Chernozems in the Austrian and WRB classification system

by

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Chernozems are important soils for agriculture, though their classification worldwide is not standardized. This study aimes to review the systematic relationship of the Austrian "Tschernosem" and the international regarded Chernozem. 137 Chernozem-like soils of Lower Austria were classified after WRB 3rd edition using a semi-automated classification approach. The results show that there is no rule of thumb which can be used for easy translation between the two systems.. They also reveal potential problems of misclassification which are caused by ill-defined WRB criteria. This misclassification might also be caused by strong human influence on soils such as erosion.

Keywords: Chernozem, Kastanozem, Phaeozem, soil classification, WRB, mollic, calcic horizon, erosion

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Tschernoseme in der österreichischen und internationalen Bodensystematik (WRB)

Peter Bock

Tschernoseme sind wichtige Böden in der Landwirtschaft. Ihre Klassifikation ist jedoch nicht einheitlich und unterscheidet sich weltweit. Diese Arbeit befasst sich mit der systematischen Verwandtschaft von Tschernosemen gemäß der österreichischen Bodensystematik und jener der FAO-Klassifikation. Dazu wurden 137 Tschernoseme oder ähnliche Böden halbautomatisch nach der WRB klassifiziert. Die Ergebnisse zeigen, dass die Böden nach keiner einfachen Regel von der österreichischen in die internationale Systematik zu übersetzen sind. Auch zeigt sich, dass die WRB-Kriterien manchmal zu unscharf formuliert sind und so Fehlklassifikationen ermöglichen. Dies könnte aber auch so interpretiert werden, dass der Einfluss des Menschen auf die Böden so stark ist, dass er sich sogar bis auf die Bodenklassifikation auswirkt.

Stichworte: Tschernosem, Feuchtschwarzerde, Braunerde, Bodensystematik, WRB, Kalk, Humus, Erosion

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II. Introduction

A STORY TO BEGIN WITH....

Let's just imagine a village of farmers somewhere around 3000 BC. It doesn't matter where this village is located. Let's just assume that the people rely more or less on agriculture, so focus is on the adjacent ecosystem and its soils. Over the years of farming people have recognized that some soils are more fertile than others. It has come, that during work on the fields, the farmers realized that all of the fertile soils have brown color. Despite that some of them contain more stones or have a different texture, they all feature brown hues. Due to this discovery it happened that people linked the color more and more with fertility and eventually began to talk of "brown soils" when they meant "fertile soils"

One characteristic emerged to a level where it was used to describe a bunch of characteristics. We can assume that in the past easy-to-recognize-properties would have been used to describe and characterize soils. By grouping of elements, we make sense of the world (Brady and Weil 1999, 71).

If a person from another village talked to the farmers, it could be that he shared not the experience of the farmers and linked the term "brown soil" differently or not at all. In every case, one can see that the problem of such local definitions is, that non-locals can have difficulties in understanding. Additionally, without a definition it lies upon the individual to determine whether he/she considers a soil as "brown soil" or not.

AIM OF THIS STUDY

Soil classification systems are used worldwide. Unfortunately, the systems often are not comparable or yield different results. Austria has its own classification system, adapted well to the country's soils, however soils not occurring in Austria can, if at all, only described badly. Classifications that work on a global scale do not face these problems, but may yield not optimal results for specific countries. These issues are addressed by continuously updating systems and updating of diagnostic features to guarantee a good fit to specific regions of the world. For Austria, Nestroy (2002) had reviewed Chernozems and related soils for the first edition of the classification of the Food and Agricultural Organisation (called WRB). Since then, a lot of work has been done and 2014 the third edition of WRB was released. It is now time to take look on how the actual classification represents Austria's soils in a worldwide context.

This work is centered around the following consideration:

By simply playing around with the WRB we recognize that the Austrian *Tschernosem*[1] is not always the WRB *Chernozem*. We can ask ourselves now, if both terms are the same and only written differently due to language issues or if the concepts behind these terms also differ.

To answer this question we have to go through a few topics before:

- What are classification systems and how do they work? (p. 7)
- What are Chernozems/Tschernoseme in terms of soil science? How are they formed? (p. 13)
- How are Chernozems/Tschernoseme reflected in classification systems (p. 21)
- If we classify Tschernoseme after WRB, what will we get? (p. 33)
- Does the classification result represent the real world and the concepts of soil science? (p. 42)

[1] For a clear understanding, a soil classified after the Austrian system will be denoted as Tschernosem, a soil classified after WRB as Chernozem.

CLASSIFICATION SYSTEMS

Classification systems enable soil scientists to name soils correctly. They consist of complex rules which take specific soil properties into account as well as climate or soil formation to create distinct names. These names should form a picture of soils in the heads of people and should allow for easy and clear communication.

Definitions

The term "Classification" has three meanings (after Rozhkov 2010, 1290):

1. The process of the creation of a classification system
2. The classification system (the result of 1)
3. The procedure of the use of this system for the identification of particular soil objects (or soil correlation)

So if we talk about classification, we have to say, what we mean with this term. For the sake of clear understanding, the simple term "classification" is avoided as often as possible and if a classification system is meant, it is also written as such, whereas the procedure of classification is denoted by the verb "to classify".

General

At first, we have to elucidate the terms "data" and "information". The term "data" refers to simple values (like length, weight, temperature). The data itself can serve for various purposes and is provided "as is", meaning there is no idea behind it, it is simple data. If data is linked together, it becomes information. Information in certain pattern means knowledge (information is put into a framework)[2] (Bellinger et al. 2004, s.p.)

Knowing this, we can make an important differentiation:

A soil data base holds data. This seems kind of obvious but means that the data base itself is meaningless.

A soil classification system is designed to serve a particular interest and soils are classified with the focus on particular matter, be it genesis, or usability for agriculture, climatic factors etc. Conversely, a soil data base is shaped to fit many particular interests (Rozhkov 2010, 1290).

Thus it is important to consider that a classification system always highlights some aspects and hides other items from our perception. From a soil, with a theoretical endless amount of data, only a part of it is considered (this is the first step of selection, to select which data to record and which not). Only a part out of these data will be considered for a classification system. It is therefore a tool for the soil scientist to look at the world and to communicate to the world.

[2] Understanding and wisdom are consecutive categories which are not explained here. For details, see Bellinger et al. 2004.

Because of the fact that people have different opinions and view in various ways at the world, they also make different tools for themselves. This is one reason why we have to deal with more than one soil classification system today.

History

The first classification systems emerged in Europe sometimes 2000 BC when Greek philosophers invented first concepts of soil classification and also the Romans knew soil classification according to parameters like particle size, color, density, structure and fertility and also had tests to check these in the field. In Asia the first known taxonomy has been developed in China around 4000 BP. Soil fertility, color, texture moisture and vegetation was included in the system. In America we know of the classification system developed by the Aztecs, which took fertility, texture, moisture and genesis into consideration as well as topographic location, vegetation and farmer's practices.

In the 18th century soil mapping became important for taxing purposes in Europe, the first soil map of America was released in 1841.

The concept of the soil profile was first introduced by the Greek but it was not until 1875 and onwards when various Authors developed the concept of soil horizons and specific letters for their designation. One of them, V.V. Dokuchaev, a russion soil scientist, was the first to come up with the idea of soil genesis. By this time, most of the classification systems and soil maps were based on (geological) characteristics. With collaboration of less known scientists like P.A. Kostychev and N.M. Sibirtsev they introduced the idea of soil genesis and time as a soil forming factor. (Brevik and Hartemink 2010)

From then on, there were two approaches for classifying soils. Approaches based solely on characteristics and others which also took the genesis into account.

In the United States, a system called the U.S. Soil Taxonomy is used. It provides either hierarchical grouping of soil bodies only based on soil properties and a nomenclature giving definite connotations regarding the major characteristics of a soil. These two unique features distinguish it from other systems (Brady and Weil 1999, 74). In contrast to this, most Russian soil systems are based on genetic factors, soil formation and processes, therefore relying more on the environment than on specific soil properties (Gerasimova 2005, 223). If we consider a bar were the Russian system is on the one side and the American on the other, we can arrange every system worldwide according to its principles along this bar, with some being more on the ends of the bar and some holding the balance between true morphological and genetic systems.

Even if there were only one approach, there would remain another problem: Soils are found to be more of a continuum, where properties change over distance, sometimes abruptly, sometimes more diffuse, resulting in one soil gradually shifting into another. Even to the trained eye it is easy to differentiate between the endpoints, but where is limit in between? The limit where we do not longer talk of Soil A, but of Soil B?

To deal with that fact, we choose limits and thresholds and introduce artificial archetypes of soils just to make communication possible. That is the fundamental idea behind a soil classification system: Defining limits in order to categorize soils. These limits of course were not chosen randomly only, they rather contain our ideas about soils, accommodate to our needs or are just given by practical constraints (it doesn't make sense to define a limit which we cannot measure somehow).

Unfortunately, if people have agreed on certain categories and their boundaries, they did it differently in the parts of the world. Additionally, the underlying concepts differ (as mentioned before), which overall makes it difficult to compare at a larger scale. The individual village (to stick to our example) agreed on some definition but this not necessarily means that the neighbouring villages see it the same way! They rather have some different view on that and have their own consent on soil classification. Thus, communication in soil science and a "common language" are difficult to obtain (Rozhkov 2010, 1289).

To close this gap, the Food and Agricultural Organization evolved its own classification system in 1998 and the International Society of Soil Science, a group of soil scientists representing a broad range of soil institutions adopted it for being the officially recommended terminology to name and classify soils. This classification system, called the "World Reference Base for Soil Ressources" (WRB) was extensively revisioned in the period of 1998 – 2006; efforts were taken to harmonize it with other major classification systems around the world and some countries adopted features of the WRB to their national systems. The European Union released the Soil Atlas of Europe based on the WRB (FAO 2006b, 2).

In June 2014, the FAO released the 3rd edition of WRB, dealing with problematic issues and making the system applicable for soil mapping legends.

The World Reference Base for Soil Ressources (WRB)

The WRB is a comprehensive classification system which is centered around the idea of diagnostic horizons, properties and materials. Those are considered diagnostic, if they meet morphological and analytical criteria like minimum depths, certain color values, particle sizes etc. As such, the system can be considered as being more on the side of the morphological approach. The system comprises (in the 3rd edition) 37 diagnostic horizons, 18 diagnostic properties, 17 diagnostic materials, 32 Reference Soil Groups and 194 Qualifiers.

To classifiy soils, a triple tiered approach is being used (FAO 2006b, 8):

Firstly, the soil material is checked against the requirements listed for diagnostic horizons, properties and material. Those diagnostic features interact with each other as some horizons have properties or materials listed in their criteria, a process which leads to a stacking of requirements and makes the manual classification sometimes exhausting as the user has to keep track of many different values listed on different pages.

Secondly, with the results from step one, the WRB key is searched through for a matching soil. This process, however, is not done liberately, but systematically. The user has to start with the first Reference Soil Group (RSG) and looks, if it matches all of the criteria. If it does not match all of them, he has to go on to the next group. This process is repeated until a complete match has been found or the last of the 32 RSGs has been reached. The key requests additional requirements and renders the findings of step one more precisely. Note, that due to the nature of the key, you will always end up in some RSG, there is no dead end.

As a third step, the RSG is described in more detail by applying prefices (called Principal qualifiers) and suffices (Supplementary qualifiers) to it. This is done by checking your findings from step one against listed criteria in this section.

The result of the whole classification process is a soil name (the RSG name) with additional terms attached to it. This process, while being objective, allows skilled users to recognize certain soil features just by the name.

Due to the nature of some of the diagnostic values, they (yet) cannot be measured in the field. The final result cannot be obtained without laboratorial aid. It therefore might be a problem to get to good results only with field data. This is, however, addressed in the manual (FAO 2006b, 9) and hints are given for certain values to make at least estimates in the field.

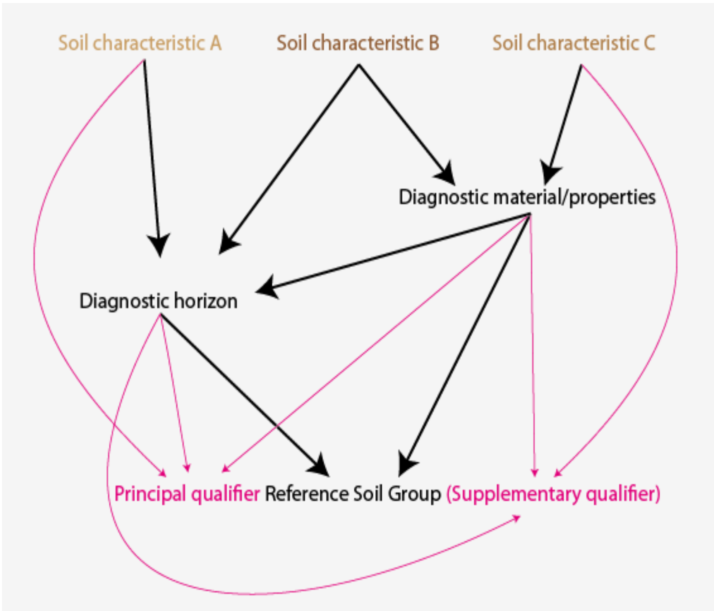

Figure 1 – Schematic drawing of the classification process in the WRB 2014 (own work)

Österreichische Bodensystematik (Austrian Soil Taxonomy)

The Austrian Soil Taxonomy is the national soil classification system of Austria. The underlying principle is that of a genetic system. Therefore it focuses on the environment and soil forming factors. It is explicitly stated that the system is not constructed on definite limits or values. Indeed, the Austrian system lacks most of the strict requirements and definitions which in contrast characterize the WRB. The concept behind it is that the variety of soils cannot be reflected by a highly theoretical system and cannot be tied to absolute values. The knowledge of pedogenesis is given high priority in order to assess a given soil profile. The intent is that a soil scientist with enough background knowledge should yield good results even in the field without laboratory data. The classification process should be carried out by making a holistic assessment in the field, backed up by the experience of the user (ÖBG 2011, 10ff). This may be criticized, because one needs experience to classify properly. In contrast, the WRB tries to avoid this by giving all of the demanded limits, so that even untrained users with a basic understanding of soils can yield proper classification results. In the Austrian system, these limits are rather moved to decision by the individual user, expressed as their experience. Strictly speaking, even the Austrian system demands reference values, but these are more or less present in the mind of the people using it and therefore prone to changes over time.

However, it is not possible to say, whether this approach is better or worse to that realized in the WRB. Leaving judgements open to the user can be a significant advantage as trained users can deal with the heterogeneity occurring in the field. On the other hand, untrained users will easily find themselves lost in the numerous soil types and horizon sequences.

As stated above, the Austrian system strongly relies on knowledge about the location. To qualify soils, the following procedure has to be followed:

The first level of differentiation is that of the water regime. According to this, the user has to decide, whether the soil's development has been substantially influenced by water or not. Based on this decision, the key divides into the order of terrestrial soils and the order of hydromorphous soils.

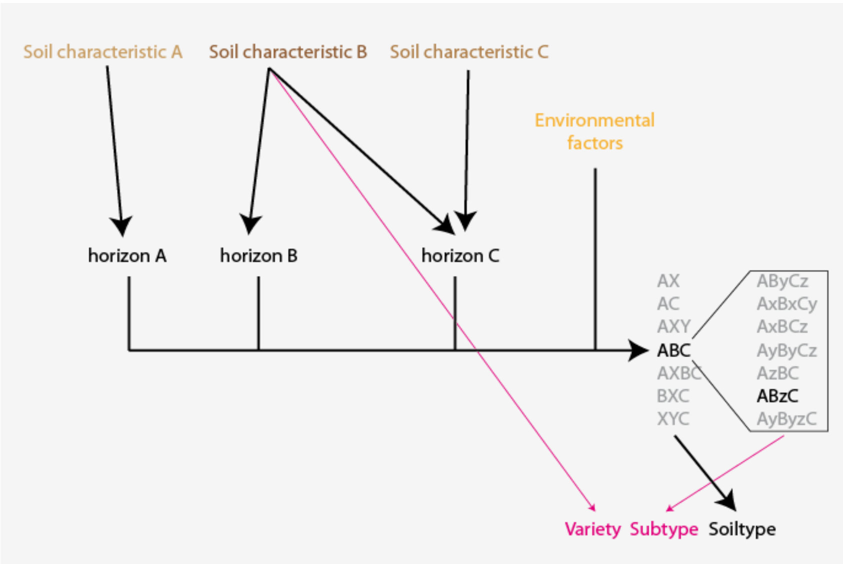

Figure 2 - Schematic drawing of the classification process in the Austrian Soil Taxonomy 2011 (own work)

After that, the soil class has to be determined. For this step, the user has to know in advance, in which class the soil will probably to prevent tedious searching through the key. This is due to the differentiation of the classes based on their dominant soil forming factors. Failing to recognize the dominant pedogenetic process may cause serious problems.

The next step is to go for the Soil type (comparable to soil groups in other systems). To do this, the horizon sequence has to be determined. The Austrian system lists 165 sequences spread over all Soil types (Appendix III gives a summary of them). Given the horizons of the soil profile in question, one has to find the corresponding sequence and gets to the Soil type. For each type, criteria which differentiate it from other types, are given.

In the last step, Subtypes and Varieties are chosen, accounting for dominant and minor characteristics.

HUMUS-RICH SOILS WITH HIGH BASE STATUS

In (former) Steppe regions of the world, soils with high organic matter content are found. Due to climate, humus accumulates in the soil and nutrients are not washed out. This sets these soils among the best for agriculture worldwide. They are known as *Chernozem*, *Kastanozem* and *Phaeozem*.

Soil formation[3]

Chernozems are deep, well drained soils with dark, humus-rich surface layers which gradually fade into the parent material. In this chapter, the main processes of Steppe soils, like humus and carbonate accumulation and faunal turbation with respect to the climate are discussed. We will also look at the relationship between Chernozems and their drier cousins, the Kastanozems and the ones in more humid conditions, the Phaeozems.

Fundamental climatic conditions
Steppe regions are characterized by long, dry summers and harsh winters, leading to tree-less grass lands. This environment can be found in Europe in the Eurasian steppe belt, which reaches from the Hungarian basin over Ukraine further eastwards through Kazakhstan and Mongolia until China and the region around Amur river in Southeast Russia. Similar conditions can be found in North America, where this land is called “Prairie” and in Argentina, where it is known as “Pampa”.

The mean annual precipitation and temperature mainly determines the growth of plants and the resulting type of steppe and soil. Precipitation of about 500-650mm[4] and mean annual temperatures of 5-9°C is typical for Forest steppe, 300-600mm and 6-10°C in the Tallgrass steppe and 250-350mm and 5-9°C in the Shortgrass steppe (Schmidt and Heim 2007, 82 after Hintermaier and Zech 1998).

Evaporation exceedes precipitation[5], thus waterbalance is negative, and even if the highest precipitation is experienced during the summer months (like in the North American prairies), water seldom reaches layers beyond the rooting zone, because grassland experiences much more evaporation than forests do, which shade the ground and protect the covered area of drying winds (Eyre 1968, 110 & 119).

The low precipitation prevents tree growth and leaves space for small bushes and grasses. Many of the latter belong to the family of the Poaceae. These plants have a homogenous rooting system which is dense below the surface and is thought to be a key factor in the adaption of Poaceae to

[3] Soil formation of Chernozems is still discussed. The process presented here reflects the widely accepted belief that these soils formed under steppe conditions. Though, there are soils which cannot be explained with this theory and scientific discussion is going on regarding this topic. See Eckmeier et al. (2007) for further reference. Theories regarding black carbon and contribution of fires to organic matter are also not discussed in this work.
[4] Depending on the source, the limits can vary up to 100mm. They should be considered more as a hint to imagination than as accurate values.
[5] An “Ordinary Chernozem” (Russian Classification) in the Region of Dnepropetrovsk (Ukraine) receives about 410-490mm precipitation but looses 750-850mm through evaporation (International Soil Museum, s.a. – sample representative for large area of the world)

these climatic conditions as it enables them to suck up incoming rainwater very quickly. Rains can be easily converted to biomass (Frey and Lösch 2010, 439).

Parent material

The parent material of most Chernozems in Europe consists of loess or fluviatile loess-rich sediments. Loess is an aeolian sediment, eroded and transportet by wind. During the Pleniglacial (a subdivision of the Pleistocene) between 20.000 and 13.000BP, temperatures decreased, the continents became largely covered with thick ice layers and due to this huge shift of water from the sea to the land, the sea level dropped by 130m compared to nowadays. This resulted in aridic conditions and further in decay of plant biomass, robbing the soils of their cover and leaving them wide open for erosion (FAO 2001a). The fact that the fraction most susceptible to wind erosion is around 100µm (Funk and Reuter 2006, 569), means that loess contains a very high fraction of silt and fine sands. This combination leads in general to very favorable soil properties in terms of plant growth, as loess contains an optimal pore size distribution to maintain enough plant-available water while having enough aeration at the same time (Scheffer and Schachtschabel 2010, 220). Loess contains beside quartz, feldspar, some micas and clay minerals also calcium carbonate (FAO 2001a), so that loess layers are generally well supplied with Calcium and Magnesium and show a high base saturation.

The bedrock of the Russian plains consist mostly of marl in the north, more southwards loess and eventually marl of fluviatile or aeolian origin (Stahr et al. 2012, 204).

Humus accumulation

Organic matter input happens at two levels. Firstly, above the surface, where plants wither during summer (Frey and Lösch 2010, 439) and secondly, below ground, where the fine, deep rooting of Poaceae also contributes to deep humus distribution into the soil, due to the fact, that the fine roots penetrate the solum homogenously and are, once dead, easily humified because of their relative high surface area. Grasses, in general, take up greater quantities of nutrients, particulary more calcium than forests. Once the nutrients are released of dead plant tissue, they are quickly incorporated by the extensive root system, which establishes a close cycling of nutrients and contributes to the fertility of these soils (Eyre 1968 ,109).

The mineralization in the soil is impeded by either lack of water (during summer) or low temperatures (during winter). The decomposing material therefore accumulates dependend on the prevailing conditions.

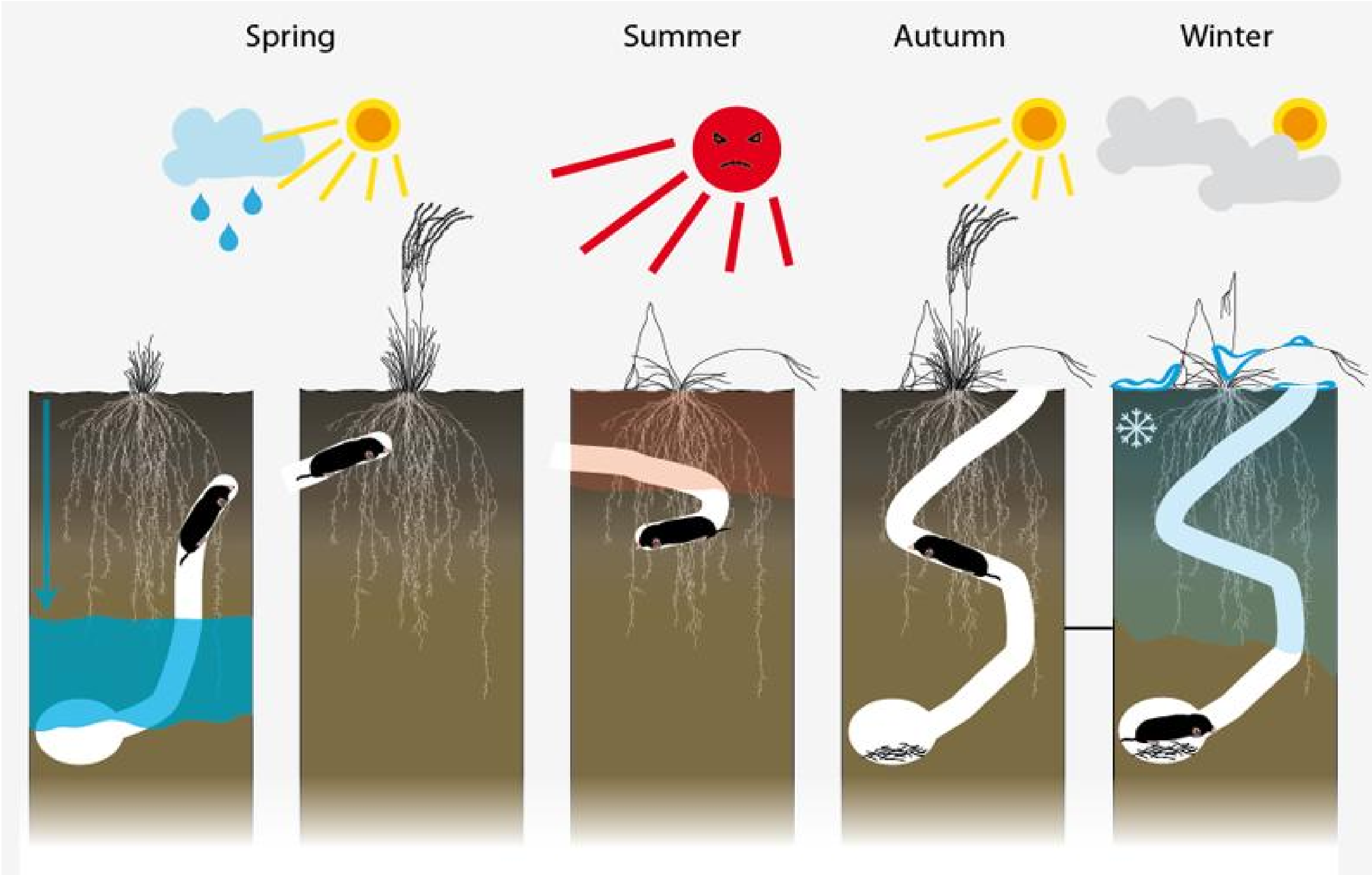

Figure 3 - Depth of activity of soil burrowing rodents over the year (own work).

Animal activity, turbation and soil structure
Soil turbation is mainly caused by burrowing animals[6] which move to deeper or higher soil layers according to the climatic conditions. In spring, snow melt causes water to percolate down the profile, which in turn puts an abrupt end to the hibernation of animals. These move up to surface layers, until high temperatures during summer force them again deeper. In autumn, the animals use plant materials for building a den. It is situated at a depth were the soil is not affected by frost during the winter and is deeper in areas with longer and colder winters. Frost can reach depths up to one meter (Fiedler s.a., 2), we can therefore see deep mixing in tallgrass areas where animals dig deeper into the soil than in shortgrass regions with higher mean temperatures and frost penetrating only to shallow depths (Stahr et al. 2012, 207). Due to high earthworm activity, the soil particles are moved around and clods and blocks are broken into smaller pieces. This, as well as dense rooting make a granular or crumbly structure and a permeable soil (Brady and Weil 1999, 130; Eyre 1968, 109). This is beneficial for plants because almost all of the soil volume is available to roots and no nutrients are locked inside of greater structures. Also, this structure is well suited for agriculture as seedlings and young plants can easily penetrate the soil.

The high animal activity occurs in these organic-matter-rich horizons, where plant- as well as soil material is transported to depths it would not reach otherwise. Soil borders are waived and the surface horizon grades into the underlying material.

[6] *Cricetus cricetus* (Hamster), *Citellus spp.* (European ground squirrel), earthworms, *Gynomus spp.* (prairie dog) (Frey and Lösch 2010, 439), *Talpa europea* (Eurasian mole) (FAO 2001) and Spalax microphthalmus (Eyre 1968, 118)

Calcium carbonate accumulation

The amount of carbonate in a soil layer is a function of the original carbonate content of the parent material, accumulation and leaching. The parent material contains, as stated earlier, calcium carbonate which is normally leached from the profile under humid conditons, though under arid conditions it can accumulate and precipitate as soft nodules or even harder concretions.

Calcium carbonate, when dissolved in water, forms dissolved calcium and bicarbonate ions. Carbon dioxide and water can additionally form carbonic acid. Carbonate and carbonic acid are in equilibrium with calcium and bicarbonate ions. Equations 1 and 2 show this process:

$H_2O + CO_2 \leftrightarrow H_2CO_3$ *(Equation 1)*

$CaCO_3 + H_2CO_3 \leftrightarrow Ca^{2+} + 2\ HCO_3^-$ (*Equation 2)*

Chernozems have, as shown above, surface horizons with high activity of soil biota and high root mass. Soil life as well roots produce carbon dioxide and water as waste products of a process called oxidative phosphorylation, which is used to regenerate ATP (commonly referred to as respiration). Dead tissue of plants and animals eventually release water and carbon dioxide during mineralization. The calcium source is the parent material as well as the plants, which act as constant calcium pumps towards the surface. If we look at *Equation 1*, we can see that an increase in carbon dioxide and water will lead to formation of carbonic acid, which in turn will shift the reaction of *Equation 2* to the right side. Carbonate dissolves. Calcium now can move down in the profile with percolating water until the partial pressure of carbon dioxide changes. This is because microbial activity and root density decrease with depth. It can also decrease in the vicinity of pores and channel systems that have connection to fresh air, which has lower carbon dioxide pressures than is normal the case at these depths. The decrease of partial pressure forces carbon dioxide out of the solution. Another factor can be the evapotranspiration, which removes water. In both cases, the reaction (*Equation 2*) moves back to the left. Carbonate precipitates (FAO 2001b, Schmidt and Heim 2007, 67). The depth of occurence of this pedogenic carbonate indicates the most frequent leaching depth (Hallmark 1985, 54)

The downward transport is not countered by upward movement of water, because most of the water moves in the vapour phase. If there is connection to groundwater and capillary rise, we will find the calcium carbonate precipitation at that depth, where the water evaporates. (FAO 2001b).

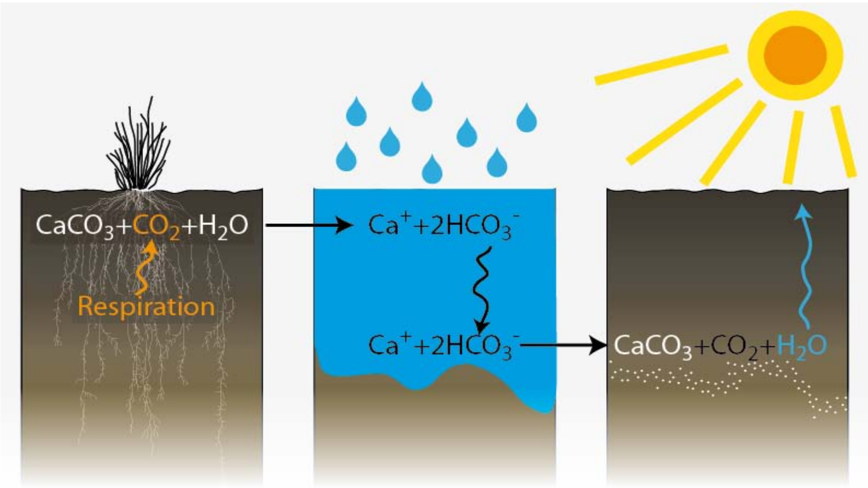

Figure 4 - Schematic drawing of the process of calcium carbonate precipitation in the soil (own work)

Formation of carbonic acid also depends on temperature. Gasses are less soluble in hot water than in cold one. Rise in temperatures would therefore result in less carbon dioxide to be dissolved, shifting the reaction to the left: carbonate precipitates (Butler, s.a.). This can happen in warmer climates where soil temperatures are higher. Lower soil respiration, higher temperatures and upward movement of water under dry conditions all contribute to carbonate accumulation.

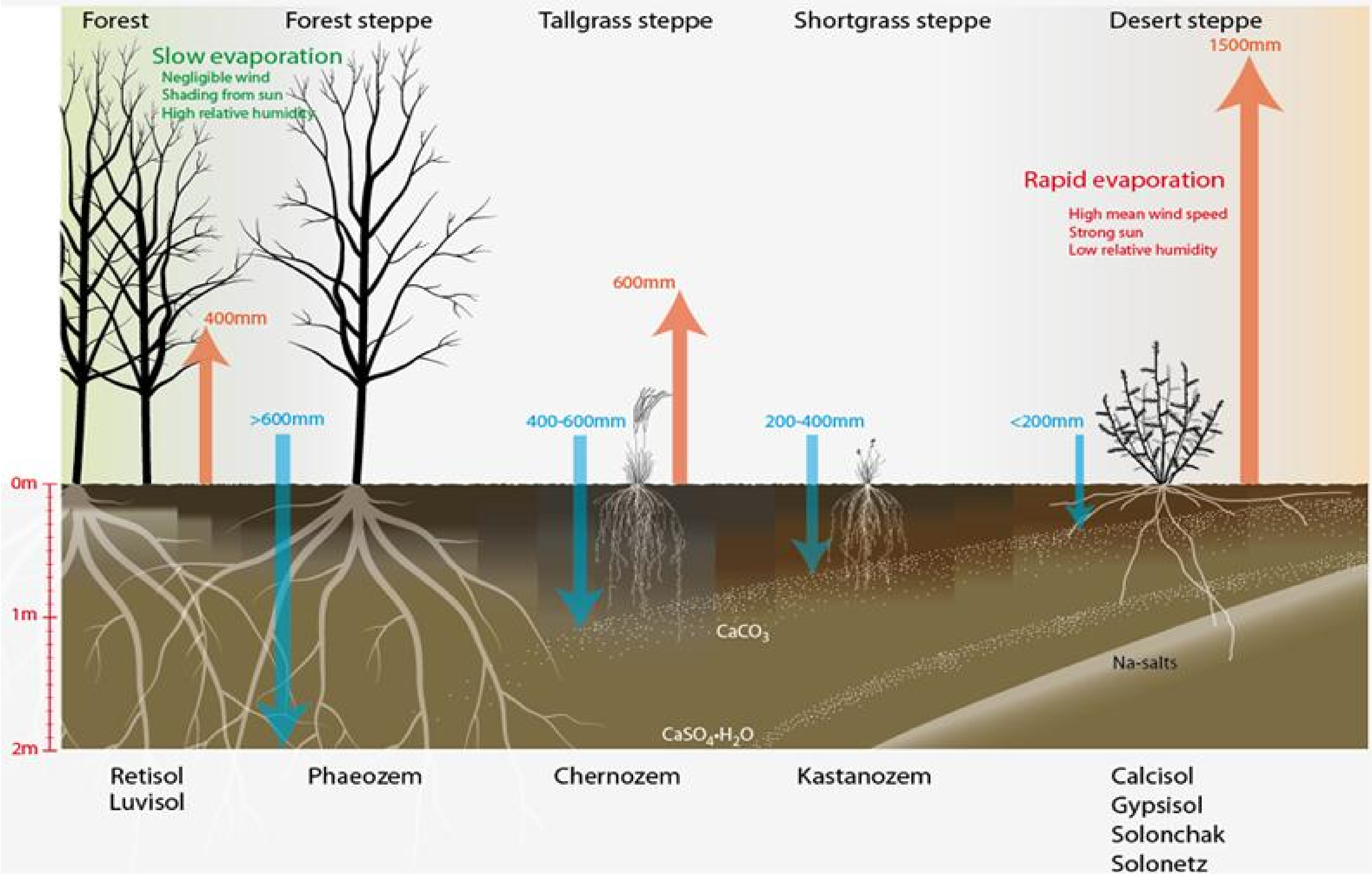

Figure 5 - Relationship of humus-rich soils (zonal concept). Data based on Scheffer & Schachtschabel 2010, 375, Schmidt & Heim 2007, 81, Eyre 1968, 119, FAO 2001, Stahr et al. 2012, 204 and ISSS 1998, 61

Relationship of humus-rich soils with high base status

The conditions mentioned above lead to the formation of soils with dark-colored surface horizons and carbonate accumulation in the subsoil. These soils are typical for steppe regions. Following a climate gradient, the soils change continously one into another. These gradients can be seen in Eurasia (Moscow – Volgograd – Aral Sea) as well as in North America (Alberta (CAN) – Texas (USA)) or in South America (Uruguay – Bolivia) (Stahr et al. 2012, 204f).

The soil catena with respect to the climate is shown in Figure 5. The following text describes the transition of soils and climate in the Eurasian steppes (after Stahr et al. 2012, 205ff and Smelansky and Tishkov, s.a.).

The steppe belt is bordered in the north by **Forest** (the Taiga). The climatic conditions can be described as humid, which leads to soils that have humus-rich surface layers, although with already low pH and a lightcolored subsurface horizon, which is depleted in organic matter and clay minerals due to leaching. The leaching and seperation is not yet prominent enough to speak of Podzols, so these soils are called *Retisols*[7].

Moving southwards to the region around Moscow, we encounter **Forest steppe**. Precipitation is less, but still sufficient that leaching and movement of clay minerals takes place, but the leaching process has not yet occured to an excess where the soil becames depleted of bases and other nutrients. These soils are called *Phaeozems* (from Greek “phaios”, dusky) (FAO 2001; FAO 2006b, 84). They do not show signs of accumulation of calcium carbonate neither bleached horizons because of the mixing activity of soil fauna.

Around Kursk, the vegetation changes again into so called **Tallgrass steppe(High input of organic matter – low mineralisation)**, which can be further divided in Meadow steppes and Genuine forbs-bunchgrass steppes, the former being the moist type of steppes with high primary production and even some trees, the latter comprising zones with a drier climate but still sufficient for dense vegetation. The land is almost to 100% covered and the productivity is about 18-25t.$ha^{-1}.a^{-1}$ with a large proportion of biomass occuring above ground. Growing season is from April to October which can be interupted during summer in the forbs-bunchgrass steppes. The high input of organic matter combined with reduced decomposition builds up deep layers of humus-rich surface horizons. These soils are called *Chernozems* (from Russian “chern”, black and “zemlja”, earth). Leaching is restricted to the upper decimetres of the profile. They usually have layers with carbonate accumulation (calcic horizons), but do not show enrichment of other salts within the profile. This is because salt movement is dependent on solubility and occasional downpours of water move more soluble salts deeper into the profile than calcium carbonate (Eyre 1968, 110).

Coming near Wolgograd, the land grades slowly into **Shortgrass steppe (Medium input – medium mineralisation)** divided into Genunine (dry) bunchgrass steppes and Desertified and desert steppes are characterize by dry conditions which are reflected by less dense, or in the case of desert steppes, sparse vegetation. The balance shifted in favor of the underground biomass and conditions become more and more aridic. The biomass production is not sufficient to build up thick organic layers and mineralization is favored by higher mean temperatures which results in lighter colors. Also, surface horizons are not as thick as in Chernozems, because the frost border within the soil lies closer to the surface, thus soil fauna does not dig deep into the soil, limiting turbation activity to the surface layers. *Kastanozems* (from Latin “castanea”, chestnut, owing to their browner colors) form the dominant soils. They show hardly any signs of base depletion and have calcic horizons within 1m of depth.

The southern border of the steppe region is formed by landscapes, where precipitation is not sufficient anymore for annual grasses. They are replaced by small bushes, which can cope with the dry environment. Organic matter production is therefore limited and not the dominating soil forming factor, as evaporation greatly exceeds precipitation. Soils show accumulation of various salts and layers of calcium carbonate, gypsum and other salts can be frequently found. According to this, they are called *Calcisols*, *Gypsisols*, etc. Salty layers move almost up to the soil surface (periodic heavy rain washes the salts out from the first few centimeters (Scheffer and Schachtschabel 2010, 291).

[7] Replacing the former Albeluvisols of WRB 2006

.

Figure 6 gives an overview about the distribution of Phaeozems, Chernozems and Kastanozems worldwide.

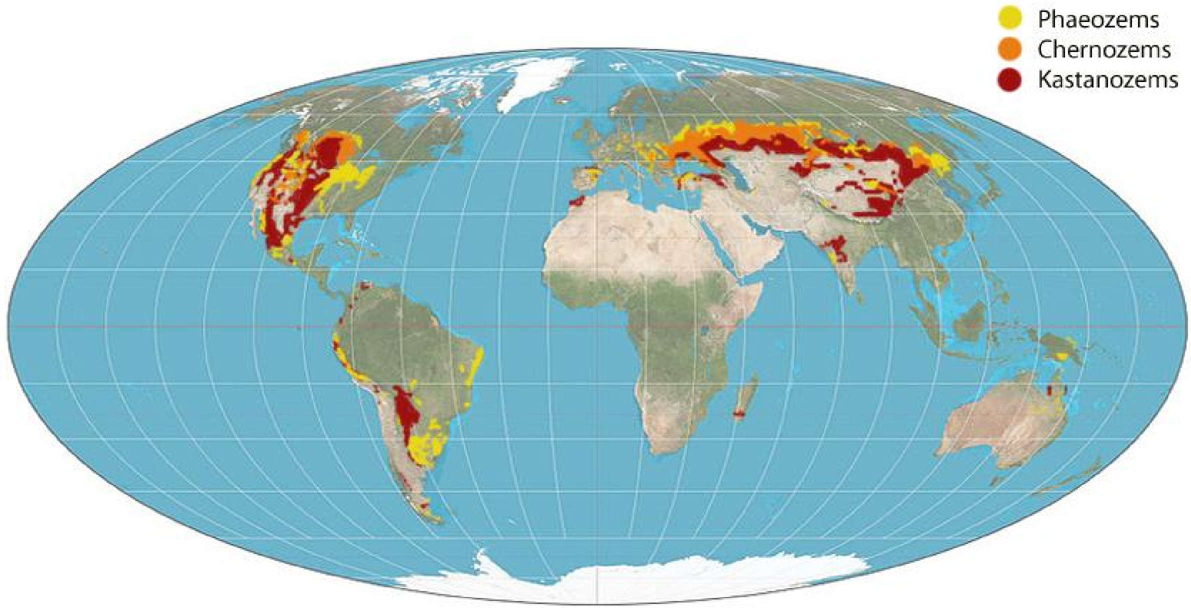

Figure 6 - World map, showing the distribution of organic-matter-rich soils with high base status. The data was derived from FAO 2001a and simplyfied for an enhanced overview .

Conclusion

Chernozems are in general excellent soils for agriculture. Their deep surface horizons paired with high amounts of organic matter and suffient base saturation provide good growth conditions for most crops. One drawback for agriculture is that these soils usually occur in areas where precipitation is the limiting factor for crop growth, reducing their theoretical high yield potential (Stahr et al. 2012, 207). Still, these soils are ranked among the best soils in the world (FAO 2001a), especially for wheat production (Scheffer and Schachtschabel 2010, 321). With less than half of all Chernozems in Eurasia being used for arable cropping, these soils constitute a formidable resource for the future (FAO 2006b, 76).

Situation in North-East Austria (Lower Austria)

Climate

The Austrian climate is considered as temperate. The west of the country is shaped by ozeanic influence with dominating west winds. The east is more influenced by continental climate with hot summers and cold winters. Annual mean temperature ranges from -6°C in some alpine regions to over 10°C in the east. Annual mean precipiation is 1228mm, with a maximum in the Bregenzerwald (3090mm) and a minimum of 551mm in Krems (Auer et al. 2001). BMLFUW (1985, 49) even cites minimum values as low as 501mm (monitoring station Haugsdorf). Both are located within the red area in Fig. 7. In this area, relatively high wind speed (2-4m/s) is occuring, which accelerates evaporation, which is about 80% of precipitation (400-480mm).

Soils

Parent material within the marked area is mainly loess, accompanied by clay-rich tertiary sediments, colluvial and alluvial material and sand/gravel (BMLFUW 1985, 53). Soil formation led mainly to humus-rich soils. Their name is Tschernosem in Austrian Soil Taxonomy and they are regarded as soils having humus-rich topsoils, but no further soil developement, thus combining WRB Chernozems, Kastanozems and Phaeozems into one group of soil. Figure 7 shows that the major occurence of these soils is in the northeastern part of Austria.

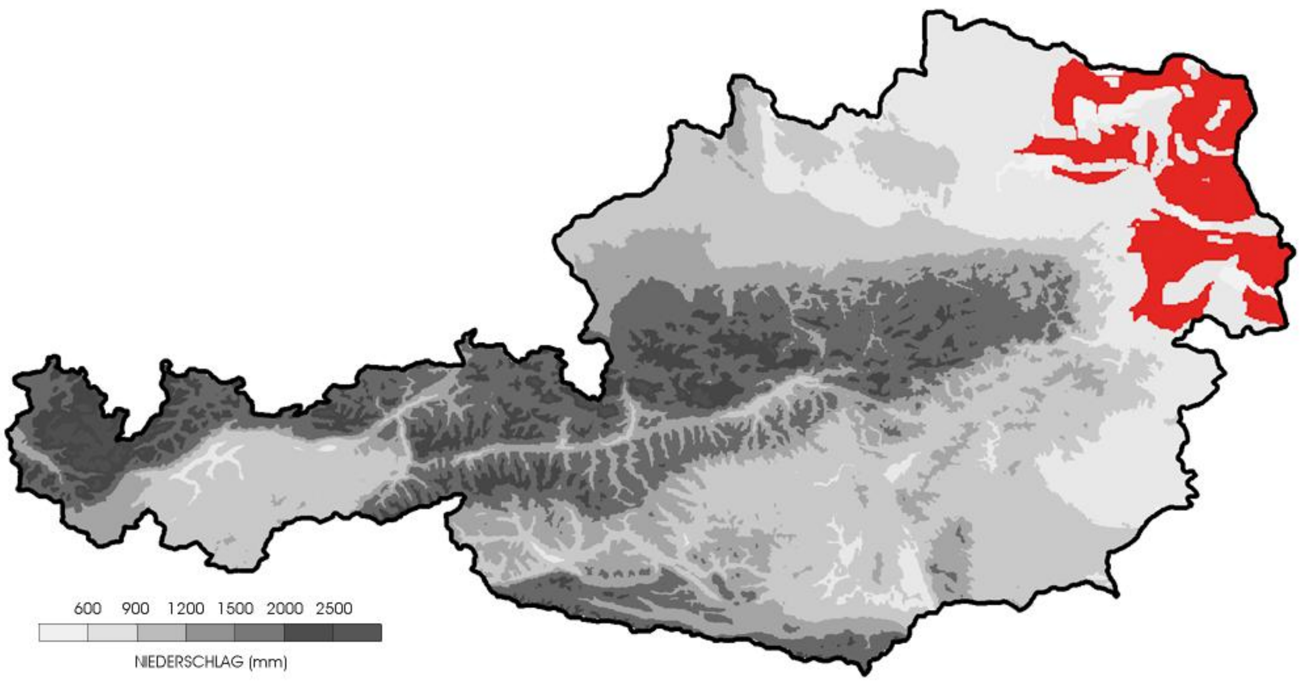

Figure 7 - Precipitation (Niederschlag) in Austria. Red area shows approximate distribution of Tschernosem in Austria. Clearly visible is that these soil mainly occurs in regions with precipitation <900mm. Data from ISRIC – World soil 1km grid and Auer et al. 2001.

Summarizing these factors, we would expect, that the Austrian Tschernosem would correlate mostly with Phaeozems and Chernozems.

REPRESENTATION OF CHERNOZEMS IN SOIL CLASSIFICATION

Chernozems are described differently in WRB and the Austrian Soil Classification. While WRB Chernozems are not so common due to their strict requirements, the Austrian *Tschernosem* frequently keys out as Phaeozem or Kastanozem.

Though, soils not regarded as *Tschernosem* may also fall into the equivalent categories of WRB.

Relationship between Chernozems and other soils in WRB

Chernozems are quite specific soils in terms of soil classification after WRB as they require many criteria to be met. Figure 5 shows the relationship between them and other soils. Chernozems are amongst those soils in the WRB which are characterized by having a chernic horizon in the first place.

Chernic horizons represent dark horizons enriched with organic matter and high base saturation. Therefore, the horizon in question needs to show a moist value of ≤3, dry ≤5 and chroma of ≤2. The idea behind is, that the strict color requirement separates these soils from ones in a drier region as chroma values of more than 2 are seen as signs of increasing aridity (FAO 2001a). Organic carbon needs to be ≥1%. If more than 40% of finely divided lime is present, moist values increase to ≤5 and organic carbon to ≥2.5%. Soil structure has to be granular or subangular blocky. An additional change requirement ensures, that the chernic horizon differs in soil color or soil organic carbon from the underlying layer/parent material. The base saturation has to be 50% or higher and the horizon must be at least 25cm thick (IUSS 2014, 24).

Additionally, Chernozems require calcium carbonate to be present within 50cm under the lower border of the mollic[8] horizon. It can be present as calcic horizon which is characterized by higher calcium carbonate content relative to an underlying horizon. This carbonate has accumulated in diffuse form or as discontinuous concentrations (pseudomycelia, cutans, soft and hard nodules or veins). A minimum content of 15% in the fine earth as well es 5% or more relative to the underlying layer or 5% or more (by volume) secondary carbonates are required (IUSS 2014, 21). If the requirement of a calcic horizon is not met, ≥5% of secondary carbonates can be sufficient (protocalcic properties).

Lastly, base saturation has to be below 50% from the surface to the upper limit of the calcic horizon/secondary carbonates throughout.

A horizon which is quite similar to the chernic horizon is the mollic horizon. It is basically a chernic horizon with lowered diagnostic limits. A chroma of ≤3 is now allowed, organic carbon content is decreased to ≥0.6% and now only inexistent or massive structure is forbidden. Also the minimal thickness is lowered to ≥20cm.

[8] Chernic horizons are also mollic horizons.

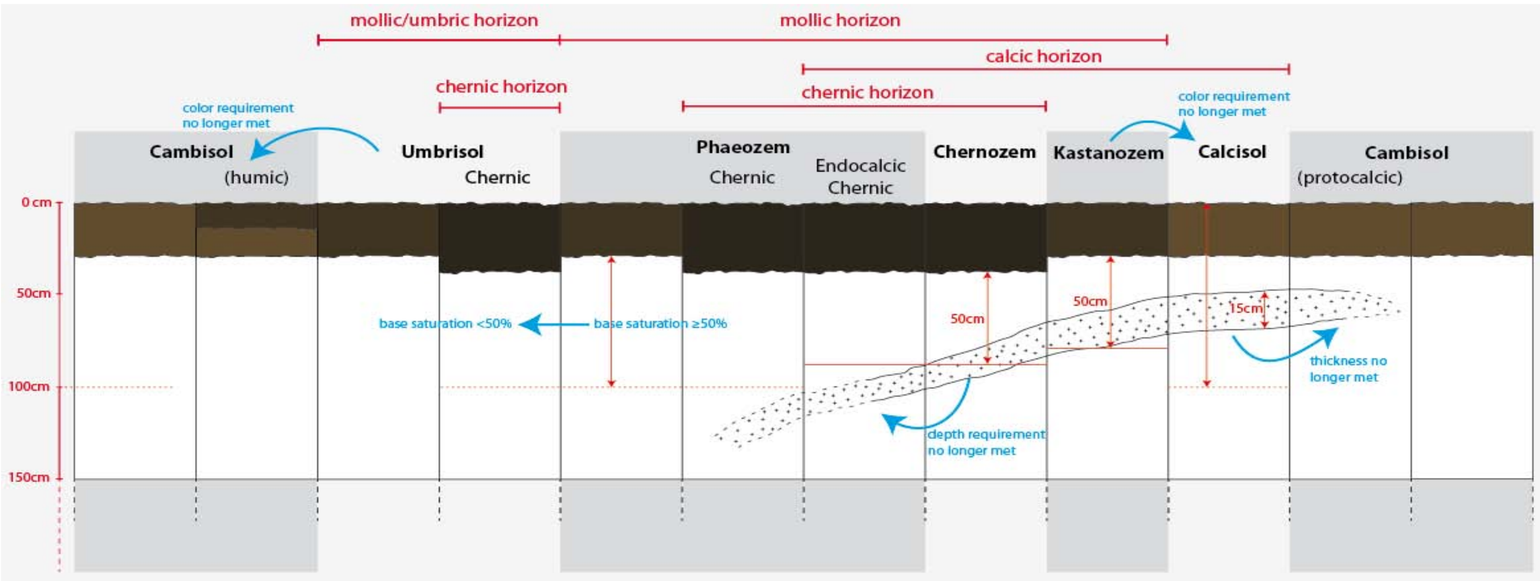

Figure 8 - Systematic relationship between some Reference Soil Groups. The dotted layer represents secondary carbonates. Note that the purpose of this figure is to show classification limits in the WRB, not real-world relationships. (Own work)

Figure 8 shows how the RSGs regarding humus- and carbonate-rich soils intergrade. Within them, **Chernozems** have the strictest diagnostic requirements.

A humus-rich soil having a mollic horizon is not classified as Chernozem, if the calcium carbonate requirement is not met, even though the base saturation is still above 50%. Depending on the surface horizon, the soil would key out as (Chernic) **Phaeozem**, a new feature in the 3rd edition of WRB.

If base saturation between the surface and a depth of 100cm (or to continous rock, an indurated layer etc.) drops below 50% at some point, the result is an **Umbrisol**.

Absence of mollic/umbric horizons will lead to **Cambisols**, which can be humic.

A soil having a calcic horizon/protocalcic properties but lacking the requirements of a chernic horizon will key out as a **Kastanozem**. Failing also the requirements for a mollic horizon will lead to classification as **Calcisol**.

If the calcic horizon is absent within 100 cm, the soil is classified as a **Cambisol**(protocalcic) if still showing secondary carbonates, otherwise as a **Cambisol**.

Relationship between Tschernosems and other soils in the Austrian Soil Taxonomy

Tschernosems are soils characterized as having an A-C, A-AC-C or A-AC-Cu horizon sequence. There are several other soils, which show A-C sequences and how they are delineated[9] is shown in Figure 9. Firstly, dominant features defining each of these groups[10] can be recognized. Though not officially mentioned in the Austrian Soil Taxonomy, the method for determining the class of the soil is shown in Figure 9. The first row shows A-C-soils which have features that are particular different to justify an own soil group. If none of these features prevail, the soil is classified according to its origin. Terrestrial ones are split further depending on their calcium carbonate content. The groups in detail are:

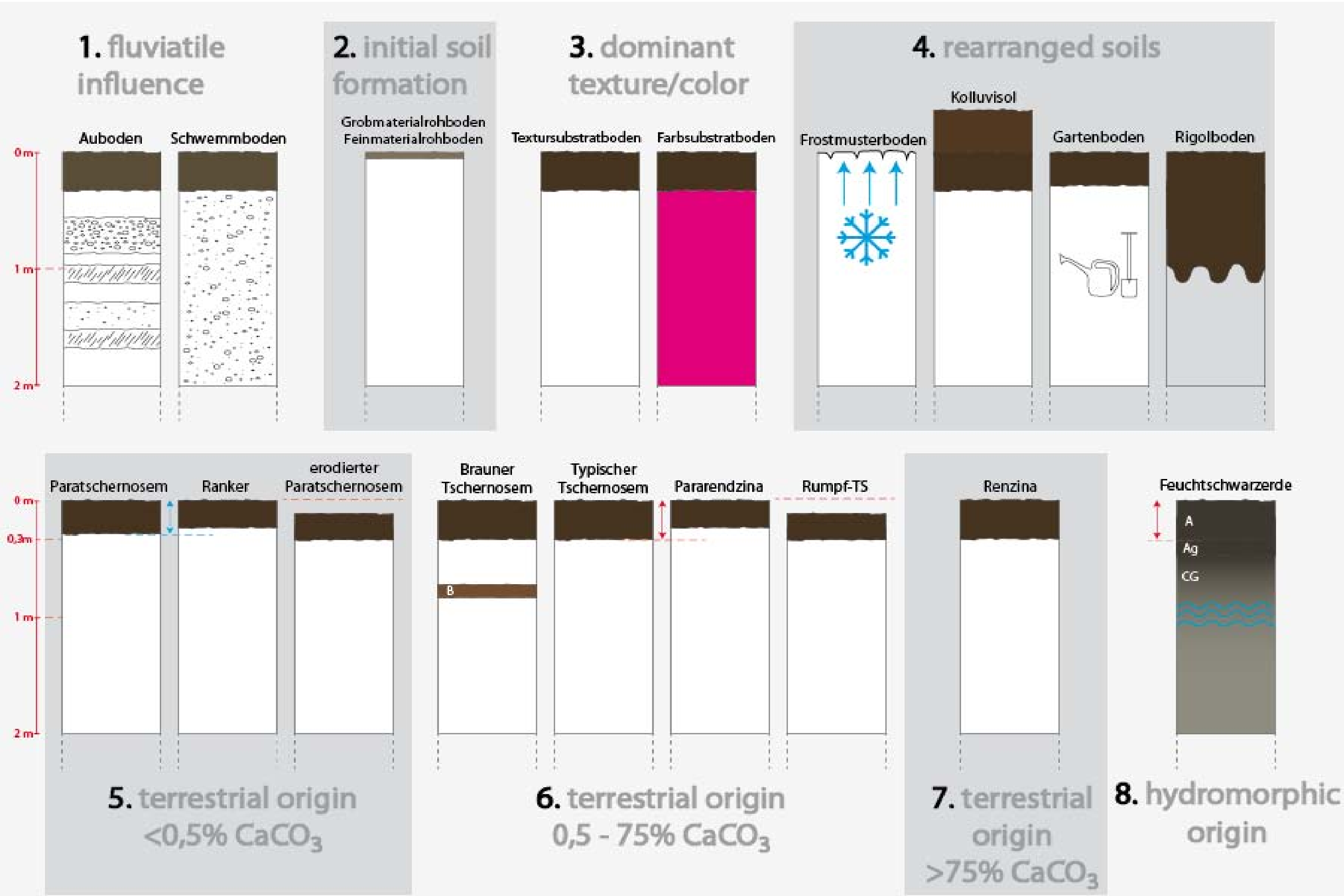

Figure 9 - A-C-soils occuring in the Austrian Soil Taxonomy shown with their dominant features which make them unique within the system. Each soil is denoted by its name in the Austrian soil taxonomy. Soils which do not qualify for 1-4 are distributed on 5-7 based on their calcium carbonate content. If hydromorphic origin is evident, the soil is moved to 8 instead. Detailed explanation in text. (Own work)

[9] There exist some errors in the definitions, which make this process more difficult. See Appendix IV for further details.

[10] These groups are not to be confused with Soil classes, types or subtypes. They are rather “functional” groups.

1. Soils which are considered being fluviatile influenced primarily by their position in the landscape. Irregular textural differentiation, layers of sorted cobbles, stones etc are typical features of Auböden (floodplain soils). These features may not present and soil still qualifies for this category, if the influence of a water stream is recognizable (Schwemmböden).
2. Soils with only initial soil formation. Applies only to soils which have an A-horizon of ≤2cm.
3. Dominant texture and/or color. If the texture is characterized in a way, that it is hiding signs of pedogenetic processes or if the parent material possesses a color which hides those, the soils are named Textursubstratböden or Farbsubstratböden (texture substrate soils/color substrate soils).
4. Soils that show signs of rearrangement of their horizons either by natural or anthropogenic processes, are called "rearranged". The graphic comprises soils which show cryogenic features on their surface (Frostmusterböden), soils where colluvial material of adjacent soils accumulated, soils with high organic matter content due to gardening and soils that have been ripped to depth of about a meter (to distinct between ripping and deep ploughing).

5 – 7. If none of these characteristics applies, a division based on the carbonate content is made.

8. Features present that point to the hydromorphic origin of the soil. The topsoil is already a terrestrial one, but subsequent layers still show gleyic features and hydromorphic humus. Groundwater influence is still possible but is not sufficient to classify the soil as a Gleysol.

From a taxonomical point of view, Tschernosems are lower-ranked soils, which means that although they cannont occur in floodplain areas where they would always be classified as group 1. Only if none of the features 1-4 is present, the classification can yield a Tschernosem given that its own requirements (depth of A-horizon) are met. Ranker, Pararendzina and Rendzina can be considered as left-over-soils which neither show any features characterizing groups 1 to 4 nor meet requirements for (Para)tschernoseme. From a practical viewpoint, especially the groups 2, 3, and 4 can be neglected in most of the cases when dealing with arable land in the east of Austria (except for the Kolluvisol).

There is no equivalent of Calcisols in the Austrian system. Potential Calcisol would be classified after other features and can therefore end up as any soil type.

III. Methods

The classification was carried out automatically by an algorithm programmed in Microsoft Excel® using the rules given in the WRB manual. These rules demand a bunch of parameters. If those were not available, they had been recalculated using existing data or assumptions were made.

DATA AND DATA SELECTION

For this study, 100 soil profiles described by the Austrian Soil Survey were used. The data comprise information on the climate and the geological background of the sampled area as well as detailed soil profile descriptions.

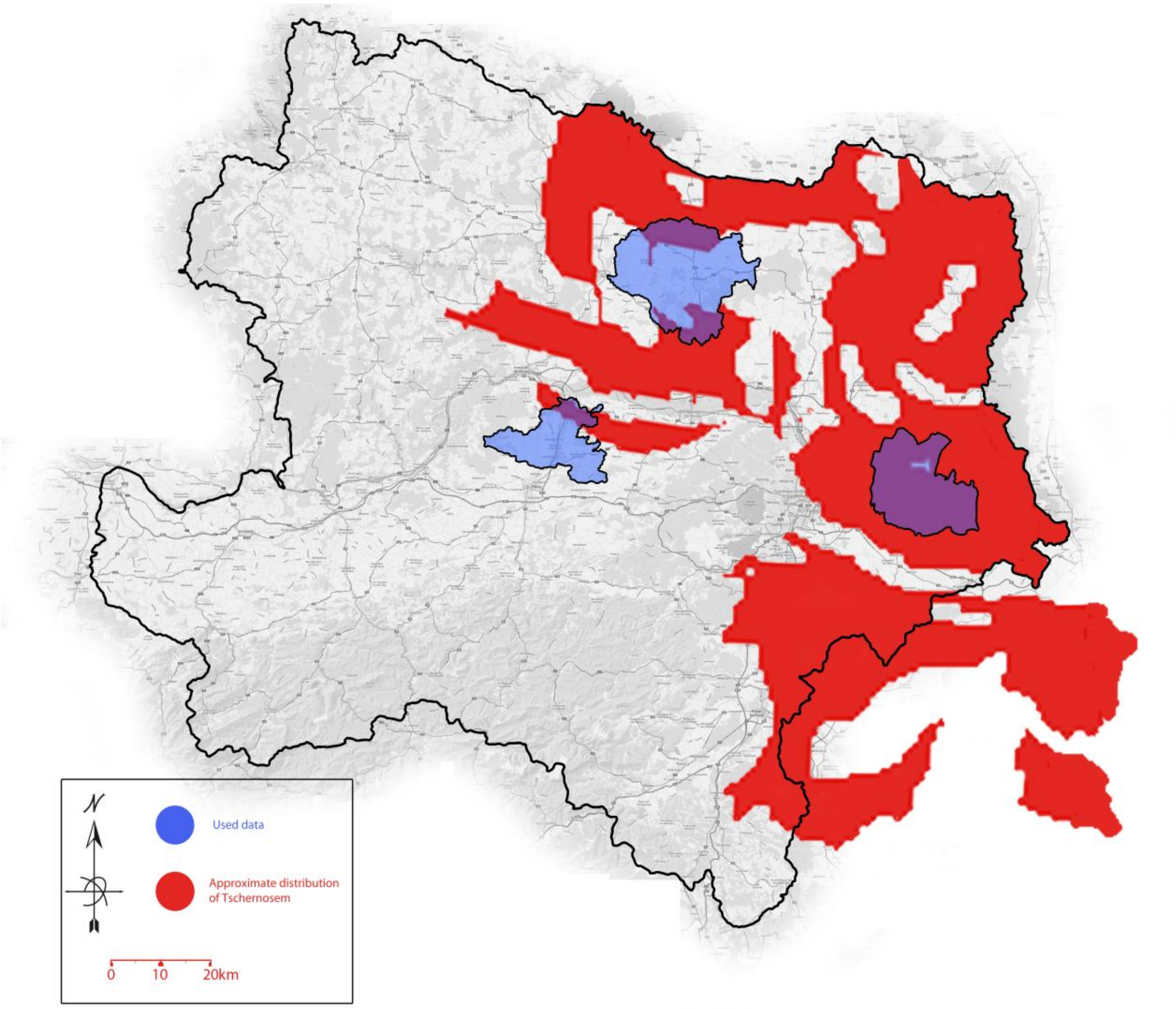

Figure 10 - Map of Lower Austria. Red areas show the approximate distribution of Chernozems based on the ISRIC automated 1km grid. Blue are the soil survey districts where the data for this work were derived from. It can be seen, that one area is in the core area of Chernozem distribution. Selection of these districts should ensure that a potential east-west-gradient is covered. Data from Google Maps and ISRIC World Soil 1km grid.

In the study area widely distributed A-C-soils like Tschernosem, Feuchtschwarzerde, Rohboden, Braunerde etc. were included. Soils which obviously would key out before Chernozems in the WRB key (e.g. Gleysols) were excluded. This also applies for soils which would clearly not qualifiy for a mollic horizon (Value or Chroma >3 and ≤40% $CaCO_3$) and similar soils of that type were already in the selection.

CLASSIFICATION

Background

The first step in the WRB classification procedure involves the assessment of the soil in order to identify diagnostic horizons, materials and properties, whose, the system is built around. These diagnostic items are listed on 63 pages in the WRB 2014 manual and to classifiy a soil, the user has to go through all of them and check if any of them qualifies. Each of the 72 items comprises up to nine criteria, which are linked together by “AND” operators[11], meaning they all need to be fulfilled. Within single criteria, further subcriteria can occur, linked by either “AND” or “OR” operators. Single definitions can contain “NOT” operators. On Page 20 the criteria of the mollic horizon are shown. Practically, this means reading through about 300[12] definitions for EVERY soil to complete only step 1 out of 3 of the classification procedure. Although one will soon remember some of the more prominent or often occurring criteria, the sheer amount of them can easily lead to some items being overlooked.

Fortunately, the use of Boolean operators[13] opens the possibility to program an algorithm which uses all of the given criteria to make the most difficult process easier and to make it more resilient to inconsistencies. Nevertheless, even the WRB, largely relying on absolute values which can be measured in the field, includes sometimes requirements which cannot be measured at all. For example, the question whether a soil developed under anthropogenous influence, e.g. by adding earthy manures or compost over a long time (plaggic and terric horizons for example) cannot be answered solely by soil profile information. A person with background knowledge is still needed, but can be substantially relieved of the laborious part.

It has to be further mentioned, that even theoretically computable requirements cannot be assessed that precise as a person would do. The limitation is often that only single measured values are available for each horizon, rendering it impossible to reflect different situations like distribution patterns of features within a certain layer. The system is only as accurate, as the input is.

[11] There exist a few exceptions, were main criteria are linked by OR. These are mainly found in the diagnostic properties and materials section.
[12] 72 diagnostic items + 32 RSGs + 194 qualifiers
[13] Boolean algebra is an algebraic structure using the operators AND, OR, NOT.

Mollic horizon

General description

The mollic horizon (from Latin *mollis*, soft) is a thick, dark-coloured surface horizon with a high base saturation and a moderate to high content of organic matter.

Diagnostic criteria

A mollic horizon is a surface horizon consisting of *mineral* material. For diagnostic criteria 2 to 4, the weighted average of each value is calculated and then checked against the diagnostic criteria, either for the upper 20cm, or for the entire mineral soil above *continuous rock*, *technic hard* material or a *cryic, petrocalcic, petroduric, petrogypsic* or *petroplinthic* horizon if starting < 20 cm from the mineral soil surface. If the mollic subhorizons has subhorizons that start ≥ 20 cm from the mineral surface, a weighted average for those subhorizons is not calculated; each value is checked separately against the diagnostic criteria. A mollic horizon has:

1. a throughout the horizon a soil structure sufficiently strong that it is not both massive and hard or very hard when dry (prism larger than 30cm in diameter are included in the meaning of massive if there is no structure further subdividing the prisms); ***and***
2. ≥0.6% *soil organic carbon*; ***and***
3. One or both of the following:
    a. In slightly crushed samples a Munsell colour value of ≤ 3 moist, and ≤ 5 dry, and a chroma of ≤ 3 moist; ***or***
    b. All of the following
        i. ≥ 40% (by mass) calcium carbonate equivalent in the fine earth fraction and/or a texture class of loamy sand or coarser; ***and***
        ii. In slightly crushed samples a Munsell colour a value of ≤ 5 and a chroma of ≤ 3, both moist; ***and***
        iii. ≥ 2.5% soil organic carbon; ***and***
4. One of the following:
    a. In slightly crushed samples a Munsell colour value ≥ 1 unit lower, both moist and dry, than that of:
        i. The parent material, if parent material is present, that has a Munsell colour value of > 4, moist; ***or***
        ii. The layer directly underlying the mollic horizon, if no parent material is present, and the directly underlying layer has a Munsell colour value of >4, moist; ***or***
    b. ≥ 0.6% (absolute) more *soil organic carbon* than
        i. The parent material, if parent material is present, that has a Munsell colour value of ≤ 4, moist; ***or***
        ii. The layer directly underlying the mollic horizon, if no parent material is present, and the directly underlying layer has a Munsell colour value of ≤4, moist; ***and***
5. a base saturation (by 1 *M* NH_4OAc, pH 7) of ≥ 50% on a weighted average, throughout the entire thickness of the horizon; ***and***
6. a thickness of one of the following:
    a. ≥ 10 cm if directly overlying *continous rock*, *technic hard* material or a *cryic, petrocalcic, petroduric, petrogypsic* or *petroplinthic* horizon; or
    b. ≥ 20 cm.

1.
IF IF(OR(Structure=granular; Structure=subangular);
THEN FALSE;
ELSE TRUE)
2.
IF(Organic carbon≥0.6;TRUE;FALSE)
3.
IF(OR(
IF(AND(Value≤3;Chroma≤3);TRUE;FALSE);
IF(AND(OR(Carbonate≥40;Texture≤loamysand);
Value≤5;Chroma≤3; Organic carbon≥2.5)
);TRUE;FALSE)
4.
IF(OR(
IF(*Parent material*=TRUE;IF(Value>4;IF((Value(p)-Value)>=1;TRUE;FALSE);FALSE);IF(Value(sub)>4;IF((Value(sub)-Value)>=1;TRUE;FALSE);FALSE))
IF(*Parent material*=TRUE;IF(Value≤4;IF((Organic carbon(p)-Organic carbon)>=0.6;TRUE;FALSE);FALSE);IF(Value(sub)≤4;IF((Organic carbon(sub)-Organic carbon)>=0.6;TRUE;FALSE);FALSE))
);TRUE;FALSE)
5.
IF(pH≥5,5;
TRUE;
FALSE)
6.

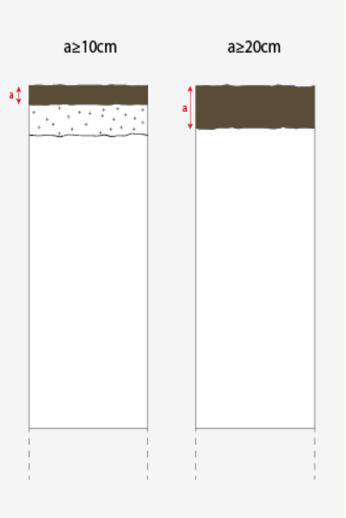

Figure 11 – Description of the mollic horizon in WRB 2014 (left) and its translation to the classification algorithm (right).

Semi-automatic classification

Microsoft Excel® has been found useful for executing this task and consequently has been programmed for semi-automatic classification.

The WRB criteria have been transformed into a form that the program can compute them (Figure 11 on the right side). Up to seven individual horizons can be computed simultaneously, allowing also criteria, which relate to layers lying above or below the current layer.

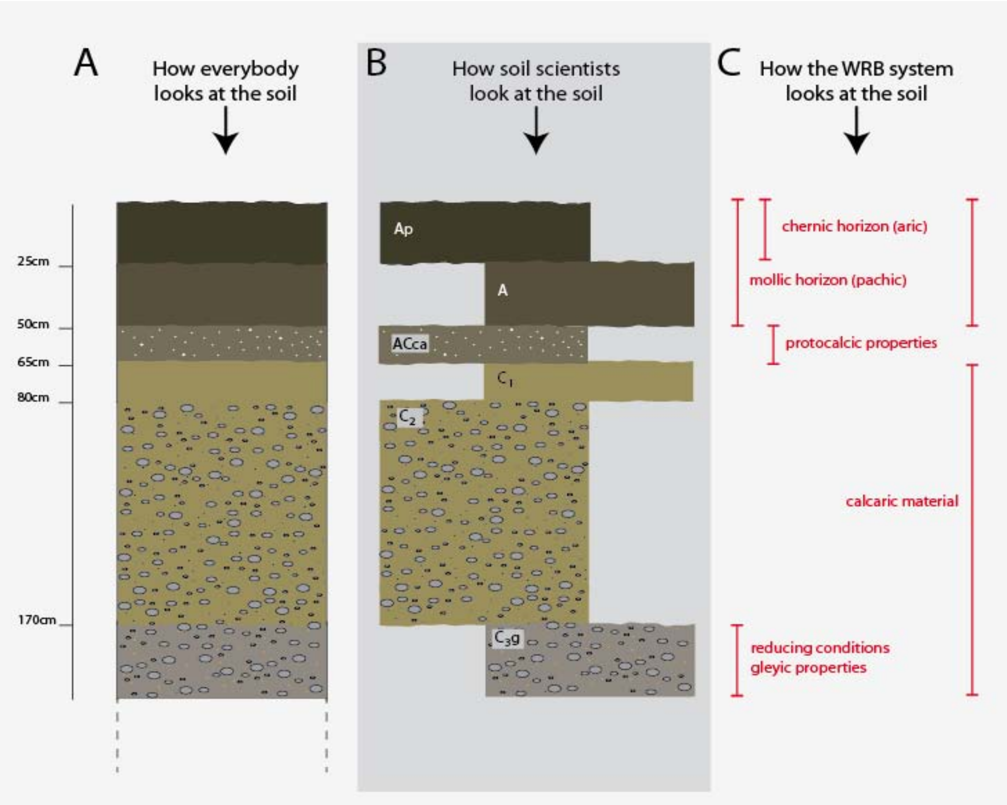

Figure 12 - People look at soils in different ways. So do classification systems. (Own work)

The results of the single horizons are then merged, to cumulate adjacent layers with the same features into a single one. Figure 12 enlightens this process. The process is basically the same as humans would approach the classification procedure. First checking the layers one by one, and then putting same horizons together (step B to C).

Used data

If parameters were required which were not available but could be calculated back from available data, this has been done. The calculation procedure is mentioned and parameters recalculated this way are marked with an asterisk (*).

Depth

Available data was used. Measurements in centimeters.

Color

Available data was used. Color was only available from moist soil samples. Some criteria also demand dry colors to correctly qualify certain parameters. This could be a source of misinterpretion of some features and will be discussed later on.

<u>*Texture and particle size</u>

<u>≤2mm</u>

Particle distribution of sand, silt and clay expressed as percentages was available. The texture was calculated from particle distribution using the WRB texture triangle (FAO 2006, 27). Note that the limits between textural fractions of the used data are not exactly the same as in the WRB texture triangle.

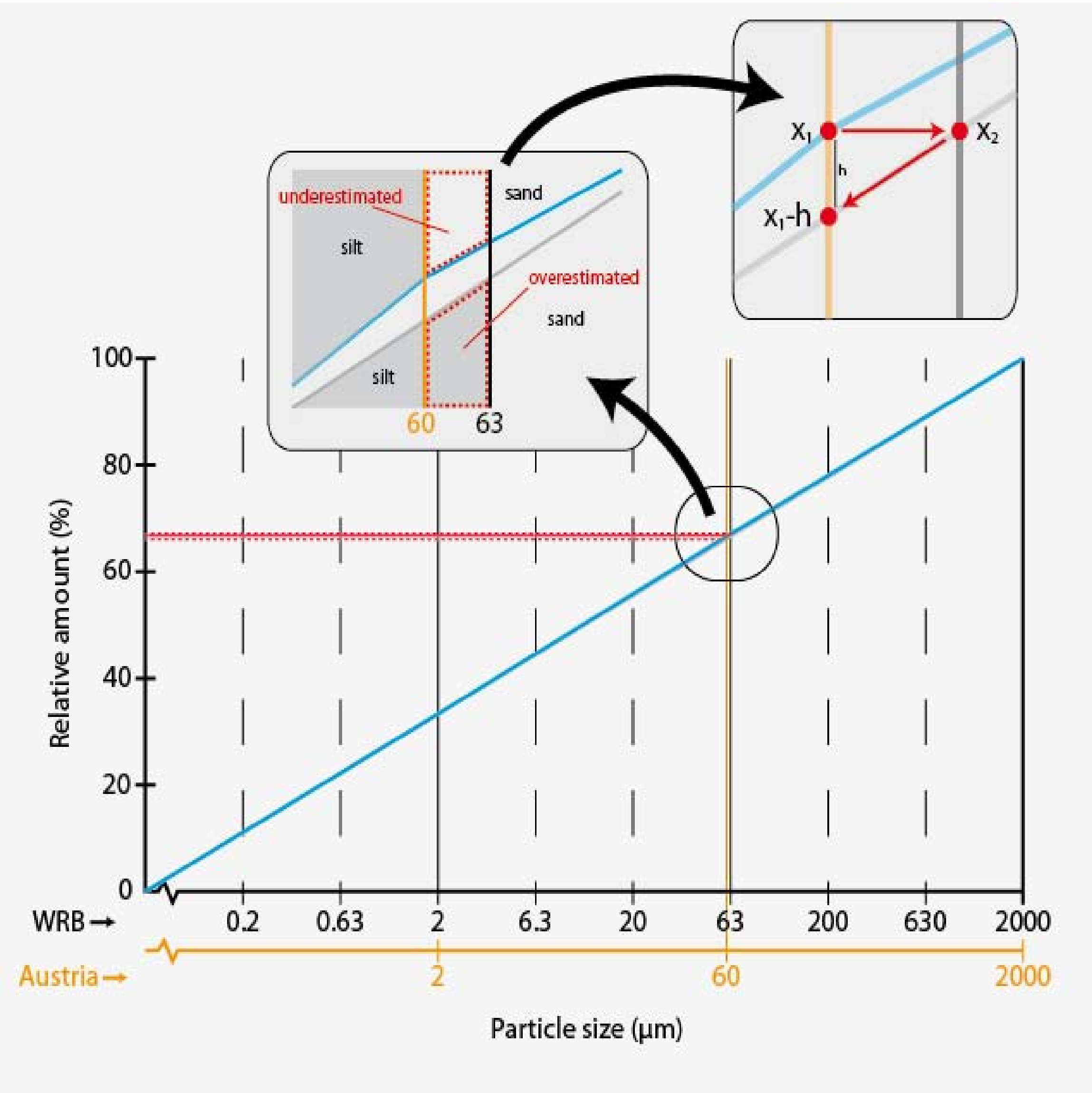

Figure 13 - Hypothetical particle size summation curve with one third of clay, silt and sand. The grey line represents the WRB, the blue line the Austrian curve. A given amount of x_1 measured in the Austrian system is transferred to the WRB size classes (x_2). Going back on the grey line to 60µm shows that the amount of silt is overestimated by the amount of h. The sand portion is underestimated by h respectively. (Own work)

Figure 13 shows the different particle size classes. The Austrian systemhas its border between silt and sand at 60µm, whereas the WRB uses 63µm as the borderline. If the Austrian data is therefore used with WRB particle size classes, the amount of silt is slightly overestimated and the amount of sand is slightly underestimated.

>2mm

Information about coarse material was available as discrete classes. The median of each class was used for calculation (for example: class: 10-20, used value: 15)

Structure

The soil structure classification used in Austria was transferred to the WRB according to Table 1.

Structure in soil survey	**Structure in WRB**
ohne Struktur/lose	single grain
feinkrümelig	crumbly
grobkrümelig	crumbly
feinblockig kantenscharf	angular blocky
grobblockig kantenscharf	angular blocky
feinblockig kantengerundet	subangular blocky
grobblockig kantengerundet	subangular blocky
massiv/dicht	massive
Lößgefüge	porous massive
plattig	platy

Table 1 – Structure in the soil survey and its equivalent in the WRB. This list is not final and does only show the structure types encountered in the data.

*pH

Acidity was available as pH(KCl). For classification purposes the pH(H_2O) was recalculated using the regression function given by Beery and Wilding (1971, 54) which is displayed in *Equation 3*:

$$pH_{H2O} = (pH_{KCl} + 1) \qquad \textit{Equation 3}$$

Carbonate

Carbonate content was available, determined after the Scheibler method.

*Base saturation

There were no base saturation values measured by the Soil Survey so they had to be calculated back from pH. According to Beery and Wilding (1971, 52), a pH of 5,5[14] could be used to differentiate between a base saturation above or below 50%. In most of the cases (90%) this estimation works correctly for horizons rich in organic matter. For classification purposes, a base saturation of 50% or more marks the transition of umbric to mollic horizons.

[14] The WRB (2007, 39) also mentions this value at the Umbric horizon. Interestingly, in the description of the mollic horizon, a value of 6.0 is given.

For Voronic horizons and the limit was set to pH 6,5 reflecting their base saturation requirement of 80%. This limit was calculated by using the equation for Mollic Ap horizons supplied by Beery and Wilding (1971, 52).

Their equation suggested for Alfisols (US Soil Taxonomy) allows a good estimation of a base saturation of 75% for horizons not rich in organic matter. The limit value was set to pH 6,5[15]. Calculations done by Ciolkosz (2001, 6) also support this assumption.

*Organic carbon

Data regarding organic matter determined after the Walkley procedure was available. Organic matter was calculated back by dividing the value of organic matter by 1,72 (Kumar 2006, 138).

Mottles and concretions

Color

The horizon descriptions also contain information on the color, size and extent of mottling as well as the chemical properties. Color was often expressed verbally ("red") rather than in Munsell values. Extent was also not given in absolute values, but in discrete classes. To make calculations possible, the color and extent of mottling were divided into classes and are given in Table 2. The diagnostic horizons were then allocated to the corresponding color of the substances they qualify. This means that the algorithm would assume that if white mottles occur that they would either be of calcite, gypsum or silica origin.

Due to lack of data there was no distinction possible between mottling and concretions.

Extent

Descriptions include information about the size and area covered with mottles.

Extent of mottles	Color of mottles
None	None
≥1%	White
≥5%	Yellow
≥10%	Yellow-brown
≥15%	Brown
≥40%	Red-brown
	Red
	Black

Table 2 - Distribution and color of mottles as used by the algorithm. The values and colors are the same that are used in the WRB manual.

Arbitrary parameters

Some parameters were neither available nor suitable for recalculation. Most of them require additional knowledge about the individual location and are often not included in the soil descriptions of the Austrian soil survey. Decision whether they apply or not, is left to the user. Their occurrence is computed by ticking checkboxes (TRUE/FALSE). This was done for determining the following characteristics:

[15] The pH-value was set after the equations for B1 and B2 horizons. The mean value of both results was used.

- Ploughed layer
- Human-induced-horizon
- ≥25% (by volume) of animal pores, coprolites or other traces of soil animal activity.
- Fluvic material (decision was based on the parent material: Young sediments were assumed to indicate fluvic material)
- Water saturation for 30 consecutive days or more in most years (unless drained)
- Stagnic color pattern
- Reducing conditions
- Mottles in platy, polygonal or reticulate pattern
- Mottles with a diameter of 2 mm or more (ferric horizons)
- Mottles with a diameter of 1 cm or more (duric horizons)

IV. Results

The results of the classification process are displayed in Table 3 and Figures 14 and 15. Information on diagnostic horizons, properties etc. of the respective soil is provided in Appendix I.

Area	No.	Austrian Soil Taxonomy		WRB 2014		
	n=100	Subtyp	Bodentyp	Principal qualifier	RSG	Supplementary qualifier
He	Tf 25	kalkhaltige	*Braunerde (Fels-)*	Eutric Calcaric Skeletic Relictigleyic Leptic	**Cambisol**	(episiltic, aric)
Ho	Tf 32		*Braunerde (Lockersediment-)*	Eutric Stagnic	**Cambisol**	(epiloamic, endoarenic, aric, endomanganiferric)
Ho	Tf 33		*Braunerde (Lockersediment-)*	Eutric Stagnic	**Cambisol**	(epiloamic, amphiarenic, aric, manganiferric, ochric)
Ho	Tf 30		*Braunerde (Lockersediment-)*	Endocalcic	**Kastanozem**	(amphiloamic, aric, endostagnic)
Ho	Tf 34	kalkhaltige	*Braunerde (Lockersediment-)*	Skeletic Abruptic	**Luvisol**[16]	(epiloamic, amphiclayic, aric, differentic)
He	Tf 26	kalkfreie	*Braunerde (Fels-)*	Orthoskeletic Cambic Leptic	**Phaeozem**	(epiloamic, aric)
He	Tf 28	kalkhaltige	*Braunerde (Lockersediment-)*	Calcaric Skeletic Epicalcic	**Phaeozem**	(epiloamic, aric)
He	Tf 32	kalkhaltige	*Braunerde (Lockersediment-)*	Calcaric Cambic Endoluvic Gleyic	**Phaeozem**	(amphisiltic, endoloamic, aric)
Ho	Tf 31		*Braunerde (Lockersediment-)*	Haplic	**Phaeozem**	(amphiloamic, endosiltic, aric)
Gr	Tf 23a	kalkhaltige	*Feuchtschwarzerde*	Haplic	**Calcisol**	(pantosiltic, gleyic)
Gr	Tf 24		*Feuchtschwarzerde*	Eutric Calcaric Gleyic	**Cambisol**	(pantoloamic)
Gr	Tf 25	kalkhaltige	*Feuchtschwarzerde*	Eutric	**Cambisol**	(amphisiltic, humic)
Gr	Tf 26	anmoorige, kalkhaltige	*Feuchtschwarzerde*	Eutric	**Cambisol**	(amphiloamic, humic)
Gr	Tf 28	anmoorige, kalkhaltige	*Feuchtschwarzerde*	Eutric Calcaric	**Cambisol**	(amphiloamic, endodensic)
Ho	Tf 25	kalkhaltige	*Feuchtschwarzerde*	Eutric Calcaric Endocalcic Chernic	**Gleysol**	(episitlic, amphiloamic, aric, humic, pachic)
Ho	Tf 26	anmoorige, kalkhaltige	*Feuchtschwarzerde*	Eutric Chernic	**Gleysol**	(epiclayic, amphiloamic, aric, humic, pachic)
Ho	Tf 27	kolluvial überlagerte, anmoorige, kalkhaltige	*Feuchtschwarzerde*	Eutric Chernic	**Gleysol**	(pantoloamic, aric, colluvic, humic, pachic)
Ho	Tf 29	kolluvial überlagerte, anmoorige, kalkhaltige	*Feuchtschwarzerde*	Eutric Chernic	**Gleysol**	(amphiloamic, amphiclayic, aric, colluvic, humic, pachic)
Gr	Tf 27a	anmoorige, kalkhaltige	*Feuchtschwarzerde*	Eutric Endocalcic Chernic	**Gleysol**	(epiloamic, endosiltic, humic, pachic, petrogleyic)
Gr	Tf 27b	anmoorige, kalkhaltige	*Feuchtschwarzerde*	Eutric Calcaric Chernic	**Gleysol**	(amphisiltic, humic, pachic)
Gr	Tf 27c	anmoorige, kalkhaltige	*Feuchtschwarzerde*	Eutric Calcaric Chernic	**Gleysol**	(pantoloamic, humic, pachic)
Gr	Tf 29a	anmoorige, kalkhaltige	*Feuchtschwarzerde*	Eutric Calcaric Mollic	**Gleysol**	(amphiloamic, humic, pachic)

[16] Due to data constraints, it was not possible to differentiate between the five soils featuring an argic horizon. If a soil was about to key out from a Retisol onwards, Luvisol was chosen as default option.

Gr	Tf 29b	anmoorige, kalkhaltige	*Feuchtschwarzerde*	Eutric Calcaric Chernic	**Gleysol**	(amphiclayic, humic, pachic, petrogleyic)
Gr	Tf 23b	kalkhaltige	*Feuchtschwarzerde*	Endocalcaric	**Luvisol**	(amphisiltic, endoclayic, differentic, humic)
He	Tf 24	kalkhaltige	*Feuchtschwarzerde*	Calcaric Gleyic Chernic	**Phaeozem**	(amphiloamic, endosiltic, aric, pachic)
Ho	Tf 28	anmoorige, kalkhaltige	*Feuchtschwarzerde*	Gleyic Chernic	**Phaeozem**	(pantoclayic, aric, pachic)
Gr	Tf 30	anmoorige, kalkhaltige	*Feuchtschwarzerde (mit Verkittungen im Unterboden)*	Calcaric Endogleyic Chernic	**Phaeozem**	(pantoloamic, endodensic)
He	Tf 11	kalkhaltiger	*Grauer Auboden*	Eutric Calcaric Skeletic Fluvic Relictigleyic	**Cambisol**	(episiltic, epiloamic, aric, humic)
He	Tf 15	vergleyter, kalkhaltiger	*Grauer Auboden*	Eutric Calcaric Fluvic Chernic	**Gleysol**	(pantosiltic, humic)
He	Tf 16	vergleyter, kalkhaltiger	*Grauer Auboden*	Eutric Calcaric Fluvic Epicalcic Mollic	**Gleysol**	(epiluvic, amphisiltic, amphiloamic, humic)
Ho	Tf 3	vergleyter, kalkhaltiger	*Grauer Auboden*	Eutric Mollic	**Gleysol**	(pantoloamic)
Ho	Tf 1	kalkhaltiger	*Grauer Auboden*	Protocalcic	**Luvisol**	(amphisiltic, amphiloamic, aric, differentic, humic)
He	Tf 12	kalkhaltiger	*Grauer Auboden*	Calcaric Fluvic Relictigleyic	**Phaeozem**	(amphiloamic, aric)
He	Tf 13	kalkhaltiger	*Grauer Auboden*	Calcaric Cambic Fluvic Chernic	**Phaeozem**	(amphisiltic, amphiloamic, aric)
He	Tf 14	schwach vergleyter, kalkhaltiger	*Grauer Auboden*	Calcaric Fluvic Relictigleyic Chernic	**Phaeozem**	(pantosiltic, aric)
Ho	Tf 2	vergleyter, kalkhaltiger	*Grauer Auboden*	Eutric Calcaric Gleyic	**Regosol**	(pantosiltic, aric)
Ho	Tf 44	kalkhaltiges	*Kolluvium (Tschernosem)*	Eutric Calcaric	**Cambisol**	(pantosiltic, aric, colluvic)
Ho	Tf 46	kalkhaltiges	*Kolluvium (Tschernosem)*	Eutric calcaric Bathygleyic	**Cambisol**	(pantoloamic, aric, colluvic, ochric)
Ho	Tf 43	kalkhaltiges	*Kolluvium (Tschernosem)*	Endocalcaric Protocalcic	**Luvisol**	(episiltic, amphiloamic, aric, colluvic, differentic)
He	Tf 46	kalkhaltiges	*Kolluvium (Braunerde)*	Calcaric Gleyic Chernic	**Phaeozem**	(pantosiltic, aric) over Calcaric Phaeozem (pantoloamic)
He	Tf 45	kalkhaltiges	*Kolluvium (Tschernosem)*	Eutric Calcaric Colluvic	**Regosol**	(pantosiltic, aric, humic)
Ho	Tf 45	kalkhaltiges	*Kolluvium (Tschernosem)*	Eutric Calcaric Colluvic Endogleyic	**Regosol**	(pantoloamic, aric)
He	Tf 41	kalkhaltiger	*Kulturrohboden*	Haplic	**Calcisol**	(pantoloamic, aric, hypocalcic, gleyic)
Ho	Tf 37	kalkhaltiger	*Kulturrohboden*	Haplic	**Calcisol**	(pantosiltic, aric, hypocalcic)
Ho	Tf 38	kalkhaltiger	*Kulturrohboden*	Endoluvic	**Calcisol**	(amphiloamic, endoclayic, aric, hypocalcic, stagnic)
Gr	Tf 31	kalkhaltiger	*Kulturrohboden*	Haplic	**Calcisol**	(amphisiltic, amphistagnic)
He	Tf 38	kalkhaltiger	*Kulturrohboden*	Eutric	**Cambisol**	(pantoloamic, aric, protocalcic)
He	Tf 39	kalkhaltiger	*Kulturrohboden*	Eutric Calcaric	**Cambisol**	(pantosiltic, aric, protocalcic, ochric)
He	Tf 40	kalkhaltiger	*Kulturrohboden*	Eutric Gleyic	**Cambisol**	(pantosiltic, aric manganiferric, fractic)
He	Tf 42	kalkfreier	*Kulturrohboden*	Eutric Gleyic	**Cambisol**	(pantoloamic, aric)
Ho	Tf 39	kalkhaltiger	*Kulturrohboden*	Eutric Calcaric	**Cambisol**	(pantosiltic, aric, ochric)
Ho	Tf 40	kalkhaltiger	*Kulturrohboden*	Endocalcaric Stagnic	**Luvisol**	(amphiclayic, aric, differentic)
He	Tf 21		*Pararendsina*	Eutric Calcaric Skeletic	**Cambisol**	(episiltic, aric)
Gr	Tf 21		*Paratschernosem*	Eutric Endoskeletic	**Cambisol**	(amphiloamic, endoarenic)
Gr	Tf 37		*Paratschernosem*	Akroskeletic	**Phaeozem**	(epiloamic)
Gr	Tf 38		*Paratschernosem*	Skeletic	**Phaeozem**	(epiloamic, epidensic)
Gr	Tf 39		*Paratschernosem*	Haplic	**Phaeozem**	(amphiloamic, pachic)
Gr	Tf 22		*Paratschernosem*	Eutric	**Regosol**	(amphiarenic)
Ho	Tf 6		*Rendsina*	Luvic Hypercalcic	**Kastanozem**	(amphiloamic, endoclayic, aric, pachic)

Ho	Tf 7		*Rendsina*	Calcaric Leptic Epialcic Rendzic	**Phaeozem**	(pantoloamic, aric)
Ho	Tf 41	kalkhaltiger	*Rigolboden*	Haplic	**Calcisol**	(pantoloamic, aric)
He	Tf 43	kalkhaltiger	*Rigolboden*	Eutric Calcaric Leptic	**Cambisol**	(epiloamic, amphisiltic, aric, humic)
He	Tf 44	kalkhaltiger	*Rigolboden*	Calcaric Chernic	**Phaeozem**	(pantosiltic, aric)
He	Tf 10		*Tschernosem*	Haplic	**Calcisol**	(amphisiltic, aric, hypercalcic, fluvic, relictigleyic)
Ho	Tf 13		*Tschernosem*	Haplic	**Calcisol**	(amphiloamic, endoarenic, aric, endorelictigleyic)
Ho	Tf 18		*Tschernosem*	Haplic	**Calcisol**	(pantoloamic, aric, hypocalcic, gleyic)
Gr	Tf 34		*Tschernosem*	Cambic	**Calcisol**	(amphiloamic, hypocalcic)
He	Tf 9		*Tschernosem*	Eutric Skeletic Fluvic	**Cambisol**	(episiltic, amphiarenic, aric, humic)
He	Tf 17		*Tschernosem*	Eutric Calcaric Skeletic Fluvic Gleyic	**Cambisol**	(episiltic, epiloamic, aric)
Ho	Tf 12		*Tschernosem*	Eutric Calcaric	**Cambisol**	(amphiloamic, endoarenic, aric)
Gr	Tf 14		*Tschernosem*	Eutric Endoskeletic	**Cambisol**	(episiltic, epiprotocalcic, humic)
Gr	Tf 15		*Tschernosem*	Eutric	**Cambisol**	(amphiloamic, endoprotocalcic, humic)
Gr	Tf 16		*Tschernosem*	Eutric Calcaric	**Cambisol**	(epiloamic, amphiarenic)
Gr	Tf 17a		*Tschernosem*	Eutric	**Cambisol**	(amphisiltic, endoarenic)
Gr	Tf 17b		*Tschernosem*	Eutric	**Cambisol**	(amphiloamic, endoarenic, endoprotocalcic)
Gr	Tf 18		*Tschernosem*	Eutric Calcaric	**Cambisol**	(pantoloamic, bathyarenic)
Ho	Tf 15		*Tschernosem*	Relictigleyic Amphicalcic	**Chernozem**	(pantoloamic, aric)
Ho	Tf 17		*Tschernosem*	Relictiglyic Endocalcic	**Chernozem**	(amphiclayic, endoloamic, aric, pachic)
Ho	Tf 20	kolluvial überlagerter, entkalkter	*Tschernosem*	Endoprotocalcic	**Chernozem**	(pantoloamic, aric, colluvic, pachic)
Ho	Tf 21	entkalkter	*Tschernosem*	Relictigleyic Endocalcic	**Chernozem**	(pantoloamic, aric, pachic)
Ho	Tf 22	kolluvial überlagerter, entkalkter	*Tschernosem*	Gleyic Endohypocalcic	**Chernozem**	(amphiclayic, endoloamic, aric, pachic)
Ho	Tf 23	entkalkter	*Tschernosem*	Relictigleyic Endohypocalcic	**Chernozem**	(pantoloamic, aric, pachic)
Gr	Tf 19		*Tschernosem*	Endocalcic	**Chernozem**	(pantosiltic, pachic)
Ho	Tf 8		*Tschernosem*	Endocalcic	**Kastanozem**	(pantosiltic, aric, cambic)
Ho	Tf 9		*Tschernosem*	Calcic	**Kastanozem**	(pantosiltic, aric)
Ho	Tf 11		*Tschernosem*	Endocalcic	**Kastanozem**	(pantosiltic, aric, pachic)
Ho	Tf 19	entkalkter	*Tschernosem*	Endohypocalcic	**Kastanozem**	(pantoloamic, aric)
He	Tf 18		*Tschernosem*	Calcaric Chernic	**Phaeozem**	(episiltic, amphiloamic, aric, pachic)
He	Tf 22	kalkhaltiger, brauner	*Tschernosem*	Calcaric Chernic	**Phaeozem**	(episiltic, endoloamic, aric, pachic, siltinovic, transportic)
He	Tf 23	entkalkter, brauner	*Tschernosem*	Chernic	**Phaeozem**	(amphiloamic, endosiltic, aric, pachic)
Ho	Tf 10	kolluvial geprägter	*Tschernosem*	Chernic	**Phaeozem**	(pantoloamic, aric, pachic)
Ho	Tf 14		*Tschernosem*	Chernic	**Phaeozem**	(pantoloamic, aric, pachic)
Ho	Tf 24	kolluvial überlagerter	*Tschernosem*	Relictigleyic Chernic	**Phaeozem**	(pantoclayic, aric, colluvic, pachic)
Gr	Tf13		*Tschernosem*	Leptic Chernic	**Phaeozem**	(epiloamic)
Gr	Tf 32		*Tschernosem*	Leptic	**Phaeozem**	(epiloamic)
Gr	Tf 33		*Tschernosem*	Calcaric Cambic	**Phaeozem**	(amphiloamic)

Gr	Tf 35		*Tschernosem*	Calcaric Cambic Chernic	**Phaeozem**	(episiltic)
Gr	Tf 36	entkalkter	*Tschernosem*	Cambic	**Phaeozem**	(amphiloamic)
Ho	Tf 16		*Tschernosem*	Eutric Calcaric Skeletic	**Regosol**	(epiloamic, aric)
Gr	Tf 20		*Tschernosem*	Eutric Calcaric	**Regosol**	(pantoloamic)

Table 3 - Results of the classification process. Sample **area** is coded (He=Herzogenburg [A], Ho=Hollabrunn [B], Gr=Großenzersdorf [C]). **No.** indicates number of soil profile description in the soil survey book. Tf=Teilform. Diagnostic items of the respective soils are listed in Appendix I.

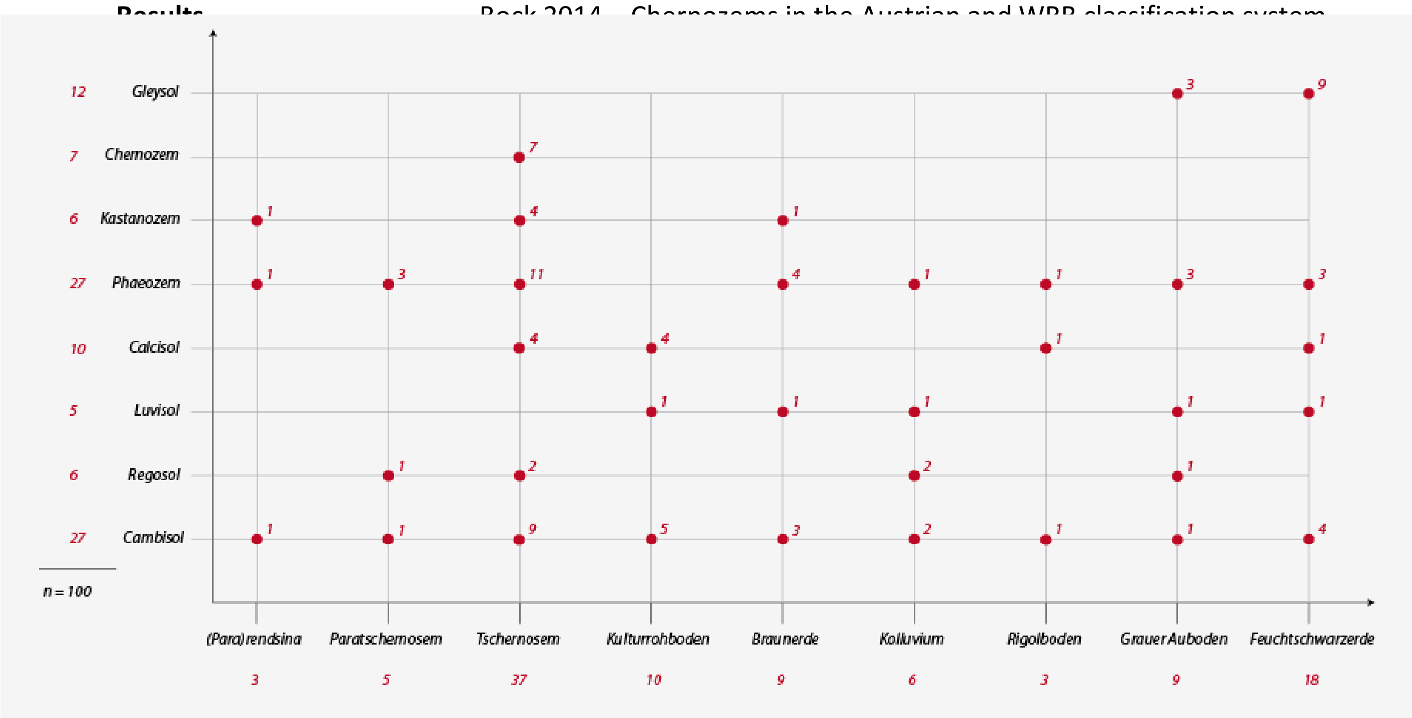

Figure 14 - Austrian classification (abscissa) drawn against WRB reference soil groups (ordinate).

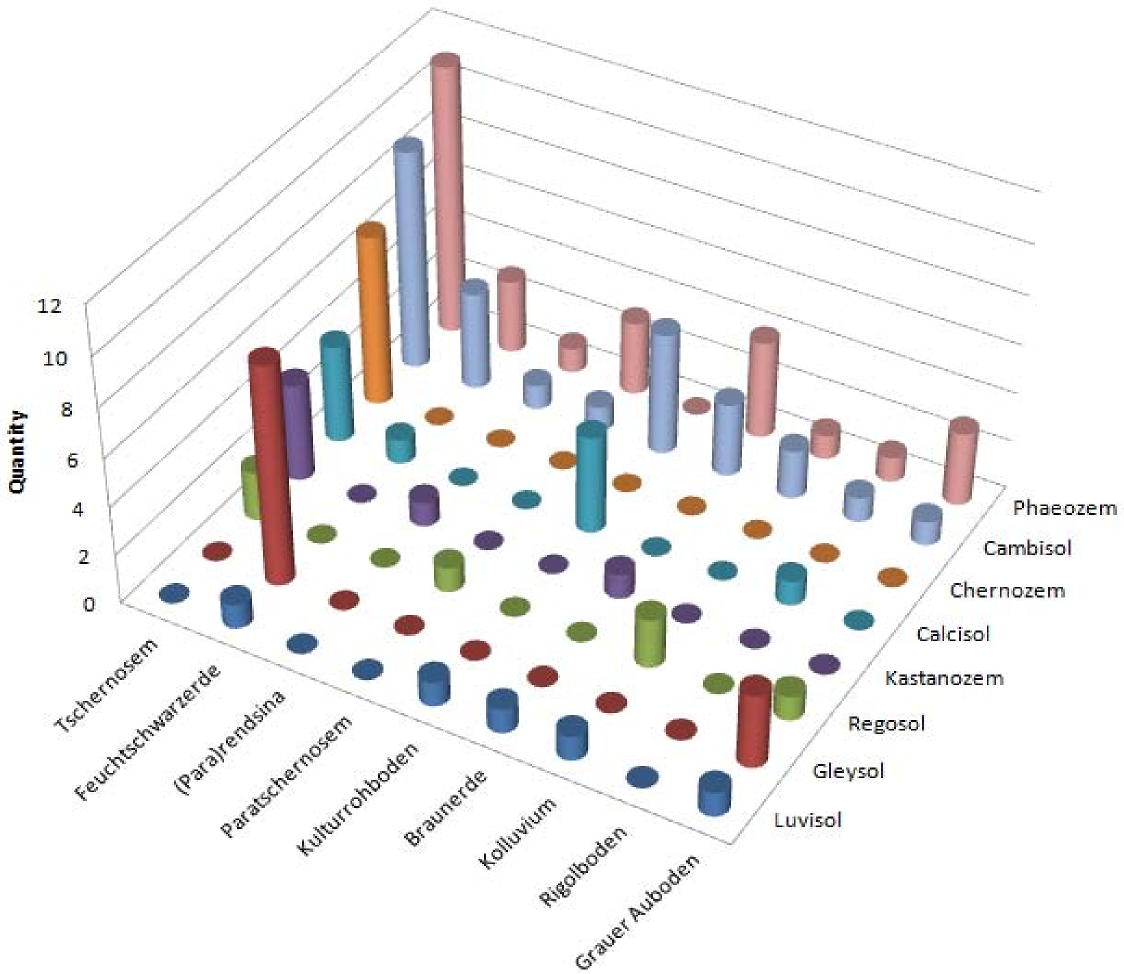

Figure 15 – Different representation which shows the abundance of samples in the respective soil classes.

The soil types chosen for the study represent the types frequently occuring in the north-east of Austria. The text explains the Austrian soil type in short and lists the frequent WRB results in bold letters.

Tschernosem

The results show, that a Tschernosem is in most cases either a **Phaeozem**, **Chernozem**, or with lighter colors, a Cambisol or Calcisol. The current classification also results in Kastanozems, but this has to be questioned (see Discussion). This distribution is caused by the existence of color-limits in the WRB which have no corresponding counterpart in the Austrian system. Therefore, lighter-colored Tschernoseme (Munsell value of ≥4) do not qualify for a mollic horizon and result in lower-ranked soils within the RSG-key. Depending on the existence of a calcic horizon, they would key out as Calcisol or Cambisol.

Calcisols represent soils where secondary calcium carbonate accumulation is a dominant feature, **Cambisols**, being on the lower end of the key, are basically a pool for soils which feature profile differentiation, which is not yet developed to a degree, where dominant processes can be identified and therefore no meaningful further classification can be made. This is also true for **Regosols**, which stand for soils which do not show any signs of profile development neither consist of materials that would make a classification possible.

Feuchtschwarzerde

The idea of this soil type is to make a category for humus-rich soils which are still under groundwater influence. If the water influence is dominant, the soil would key out as **Gleysol**, if not, the same applies as being said for Tschernosems. Luvisols, the RSG directly above Cambisols, standing for clay illuviation, did occur within this soil type, but could be results of misclassification of an argic horizon due to lack of data[17].

(Para)rendsina

Both represent soils with shallow A-horizons directly above the parent material. This is carbonate rock in the case of a Rendsina and other carbonate-rich material in the case of a Pararendsina. The sample amount was too low to make any qualified prediction[18].It may be assumed that the Pararendsinas would probably result in the same RSGs as Tschernoseme would do.

Paratschernosem

Paratschernosems are considered as Tschernosem-like soils, yet they do not have calcium carbonate present, so they basically are calcium carbonate-free Tschernosems. They cannot be classified as

[17] Argic horizons represent clay-enriched subsurface horizons due to clay illuviation. The diagnosis can be based solely on differences in the clay amount (differentic qualifier). However, differences in the clay content caused by differences of the parent material (such as alluvial deposits) do not count as argic horizons. Determining whether the difference was caused by illuviation or not, was not possible with the given data.

[18] Additionally, the classification made by the Soil Survey in these cases seems to be inaccurate and therefore contributing to another source of error.

Chernozems or Kastanozems, but may be **Phaeozems**, if the base saturation is still high enough. Other options are the low-ranked soils like **Cambisols** or **Regosols**.

Kulturrohboden

These soils describe eroded A-C soils, therefore depicting beheaded Tschernosems. Although the topsoil is darker than the underlying layers, it is insufficient to qualify for mollic horizons and key out as Calcisols, if they show secondary carbonates or as **Cambisols** or **Regosols**. Also a Luvisol occurred, which is also possible but probably not the regular case.

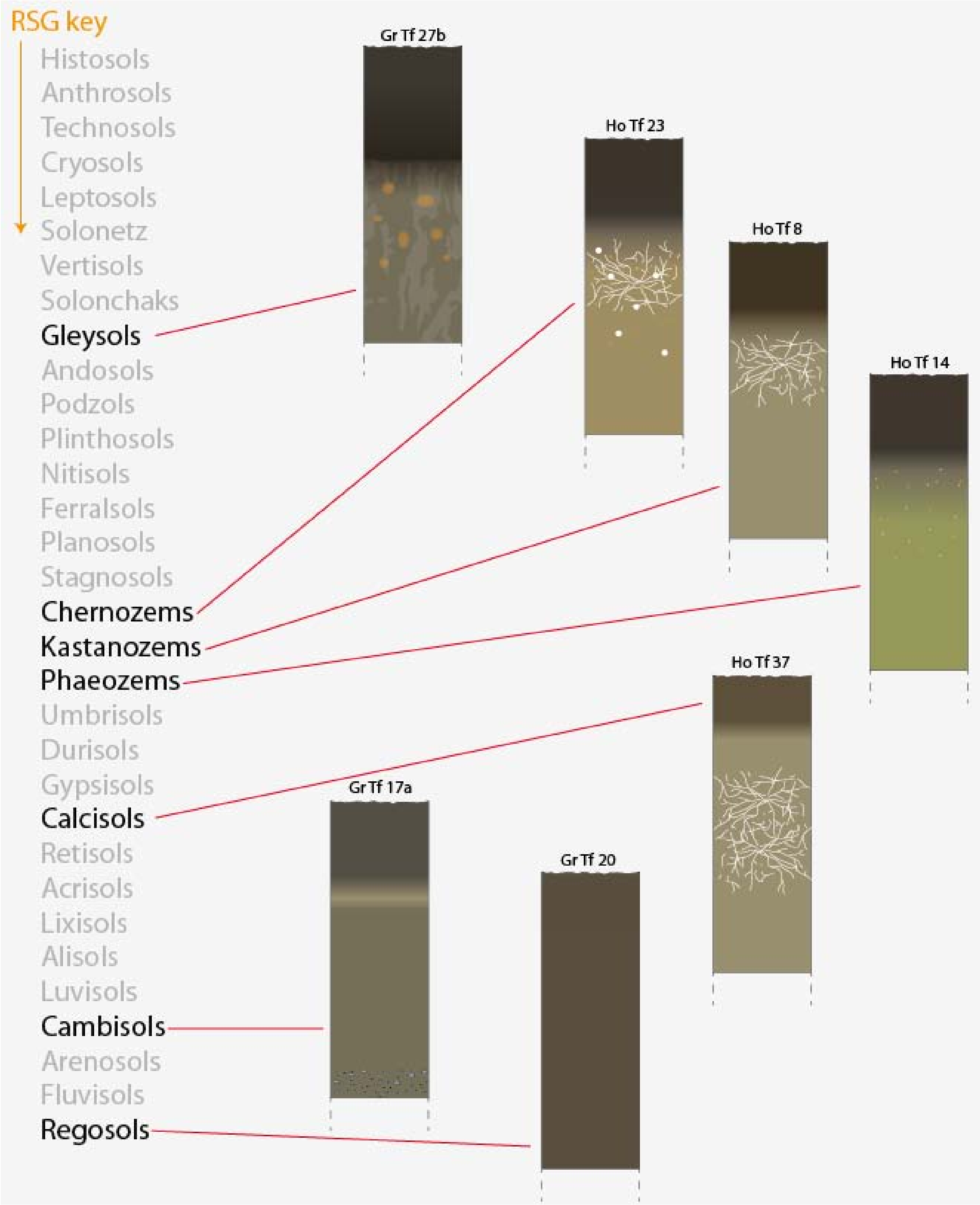

Figure 16 – RSG key and example soils which keyed out in the respective groups. The soils can be found with their actual WRB soil name in Table 3 and with their diagnostic items in Appendix I. (Own work)

Braunerde

The Braunerde, often mentioned as the Austrian representation of the **Cambisol**, is a soil which has brown color due to iron oxides (mainly goethite). Despite the regular claim, Braunerden do not necessarily key out as Cambisols, and as a proof, at least the same number of profiles keyed out as **Phaeozem**. This is not surprising, because as mentioned for the Tschernosem, the Austrian system does not have advanced color limits and like Tschernosems with a value and chroma of 4/3, also Braunerden with 3/3 respectively occur and supposing the other parameters, would result in mollic horizons and therefore being Phaeozems due to the carbonate-rich parent material. Of course, depending on other parameters, classification can also result in other soils and even one Kastanozem was encountered.

Kolluvium

Describes soils which have new material deposited on their top. The WRB qualifiers colluvic, transportic or novic might apply here. According to the concept these soils accumulate the material eroded from a Kulturrohboden. Thus, all the RSGs which can result for Tschernosem can also be applied here. If the new material is not thick enough (50cm)[19], the original soil is classified with preference, which can result in a Colluvic Regosol.

Rigolboden

Such soils are rearranged soils, meaning rearranged by deep ploughing or ripping, which can be visible in the soil profile. Depending on the original soil and the disturbance, the soils would key out appropriately.

Grauer Auboden

This soil type represents flood plain soils which are of grey color. For classification purposes, they can be treated like Feuchtschwarzerden: If water influence and gleyic properties are dominant, they would key out as **Gleysols**, if not, **Phaeozems** could occur as well as lower ranked soils.

[19] The exact rules of classifying buried soils are a bit more complicated but not necessary for this explanation.

V. Discussion

Considering the climate catena, one can expect that most of the soils in Austria which are classified in Austria as Tschernoseme would either key out as Phaeozems or as Chernozems[20]. This expectation turned out to be true, although some soils keyed out as Kastanozems. This is an astonishing result as it does not back the concept of zonal soils. This concept means that Kastanozems should not occur in Austria due to too high precipitation.

Due to the unexpected classification results, the data was checked again and two sources of error were identified. Although the data were recorded by soil scientists a wrong determination of soil colors cannot be ruled out. This means that some Kastanozems would instantly turn into Chernozems if the chroma was one value lower.

The surveys were conducted up to 40 years ago and the recording protocols might not fulfil today's standards anymore. This is especially problematic in the case of secondary carbonates, because for WRB classification information is necessary whether the accumulations are permanent or disappear upon moistening (cf. IUSS 2014, 64). Soil survey data lack this information, in most of the cases only "Pseudomycelium" is added to the horizon description without any further details. This means, that some of the soils classified as Kastanozems/Chernozems might be (Chernic) Phaeozems.

However, the study reveals at least a potential gap within WRB where misclassification can happen due to different concepts lying behind the idea of a soil type and its diagnostic criteria.

Taking results and the soil formation theory into account, it is evident, that there is either something wrong with the concept of zonal soils or with its application in the WRB system. It might turn out that the zonal concept does not work so well for Austrian territory, because local factors exert stronger pressures on the soil than climatic ones[21]. On the other hand, the WRB is also not so clear on these soils. Given, that the WRB uses both the denotation of Russian soil science and also gives hints to the underlying zonal concept in Annex 1 (cf. IUSS 2014, 135ff) the question arises, why a morphological system like the WRB uses such concepts. If the WRB wants to incorporate such concepts, based on the present data, this attempt must be marked as unsuccessful. The reason is that the zonal concept is not reflected well by WRB criteria. To illustrate the problem, we will look in the following at the concept of the respective soil and the reflection in WRB.

[20] Low-ranked RSGs (Luvisols etc.) always have to be expected and are therefore not mentioned.

[21] "Soil formation is not easily explained and there is only close correlation between vegetation and soil. Vegetation is so effective in controlling the microclimate and type of humus that it overrides other factors" (Eyre 1968, 120)

TYPICAL SOILS IN LITERATURE

Typical Chernozem

Chernozems are defined having a humus-rich topsoil with a depth to 50-80 cm, rarely up to 2m (Fiedler 2001, 306). Similarily, Scheffer and Schachtschabel (2010, 319) gives a top soil thickness of at least 40 cm. The first 20-40 cm are decalcified (Stahr et al. 2012, 206). Precipitation is 350 – 600 mm, potential evapotranspiration is ≥600 mm (ISSS 1998, 61). Furthermore, calcium carbonate concentrations are found in deeper layers, occurring as pseudomycelia or as concretions (Fiedler 2001, 306; Stahr et al. 2012, 206).

Typical Kastanozem

Fiedler (2001, 308) describes Kastanozems as calcium carbonate or gypsum enriched soils which are formed in a warm and dry climate under steppe. They receive about 370 mm of precipitation. Similarily, in Krupenikov (2011, 78) these soils are described as having a thinner mollic horizon (than Chernozems) not so rich in humus and a more strongly developed lime-rich layer. According to Stahr et al. (2012, 207), decalcification has occured, if at all, only to the first few centimetres. The mollic horizon is only about 40 cm thick.

In the Introduction to the WRB (ISSS 1998, 93) Kastanozems are also described in the same way: Having mollic horizons less in depth and lighter in color than Chernozems.

Typical Phaeozem

Phaeozems are humus-rich, decalcified soils which form the typical soils in wintercold area Forest-steppe with precipitation of 500-700mm (Scheffer and Schachtschabel 2010, 375). Paralell to the decalcification, clay minerals were transported down, although this cannot be seen in the profile, because bioturbation mixed also organic matter deeper into the solum, resulting in black Bt-horizons (Stahr et al. 2012, 206). Uncoated silt and sand grains could be present and calcium carbonate is absent from the first meter of the soil, although base saturation is still high (FAO 2001a).

SOILS IN WRB

The WRB key lists these three soils and the diagnostic features are as following:

Chernozem: Dark colored topsoil (Value ≤3, Chroma ≤2) with secondary carbonates. High base saturation.

Kastanozem: Not so dark colored topsoil (Value ≤3, Chroma ≤3) with secondary carbonates. High base saturation.

Phaeozem: Not so dark colored topsoil[22]. High base saturation.

[22] Although the topsoil could have a color like that required for Chernozems. This would be denoted by the *Chernic* qualifier.

So if we look at the concept of zonal soils, where is the problem? The problem is that the limits created by WRB do not reflect the climatic conditions properly. It can easily be seen, that literature describes Kastanozems as soils with lighter colors with respect to Chernozems (this is reflected by diagnostic criteria) and states, that Kastanozems have shallower A horizons than Chernozems, often the depth of 40cm is mentioned (this is not displayed in WRB).

ZONAL CONCEPT AND WRB

This gap between WRB and real world arises because the limits used for differentiation in literature are not used as diagnostic properties. In the Chernozem-Kastanozem-Phaeozem-catena, Chernozems are the most exclusive group due to their comprehensive diagnostic limits. The remaining soils are divided in Kastanozems and Phaeozems, using the occurrence of a calcic horizon as the only matter of differentiation. Considering the climatic catena (Figure 5) this is a well-intentioned approach, because the catena can be expressed as a function of calcium carbonate in the surface horizon. However, this approach does not take the thickness of a mollic horizon into account, which also reflects the climatic conditions. With the given system, a soil with a mollic horizon, 100cm thick and a calcic horizon at 150cm would key out as Kastanozem (173 Tf31 in Appendix II). This can happen because neither the thickness of the mollic horizon nor the depth of the calcic horizon do have influence on the classification result[23].

To elucidate the extent of this potential misclassification, all available soil survey data of Lower Austria has been searched for soils which, with high probability, will key out as Kastanozems. The results are given in Table 4.

[23] Only the relative depth of both horizons is reflected by demanding the starting depth of the calcic horizon being must be below the lower limit of the mollic horizon (cf IUSS 2014, 95f). This causes additional problems discussed below.

No.	Austrian Soil Taxonomy		WRB 2014			Area
n=37	Subtyp	Bodentyp	Principal qualifier	RSG	Supplementary qualifier	(ha)
145	Lockersediment	*Braunerde*	Amphiprotocalcic	**Kastanozem**	(epiloamic, endosiltic, aric)	285
146	entkalkte Lockersediment	*Braunerde*	Endoluvic Endogleyic Endohypocalcic	**Kastanozem**	(episiltic, amphiloamic, aric)	30
148	entkalkte Lockersediment	*Braunerde*	Amphiluvic Endoprotocalcic	**Kastanozem**	(amphiloamic, endosiltic, aric, manganiferric)	1170
149		*Braunlehm*	Amphiluvic amphiprotocalcic	**Kastanozem**	(epiloamic, amphiclayic, aric, manganiferric)	30
151	kalkhaltige Lockersediment	*Braunerde*	Endohypocalcic	**Kastanozem**	(epiloamic, endosiltic, aric)	36
153		*Tschernosem*	Amphihypocalcic	**Kastanozem**	(amphiloamic, aric)	386
154		*Tschernosem*	Amphihypocalcic	**Kastanozem**	(amphisiltic, endoloamic, aric)	300
155		*Tschernosem*	Amphicalcic	**Kastanozem**	(amphisiltic, aric)	305
156		*Tschernosem*	Protocalcic	**Kastanozem**	(amphiloamic, endoarenic, aric, pachic)	1113
157		*Tschernosem*	Endocalcic	**Kastanozem**	(amphisiltic, epiloamic, aric)	1094
158		*Tschernosem*	Epihypocalcic	**Kastanozem**	(pantosiltic, aric)	3580
159	mittelgründiger, schwach verbraunter	*Tschernosem*	Skeletic Leptic Epicalcic	**Kastanozem**	(epiloamic, densic)	130
161		*Tschernosem*	Endocalcic	**Kastanozem**	(pantosiltic, aric, pachic)	2900
162		*Tschernosem*	Skeletic Endoprotocalcic	**Kastanozem**	(epiloamic, endoarenic, aric, pachic)	20
164		*Tschernosem*	Epicalcic	**Kastanozem**	(episiltic, amphiloamic, aric)	445
166		*Tschernosem*	Amphihypocalcic	**Kastanozem**	(pantosiltic)	1400
167	kalkiger	*Tschernosem*	Amphihypocalcic	**Kastanozem**	(amphisiltic, endoclayic, aric, endostagnic)	115
168		*Tschernosem*	Amphihypercalcic	**Kastanozem**	(epiloamic, amphisiltic, aric, amphistagnic)	135
169		*Tschernosem*	Endoprotocalcic	**Kastanozem**	(pantosiltic, aric, pachic)	125
172	kalkhaltige	*Feuchtschwarzerde*	Endogleyic Amphicalcic	**Kastanozem**	(amphisiltic, endoloamic, aric, pachic)	70
173		*Tschernosem*	Bathyprotocalcic	**Kastanozem**	(pantosiltic, aric, pachic, bathygleyic)	35
174	kalkhaltige Lockersediment	*Braunerde*	Endoprotocalcic	**Kastanozem**	(pantoloamic, aric, pachic)	15
175	kalkhaltige Lockersediment	*Braunerde*	Endoprotocalcic	**Kastanozem**	(pantosiltic, aric)	30
177	vergleyter, kalkhaltiger	*Grauer Auboden*	Endocalcic	**Kastanozem**	(pantoloamic, aric, cambic)	1210
182		*Tschernosem*	Endocalcic	**Kastanozem**	(pantosiltic, aric, endovermic)	1580
183		*Tschernosem*	Amphihypocalcic	**Kastanozem**	(amphisiltic, amphiloamic, aric)	2155
184			Amphiprotocalcic	**Kastanozem**	(amphioamic, aric)	615
186		*Braunlehm*	Endoprotocalcic	**Kastanozem**	(amphiloamic, endoarenic, aric)	19
187		*Tschernosem*	Endocalcic	**Kastanozem**	(pantosiltic, aric, pachic)	110
188	kalkarme bis schwach kalkhaltige Lockersediment	*Braunerde*	Endoprotocalcic	**Kastanozem**	(pantoloamic, aric)	81
189	schwach vergleyter, kalkhaltige Lockersediment	*Braunerde*	Endoprotocalcic	**Kastanozem**	(amphiloamic, amphisiltic, aric, cambic, endogleyic)	131

192		*Parabraunerde*	Amphiluvic Endohypocalcic	**Kastanozem**	(pantosiltic, aric, amphistagnic, endovermic)	649
194	kalkhaltiges	*Anmoor*	Endogleyic Amphihypocalcic	**Kastanozem**	(amphiloamic, endoarenic)	34
196		*Tschernosem*	Endocalcic	**Kastanozem**	(pantosiltic, pachic, bathystagnic)	1998
197	Lockersediment	*Braunerde*	Endocalcic	**Kastanozem**	(epiloamic, endosiltic, aric)	61
198	kalkhaltiger	*Kulturrohboden*	Amphicalcic	**Kastanozem**	(pantoloamic, aric, amphistagnic)	88
199		*Tschernosem*	Endogleyic Bathyprotocalcic	**Kastanozem**	(pantoloamic, pachic)	298
					∑	**22778**

Table 4 - Results of the classification process of suspected Kastanozems. **No.** Indicates the internally reference number for the profile (of no use here). Information on diagnostic horizons, properties etc. of the soils shown here is provided in Appendix II.

Results of this second test show, that mostly Tschernoseme and Braunerden key out as "Kastanozems", although some soils which would not be expected here, are also shown. The Anmoor (half-bog) and the Feuchtschwarzerde should key out as Histosol or Gleysol respectively, but did not meet the criteria for those and therefore keyed out as Kastanozems as well.

Beside some minor problems like the assignment of manganiferric qualifiers a more serious problem was the classification of mollic horizons which were so deep that the soil survey records did not show horizons other than A. This happens frequently in the class of Kolluvium (colluvic soils), especially when the material is very homogenous and therefore no changes in color or organic carbon are present which are sufficient for criterium 4a & b of the mollic horizon. Those soils therefore mostly key out as Cambisols, with calcic horizons present also Calcisol could occur.

Looking at the climatic considerations and the position of the Kastanozem in the zonal concept as the driest part of those three soils, this restriction does not work out well.

By now, we can conclude, that the Kastanozem is not well reflected in WRB. Both the concepts and ideas which form a Kastanozem are different to what is actually implemented in WRB. There is no reflection of shallower A horizons with respect to chernozems and there are also problems with calcic horizons. Additionally, classification results show that there is some need for overhauling some diagnostic criteria, to prevent soils with mollic horizons up to one meter being classified as Kastanozems.

Russian classification

To make even further clear, that there is an issue; we will now look how Kastanozems are displayed in one of the countries where they occur mainly – in Russia. We will therefore look at the Russian classification system and see, which features make up a Kastanozem.

USSR Soil classification (1977):
A – humus horizon, thickness 15-30 cm, chestnut color;

AB1 – humus horizon with lower humus content, often a transitional horizon of grey-brown color, thickness 10 cm;

AB2 – transitional horizon, heterogeneous in color with darker humus spots on the greyish background, has carbonates (reacts with HCl), 10 cm thick;

Bca – yellow-brownish in color, well structured (prismatic structure), saturated with carbonates, which can be seen with the naked eye, thickness 50-100 cm;

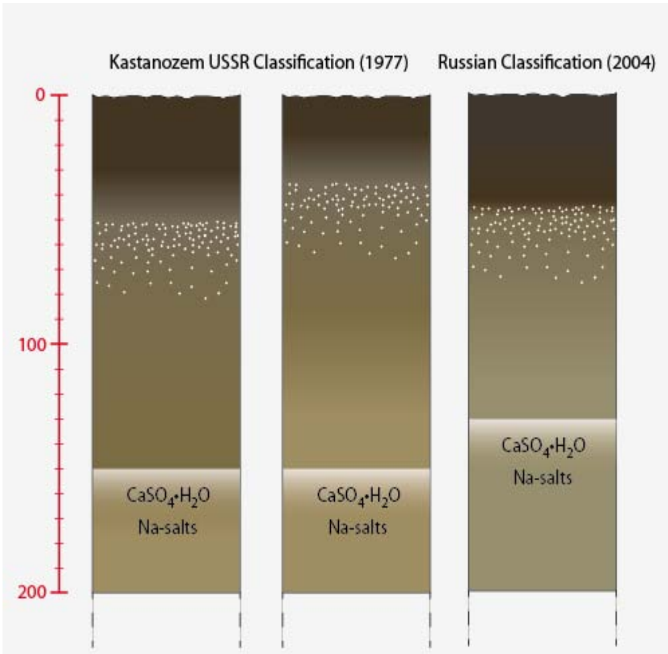

Figure 17 – Kastanozems in Russian soil classification 1977 and 2004. (Own work)

Bcs – horizon pale in color with gypsum (CaSO4) and salts(NaCl);

C – parent material.

Russian Soil Classification (2004):
A – humus horizon, thickness 15cm, humus content 2-3.5%

Bm – metamorphic horizon, chestnut color, humus content 1.5-1.8% (range from 1.3 to 2%), prismatic structure; thickness 30cm. This horizon was called AB1 in the USSR classification and has a metamorphic origin. This horizon is typical for Kastanozems

Bcat – textural carbonate horizon, saturated with carbonates (at the 45-75 cm depth); gypsum and salts at the depth of 130-150 cm.

Cca – parent material with carbonates

CONCLUSION REGARDING THE SITUATION IN AUSTRIA

The results show, that there are two major issues to address: On the one hand there is a potential problem with the WRB classification which puts soils into the Kastanozem reference group which are very far away from the zonal concept considering their genesis. Soils with mollic horizons extending 60 cm and more are not considered as Kastanozems anymore. Tightening up the WRB criteria on this would probably contribute to partitioning of steppe soils which is more congruent with the underlying concepts. This would probably involve restricting the depth of a mollic horizon for a Kastanozem and making some regulation regarding the depth of the calcic horizon. Maybe Kastanozems need to be moved previous to Chernozems, reflecting the climate catena also in the RSG key (dry to wet).

On the other hand there are definitely soils in Austria which still will key out as Kastanozems because their mollic horizons are shallow enough and the calcic horizon is not too deep. A possible explanation for this is, that the topsoil was removed by erosion and the remaining "trunk soil" suddenly fulfils the criteria of a Kastanozem. The used data is in most of the cases around 40 years old and yet some of the soils are classified as Kastanozems. If this "misclassification" is based on erosion, than it would be very interesting to classifiy the samples again, 40 years later and see, if more soils translate to Kastanozems.

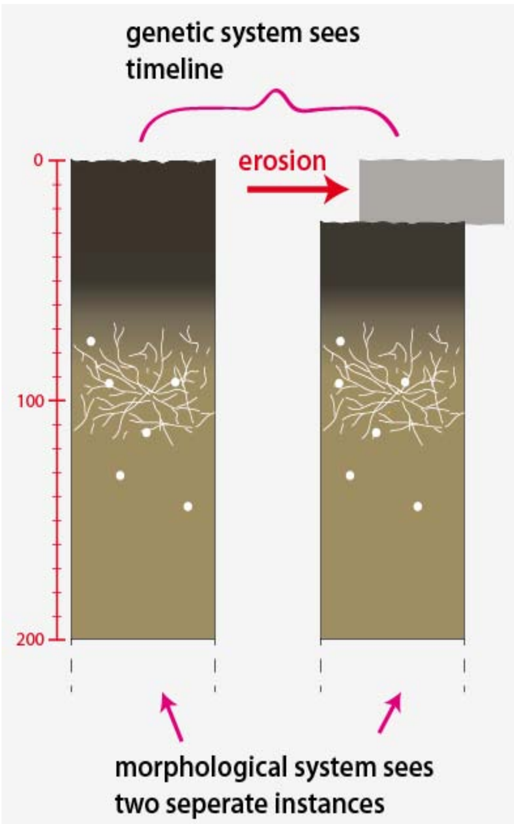

Figure 18 – A possible source of misclassification of morphological systems is the failure to recognize changes over time. Genetic systems usually have fewer problems with this. (Own work)

Therefore, the classification result may also be seen as a highly up-to-date result, because if even the soil classification which is based on natural processes, has problems with proper aligning of concept and reality, this might indicate, that the human impact on soils can be traced back even into soil classification.

VI. List of illustrations and tables

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VII. Literature

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VIII. Appendices

APPENDIX I

Diagnostic horizons, materials and properties of the soils listed in Table 3 (Results).

Area	No.	Diagnostic items
He	Tf 9	cambic 20-35, fluvic 0-200
He	Tf 10	calcic 50-80, (mollic 25-50), gleyic 0-65, albic 0-25;50-80, calcaric 0-65
He	Tf 12	mollic 0-25, gleyic 0-55, albic 25-85, calcaric 0-85, (cambic 25-85)
He	Tf 11	cambic 25-60, gleyic 0-25, albic 0-25, calcaric 0-60
He	Tf 13	cambic 25-200, mollic 0-25, gleyic 90-200, calcaric 0-200, fluvic 0-200, chernic 0-25
He	Tf 14	cambic 25-200, chernic 0-25, mollic 0-25, gleyic 0-200, albic 25-200, calcaric 0-200, fluvic 0-200
He	Tf 15	cambic 25-50;75-200, chernic 0-25, mollic 0-25, gleyic 0-200, albic 25-200, calcaric 0-200, fluvic 0-200
He	Tf 16	argic 20-35, calcic 20-35, (cambic 0-200), mollic 0-20, gleyic 0-200, albic 20-200, calcaric 0-200, fluvic 0-200
He	Tf 17	cambic 30-45, gleyic 0-30, calcaric 0-45
He	Tf 18	chernic 0-85, mollic 0-85, calcaric 0-85
He	Tf 21	cambic 0-45, albic 0-45, calcaric 0-45
He	Tf 22	cambic 0-30;85-200, chernic 30-85, mollic 30-85, albic 0-30, calcaric 0-200
He	Tf 23	cambic 80-200, chernic 0-25, mollic 0-55, calcaric 80-200
He	Tf 24	cambic 75-200, chernic 0-25, mollic 0-75, gleyic 25-200, calcaric 0-200
He	Tf 25	cambic 25-50, gleyic 0-25, albic 0-25, calcaric 0-50
He	Tf 26	mollic 0-25, cambic 25-50
He	Tf 28	calcic 0-25, mollic 0-25, albic 25-50, calcaric 0-50
He	Tf 32	argic 70-200, cambic 25-70, mollic 0-25, gleyic 0-25;70-200, albic 70-200, calcaric 0-200
He	Tf 38	protocalcic 30-200, albic 30-200, calcaric 0-30, cambic 30-200
He	Tf 39	protocalcic 20-200, cambic 20-200, gleyic 0-20, albic 0-20, calcaric 0-200
He	Tf 40	cambic 0-200, ferric 25-200, gleyic 0-25, albic 0-200, calcaric 25-200
He	Tf 41	ferric 20-200, calcic 20-200, gleyic 20-200, albic 20-200, calcaric 0-20
He	Tf 42	cambic 25-200, gleyic 0-25, albic 0-200
He	Tf 43	cambic 30-60, albic 0-30, calcaric 0-60
He	Tf 44	25-90 cambic, chernic 0-25, mollic 0-25, albic 25-200, calcaric 0-200
He	Tf 45	albic 0-200, calcaric 0-200
He	Tf 46	mollic 0-25, gleyic 0-70, albic 25-70, calcaric 0-200
Ho	Tf 1	argic 30-75, gleyic 160-200, protocalcic 75-160, albic 0-200, calcaric 0-75
Ho	Tf 2	cambic 90-140, ferric 30-140, gleyic 30-90, calcaric 0-200
Ho	Tf 3	cambic 25-200, mollic 0-25, gleyic 0-200, albic 25-200, calcaric 0-80
Ho	Tf 6	argic 65-125, calcic 50-125, mollic 0-50, abrupt text ch at 65, albic 50-125, calcaric 0-65
Ho	Tf 7	calcic 0-25, cambic 40-70, mollic 0-40, gleyic 40-55, albic 40-70, calcaric 0-70
Ho	Tf 8	calcic 60-200, cambic 45-60, mollic 0-45, albic 45-200, calcaric 0-60
Ho	Tf 9	calcic 30-200, mollic 0-30, albic 30-200, calcaric 0-30
Ho	Tf 10	cambic 100-115, chernic 0-80 mollic 0-100, albic 100-200, calcaric 0-30;100-110
Ho	Tf 11	calcic 60-80, mollic 0-60, albic 60-90, calcaric 0-60
Ho	Tf 12	cambic 30-60, gleyic 60-200, albic 60-200, calcaric 0-120
Ho	Tf 13	calcic 30-70, cambic 0-30, gleyic 70-200, albic 0-200, calcaric 0-200
Ho	Tf 14	cambic 50-200, chernic 0-50, mollic 0-50, gleyic 50-65, albic 50-200, calcaric 50-200
Ho	Tf 15	calcic 35-200, chernic 0-35, mollic 0-35, albic 70-200, calcaric 0-35, gleyic 35-200
Ho	Tf 16	calcaric 0-30
Ho	Tf 17	calcic 70-200, cambic 55-70, chernic 0-55, mollic 0-55, gleyic 55-200, albic 55-200, calcaric 55-70

Ho	Tf 18	cambic 30-200, gleyic 40-200, calcic 40-200, albic 0-30, calcaric 0-30
Ho	Tf 19	calcic 70-85, cambic 55-70, 85-200, mollic 0-30, albic 55-200, calcaric 55-200
Ho	Tf 20	cambic 105-200, chernic 0-90, mollic 0-90, protocalcic 90-105, albic 90-200, calcaric 105-200
Ho	Tf 21	calcic 50-200, chernic 0-50, mollic 0-50, albic 50-200
Ho	Tf 22	calcic 85-200, cambic 70-85, chernic 0-70, mollic 0-70, albic 85-200, (gleyic 85-200)
Ho	Tf 23	calcic 65-200, cambic 50-65, chernic 0-50, mollic 0-50, gleyic 50-200, albic 50-200, calcaric 50-65
Ho	Tf 24	cambic 70-200, chernic 0-30, mollic 0-70, gleyic 70-200, albic 70-200, calcaric 70-200
Ho	Tf 25	calcic 60-80, cambic 80-200, chernic 0-60, mollic 0-60, gleyic 60-200, albic 60-200, calcaric 0-200
Ho	Tf 26	cambic 50-130, chernic 0-50, mollic 0-50, gleyic 50-130, albic 65-200, calcaric 50-130
Ho	Tf 27	cambic 95-110, chernic 0-95, mollic 0-95, gleyic 95-200, albic 110-200, calcaric 0-30
Ho	Tf 28	cambic 60-200, chernic 0-60, mollic 0-60, gleyic 60-200, albic 60-200, calcaric 0-30;60-200
Ho	Tf 29	gleyic 90-200, calcic 90-200, chernic 0-90, mollic 0-90, albic 90-200, calcaric 0-90
Ho	Tf 30	calcic 55-200, cambic 30-55, mollic 0-30, albic 30-200, calcaric 30-55
Ho	Tf 31	cambic 45-200, mollic 0-25, albic 45-200, calcaric 45-200
Ho	Tf 32	ferric 70-200, cambic 30-70
Ho	Tf 33	cambic 0-30, ferric 30-70, gleyic 70-200, albic 30-70
Ho	Tf 34	argic 30-60, cambic 0-30, abrupt textural change at 30
Ho	Tf 37	calcic 30-200, albic 30-200, calcaric 0-30
Ho	Tf 38	argic 90-200, calcic 15-90, cambic 0-15, abrupt textural change at 90, gleyic 15-200, albic 0-200, calcaric 0-15,90-200
Ho	Tf 39	cambic 0-30, albic 0-200, calcaric 0-200
Ho	Tf 40	argic 25-200, cambic 0-25, stagnic 0-200, albic 0-200, calcaric 0-200
Ho	Tf 41	calcic 50-200, cambic 0-50, albic 0-200, calcaric 0-50
Ho	Tf 43	argic 30-90, protocalcic 90-200, calcaric 0-90
Ho	Tf 44	cambic 30-200, albic 30-200, calcaric 0-200
Ho	Tf 45	gleyic 70-200, calcaric 0-140
Ho	Tf 46	cambic 35-150, gleyic 150-200, albic 35-150, calcaric 0-150
Gr	Tf13	chernic 0-25, mollic 0-25, calcaric 0-25
Gr	Tf 14	cambic 0-25, protocalcic 25-50, albic 0-25, calcaric 0-25
Gr	Tf 15	cambic 0-75, (mollic 25-55), gleyic, protocalcic 75-200, albic 0-25,55-75, calcaric 0-75
Gr	Tf 16	cambic 0-30, gleyic 30-200, albic 0-200, calcaric 0-200
Gr	Tf 17a	cambic 25-65, gleyic 65-200, albic 0-200, calcaric 0-65
Gr	Tf 17b	cambic 30-70, protocalcic 70-90, albic 0-90, calcaric 0-70
Gr	Tf 18	cambic 0-110, gleyic 30-160, albic 0-160, calcaric 0-110
Gr	Tf 19	calcic 55-70, cambic 70-110, chernic=mollic 0-55, gleyic 55-70, albic 55-70,110-200, calcaric 0-110
Gr	Tf 20	albic 0-200, calcaric 0-200
Gr	Tf 21	cambic 0-25
Gr	Tf 22	
Gr	Tf 23a	calcic 50-80, cambic 0-50, 80-100, gleyic 30-200, albic 0-110, calcaric 0-110
Gr	Tf 23b	argic 70-100, albic 0-25, calcaric 0-100, cambic 0-70
Gr	Tf 24	cambic 0-45, gleyic 25-60, albic 0-60, calcaric 0-120
Gr	Tf 25	cambic 0-95, (chernic=mollic 30-80), gleyic 95-200, albic 0-30, 80-200, calcaric 0-95
Gr	Tf 26	cambic 50-70, gleyic 50-70, albic 0-70, calcaric 0-70
Gr	Tf 27a	calcic 65-110, chernic=mollic 0-50, gleyic 50-60, 110-200, protocalcic 50-65, albic 50-65, 110-200, ferric 65-110, calcaric 0-50
Gr	Tf 27b	chernic 0-25, mollic 0-100, gleyic 100-200, albic 100-200, calcaric 0-100
Gr	Tf 27c	cambic 50-65, chernic=mollic 0-50, gleyic 50-65, calcaric 0-120

Gr	Tf 28	cambic 0-90, gleyic 30-170, albic 0-40, calcaric 0-170
Gr	Tf 29a	cambic 0-65, mollic 0-65, gleyic 0-30, 65-85, albic 65-85, calcaric 0-65
Gr	Tf 29b	cambic 25-75, chernic 0-25, mollic 0-50, gleyic 50-200, albic 50-200, calcaric 0-200
Gr	Tf 30	chernic=mollic 0-25, gleyic 90-200, albic 90-100, calcaric 0-100
Gr	Tf 31	calcic 25-70, cambic 70-90, gleyic 0-25, stagnic 0-25, albic 0-25, 70-90, calcaric 0-90
Gr	Tf 32	mollic 0-35, calcaric 0-35
Gr	Tf 33	cambic 25-80, mollic 0-25, albic 80-130, calcaric 0-130
Gr	Tf 34	calcic 60-80, cambic 0-60, albic 0-25, calcaric 0-60
Gr	Tf 35	cambic 25-75, chernic 0-25, mollic 0-45, calcaric 0-200, albic 45-70
Gr	Tf 36	cambic 25-65, mollic 0-25, calcaric 80-130
Gr	Tf 37	mollic 0-25
Gr	Tf 38	mollic 0-40
Gr	Tf 39	mollic 0-55

Table 5 - Diagnostic items of the soils displayed in Table 2. The items shown here are the results of the automatic classification. “gleyic 90-200” means for example, that the automatic classification revealed that there could be gleyic properties as listed in the WRB. 90-200 marks the depth of occurrence in cm. A value of 200 does not necessarily mean that the listed feature occurred to a depth of 200, it only indicates that this feature occurred in the deepest horizon described by the soil survey. For example, if a soil had been described up to a depth of 150cm, and a feature is present at a depth from 120-150, the system will state “120-200”, unless continuos rock is at the base of the horizon, in which case the actual 150 would be shown.

APPENDIX II

Diagnostic horizons, materials and properties of the soils listed in Table 4 (Kastanozems).

No.	No.2	Diagnostic item	Secondary carbonates	Kartierungsgebiet
145	Tf 55	cambic 70-140, mollic 0-40, protocalcic 40-70, albic 40-200, calcaric 0-40;70-140	Myzel	Hainburg a/d Donau
146	Tf 56	argic 80-110, calcic 80-110, fragic? 45-80, mollic 0-45, reducing 80-200, albic 80-200	Kalknester	Hainburg a/d Donau
148	Tf 45	argic 25-65, ferric 25-100, mollic 0-25, protocalcic 65-200	viele Kalkkonkr 3mm	Stockerau
149	Tf 30	argic 40-200, fragic? 25-200, mollic 0-25, protocalcic 40-200, (stagnic 25-40), ferric 40-200	Kalkkonkr 5mm	Ravelsbach
151	Tf 72	calcic 50-200, mollic 0-25, protocalcic 25-50, calcaric 0-25	viele Kalkkonkr 20mm	Zistersdorf
153	Tf 13	cambic 40-90, mollic 0-40, albic 40-200, calcaric 0-200, calcic 40-90	Kalkdifferenz	Marchegg
154	Tf 30	calcic 30-80, cambic 80-150, mollic 0-30, gleyic 80-130, albic 30-150, calcaric 0-150	Kalkdifferenz	Marchegg
155	Tf 43	calcic 35-200, mollic 0-25, albic 25-200, calcaric 0-35	Myzel	Marchegg
156	Tf 44	mollic 0-70, protocalcic 30-85, albic, calcaric 85-95	Kalkkrusten & Myzel	Marchegg
157	Tf 45	calcic 65-200, cambic 45-65, mollic 0-45, albic 45-200, calcaric 0-65	Myzel	Marchegg
158	Tf 7a	calcic 25-50, cambic 50-65, (chernic 25-50), mollic 0-50, albic 50-200, calcaric 0-200	Kalkdifferenz	Haugsdorf
159	Tf 26	calcic 0-45, mollic 0-45	Kalkkrusten	Baden
161	Tf 29	calcic 50-200, mollic 0-50, calcaric 0-50	Myzel	Kirchberg am Wagram
162	Tf 35	mollic 0-50, protocalcic 50-60, albic 50-60, calcaric 0-50	mehrere Kalkkonkr	Kirchberg am Wagram
164	Tf 14	calcic 35-200, mollic 0-35, albic 35-200, calcaric 0-35	Myzel	Gänserndorf
166	Tf 29	calcic 45-60, cambic 60-160, mollic 0-45, albic 45-200, calcaric 0-45;60-100	Myzel	Gänserndorf
167	Tf 34	calcic 45-100, mollic 0-45, gleyic 45-200, albic 45-200	viele Kalkkonkr 5mm	Gänserndorf
168	Tf 58	calcic 35-105, mollic 0-35, gleyic 105-200, protocalcic 105-200, albic 35-200, calcaric 0-35	viele Kalkkonkr 1-4mm	Gänserndorf
169	Tf 60	cambic 90-200, chernic 30-90, mollic 0-90, protocalcic 60-90, albic 110-200, calcaric 0-30; 90-200	Myzel	Gänserndorf
172	Tf 23	calcic 30-90, cambic 90-105, mollic 0-90, gleyic 90-200, albic 90-200, clacaric 0-105	Kalkdifferenz	Wien Nordost

173	Tf 31	(chernic 30-100), mollic 0-100, protocalcic 150-200, albic 100-200, albic 100-200, calcaric 0-30	Myzel	Wien Nordost
174	Tf 37	cambic 90-200, mollic 0-55, protocalcic 55-90, albic 90-200, calcaric 90-200	ausgeprägtes Kalkmyzel	Wien Nordost
175	Tf 38	cambic 90-110, mollic 0-35, protocalcic 60-80, albic 110-200, calcaric 0-35	Myzel	Wien Nordost
177	Tf 3	calcic 75-200, cambic 25-75, mollic 0-25, albic 75-200, calcaric 0-75	einz Kalkkonkr 2-5mm, Pseudomyzel stark ausgeprägt	Neusiedl am See Nord
182	Tf 29	calcic 65-200, cambic 35-65, mollic 0-35, albic 35-200, calcaric 0-65	mehr Kalkkonkr 5-10mm	Neusiedl am See Nord
183	Tf 32	calcic 45-85, cambic 45-65, mollic 0-45, albic 45-85, calcaric 25-200	Kalkdifferenz	Neusiedl am See Nord
184	Tf 36	cambic 20-35, mollic 0-20, protocalcic 35-100, calcaric 0-35	viel Kalkkonkr 25mm	Neusiedl am See Nord
186	Tf 65	fragic? 30-80, mollic 0-30, protocalcic 80-200, albic 80-200	Kalknester	Poysdorf
187	Tf 42	calcic 65-200, mollic 0-65, albic 80-200, calcaric 0-65	Kalkmyzel & viele runde Kalkkonkr 1-2mm	Horn
188	Tf 49	mollic 0-35, protocalcic 80-200, albic 80-200	leichtes & starkes Kalkmyzel	Horn
189	Tf 50	cambic 35-85, mollic 0-35, protocalcic 85-200, albic 85-200, calcaric 0-85	Myzel	Horn
192	Tf 59	argic 25-55, calcic 55-200, mollic 0-25, albic 55-200	Kalkmyzel	Horn
194	Tf 2	calcic 30-70, mollic 0-30, albic 30-70, calcaric 0-200	Kalkdifferenz	Bruck a/d Leitha
196	Tf 37	argic 110-200, calcic 70-110, cambic 50-70, mollic 0-50, abrupt textural change at 110, albic 50-200, calcaric 0-200	Kalkdifferenz	Bruck a/d Leitha
197	Tf 51	calcic 50-200, mollic 0-30, albic 50-200	Myzel	Bruck a/d Leitha
198	Tf 53	calcic 20-200, mollic 0-20, gleyic 60-200, albic 60-200, calcaric 0-20	mehr Kalkkonkr 50-60mm	Bruck a/d Leitha
199	Tf 67	cambic 80-100, mollic 0-80, protocalcic 100-200, albic 80-200, calcaric 0-100	einz Kalkkonkr 30-50mm	Bruck a/d Leitha

Table 6 - Diagnostic items shown for the soils listed in Table XY. Notes how to read this table are given in Table XY-1. The second column shows the description of the secondary carbonates as it is given by the soil survey. Myzel = Pseudomycelium, Kalknester = Spots of carbonate, Kalkkonkr = carbonate concretions, Kalkdifferenz = diagnosis of calcic horizon is based on difference in carbonate conten

APPENDIX III

Complete list of the horizon sequences in the Austrian Soil Taxonomy:

Terrestrial soils	Designation of horizon							
Kalklehmrendzina					F	H	A	BrelC
Ranker							A	C
Rumpftschernosem							A	C
Paratschernosem							A	C
Paratschernosem							A	Cu
Farbsubstratboden							A	C
Textursubstratboden							A	C
Frostmusterboden							A	C
Kolluvisol							A	Cu
Gartenboden							A	C
Kalklehmrendzina						Ahb	AB	C
Kalklehmrendzina					F	H	AB	C
Brauner Tschernosem							Ab	Cb
Braunerde							AB	C
Kolluvisol						A	AB	Cu
Planieboden						Ynat	Abeg	Cu
Typischer Tschernosem						A	AC	C
Typischer Tschernosem					A1	A2	AC	Cca
Typischer Tschernosem						A	AC	Cu
Paratschernosem						A	AC	Cu
Farbsubstratboden						A	AC	C
Textursubstratboden						A	AC	C
Brauner Tschernosem						Ab	ACb	Cca
Paratschernosem						A	ACb	Cu
Kolluvisol						A	Ag	
Protorendzina						F	Ahb	C
Mullrendzina							Ahb	C
Mullartige Rendzina						L	Ahb	C
Mullartige Rendzina					L	H	Ahb	C
Moderrendzina				L	F	H	Ahb	C
Tangelrendzina				L	F	H	Ahb	C
Pechrendzina						H	Ahb	C
Kalklehmrendzina							Ahb	BrelCv
Pararendzina							Ahb	C
Pararendzina					F	H	Ahb	C
Ranker					F	H	Ahb	C
Ranker					F	H	Ahi	C
Grobmaterialrohboden							Ai	C
Grobmaterialrohboden						F	Ai	C
Feinmaterialrohboden							Ai	C
Feinmaterialrohboden						F	Ai	C
Frostmusterboden							Ai	C
Mullrendzina							Ap	C
Rumpftschernosem							Ap	C
Kulturrohboden							ApC	C

Rigolboden							Arig	C
Kalklehmrendzina						A	B	C
Gartenboden						A	B	C
Braunerde						A	BC	C
Podsol					A	E	Bh	C
Staupodsol					Agd	Egd	Bh	C
Semipodsol					Ahi	Ae	Bh,s	C
Podsol					A	E	Bh,s	C
Semipodsol			L	F	H	Ahe	Bs	C
Podsol	L	F	H	Ae	E	Bh	Bs	C
Podsol	L	F	H	Ahi	E	Bh	Bs	C
Staupodsol					Agd	Egd	Bs	C
Staupodsol				Agd	Egd	Bh	Bs	C
Parabraunerde						Al	Bt	C
Parabraunerde						Ap	Bt	C
Braunerde						A	Bv	C
Parabraunerde				Al	Bl	Bt	Bv	C
Parabraunerde					Al	Bt	Bv	C
Staupodsol	L	F	H	Ae,gd	Egd	Bs	Bv	C
Kalkbraunlehm						A	Bv	C
Rigolboden						Arig	Bv	C
Kalkbraunlehm						A	Bv,rel	C
Kalkrotlehm						A	Bv,rel	C
Paratschernosem						A	CBv,rel	Cu
Braunerde					A	Bv	Cca	C
Carbonathaltiger Felsauflagehumusboden							F	Cu
Carbonatfreier Felsauflagehumusboden							F	Cu
Protorendzina						F	H	C
Mullartige Rendzina							H	C
Moderrendzina					L	F	H	C
Carbonathaltiger Felsauflagehumusboden						F	H	Cu
Ranker						F	H	C
Carbonatfreier Felsauflagehumusboden						F	H	Cu
Pechrendzina							Hzo	C
Mullartige Rendzina							M	C
Deponieboden						Ay	Y	Cu
Deponieboden						AY	Y	Cu
Planieboden						A	Ynat	Cu
Planieboden							Ynat	Cu
Haldenboden						A	Ynat	Cu
Haldenboden							Ynat	Cu
Hydromorphic soils	**Designation of horizon**							
Typischer Pseudogley						A	P	S
Typischer Pseudogley						Agd	P	S
Typischer Pseudogley						Al	P	SC
Typischer Pseudogley						A	BP	S

Typischer Pseudogley					A	Bgd	P	S
Stagnogley						AP	P	S
Stagnogley						Agd	P	S
Typischer Stagnogley						AP	P	S
Anmooriger Stagnogley						AgdP	P	S
Hangpseudogley						A	P	S
Hangpseudogley						Agd	P	S
Hangpseudogley							Agd	S
Haftnässepseudogley					A	P	B	C
Haftnässepseudogley						Agd	P	C
Reliktpseudogley						A	Prel	Srel
Reliktpseudogley					A	Prel	Srel	SCv,rel
Reliktpseudogley						Ae	Prel	Srel
Reliktpseudogley					A	Erel	Prel	Srel
Auboden					L	F	A	C
Auboden						A	BC	C
Auboden					A	AB	B	C
Auboden					A	C	Abeg	C
Auboden							A	C
Auboden						A	C	Cg
Augley				L	F	A	Go	Gr
Augley		L	F	A	Go	Abeg	Go	Gr
Augley						A	Cg	Gr
Schwemmboden					L	F	A	C
Schwemmboden					A	C	Abeg	C
Rohauboden							Ai	C
Rohauboden				L	F	H	Ai	C
Gley						A	Go	Gr
Gley						A	Go	Go,r
Gley						Agg	Go	Gr
Gley					A	BG	Go	Gr
Gley						A	Agg	AG
Brauner Gley						A	BG	Go
Brauner Gley					A	BG	Go	Gr
Brauner Gley					A	Bgg	Go	Gr
Brauner Gley					A	Bgg	Gew	Go
Nassgley						Ago	Go	Gr
Nassgley						AGo	Go,r	Gr
Nassgley							AG	Gr
Nassgley						Hgg	AG	G
Anmooriger Nassgley							AG	Gr
Anmooriger Nassgley						AG	Go,r	Gr
Entwässerter Torfnassgley							Ag,ew	Gew
Entwässerter Torfnassgley						Ag,ew	Gew	G
Entwässerter Torfnassgley						Ag,ew	Go,ew	Gr,ew
Hanggley (Quellgley)						AGo	Go	Gr
Hanggley (Quellgley)						AG	Go,r	Gr
Hanggley (Quellgley)						Agg	Go	Gr

Hanggley (Quellgley)							A	Go
Entwässerter Torfhanggley						Agg	Gew	G
Entwässerter Torfhanggley							AGew	Gew
Entwässerter Torfhanggley						AGew	Gew	G
Verbraunter Torfhanggley						A	BG	Go
Solontschak							Asa	G
Solontschak							Ai,sa	Go,r
Solontschak							Asa	Gr
Solontschak							Ai,gg,sa	G
Solonetz						AE	Bh	G
Sekundärer Solonetz						A	AbegBh	G
Solontschak-Solonetz							Asa	G
Solontschak-Solonetz						Asa	AG	G
Solontschak-Solonetz						A	Bh	G
Solontschak-Solonetz						A	Ahb	G
Solontschak-Solonetz							A	G
Hochmoor							T	Cu
Hochmoor							T	G
Niedermoor							T	Cu
Niedermoor							T	G
Anmoor							Agg	Cu
Anmoor							Agg	G
Anmoor							Agg	GC
Anmoor						Agg	AG	G
Anmoor						T	AG	G
Feuchtschwarzerde					A	Agg	Cgg	Cu
Feuchtschwarzerde						A	Agg	CG
Dy								
Gyttja								

Table 7 - Complete list of Soil types in the Austrian Soil Taxonomy with their respective horizon sequences.

APPENDIX IV

Incorrect definitions and faulty criteria in the Austrian Soil Taxonomy:

Distinction of Paratschernosem and Ranker: In the entry regarding the Ranker of the manual (p.48) says that if the A-horizon is thicker than 25cm, it is regarded as a Paratschernosem. In contradiction, the entry there (p.53) names 30cm as the limit.

Distinction of Rendzina and Pararendzina: A carbonate content of 75% would qualifiy for both Soil types. The entry at the Pararendzina (p.46) incorrectly states “≥75%”, it should mean “>75%”.

Distinction between Tschernosem and Braunerde: The limit (p.50) should say: “more than 10cm B-horizon and more than 15% of the whole profile”.