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Short Report

Primary Mineral Characteristics of Topsoil Samples from Lowlands in Seven West African Countries

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Introduction

Abe *et al.* (2006) examined the clay mineral composition of 87 topsoil (0-15 cm) samples from lowlands in West Africa by X-ray diffraction (XRD) analysis and revealed their poor mineralogical properties characterized by the predominance of kaolinite and a small amount of 2:1 type phyllosilicate minerals such as smectite and illite. They also found that these characteristics were significantly associated with the low fertility status of the lowland soils in the region, as reported by Issaka *et al.* (1996; 1997) and Buri *et al.* (1999; 2000).

Although highly weathered tropical soils usually display a relatively monotonous mineralogy, these soils still reflect the nature of the parent materials in general (Schwertmann and Herbillon, 1992). In addition, since lowland soils are largely underdeveloped in terms of pedogenesis, the characteristics of the parent materials are particularly important to evaluate the soil fertility (Kyuma *et al.*, 1986). However, only few attempts have been made so far to analyze the primary mineral properties of lowland soils in West Africa.

Therefore, the objective of the present study was to examine the primary mineral characteristics of topsoil samples collected from 87 locations of inland valleys and flood plains in seven West African countries, i.e., Côte d'Ivoire, Ghana, Guinea, Mali, Nigeria, Niger and Sierra Leone, based on XRD analysis and petrographic measurements.

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Materials and Methods

Brief description of the sampling sites and the soil examined in the present study is given in Table 1. The physicochemical properties of these samples were reported by Issaka *et al.* (1996; 1997) and Buri *et al.* (1999; 2000), while their clay mineral composition was described by Abe *et al.* (2006).

The fine-sand fraction (20-212 μm) was collected by sedimentation and sieving. Organic matter was digested with 10% (w/w) hydrogen peroxide on a hot plate, while no iron removal treatment was employed because the content of iron extracted under the DCB system was generally low in these samples (Issaka, 1997; Buri, 1999). The fraction obtained was finely ground and mounted on a non-reflectable silicon plate according to the method of Marumo (1993). The operating conditions of the X-ray diffractometer (Geiger flex of Rigaku Co., Tokyo) were reported previously (Abe *et al.*, 2006), except for the angle range (5-40° 2θ) examined. In addition, the petrographic measurements were conducted after gravity separation of fine-sand grains using bromoform solution (s.g. 2.89). Mineral grains were identified according to their optical properties (e.g. color, shape, pleochroism, birefringence and extinction).

Results and Discussion

XRD patterns of the fine-sand fraction from several representative samples are shown in Fig. 1, and the primary mineral composition of the samples determined by the XRD analysis is summarized in Table 1. Quartz was predominant in all the samples as indicated by the diffraction at 0.427, 0.334, 0.246 and

Table 1 General description of the sampling sites and primary mineral composition of the topsoil (0-15 cm) samples revealed by XRD analysis

Site No.	Location	Country	Topo-graphy [a]	Agro-eco zone [b]	Soil Taxonomy	Clay types [c]	Primary minerals [d]			
							Qt	K-Fds	Pg	Others
1	Dahwenya	Ghana	IVs	GuS	Typic Tropaquept	14	++++	—	++	Ov tr?
2	Mongonu-1	Nigeria	IVs	SaS	Typic Pellustert	14-7	++++	++	+	—
3	Mongonu-2	Nigeria	IVs	SaS	Typic Chromustert	14-7	++++	++	+	—
4	Lumda-1	Nigeria	FPs	SaS	Typic Pellustert	14-7	++++	tr	—	—
5	Dwam/Yola-2	Nigeria	FPs	SuS	Tropic Fluvaquent	14-7	++++	++	++	—
6	Bende-2	Nigeria	IVs	EF	Fluvaquentic Epiaquept	14-7	++++	+	—	—
7	Mongonu-3	Nigeria	IVs	SaS	Oxic Ustropept	14-7	++++	tr	—	—
8	Abakaliki-5	Nigeria	IVs	EF	Typic Fragiudept	14-7	++++	—	—	—
9	Lumda-2	Nigeria	FPs	SaS	Typic Chromustert	14-7	++++	tr	—	—
10	Lumda-3	Nigeria	FPs	SaS	Oxic Ustropept	14-7	++++	+	—	—
11	Abakaliki-3	Nigeria	IVs	EF	Aeric Fragiaquept	14-7	++++	—	—	—
12	Abakaliki-2	Nigeria	IVs	EF	Fluvaquentic Epiaquept	14-7	++++	—	—	—
13	Gashua-1	Nigeria	FPs	SuS	Tropic Fluvaquent	14-7	++++	++	tr	—
14	Dwam/Yola-1	Nigeria	FPs	SuS	Typic Tropaquent	14-7	++++	+++	+++	—
15	Kadawa	Nigeria	FPs	SuS	Typic Tropaquent	14-7	++++	+	—	—
16	Bende-3	Nigeria	IVs	EF	Fluvaquentic Humaquept	7-14	++++	tr	—	—
17	Gadza/Bida-3	Nigeria	IVs	GuS	Typic Tropaquept	7-14	++++	+	—	—
18	WARDA-4	Côte d'Ivoire	IVs	EF	Typic Tropaquept	7-14	++++	+	+	—
19	Dwinyama-1	Ghana	IVs	EF	Typic Tropaquept	7-14	++++	—	tr	—
20	Gashua-2	Nigeria	FPs	SuS	Typic Tropaquept	7-14	++++	++	tr	—
21	Koutoukale-3	Niger	FPs	SuS	Tropic Fluvaquent	7-14	++++	+	—	—
22	Abakaliki-1	Nigeria	IVs	EF	Fluvaquentic Epiaquept	14-7	++++	—	—	—
23	WARDA-3	Côte d'Ivoire	IVs	EF	Typic Tropaquept	7-14	++++	+	+	—
24	Atani-1	Nigeria	FPs	EF	Typic Kandiudult	7-14	++++	++	++	—
25	Atani-2	Nigeria	FPs	EF	Tropic Fluvaquent	7-14	++++	++	++	—
26	Gao	Mali	FPs	SaS	Typic Tropaquent	7-14	++++	+	tr	—
27	WARDA-2	Côte d'Ivoire	IVs	EF	Typic Tropaquept	7-14	++++	+++	+	Ca tr?
28	Touba	Côte d'Ivoire	IVs	EF	Typic Tropaquept	7-14	++++	++	++	—
29	Atani-4	Nigeria	FPs	EF	Typic Tropaquept	7-14	++++	+++	++	—
30	Koutoukale-2	Niger	FPs	SuS	Tropic Fluvaquent	7-14	++++	tr	tr	—
31	Dwam/Yola-3	Nigeria	FPs	SuS	Typic Kandiustalf	7-14	++++	—	—	—
32	Ayorou	Niger	FPs	SaS	Tropic Fluvaquent	7-14	++++	+	+	—
33	Koutoukale-1	Niger	FPs	SuS	Tropic Fluvaquent	7-14	++++	tr	—	—
34	Seberi-1	Niger	FPs	SuS	Typic Pellustert	7-14	++++	tr	tr	—
35	Korienza-2	Mali	FPs	SaS	Typic Tropaquept	7-14	++++	tr	—	—
36	WARDA-1	Côte d'Ivoire	IVs	EF	Typic Tropaquept	7-14	++++	+	+	—
37	Oronaja	Nigeria	IVs	EF	Typic Tropaquept	7-14	++++	+	tr	—
38	Sakawa-1	Niger	FPs	SuS	Typic Udifluvent	7-14	++++	+	tr	—
39	Nyanpkala-1	Ghana	IVs	GuS	Tropic Fluvaquept	7-10-14	++++	—	—	—
40	Seberi-2	Niger	FPs	SuS	Typic Pellustert	7-14	++++	tr	—	—
41	Gadza/Bida-5	Nigeria	IVs	GuS	Typic Kandiustult	7-14	++++	tr	—	—
42	Korienza-1	Mali	FPs	SaS	Typic Tropaquent	7-14	++++	—	—	—
43	Nyanpkala-2	Ghana	IVs	GuS	Typic Kandiustalf	7-14	++++	—	—	—
44	Gadza/Bida-1	Nigeria	IVs	GuS	Typic Tropaquept	7-14	++++	+	tr	—
45	Sakawa-2	Niger	FPs	SuS	Typic Ustropept	7-14	++++	tr	—	—
46	Sakawa-3	Niger	FPs	SuS	Typic Udifluvent	7	++++	+	tr	—
47	Gadza/Bida-4	Nigeria	IVs	GuS	Aquic Quartzipsamment	7-14	++++	tr	—	—
48	Bende-5	Nigeria	IVs	EF	Aquic Kandiudult	7	++++	—	—	—
49	Gadza/Bida-6	Nigeria	IVs	GuS	Typic Kandiustult	7-14	++++	tr	—	—
50	Nupeko/Bida-4	Nigeria	FPs	GuS	Typic Kandiustalf	7-10	++++	++	+	Mv tr
51	Daloa-1	Côte d'Ivoire	IVs	EF	Typic Tropaquept	7	++++	+	tr	—
52	Niono	Mali	FPs	SuS	Oxic Ustropept	7	++++	tr	—	—
53	Makurdi-3	Nigeria	FPs	GuS	Tropic Fluvaquent	7	++++	+	—	—
54	Nupeko/Bida-1	Nigeria	FPs	GuS	Typic Tropaquept	7-10	++++	++	+	—
55	Gadza/Bida-2	Nigeria	IVs	GuS	Typic Tropaquept	7	++++	tr	—	—
56	Dogon	Mali	IVs	SaS	Typic Tropaquept	7-10	++++	+	—	—
57	Sawulia-1	Sierra Leone	IVs	EF	Typic Tropaquept	7	++++	++	—	—
58	Massina-2	Mali	IVs	SuS	Typic Tropaquept	7	++++	tr	—	—
59	Makurdi-1	Nigeria	FPs	GuS	Typic Ustifluvent	7	++++	tr	—	—

Table 1 Continued

Site No.	Location	Country	Topo-graphy [a]	Agro-eco zone [b]	Soil Taxonomy	Clay types [c]	Primary minerals [d]			
							Qt	K-Fds	Pg	Others
60	Baro-2	Guinea	IVs	GuS	Typic Tropaquept	7	++++	—	—	—
61	Daloa-2	Côte d'Ivoire	IVs	EF	Typic Tropaquept	7	++++	++	+	—
62	Sawulia-2	Sierra Leone	IVs	EF	Typic Tropaquept	7	++++	+	—	—
63	Massina-1	Mali	IVs	SuS	Typic Tropaquept	7	++++	+	—	—
64	Makurdi-2	Nigeria	FPs	GuS	Typic Udifluvent	7	++++	+	—	—
65	Dwinyama-3	Ghana	IVs	EF	Typic Kandiustalf	7	++++	—	—	—
66	Baro-1	Guinea	FPs	GuS	Typic Tropaquept	7	++++	++	—	Ch +?
67	Falaba-1	Sierra Leone	IVs	EF	Typic Tropaquept	7	++++	++	+	Ch tr?
68	San	Mali	IVs	SuS	Tropic Fluvaquept	7	++++	tr	tr	—
69	Kankan	Guinea	FPs	EF	Typic Ustropept	7	++++	++	+	Ch ++?
70	Niandan river	Guinea	FPs	EF	Tropic Fluvaquent	7	++++	++	—	Gb tr
71	Gueckedou	Guinea	IVs	EF	Typic Tropaquept	7	++++	+	tr	—
72	Makurdi-4	Nigeria	FPs	GuS	Aquic Kandiudult	7	++++	+	—	—
73	Mamou	Guinea	IVs	GuS	Typic Tropaquept	7	++++	++	+++	—
74	Djenne	Mali	IVs	SuS	Typic Tropaquept	7	++++	+	—	—
75	Kissidougou	Guinea	IVs	EF	Typic Tropaquept	7	++++	+	—	—
76	Nzerekore-1	Guinea	IVs	EF	Typic Tropaquept	7	++++	tr	—	—
77	Siguire	Guinea	FPs	GuS	Tropic Fluvaquent	7	++++	+	—	—
78	Mopti	Mali	FPs	SaS	Tropic Fluvaquent	7	++++	tr	—	—
79	Falaba-2	Sierra Leone	IVs	EF	Typic Tropaquept	7	++++	++	tr	—
80	Birinin Koni	Niger	FPs	SaS	Typic Ustifluvent	7	++++	—	—	—
81	Heremakono-1	Guinea	IVs	GuS	Typic Tropaquept	7	++++	—	—	—
82	Heremakono-2	Guinea	IVs	GuS	Typic Tropaquept	7	++++	—	—	—
83	Dwinyama-2	Ghana	IVs	EF	Typic Tropaquept	7	++++	+++	+	Ch tr?; Ca, tr?; Gb tr
84	Nzerekore-2	Guinea	IVs	EF	Typic Tropaquept	7	++++	+	—	—
85	Argungu-1	Nigeria	FPs	SuS	Tropic Fluvaquent	7	++++	—	—	—
86	Makurdi-5	Nigeria	FPs	GuS	Typic Kandiustalf	7	++++	tr	—	—
87	Argungu-2	Nigeria	FPs	SuS	Tropic Fluvaquent	7	++++	—	—	—

[a] IVs, inland valleys; FPs, flood plains

[b] EF, equatorial forest zone; GuS, Guinea savanna zone; SuS, Sudan savanna zone; SaS, Sahel savanna zone

[c] Abe *et al.* (2006)

[d] Abbreviations: Ca, calcite; Ca/Na-Fds, calcium- or sodium-feldspars; Ch, chlorite; Gb, gibbsite; Mv, muscovite; K-Fds, potassium feldspars; Ov, olivine; Qz, quartz; Zn, zircon

—, none; tr, trace; +, scarce; ++, minor; +++, common; ++++, predominant; ?, suspected

0.228 nm (Fig. 1). XRD analysis enabled to identify differentiate two types of feldspars, i.e. potassium-feldspars (K-Fds, diffraction between 0.332 and 0.318 nm but usually at 0.324 nm) and calcium- or sodium-feldspars (Ca/Na-Fds, reflection around 0.319 nm), as described by Shirozu (1988). In several cases, diffraction between 0.42 and 0.34 nm was also due to feldspars, although the value of *d*-spacing varied significantly with their structure. Feldspars were usually identified in these samples, although their contents were very low in most samples. On the other hand, K-Fds are more common in lowland soils of West Africa than Ca/Na-Fds, since K-Fds (orthoclase) would be more resistant to weathering than Ca/Na-Fds (plagioclase) (Oba and Nagatsuka, 1988). However, other minerals could be hardly identified by XRD analysis. For example, micas were scarcely observed in the fine-sand fraction even in the soils at sites Nos. 39, 50, 54 and 56, which contained a relatively high amount of illite (Abe *et al.,* 2006), because of the absence of diffraction at 1.0, 0.33 (biotite) or 0.31 nm (muscovite).

The petrographic investigation indicated that the mineral composition of the fine-sand fraction of some representative samples consisted predominantly of quartz (84-93%) (Table 2), which confirmed the results obtained by XRD analysis (Table 1). In addition, a small amount of zircon, a resistant mineral, was observed in these samples, although XRD analysis did not enable to detect zircon, since most intense peaks originating from zircon (0.330, 0.443 and 0.252 nm) would be masked by those of other minerals such as quartz and feldspars. The contents of weatherable minerals such as feldspars and muscovite were very low in these samples, and some of the minerals were undetectable by XRD analysis, as well. Accordingly, XRD analysis was considered to be limited for the detection of very low contents of minerals, which could be identified by the petrographic measurements.

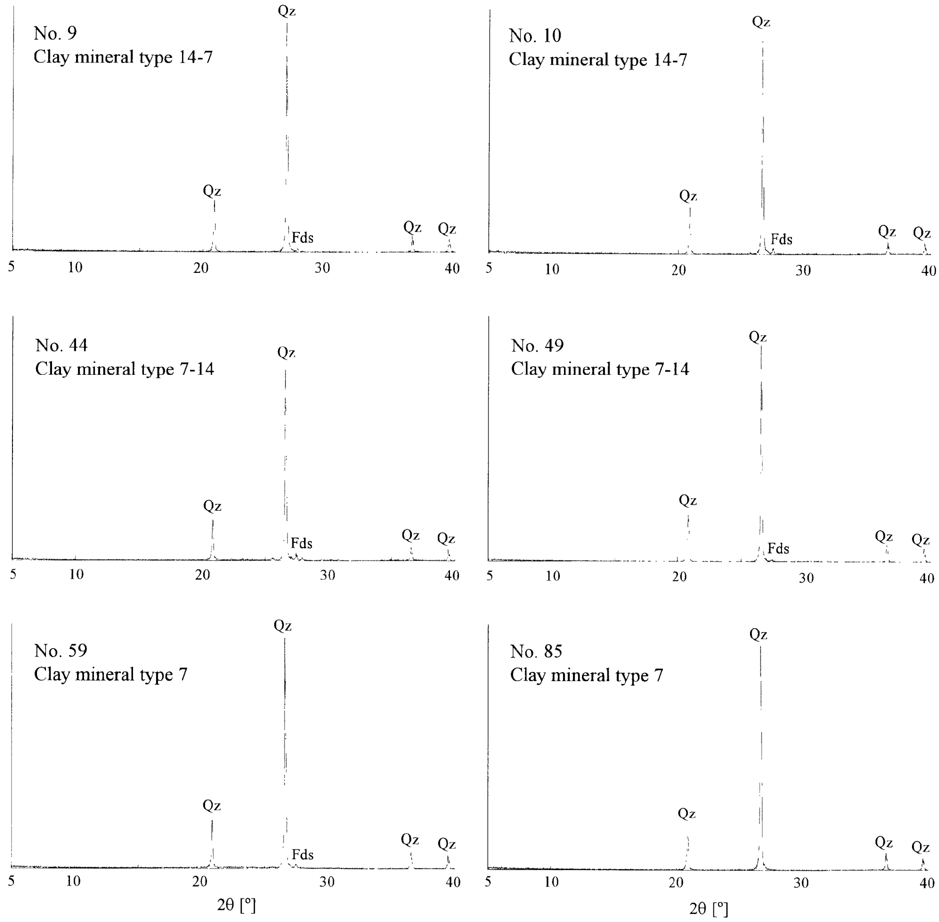

Fig. 1 XRD patterns of the fine sand fraction (20-212 μ m) of selected topsoil (0-15 cm) samples from lowlands in West Africa.

Table 2 Primary mineral composition of the representative samples revealed by the petrographic measurements

Site No.	Primary mineral composition (%)				
	Quartz	Muscovite	Feldspars	Zircon	Opaque
5	84	—	5	7	4
9	84	—	8	8	—
10	90	—	7	3	—
31	88	—	6	3	—
44	92	2	4	2	—
47	90	—	4	6	—
49	87	—	5	5	3
59	90	4	4	2	—
72	93	—	3	4	—
85	92	—	4	4	—

The composition was calculated as the percentage of individual mineral grains to total grains counted.

However, even if some other XRD-undetectable minerals coexisted in the fine-sand fraction, quartz and feldspars, chiefly the former, undoubtedly accounted for the most part of this fraction. The total elemental analysis of these samples performed by Buri *et al.* (2000) also supported the findings of the present study, because of the low levels of total basic oxides (K_2O, CaO and MgO) but high contents of SiO_2, Al_2O_3 and Fe_2O_3, in addition to the high Si/Al ratio.

XRD analysis and the petrographic measurements revealed that the mineralogical composition of the fine-sand fraction was much more monotonous than that of the clay fraction that was described by Abe *et al.* (2006). On the other hand, there was no trend in the findings of the primary mineral composition between soils with contrasting clay mineral types or between soils in inland valleys and flood plains exposed to different climatic conditions (Table 1). These results suggested that strong weathering over a long period of time has led to a substantial destruction of weatherable minerals in the fine-sand fraction and had masked the inherent characteristics of parent rocks, regardless of the differences in the clay mineral composition. However, Abe *et al.* (2006) assumed that the clay mineral composition of these soils reflected the nature of the parent materials rather than the effects of climatic and topographical conditions, based on the geographical distribution of the soil clay mineral types.

Conclusion

In the present study, it was demonstrated that prolonged and intensive weathering resulted in the substantial destruction of weatherable minerals and in the predominance of persisting resistant minerals like quartz in the lowland soils of West Africa. These findings could reinforce general assumptions (e.g., Moormann and Veldcamp, 1978) that had not been corroborated by sufficient scientific evidence.

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西アフリカ７カ国の低地より採取した表層土壌試料の一次鉱物特性

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