VOLCANIC SOILS

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Contents

Summary

This chapter gives an overview of the distribution, classification and main mineralogical, physical and chemical properties of volcanic soils. It discusses their land use potential and limitations for various uses, ranging from engineering to agricultural, rangeland and forestry uses, as well as to environmental considerations.

Many volcanic soils have excellent physical properties that make them highly desirable for a wide range of uses. Chemically, they suffer from a high phosphate retention, and they may be limiting in K and some micronutrients. Nevertheless, these soils are amongst the most fertile lands in the world and are, therefore, very intensively cultivated, even if the users are aware of the risks of volcanic outbursts.

1. Introduction

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Volcanic soils cover 1% of the Earth's surface yet support 10% of the world's population, including some of the highest human population densities. This is usually attributed to their high natural fertility. However this is true only in part. Clearly such soils represent the surface areas of our planet that are being replenished with new minerals escaping from the interior of the Earth. However, some deep magmatic processes do lead to an imbalance of elements in volcanic soil parent materials which can impact on the health of plants and animals growing in or on them. In contrast, all other soils express various stages of the degradation (weathering) of these minerals. This account addresses the specific features and genesis of volcanic soils, how they are classified, the problems when they are farmed or cropped, and how they are used and abused in various global environmental settings.

2. Parent Materials

As their name implies, this grouping of soils is found only on volcanic parent materials. Few other soils are restricted to a single type of material except organic soils derived from peat, and rendzinas from limestone. The reason for this distinction is because of the unique combination of soil properties that result from the weathering of volcanic rocks and in particular volcanic glass. Only under strong tropical weathering will lavas weather to finer grained volcanic soils, so it is usually parent materials of a volcaniclastic origin which result in the high-producing volcanic soils of the world. Soils formed directly from lava are usually low producing (and some may not fit the definition of an Andisol – see below).

Volcaniclastics are usually grouped into two main divisions of pyroclastic (explosive) and epiclastic (erosional) origin. Pyroclastics include the deposits of incandescent, high velocity gas charged clouds with entrained rocks and sand; close to source ballistics that include molten volcanic bombs or vesiculated scoria (or cinders); and aerially ejected particles that travel high into the atmosphere (tephra) before falling back to earth, usually cold. Tephra particles range from ash (<2 mm), to lapilli (2-64 mm), to blocks (solid) and bombs (molten) (>64 mm). Epiclastics include all the forms of volcaniclastic remobilization on the landscape post-deposition and include deposits from volcanic debris avalanches; volcanic mudflows, debris flows and hyper-concentrated streamflows (lahars); alluvium on the flanks of a volcano; and volcanic loess (deposited by the wind in more arid and high altitude environments). Of soils directly formed from lava, it is basaltic lavas that form the most extensive volcanic soil parent materials because of this lava's low viscosity and ability to flow large distances on low gradients.

Irrespective of the chemical composition of the volcanics, all will contain varying proportions of volcanic glass which provides the initial distinctive weathering products of this soil grouping. Generally the lower silica, higher mafic (high magnesium and iron) volcanics tend to weather more readily than the higher silica, lower mafic (high sodium and potassium) volcanics. Two other variables are the initial grain size and the vesicularity of the parent materials. For example, a dense, high silica rhyolite will weather considerably more slowly than a less dense and highly vesicular pumice of identical composition. This is mainly related to the much greater surface area available in the pumice to weather and break down to primary weathering products.

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Volcanic soils are usually the dominant soil in young volcanic landscapes (but may be in association with lesser areas of other soils such as organic soils). Coarser textured soils tend to occur on the flanks of most stratovolcanoes, shield volcanoes and tuff cones, as well as in proximity to calderas, where they are usually pumice dominant. Surrounding the volcanoes and for large distances downwind there may be a wide variety of landscapes upon which finer ash has accumulated over thousands of years by tephra accretion. On surrounding lowlands the tephras may have accumulated to great thickness (from 1 to >10 m depth) producing deep fertile volcanic soils. In contrast, in hilly landscapes the tephras may be of variable thickness due to past erosional histories, more especially during the Last Glacial Maximum, leading to shallow bedrock and thinner soil profiles.

3. Distribution

Volcanic soils cover more than 124 million hectares of the Earth's surface. The major areas of volcanic soils rim the Pacific where oceanic plate subduction produces extensive rhyolitic and andesitic volcanism. Major areas of volcanic soils occur in Chile, Peru, Ecuador, Colombia, Central America, the United States, Kamchatka, Japan, the Philippines, Indonesia, New Zealand, and the independent island states of the south-west Pacific. Basaltic volcanism dominates in the islands of the Pacific, Indian and Atlantic oceans where new lithosphere is being added to existing plates, such as in Iceland or where hot mantle plumes pierce through the lithosphere, as in Hawaii.

The second major area of volcanic soils extends along the East African Rift Valley where the Nubian and Somalian plates diverge, and through the Mediterranean region where the Nubian and European plates converge. The third significant region is in the equatorial Atlantic, principally comprising the Canary Islands and the Azores, plus the many islands of the West Indies, where volcanic soils are a major natural resource to the economies of many small island states.

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4. Classification

An in-depth study and classification of volcanic soils received major attention in the second half of the 20th century. The aim was to quantitatively define what is meant by a volcanic soil, in particular in countries of the circum-Pacific margin. In Japan, these soils carried an unusually dark black topsoil (epipedon) assigned by the name "ando" or dark soil. Apparently, these black surface layers are not so much a result of the volcanic origin but of a property inherited from the original vegetation.

When the FAO/UNESCO (1974) Soil Map of the World was compiled, there was international agreement that volcanic soils be designated in their own order of **Andosols**. Key criteria included a low bulk density (<0.85 g cm^{-3} in the < 2 mm fraction at – 33 kPa water retention); an exchange complex dominated by amorphous material; and/or ≥ 60% vitric volcanic ash, cinders or other vitric pyroclastic material in the profile. Four suborders were recognized, three of them being based on the nature of the organic horizon at the surface; they were distinguished into Mollic, Humic and Ochris Andosols. The fourth suborder identified the glassy or pumiceous Vitric Andosols. The FAO/UNESCO terminology is followed in this text, except where specific reference is made to Soil Taxonomy (1999).

The United States Soil Conservation Service had been contemporaneously devising a new system of soil classification, which at the time was internationally known as the Seventh Approximation. This system was published as Soil Taxonomy (1975), in which volcanic soils which were neither Entisols nor Podzols were grouped into the Inceptisols as a suborder of Andepts. Subsequently, as this system was applied outside of the United States, it became apparent that this placement did not allow sufficient information to be conveyed about climatic conditions which related to their expected behavior.

In 1978, it was proposed to elevate these soils to a new order of **Andisols** (maintaining the etymology of not using an "o" as a connecting vowel for words without Greek formative elements). This new name served to distinguish the United States soil order and the FAO/UNESCO term. An International Committee on the Classification of Andisols (ICOMAND) then worked over 12 years to elevate the suborder to order status and check out its validity at numerous locations around the world.

In the second edition of Soil Taxonomy (1999) the Andisols are recognized at the Order level as those soils having **andic soil properties** in more than 60% of the profile thickness, or are developed from cindery, fragmental or pumice materials, and do not fit the definition of Entisols or Histosols. The definition of andic soil properties recognizes the distinctive Andisol properties and attempts to define them quantitatively. In this revision, suborders now recognize distinctive anaerobic, very cold, tropical, arid, and seasonally dry environments, together with those soils derived from very glassy parent materials (that do not fit the andic criterion). The definition of andic soil properties is intended to recognize the limits in properties associated with Andisols.

A clear distinction is made between Andisols and Entisols in Soil Taxonomy (1999) because recently deposited volcaniclastics do not have andic soil properties; they cannot be inherited, rather they take time to develop. Hence an Andisol must show a degree of pedogenic alteration from its primary parent material. Clearly the alteration is an expression of weathering which produces a continuum of soils along which some threshold values have been chosen to define andic soil properties. So too, with advanced weathering andic soil properties may be lost with changes in soil profile development (e.g. podzolization) or clay mineralogy, (e.g. formation of Ultisols).

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5. Distinctive Clay Mineralogical Properties

Volcanic glass is usually the first component of volcanic rocks to undergo weathering. Depending on its silica content it may be resistant (high silica) or susceptible (low silica) to degradation to clays. The clays that form first are very distinctive (but are not exclusive) to volcanic soils. They were originally thought to lack any crystalline structure because no distinctive peaks could be determined on x-ray diffraction analysis, and so were referred to as "amorphous" clays. Subsequently higher resolution techniques of differential x-ray diffraction, infra-red, differential thermal analysis, and electron microscopy have revealed four distinctive clays that are common to volcanic soils and show a "weak" degree of crystallinity that is referred to as "short range order".

Hence they can be referred to as "short range order clays" (SROC).

The first of these SROCs to be identified was the aluminosilicate **allophane**. Under electron microscopy (EM) it can be identified by its indistinctive "grainy" appearance, but under high resolution EM it can be seen to comprise hollow spherules of 3.5-5.5 nm diameter. The thickness of the wall of the spherules is estimated to be 0.7 nm. A second aluminosilicate named **imogolite**, of similar composition to allophane, was identified by EM as a tubular, thread-like material with internal and external diameters of 1.0 and 2.0 nm respectively; so fine its wall thickness is only 5 atoms thick. Subsequently a third SROC named **proto-imogolite** has been identified as a precursor of imogolite. All have specific surface areas of about 1000 m^2 g.

Allophane is thought to form inside weathered glass fragments or pumice grains in which the hydrolysis of glass proceeds at a high silicon concentration and high pH, whereas imogolite is thought to form outside, possibly by alteration of allophane, being exposed to external solutions of lower silicon concentration and higher acidity, or by precipitation from such solutions. The potential transformation of these clays from one form to another under varying environmental conditions, and to other clays has been extensively debated in the literature. The generally accepted model would be that SROCs are intermediary steps between the hydrolysis of volcanic glass and feldspars to more ordered clay minerals like halloysite, kaolinite, gibbsite and montmorillonite.

A fourth SROC named **ferrihydrite**, is an iron hydroxide that weathers from intermediate and mafic glasses or from mafic crystals in the primary volcanic parent material. Its presence can be quantified by the difference between dithionite citrate-extractable and oxalate–extractable iron. Ferrihydrite has a surface chemistry that in many ways behaves like allophane.

In older volcanic soils that are in more advanced stages of weathering, halloysite and gibbsite appear more common as SROCs decrease. Ultimately smectites and chlorites may form pedogenically (or become incorporated from loess or aerosolic dusts). In unusual circumstances zeolites may also be important.

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Biographical Sketch

Vincent Neall is Professor in Earth Science at Massey University, in Palmerston North, New Zealand. He completed his BSc(Hons) in 1967 and PhD in 1973 at the Geology Department, Victoria University of Wellington. He is a Fellow of the Geological Society of America and the New Zealand Society of Soil Science.

His principal research interests during his career have centered on volcanic deposits, volcanic soils, volcanic hazards, and more recently volcanic risk. He has worked on volcanic soils in the U.S.A., Fiji, Papua New Guinea and New Zealand, including recent research associated with archaeological sites and artifacts found within volcanic ash (extending back to 40,000 years ago in PNG). He has produced a number of maps of volcanic soils, as well as Quaternary volcanic maps and volcanic hazard maps. For his research work he received the McKay Hammer Award and the Hochstetter Lectureship of the Geological Society of New Zealand; the Norman Taylor Award of the NZ Society of Soil Science; and a NZ Science and Technology Medal from the New Zealand Government. He is a former deputy chair of New Zealand's National Science Subcommission for UNESCO, and currently is New Zealand's Senior Adviser for the International Year of Planet Earth.

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