration material outcrop. Notice the shallow soil and the orientation of the underlaying dense volcanic alteration material.

b. Alteration material. Notice the perfectly well-preserved structure and the pinkish colour of this dense alteration material.

c. TEM photomicrograph of the alteration material.

Notice : K) Kaolinite platelets
G) Spindle shaped goethite

PLATE I



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