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Clay mineralogy and its relationship to soil solution composition in soils from different weathering environments of humid Asia: Japan, Thailand and Indonesia

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Abstract

We studied the relationship between the clay mineralogy of subsurface soils from 204 sites and their water extracts in upland soils of humid Asia (Japan, Thailand and Indonesia) to understand their formation. The clay minerals were identified by XRD and the kaolin minerals and gibbsite were quantified with DTA. Their thermodynamic stability was related to the ion activity of soil water extracts. In soils on mica-free andesitic or mafic parent material, kaolin minerals and smectite dominated in all regions. Among mica-containing soils derived from felsic or sedimentary rocks, mineralogical and soil solution compositions indicate that, in Thailand, mica was stable at high pH (5.4–6.5), whereas in soils from Japan and Indonesia mica turned into hydroxy-Al interlayered vermiculite (HIV) or vermiculite at lower pH (4.3–5.5). In Japanese soils, HIV and gibbsite form under high activity of Al–OH species. In contrast, the low activity of Al–OH species in Indonesian soils resulted in the dissolution of Al hydroxides between 2:1 layers and gibbsite and the dominance of kaolin minerals and vermiculite. We conclude that three factors play an important role for the clay mineralogy in humid Asia: the nature of parent material (i.e. presence or absence of mica), soil pH (as affected by precipitation and evapotranspiration) and activity of Al–OH species in soil solution (reflecting soil age).

Keywords: 2:1 type clay minerals; Hydroxy-Al interlayered vermiculite; Vermiculite; Gibbsite; Thermodynamic analysis; Stability diagram

1. Introduction

To assess inherent soil fertility for appropriate large-scale land management, it is important to understand how clay mineralogy relates to geological and weathering conditions. Important processes in the formation of clay minerals are the neoformation of gibbsite, kaolin minerals and smectite, and the transformation of mica. Neoformation is mainly controlled by $H_4SiO_4^0$ activity. Gibbsite forms under conditions of strong desilication, where $H_4SiO_4^0$ activity is low (Huang et al., 2002). Kaolin minerals form under moderate $H_4SiO_4^0$ activity conditions and smectite under high activity (Reid-Soukup and Ulery, 2002). Mica, which is commonly present in felsic and sedimentary rocks, weathers to vermiculite and smectite, with a decrease in the layer charge and release of alkaline metals. The increased resistance to weathering of dioctahedral mica means that dioctahedral

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Table 1
Fundamental information and general physicochemical properties (-S: sedimentary origin, -V: volcanic origin, JV: Java, SM: Sumatra, EK: East Kalimantan)

Sample group	Sample name	Soil classification	Parent rock	Horizon	Depth (cm)	pH		Total C (%)	CEC (cmolc kg^{-1})	Exchangeable cations				Particle size distribution		
						(H_2O)	(KCl)			Ca (cmol$_c$ kg^{-1})	Mg (cmol$_c$ kg^{-1})	K (cmol$_c$ kg^{-1})	Na (cmol$_c$ kg^{-1})	Sand (%)	Silt (%)	Clay (%)
Japan (JP)	JP1	Typic Dystrudepts	Granite	Bw	7–20	4.4	3.9	3.1	14.0	0.00	0.00	0.17	0.07	57	17	27
				BC	32–42	4.5	4.1	0.7	8.9	0.00	0.00	0.13	0.05	61	12	27
Mesic–thermic (12.1 °C)	JP2	Typic Udorthents	Granite	C1	4/7–32/39	4.9	4.2	0.9	6.9	0.00	0.00	0.17	0.08	66	15	19
Udic (1508 mm)				C3	55/65–92	5.1	3.9	0.1	5.3	0.16	0.00	0.14	0.09	70	13	16
Potential evapotranspiration	JP3	Typic Dystrudepts	Rhyolite	AB	8–17	4.8	3.6	0.7	9.9	0.42	0.35	0.16	0.06	56	25	19
(700 mm)				BC	30–40	5.0	3.6	0.3	9.4	0.50	0.23	0.18	0.06	55	23	22
(Shiga, Kinki)	JP4	Typic Dystrudepts	Rhyolite	AB	9–20	4.6	3.7	1.1	14.8	0.08	0.00	0.15	0.06	39	25	35
				BC	33–45	4.6	3.9	0.4	12.1	0.00	0.00	0.11	0.07	57	15	28
	JP5	Acrudoxic Melanudands	Andesitic volcanic ejecta	AB	35–44	5.0	4.6	9.4	34.7	0.18	0.00	0.17	0.04	38	27	35
	JP6	Typic Dystrudepts	Gabbro	AB	6–12	4.3	3.7	4.5	24.9	0.79	0.36	0.20	0.09	22	33	45
				Bw	23–39	4.5	3.8	1.2	20.2	0.17	0.00	0.10	0.07	23	31	46
	JP7	Lithic Haplorthods	Shale	E	2.5–11	3.5	3.2	3.0	18.9	0.00	0.00	0.14	0.09	43	27	30
				Bs	11–27	3.8	3.7	3.9	27.8	0.00	0.00	0.23	0.11	32	23	45
	JP13	Alic Hapludands	Shale	Bw1	24–38	4.5	3.9	6.1	26.9	0.05	0.09	0.07	0.05	20	32	48
Thailand (TH)	TH1	Typic Haplustults	Granite	AB	10–20	5.5	4.1	0.9	7.9	0.05	0.69	0.23	0.01	60	15	26
				Bt	30–40	5.4	4.0	0.7	8.5	0.05	1.43	0.28	0.02	52	15	33
Isohyperthermic (25.9 °C)	TH2	Typic Haplustults	Granite	Bt	30–40	5.5	4.1	0.8	13.9	0.51	1.24	0.60	0.02	43	12	46
Ustic–udic (1197 mm)	TH3	Ustic Haplohumults	Granite	Bt	30–40	5.5	4.3	1.0	9.6	2.39	0.73	0.31	0.02	53	16	32
Potential evapotranspiration	TH4	Ustic Haplohumults	Granite	Bt	30–40	5.5	4.2	1.5	17.3	0.16	0.20	0.46	0.03	34	17	49
(1587 mm)	TH5	Kanhaplic Haplustults	Andesite–rhyolite	Bt	30–40	5.7	4.1	0.6	11.3	0.09	0.00	0.50	0.04	17	29	54
(Chaing Mai, northern Thailand)	TH6	Ustic Haplohumults	Shale	Bt	30–40	5.2	4.0	1.3	17.5	0.12	0.65	0.40	0.02	7	15	78
	TH7	Kanhaplic Haplustults	Sandstone–mudstone	AB	10–20	6.5	5.0	1.8	11.8	3.70	2.43	0.47	0.03	32	22	46
				Bt	30–40	5.5	4.4	0.9	12.5	0.95	1.28	0.19	0.02	22	17	61
	TH9	Ustic Haplohumults	Sandstone–mudstone	Bt	30–40	5.0	4.0	1.4	18.4	0.56	0.81	0.47	0.03	8	23	69
	TH10	Typic Dystrustepts	Sandstone–mudstone	Bw	30–40	5.0	3.9	0.4	7.9	0.06	0.32	0.45	0.04	55	15	30
	TH11	Kanhaplic Haplustults	Sandstone–mudstone	Bt	30–40	4.8	4.0	0.9	12.4	0.24	0.18	0.06	0.05	14	29	57
	TH12	Ustic Haplohumults	Sandstone–mudstone	Bt	30–40	5.2	4.0	1.3	21.7	0.18	0.73	0.19	0.05	10	14	76
	TH13	Ustic Haplohumults	Sandstone–mudstone	Bt	30–40	5.4	4.0	1.1	14.6	0.48	0.29	0.53	0.02	10	25	65
	TH14	Andic Dystrustepts	Sandstone–mudstone	Bw	30–40	5.1	4.4	4.7	17.7	0.55	1.74	0.30	0.01	42	24	35