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Mind the gap: A classification system for integrating the *subsolum* into soil surveys

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ABSTRACT

As soil surveys were traditionally conducted in support of agriculture, soil classification tended to focus on upper soil horizons and their characteristics. However, when dealing with environmental issues – such as vegetation ecology or water quality – an integrated knowledge of the soil, soil-to-substratum, and deeper substratum continuum is required. In both World Reference Base for soil resources (WRB) and Soil Taxonomy (ST), the lower boundary for soil classification is arbitrarily set at 2 m, including weathered and continuous rock. However, as soil classification hinges on diagnostic horizons and characteristics, which often occur within the first 100 cm, collecting data on the *subsolum* is often neglected. We propose a classification system of the *subsolum*, the structure of which is inspired by WRB. We define *Regolite*, *Saprolite*, *Saprock* and *Bedrock* as four subsolum reference groups corresponding to different weathering stages. Intergrades of these reference groups can be qualified with principal qualifiers, while morphologic and lithologic characteristics can be presented with supplementary qualifiers. The proposed *subsolum* classification system is not intended to substitute geological surveys, but rather to complement existing soil classification systems such that at least the whole 2 m can be categorized. Still, whenever desired the system can also be used for deeper materials.

1. Introduction

Since in the past soil surveys were mainly conducted in support of agricultural development, soil classification systems tended to focus on the *solum* representing the upper part of the soil cover exploited by crops while the *subsolum* has largely been neglected (Brevik et al., 2015). As a consequence, and despite the importance of the *subsolum* for both ecological and hydrological studies, systematic inventories of weathered bedrock are often lacking (Graham et al., 1994; Miller and Lee Burras, 2015; Wald et al., 2013; Wrede et al., 2014; Zanner and Graham, 2005). As stated by the Soil Survey Staff (2014), in its traditional meaning, the word *soil* is the natural medium for the growth of plants, whether or not it has discernible soil horizons. Commonly, soil grades at its lower boundary to hard rock or to earthy materials virtually devoid of animals, roots, or other marks of biological activity. The lower boundary that separates "true soil" (*solum*) from the "nonsoil" underneath (*subsolum*) is however most difficult to define. In the two most widely adopted international soil classification systems – Soil Taxonomy (Soil Survey Staff, 2014) and World Reference Base for soil resources (IUSS Working Group WRB, 2014) – the lower limit for soil classification is arbitrarily set at 2 m. In this way the problem of defining the lower boundary separating the *solum* from *subsolum* is circumvented.

In Soil Taxonomy (ST), *soil* is defined as "a natural body that comprised solids (minerals and organic matter), liquid, and gases that occur on the land surface, occupies space, and is characterized by one or both of the following: horizons, or layers, that are distinguishable from the initial material as a result of additions, losses, transfers, and transformations of energy and matter or the ability to support rooted plants in a natural environment. […] The horizontal boundaries of soil are areas where the soil grades to deep water, barren areas, rock, or ice." (Soil Survey Staff, 2014: p. 1). In World Reference Base for soil resources (WRB) an even more comprehensive approach has been taken by defining the object of soil classification as "any material within 2 m of the Earth's surface that is in contact with the atmosphere, excluding living organisms, areas with continuous ice not covered by other material, and water bodies deeper than 2 m" (IUSS Working Group WRB, 2014, p. 4). In both ST and WRB, classifying soils hinges on identifying diagnostic horizons and characteristics based on the presence or absence of which soil units are defined. Diagnostic characteristics relate to surface horizons or layers (H, O and/or A horizons/layers) or to underlying subsurface horizons (E and/or B horizons). *Subsolum* material, commonly designated as C and R horizons or layers, is only by default "diagnostic" when diagnostic characteristics of other horizons or layers are not expressed. As observed by Wysocki et al. (2005), during soil survey the *subsolum* receives less descriptive emphasis than upper soil horizons. Soil scientists map and classify soils based mainly on the characteristics of the H, A, E and B horizons. Given that the *subsolum* material

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is neither in ST nor in WRB explicitly accounted for in the classification system, distinct properties of the *subsolum* are not included in the classification and hence get underreported in soil surveys. Even though soils are mostly classified based on characteristics occurring within the first 100 cm, at least in the 3rd edition of WRB (IUSS Working Group WRB, 2014) characteristics at greater depth can be indicated with supplementary qualifiers to which the specifier "Bathy-" can be added, e.g. *Bathygleyic*, *Bathyruptic*, *Bathyskeletic*. Still, the current list of qualifiers does not allow conveying precise information on the morphology nor on the nature of the *subsolum*.

Various authors have pointed to the importance of characterizing the soil-subsolum continuum in relation to vegetation ecology, groundwater recharge, water quality or waste disposal. Combining data on the *subsolum* with soil survey data, would particularly increase the relevance of soil surveys for studies seeking to integrate insights into the relation between water, soil, rock, air and biotic resources, the so-called "Critical Zone" (Anderson et al., 2004; Lin, 2010). Ohnuki et al. (2008), for example, demonstrated the importance of variation in soil hardness, water content and extent of the rooting system of a dry evergreen forest in Cambodia. Langohr and Cuyckens (1986) highlighted the importance of the presence of calcaric loess under acidic *Glossic Fragic Retisols* (WRB) (or *Fraglossudalfs* in ST) for understanding the ecology of beech (*Fagus sylvatica* L.) in the Soignes forest (Belgium). How soil survey and geological data can complement each other has been demonstrated by e.g. Brevik and Fenton (1999); Juilleret et al. (2012) and Miller and Lee Burras (2015). Hartemink and Minasny (2014) argued that the future of soil surveys lies in improving our prediction of soil properties and classes from the landscape to global scales and should include the subsoil even below 2 m. Recognising the great impact of the weathering rock on land use, Van Huyssteen et al. (2014) even proposed that weathering rock would be considered as diagnostic characteristics in WRB.

Despite the recognised importance of the *subsolum*, procedures for characterising and classifying *subsolum* material have not yet been adopted. To fill this gap, and drawing on our experience in soil survey and hydrology, we present a classification system for *subsolum* layers and which can be combined with modern soil classification systems. Gray and Murphy (1999, 2002) proposed classifying the soil parent material into ten categories based on its chemical composition. Buol (1994) proposed a classification system of the saprolite-regolith in a Soil Taxonomy like approach, with at the first categorical level Alluvium, Colluvium, Petrosediments and Saprolite. We opted for a morphogenetic approach, particularly on the consideration that groundwater flow in sedimentary rock, and in soils derived from such material, is strongly influenced by layers and fractures (McKay et al., 2005; Wrede et al., 2014). In the following sections, we first review key concepts of the *subsolum* in relation to soil classification. Subsequently, we present the classification system that has a structure similar to WRB. The *subsolum* classification is primarily aimed at complementing current soil classification systems by categorizing the material now regarded as "non-diagnostic" but which is still found within the first 2 m from the surface defined as soil in WRB, and therefore ought to be classified as well. The categorical units are intended to convey information on the nature of the subsolum relevant for ecological, hydrological and environmental studies in general. The *subsolum* units are identified based on diagnostic layers and characteristics directly observable in the field. The *subsolum* classification can be combined with WRB soil unit names, but just as well with ST names or indeed with any other soil classification system. Finally, after presenting four examples, we discuss in conclusion the advantages, limitations and scope for further development of the proposed *subsolum* classification.

2. Concepts of the regolith: *solum* and *subsolum*

The term regolith was first coined by Merrill (1906, 287-288) as "[the] entire mantle of unconsolidated material, whatever its nature or origin. […] According to its origin, whether the product of transporting agencies [as noted above], or derived from the degeneration of rocks in situ, the regolith is found lying upon a rocky floor of little changed material, or becomes less and less decomposed from the surface downward until it passes by imperceptible gradations into solid rock." Merrill (1906, 288) further specified that, "[The] extreme upper, most superficial portion of this regolith, that which affords food and foothold for plant life, is commonly designated as soil; that immediately underlying the soil, and passing into it by insensible gradations, is known as the subsoil". The term Regolith encompasses the whole "soil-bedrock continuum" and allows not having to make the distinction between "pure soil" and "pure rock/parent material". The regolith material can either have been transported to a site by gravity, water, wind, ice or human action or may have been formed in place as bedrock weathers. Transported regolith can take many forms, such as alluvium, colluvium, glacial drift or eolian loess or sands (Keary, 2001; Schaetzl and Thompson, 2015; Thomas and Goudie, 2000).

According to the above definition the Regolith encompasses in its upper parts the *solum* – i.e. where pedogenic processes are dominant and where biota play an important role – and the *subsolum* in its lower parts where the original rock structure or fabric of the Bedrock is preserved – i.e. where geogenic still dominate. Here, depending on the degree of weathering the Saprock and/or Saprolite can be distinguished. The Saprock corresponds to mechanically coherent *in situ* rock (hardrock) and is characterized by having less than 20% of altered weatherable minerals; the Saprolite corresponds to a non-coherent in situ rock or softrock in which more than 20% of the weatherable minerals are altered (Scott and Pain, 2009).

In standard textbooks on soils (e.g. Brady and Weil, 2008; Buol et al., 2011; Schaetzl and Thompson, 2015; White, 2006), the *solum* is defined as the part of the regolith which under the influence of climate and organism has been weathered to form horizons: the H, O and A horizons where organic matter accumulated at the surface, the E horizons which have been subject to eluviation, the B horizons which have been subject to weathering and/or illuviation. When defining the subsoil pedologists refer to C horizons as mineral horizons, excluding hard bedrock, that have been little affected by pedogenic processes and lack properties of H, O, A, E or B horizons (FAO, 2006; Soil Survey Division Staff, 1993). C layers can be either the parent material from which the *solum* has been formed (Neuendorf et al., 2005, Soil Survey Division Staff, 1993, FAO, 2006) or another material with no genetical link with the above *solum* and referred as substratum (Lozet and Mathieu, 2011, Soil Science Glossary Terms Committee (SSGT), 2008). Hence, it concerns mineral layers that retained some rock structure (if developed in situ) or sedimentary structure (if developed in transported regolith); included as C horizons are deeply weathered, soft saprolite (FAO, 2006; Schaetzl and Thompson, 2015). In this case the saprolite is understood as thoroughly in situ weathered or partially weathered bedrock (Keary, 2001; Thomas and Goudie, 2000) and represents the "unconsolidated residual material underlying the soil and grading to bedrock below" (Soil Science Glossary Terms Committee (SSGT), 2008). In the USA in the early nineteenth century, pedologist used the D horizon to define the geological material below C horizon consisting of unaltered and unjointed horizon lacking the hardness of the R layer (Schaetzl and Thompson, 2015; Tandarich et al., 1994). As naked eyes' observation of the diagnostic differences between C and D horizon are subtle and often necessities chemical and mineralogical analyses the D horizon was finally merged into the C horizon concept (Tandarich et al., 1994). Nowadays, the D horizon remains informal and is not recognize as a master horizon either in the Soil Survey Manual (Soil Survey Division Staff, 1993) or the Guidelines for Soil Description (FAO, 2006). This definition of the C horizon or layer remains vague and largely depends on asserting the "lack of pedogenic processes" without specifying how these should be identified in the field. Drawing on the above concepts of Regolith, Saprolite, Saprock and Bedrock, the following definitions should address this problem by specifically defining different forms of *subsolum* materials and layers.