19th World Congress of Soil Science

Working Group 1.1
The WRB evolution

Soil Solutions for a Changing World,

Brisbane, Australia

1 – 6 August 2010

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Diversity and classification problems of sandy soils in subboreal zone (Central Europe, Poland)

Michał Jankowski

Faculty of Biology and Earth Sciences, Nicolaus Copernicus University, Toruń, Poland, Email mijank@umk.pl

Abstract
The aim of this study was to present some examples of sandy soils and to discuss their position in soil systematics. 8 profiles represent: 4 soils widely distributed in postglacial landscapes of Poland (Central Europe), typical for different geomorphological conditions and vegetation habitats (according to regional soil classification: Arenosol, Podzolic soil, Rusty soil and Mucky soil) and 4 soils having unusual features (Gleyic Podzol and Rusty soil developed in a $CaCO_3$-rich substratum and two profiles of red-colored Ochre soils). According to WRB (IUSS Working Group WRB 2007), almost all of these soils can be named Arenosols. Considering their individual morphological features (stage of development, sequence of horizons) and different ecological value, most of the studied soils should be classified into other Reference Soil Groups or even distinguished in individual units.

Key Words
Soil classification, Soil geography, Soil morphology, Arenosols, Podzols, Sand.

Introduction
Soils developed from loose quartz sands generally represent the least fertile mineral soils in the World. According to WRB soil classification (IUSS Working Group WRB 2007), one genetic variant - Podzols - is distinguished as individual unit from that textural group of soils. Most of the other sandy soils can only be classified as Arenosols, irrespective to their development rate, soil horizons sequence or ecological properties. Such arrangement does not reflect the real diversity of sandy soils, especially in comparison to the number of divisions covering soils of heavier texture. In some regions of the Earth, for example in postglacial landscapes of Central Europe (European sand belt; Zeeberg 1998), subboreal zone, soils built from glacial, glaciofluvial, glaciolacustrine, fluvial, lacustrine and aeolian sands occupy big areas and represent diverse, mature morphological and ecological variants associated with different plant communities.

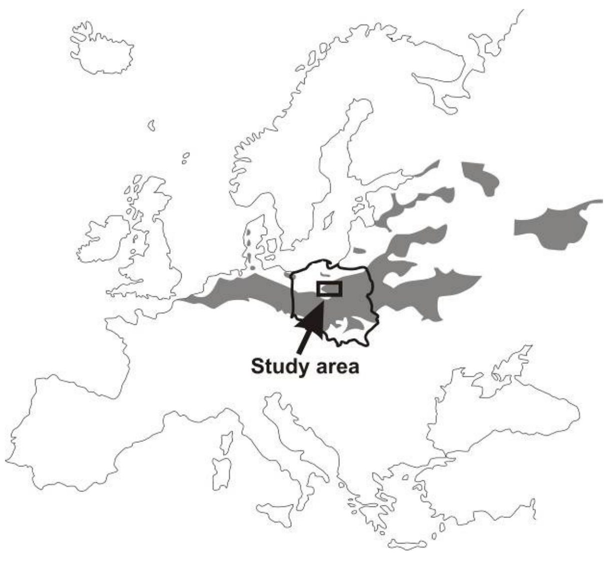


Figure 1. Location of the study area in the European sand belt (Zeeberg 1998)

The aim of this work is to emphasize sandy soils diversity and necessity of their more detailed classification, important for both scientific and practical aspects.

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

Methods

The study area is located in Northern Poland, Central Europe (Figure 1). The climate in the region is of a temperate, humid type (average annual temperature 7-8 ^{o}C, precipitation 450-650 mm) and deciduous and coniferous forests are the potential natural vegetation. Eight representative profiles of morphologically and ecologically different sandy soils were chosen for studies in two groups: typical soils, widely distributed in the area (profiles 1-4), and examples of more rare soils with specific, unusual features (profiles 5-8). During field works site conditions were determined in respect to geomorphological situation, vegetation and moisture regime, as well as soil morphology. In samples taken from all genetic horizons, basic properties were determined using standard methods: texture, organic carbon and nitrogen contents, pH, $CaCO_3$ content, total Fe, oxalate extractable Fe and Al contents. The typological position of soils was established using criteria of WRB (IUSS Working Group WRB 2007) and regional classification systems: Systematics of Polish Soils (SPS 1989) and Classification of Polish Forest Soils (CPFS 2000).

Results

All studied soils developed from poor, loose sands building geomorphological forms of various origin: aeolian, glaciofluvial, fluvial and lacustrine (Table 1).

Table 1. Site characteristics and classification of soils according to WRB (IUSS Working Group WRB 2007) and regional, Polish classification systems (SPS 1989, CPFS 2000)

No	Geomorphology	Vegetation	Soil classification	
			WRB	Regional names
1	aeolian cover	dry grassland (*Corynephorus canescens*)	Haplic Arenosol	Arenosol
2	dune	humid coniferous forest (*Pinus sylvestris*)	Albic Arenosol	Podzolic soil
3	glaciofluvial outwash plain	humid mixed forest (*Pinus sylvestris/Quercus robur*)	Brunic Arenosol (Orthodystric)	Rusty soil
4	glaciofluvial marginal valley terrace	wet deciduous forest (*Alnus glutinosa/Fraxinus excelsior*)	Haplic Gleysol (Humic, Arenic) or Umbric Gleysol (Arenic)	Mucky soil
5	glaciofluvial outwash plain	humid deciduous forest (*Quercus robur/Carpinus betulus*)	Brunic Arenosol (Endoeutric)	Rusty soil
6	lake terrace with $CaCO_3$ gytia interlayer	wet mixed forest (*Pinus sylvestris/Quercus robur*)	Gleyic Podzol	Gleyic Podzol
7	fluvial terrace	wet mixed forest (*Picea abies, Alnus glutinosa*)	Rubic Arenosol	Ochre soil
8	glaciofluvial terrace	humid mixed forest (*Pinus sylvestris/Quercus robur*)	Rubic Arenosol	Ochre soil

They represent anthropogenic initial grassland (profile 1) or, more natural for the area, coniferous, mixed and deciduous, humid and wet forests (profiles 2-8). According to WRB 2007, six of these profiles belong to the Arenosols, one to the Gleysols and one to the Podzols. Using regional names (SPS 1989, CPFS 2000) only the first profile represents an Arenosol - a weakly developed sandy soil without any genetic horizon, apart from an initial AC horizon (Figure 2, Table 2). The rest of the WRB Arenosols are mature, well developed soils. They have clearly visible sequences of genetic horizons with distinct, individual features, being the effect of different soil-forming processes: high organic matter accumulation in the A horizon, (Mucky soil, Rusty soils, Ochre soil), visible iron and aluminum translocation from the E to the Bhs (Podzolic soil and Gleyic Podzol), gleyic properties in the Cr (Mucky soil, Gleyic Podzol and Ochre soil), residual concentrations of iron in the Bwo (Rusty soils) or allochthonous concentrations of iron in the Bwo (Ochre soils).

Apart from the weakly developed Arenosol, all soils show a distinct organic carbon content in the A horizon (1 to 4 %). C/N ratio values vary from 11 to 27. The reaction of the genetic horizons is mostly acid (pH KCl 2.6 to 6.5), even when the soils are formed in materials primarily containing high amounts of calcium carbonate (Gleyic Podzol, Rusty soil).

Although the weakly developed soil (Haplic Arenosol), the strongly podzolized, gleyed soil (Gleyic Podzol) and the humus rich, gleyed soil (Haplic Gleysol (Humic, Arenic) or Umbric Gleysol (Arenic)) can be classified into particular Reference Soil Groups reflecting their individual features, the position of the Podzolic soil, the Rusty soils and the Ochre soils among Arenosols is controversial. The Podzolic soil, although it does not meet the quantitative criteria of WRB Podzols, shows clear evidences of podzolization (Charzynski 2000). The Rusty soils and the Ochre soils represent individual, mature soil variants, morphologically closer to Cambisols than to Arenosols, but lacking a cambic horizon due to their sandy texture.

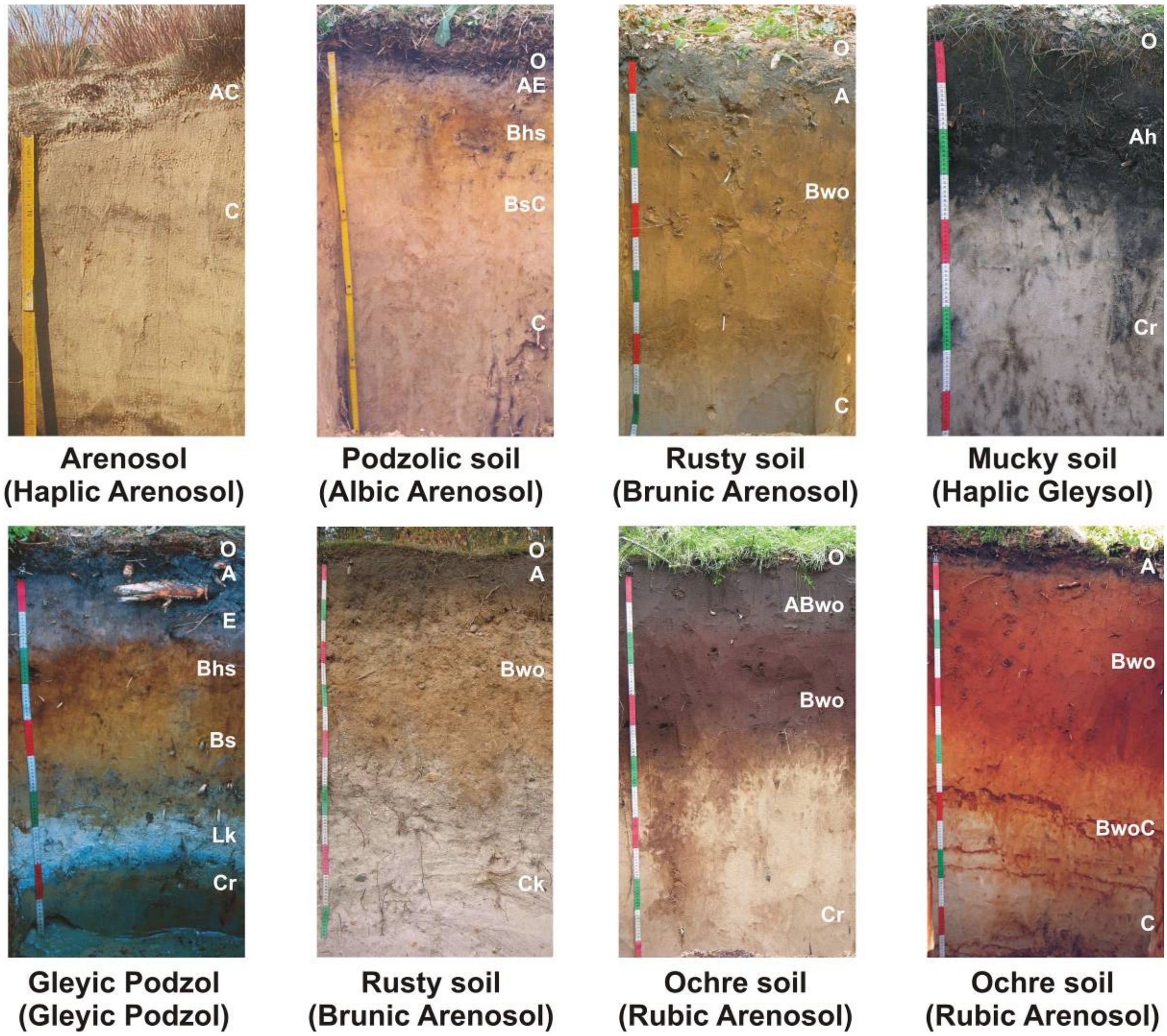


Figure 2. Morphology of sandy soils under study

Table 2. Main properties of soils

No	Soil regional names	Morphology	Texture sand/silt /clay [%]	pH KCl A-C	OC in A [%]	C/N in A	Fe_t [%]	Fe_o [%]	Al_o [%]
1	Arenosol	AC-C	97/3/0	4.3-4.4	0.24	12	AC 0.18 C 0.12	0.03 0.02	0.03 0.03
2	Podzolic soil	AE-Bhs-BsC-C	96/4/0	3.4-4.7	1.10	24	E 0.30 Bhs 0.40 C 0.40	0.05 0.15 0.05	0.04 0.17 0.12
3	Rusty soil	A-Bwo-C	100/0/0	3.6-4.5	2.22	22	A 0.46 Bwo 0.46 C 0.23	0.18 0.07 0.03	0.17 0.10 0.03
4	Mucky soil	Ah-Cr	97/2/1	4.5-4.8	2.51	17	Ah 0.25 Cr 0.14	0.12 0.01	0.30 0.06
5	Rusty soil	A-Bwo-Ck	97/3/0	3.4-9.0 18 % $CaCO_3$	3.20	27	A 0.49 Bwo 0.58 Ck 0.36	0.13 0.08 0.02	n.d.
6	Gleyic Podzol	A-E-Bhs-Bs-Lk-Cr	97/2/1	2.6-8.6 18% $CaCO_3$	1.33	22	E 0.12 Bhs 0.70 Cr 0.26	0.01 0.11 0.02	0.01 0.19 0.01
7	Ochre soil	ABwo-Bwo-Cr	85/14/1	5.8-7.0	4.21	11	A 2.07 Bwo 4.28 Cr 0.37	0.35 1.10 0.01	0.08 0.10 0.02
8	Ochre soil	A-Bwo-BwoC-C	90/6/4	4.5-5.8	1.57	19	A 0.81 Bwo 1.92 C 0.24	0.55 1.17 0.04	0.07 0.07 0.01

Among the presented profiles, the most atypical for sandy soils of the region are: the strongly acid Gleyic Podzol and the Rusty soil, both developed from sediments containing carbonates and the Ochre soils having an unusual red colour (2.5R-5YR by Munsell) as well as high concentrations of iron (up to 4.5 %).

Conclusions

It is worth to notice that, although sandy soils generally have disadvantageous properties for agriculture, as forest sites they constitute productive habitats. Even within the narrow texture group, these soils are morphologically, chemically and ecologically diverse. In regions, where different variants of sandy soils occupy big areas, there is a need to distinguish more detailed classification units, as it is proposed in WRB (2007) for Arenosols. Including all sandy soils in one Reference Soil Group only on the basis of texture, irrespective of their development rate, horizons sequence and ecological value, does not reflect their real diversity. The advanced developmental stage of some sandy soils suggests that they should be classified on the same level of classification as other typologically mature soils.

References

Charzynski P (2000) The comparison between definitions of Podzols according to WRB (Draft) and podzol and podzolic soils according to PTG. In 'Comparison of Polish and German soil classification systems for soil cartography of the mountain and sub-mountain areas' International Conference, Wroclaw, Poland pp. 111-117.

IUSS Working Group WRB (2007) World Reference Base for soil resources 2006. World Soil Resources Reports, No 103, FAO, Rome. Electronic update 2007: http://www.fao.org/ag/agl/agll/wrb/.

Classification of Polish forest soils (2000) Centrum Informacyjne Lasów Państwowych, Warszawa. (in Polish)

Systematics of Polish Soils (1989) *Roczniki gleboznawcze* **40**(3-4) (in Polish)

Zeeberg J (1998) The European sand belt in eastern Europe - and comparison of Late Glacial dune orientation with GCM simulation results. *Boreas* **27**(2), 127-139.

Finding a way through the maze – WRB classification with descriptive soil data

Einar Eberhardt[A] and István Waltner[B]

[A]Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Stilleweg 2, D-30655 Hannover, Germany, einar.eberhardt@bgr.de
[B]Szént István University, 2103 Gödöllő, Páter Károly utca 1, Hungary, Waltner.Istvan@mkk.szie.hu

Abstract
Huge amounts of soil data are recorded in national databases using national nomenclatures. To use them in international context, they have to be harmonized with an international nomenclature. The World Reference Base for Soil Resources (WRB) provides such a framework. We present our approach to retrieve information from existing soil databases and nomenclatures for classifying the soils according to WRB in the form of graphical algorithms. Our study identifies some general mismatches between typical soil profile database structures and the data requirements for testing the presence or absence of WRB diagnostics. In addition, the difficulties originating e.g. from the data structure for recording horizon-related data, differing class limits in national and FAO soil description systems, and ill-determined rules for soil description have to be addressed for proper identification of WRB diagnostics with existing soil data.

Key Words
Soil profile database, database structure, data harmonisation, soil classification.

Introduction
New soil classifications will always be challenged by existing profile data. This applies particularly to the World Reference Base for Soil Resources WRB (IUSS Working Group WRB 2007), which is intended to be a framework for international correlation, and is likely to be used with existing national data. The huge amount of existing national soil data - e.g. in the European Union at least 330,000 digitally available soil profile datasets recorded using national nomenclatures (Baritz *et al.* 2008) - requires tools for automated transformation into internationally usable data.

Connections between morphogenetic soil classification systems and WRB can often not be established in a clear and unambiguous way (e.g. a correlation between German soil taxa with WRB Reference Soil Groups (RSG) as implemented in Adler *et al.* 2004 can be established for about 50 percent of the taxa only). Levels of detail of soil descriptions vary and are related to national survey guideline design and the purpose of individual survey campaigns for which the data were obtained. Hence, it is necessary to develop specific algorithms for each national description system in order to optimally evaluate the data. Furthermore, challenges arise from the structures in which soil data are recorded on the one hand and what information has to be derived from it for WRB classification purposes on the other.

In the present paper we present our approaches to retrieve information from existing soil databases for classifying the described soils according to WRB. We identify typical mismatches between WRB definitions of diagnostics (diagnostic horizons, materials and properties), the key to the Reference Soil Groups (RSG) and the definitions of qualifiers on the one hand and existing (German and Hungarian) soil data structures and database content on the other.

Source structure
The source of the data used here is taken from typical national soil profile and analytical databases. For the German study, the parameters and code lists of the German soil mapping guideline (Ad-hoc-AG Boden 2005) have been used. Data for the validation of these algorithms comprise: (1) A synthetic dataset that covers a huge number of edge cases, (2) German soil profiles of the European forest soil assessment (ICP Forests programme, ICP Forests 2009), and (3) Soil descriptions (German and according to FAO 2006) with WRB classification in the field obtained for this study and representing widespread, but possibly problematic soil types from various landscapes. For the Hungarian study, validation data (soil profile descriptions and analytical parameters) were collected from various institutions. Number and kind of parameters vary widely between both national studies.

Target structure
Analyses of the definitions of diagnostics, RSGs, qualifiers and specifiers are based on IUSS Working Group WRB 2007. The WRB classification is based on the presence or absence of diagnostics, i.e. diagnostic horizons, diagnostic materials, and diagnostic properties. The key to the Reference Soil Groups gives additional specifications, e.g. depth of diagnostics or stricter colour requirements. Qualifier definitions often ask for presence of a diagnostic only, but may also give further specifications; furthermore, an overall rule defines that a qualifier only applies if not a more specific one that also expresses all its requirements is assigned as well. Specifiers always express further detail, but are not based on diagnostics.

WRB distinguishes between typically associated, intergrade and other qualifiers. For our purpose, it is more important to distinguish between basically two types of qualifiers: the one stating that the relative difference in the expression of a parameter over the profile is above a specific level (relative type), and the other expressing that a profile part fulfils absolute requirements with regard to a specific parameter (absolute type). Complex WRB diagnostics include very often both types of definitions, e.g. by combining an absolute threshold value with a difference to underlying or overlying layers (complex type, e.g. the *argic horizon*).

Results and Discussion
Starting from existing soil profile and analytical database structures, we developed graphical algorithms that check the presence of WRB diagnostics (diagnostic horizons, properties and materials, Figure 1). The algorithms take into account various levels of data availability and detail, e.g. classified instead of number values. Figure 1 presents the algorithm for the *argic horizon* based on German soil data. Missing lab data can be substituted by the morphological horizon description. This may cause imprecise results, if classified parameters have class boundaries that do not conform to the respective FAO/WRB classes, e.g. national texture class data. Alternative parameter combinations are tested one after another, sometimes with a decreasing reliability. Note that in this case, the definition of the horizon symbol *Bt* is so near to the

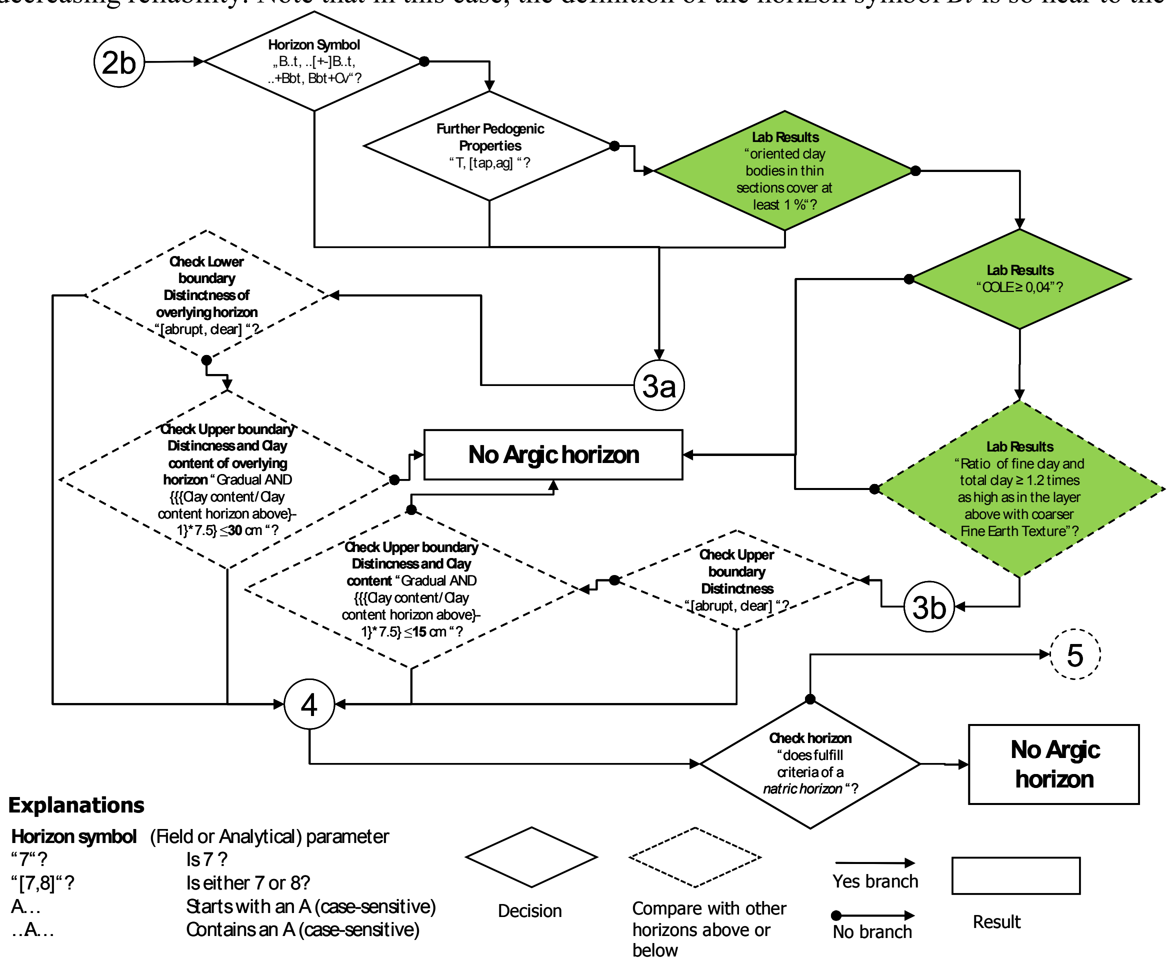


Figure 1. Graphical algorithm. Example: medium part of the algorithm for the *argic horizon* with German soil data, which includes altogether 31 decisions. Lab parameters are highlighted with green colour, numbers relate to criteria of WRB (continuous line marks start of the criterion, dashed line means 'continue with the respective criterion').

definition of the *argic* that it can be assumed almost any *B..t* horizon is an *argic horizon* and therefore, the horizon symbol criterion is put in the beginning of this part of the algorithm. Many other horizon symbol definitions deviate substantially from their FAO analogues or definitions are too wide for a direct correlation, in the German as well as the Hungarian system.

The criteria for the presence of an *argic horizon* comprise absolute and relative elements. The absolute criteria can be determined easily from a database holding the respective parameters. For each morphogenetic horizon the value of the respective parameter is checked whether it fits the requirements of the diagnostic; for cumulative depth requirements, the thickness of all genetic horizons matching the requirements is calculated. Simple thickness requirements are more difficult to check, because more than one pedon section - each consisting of one or more pedogenetic horizons - might fulfil the requirements of a diagnostic. For each section it thus has to be checked independently whether it meets the thickness requirement. The relative criteria - e.g. difference of clay content for an *argic horizon* - are technically challenging because neither upper nor lower boundary can be fixed from the beginning of the analysis, which means that it is not clear which value (and possibly mean value over several adjoining genetic horizons) is to be compared with the respective value of which genetic horizon above or below. For definitions comprising absolute and relative elements, it is therefore recommended to check absolute requirements first, and only for those genetic horizons that match these requirements, to check the relative requirements afterwards.

Morphogenetic descriptions, particularly with classified parameters, may hinder the identification of WRB diagnostics (Figure 2a). The way how soil horizon related data are recorded in typical database structures may even hide WRB diagnostics (Figure 2b). These problems may originate from the differences between the traditional and the WRB approach to the soil profile: in the former, you identify (morphogenetic) horizons, describe their properties and those of their boundaries, while using the latter, you look for the presence or absence of diagnostics, sometimes applying many and very complex criteria. The former approach provides an inherent, horizon-based structure for the data. In contrast, WRB diagnostics are structurally related directly to the profile as a whole and provide no simple inherent structure for data recording.

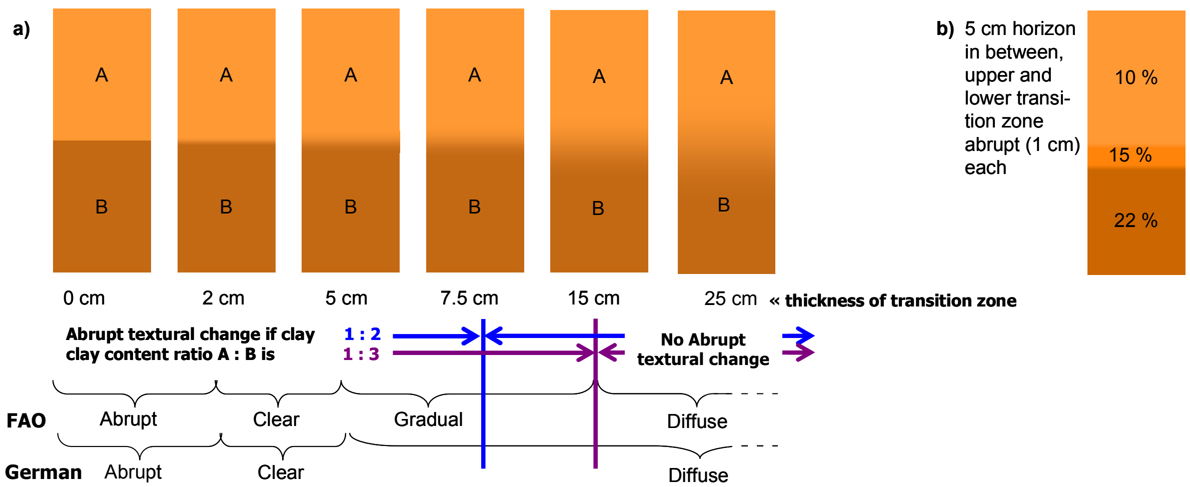


Figure 2. Identification of an *abrupt textural change* (ATC). a) Distinctness of the transition between morphogenetic horizons is recorded with definite classes, while the definition of the ATC is based on relative change. In very few cases, class limits equal the relative threshold values, e.g. when clay content triples (purple threshold line, matching the class limit between *gradual* and *diffuse* horizon transition acc. to FAO 2006). In contrast, the threshold when clay content doubles does not match a class limit (blue line). The German horizon description fails in both cases because the lower class limit for *diffuse* already starts at 5 cm. b) A shallow horizon with intermediate clay content hides the ATC when only adjoining horizons are compared with each other regarding their clay contents.

Different styles in describing soils can produce inconsistent datasets, mostly when detailed survey guidelines are not followed nation-wide or over time (as e.g. in Hungary), or are - although quite elaborated - ambiguous to some extent. E.g. the detection of an *albeluvic tonguing* is relatively easy when the lower boundary of the bleached horizon is described as tongue-like (Figure 3, left); when tongues are long, it is more likely that the surveyor describes a so-called combination horizon with eluviated and illuviated domains (Figure 3, right). In the latter case, the information that the upper horizon penetrates into the *argic horizon* with tongues is lost, because no data on the distribution and shape of the different domains is recorded. No threshold value for the thickness of the transition zone has been defined below which the former and above which the latter way of description shall be used.

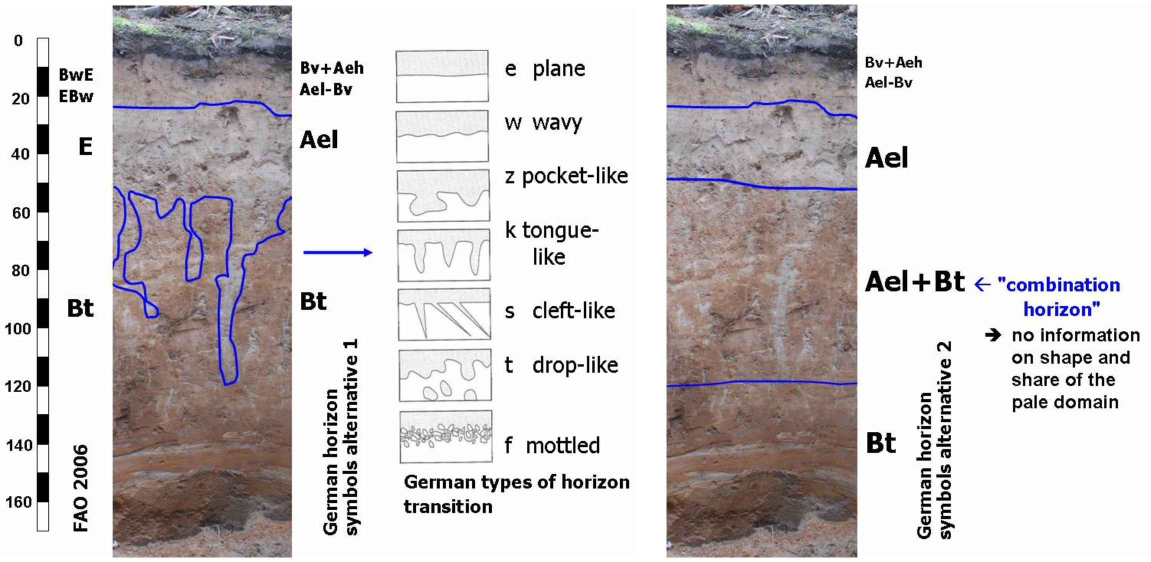


Figure 3. Alternatives for the description of the morphogenetic horizonation according to the German soil mapping guidelines (Ad-hoc-AG Boden 2005) with the possibility to identify *albeluvic tonguing* from the profile description (left) and without (right). Both styles would be compliant with the guideline, the latter case is more common.

Conclusion

Several types of mismatches between the requirements of WRB and the existing data have to be addressed: 1. Missing data. 2. Analytical data obtained with deviating methods. 3. Mismatch of class boundaries for classified values between national and FAO (Food and Agriculture Organization of the United Nations 2006) or WRB nomenclature. 4. Inconsistencies if proxy parameters are used. 5. Description alternatives in guidelines that evoke various rule-conform author's styles. 6. Morphogenetic horizonation may hide the presence of diagnostics. 7. Structure of recording depth information affects identification of diagnostics. While 1-4 are content-related and to be solved individually for each description system, 6 and 7 result from soil data structure and have to be considered in the technical implementation. Many of the inconsistencies can be overcome by proper data analysis.

Acknowledgements

We are indebted to Peter Schad, Erika Michéli and Dana Pietsch for their support. The authorities of several German federal states and Hungarian institutions kindly provided us with soil profile and analytical datasets. Financial support for parts of our studies received from the European Union (project eSOTER, EU's Seventh Framework Programme) is kindly acknowledged.

References

Ad-hoc-AG Boden (2005) 'Bodenkundliche Kartieranleitung. 5th ed.' (Schweizerbart: Stuttgart).

Adler GH, Behrens J, Eckelmann W, Feinhals J, Hartwich R, Krug D (2004) 'Übersetzungsschlüssel zum Transfer von Bodendaten aus den deutschen Klassifikationen KA3 nach KA4 und von KA4 in die internationalen Klassifikationen nach WRB und FAO.' *Arbeitshefte Boden* **1**, 7–49.

Baritz R, Heineke HJ, Eberhardt E, Jones RJA (2008) 'Where is the information from 100 years of soil surveys and research in Europe?' (unpubl. pres., EuroSoil 2008: Vienna).

FAO (2006) 'Guidelines for soil description, 4th ed.' (Food and Agriculture Org. of the UN: Rome).

ICP Forests (2009) International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests. (ICP Forests: Hamburg) www.icp-forests.org/.

IUSS Working Group WRB (2007) 'World reference base for soil resources 2006, update 2007, 2nd ed.' World Soil Resources Reports 103. (FAO: Rome). http://www.fao.org/ag/agl/agll/wrb/doc/wrb2007_corr.pdf, 21.10.2009).

Guidelines for constructing small-scale map legends using the World Reference Base for Soil Resources

Otto Spaargaren[A], Peter Schad[B], Erika Micheli[C], Arwyn Rhys Jones[D]

[A]Duivendaal 9, 6701 AR Wageningenn, The Netherlands, Email worldreferencebase@gmail.com
[B]Lehrstuhl für Bodenkunde, Technische Universität München, 85350 Freising-Weihenstephan, Germany, Email schad@wzw.tum.de
[C]Department of Soil Science and Agricultural Chemistry, Szent Istvan University, 2100 Gödöllő, Hungary, Email micheli.erika@mkk.szie.hu
[D]European Commission, Joint Research Centre, Ispra, Italy, Email arwyn.jones@jrc.ec.europa.eu

Abstract
The World Reference Base for Soil Resources (WRB) is a tool for classifying soils (pedons) and an instrument to help communication between soil scientists using different national soil classification systems. However, there is an increasing demand to use it as a legend for soil maps, at least at smaller scales. To satisfy that need, in January 2010, the IUSS Working Group WRB published the "Guidelines for constructing small-scale map legends using the World Reference Base for Soil Resources" as an addendum to the WRB. These Guidelines are presented here.

Key Words
World Reference Base for Soil Resources, soil classification, soil maps, map legends, scale.

Main text
In January 2010 an addendum to WRB 2006, first update 2007 (IUSS Working Group WRB 2007), was published electronically (IUSS Working Group WRB 2010). In this addendum guidelines are provided to construct map units (or soil typological units) and map legends for scales of 1:250 000 and smaller. For terms and definitions in these guidelines the user is referred to IUSS Working Group WRB (2007).
When classifying soils, the WRB is capable of indicating most of the soil's properties, and in most cases the result is a quite satisfactory and informative soil name. However, when generalization is required, e.g. in mapping, important information may not show, depending on how the generalization is carried out. Although WRB was not primarily designed to serve mapping purposes, it is increasingly used for that. This addendum has been developed to serve the need for small-scale mapping.

In IUSS Working Group WRB (2007) it is suggested to use for small-scale maps the prefix qualifiers only and for large-scale maps additional suffix qualifiers. If this approach is taken with the current configuration of the qualifiers, important information on certain soil characteristics may not be revealed for small-scale maps. For example, the occurrence of clay skins (Cutanic) is recognized at prefix level, and, when generalizing, Luvisols (and related soils) become Cutanic Luvisols or Cutanic other soils, which for temperate and subtropical regions does not give satisfactory differentiation. Similarly, Rhodic in Ferralsols and Nitisols, and Xanthic in Ferralsols, important qualifiers to indicate their environmental setting and geological relationship, are suffix qualifiers, yielding in generalizations only Haplic Ferralsols and Nitisols.
These guidelines (IUSS Working Group WRB, 2010) are based on the following considerations:

- The soil units and their ranking in the FAO-UNESCO Legend (FAO 1974) and Revised Legend (FAO 1988) of the Soil Map of the World (SMW);
- The occurrence and significance of soil properties in other classification systems;
- The relevance of differentiation characteristics for environmental and management functions;
- The availability of soil information (legacy and modern);
- The mappability of soil characteristics at scales of 1:250 000 and smaller.

Intergrade qualifiers are excluded from the map unit qualifier list once the RSG is passed in the Key, unless a specific exclusion is made or the feature is considered to be very important. All qualifiers have been taken into account, regardless whether they are prefix or suffix qualifiers for classification purposes. It must be emphasized that no new definitions and no new qualifiers are introduced; only the ones that are listed in the above-mentioned WRB publication will be used. However, in order to obtain consistent lists, the obligatory "Endo-" specifier has been removed in some cases.

In this addendum, for every Reference Soil Group, the qualifiers are given that can be used to construct small-scale map units and map legends. They are divided into lists of main map unit qualifiers and optional map unit qualifiers. The main map unit qualifiers are ranked and have to be used in the given order. The optional map unit qualifiers are listed alphabetically and may be added according to the need of the user. Some of the optional map unit qualifiers may not be mappable on the scales under consideration.
The following rules apply:

- A map unit consists either of the dominant soil only or of the dominant soil plus a co-dominant soil or one or more associated soils; dominant soils represent 50% or more of the soil cover, co-dominant soils 25% or more, and associated soils are mentioned only if they represent 5% or more of the soil cover or are of high relevance in the landscape ecology; instead of one dominant soil, a combination of at least two co-dominant soils is also possible; if co-dominant or associated soils are indicated, the words "dominant:", "co-dominant:" and "associated:" are written before the name of the soil; the soils are separated by semicolons;
- The number of qualifiers specified below refers to the dominant soil; for co-dominant or associated soils, smaller numbers of qualifiers (or even no qualifier) may be appropriate;
- For map scales of 1 : 5 000 000 and smaller, either the Reference Soil Group (RSG) name or the RSG name plus the first applying qualifier of the main list is used; the qualifier is placed before the RSG name;
- For map scales from 1 : 1 000 000 to 1 : 5 000 000, the RSG name plus the first two applying qualifiers of the main list is used; the qualifiers are placed before the RSG name; the first applying qualifier stands closest to the RSG name;
- For map scales from 1 : 250 000 to 1 : 1 000 000, the RSG name plus the first three applying qualifiers of the main list is used; the qualifiers are placed before the RSG name; the first applying qualifier stands closest to the RSG name, the second one stands in the middle;
- Additional qualifiers of the main list or qualifiers of the optional list may be used in brackets behind the RSG name; if two or more qualifiers behind the RSG are used, the following rules apply: (a) the qualifiers are separated by commas, (b) the additional qualifiers from the main list are placed first and out of them the first applying qualifier stands first, (c) the sequence of the qualifiers from the optional list is according to the preference of the soil scientist who makes the map;
- In case two or more main map unit qualifiers are listed separated by a slash (/), only the dominant one is used;
- If there are less qualifiers applying than described above, the smaller number is used;
- Redundant qualifiers (the characteristics of which are included in a previously used qualifier) are not added; the qualifier Haplic cannot be used in combination with other qualifiers before the RSG name.
- The use of the specifiers Epi- (the qualifier applies only between 0 and 50 cm from the mineral soil surface) and Endo- (the qualifier applies only between 50 and 100 cm from the mineral soil surface) is encouraged, where applicable.

In the following, we give an example with Leptosols and Regosols:

LEPTOSOLS

Main map unit qualifiers	*Optional map unit qualifiers*
Nudilithic/Lithic	Andic
Hyperskeletic	Aridic
Rendzic	Brunic
Folic/Histic	Calcaric
Mollic/Umbric	Cambic
Dystric/Eutric	Drainic
	Gelic
	Gleyic
	Greyic
	Gypsiric
	Humic
	Novic
	Ornithic
	Oxyaquic
	Placic
	Protothionic
	Salic
	Skeletic
	Sodic
	Stagnic
	Technic
	Tephric
	Vertic
	Vitric
	Yermic

REGOSOLS

Main map unit qualifiers	*Optional map unit qualifiers*
Leptic/Skeletic	Arenic
Gleyic	Aric
Gelistagnic/Stagnic	Aridic
Thaptovitric/Thaptandic	Brunic
Tephric	Clayic
Colluvic	Densic
Gypsiric/Calcaric	Escalic
Dystric/Eutric	Folic
	Gelic
	Humic
	Hyperochric
	Hyposalic
	Ornithic
	Oxyaquic
	Siltic
	Sodic
	Takyric
	Technic
	Transportic
	Turbic
	Vermic
	Yermic

Example: In a map unit, 80% of the surface is covered by a severely eroded calcareous soil with 50% gravel over hard rock starting at 80 cm, in the other 20% the soil above the hard rock has 90% gravel. This unit will be denominated

- at map scales of 1 : 5 000 000 or smaller
  dominant: Regosol; associated: Leptosol or *dominant: Skeletic Regosol; associated: Hyperskeletic Leptosol* (the option *Leptic Regosol* was not chosen, because the hard rock starts only at 80 cm)
- at map scales from 1 : 1 000 000 to 1 : 5 000 000
  dominant: Calcaric Skeletic Regosol; associated: Hyperskeletic Leptosol
- at map scales from 1 : 250 000 to 1 : 1 000 000
  dominant: Calcaric Skeletic Regosol; associated: Hyperskeletic Leptosol
- (redundant qualifiers are not used; in this example the next applying qualifier for the Regosols is *Eutric*, however *Calcaric* already indicates the high base saturation; therefore at this map scale only two qualifiers are applicable)

As in this example for the Regosols a choice had to be made between *Leptic* and *Skeletic*, which are not mutually exclusive, the non-chosen qualifier may be added in brackets after the name of the RSG:

Skeletic Regosol (Leptic)
Calcaric Skeletic Regosol (Leptic)

Conclusion

The authors are convinced that these guidelines provide a viable tool for constructing small-scale map legends using the WRB.

References

FAO (1974): FAO-Unesco Soil Map of the World, Vol. 1, Legend. UNESCO, Paris.
FAO (1988): FAO-Unesco Soil Map of the World, Revised Legend. *World Soil Resources Reports* **60,** FAO, Rome.
IUSS Working Group WRB (2007): World Reference for Soil Resources 2006, first update 2007. *World Soil Resources Reports* **103,** FAO, Rome. http://www.fao.org/ag/agl/agll/wrb/doc/wrb2007_corr.pdf.
IUSS Working Group WRB (2010): Guidelines for constructing small-scale map legends using the World Reference Base for Soil Resources. Addendum to the World Reference Base for Soil Resources. FAO, Rome. http://www.fao.org/fileadmin/templates/nr/images/resources/pdf_documents/WRB_Legend.pdf.

On the origin of Planosols – the process of ferrolysis revisited

Eric Van Ranst[A], Alemayehu Regassa Tolossa[B], Mathijs Dumon[A], Jean-Thomas Cornelis[C], Jozef Deckers[D]

[A] Department of Geology and Soil Science, Ghent University, Belgium, E-mail: eric.vanranst@UGent.be
[B] Department of Soil Science, Jimma University, Ethiopia
[C] Soil Science Unit, Université Catholique de Louvain, Belgium
[D] Department of Land Management, K.U.Leuven, Belgium

Abstract
Planosols have been recognized as a Major Soil Group right from the beginning in the legend of the FAO Soil Map of the World. Also in WRB system it maintained that position at Reference Soil Group level on the account that a major pedogenetic process, ferrolysis, is underlaying the severe stagnic properties that characterize this group. With the recent introduction of Stagnosols in WRB it appears that a serious overlap has been introduced at Reference Soil Group level. This paper aims to throw new light on the genesis of Planosols, drawing from new soil surveys conducted in the south-western Ethiopian highlands. The conclusion is that it is highly unlikely that 'ferrolysis' can be called in to explain the genesis of Planosols in the Ethiopian highlands. As Ethiopia is one of the mainstays of Planosols, it is suggested that WRB rethinks its strategy on soils with stagnic properties as there is room for rationalization.

Key Words
Planosols, Stagnic properties, Ferrolysis, Stagnosols.

Introduction
International soil correlation of Planosols
The Reference Soil Group of Planosols holds soils with surface horizons that are bleached and light-coloured or have a stagnic colour pattern, show signs of periodic water stagnation and abruptly overly a dense, slowly permeable subsoil with significantly more clay than the surface horizons (Driessen *et al*. 2001). They typically occur in seasonally or periodically wet plateau areas, often above normal flood levels or nearby rivers or estuaries. Occasionally they occur on gentle or very gentle slopes, but usually the geographical extent is limited in these landscape positions.

In the old European literature these soils are mainly referred to as pseudogley soils or as clayey Podzols, however, neither of these soil groupings required an abrupt textural change from the bleached horizon to the underlying dense horizon. The U.S. classification of 1938 was the first to use the term Planosols; the present Soil Taxonomy (Soil Survey Staff 2006) includes most of the original Planosols in the Albaqualfs, Albaquults and Argialbolls. In the revised legend of the Soil Map of the World, Planosols are recognized as a major soil at highest level. Also in the World Reference Base for Soil Resources, Planosols are accommodated under the set of soils with stagnating water together with the Stagnosols (IUSS Working Group WRB 2007).

Soils with stagnogley under WRB
The WRB (IUSS Working Group 2007) accommodates four Reference Soil Groups at the highest level, which have an assemblage of stagnogley as one of the key features: in key order they are the Solonetz, the Planosols, the Stagnosols and the Albeluvisols. It is acknowledged that stagnogley is not part of the key definition in Solonetz and in Albeluvisols, however in most cases it is a major feature in these soils. Stagnosols had a turbulent history in the WRB. In the first draft of WRB in 1994, they were proposed as a reference group, however they did not make it in the 1998 version. The Working group WRB at that time did recognize the importance of stagnogley as an important soil feature. The rationale for not keeping the Stagnosols in was the fact that 'stagnogley' as such is only a consequence rather than a major pedogenetic process. This was in conflict with one of the basic principles of WRB to follow as much as possible a soil-genetic approach in the delineation of major soil groupings.

In line with the above-sketched rationale the following pedogenetic processes were considered important for recognizing the soils with stagnic properties:

- Solonetz: sodification, peptisation of the clay minerals which move into a very compact argic horizon. Upon solodization of the Solonetz it is hypothesized that the distinct textural change and the stagnogley is enhanced by a ferrolysis process at the fringe between the E and the B horizon (natric horizon).

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

- Planosols: the 'abrupt textural change' from coarse textured surface soil to finer subsoil can be caused by:
    - 'Geogenetic processes' such as sedimentation of sandy over clayey layers, creep or sheet wash of lighter textured soil over clayey material, colluvial deposition of sandy over clayey material, or selective erosion whereby the finest fraction is removed from the surface layers, and/or
    - 'Physical pedogenetic processes', such as selective eluviation-illuviation of clay in soil material with a low structural stability, and/or
    - 'Chemical pedogenetic processes' notably a process proposed under the name 'ferrolysis', an oxidation-reduction sequence driven by chemical energy derived from bacterial decomposition of soil organic matter (Brinkman 1970).
- Albeluvisols: the genesis of Albeluvisols roots back to Late Glacial times, more particularly to the Middle and the Younger Dryas periods and its respective interglacials:
    - Argilluviation (mobilization and translocation of clay) during interglacials;
    - Formation of polygonal albeluvic tonguing during the last glacial period, including compactation of the outer sphere of the soil polygons leading to the so-called 'closed box system' which eventually results in strongly expressed stagnogley on top of the compacted agric horizon. It was also inferred that the process of ferrolysis could have enhanced the textural contrast in Albeluvisols, however this claim was refuted by Van Ranst and De Coninck (2002), who proved that this process does not take place in soils with albeluvic tonguing (Albeluvisols) and in soils with stagnic colour pattern in Western Europe.

During the international conference on soil classification in 2004, at Petrozavodsk (Russian Federation, organized by the Institute of Biology, Karelian Research Centre), the decision was taken to take the Stagnosols on board again in WRB. This decision was implemented in the published 2006 and 2007 (electronic) versions of WRB during the IUSS congress at Philadelphia, USA. At the same time a call was made for fundamental research which should elucidate the above-mentioned pedogenetic processes and especially the process of ferrolysis.

On the origin of the abrupt textural change in Planosols – Ferrolysis revisited – case of SW-Ethiopia
As Planosols are most extensive in relatively hot climates with a strong seasonal variation in rainfall, they are commonly occurring in association with Vertisols in presently sub-humid to semi-arid climates. In these zones all variations intermediates between Vertisols and Planosols occur such as Vertisols with a thin layer of grey or light grey, silty upper soil horizon of variable thickness, overlaying heavy clay, with silty material "etched in" along cracks into the underlying clayey material. If this layer of silty material is only few centimetres thick, the Vertisol still stands and this coarse material is tell-tale of some important pedogenetic process which is not sufficiently understood.
Soilscapes with associations of Planosols and Vertisols are very common throughout the Ethiopian highlands, all developed from massive occurrences of Tertiary flood basalts under a sub-humid moisture regime.

Materials and methods
In the framework of a major research project in Gilgel Ghibe catchment in the Omo-River basin, we studied a typical Planosol profile near Dedo (Figure 1). Soil samples were taken at eight depths, with more frequent sampling near the point of abrupt textural change.
The samples were analyzed in the Laboratory of Soil Science at Ghent University for the following characteristics:

- ✓ Micromorphology of samples taken in Kubiëna boxes;
- ✓ On disturbed samples:
    - Standard characteristics such as pH, texture, organic carbon, CEC and exchangeable base cations and anions
    - Total element composition
    - XRD of powder samples of fine earth fractions
    - XRD of separated silt and clay fractions
    - Phytoliths (opal-A) analysis

Phytoliths (amorphous silica precipitated in plants) were extracted from plants and soil by qualitative gravimetric methods (Herbauts *et al.* 1994) and quantitative alkaline methods (Saccone *et al*. 2007). These two extractions will allow us to analyze the morphology of phytoliths in plant and soil and infer the relative contribution of phytoliths on the total content of amorphous silica in the soil samples.

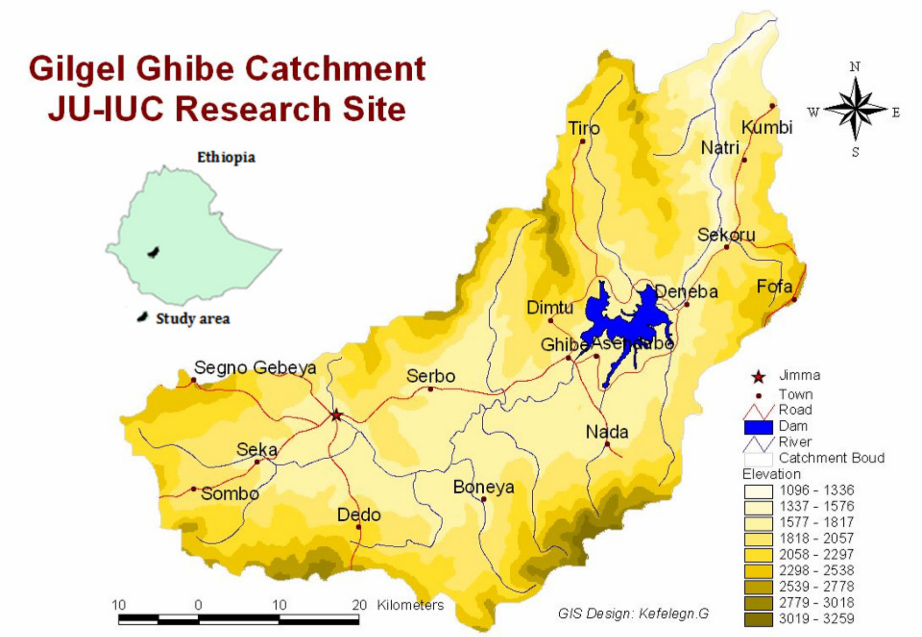


Figure 1. Situation map of Gilgel Ghibe catchment

Results

Under the microscope many phytoliths were observed in the silty and bleached upper layer (0-34 cm), while only few phytoliths were detected, mainly in cracks, in the clayey soil material (Vertisol) underneath (Figure 2).

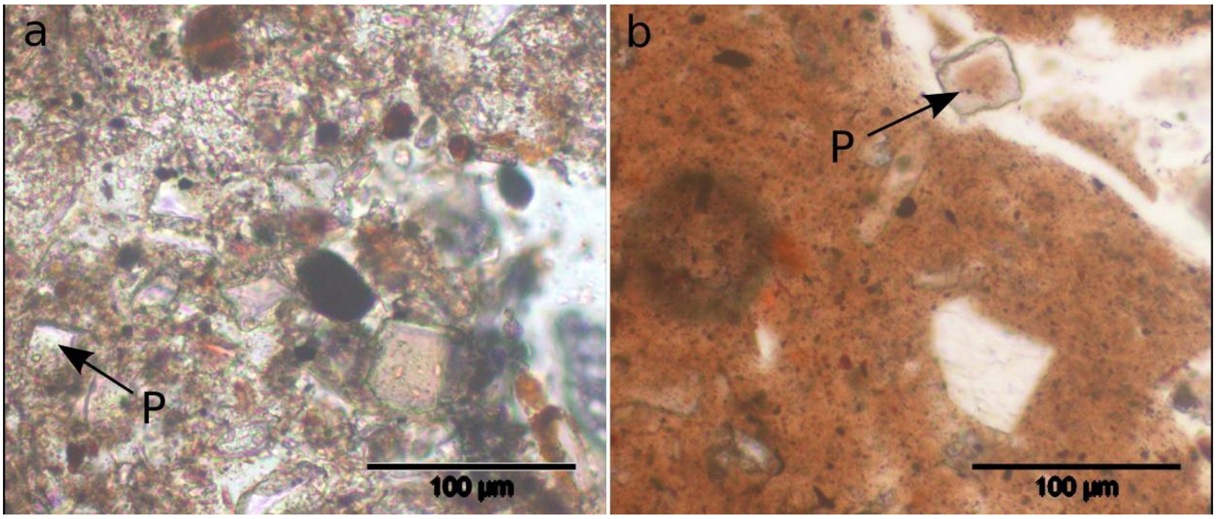


Figure 2. Groundmass in plane polarized light of (a) the silty and bleached upper layer containing many phytoliths (P), and (b) the clayey soil material (Vertisol) underneath having only few phytoliths mainly in the cracks.

XRD analysis showed that quartz and feldspars are the major mineral components in the upper soil layer. On the other hand the clayey soil material is dominated by swelling 2/1 phyllosilicate minerals, and has a much lower quartz content and only traces of feldspars in the fine earth fraction. The transition between the two soil materials is, besides an abrupt change in texture, also indicated by significant changes in chemical characteristics and total elemental composition. At the transition (depth around 34 cm), the O.C content increased from 0.5 to 0.9-1.2% suggesting a buried topsoil or migration of organic matter, while the strong increase in CEC, from 10 to 40-60 cmol(+)/kg, and also in exchangeable base cations clearly reflects the difference in mineralogical composition. Soil pH (in H_2O) and base saturation gradually increase with soil depth, but are higher than 5.3 and 57% in all horizons, respectively. The relatively high pH and base saturation at present means that the actual conditions are not inductive for ferrolysis . The upper soil layer has much higher total SiO_2 (> 70%) and Na_2O (1.2-1.4%) contents compared to the clayey subsoil (50-55% SiO_2 and 0.5% Na_2O), indicating the dominance of siliceous components and feldspars in the upper layer. At the transition, there is a clear increase in the Al_2O_3, CaO, MgO, and H_2O (loss on ignition) content, due to the smectitic minerals. Through scanning electronic microscopy (SEM), the morphology of amorphous silica in soils was compared with the morphology of phytoliths extracted from plants to make assumptions about the origin (biogenic or pedogenic) of the high content of amorphous silica in the horizon above the textural change.

Conclusions

From the results of this analysis, it seems highly unlikely that ferrolysis could have been a process under the given circumstances. Counter-indicative to ferrolysis at the point of abrupt textural change are the relatively high pH, presence of a sizeable reserve of weatherable minerals (mainly feldspars) and presence of open 2:1 phyllosilicates. The thin sections disclose high concentrations of phytoliths which are indicative of a high level of past and present biological recycling in the horizon above the textural change. Alternative geogene hypotheses are put forward in order to explain the variability of the Planosols and Vertisols in the Gilgel Ghibe catchment. The study of the dynamic of amorphous silica in the soil-plant system provided essential information to better understand the influence of biogenic and pedogenic processes on the soil properties. Last but not least, based on the analysis, recommendations are made for rationalizing the soils with stagnic properties in WRB. It seems to us that there is too much of soils with stagnic properties in the WRB system since the re-introduction of the Stagnosols. If the fundamental questions raised on the hypothesis of ferrolysis under the circumstances of the Ethiopian soilscape also apply to Planosol situations elsewhere in Africa, one could argue to subdue the Planosols to lower level in the WRB system.

References

Brinkman R (1970) Ferrolysis, a hydromorphic soil forming process. *Geoderma* **3**,199-206.

Driessen P, Deckers J, Spaargaren O, Nachtergaele F (2001) Lecture notes on the major soils of the World. *World Soil Resources Report* **94**, FAO, Rome.

Herbauts J, Dehalu FA, Gruber W (1994) Quantitative-determination of plant opal content in soils, using a combined method of heavy liquid separation and alkali dissolution. *European Journal of Soil Science* **45**, 379-385.

IUSSS Working Group WRB (2007) World reference base for soil resources 2006. *World Soil Resources Reports* **103**, FAO, Rome. Electronic update 2007: http://www.fao.org/ag/agl/agll/wrb/

Saccone L, Conley DJ, Koning E, Sauer D, Sommer M, Kaczorek D (2007) Assessing the extraction and quantification of amorphous silica in soils of forest and grassland ecosystems. *European Journal of Soil Science* **58**, 1446-1459.

Soil Survey Staff (2006) Keys to Soil Taxonomy, *USDA Department of Agriculture, Natural Resources Conservation Service*.

Van Ranst E, De Coninck F (2002) Evaluation of ferrolysis in soil formation. *European Journal of Soil Science* **53**, 513-519.

Orphans in soil classification: Musing on Palaeosols in the World Reference Base system

Karen Vancampenhout[A,B] and Jozef Deckers[A]

[A]Department of Earth and Environmental Sciences, K.U.Leuven, Celestijnenlaan 200E, 3001 Leuven, Belgium. Email karen.vancampenhout@ees.kuleuven.be and seppe.deckers@ees.kuleuven.
[B]Department of Biosciences and Technology, KHKempen University college, Kleinhoefstraat 4, 2440 Geel, Belgium

Abstract
Despite the ongoing discussion, there is a strong need for a well-defined, widely usable classification for buried palaeosols that can accurately represent the main palaeosol characteristics. Rather than developing a separate system, the authors evaluate the use of WRB 2007 without major alterations. For palaeosols buried deeper than 2m, they propose to consider the upper boundary of the palaeosol as the 'soil surface' and add the word 'Buried'. RSGs and qualifiers can then be used unaltered to represent an array of major palaeosol characteristics, making this approach particularly suitable to classify welded or polygenetic palaeosol-complexes. Not all definitions used in WRB 2007 can be indisputably applied to palaeosols, but small adaptations in future versions could easily solve this problem. The use of WRB 2007 is assessed for five benchmark palaeosols or pedo-stratigraphic markers from Belgium and this case study illustrates that the concept of WRB could easily be extended to include palaeosol classifications.

Key Words
Palaeosols, soil classification, WRB, Tertiary palaeosols, Rocourt, Usselo.

Introduction
Classifying buried palaeosols still is an issue of debate. Although most soil classification systems are not primarily indented to classify palaeosols, there is a strong need for an interdisciplinary reference: the vast array of ill-defined terms, concepts and adaptations today is confusing. Moreover, a well-designed classification system would enable a rapid understanding of the main properties of a certain palaeosol. This paper aims at establishing a proof of concept for the applicability of World Reference Base 2007 (IUSS Working Group WRB 2006/07) in classifying palaeosols, by evaluating its performance in describing the properties of five Belgian Tertiary and Quaternary palaeosols (both deep seated as more superficial).

State of the art
Mack *et al.* (1993) and James *et al.* (1998) proposed a system based on Soil Taxonomy (Soil Survey Staff 1992), further elaborated upon by Nettleton *et al.* (1998) for buried soils. Krasilnikov and Garcia Calderon (2004) state that WRB is more suitable and propose to use the prefix Thapto- followed by the (modified) name of (modified) Reference Soil Group (RSG). These types of adapted system emphasize on only one diagnostic horizon, while palaeosols are often polygenetic. Moreover, adaptations of existing systems may cause confusion. Proposing a completely new system for buried palaeosols is not advantageous either, as the main goal of any classification system, i.e. to provide a reference to a large a number of soil scientists, is not attained.

Therefore, the option of using a basically unaltered well-known classification system merits more attention. A system based on strictly defined profile characteristics such as WRB eliminates the need for speculation and can be used without major adaptations: only the traditional constraint for material within 2 m of the Earth's surface needs to be adapted to make the system applicable to deep-seated soils. The authors propose to substitute the palaeosol top for the surface (if >2m) and to add the word 'Buried'. The qualifier system used in WRB moreover allows to focus on multiple properties. Hereby it should be noted that in WRB qualifier lists in the Reference Soil Groups are not restrictive.

Classification of five benchmark palaeosols

The 'chocolate sands' near Pellenberg

A deep seated (>10m), up to 4m thick, chocolate brown colored palaeosol occurs in the Early Oligocene Tongerian Kerkom sands near Pellenberg (Figure 1). These sands are chemically poor, coarse and cross-bedded, illustrating a fluvio-marine environment. The 'chocolate' dull brown to very dark brown horizon contains C_{org} up to 0.6%, cementation and cracked coatings on sand grains. Slightly darker lamellae of variable thickness occur with carbon contents up to 1.27%. It is interpreted as the B horizon of a giant coastal Podzol with lateral groundwater flow and fulfils the requirements of a spodic horizon (Buurman *et al.* 1998; Van Herreweghe *et al.* 2003). Hence this soil should be termed a "Buried Carbic Podzol", totally in line with the available data on this soil (Buurman *et al.* 1998; Van Herreweghe *et al.* 2003). Arenic and Dystric also apply to this soil, but can be considered redundant and not considered in the qualifier's list of the Podzols. Other qualifiers such as Fluvic or Tidalic or Gleyic would capture more properties of this soil, but their current definition is not indisputably applicable on palaeosols. Hence, the introduction of Palaeofluvic, Palaeotidalic or Palaeogleyic should be considered. Furthermore, it would be useful to extend the definition of Lamellic (currently only for clay lamellae) and Profondic (currently only for argic horizons) to account for the hyper-dimensions (4-10m) of the spodic horizon. Its genesis by lateral intrusion of DOC is not accounted for in the classification.

Figure 1. The 'chocolate sands' near Pellenberg.

Figure 2. The Boom Clay near Pellenberg.

The Boom clay near Pellenberg

The Tertiary Boom Clay is a deep seated (>7m) tropical marine formation (Rupelian) of black, acid clays. A soil has formed in its top including 2-4% organic material, jarosite infillings, concretions of gypsum and silicified septaria (Vandenberghe *et al.* 1997). The boom clay can be accurately defined as a thionic horizon. Given its clear marine origin, this soil logically should be termed a "Buried Fluvisol (Thionic, Gypsiric, Clayic)". However, the current definition of fluvic material is problematic for palaeosols, as it requires "sediments that receive fresh material at regular intervals or have received it in the recent past". An exception for palaeosols could be a solution. If not, a "Buried Umbrisol (Thionic, Gypsiric, Clayic)" should be the correct classification. Again, a Palaeotidalic or Palaeofluvic qualifier would be useful as would one that accounts for the septaria, e.g. Septaric.

The Rocourt Pedocomplex (Veldwezelt-Hezerwater)

The Rocourt Pedosequence is a pedo-stratigraphic marker for the last interglacial and early glacial period in Upper Pleistocene loess deposits. Most typically it is described as a complex of one or more reddish B horizons showing clay coatings and a polygonal network of bleached desiccation cracks. They are overlain by a banded light-gray bleached layer caused by stagnating, laterally moving melt water and at the top a complex of A horizons with slightly more organic matter. The pedocomplex is intensely welded and highly influenced by frost action. At Veldwezelt-Hezerwater, the B horizons in the profile described by Vancampenhout *et al.* (2008) do not fulfil the requirements for an agric horizon and part of the clay coatings originate from soil welding, i.e. they were formed when these horizons were no longer near the surface. The organic matter content of the A horizons is 0.5% or less. Requalification at the top of the profile resulted in very high base saturation of the upper horizons.

This soil may therefore be named a “Buried Fragic Endostagnic Protoluvic Cambisol (Hypereutric, Siltic, Chromic)”. The qualifiers Turbic, Glossalbic and Cutanic would be useful to express the observed, cryoturbation, albeluvic properties and clay cutans in this profile. However, the cryoturbation is -at present- not at the palaeosol surface or above a cryic horizon and the albeluvic properties and clay coatings do not occur in a natric or argic horizon. The qualifier Ochric would be very appropriate to represent the organic horizons, yet is no longer used in WRB 2007. If these additional qualifiers can be used, the WRB classification successfully captures all main properties of this complex, intensively welded, polygenetic palaeosol.

Figure 3. The Rocourt Pedocomples at Veldwezelt-Hezerwater

Figure 4. The Usselo Soil (dry variant)

Figure 5. The Usselo Soil (wet variant)

The Usselo soil near Lommel
The ‘Usselo-palaeosol’ represents the soil formed during the Allerød interstadial in Quaternary coversands. It is found <2 m below present-day surface and is overlain by Podzols. It consists of a bleached layer containing charcoal particles and beetle bioturbations and some cryoturbation (white veins originating from ice lenses) in the dry variants, while peaty accumulations of organic material characterize the wet variants. Some variants of the Usselo soil have a subdued rubified expression (Kaiser *et al*. 2009). As the palaeosol is not buried deeper than 2m, the regular WRB classification applies. The present-day soil profile and included palaeosol classify as a “Haplic Podzol (Thaptoalbic)” for the dry variant and a “Carbic Podzol (Thaptohistic)” for wet variant. The rubified expressions could not be accounted for in WRB 2007. Indications for the palaeo-cryoturbations (at present not linked with a cryic horizon) and beetle bioturbations would likewise be useful.

The buried Albeluvisols near Bertem
The forest near Bertem is featured by an unaltered topography, characterized by a Holocene flat-bottomed valley catena of undisturbed Albeluvisols (plateau), Atlantic Luvisols or Alisols (slopes) and buried palaeosols (valley bottom). This valley topography originates from the Dryas stadials, when the slopes eroded by solifluction and the valley bottom was covered by the eroded material The profile in the valley bottom shows prominent albeluvic tonging at a depth of ca. 70 cm. This palaeosol is overlain by a Haplic Alisol rich in manganese and iron accumulations (Brahy *et al.* 2000). As the palaeosol occurs at shallow depth, the profile classifies as a ‘Haplic Alisol (Manganiferric, Dystric) over Albeluvisol’, which perfectly describes its main characteristics.

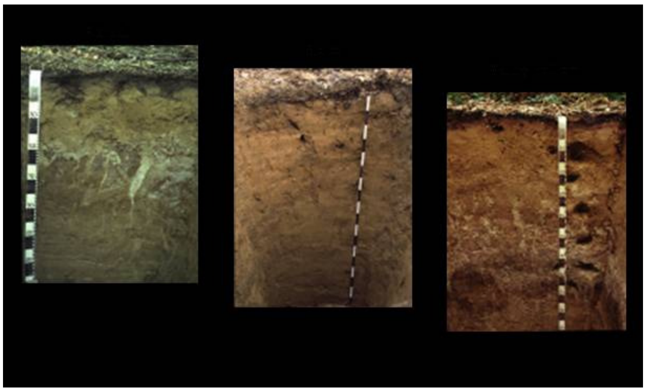


Figure 3. The Bertembos-valley catena: plateau soil (left), slope soil (center) and valley bottom soil (right)

Conclusion

If the upper boundary of a palaeosol is regarded as the 'soil surface', the definitions of WRB can very successfully be used for palaeosols. Qualifiers are well suited to comprehensively indicate the main properties of palaeosols, even the complex nature of polygenetic palaeosols on loess is well represented. In order to use WRB more effectively for palaeosols, a revision of the boundary conditions for the use of certain qualifiers would be advantageous. New qualifiers may also be proposed and the use of applicable qualifiers that are not enlisted in the reference groups is to be encouraged.

References

Brahy V, Titeux H, Delvaux B (2000) Incipient podzolization and weathering caused by complexation in a forest Cambisol on loess as revealed by a soil solution study. *European Journal of Soil Science* **51**(3), 475-484.

Buurman P, Jongmans AG, Kasse C, van Lagen B (1998) Oil Seepage or fossil podzol? An Early Oligocene oil seepage at the southern rim of the North Sea Basin, near Leuven (Belgium) - discussion. *Netherlands Journal of Geosciences* **77**, 93-98.

IUSS Working Group WRB (2006/07) World Reference Base for Soil Resources 2006. World Soil Resources Reports 103. (FAO: Rome). Electronic update 2007: http://www.fao.org/ag/agl/agll/wrb/.

James W C, Mack GH, Monger HC (1998) Paleosol classification. *Quaternary International* **51**(2), 8-9.

Kaiser K, Hilgers A, Schlaak N, Jankowski M, Kühn P, Bussemer S, Przegie˛tka K (2009) Palaeopedological marker horizons in northern central Europe: characteristics of Lateglacial Usselo and Finow soils. *Boreas* **38**, 591–609.

Krasilnikov P, Garcia Calderon NE (2004) Palaeosols place in world classification. In 'IUSS and INQUA international conference on Palaeosols: memory of ancient landscapes and living bodies of present ecosystems (Florence, June 2004)'. Book of abstracts.

Mack GH, James WC, Monger HC (1993) Classification of paleosols. *GSA Bulletin* **105**(2), 129-136.

Nettleton WD, Brasher BR, Benham EC, Ahrens RJ (1998) A classification system for buried palaeosols. *Quaternary International* **51**, 175-183.

Soil Survey Staff (1992) Keys to Soil Taxonomy, 5th edition. Soil Management Support Services Technical Monograph 19. (Pocahontas Press Inc.,Blacksburg).

Van Herreweghe S, Deckers S, DeConinck F, Merckx R, Gullentops F (2003) The paleosol in the Kerkom Sands near Pellenberg (Belgium) revisited. *Netherlands Journal of Geosciences* **82**, 149-159.

Vancampenhout K, Wouters K, Caus A, Buurman P, Swennen R, Deckers J (2008) Fingerprinting of soil organic matter as a proxy for assessing climate and vegetation changes in last interglacial palaeosols (Veldwezelt, Belgium). *Quaternary Research* **69**, 145-162.

Vandenberghe N, Laenen B, VanEchelpoel E, Lagrou D (1997) Cyclostratigraphy and climatic eustasy. Example of the Rupelian stratotype. *Comptes Rendus De l'Academie Des Sciences Serie I -Sciences De La Terre Et Des Planetes* **325**, 305-315.

Pedometrics application for correlation of Hungarian soil types with WRB

Vince LÁNG[A*] - Márta FUCHS[A] - István WALTNER[A] – Erika MICHÉLI[A]

[A] Department of Soil Science and Agricultural Chemistry, Szent Isván University, H-2103, Gödöllő, Páter K. u. 1., Hungary
[*]Corresponding author: Lang.Vince@mkk.szie.hu

Abstract
The development of the recent European and global initiatives resulted in an increasing demand for harmonized digital soil information. The correlation of different national classification systems has an increased importance in the development of European and global databases.
Since 1998, the World Reference Base for Soil Resources (WRB) is the global correlation scheme for soil classification and international communication.

Minasny *et al*. (2009) introduced an attempt to visualize the taxonomic distances between the WRB Reference Soil Groups (RSGs). The modified method of Minasny's approach may provide a new tool to correlate different soil classification systems based on the taxonomic relationships of the classification units. A study was conducted to test new correlation possibilities with WRB on the example of the Brown forest soils (BFS) main type of the Hungarian Soil Classification System (HSCS) where the lack of definitions and limits often causes difficulties in classification and correlation.
In this study, we attempt to determine the taxonomic distance between the different types of BFS of Hungary and related WRB RSGs based on dominant identifiers.

Key words
Correlation, dominant identifiers, taxonomic relationship, World Reference Base for Soil Resources.

Introduction
The recognized need for harmonized soil information resulted in EU and global projects such as e-SOTER (Regional pilot platform as EU contribution to a Global Soil Observing System). In order to achieve harmonized databases, objective correlation methodologies are required.

Based on the different approaches of national soil classification systems, or varying criteria of similar soil units, this task is often complicated. The initiation of a new, harmonized field survey campaign seems unrealistic in the near future, thus the only solution is the harmonization of existing data, which requires a common system and classification of soil variables (Dobos 2006).

To solve this problem, a correlation system had to be created. Based on the Legend and the Revised Legend of the Soil Map of the World of the Food and Agriculture Organization of the United Nations (FAO), a Working Group of the International Soil Science Society (ISSS, now International Union of Soil Sciences - IUSS) established a framework through which existing soil classification systems could be correlated and harmonized. This framework was published in 1998 as the first edition of the World Reference Base for Soil Resources (WRB) was published. The same year, the ISSS endorsed WRB as the global correlation scheme for soil classification and international communication, and the European Commission also selected it as the correlation scheme for harmonized soil maps and databases for Europe. These decisions provided an opportunity to use a common and global language in soil science and also provided a system to supply harmonized soil information. Most correlation studies are based on morphological and analytical data of selected soil profiles or general descriptions of the soil units.

The "revisited" numerical classification can be a new tool for correlating different classification systems. The idea of numerical taxonomy mainly comes from botanists (Adanson 1763), and the methodology came into reality in the 1950s thanks to digital computers. The first application for soil classification was made by Hole and Hironaka (1960), later Bidwell and Hole (1964a) calculated numerical indices of similarity for some US soils. In the early stages of numerical classification many studies were completed for soil classification (Bidwell *et al.* 1964b, Sarkar *et al.* 1966, McBratney *et al.* 2000), but mainly based on local data with limited scope. National and international experiments were not done yet (McBratney *et al.* 2009). The increasing demand for harmonized digital soil information resulted in the claim for new correlation methods.

Minasny *et al.* (2009) introduced an attempt to visualize the taxonomic distances within the WRB Reference Soil Groups (RSGs). The modified method of Minasny's approach may provide a new tool to correlate different soil classification systems based on the taxonomic relationships of the classification units.
A study was conducted to test new correlation possibilities with WRB on the example of the Brown forest soils (BFS) main type of the Hungarian Soil Classification System (HSCS) where the lack of definitions and limits often causes difficulties in classification and correlation.

Materials

The WRB (IUSS Working Group WRB 2006) is based on a diagnostic approach. 32 Reference Soil Groups (RSGs) are defined by a key, based on the presence, sequence or exclusion of diagnostic horizons, properties and/or materials. The lower levels are defined by qualifiers added to the names of the reference soil groups for specific soil characteristics.

The current Hungarian Soil Classification System (HSCS) was developed in the 1960s, based on the genetic principles of Dokuchaev. The central unit is the soil type grouping soils that were believed to have developed under similar soil forming factors and processes. The major soil types are the highest category which groups soils based on climatic, geographical and genetic bases. Subtypes and varieties are distinguished according to the assumed dominance of soil forming processes and observable/measurable morphogenetic properties.
On the highest, *Major Soil Type* level, 9 categories are distinguished: skeletal soils, shallow soils influenced by the parent material, brown forest soils, chernozems, salt affected soils, meadow soils, peat soils, soils of swampy forests, and soils of alluvial and slope sediments.
In the highest extent (24,6%) the brown forest soils cover the territory of Hungary (Figure 1).

Brown forest soils of HSCS

The brown forest soils (BFS) generally formed under forest vegetation and are characterized by dominant downward moisture movement. This main type is a broad category that includes members without or with distinct subsurface horizons, thus the lack of definitions and limits often causes difficulties in classification and correlation. In the BFS main type 7 subtypes are distinguished: Chernozem BFS, Brown earths, Lesivated BFS, Podzolised BFS, Pseudogley BFS, Lamellic BFS, Acidic non podzolised BFS (Micheli *et al.* 2006).

Methods

The approach of Minasny *et al.* (2009) to determine taxonomic distance for WRB soil groups was further improved for correlation purposes.

The taxonomic distance measurement was based on Table 1, which contains the 7 Hungarian BFS classes and the 14 possibly related RSGs. The selection of the RSGs was based on previous correlation attempts (Micheli *et al.* 2006) and field experiences.

Based on the criteria defined in the WRB 2006 key and on the information content of the BFS classification units, dominant identifiers were selected. From all the diagnostic horizons, properties or materials in the key that determine and characterize the selected RSGs, 16 were selected that occur between the environmental conditions of Hungary. This list was completed with 2 more characteristics that are present just at the lower (qualifier) level of WRB, but are important to determine the BFS of the HSCS.

The 18 identifier properties were matched with the 21 soil groups, and were coded 0 when the condition cannot be present, 0.5 when the condition can be present, and 1 when the condition is a criteria for the selected group (Table 1). Compared to Minasny *et al.* (2009), code 0.5 was introduced newly and the definition of code 1 was changed from "likely to be present" to "obligatory to be present", for better characterization of the soil. In case of BFS expert judgment was needed during the coding due to the lack of definitions and quantitative criteria.

Based on the matrix, the distance between the selected WRB and Hungarian BFS groups was calculated:

$$d_{ij} = \sqrt{\left(\mathbf{x}_i - \mathbf{x}_j\right)^{\mathrm{T}}\left(\mathbf{x}_i - \mathbf{x}_j\right)}$$

where d_{ij} is the element of distance matrix *D* with size *(c×c)*, c is the number of soil groups. The value of d_{ij} represents the taxonomic distance between soil group *i* and group *j*, and *x* refers to a vector of indicators of the soil identifiers (Minasny *et al.* 2009).

Results and discussion

In Table 1, 21 soil groups (14 RSGs of WRB and 7 BFS units of HSCS) were matched and coded with the selected dominant identifiers.

Table 1. 21 soil groups matched and coded with the selected dominant identifiers

	Podzols	Planosols	Stagnosols	Chernozems	Kastanozems	Phaeozems	Calcisols	Alisols	Luvisols	Lixisols	Umbrisols	Arenosols	Cambisols	Regosols	Chernozem BFS	Brown earths	Lessivated BFS	Podzolised BFS	Pseudogley BFS	Lamellic BFS	Acidic, non-podzolised BFS
Histic, Folic	0,5	0,5	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,5	0,0	0,5	0,5	0,0	0,0	0,0	0,0	0,0	0,5	0,5
Vertic	0,0	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,0	0,0	0,0	0,5	0,0	0,0	0,0	0,5	0,0	0,5	0,0	0,0
Fluvic	0,0	0,0	0,0	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,5	0,0	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Natric,Sodic	0,0	0,5	0,5	0,5	0,5	0,5	0,5	0,0	0,5	0,0	0,0	0,0	0,5	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Salic	0,0	0,5	0,5	0,5	0,5	0,5	0,5	0,0	0,0	0,0	0,0	0,5	0,5	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Gleyic	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Spodic	1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,5	0,0	0,0	0,0
Abrupt textural change	0,0	1,0	0,0	0,0	0,0	0,5	0,0	0,5	0,5	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,0	0,0	0,0
Stagnic	0,5	0,5	1,0	0,5	0,5	0,5	0,0	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,0	0,0	0,0	0,0	1,0	0,0	0,0
Mollic	0,0	0,5	0,5	1,0	1,0	1,0	0,0	0,0	0,0	0,0	1,0	0,0	0,0	0,0	1,0	0,5	0,5	0,0	0,0	0,5	0,0
Calcic, Calcaric	0,0	0,5	0,5	1,0	1,0	0,5	1,0	0,0	0,5	0,5	0,0	0,0	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Umbric	0,5	0,5	0,5	0,0	0,0	0,0	0,0	0,5	0,0	0,0	1,0	0,0	0,0	0,0	0,0	0,0	0,5	0,5	0,5	0,5	0,5
Arenic	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	1,0	0,0	0,5	0,0	0,5	0,0	0,5	0,0	1,0	0,0
Cambic	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,5	0,0	1,0	0,0	0,5	1,0	0,5	0,5	0,5	0,5	1,0
Argic (high CEC, high base)	0,0	0,5	0,5	0,5	0,5	0,5	0,5	0,0	1,0	0,5	0,0	0,0	0,0	0,0	1,0	0,0	1,0	0,0	1,0	0,5	0,0
Argic (high CEC, low base)	0,0	0,5	0,5	0,0	0,0	0,0	0,0	1,0	0,0	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,5	0,0	0,0	0,0
Lamellic	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,5	0,5	0,5	0,0	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,0	0,0
Dystric	1,0	0,5	0,5	0,0	0,0	0,0	0,0	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,0	0,0	0,0	1,0	0,5	0,5	1,0

Based on Table 1, the taxonomic distances between the selected WRB RSGs and the Hungarian BFS units were calculated. The 3rd and 4th column of Table 2 show the two nearest RSGs correlated with the different BFS units. Our results show good relationship with previous studies on the correlation of the HSCS with WRB (2nd column of Table 2).

Table 2. Hungarian BFS units and their possible correlations in WRB

HBFS Units	Possible correlations based on Micheli *et al.* (2006)	Closest RSGs based on distance matrix	2nd closest RSGs based on distance matrix
Chernozem BFS	Chernozems, Kastanozems, Phaeozems	Phaeozems	Kastanozems
Brown earths	Cambisols	Regosols, Cambisols, Arenosols, Umbrisols	Phaeozems, Lixisols
Lesivated BFS	Luvisols	Phaeozems, Luvisols	Calcicols
Podzolised BFS	Luvisols, Umbrisols	Podzols	Alisols
Pseudogley BFS	Luvisols	Luvisols	Stagnosols, Umbrisols
Lamellic BFS	Luvisols	Arenosols	Lixisols, Umbrisols
Acidic, non-podzolised BFS	Cambisols, Umbrisols	Cambisols	Umbrisols, Regosols, Podzols

The main difference between the previous studies and the new approach was found in case of the Podzolized BFS unit. The accumulation horizon of most Podzolized BFS does not satisfy the criteria of the diagnostic spodic horizon (Micheli *et al.* 2006), so these soils do not correlate with WRB Podzols but with low base saturation Alisols or Umbrisols. The uncertainty of our results is possibly due to the different approach of the two studied classification systems, and the lack of definitions and quantitative criteria in HSCS. We suggest the check of the results with classification experts of the studied area.

CONCLUSIONS

Taxonomic distances between BFS and related WRB soil groups have been established.

The modified approach of Minasny *et al.* (2009) was found suitable for correlation purposes, with the following suggestions:

- The changing of the definition of code 1 and the introduction of code 0.5 was found more appropriate to determine taxonomic distance between soil groups.
- The correlation of diagnostic and genetic-based soil classification systems is possible with the tool of taxonomic distance measurement, but the selection of related soil groups and the coding against the dominant identifiers need previous studies or expert judgement. For similar reasons we suggest to check the final results also with classification experts of the studied area.
- Based on the reviewed literature and our results we conclude that this paper is only the beginning of our work. In the future we try to give a better understanding of the correlations with more soil types/groups.

REFERENCES

Adanson M (1763) Familles des Plantes, 1. Vincent, Paris. Preface, pp cliv et seq., clxiii, clxiv. 2v.

Bidwell OW, Hole FD (1964a) An Experiment in the Numerical Classification of Some Kansas Soils. *Soil Science Society of America Proceedings* **26**, 263-268.

Bidwell OW, Hole FD (1964b) Numerical taxonomy and soil classification. *Soil Science* **97**, 58-62.

Dobos E (2006) The future of soil scince: a vision from Europe. In 'he future of soil science'. (Ed AE Hartemink) pp. 34 – 37. (IUSS, Wageningen).

Hole FD, Hironaka M (1960) An experiment in Ordination of Some Soil Profiles. *Soil Science Society of America Proceedings* **24**, 309-312.

IUSS Working Group WRB (2006) World reference base for soil resources 2006. World Soil Resources Reports No. 103. FAO, Rome.

McBratney AB, Odeh IOA, Bishop TFA, Dunbar MS, Shatar TM (2000) An overview of pedometric techniques for use in soil survey. *Geoderma* **97,** 293-327.

McBratney AB, Minasny B, Viscarra Rossel R (2009) Numerical classification: a missed, but not a lost, opportunity. From the Dokuchaev School to numerical classification conference abstracts. Gödöllő, Hungary

Michéli E, Fuchs M, Hegymegi P, Stefanovits P (2006) Classification of the Major Soils of Hungary and their Correlation with the World Reference Base for Soil Resources (WRB). *Agrokémia és Talajtan* **55**(1), 19-28.

Minasny B, McBratney AB, Hartemink AE (2009) Global pedodiversity, taxonomic distance, and the World Reference Base. *Geoderma*, doi:10.1016/j.geoderma.2009.04.024

Sarkar PK, Bidwell OW, Marcus LF (1966) Selection of Characteristics for Numerical Classification of Soils. *Soil Science Society of America Proceedings* **30**, 269-272.

The classification of Leptosols in the World Reference Base for Soil Resources

Freddy Nachtergaele[A]

[A]Food and Agriculture Organization of the United Nations, Email freddy.nachtergaele@fao.org

Abstract
Mountain soils, often characterized by shallow soils on steep slopes, have received relatively little interest in soil science. The areas where they occur are thought to be sparsely populated and the soils themselves 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 their importance to provide a livelihood for 12 % of the Earth's population. The classification of Leptosols, the main mountain soils, on the contrary, has become more complex over the years. From three simple classes in the FAO Legend of 1974, the number of sub-classes has exponentially grown to at least 36 units in the World Reference Base for Soil Resources. It is highly recommended that this number be revised downward.

Key Words
Leptosols, mountain soils, soil classification, World Reference Base.

Introduction
Mountain soils, often characterized by shallow soils on steep slopes have received relatively little interest in soil science. The areas where they occur are often sparsely populated and the soils themselves only suitable for marginal pastures and forests. To illustrate this lack of interest Nachtergaele (1977) made a statistical analysis of soil surveys in the Philippines and found that the chance of a mountain soil being sampled was statistically very small and not in relation at all with the area extent of these soils. Likewise Batjes *et al.* (1997) while discussing soil parameters in the WISE database found very few examples among the soil profiles that could be associated with mountain soils (only five Leptosol profiles occur in the global soil profile database that contains more than 1000 soil profiles), this is in stark contrast with the fact that Leptosols are considered to be the most common soils in the world with an area extent estimated at 1655 Million ha (ISSS Working Group RB 1998) of which 545 Million ha occur in a mountainous environment. The most common soils in mountainous areas associated with Leptosols are Regosols and Cambisols, both are also characterized by their limited soil profile development. A special case of mountain soils are those in volcanic areas, many of which are Andosols. These are not discussed here. The importance of mountains as an important ecosystem for humans has been often underestimated. Around 720 million people (12% of the World's population) live in a mountain environment.

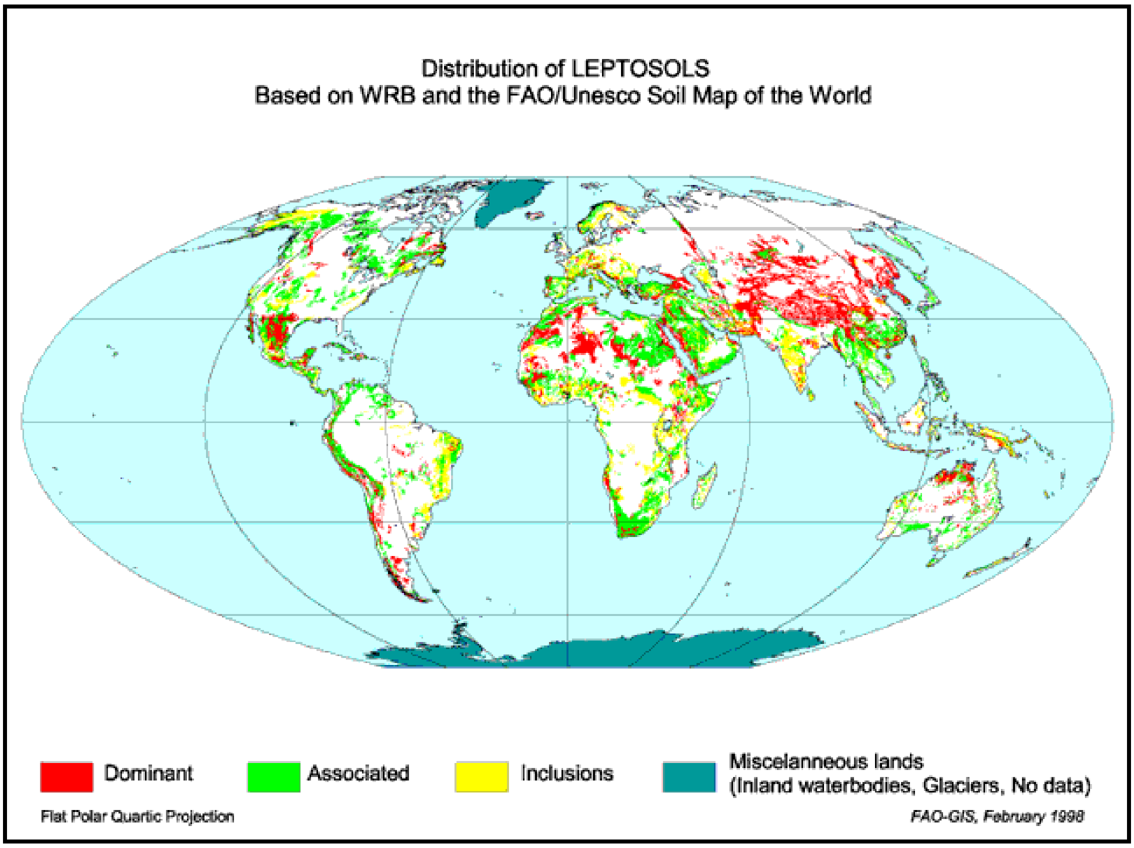
Leptosols
In soil classification, the shallow soils (characteristic for many mountain soils) in Soil Taxonomy (USDA 1999) are only recognized at (lithic) sub-group level, grouping together all soils that are less than 50 cm thick to hard rock. On the contrary FAO, in the inception of the Legend of the Soil Map of the World (1974), did recognize at the highest level of classification three major types of mountain soils: Lithosols, Rendzinas and Rankers. None of these Soil Groups had further subdivisions.

Lithosols were defined as: "soils other than Histosols that were limited in depth by continuous coherent and hard rock within 10 cm of the soil surface."
Rendzinas were defined as: "soils having a mollic A horizon which contains or immediately overlies calcareous material with a CaCO3 content of 40 percent or more."
Rankers were defined as: "soils having an umbric A horizon which is not more than 25 cm thick without other diagnostic horizons"

Consequent mapping of these soils at world scale revealed however that the latter two (Rendzinas and Rankers) had only a very limited extent and rarely could be mapped as dominant soils in a mapping unit, while the rather strict limit (10 cm to rock in Lithosols) was found to be too strict as a mapping criteria. Consequently in 1988, the Revised Legend of the soil map of the world introduced the concept of Leptosols which were defined as follows: "Soils that are limited in depth by continuous hard rock or highly calcareous material ($CaCO_3$> 40 percent) or a continuous cemented layer within 30 cm of the surface, or having less than 20 percent 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." Seven different soil units which were recognized within the Leptosols: Gelic (the cold ones), Lithic (less than 10 cm soil depth – the former Lithosols-), Rendzic Leptosols (those with high $CaCO_3$, the former Rendzinas), Umbric Leptosols (soils with an Umbric horizon, which group the more shallow of the former Rankers), Mollic Leptosols, Eutric and Dystric Leptosols.

When the work of the World Reference Base for Soil Resources working group of the IUSS took off, with the publication of the first official version (FAO/ISRIC/ISSS 1998) the basic FAO definition was retained, although some limits were adapted:
Leptosols were hence defined as: "soils which are either:
1. Limited in depth by continuous hard rock within 25 cm from the soil surface; or
2. overlying material with a calcium carbonate equivalent more than 40 percent within 25 cm of the soil surface; or
3. containing less than 10 percent (by weight) fine earth to a depth of 75 cm or more from the soil surface; and
4. having no diagnostic horizons other than a mollic, ochric, umbric, yermic or vertic horizon."

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 percent fine earth) in rocky/gravely 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.



The definition of Leptosols in the Key to WRB 2007 (IUSS Working Group WRB 2006, update 2007) was simplified:
Leptosols are other soils (excluding Histosols, Anthrosols, Technosols and Cryosols) having
1. one of the following:
a. limitation of depth by continuous rock within 25 cm of the soil surface; or
b. less than 20 percent (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."

The introduction of the new RSG of Technosols before the Leptosols is noted; the reference to the Rendzina-like soils has been omitted (although the Rendzic qualifier has been maintained); the limits of the fine earth allowed have been set again at 20 percent, 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. Most diagnostic horizons are allowed with the exception of the calcic, gypsic, petrocalcic, petrogypsic and spodic horizon. "Hard Rock" traditionally classified as "non Soil" is considered as a specific type of Leptosol (Nudilithic qualifier). Unfortunately, at the same time the number of "qualifiers" foreseen in Leptosols skyrocketed to a total number of 36, which, given the fact that Leptosols are seldom mapped in any detail, is not justified.

Over the last 30 years soil classification has changed the groupings of the shallow and very gravely soils which are dominant in many mountain regions, but few new insights have been achieved, except perhaps perfecting definitions reflecting more correctly reality or facilitating mapping. The more recent development in the World Reference Base for Soil Resources where a great number of intergrades and extra-grades is allowed is however considered unhelpful and unpractical. From the original three FAO Soil Groups in 1974 we now have the choice of a single Reference Soil Group with 17 prefixes and 19 suffixes which allow, theoretically, for an infinite number of units by using all allowed combinations. It is proposed (IUSS Working Group WRB 2006/07) to limit the first level qualifiers in Leptosols to the following: Lithic (with Nudilithic as a subdivision of Lithic), Hyperskeletic, Rendzic, Organic (= Folic and Histic), Mollic, Umbric, Dystric and Eutric. All other qualifiers identified should be listed under the suffixes as they refer to local conditions, or can only be mapped at large scales.

Conclusions

Soils in mountains have received little attention in soil science, they are often not sampled and this lack of knowledge is in stark contrast with their overall extent and their importance to provide a livelihood for 12 % of the Earth's population. The classification of mountain soils on the contrary, has become more complex over the years. From 3 simple classes in the FAO Legend of 1974, the number of sub-classes has exponentially grown to at least 36 units in the World Reference Base for Soil Resources. It is highly recommended that this number is revised downward.

References

Batjes NH, Fischer G, Nachtergaele FO, Stolbovoy VS, van Velthuizen HT (1997) 'Soil data derived from WISE for use in global and regional AEZ studies'. Interim Report IR 97-025. (FAO/IIASA/ISRIC.: IIASA, Laxenburg, Austria).

FAO (2003) 'Towards a GIS-based analysis of mountain environments and populations'. Environment and Natural Resources Working Paper No 10. (FAO: Rome).

FAO/UNESCO (1974) 'Soil Map of the World'. Vol. I Legend. (Unesco: Paris).

FAO/UNESCO/ISRIC (1988) 'Soil Map of the World'. Revised Legend. World Soil Resources Report 60. (FAO: Rome).

FAO/ISRIC/ISSS (1998) 'World Reference Base for Soil Resources'. World Soil Resources Reports 84. (FAO: Rome).

ISSS Working Group RB (1998) 'World Reference Base for Soil Resources'. Atlas. (Eds NH Batjes, M Bridges, FO Nachtergaele). (Acco: Leuven, Belgium).

IUSS Working Group WRB (2006/07) 'World Reference Base for Soil Resources 2006. A framework for international classification correlation and communication'. World Soil Resources Reports 103. (FAO: Rome). Electronic update 2007. http://www.fao.org/ag/agl/agll/wrb/

Nachtergaele FO (1977) 'Basic Statistical Methods applied to soil fertility data of Cebu Province'. (Bureau of Soils, Department of Agriculture: Manila, Philippines).

USDA (1999) 'Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys'. 2nd Edition. Agricultural handbook 436. (Washington DC, USA).

The World Reference Base for Soils (WRB) and Soil Taxonomy: an initial appraisal of their application to the soils of the Northern Rivers of New South Wales

David T. Morand[A, B]

[A]School of Environmental Science and Management, Southern Cross University, PO Box 157, Lismore, 2480, NSW, Australia.
[B]Department of Environment, Climate Change and Water, PO Box 856, Alstonville, 2477, NSW,
Email David.Morand@environment.nsw.gov.au

Abstract
Few, if any, soil surveys in New South Wales have utilised international soil classifications. Extensive morphological and laboratory data collected during soil survey in the region provided a strong basis for correlation with the World Reference Base for Soil Resources (WRB) and Soil Taxonomy. Of the 32 reference soil groups composing the WRB, 19 were found to exist locally; 9 of the 12 Soil Taxonomy orders were present. Several correlation problems were apparent, most of which are common to both international schemes. Fundamental reliance on laboratory data is probably the most outstanding limitation. Soils with strong texture-contrast are not adequately differentiated to suit Australian conditions. Of the two international schemes, the WRB seems to have more appropriate classes and was consequently the easier to apply locally, although it is evident that more Australian input is necessary in order to make this a truly international soil classification/correlation scheme.

Key Words
Soil classification, soil correlation, soil survey, Australian soil classification.

Introduction
There are two soil classification schemes that are generally regarded as having worldwide application - the World Reference Base (WRB) (IUSS Working Group WRB 2006) and the USDA Soil Taxonomy (Soil Survey Staff 1999). Neither has been popular in Australia, although some state authorities have identified major soils in soil survey reports in terms of the USDA Soil Taxonomy (Isbell 1992). The lack of interest in international classification schemes is not surprising given this continent's unique landscape and soil evolution and its marked difference to Northern Hemisphere conditions. However, consideration of international systems is becoming increasingly important for communication of soil studies and knowledge. This situation was highlighted recently when the Australian soil science community received criticism for its lack of contribution to the development of the World Reference Base (Gray 2003) despite warnings of the hazards of ignoring international soil classifications (Isbell 1992, McKenzie 2003).

As a small step towards stimulating interest in utilising international soil classification schemes, soil data collected during soil surveys within the Northern Rivers of New South Wales has been utilised to correlate the Australian Soil Classification (ASC, Isbell 2002) with the WRB and Soil Taxonomy. Emphasis has been given to the WRB in this exercise because it was devised for correlation with national classifications. The application of the schemes has been considered from a broad-scale mapping context.

Many of the dilemmas associated with applying the WRB and Soil Taxonomy to Australian conditions are discussed in Isbell (2002) and Isbell, McDonald and Ashton (1997). The soils of the Northern Rivers are no exception.

The Northern Rivers - a brief overview
Location
The Northern Rivers are located on the far north coast of New South Wales, Australia (Figure 1).

Climate
The climate is subtropical to temperate, with distinct summer maximum rainfall and dry winters. Temperatures are generally mild throughout the year.

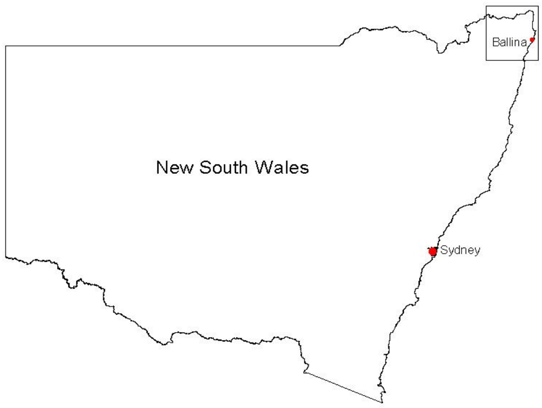


Figure 1. Location of the Northern Rivers of New South Wales.

Geology
The Northern Rivers lie within the Mesozoic Clarence-Moreton Basin (CMB), a structure comprising lithic and quartz sandstones, siltstones, shales and conglomerates. Draping much of the Northern Rivers section of the basin are Tertiary volcanics that have originated from the Tweed Shield Volcano, centred in the Tweed Valley, and the Focal Peak Volcano, located in southeast Queensland. The lavas are dominated by basalt with lesser amounts of acid volcanics. Large areas of Quaternary alluvium occur throughout the region and extensive Quaternary sand bodies flank the coast. Palaeozoic metasediments form much of the landscape of the eastern part of the catchment.

Soils
Brown, Yellow, Red and Grey Kurosols generally form on the sedimentary rocks of the CMB and the metasediments. Red Ferrosols and Brown Dermosols are found on the basaltic hills, while Vertosols occur on basaltic footslopes and drainage depressions. Soils formed on alluvium are variable, but Vertosols are dominant where basalt is the major source of sediment. Otherwise Grey Kurosols, Dermosols, Kandosols, Vertosols and Hydrosols occur in varying combinations. Podosols have formed on the coastal sand bodies, interspersed with Organosols. Sulfidic or Sulfuric Hydrosols generally occupy estuarine areas.

Soil Landscape Mapping
Soil landscape mapping undertaken by the Department of Environment, Climate Change and Water (DECCW) and its predecessor organisations has provided the basis for this study. Three relevant soil landscape maps and reports exist: Lismore-Ballina, Murwillumbah-Tweed Heads and Woodburn (Morand 1994, 1996, 2001). A fourth, Western Richmond, is underway. The scale of mapping is 1:100 000 and data collected includes detailed soil profile descriptions and comprehensive laboratory analyses. All the ASCs were correlated as closely as possible with the WRB and Soil Taxonomy. Although soils were classified to qualifier level (WRB) and to subgroup level (Soil Taxonomy), only the primary reference groups or orders have been reported in this paper due mainly to space limitations.

Results and Discussion
Table 1 shows the equivalent WRB and Soil Taxonomy classes found in this study based on 141 profile descriptions with complete lab data. 19 of the 32 WRB reference groups and 9 of the 12 Soil Taxonomy orders were found to be present within the Northern Rivers.

General Comments
The outstanding difference between the international schemes and the ASC is the very high level of dependence on lab data in the former.

Assuming the resources are available, the lab tests required for WRB and Soil Taxonomy should not pose a problem in themselves, but in the Northern Rivers (and Australia in general) these resources, including pedologists, are minimal. In deriving many WRB and Soil Taxonomy classes using the available data many presumptions are required.

Table 1. Australian Soil Classification and international equivalents as applied to soils of the Northern Rivers, NSW. Figure in brackets is the number of profiles classified (total classified is 141).

ASC	WRB	Soil Taxonomy
Dermosols(15)	Luvisols(4), Acrisols(3), Phaeozems(3), Cambisols(2), Lixisols(2), Chernozems(1)	Mollisols(6), Ultisols(4), Inceptisols(3), Alfisols(1)
Ferrosols(8)	Nitisols(5), Acrisols(2), Lixisols(1)	Oxisols(4), Ultisols(3), Alfisols(1)
Hydrosols(24)	Gleysols(10), Fluvisols(6), Planosols(2), Histosols(1),Phaeozems(1), Acrisols(1), Luvisols(1),Lixisols(1), Solonchaks(1)	Inceptisols(8), Alfisols(8), Mollisols(3), Entisols(3), Histosols(1), Vertisols(1)
Kandosols(11)	Acrisols(4), Lixisols(2), Gleysols(1), Cambisols(1), Phaeozems(1), Luvisols(1), Planosols(1)	Alfisols(6), Mollisols(3), Ultisols(2)
Kurosols(44)	Acrisols(25), Lixisols(6), Planosols(6), Luvisols(4), Solonetz(2), Regosols(1)	Alfisols(23), Ultisols(21)
Organosols(1)	Histosols(1)	Histosols(1)
Podosols(17)	Arenosols(11), Podzols(6)	Inceptisols(11), Spodosols(4), Entisols(1), Mollisols(1)
Rudosols(1)	Regosols(1)	Entisols(1)
Sodosols(2)	Solonetz(2)	Alfisols(2)
Tenosols(10)	Regosols(4), Lixisols(3), Arenosols(2)	Inceptisols(4), Entisols(4), Mollisols(2)
Vertosols(7)	Vertisols(7)	Vertisols(7)
Anthroposols(1)	Technosols(1)	

Those classes based predominantly on morphology were the simplest to correlate. Thus Vertosols (ASC) were relatively easy to correlate with Vertisols (WRB and Soil Taxonomy). Podosols generally fitted into Podzols (WRB) and Spodosols (Soil Taxonomy), in spite of some diagnostic tests being required for the international schemes. Where diagnostic horizons occurred below 2m, as is common with many of the Podosols in the Northern Rivers, they were easily classified as Arenosols (WRB) and Inceptisols (Soil Taxonomy). In comparison, six WRB reference groups were found to be equivalent to Kurosols (ASC) - Acrisols, Lixisols, Planosols, Luvisols, Solonetz and a Regosol. The Planosols and Solonetz can generally be distinguished by morphology, but the remainder are soils with argic horizons that are discriminated by lab data alone, making them difficult to identify in the field. Within the Northern Rivers there were no apparent morphologic or geomorphic features that assisted in identifying these particular soils. However, the reference soil group most commonly equated with the strongly acidic (pH_w<5) Kurosols is the low base status Acrisols (Table 1), confirming that field pH can assist in determining a field classification.

Texture differentiation, though accommodated in the international schemes, is not treated with the same degree of importance as in Australia. Hubble *et al.* (1983) noted the widespread occurrence of texture-contrast soils, often with sodic subsoils, as being a feature unique to this country. This is reflected in the ASC orders specifically defined by abrupt textural changes, notably the Kurosols, Chromosols and Sodosols. Within the international schemes, soils containing an argic (WRB) or argillic (Soil Taxonomy) horizon with an abrupt textural change, the nearest equivalent to the *clear or abrupt textural B horizon* (ASC) occur in several ASC orders. The ASC and the international schemes have differing criteria for (i) clay content increases, (ii) minimum clay contents in the argic/argillic horizon and (iii) sharpness of horizon boundary changes. More substantial clay increases over sharper boundaries (Isbell 2002, McDonald and Isbell 2009) are required for ASC texture-contrast soils. Use of WRB and Soil Taxonomy tends to group such soils with others that, by Australian standards, lack strong texture-contrast.

One aspect of both the WRB and Soil Taxonomy that facilitated easier classification is the use of depth intervals for diagnostic horizons rather than using specific designated horizons. The high level of importance given to the identification of the B horizon in the ASC can be a problem if that horizon cannot be identified, such as in many Podosols (or if it is misidentified by the soil surveyor).

Both international schemes have classes for disturbed soils, albeit at different hierarchical levels. The WRB has the Anthrosol and the Technosol reference groups, Soil Taxonomy has relevant subgroups. Technosols generally equate with the Anthroposols (soils resulting from human activities) of the ASC. Anthrosols and the Soil Taxonomy subgroups generally apply to agricultural soils that have been modified over centuries - neither correlated with the Anthroposols.

Conclusions

Despite some problems, the WRB can and should be used for soil correlation in the sub-tropical and temperate areas of northern New South Wales. Indeed Powell (2008) recommends using the WRB whenever possible. Although dependence on laboratory data is a problem, there is no reason why soils can't be correlated using confidence levels as is done in the ASC (WRB does recognise the use of an initial field classification, roughly equivalent to ASC confidence levels 2 or 3). The Australian soil science community needs to contribute more local perspective to the WRB. For example, the addition of a qualifier, or even a new reference group, that takes into account soil texture changes with sharp or abrupt boundaries ("duplexic"?) may be appropriate for Australian conditions.

On the other hand, Soil Taxonomy seems to have limited value due to its greater reliance on laboratory data. Murphy and Murphy (2000) briefly review Soil Taxonomy, providing some good reasons as to why it has limited applicability to Australia.

The use of the WRB as a complement to the ASC will only strengthen Australia's capacity for unambiguous communication with the world soil community. Furthermore, the nature of the WRB, its reference groups and their derivations and the analyses required, enable soils to be considered from a viewpoint other than that provided by the ASC - this can only enhance our quest for the understanding of soil formation, soil behaviour, and soil and landscape relationships.

References

Gray J (2003) Arid soils tour of South Africa and Namibia (and some implications for Australian soil science). *Profile* **133,** 12.

Hubble GD, Isbell RF, Northcote KH (1983) Features of Australian Soils. In 'Soils: an Australian viewpoint'. (Division of Soils, CSIRO) pp. 17-47. (CSIRO: Melbourne/Academic Press: London).

Isbell RF (1992) A brief history of national soil classification in Australia since the 1920's. *Australian Journal of Soil Research* **30,** 825-842.

Isbell RF (2002) 'The Australian Soil Classification, Revised Edition'. (CSIRO: Canberra, ACT).

Isbell RF, McDonald WS, Ashton LJ (1997) 'Concepts and Rationale of the Australian Soil Classification'. (ACLEP, CSIRO Land and Water: Canberra).

IUSS Working Group WRB (2006) 'World Reference Base for Soil Resources 2006'. World Soil Resources Reports No. 103. (FAO: Rome).

McDonald RC, Isbell RF (2009) Soil Profile. In 'Australian Soil and Land Survey Field Handbook. 3rd edition'. (CSIRO Publishing: Melbourne).

McKenzie N (2003) Understanding the World Reference Base. *ACLEP Newsletter* **11/1,** 13-14.

Morand DT (1994) 'Soil Landscapes of the Lismore-Ballina 1:100 000 Sheet'. (Soil Conservation Service of New South Wales: Sydney).

Morand DT (1996) 'Soil Landscapes of the Murwillumbah-Tweed Heads 1:100 000 Sheet'. (Department of Land and Water Conservation: Sydney).

Morand DT (2001) 'Soil Landscapes of the Woodburn 1:100 000 Sheet'. (Department of Land and Water Conservation: Sydney).

Murphy BW, Murphy CL (2000) Systems of Soil Classification. In 'Soils: their properties and management. 2nd Edition'. (Eds PEV Charman, BW Murphy) pp. 83-105. (Oxford University Press: Melbourne, Australia).

Powell B (2008) Classifying soil and land. In 'Guidelines for Surveying Soil and Land Resources. 2nd Edition'. (Eds NJ McKenzie, MJ Grundy, R Webster, AJ Ringrose-Voase) pp. 307-315. (CSIRO Publishing: Melbourne, Australia).

Soil Survey Staff (1999) 'Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys, 2nd Edition'. USDA, Agriculture Handbook No. 436. (Govt. Printer: Washington DC).

A short guide to the soils of South Africa, their distribution and correlation with World Reference Base soil groups

Martin V. Fey[A, B]

[A]School of Earth and Environment, The University of Western Australia, Crawley, WA 6009, Australia Email martin.fey@uwa.edu.au
[B]Department of Soil Science, Stellenbosch University, Private Bag X1, Matieland, 7602, South Africa

Abstract
The 73 soil forms of the South African classification can be placed into 14 groups (organic, humic, vertic, melanic, silicic, calcic, duplex, podzolic, plinthic, oxidic, gleyic, cumulic, lithic and anthropic) which are identified by means of an eliminative key based on the presence of defined diagnostic horizons or materials. This allows generalizations more readily to be made about properties, genesis, distribution and environmental significance. Correlation with the World Reference Base (WRB) classification reveals that 25 reference soil groups are represented and with the aid of new distribution maps the regional abundance of WRB groups in South Africa can approximately be assessed.

Key Words
Soil classification, soil maps, diagnostic horizon, soil resources

Introduction
The only comprehensive account of the soils of South Africa is that by Van der Merwe (1940). The classification of South African soils has nevertheless evolved, with the publication of numerous regional studies, through various approximations and is currently well established, with 73 soil forms constituting the highest level grouping (Soil Classification Working Group 1991). A new account is now available (Fey 2010) which covers geographic distribution, properties (including selected profile descriptions and analytical data), classification (including correlation with major international systems), genesis, and environmental significance. The objectives of this paper are to present a synopsis of the soil groups that were created as the basis for this general account, to show their distribution and frequency of occurrence, and to broadly indicate how they relate to the groups of the World Reference Base (IUSS Working Group WRB 2006).

The soil groups
Fourteen soil groups have been created (Fey 2010) with the guiding principle being the identification of a diagnostic horizon, as defined by the Soil Classification Working Group (1991), so as to construct an eliminative key (Table 1) which is similar in operation to those employed by a number of international classifications. A representative illustration of each group is provided in Figure 1. If one of four special kinds of topsoil horizons is not present (i.e. the topsoil is orthic) then the direction and degree of development of the subsoil are considered. If none of the seven categories of subsoil development is sufficiently expressed then the soil is placed in one of the remaining, immature soil groups which are differentiated on the basis of three broad categories of parent material (Table 1).

Distribution maps
The maps in Figure 2, which exclude the organic and anthropic soil groups since these are infrequent and sporadic, were constructed from data contained in the land type survey of the Institute for Soil, Climate and Water. The map units are based on frequency of occurrence of soil groups within each land type.

World Reference Base correlation
The correlation with WRB soil groups is shown in Table 2. The cross-cutting of the two classifications, whereby some WRB groups appear in several of the South African soil groups, is not unexpected in view of the different priority given to criteria on which the respective identification keys are based. Despite this, the correlation, in conjunction with the maps in Figure 2, provides those unfamiliar with South African classification an opportunity to quickly assess the regional distribution of soil types using familiar terminology. Conversely it allows South African scientists more readily to look beyond their borders and consider local knowledge in a global context.

Acknowledgements
The E J Lombardi Trust funded this project. Support for MVF is currently provided by Alcoa World Alumina Australia and BHP Billiton Worsley Alumina (Pty) Ltd. Theo Dohse, Jeff Hughes, Jan Lambrechts, Antoni Milewski and Anthony Mills contributed to the monograph on which this paper is based. Illustrations in Figures 1 and 2 are reproduced with the permission of Cambridge University Press.

References
Fey MV (2010) Soils of South Africa. Cambridge University Press, Cape Town, 287 pp.
IUSS Working Group WRB (2006) World Reference Base for Soil Resources 2nd edition. World Soil Resources Reports 103. FAO, Rome.
Soil Classification Working Group (1991) Soil Classification – a Taxonomic System for South Africa. Memoirs on the Agricultural Natural Resources of South Africa No. 15. Department of Agricultural Development, Pretoria.
Van der Merwe CR (1940) Soil Groups and Sub-Groups of South Africa. Science Bulletin 231, Department of Agriculture and Forestry, Pretoria, 316 pp.

Table 1. Key to the soil groups.

Differentiating principle	Soil group		Concept	Diagnostic horizon or material for identification
Soils with special topsoil characteristics	1	Organic	Wetland or montane peat	Organic O
	2	Humic	Humus enrichment; free drainage; low base status; humid climate	Humic A
	3	Vertic	Swelling, cracking clay; basic parent material; semi-arid to sub-humid climate	Vertic A
	4	Melanic	Dark, structured clay; high base status; semi-arid to sub-humid climate	Melanic A
Soils with special subsoil characteristics relating to pedogenic accumulation and having an orthic topsoil	5	Silicic	Cementation by amorphous silica or sepiolite; arid climate	Dorbank (duripan) or sepiocrete
	6	Calcic	Carbonate or gypsum enrichment; arid climate	Soft or hardpan carbonate or gypsic B
	7	Duplex	Marked textural contrast through clay enrichment	Pedocutanic or prismacutanic B
	8	Podzolic	Metal humate enrichment; siliceous parent material	Podzol B
	9	Plinthic	Absolute iron enrichment; localised, hydromorphic segregation with mottling or cementation	Soft or hard plinthic B
	10	Oxidic	Residual iron enrichment through weathering; uniform colour	Red apedal, yellow-brown apedal or red structured B
	11	Gleyic	Protracted reduction in an aquic subsoil or wetland	G horizon
Young soils with an orthic topsoil but weakly developed subsoil	12	Cumulic	Incipient soil formation in colluvial, alluvial or aeolian sediment	Neocutanic or neocarbonate B, regic sand, thick E horizon or stratified alluvium
	13	Lithic	Incipient soil formation on weathering rock or saprolite	Lithocutanic B or hard rock
	14	Anthropic	Human disturbance	Disturbed material

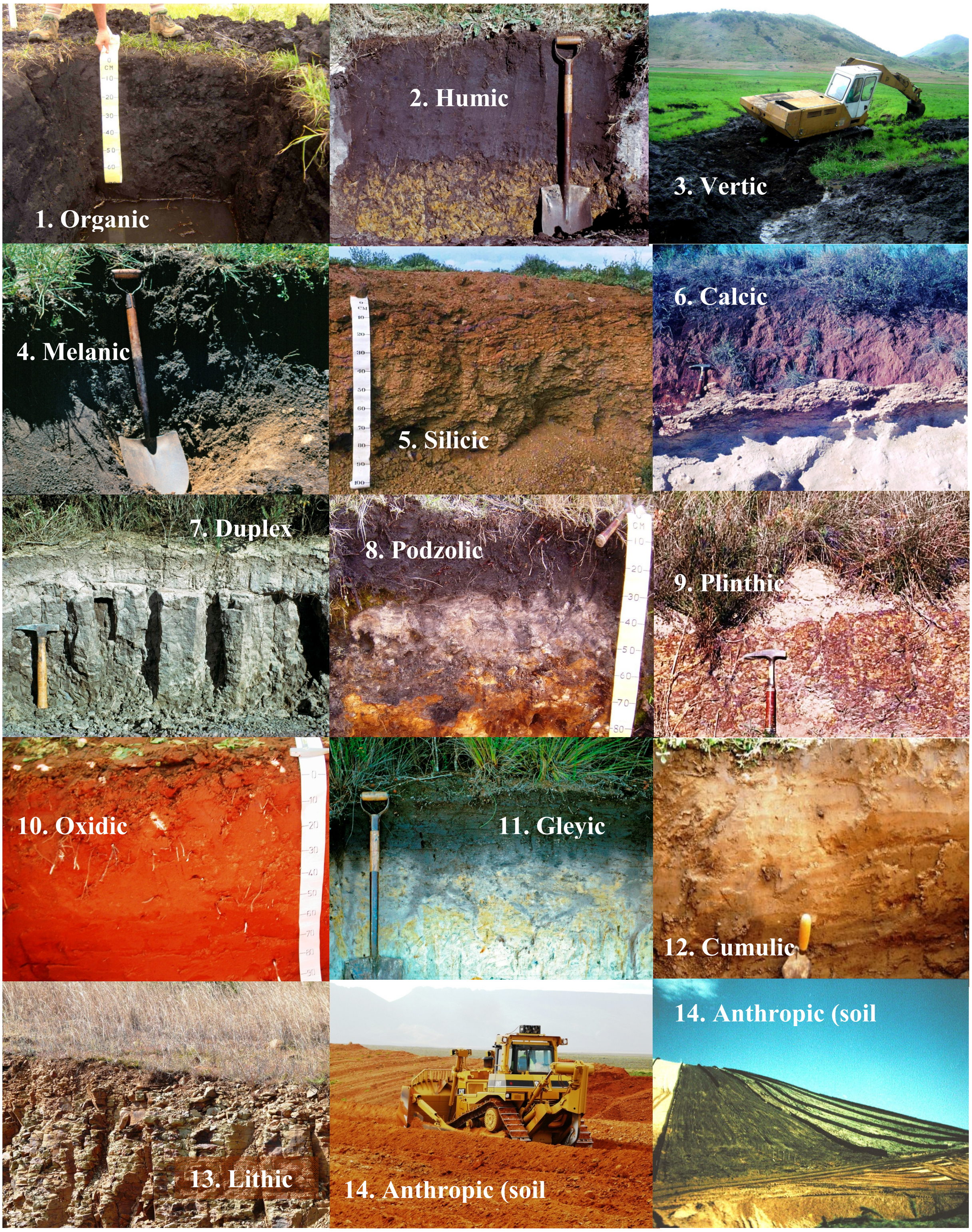


Figure 1. Illustration of the fourteen soil groups (Compiled from Fey 2010, with the publisher's permission).

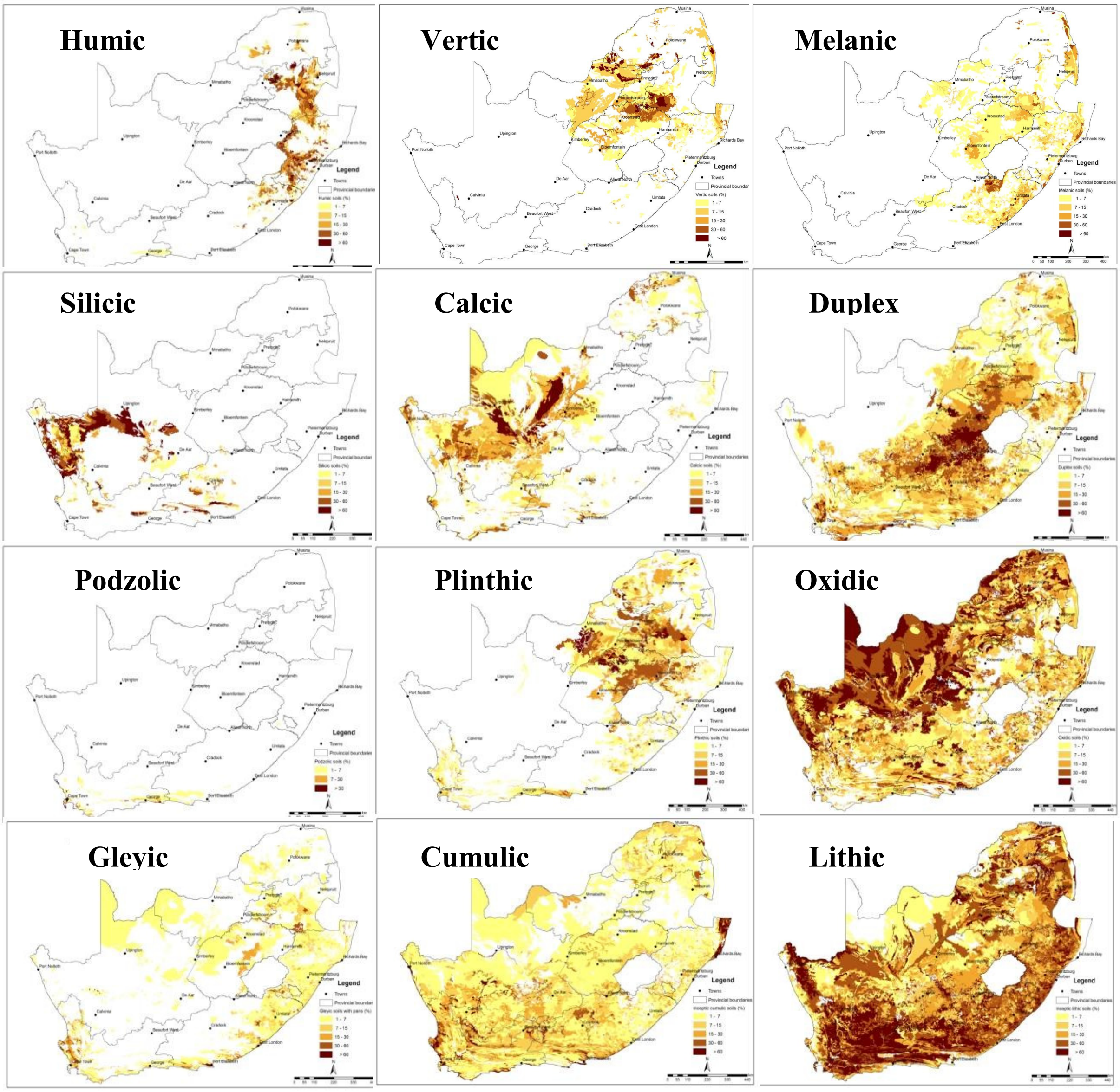


Figure 2. Distribution of the soil groups. The darkest colour indicates > 60 percent of soils in the mapping unit and the lightest yellow colour between 1 and 7 percent (From Fey 2010, with the publisher's permission).

Table 2. Correlation of South African soil groups with World Reference Base soil groups.

Soil group	WRB correlation (IUSS Working Group 2006)
1. Organic	Histosols Gleysols
2. Humic	Umbrisols Ferralsols Acrisols Luvisols Lixisols Cambisols
3. Vertic	Vertisols Gleysols Phaeozems
4. Melanic	Chernozems Umbrisols Gleysols Phaeozems Kastanozems Luvisols Calcisols Leptosols Fluvisols
5. Silicic	Durisols
6. Calcic	Calcisols Gypsisols Luvisols Lixisols
7. Duplex	Planosols Solonetz Luvisols Albeluvisols Lixisols
8. Podzolic	Podzols
9. Plinthic	Plinthosols Ferralsols Acrisols Stagnosols Lixisols Arenosols
10. Oxidic	Acrisols Alisols Ferralsols Luvisols Lixisols Arenosols Cambisols Nitisols
11. Gleyic	Gleysols Stagnosols Planosols
12. Cumulic	Cambisols Arenosols Fluvisols Luvisols Acrisols Lixisols
13. Lithic	Leptosols Cambisols Acrisols Lixisols
14. Anthropic	Anthrosols Technosols