Introduction to Studies on Volcanic Ash Soils in Japan and International Collaboration

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1. Outlining properties of volcanic ash soils

The Japanese Islands are the places where 4 tectonic plates, that are Pacific, North American, Eurasia and Philippine Sea plates, meet. There are active volcanoes more than 80, and medium and small-scale eruptions frequently occur somewhere in Japan. Volcanic ash soils cover approximately one-sixth of the Japanese land surface. Volcanic ash soils are mainly distributed in southern and eastern parts of Hokkaido, eastern part of Tohoku, Kanto, Chubu, around the Mt. Daisen in Chugoku, and central and south Kyushu districts (Saigusa and Matsuyama, 1998). The word "volcanic ash soil" is used for any soil derived from volcanic ash. Kurobokudo is a name used more specifically for a black and fluffy soil, and is the major soil derived from volcanic ash on the uplands in Japan. Kurobokudo, Andisols, Andosols and Ando soils are the names used for the volcanic ash soils rich in active Al and Fe, and the definitions of these words are similar in many respects. In this paper, "Ando soils" is used as a common name.

a. Morphological properties

The matured Ando soils show a unique set of morphological, mineralogical, chemical and physical properties. A thick, humus-rich, dark-colored A horizon underlain by a brown Bw horizon is a typical profile of these soils. The black A horizon is formed under grass vegetation dominated by C4 plants (Yoneyama et al., 2001) and the grass vegetation was maintained by intensive human activities like setting fire to the fields. On the other hand, the dark brown A horizon is formed under forest vegetation. Thick multi-sequum soils locate near large volcanoes as a result of repeated huge eruptions with long dormant periods. Fresh deposits of air-borne ash and lahar are sandy layers, and they are vitrandic Entisols or volcanogenous regosols.

b. Mineralogical properties

Volcanic glass is the major component of the fresh volcanic ash and it is the major parent material of the Ando soils. Non-crystalline or poorly crystalline minerals such as allophane, imogolite, ferrihydrite and opalline silica are the characteristic secondary minerals in the Ando soils. Allophane has a very small hollow spherical structure 3 to 5 nm in diameter (Wada, 1989). Imogolite has very thin tubular structure 1 and 2 nm in inner and outer diameters, respectively. The typical allophane shows elemental composition close to $SiO_2 \cdot Al_2O_3 \cdot nH_2O$ similar to that of imogolite (Wada, 1989). Opalline silica shows thin ellipsoidal shape, consists mostly of silica, and is often found in the A horizon of young Ando soils (Shoji and Masui, 1971).

c. Chemical properties

Ando soils show unique chemical properties such as high phosphate sorption capacity, variable charge, etc. due to abundant non-crystalline secondary minerals and highly humified humus complexed with Al (Shoji et al., 1993). Phosphate is sorbed by the active Al contained in allophane, imogolite and Al complexed with humus and by the active Fe in ferrihydrite. A series of reactions are accompanied by the phosphate sorption such as a decrease in the amount of positive charge of the soil, release of hydroxide ion, silicate ion and soluble organic matter from the soil, and an increase in negative charge of the soil (Nanzyo and Watabanbe, 1981; Nanzyo, 1988). The variable charge means the amount of positive and negative charges dependent on pH and concentration

of an indifferent electrolyte. The positively charged site is formulated as a protonated hydroxo-ligand bound to active Al and Fe. The negative charge arises from dissociation of hydroxyl group bound to the active Al and Fe and dissociation of carboxyl groups. The negative variable charges show high preference to multivalent cations, including heavy metals (Wada, 1989).

d. Physical properties

The noncrystalline and poorly crystalline secondary minerals and humus also affect the physical properties of Ando soils (Shoji et al., 1993). Allophane, imogolite, ferriydrite and humus form stable and highly aggregated structures that have abundant micro, meso and macro pores. These highly porous structures hold a large amount of hygroscopic and plant-available water. The porous structure also leads to high hydraulic conductivity of these soils. The highly porous structure is the reason for the low bulk density of these soils. Due to the high stability of porous micro aggregates that accommodate water inside, these soils show high liquid and plastic limits. Allophane and imogolite hardly disperse at neutral pH range because they have the zero point of charge in this pH range. Abundant humus further stabilizes the aggregated structure. Water holding capacity, dispersibility of noncrystalline clays, liquid and plastic limits of these soils irreversibly decrease with drying.

e. Classification

Some of the properties mentioned above are used in the criteria of soil classification systems. High phosphate sorption capacity defines the Kuroboku soil group in the classification of Japanese cultivated soils. The Kuroboku soil group corresponds to Andisols in the Soil Taxonomy (ST) of the United States Department of Agriculture (Soil Survery Staff, 1999; 2006), and Andosols of the World Reference Base for Soil Resources (WRB) (FAO, 2006). Abundant oxalate-extractable Al and Fe, low bulk density and high phosphate retention are the important requirements to define matured Andisols and Andosols (WRB). Volcanic glass content is also used to characterize young Andisols and vitric Andosols (WRB). Subdivision into allophonic and nonallophanic ones according to the predominance of allophane-imogolite or Al-humus complex is included at least partly in all the classification systems of the Kuroboku soil group, Andisols and Andosols (WRB).

f. Genesis

Ando soils are mostly formed on uplands under humid climates (Shoji et al., 1993; 2006). Volcanic glass, commonly rich in Si, is dissolved forming Al-rich colloidal materials that are allophane, imogolite

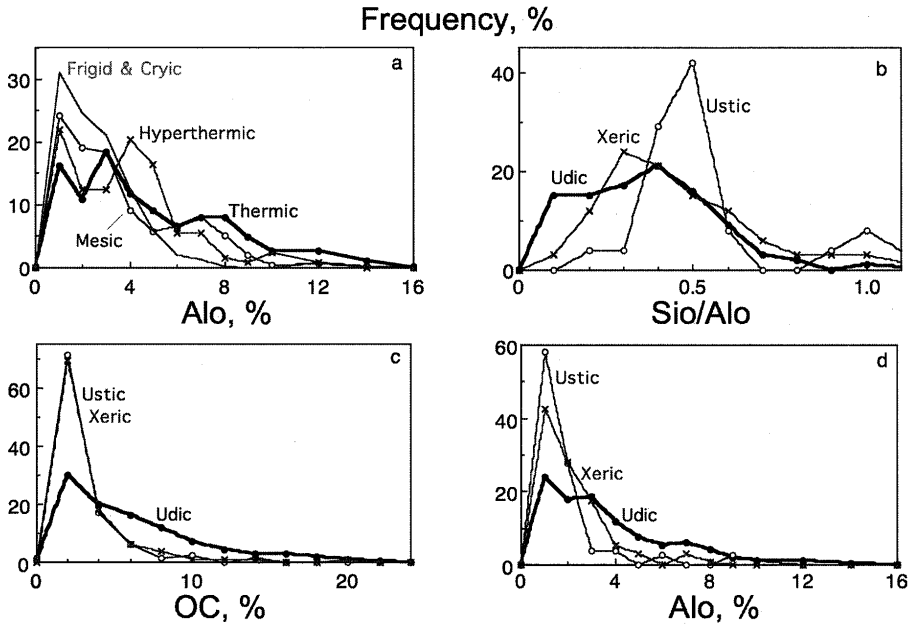

Fig. 1. Effect of climate on Ando soil formation (Shoji, et al., 2006).

and Al-humus complex and Fe-rich ferrihydrite. Rapid dissolution of volcanic glass and removal of Si and basic cations needs humid climate and location on uplands with good drainage (Fig. 1). Inceptisols are also formed under semi-dry and dry climates and in the poorly drained areas possibly due to slower removal of Si. Spodosols are possibly formed under humid and cold climate due to intensive formation of soluble chelating organic materials in the overlying organic layer (Shoji et al., 2006).

g. Utilization

Ando soils in Japan were previously the problem soils due to phosphorus deficiency, high Al toxicity of non-allophanic Ando soil, Cu and Zn deficiency and so on. These chemical problems have been amended and the Ando soils are used as excellent upland fields having good physical properties such as high air and water permeability, and high water holding capacity (Shoji et al, 1993). Root crops such as horse raddish, chinese yam, burdock, are especially suitable for Ando soils as well as many other upland crops. In the tropical countries, Ando soils are relatively graded better than in Japan possibly due to high temperature enhancing phosphorus release, nitrogen mineralization and plant growth.

2. Studies on volcanic ash soils in Japan

It is almost a century since Seki's early work on volcanogenous loam was published (Shoji et al., 1993). Several monographs on volcanic ash soils were published in English in the latter half of the 20th century. In 1964, the Ministry of Agriculture and Forestry (1964), Japanese Government, compiled "Volcanic Ash Soils in Japan". The book includes ten chapters that are distribution of volcanic ash soils, land use, soil minerals, physical properties, soil erosion, chemical properties, microbiological properties, classification, valuation on productivity of volcanic ash soils, and development of soil productivity. By that time, variable charge properties (Iimura, 1966) and high phosphate sorption capacity of Ando soils were recognized, and Yoshinaga and Aomine (1962) discovered imogolite. Humic acid type in Ando soils was found to resemble that of Tsuernozems by Kumada et al. (1967). In 1986, Wada published "Ando Soils in Japan". This book includes detailed soil characterization data of 26 soil profiles covering south to north of representative sites in Japan (Wada, 1986). By that time, opalline silica was reported by Shoji and Masui (1969) in the A horizon of young Ando soils. Then, unique shape of allophane particles was described by Kitagawa (1971) and was confirmed by Henmi and Wada (1976). A comprehensive book "Volcanic Ash Soils-genesis, properties and utilization was published by Shoji, Nanzyo and Dahlgren (1993) integrating the developments made by International Committee on the Classification of Andisols (ICOMAND) and other research works from all over the world as well as those from Japan. By this time, the Andisol order was established in ST as the eleventh soil order (Eswaran and Beinroth, 2000).

Moreover, many valuable review papers and special issues on Ando soils were published by Japanese authors as follows: Amorphous clay constituents of soils (Wada and Harward, 1974), Physical properties of allophane soils (Maeda et al., 1977), The distinctive properties of Andosols (Wada, 1985), Allophane and imogolite (Wada, 1989), Clay mineralogy and chemistry of soils formed in volcanic material in diverse climatic regions (Mizota and Reeuwijk, 1989), Volcanic ashes and their soils (Matsumoto, 2002), The nature, properties and management of volcanic soils (Dahlgren et al., 2004), and Factors of soil formation: climate. As exemplified by volcanic ash soils. (Shoji et al., 2006).

3. International collaboration

Many collaborative works between Japan and overseas countries have been done to develop sciences on volcanic ash soils. The name "Ando soils" was introduced in 1947 during reconnaissance soil survey in Japan by American soil scientists (Simonson, 1979; Hirai and Hamazaki, 2004). In 1964, FAO soil correlation meeting on volcanic ash soils was held in Tokyo. During this meeting, the attendants visited 8 pedons in Hokkaido, Kanto and Kyushu districts, and definition of Kurobokudo were discussed based on their properties (Oyama, 1965). Two seminars on amorphous materials in soils were held at Kyushu University and Oregon State University in 1969 and 1976, respectively, for the direct exchange of information and cooperative studies (Van Olphen, 1971; Haward and Wada, 1976). In 1978, ICOMAND was established after the Andisol proposal of G.D. Smith. Many workshops and meetings were held during the ICOMAND activities for more than 10 years (Eswaran and Beinroth, 2000). The 9th International Soil

Fig. 2. Participants to 9th International Soil Classification Workshop.

Classification Workshop was held in Kanto, Tohoku and Hokkaido districts, Japan, in 1987 (Fig. 2). The tour guide describing geological and climatic information, morphology of soil profiles and characterization data of 23 pedons were delivered at the meeting (SMSS and Japanese Committee of the Ninth International Soil Classification Workshop, 1987; Shoji and Otowa, 1987) and the proceedings were published by Kinloch et al. (1988). The number of attendants was about 120 from Japan and 40 from 16 overseas countries. The central concept of Andisols was revised from the exchange complex dominated by amorphous materials to abundant active Al and Fe including humus-Al complex during the ICOMAND activities. Collaborative works were also done in Indonesia (Miyake, 1983) and Philippines (Otsuka et al., 1988; Otsuka, 1991; Yoshida and Takahashi, 1992; BSWM and SRDC, 1993; Samonte et al. 1995; Nanzyo, 1996; Nanzyo et al, 1999) under the projects and supports of the former Tropical Agricultural Research Center, Japan International Cooperative Agency, the Japanese Government, and the Ministry of Education, Science, Sports and Culture of Japan.

Many Japanese researchers visited USA, New Zealand, European countries etc., to attend meetings and to study Ando soils in overseas countries. The meeting on soils with variable charge was held in New Zealand in 1980 (Theng, 1980). International symposium was held on Rehabilitation and Improvement of Productivity in Pinatubo Lahar and Ashfall Areas in Central Luzon, Philippines (National Research Council of the Philippines, 1997). A series of meetings were held between 1998 and 2004 as the European Cooperation in the field of science and technical research (COST) action titled Soil Resources of European Volcanic Systems (COST-622) (Bartoli et al., 2003; Arnalds and Stahr, 2004; Oskarsson and Arnalds; 2004; Arnalds et al., 2007; Buurman et al., 2007). The Field Science Center, Tohoku University held an meeting on New Perspectives of Volcanic Ash Soils in the Integrated Ecosystems in 2004 having 6 speakers from overseas countries in the Circum Pacific Volcanic Zone (Nanzyo et al., 2005). Recent developments of the studies on Ando soils were discussed and a field workshop was held in the Mt Fuji area in Japan (Takesako, 2006; Lowe, 2006). The main objectives of IVth International Symposium on Deteriorated Volcanic Soils (ISVO'06) were to promote the exchange and discussion about the general problem of deteriorated volcanic soils, the improved management approaches and the challenges that lie ahead of the agricultural and soil scientists, and particularly of the farmers living in volcanic regions all over the world (Bravo et al., 2006). Participants were from Central and South America, Europe, USA and Japan. Intensive research activies of the European soil scientists in collaboration with the Central and South American countries were introduced in this meeting.

The titles of symposium related to Andosols in the recent World Congresses of Soil Science are "Physical, chemical and mineralogical characteristics of Ando soils" at Kyoto in 1990, "Indurated volcanic

soils: use and management" at Acapulco in 1994, "Crystal chemistry of trace elements and evolution in soils of short range ordered minerals" at Montpellier in 1998 and "Andisols and related soils" at Philadelphia in 2006. Many presentations on the clay fraction of Ando soils and a session on "soil and non-crystalline clays" were included in the International Clay Congress held in Japan in 1969 (Heller, 1969; 1970) and in 2005 (Narita, 2006), respectively.

4. Perspectives

Human impacts on soils and environments are increasing now. Even under these situations, objectives of soil science are to elucidate material cycles quantitatively in the surface layer of the earth, to control the material cycles for environmental conservation and sustainable crop production, to keep the soil quality high, etc. High buffering capacities of Ando soils in many reactions appear useful to ameliorate some environmental problems. International collaboration will contribute to exchange our information and help our development because the properties of Ando soils are dependent on regional climates and human activities. Integration of developments in the different scientific fields and new fact-findings will also be effective to approach our goals.

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