

# A holistic and universal view of soil

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## Abstract

The best scientific definition of any entity is one that is most useful and comprehensible to a spectrum of scientists and the lay public. It especially should be simply expressed, scientifically sound, easily explainable, and cover all cases. In sum, it should be clear, simple, logical, unequivocal, broad, and ideally universal. A definition of soil that meets these criteria that is applicable to soil on Earth and all other generally lithic-composed or non-gaseous celestial bodies is: *Soil is substrate at or near the surface of Earth and similar bodies altered by biological, chemical, and/or physical agents and processes.*

## Key Words

Planetary-soils, biomantle, biota, bioturbation, pedogenesis, astropedology

## Introduction

In the Elkhorn Slough Visitor's Center at the head of Monterey Bay, California, is a diorama titled "A Bountiful Bucket of Mud," showing a shore bird feeding in a bucket of mud from the adjacent slough. The diorama asks: "What lives in this much mud? 500 billion bacteria, 500 million diatoms, 50,000 protozoa, 50,027 worms, 5,000 crustaceans, 39 clams" (Figure 1). While we cannot vouch for the accuracy of the estimate, what we have learned over the last few decades about soil organisms and numbers suggests it may be low. But, aside from questions about biota, in pondering the diorama several other questions are raised. Does slough mud qualify as soil? If so, what is soil, and how should we define it? Should our definition apply only to Earth, or to Earth and all other generally lithic-composed planets and satellites – even biologically inert ones?



Figure 1. Marbled godwits feeding in slough soil, Elkhorn Slough, California (right photo by Robert Morris).

## Does slough mud qualify as soil?

Yes, slough mud with its myriad organisms does qualify as soil, but it qualifies more in a natural state -- before being slurried as mud. While the conventional idea that soil forms on land has a long tradition, the idea that it might also form underwater also has long been espoused (e.g., Post, 1862; Dokuchaev, 1883; Robinson, 1930, and others). Such expressions as 'submerged soils,' submarine soils,' 'ocean soils,' 'freshwater soils,' and 'subaqueous soils' follow on this tradition, and now garner validity (Buurman, 1975; Soil Survey Staff, 1999, p. 9; Demas and Rabenhorst, 2001). However, while most above observers used the word "soil," they more likely were alluding to its normally organic-rich upper part – its biomantle, where most organisms live, metabolize, bioturbate, die, and re-assimilate.

## What is soil?

Views and paradigms of soil have been in flux, not only for agronomists, soil scientists, and pedologists, but also for archaeologists, astropedologists, biologists, cosmologists, ecologists, foresters, geographers, geologists, oceanographers, and many others. Such a community of scientists must deal with a broad concept of soil, one that embraces both applied and pure science research, transcends multiple disciplines, and encompasses all environmental and disciplinary contexts. A definition of soil that is compatible with such an agenda is a necessary step. In advance of this task -- and to gain a sense of the entrenched mindsets that might resist such a broadened

view of soil, we must briefly examine the gardener-farmer-agronomic practical traditions that underlie conventional views of soil, and that link traditional soil science tenuously to pedology, the two disciplines that claim soil as an object of study. Soil science has a broad societal practical agenda-domain that includes crop yields, soil amendments (fertilizers, pesticides, herbicides, fungicides), plant diseases, soil survey-classification-mapping, soil genesis, soil quality, soil and natural resources conservation and management, extension-outreach services, etcetera. The thematic domain of pedology, clearly overlapping somewhat, is narrower and less practical, with a focus on a scientific understanding of the nature of soil, how it forms, its properties, depth (thickness), its environmental functionality, and similar attributes -- subtle though very basic distinctions. (Some would include within the focused domain of pedology -- understandably, and with historic and philosophical justification -- soil survey, classification, and mapping.)

The question "What is soil?" was asked by Hungarian Professor Gorjanovic-Kramberger during a field excursion of the First International Conference on "Agrogeology" held in Budapest in 1909. As reported by Yarilov (1936), the professor "obtained a whole gamut of answers" by scientists from various countries, each revealing their different approaches and ethnic backgrounds. As most soil scientists and pedologists know, a general widely acceptable soil definition has been elusive, most reflecting the specialty and specific interests of the definer.

### Two Gatekeeper Soil Documents

For most soil scientists, agronomists, horticulturalists, gardeners, farmers, and probably most ecologists, the answer to "What is soil?" may be simply that soil is what plants grow in. This was in fact a common definition in the 19th and 20th Century literature of soil in the agricultural sciences, and still is. Several similar, though more specific and lengthier, definitions are given in recent editions of two gatekeeper soil compendia, *Soil Survey Manual* (Soil Survey Division Staff, 1993, pp. 7-8), and *Soil Taxonomy* (Soil Survey Staff, 1999, p. 9), both hereafter referred to as *Manual* and *Taxonomy*. Both are conceptual and operational 'reference bibles' for many soil specialists and practitioners. Both also foster, in the first instance, a practical agronomic agenda where soil survey, classification, and mapping -- not necessarily ecologic functionality or biospherical understanding -- are principal stated goals. This practical focus defines the traditional domain of soil science, and is what separates it from pedology, whose focus, as stated, is a more purely scientific study of soil.

The 1999 *Taxonomy* has a distractingly long definition of soil, 360-plus words, very similar to *Manual's* -- both notable for their conceptual narrowness and limitations. First, like many definitions of soil, both are extensions of Dokuchaev's late 19th Century 'five factors' model, updated in 1941 by Jenny, where Soils form as functions of climate, organisms, relief, and parent material over time: or  $S = f(\text{clorpt})$ . Even though the definition implicitly equates the 'o' factor to plants, built-in provisos limit soil depth on land to 2 m for purposes of survey and classification -- a strictly utilitarian (and arbitrary) contrivance. Depth of rooting, however, is actually far deeper for many plants (Nepstad *et al.*, 1994; Schenk and Jackson, 2002). Also for substrate to be considered soil, according to the agronomic definition, it must show evidence of horizonation and be capable of supporting rooted plants in natural environments. Substrates lacking either are "not-soil" or "non-soil". The definition includes shallow water substrates as soil, but only if plants are rooted in them, and then only to 2.5 m water depth. However, vascular plants in marine environments may root at water depths of 10-40 m, occasionally even 90 m (Hartog, 1970). In sum, soil depth in *Manual* and *Taxonomy* is arbitrarily set at 2 meters on land and 2.5 meters underwater -- all for the practical need to survey, map, and classify soils.

Such arbitrariness for defining the domain of soil, initiated in the late 1920s, understandable and perhaps necessary for its practical agenda, has created conceptual confusion, uncertainty, and even misinformation amongst pedologists. Additionally, such a plant based, agronomically inspired definition inadequately serves those in the broader Earth, marine, planetary, and environmental-ecological-ecosystemic sciences. Even amongst soil scientists, the definition inadequately explains many meters-thick biomantles in some humid tropical-subtropical soils (*Taxonomy*, p. 36; Fey 2009; van Breeman and Buurman 2002, p. 81; Johnson 1995; Johnson *et al.*, 2005; Morrás *et al.*, 2009), and their far deeper subsoil weathering zones and saprolites. Rooted plants can also grow in many different environments in totally non-soil contexts -- in air (on building roofs, parapets, gutters, walls, abandoned autos, as epiphytes on power lines, tree-trunks, and branches), as free-floating plants in water (aquatic hydrophytes, some with dangling water-roots), on animals (three-toed sloths, other animals), in quartz or gypsum sand, on rocks, under translucent quartzose-type rocks (even within some porous rocks), on freshly exposed bedrock cores of bulldozed mountains, on fresh unweathered quarry spoil, on vertical walls of bedrock quarries and buildings, and so on. Furthermore, emphasizing plants as a major -- or the major -- condition for defining soil sends two messages: Firstly, it underscores the deep gardener-farmer-agronomic

pragmatic roots of the *Manual* and *Taxonomy* definitions. Secondly, it conceptually suppresses all other non-plant life forms that also play key roles – in many cases more important roles -- in producing soil. Such life forms comprise the deep, rich, and enormously diverse reservoir of organisms that, with plants, power Earth's ecosystems. Most of the myriad non-plant life forms on Earth spend at least part of their life cycles on or in soils and substrates, and to which most contribute their metabolic products while alive – and all contribute their bodies upon death. Non-plant life forms collectively far outnumber plants in both species and total numbers, by many orders of magnitude (Brussard *et al.*, 1997; Nardi, 2007; Wall *et al.*, 2001).

In fact, many members of all life form groups are involved in forming soil and likewise modifying substrate, and animals in bioturbationally sorting it to produce texturally distinct biomantles. No question exists regarding the role of plants in soil formation; the issue is the traditionally lopsided 'clorpt' emphasis on their role to the conceptual suppression of other biota. The 'o' in 'clorpt' is for all soil organisms, but its meaning in conventional-practical soil science has traditionally (and philosophically) meant plants. We submit that the consequence of linking the 'o' factor mainly with plants, plus the near-exclusive reliance on the 'clorpt' model for soil studies and teaching, has severely limited the kinds of questions we can ask to expand our understanding of soil genesis and the way Earth-systems operate. Further, regarding the condition that soils must display horizons or layers produced by pedogenic processes, we must remember that pedogenesis includes bioturbation, a preeminent upper soil process (Fey, 2009; Johnson *et al.*, 2005; Paton *et al.*, 1995; Schaetzl and Anderson, 2005; Wilkinson and Humphreys, 2005; Wilkinson *et al.*, 2009). Bioturbation can mix and destratify geogenic stratifications, plus mix preexistent soil horizons and create new ones in the process. Pedogenesis can alter any substrate, and its products should be considered soil even if only nanometers thick. But calling nanometer-altered substrate a soil or horizon, especially if disturbed and micromixed, falls outside of practical agronomic conventions of what soils and horizons are. (This raises technical questions of how might soil horizons and 'horizonation' be defined, and even what might constitute pedogenesis?) Further, in light of active space explorations and the search for extraterrestrial life, should a definition of soil be exclusively Earth-bound?

### Universal Definition of Soil

So, how should we define soil insofar as it technically is the 'skin' of landforms, an integument of planets, and in the case of Earth primarily biophysically-biochemically produced with an epidermal biomantle? The best scientific definition is one that is most useful and comprehensible to a spectrum of scientists and the lay public. It should be simply expressed, scientifically sound, easily explainable, and cover all cases (Johnson *et al.* 1997), and ideally have universality. Being applicable to soil on Earth and on all other generally lithic-composed planets and planetoids, a definition that fits these criteria is: *Soil is substrate at or near the surface of Earth and similar bodies altered by biological, chemical, and/or physical agents and processes.*

The definition is brief and applies broadly and universally. The qualifier "or near" acknowledges that soil on at least one planet, Earth, has variable depth. It also covers subaqueous soils and their biomantles, for such -- even where applied to lacustrine and marine substrates, are still relatively near Earth's planetary surface. The two words also embrace notions of "suspended soils" (Kevan, 1962), and "soil body extensions" (Hole, 1981), which cover temporary aboveground pockets of organic-rich soil in rainforest canopies, and soil incorporated into nests of birds, wasps, termites, and other aboveground contexts. The words "or near" also cover wind-deposited soil on rooftops and other human structures (in which plants, insects, and other soil life invariably live), as well as temporary islands and rafts of vegetation-bound soil floating on rivers, estuaries, and lakes. The definition also covers soil that washes into bedrock cavities, caves, joints, fractures, and vugs in carbonate (limestone) and other rocks. Further, it focuses attention on the fact that one celestial body, Earth, is the only one that uniquely hosts all three agents and processes. The definition also accommodates the fact that 'soil' is now being increasingly applied to extreme substrate environments on Earth and other planets, including 'exotic' soils formed on such materials as ice, solid methane, and so on. Finally, the definition reminds us that soil is not simple, that we must recalibrate our thinking about soils, planetary soils, and soil in general, and that on Earth it is -- in the first instance, a predominantly biophysical and biochemical entity.

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