Bulletin of Geography. Physical Geography Series, No. 14 (2018): 49–62
http://dx.doi.org/10.2478/bgeo-2018-0004

Classification of shallow and skeletal mountain soils with the WRB system on the example of the Trialeti Range, Lesser Caucasus (Georgia)

ISSN 2080-7686

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Abstract. The aim of the paper is to evaluate the usefulness of the World Reference Base for Soil Resources (WRB) 2015 to classify shallow soils on mountains of the Trialeti Range, Lesser Caucasus, Georgia. The article also presents the evolution of the concept of Leptosols and of the qualifier "Leptic" and the diagnostic property of continuous rock. It also provides approaches to defining keys in the reference soil group (RSG) of Leptosols and identifying principal and supplementary qualifiers in WRB 2015 on example of soils of the Trialeti Range. The article gives few examples of classification for such shallow and stony soils with different set of qualifiers. Most of them fulfil the criteria of Leptosols and Regosols. These soils occur on the mountain range together with other RSGs (e.g. Pheozems). The authors propose to add the qualifier Technolithic to the list of Principal/Supplementary qualifiers of Leptosols.

Key words:
WRB,
Regosols,
continuous rock,
Leptosols,
Hyperskeletic,
Skeletic,
Leptic qualifiers

Introduction

Georgia is located between latitudes 41°07' and 43°35'N and longitudes 40°05' and 46°44'E, with an area of 67,900 km^2 in the south of the Greater Caucasus range. Georgia has very diverse soil cover (Urushadze 1977; Gracheva 2011; Urushadze and Blum 2014) and is considered a "Natural Museum of Soils". It is a mountainous country, with 53.6% of the territory covered by mountains, 33.4% by foothill areas and only 13% by lowland (Urushadze and Ghambashidze 2013). The average altitude of the country is 1,500 m above sea level (a.s.l.) (East Georgia 1,691 m, West Georgia 1,313 m). 54.2% of the territory is above 1,000 m and 14.8% is above 2,000 m (Talakhadze et al. 1983).

Therefore, extensive study of mountain soils is important, as they cover most of the country. These soils are very diverse and change mainly depending on climate and landscape. Surveying and mapping of mountain soils is crucial to identify challenges for the sustainable development of mountain regions in Georgia. It will foster assessment of soils as a natural resource and the main medium for agriculture. It is also important because in recent times degradation processes of mountain soils have intensified because of climate change, unsustainable land use practices (e.g. deforestation and overgrazing) and erosion, which is the biggest contributor (Tsereteli et al. 2011; Urushadze et al. 2015; Patarkalashvili 2016).

Successful investigation of the large variety of soils is impossible without scientific classification.

Using and participating in developing the international classification system is essential for modern soil scientists. Therefore, the World Reference Base for Soil Resources (WRB) (IUSS Working Group WRB 2014, update 2015) was used in this research. This is the most advanced soil classification system in the world and at the end of twentieth century Georgia was one of the first countries in the post-Soviet area where basic types of soils were defined according to the WRB. In 1999 a 1:500 000-scale map of soils of Georgia was published (Urushadze et al. 1999). The nomenclature of soils in its legend was still based on the national classification (Urushadze 1997), including the soil resources of the world, according to the available basic data (Urushadze et al. 2016). Before and since then, a few researches were conducted using this system (Lezhava 1997; Urushadze et al. 2011; Urushadze et al. 2014, 2016; Jorbenadze et al. 2017; Kunchulia 2017; Lortkipanidze et al. 2018). The newest edition of the WRB was translated and published in early 2017 in the Georgian language (Kvrivishvili et al. 2017).

Mountain soils, often characterised by shallow soils on steep slopes, have received relatively little interest in soil science. The areas where they occur are often only suitable for marginal pastures and forests. They are often not sampled, and this lack of knowledge is in stark contrast with their overall extent and importance (Nachtergaele 2010). The same can be said of the shallow soils of Georgia. Also, the existing literature and examples of classification of such soils is not yet very diverse.

In Georgia shallow soils have been classified or included in map legends as “primitive” or “weakly developed” soils with abundant rock fragments (skeletic) as well as lithogenic “bare rocks” and “rock outcrops”. They have always been associated with high-mountain and alpine environments and were not studied or classified well. They are not even included in the modern soil classification system in Georgia except as “Raw carbonate” soils (Rendzic Leptosols) (Talakhadze 1964, 1980; Urushadze 1997, 2013) that are azonal soil types following carbonate parent materials.

In Soil Taxonomy (Soil Survey Staff 1999), soils in lithic subgroups have hard rock within 50 cm of the surface and meet the definition of Lithosols in that they contain abundant coarse fragments and may occur on steep slopes (Bockheim 2015). Also, there are Rendolls – a soil suborder that correlates with Rendzic Leptosols (Krasilnikov et al. 2009). In other countries, shallow/rocky soils are classified as following: in Brasil: Lithic Neosols – shallow soils (≤50 cm) containing ≥90% coarse fragments (Krasilnikov 2002), Neossolos order and Chernossolos rêndzicos Líticos – Rendzic Leptosols; Neossolos Litólicos (Solos Litólicos) suborder – Leptosols (Krasilnikov et al. 2009); in Australia: Leptic Rudosols or Leptic Tenosols – soils <50 cm in depth and Lithic Calcic Calcarosols ≈ Leptic Calcisols / Calcic Leptosols, Paralithic Calcic Calcarosols ≈ Calcisols (Skeletic) / Leptosols (Calcaric), Lithic and Leptic suborder Raw and Recent orders (Krasilnikov et al. 2009); in Russia: Petrozems and Lithozems – shallow soils (<10 cm) and soils between 10 and 50 cm in depth as Rendzinas or Rankers with a lithic phase (Bockheim 2015); in France: Dolomitosols, Organosols tageliques, Rankosols, Rendisols, Rendosols; in Netherlands: Xeroearth soils suborder with Krijt soil group; in Germany: Ranker, Rendzina, Pararendzina; in China: Yellow and Brown limestones, Phospho-calc, Rendzinas, Leptisols, Skeletisols (Krasilnikov 2002); in Japan: Koketsu gansetu-do (lithosols), Renjina-yo-do (rendzina-like), Regosols – great soil group, Lithic Regosols – soil group ≈ Leptosols (Krasilnikov et al. 2009); in Cuba: Lithosols, Protorendzina Rendzina type, Poco evolucionado – soil group, Lithosol Húmico sialítico – soil group (Krasilnikov et al. 2009); in South Africa: Mayo, Nomanchi, Glenrosa, Milkwood, Mispah ≈ Leptosols, Nomanci ≈ Umbric Hyperskeletic Leptosols / Leptic Umbrisols etc. (Krasilnikov 2002; Krasilnikov et al. 2009) and in Poland: Gleby inicjalne skaliste, rumoszowe (regosole), erozyjne; Rankery, Rędziny właściwe, Pararędziny, Gleby słabo ukształtowane erozyjne (Kabała et al. 2016).

To discuss the evolution of Leptosols in the WRB we must start from its history. The WRB has two roots: The Soil Map of The World (FAO-UNSECO 1971–1981) with its legend (FAO and UNESCO 1974) and its revised legend (FAO, UNESCO and ISRIC 1988) and the concepts of the IUSS Working Group International Reference Base for Soil Classification (IRB) (Blum et al. 2018). After the legend of the FAO-UNESCO Soil Map of the World (FAO and UNESCO 1974), when general knowledge and data from different countries considerably expanded and was need for revision, the Revised Legend of the Soil Map of the World was published in 1988 (FAO, UNESCO and ISRIC 1988). Table 1 illustrates the evolution of Leptosols in the WRB system.

In 1998 this classification system first appeared as the World Reference Base for Soil Resources (WRB) where the terms "Reference Soil Groups" (RSGs) and "qualifiers" (or "modifiers") were presented. The Revised Legend of FAO/UNESCO Soil Map of the World was used as a basis for the development of the WRB in order to take advantage of the international soil correlation work which had already been conducted through this project (FAO, ISRIC and ISSS 1998). After that, there were two more editions of the WRB, the first in 2006 (IUSS Working Group WRB 2006, update 2007) and the second in 2014 (IUSS working group WRB 2014, update 2015).

In the FAO-UNESCO Soil map of the world, shallow soils were presented as Lithosols, Rankers and Rendzinas. The names for the soil units used were traditional and local terms (e.g. Rendzinas and Rankers) and international terms (e.g. Lithosols), but these particular names must be understood only in accordance with the definitions which have been agreed upon, possibly at the cost of restricting the meaning which they have acquired locally (FAO and UNESCO 1974). These soil units had no subdivisions. Also, the term "Leptic" is used as a "qualifier" (soil unit) for Podzols apparently for *thin* Albic E horizon.

The Revised Legend of the Soil Map of the World (1988) saw the first appearance of "Leptosols". The term "Rankers" was not used since then in the system, but Rendzinas became the Rendzic soil unit (lower level) as well as the Lithosols to Lithic soil unit (e.g. Rendzic Leptosols and Lithic Leptosols). In total, Leptosols had seven lower-level soil units (Table 1). The term "Leptic" is not mentioned in this version of the legend. To avoid confusion created by the dissimilar use of these terms in different countries new names were coined for some soils, such as Leptosols, Fluvisols, etc. (FAO, UNESCO and ISRIC 1988).

In WRB 1998 differences with the earlier FAO (1988) definition were minor: a change in thickness of the soil layer from 30 to 25 cm, a decrease in amount of fine soil materials allowed (from 20 to 10% fine earth) in rocky/gravelly soils. At the classification level of WRB which had a single list of "qualifiers", the introduction of a *hyperskeletic* is noted as a useful distinction of the rather different nature of these soils in contrast with the FAO (1988), which did not make this important distinction at this level (Nachtergaele 2010). Since the 2006 edition, if the final name of a classified Leptosol does not contain "Hyperskeletic", then it automatically means that depth to *Continuous rock* (or *Technic hard material*) is ≤25 cm. The total number of lower-level units of RSGs became 16. The term "Leptic" was reintroduced and remains in all new editions.

The definition of Leptosols in the Key to WRB 2007 (IUSS Working Group WRB 2006, update 2007) was simplified (Table 1). The allowable limits of fine earth were set again at 20%, going back to the 1988 definition and also specifying the percentage by volume rather than by weight, which should make identification easier in the field (Nachtergaele 2010).

In the newest WRB (IUSS working group WRB 2014, update 2015) Leptosols have largely the same key to RSGs as in the 2007 edition, except for the new Diagnostic Material of *Technic hard material*, which is different from natural materials and is a result of human activities (asphalt, concrete, etc.). Also, the number of horizons that cannot fit the Leptosols almost doubled by the adding of *chernic*, *duric*, *pedroduric* and *petroplinthic* horizons.

The total number of Principal (19) and Supplementary (38) qualifiers reached 57 + Technolithic, but most of them are relatively exotic and rare, especially for mountain environments. But some new qualifiers (for example textural classes *Arenic*, *Clayic*, *Loamic* and *Siltic*, with added specifiers [where possible]) give very useful information in the name of the soil.

Principal qualifiers are ranked in order of relevance, while Supplementary qualifiers are not. Some qualifiers are only suitable for Leptosols, such as Nudilithic, Lithic, Technoleptic and Lapiadic (only if Nudilithic applies) and even Technolithic, which is part of the Lithic qualifier. The growing number of qualifiers in each successive edition of the system for Leptosols (0→7→16→36→57) is a result of the intention to precisely classify the large variety soil profiles.

The order of Leptosols in the list of soils varied per edition, but not too much: Lithosols were

Table 1. Evolution of Leptosols in the WRB system 1974-2015

Classification	Soil units	Definition of soil units (No subdivisions)	
FAO/UNESCO 1974	**LITHOSOLS**	Soils which are limited in depth by continuous coherent hard rock within 10 cm of the surface.	
	RENDZINAS	Soils having a *mollic* A horizon* which contains or immediately overlies calcareous material with a calcium carbonate equivalent of more than 40 percent; lacking hydromorphic properties within 50 cm of the surface; lacking the characteristics which are diagnostic for Vertisols; lacking high salinity. *When the A horizon contains a high amount of finely divided calcium carbonate the colour requirements of the *mollic* A horizon may be waived	
	RANKERS	Soils, exclusive of those formed from recent alluvial deposits, having an *umbric* A horizon which is not more than 25 cm thick*; having no other diagnostic horizons (unless buried by 50 cm or more new material); lacking hydromorphic properties within 50 cm of the surface; lacking the characteristics which are diagnostic for Andosols.* When the *umbric* A horizon is thicker than 25 cm, the definition of the Humic Cambisols applies.	
FAO/UNESCO/ISRIC 1988 **LEPTOSOLS**	**Major Soil Groups (Level 1)**		**Soil Units (7) Level 2**
	Soils that are limited in depth by continuous hard rock or highly calcareous material (calcium carbonate equivalent of more than 40%) *or a continuous cemented layer within 30 cm of the surface,or having less than 20% fine earth over a depth of 75 cm from the surface*; having no diagnostic horizons other than a mollic, umbric or ochric A horizon, or a petrocalcic horizon with or without a cambic horizon.		Gelic/Lithic/Rendzic/Umbric/ Mollic/Eutric/Dystric Leptosols
FAO/ISRIC/ ISSS WRB 1998 **LEPTOSOLS**	**Key to the Reference Soil Groups (RSGs) – Other soils, which are *either:***		**Lower level units of RSGs (16)**
	1. limited in depth by *continuous hard rock* within 25 cm from soil surface; ***or*** 2. overlying material with a calcium carbonate equivalent or more than $CaCO_3$>40% within 25 cm from soil surface; ***or*** 3. containing <10% (by weight) fine earth to a depth of 75 cm or more from soil surface; ***and*** 4. having no diagnostic horizons other than *mollic*, *ochric*, *umbric*, *yermic* or *vertic* horizon;		Lithic/Gleyic/Rendzic/Umbric/Yermic/Aricic/Vertic/Gelic/ Hyperskeletic/Mollic/Humic/ Gypsiric/Calcaric/Dystric/Eutric/Haplic
IUSS Working Group WRB 2006 (2007) **LEPTOSOLS**	**Key to the Reference Soil Groups – Other soils having:**	**Prefix Qualifiers (17)**	**Suffix Qualifiers (19)**
	1. one of the following: a. limitation of depth by *continuous rock* within 25 cm of the soil surface; ***or*** b. less than 20% (by volume) fine earth averaged over a depth of 75 cm from the soil surface or to *continuous rock*, whichever is shallower; ***and*** 2. no *calcic*, *gypsic*, *petrocalcic*, *petrogypsic* or *spodic* horizon.	Nudilithic/Lithic/Hyperskeletic/Rendzic/Folic/Histic/Technic/ Vertic/Salic/Gleyic/Vitric/Andic/Stagnic/ Mollic/Umbric/Cambic/Haplic	Brunic/Gypsiric/Calcaric/Ornithic/ Tephric/Protothionic/Humic/Sodic/ Dystric/Eutric/Oxyaquic/Gelic/Placic/Greyic/Yermic/Aridic/Skeletic/ Drainic/Novic
IUSS Working Group WRB 2014 (2015) **LEPTOSOLS**	**Key to the Reference Soil Groups – Other soils having**	**Principal Qualifiers (19)**	**Supplementary Qualifers (38)**
	1. one of the following: a. *continuous rock* or *technic hard material* starting ≤ 25 cm from the soil surface; ***or*** b. < 20% (by volume) fine earth, averaged over a depth of 75 cm from the soil surface or to *continuous rock* or *technic hard material*, whichever is shallower; ***and*** 2. no *calcic*, *chernic*, *duric*, *gypsic*, *petrocalcic*, *petroduric*, *petrogypsic*, *petroplinthic* or *spodic* horizon.	Nudilithic/Lithic/Technoleptic/Hyperskeletic/Skeletic/ Subaquatic/Tidalic/Folic/ Histic/Rendzic/Mollic/ Umbric/Cambic/Brunic/ Gypsiric/Dolomitic/ Calcaric/Dystric/Eutric	Andic/Arenic/Clayic/Loamic/Siltic/Aric/ Protocalcic/Colluvic/Drainic/Fluvic/Gelic/Gleyic/Humic/Ochric/ Isolatic/Lapiadic/Nechic/Novic/ Ornithic/Oxyaquic/Placic/Protic/Raptic/Salic/ Sodic/Protospodic/Stagnic/Sulfidic/Takyric/ Yermic/Aridic/Technic/Tephric/Toxic/Transportic/Turbic/Protovertic/Vitric (+ Technolithic)

named 4th, Rendzinas 6th and Rankers 7th in the 1974 FAO-UNESCO Legend, in the 1988 revised version Leptosols were 4th, and 3rd in 1998, while they were 5th in the 2007 and 2015 WRB editions.

Term "Leptic", as mentioned above, first appeared in the first legend (FAO and UNESCO 1974) in association with Podzols. In 1988, the Revised Legend of the soil map of the world introduced the concept of Leptosols (Nachtergaele 2010), but "Leptic" was not mentioned. In the first WRB in 1998 (FAO, ISRIC and ISSS 1998) Leptic reappeared meaning "having hard rock between 25 and 100 cm from the soil surface" and was allocated as a subdivision to only 12 RSGs. In the 2007 WRB edition, the qualifier Leptic is presented as a prefix for 19 RSGs. In the 2015 3rd edition (where the qualifier "Technoleptic" was introduced) Leptic is Principal qualifier for 23 RSGs and Supplementary qualifier for 1, making it the most widely distributed qualifier in the system.

It is very important to provide an overview of the concept of *Continuous rock* as a key to RSGs and a diagnostic property for the Leptic qualifier. *Continuous coherent and hard rock* had no definition in the 1974 legend but was defined in the 1988 revised version, where the term "Continuous hard rock" was introduced to improve the definition of Leptosols.

Continuous rock is a very important property for classification of Leptosols. So too is *technic hard material*, which was first introduced in WRB 2006 (as *technic hard rock*) but which was added as key to RSG Leptosols in 2014 and mostly relates to soils under infrastructure. As with the concept of the WRB in general, the term *Continuous rock* underwent development to make it maximally objective and narrow its definition. For example, "to make hand digging with a spade impractical" is not a scientific justification and can be interpreted differently, unlike stating that "an air-dried specimen 25–30 mm on a side is submerged in water for 1 hour" is to remain intact. If a parent rock cannot fulfil the requirements for *Continuous rock,* it is discontinuous.

The 2014 Soil Taxonomy (Survey Staff 1999) explains: "A lithic contact is the boundary between soil and a 'coherent underlying material,' i.e. a material that 'when moist makes hand digging with a spade impractical'". A lithic contact limits roots to a "few" with a horizontal spacing of 10 cm or more (Bockheim 2015).

This study, as a part of PhD research, investigates and classifies shallow and skeletal soils on mountains of the Trialeti Range. The aim of the paper is to evaluate the usefulness of the WRB in classification of such soils.

Materials and methods

Study Area

The Trialeti Range is a south-western range in the Lesser Caucasus Mountains in central Georgia (Fig. 1). North-east of the Javakheti volcanic plateau, the range is located on the right shore of river Mtkvari (Kura) starting west of the city Akhaltsikhe and ending in the capital Tbilisi on the east. The range is about 150 km long and has a maximum width 30 km. Peaks in the range reach 2,300–2,800 metres a.s.l. (Tskhovrebashvili 1979). Average annual temperature and precipitation are 7.2°C and 750 mm, respectively, based on the data of eight stations (average height 1,175.5 m a.s.l.) (Machavariani 2004).

The main parent materials of the range are carbonate rocks (limestones, marls) with vulcanogenic rocks (tuffs, tufobreccias, etc.), volcanites (andesites, andesite-basalts) and sedimentary rocks (sandstones, clay shales, etc.), loess, loess loams, clay shales, etc., and young lavas (andesites, basalts, dolerites) (Urushadze et al. 1999). The ages of the parent materials are upper Cretaceous, Palaeocene, Eocene, Oligocene, Miocene, Pliocene and post-Pliocene (Machavariani 2004).

Vegetation cover of the range has been modified by human activities. The foothills are used for agriculture and the lower mountains are covered with secondary vegetation with xerophytic species (*Carpinus orientalis*, *Paliurus*, etc.), while the lower belt of mountains is covered with oaks and the upper part with beech and hornbeam, and the top with sub-alpine forest. There is significant occurrence of coniferous forests especially in the west part of the range and, azonally, pine forests.

Soils occure here at the initial stage of their development or are degraded – Leptosols and Regosols, which are distributed widely but in Georgia are not studied well (Kunchulia 2017).

This territory is an important natural geographic region of East Georgia, as are most of its mountains after the Great Caucasus range, because there are several protected areas (Algeti National Park, Nedzvi, Ktsia-Tabatskuri and Tetrobi managed reserves) and many tourism resorts (Bakuriani, Tsagveri, Manglisi, Kodjori, etc.).

Including the protected areas, because of their high altitudes and mountain landscape, the Trialeti range is mainly covered with forests and grassland. It is an important summer pasture zone and meadows for nomadic herders and local communities as one of the main sources of income. Also, along its whole north–south length from west, the capital of the country, Tbilisi, is located on ridges (Satskepela, Armazi, Mskhaldidi, Lisi, Mtatsminda, Kojori, Tabori and Teleti) of the range (Lachashvili et al. 2017a, b). In June 2015 there was a landslide on the north slope of the Kojori ridge next to Tskneti that caused a serious natural disaster in the capital. It is necessary to study and classify soils of the Trialeti Range because of its importance in multiple domains.

The samples for the paper were selected mostly in the east of the range, where, according to the Georgian classification system, Brown forest soils (>1,000 m a.s.l.) and Cinnamonic soils (<1,000 m a.s.l.) occur. Also, on the Tskhratskaro Pass, which forms the central part of the range, we sampled Mountain-meadow and Mountain-forest meadow soils (>2,000 m a.s.l.). Soils were sampled according to the national classification system based on genetic horizons.

Methods

The field works were conducted in 2017 and laboratory analysis took place in 2017–18. More than 80 soil pits were examined, and more than 320 soil samples were collected from horizons. For the article 28 soil profiles were selected, and, moreover, 76 soil samples were analysed. Some profiles were classified according to the national Georgian classification (Urushadze 1997) and the WRB system (IUSS Working Group 2015).

For the laboratory analysis based on our capacity and general approaches we used the following methodologies: particle size distribution by pipette methods (Urushadze et al. 2010) and texture classes were converted to the WRB system according to the Shein method (Shein 2009). Actual soil acidity (pH) in water suspension 1:2.5; exchangeable acidity by 1 M KCl extract (pH metre – WTW inoLab® pH 7110); organic carbon (OC) content (by wet oxidation using 0.4 N potassium $K_2Cr_2O_7$) (described in Makarov et al. 2004); exchangeable bases (by 0.1 M $BaCl_2$); hydrolytic acidity (by NH_4COOH at pH 8.2); cation exchange capacity (CEC) was defined as sum of exchangeable cations and hydrolytic acidity (ISRIC 2002); and calcium carbonate content was determined by the Scheibler method (Scheibler-Dietrich-Apparatur CO_2-Gasometer). All data were analysed on the basis of methods recommended by

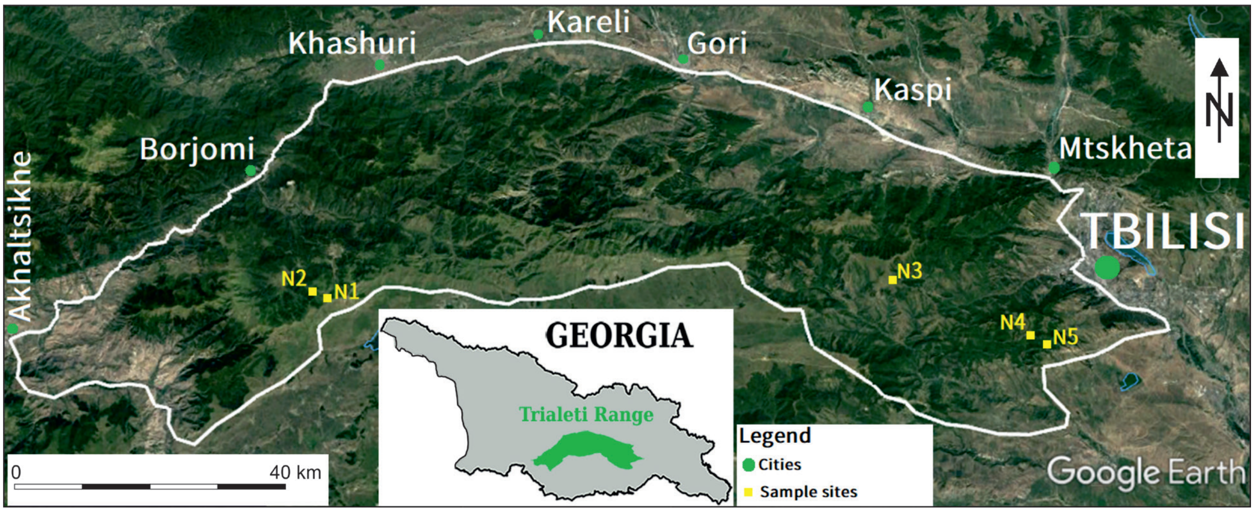

Fig. 1. Location of the study area (source: Google Earth)

the WRB (IUSS Working Group WRB 2014, update 2015).

The data were statistically analysed by using Microsoft Excel (2013); Google Earth Pro 7.3.1.4507 was used for mapping the study area and Garmin GPSMAP 64s was used for determining GPS coordinates and altitude of the sample sites; soil colours were defined by Munsell colour chart (Munsell 2015).

Fine earth and coarse fragment fractions were defined using the Guidelines for Soil Description (FAO 2006) *Abundance of rock fragments and artefacts, by volume* (Table 26) and *Charts for estimating proportions of coarse fragments and mottles* (Figure 5). Soils were sampled according to the national genetic horizons. Term "Layer", shown on photos, is introduced only for determining content of coarse fragments in the profiles and they do not match with the horizons.

For description of different properties and environmental conditions we used codes and classes from Guidelines for Soil Description (FAO 2006), namely: Slope positions in undulating and mountainous terrain (Figure 2 in FAO 2006); Slope gradient classes (Table 7 in FAO 2006); Land-use classification (Table 8) in FAO 2006; Vegetation classification (Table 11 in FAO 2006); Hierarchy of lithology (Table 12 in FAO 2006); Abundance of rock fragments and artefacts, by volume (Table 26 in FAO 2006); Classification of carbonate reaction in the soil matrix (Table 38 in FAO 2006) and Classification of the abundance of roots (Table 80 in FAO 2006).

Results

Laboratory data processing

Laboratory analyses of classified soil profiles are shown in Tables 2 and 3. All data from shallow soil profiles (28) were analysed statistically. Average altitude in the research area is 1301 metres a.s.l. (Standard deviation (SD) = 446). Average depth to bedrock in the sampled profiles is 37.54 cm (SD = 13.8 and mean = 34.9 cm). Average depth of A horizon is 10.7 cm (SD = 3.1 and mean 10.3). As was expected, no statistically significant correlation has been detected between altitude and soil depth or slope inclination.

Chemical analyses show (Table 2) that most soils have pH<7 and average index is 6.4 (SD = 1). Soil OC on average is 3.84% (SD = 1.1 and mean = 3.7), while in A horizon it is 3.95% (SD = 1.0 and mean = 3.8). CEC (cmol) on average is 29 (SD = 5.7). Because of the shallowness of the profiles, in most cases a significant amount of OC is distributed down to the bedrock.

Particle size distribution analysis showed that there are soils with textural classes of loam and silt loam (Table 3).

Examples of classification

The most important part for classification on Leptosols, the *Leptic* qualifier and *Continuous rock* (as well as many other qualifiers, horizons, materials and properties) must be conducted in the field. Leptosols have two criteria: to be classified as a Leptosol, a soil must fulfil both criteria 1 and 2, but from criteria 1 can fulfil either a or b (Criteria 1b is technically the same as the Hyperskeletic principal qualifier) (IUSS Working Group WRB 2014, update 2015). Thus, Leptosols can be either very shallow soils directly lying on bedrock, or soils with excess rock fragments in a profile. Below, we give examples of both cases, as well as classification of Leptic, Hyperskeletic and Skeletic qualifiers with other RSGs.

Profile N1. Mollic Hyperskeletic Leptosol (Humic, Episiltic)

Location and altitude: Tskratskharo Pass (41°41.240', 043°31.164'), altitude 2,435 m a.s.l;
Relief and parent material: The profile is very close to the top of the slope – Upper Slope (shoulder) – UP, inclination >35° – Class 09 – Steep, parent material is andesite-basalt – II1 and IB2;
Vegetation and land use: Grass vegetation – Herbaceous = HS short grassland, U = Not used and not managed land;
Classification: These are Saturated Mountain-meadow soils according to the Georgian classification system.

Table 2. Properties of the studied soils

Profile No.	WRB (2015)	Horizon	Depth [cm]	pH	$CaCO_3$ [%]	CEC [$cmol \cdot kg^{-1}$ of soil]	Percentage [%] from CEC					OC [%]
							Ca	Mg	K	Na	H	
N1	Mollic Hyperskeletic Leptosol (Humic, Episiltic)	A	0–10	5.10	-	28.1	54.80	24.03	3.51	0.36	17.30	4.75
		AB	10–30	5.23	-	24.4	51.21	31.51	1.27	0.26	15.76	4.63
		BC	30–50	5.61	-	18.5	48.65	30.16	2.36	0.35	18.49	3.86
		CD	50–80	5.86	-	25.8	52.39	27.17	2.64	0.34	17.46	3.23
N2	Mollic Leptosol (Siltic)	A	0–10	5.78	-	17.2	62.16	34.53	1.11	0.22	1.97	4.91
		AB	10–24	5.76	-	17.2	58.42	38.62	0.56	0.42	1.98	3.72
N3	Leptic Skeletic Phaeozem (Epiloamic)	A	0–20	5.59	-	36.2	68.71	27.10	3.04	0.18	0.97	4.79
		BC	20–40	5.70	-	32.3	79.18	18.81	0.73	0.30	0.99	4.19
N4	Eutric Hyperskeletic Leptosol (Epiloamic)	A	0–11	7.70	0.79	35.3	73.33	25.77	0.61	0.29	-	4.14
		BC	11–30	7.11	0.26	36.1	73.70	25.89	0.31	0.09	-	3.61
N5	Eutric Leptic Skeletic Regosol (Episiltic)	A	0–8	7.30	0.26	37.5	74.06	24.69	1.21	0.04	-	-
		AC	8–20	6.65	0.00	35.3	74.32	24.77	0.55	0.36	-	-

Table 3. Soil texture classes

Profile No.	WRB (2015)	Horizon	Depth [cm]	Sand [%]	Silt [%]	Clay [%]	Textural Class
N1	Mollic Hyperskeletic Leptosol (Humic, Episiltic)	A	0–10	24	61	15	Silt Loam
		AB	10–22	20	61	19	Silt Loam
		C	22–38	14	64	22	Silt Loam
		D	38–60	28	58	14	Silt Loam
N2	Mollic Leptosol (Siltic)	A	0–10	24	61	15	Silt Loam
		BC	10–24	20	61	19	Silt Loam
N3	Leptic Skeletic Phaeozem (Epiloamic)	A	0–20	43	41	16	Loam
		BC	20–40	45	39	16	Loam
N4	Eutric Hyperskeletic Leptosol (Epiloamic)	A	0–11	35	46	19	Loam
		BC	11–30	49	37	14	Loam
N5	Eutric Leptic Skeletic Regosol (Episiltic)	A	0–8	47	40	13	Loam
		AC	8–20	31	50	19	Silt Loam

A 0–10 cm – 7.5YR 2/1, granular structure, loamy, friable, common roots, skeletal;

AB 10–30 cm – 5YR 3/3.5, granular-fine blocky structure, loamy, roots, coarse gravel and stones;

BC 30–50 cm – 5YR 3/4, blocky structure, loamy, slightly compacted, very few roots, fine and medium gravels;

CD 50–80 cm – 5YR 4/4, slightly expressed structure, loam, abundant rock fragments.

There are two layers marked in the picture (Fig. 2). Absence of hard rock can be observed in <80 cm of the profile that excludes the criteria 1a. To establish average content of fine earth, we must calculate its content layer by layer. In Layer 1 (0–25 cm) it is 15%, in Layer 2 (25–75 cm) the volume of fine earth is 20%. We calculate 25·15=375 (25 cm and 15% fine earth) and 50·20=1,000 (50 cm and 20% fine earth). To average the sum is 1,375, which must be divided by 75 cm, resulting in 18.3%, which is less than 20%. The profile has Hyperskeletic qualifier and it is a Leptosol. It has also got a Mollic horizon as well as Humic and Episiltic qualifiers (Tables 2 and 3). The final name for the profile will be **Mollic Hyperskeletic Leptosol (Humic, Episiltic).**

Profile N2. Mollic Leptosol (Siltic)

Location and altitude: Tskratskharo pass (41°41.189', 043°30.662'), altitude 2,324 m a.s.l;

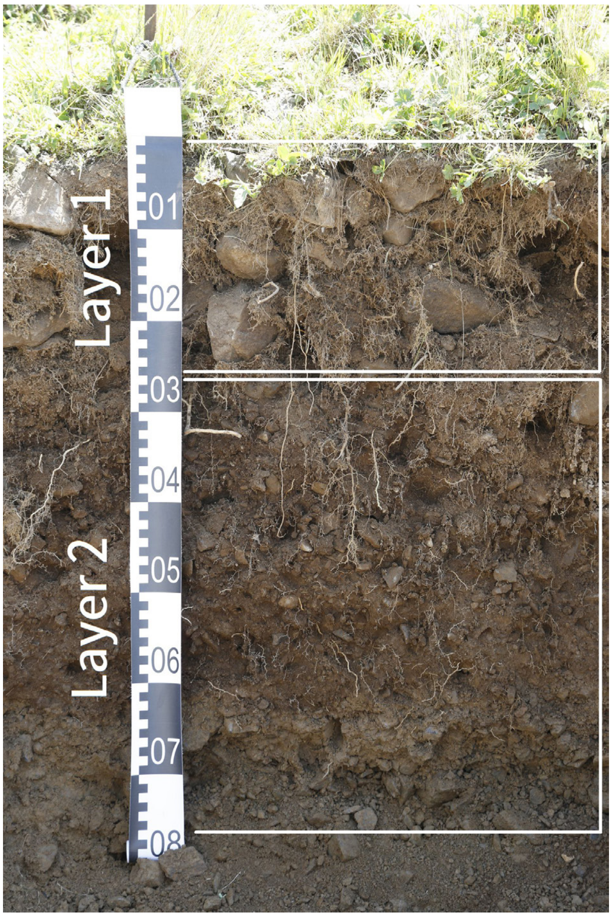

Fig. 2. Mollic Hyperskeletic Leptosol (Humic, Episiltic)

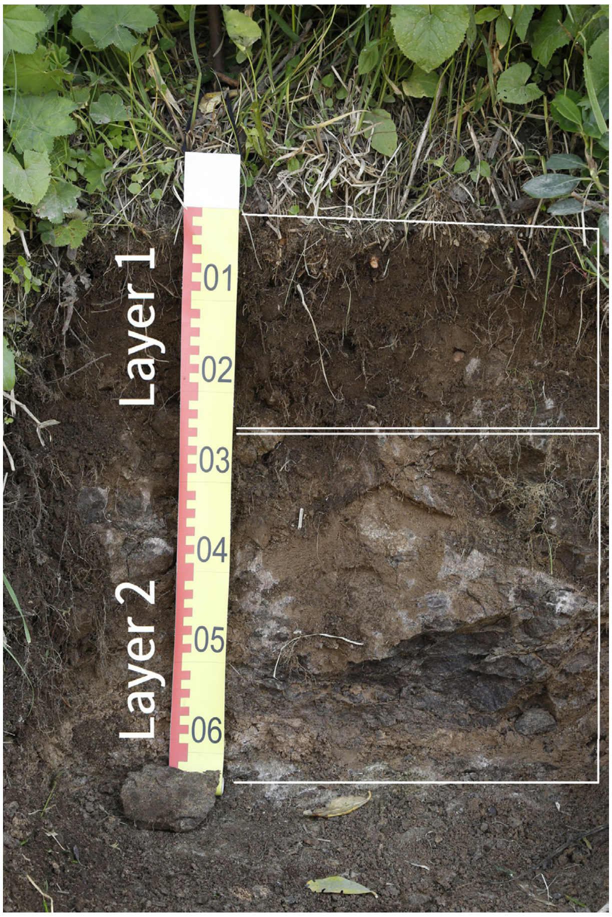

Fig. 3. Mollic Leptosol (Siltic)

Relief and parent material: The profile is on a roadside – Middle slope (back slope) – MS, inclination of the slope is >45° – Class 09 – Steep, Parent material is andesite-basalt – II1 and IB2;
Vegetation and land use: Vegetation is dominated by *Rhododendron caucasicum* – Woodland = WD Deciduous woodland, U = Not used and not managed land;
Classification: It is Saturated Mountain-forest-meadow soil according to the national classification system.

A 0–10 cm – 7.5YR 3/2, fine crumby structure, loamy, slightly compacted, common roots, a few gravels;
AB 10–24 cm – 10YR 3/2.5, blocky structure, loamy, stones, common roots, slightly compacted.

The difference with Example N1 is its lower altitude. The main difference between Mountain-meadow and Mountain-forest-meadow soils is vegetation. Climate for both types is cold, resulting from the altitude of their occurrence being >2,000 m. Vegetative period is 3–4 months, precipitation is 700–1,500 mm and average annual temperature is 3–4°C. The cold climate conditions and nature of the parent material facilitates intensive physical weathering of rocks that results in accumulation of boulders and gravel in the upper part of the soil (Urushadze and Blum 2014).

In the picture (Fig. 3) two layers are marked. Layer 1 is the upper part of the 0–24 cm profile with rock fragments and abundant roots. From 24 cm the bedrock that fulfil criteria *Continuous rock* begins (starts ≤25 cm) and is sufficiently consolidated; there are almost no cracks where roots can enter and material is intact (no significant displacement has taken place). The profile has a Mollic horizon because its base saturation is >50% throughout the entire thickness (Table 2), there no carbonates, and it has a high percentage of OC, thickness ≥20 cm and a Munsell colour value of ≤3 (moist) in all layers. The final name of the classified soil will be **Mollic Leptosol (Siltic).**

Profile N3. Leptic Skeletic Phaeozem (Epiloamic)

Location and altitude: Central part of the range, next to Algeti National Park and the start point of the river Vere (41°43.05312', 044°26.96994'), altitude 1,620 m a.s.l.;
Relief and parent material: Top of the hill – Upper Slope (shoulder) – UP, inclination 4–6° – Class 05 – Gently sloping, east exposition, parent rock is SC2 – sandstone;
Vegetation and land use: Secondary grass cover – Herbaceous = HS short grassland, in the nearby source of river Vere valley there is natural oak forest. The land is used as summer pasture for cattle and sheep – Animal Husbandry = HE2 Semi-nomadism;
Classification: According to the national classification system those are Primary saturated Brown forest soils.

A 0–20 cm – 5YR 3/1, gradient to 7.5YR 3/2, crumby structure, many roots, compacted, common biological activity (ants, bugs, etc.);
BC 20–40 cm – 7.5YR 4/3.5, friable, common roots, more than 90% rock fragments;
CD > 40 cm – strongly weathered sandstone.

The profile (Fig. 4) is divided into three layers. Layer 1 (0–20 cm) has fine earth content of 90%, Layer 2 (20–40 cm) has fine earth content of 10% and Layer 3 (40–75 cm) has fine earth content of 3%. The result is 28.1% fine earth fraction averaged over 75 cm depth. Thus, this profile cannot be a Leptosol because it cannot meet its criteria. It will end up as a Phaeozem because of the Mollic horizon and having Leptic and Skeletic principal and Epiloamic supplementary qualifiers. The final name for the profile will be **Leptic Skeletic Phaeozem (Epiloamic).**

Profile N4. Eutric Hyperskeletic Leptosol (Epiloamic)

Location and altitude: East part of the Trialeti range, Kojori ridge (41°40.04850', 044°40.56462'), altitude 1,303 m a.s.l.;
Relief and parent material: Top of the ridge – Upper Slope (shoulder) – UP, south-east exposition inclination 5° – Class 05 – Gently sloping, parent rock – SC4 – shale;
Vegetation and land use: Vegetation is grass cover – Herbaceous = HS short grassland and pine plantations with shrubs, used for pasture – Animal Husbandry = HE2 Semi-nomadism;
Classification: According to the national classification this soil type is in the zone of ordinary Brown forest soils (between 1,000 and 2,000 m a.s.l. altitude). There also occur soils that are classified as Leptic Cambisols according to the WRB system (Kunchulia 2017).

A 0–11 cm – 10YR 3\3, common roots, crumby structure, friable, no effervescence with 10% HCl;
BC 11–30 cm – 10YR 3\3, crumby structure, visible effervescence with 10% HCl of parent rock.

We can observe two layers in this profile (Fig. 5). One layer is very shallow soil with rock fragments and the second layer is bedrock with lots of cracks and roots in it. Because of abundant cracks and roots, it cannot be classified as *Continuous rock*, which prohibits it to be recognised as *Lithic* qualifier despite the fact that rocks start <10 cm. In this case the content of fine earth must be averaged. In Layer 1 (0–8 cm) content of fine earth is 80% while in Layer 2 it is 4%. Average content of fine earth is 19.2%. Eutric and Hyperskeletic principal and Episiltic supplementary qualifiers can be used. Therefore, the final name of the soil profile will be **Eutric Hyperskeletic Leptosol (Epiloamic).**

Profile N5. Eutric Leptic Skeletic Regosol (Episiltic)

Location and altitude: Kojori ridge, (41°40.04538', 044°40.61256') nearby territory to Example 4, south exposition, altitude 1,298 m a.s.l.;
Relief and parent material: Middle slope (back slope) – MS, inclination 5–7° – Class 06 – Sloping. Picture 5 shows a soil profile lying on much unconsolidated rock material that shows dissolution features – SC4 – shale;
Vegetation and land use: Secondary grass meadow – Herbaceous = HS short grassland, used as pasture – Animal Husbandry = HE2 Semi-nomadism;
Classification: According to the national classification system these are Ordinary Brown forest soils.

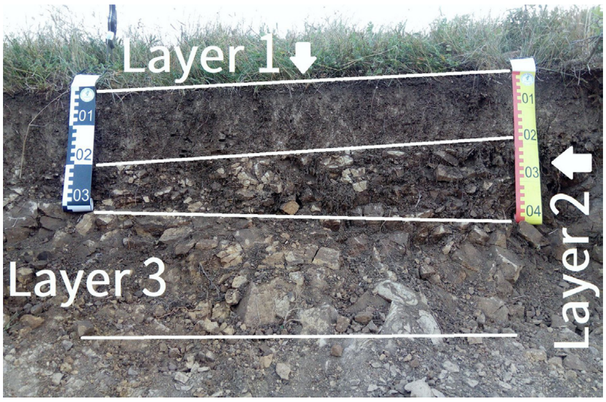

Fig. 4. Leptic Skeletic Phaeozem (Epiloamic)

Fig. 5. Eutric Hyperskeletic Leptosol (Epiloamic)

A 0–8 cm –10YR 3\3, fine granular-crumby structure, common roots, slightly compacted;

AC 8–20 cm – 10YR 4\3, rock structure, dominated by rock fragments, common roots

Layer 1 (Fig. 6) is 0–17 cm with about 70% of fine earth and Layer 2 is 17–75 cm with average fine earth content of 10%. The profile has 23.6% of fine earth. As the profile cannot fulfil criteria for Leptosol or any other RSG due to limitation of depth, it will be a Regosol with Leptic, Skeletic and Eutric Principal and Epiloamic "Supplementary" qualifiers. The final name for the profile will be **Eutric Leptic Skeletic Regosol (Episiltic)**.

Discussion

The problem with the current classification system in Georgia is that it is partly based on zonal distribution (landscape-geographic approach (Urushadze and Blum 2014)). For example, all soil types that are distributed from 900 (1,000) to 1,900 (2,000) metres above sea level are classified as Brown forest soils; also, soils between 1,800 (2,000) and 3,000 (3,200) m a.s.l. can be mountain forest meadow; or mountain meadow soils between 1,800 (2,000) and 3,200 (3,500) m a.s.l. (The main difference between last two types of soils is vegetation.) Soil types have lower-level units, such as subtype, family, variety, species, etc. (Urushadze and Blum 2014).

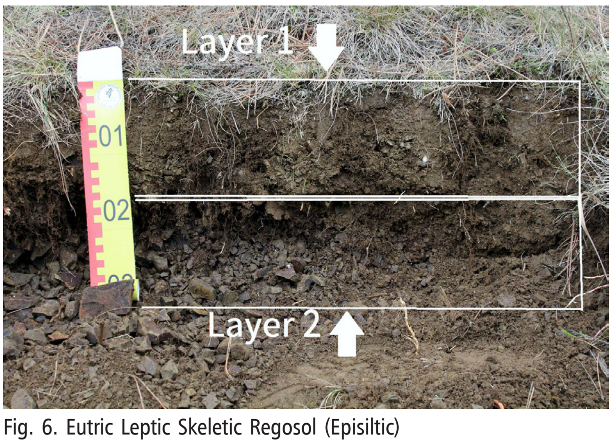

Fig. 6. Eutric Leptic Skeletic Regosol (Episiltic)

In Georgia, considering variation of climate as well as other soil-forming factors (parent rock, vegetation, age of soil cover, land use, etc.), we can assume that above 900 (1,000) metres a.s.l. there are many more RSGs according to the WRB, because Brown forest, Mountain forest meadow and Mountain meadow soils cover 50.4% of the territory of Georgia (Urushadze and Blum 2014). This kind of zonal distribution of soils leads to problems of correlation of the Georgian system with the WRB, bearing in mind the fact that every new edition of the WRB requires reclassification of the soils according to the new or updated rules and features.

In this research we classified only some of the shallow/skeletal Leptosols, Phaeozems and Regosols of the Trialeti Range. Classification of these soils has certain challenges, such as averaging the fraction of fine earth, looking for a Leptic qualifier in rocky parent material, etc.

The approach of averaging fine earth fraction over 75 cm is extremely vulnerable to the subjectivity of the scientists evaluating its content in the field. Methodology is not defined in the WRB, and that can cause mistakes. According to the WRB, if a soil has a layer of ≥15 cm consisting 100% of fine earth, it will not meet criteria 1b or the Hyperskeletic qualifier for Leptosols, because 15*100=1500 (15 cm and 100%) and 1500/75=20% (75 cm) of fine earth. Also, in certain cases digging through bedrock to 75 cm will be very hard and time consuming. This means that many shallow soils will end up out of RSG Leptosols, with qualifiers Leptic or Skeletic. If a soil cannot fulfil the criteria of any RSG it will key out as a Regosol with relevant qualifiers.

The dominant soil units in this area and conditions are Eutric/Mollic Leptosols, Cambic Leptosols, Leptic/Skeletic Phaeozems or Leptic/Skeletic Regosols with relevant qualifiers. This kind of mixing of these three types of RSGs, as well as others, is caused by the qualifier *Leptic*, which applies to 24 RSGs and can cause difficulties for mapping purposes because of its competitiveness with the RSG Leptosol.

Shallow soils are very vulnerable to land use change (Kosmas et al. 2000) as well as other natural events in changing climate conditions and increasing demand on fertile soils. It is very important to classify mountain soils well and find ways for sustainable land use.

Conclusions

The paper gives examples of classification according to the WRB system for: Mollic Hyperskeletic Leptosol (Humic, Episiltic); Mollic Leptosol (Siltic); Leptic Skeletic Phaeozem (Epiloamic); Eutric Hyperskeletic Leptosol (Epiloamic) and Leptic Skeletic Regosol (Episiltic) that, alongside other RSGs not exemplified here, occur on mountains of the Trialeti Range.

In the light of this study, it is important to standardise the process of averaging fine earth fraction in the WRB to avoid mistakes in the field and to reduce the competitiveness of certain RSGs that share the Leptic/Skeletic qualifiers for classification and mapping purposes. Layers defining amount of fine earth can be different from diagnostic horizons.

Digging through bedrock in search of the diagnostic property "Continuous rock" is not an easy task for scientists during field work. Especially when it comes to identification of cracks where roots can enter. The methodology for defining continuous rock must be simplified and be more flexible, otherwise the qualifiers "Skeletic" and "Hyperskeletic" will overtake *Continuous rock* in most cases.

It will be appropriate for the qualifier "Technolithic" to be added to the list of Principal/Supplementary qualifiers of Leptosols. This qualifier is only mentioned in Chapter 5 and Annex 3 but not included in Chapter 4 or anywhere else. It will be better to be added to Leptosols as a principal qualifier together with Lithic/Nudilithic.

Acknowledgements

The authors are very grateful to Tamar Kvrivishvili, Tengiz Urushadze and Peter Schad for their valuable contribution to the paper. Likewise, thanks to editors and reviewers of the journal Bulletin of Geography, Physical Geography Series.

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Received 2 March 2018
Accepted 27 April 2018