CLASSIFICATION OF PALEOSOLS

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ABSTRACT – The aim of this presentation is to discuss the different views about paleosol classification and give some examples of the current knowledge in Argentina. Literature about paleosols is abundant but there is not any paleosol classification totally accepted and widely used. Several classification systems for paleosols have been developed recently based on the US Soil Taxonomy and the World Reference Base for Soil Resources used for modern soils, but their use is still very limited. Some of them are applied to buried soils and the others to all kind of paleosols. The Soil Taxonomy (Soil Survey Staff, 1999) is the soil classification system used in Argentina for present soils. In soil maps we use an extended concept of the "*thapto concept*" taken from that classification and applied to shallow buried soils. On the other hand, there is not any conceptual discussion about paleosols classification from the paleopedological point of view in Argentina.
Keywords: Paleosols, classification, Argentina.

RESUMEN – *P.A. Imbellone - Clasificación de paleosuelos*. El objetivo de la presentación es discutir las diversas ideas sobre clasificación de paleosuelos y presentar algunos ejemplos del conocimiento actual en la Argentina. La literatura acerca de paleosuelos es muy abundante pero no hay actualmente ninguna clasificación de paleosuelos totalmente aceptada. En Argentina la información más voluminosa se refiere a suelos enterrados. Parece haber una tendencia de clasificación según la disciplina de origen de los investigadores que los utilizan. A partir de la Pedología, en génesis y clasificación de suelos se usa Taxonomía de Suelos con adaptaciones locales (concepto extendido de "*tapto*", Taxonomía de Suelos, 1999); si el enfoque es geológico como indicadores paleoclimáticos y/o estratigráficos, se suele hacer una descripción detallada de las características de campo, mineralógicas y micromorfológicas del perfil tipo, a veces soslayando la clasificación del los paleosuelos o mencionando tentativamente a los mismos dentro de un Orden de Taxonomía de Suelos.
Palabras clave: paleosuelos, clasificación, Argentina.

INTRODUCTION

A classification allows to systematize knowledge and open new lines of research. Unlike other disciplines of the Earth Sciences as Sedimentology, Paleontology, Pedology, etc., which possess their own systematics, Paleopedology paid limited attention to the taxonomic classification of paleosols, compared with the development in other topics. Due to its difficulties, the classification of paleosols constitutes a challenge, but provides a huge amount of information when paleosols are compared with present soils in the interpretation of past environmental conditions necessary for paleo-environmental reconstruction. In addition, a common classification in Paleopedology is necessay in order to achieve a global correlation of paleosols. The object of this contribution is to discuss the different views about paleosol classification and its situation in Argentina.

DISCUSSION

Soil Taxonomy is the official classification system in Argentina (Soil Survey Staff, 1999). It is a system developed for present soils, but it uses the prefix *"Thapto"* (Gr.: thaptos, buried) to indicate a "buried soil". This prefix applies only to subgroups of Mollisols and Entisols with a buried histic epipedon. In the soil maps of Argentina the prefix is also applied to soils of the Pampean Region, with argillic diagnostic horizons, by suggestion of Dr. Pedro H. Etchevehere (Imbellone et al., 2010). This is a vernacular criterion that allows the understanding among Argentinian pedologists and paleopedologists; it emerged from the practical need to indicate the presence of a pedologic discontinuity to define taxonomic units in soil maps. Of course, it is applicable only to shallow buried soils because it refers to two pedological entities: the upper one (present soil) and the underlying one (buried paleosol). The term can be applied either easily or with difficulty. In soils 1, 5, 7, 8 and 9 (Figure 1) the presence of a paleosol is not indicated because the thickness of the present soil is lower or higher than the required values, or the "thapto horizon" is too thin. In soil 2, the presence of a poorly developed soil is obvious, which could be important to study the soil genesis in a toposequence. Soil 4 is classified properly and the "thapto horizon" describes an isolated pedocomplex. In soils 3 and 6 the "thapto horizon" describes two welded soils; in the former, the pedocomplex possesses characteristics that can be similar to those of argillic horizons, but in the latter, the pedocomplex has characteristics of a cambic horizon overlying an argillic horizon.

In addition, the correspondence of a "thapto horizon" to a diagnostic horizon is estimated selecting some of the properties required for the diagnostic horizons of the classification, but in this case the strictness of the classification is lower than that used in present soils. So, in many cases the classification is left to the criterion of the authors (Imbellone et al., 2005) and for that reason the discussion remains open.

On the other hand, from the paleopedological perspective, no glimpse of a conceptual discussion on paleosol classification is observed in Argentina. In 1998, Zárate and Imbellone suggested the need for a special paleosol classification based on morphological features resistant to post-burial modifications, but the issue was not developed. Thus, properties and processes are studied in paleosols, with references to their classification only in some cases (Cumba and Imbellone 2004; Krause and Bellosi, 2006).

In the past ten years, there has been a growing interest in the world on this subject, both in relation to quaternary and prequaternary paleosols. To begin the

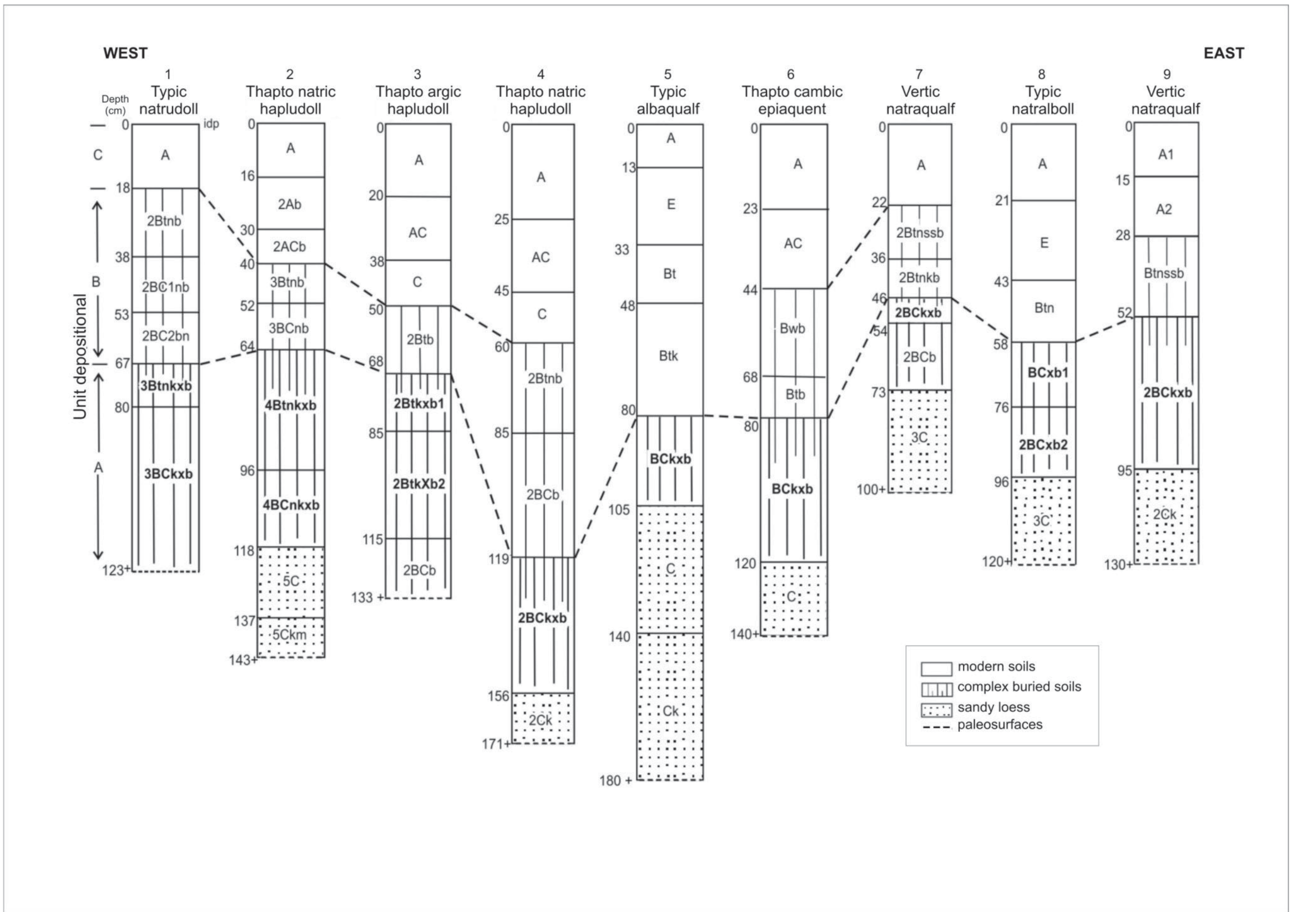

FIGURE 1. Regional distribution of buried soils. Interdune areas of the Sandy Pampa, province of Buenos Aires. 1, 2: Carlos Tejedor County; 3: Carlos Casares County; 4, 5, 6: Saladillo County; 7, 8, 9: Roque Perez County. From Imbellone et al., 2005; Imbellone et al., 2010.

discussion, the initial questions of the analysis are: 1) is it possible to classify paleosols with classifications developed for present soils?; 2) is it necessary to create specific classifications for paleosols?

A review of the literature shows that in spite of the vast literature on paleosols, there is no entirely satisfactory classification in use. The result is a wide range of designations, from those very detailed with an interpretative sense (Retallack, 1983, *series of paleosols*) to other very general or without designation of paleosols (Mack et al., 1991, *paleosols caliche*). In addition, there is a basic agreement between paleopedologists to emphasize the difficulties for implementing a paleosol classification:

1. It is not appropriate to use classifications devised for modern soils in paleosols (Mack, et al., 1993, Kraus, 1999, Nettleton, et al., 1998, Bronger and Catt, 1989, Buurman, 1998, Retallack, 2001), because they do not concentrate on specific problems of paleosols since these are not their study object. In fact, Soil Taxonomy (Soil Survey Staff, 2006) defines a soil as "a natural body characterized by horizons or layers that are distinguished from parent material or by the ability to withstand plants".
2. There is a critical reason that prevents modern classification systems from being directly applied to paleosols: some dynamic properties used in present soils do not persist in the rock record (Yaalon, 1971) because they are modified quickly after burial. They are base saturation, cation exchange capacity, pH, density, moisture content, organic matter content, etc. and even those features considered persistent in paleosols as thickness of horizons, argillic horizons and compaction (Retallack, 2001).
3. Some systems for modern soils use strict climate data in higher categories, which are impossible to obtain from a paleoclimatic model, either for a ancient geological unit or a time period. Paleoclimate is often a factor that has to be inferred from the properties of the soil and therefore it cannot be a part of a paleosol classification. In Soil Taxonomy, the various hydrothermal regimes, particularly the soil moisture regimes, are used at the Order (aridic regime) and Suborder (udic, ustic, xeric, aridic and cryic regimes) levels. The FAO-ISRIC-ISSS (1998) classification does not use climatic information but diagnostic horizons and properties, which would not permit diagenetically altered horizons to be identified. In addition, from the conceptual point of view, if the goal of classifying paleosols is to obtain paleoclimatic information from modern similarities, it is not possible to use the same elements of analysis that the object to be analyzed.
4. Classification systems for modern soils do not take into account features generated by geomorphic processes such as profile truncation (Dan and Yaalon, 1968), presence of erosion and/or deposition surfaces, polygenic or welded soils (Ruhe and Olson, 1980) or even those formed near the present land surface, or diagenized and compacted soils (Retallack, 2001). Therefore, these classifications do not reflect processes that are fundamental to paleoenvironmental reconstruction and the order in which they occur. Post-burial changes complicate their use; for example, an A horizon may be identifiable, but its original carbon content would have declined during the burial.

Taking into account the foregoing remarks, different authors propose specific classifications for paleosols, based on those for present soils. The following are briefly some of them, referring the reader to the original work for greater detail.

Among the major systems of classification for modern soils, the WRB (1998) and USDA (1999) are taxonomic systems that use the characteristics of the profile for classifying soil on the basis of diagnostic horizons and properties. The former system is used internationally and unlike the latter, it does not use climate information. How would diagenetically altered diagnostic horizons be estimated? Except for the histic horizon, surface diagnostic horizons would be difficult to recognize due to the loss of organic matter. The diagnostic properties and subsurface horizons that would probably be recognized are: argillic, natric, spodic, ferralic (oxic), calcic, gypsic and albic. The recognizable groups of soils would be: Histosols, Calcisols, Gypsisols, Podzols, Ferralsols, Plinthosols, Planosols, Podzoluvisols (now Albeluvisols) and perhaps Arenosols, Vertisols and those which have illuviation clay (Buurman, 1998). This classification is often used successfully in pedoestratigraphy of loessic (Guo et al., 1996) and volcanic soils (Solleiro-Rebolledo, 2004).

Duchaufour (1982) proposes an environmental classification for present soils, whereby soil properties are considered in terms of pedogenic processes operating under particular environmental conditions. This classification is interpretative because soil features are used to infer processes and environmental conditions. It would be relatively easy to apply in paleosols since the emphasis is on processes rather than on properties. It is used for paleosols by Kraus and Gwinn (1997) and proposed by Bronger and Catt (1998) as a base for a future paleosol classification. These authors suggest the development of a new paleopedologic classification based on Duchaufour's system: "it would be desirable to develop a natural genetic system purely based on mineralogical and micromorphological concepts of pedogenic and diagenic traits and not by those generated by important factors in modern agriculture (climatic factors, nutrient content)”.

In order to reconstruct the environment under which the paleosols formed, it is essential to obtain information on the processes that formed the soils and their intensity. A classification system of paleosols could be based on properties that allow the type and intensity of processes to be inferred (Buurman, 1998).

A breakthrough in the classification of paleosols is that of Mack et al. (1993), based on the conceptual comparison with the similar present soils, but with modifications, partially using Soil Taxonomy and WRB nomenclatures. It is a *descriptive* system applicable to all kinds of paleosols regardless of their age. All parameters that can be affected by diagenesis are excluded, except organic matter. It uses morphological and mineralogical traits that are greatly preserved in the rocks and can be easily recognized in the field and under the petrographic microscope. The system is based on the relative abundance of six pedogenic features or processes: organic matter content, horizonation, redox conditions, *in situ* mineral alteration, illuviation of insoluble minerals and compounds and accumulation of soluble minerals. The paleosols are classified in nine orders, four are taken, with modifications, from Soil Taxonomy (Histosol, Spodosol, Oxisol, Vertisol), three from the Soil Maps of the World (FAO-UNESCO, 1974) (Calcisol, Gypsisol, Gleysol) and two were partially created (Argillisol, Protosol). The orders are affected by a modifier that indicates a major feature of the paleosol. The most prominent of these six features/processes considered defines the paleosol order. To give greater flexibility to the system, no rigid hierarchy of traits and processes is established (Figure 2).

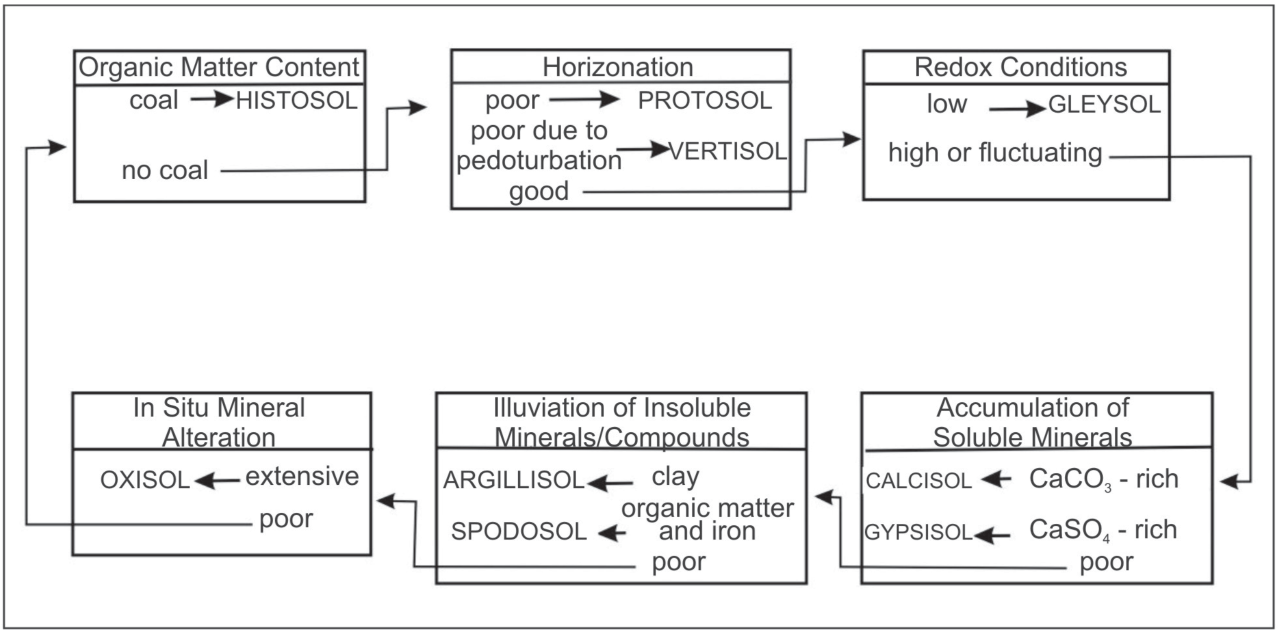

FIGURE 2. Table of simplified flow of paleosols orders, based on the determination of features or prominent pedogenetic processes in the paleosols, indicated in the upper part of each box. The flow chart can be entered at any point. After Mack et al., 1993.

The name of the paleosols with more than one dominant trait can be affected by any of the following 18 modifiers: albic, alofanic, argillic, calcic, carbonaceous, concrecionary, distric, eutric, ferric, fragic, gleysic, gypsic, nodular, ochric, salic, salicilic, vertic, vitric. For example, a paleosol with a well-developed calcic horizon (dominant feature) and an overlying argillic horizon is classified as argillic Calcisol.

This classification is simple and objective; it can be used in the field and Mack and James (1994) used it in a global paleoclimatic model. However, it is little applied, perhaps because it is restricted to paleosols, since paleopedologists, despite the reservations mentioned above, often use the present classifications to estimate the paleoenvironmental characteristics of the ancient analogues (Retallack, 2001). This classification is criticized for using names of other classifications with different meanings and by the loss of information that cause the elimination of dynamic properties of the soil, since many paleosols are not diagenetically altered. In any case, the authors consider that the classification is not a simplification and that it contemplates appropriately the stratigraphic reality.

On the other hand, and considering that a new classification should be linked to a modern system, Retallack (1998) proposes to make an adaptation of Soil Taxonomy. If a paleosol is similar to a modern soil, then it perhaps can be inferred that the ancient soil evolved in an environment similar to that of the present soil. On the conceptual basis of *taxonomic uniformitarianism*, which accepts that fossil creatures had ecological tolerance similar to that of their living counterparts, then similarly, the identification of ancient soils within a taxonomic system for modern soils may involve past conditions similar to those of a modern soil. This approach was considered to be invalid, because living creatures have a phylogeny which is absent in soils (Fastovsky, 1991, in Dahms and Holliday, 1998). Anyway, Retallack (1993) uses 11 orders of Soil Taxonomy (before the introduction of Gelisols) and later (Retallack, 2001) 12 orders for classifying paleosols, combining field-observable and petrographic features of characteristic horizons of each order (Figure 3).

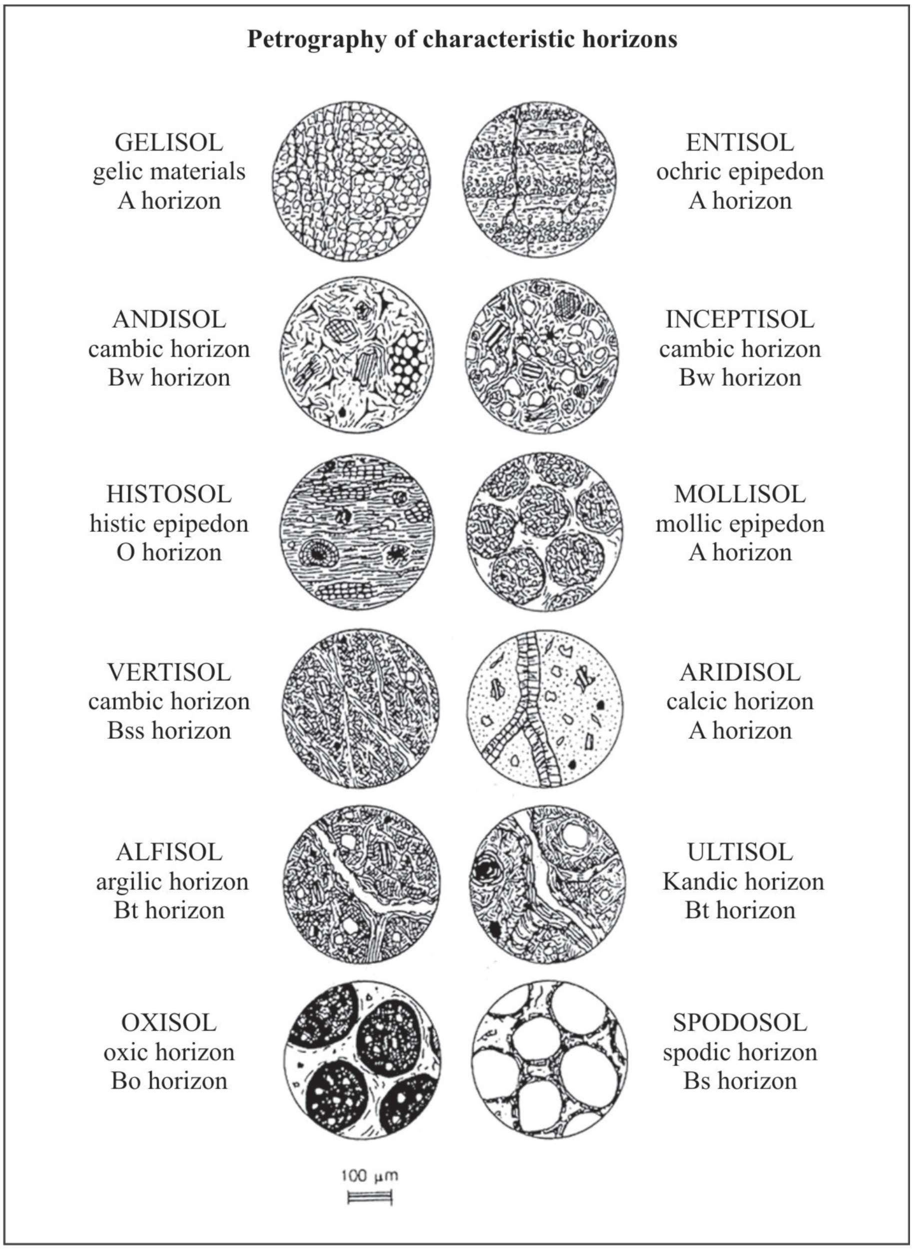

FIGURE 3. Petrographic characteristics in diagnostic horizons of Orders of Soil Taxonomy observable in paleosols. Simplified from Retallack (2001).

Similarly, Nettleton et al. (1998) proposed a classification for buried soils. Although paleosols in ancient landscapes can be buried, relict or exhumed (Ruhe, 1956), the last two are currently subaeric and they are in the same landscapes as the modern soils. That is why, in practice they are generally classified with systems for ground soils because of the difficulty to recognize them as paleosols (Bronger and Catt, 1989). The classification proposes to change the definition of buried soils in Soil Taxonomy (1999). The approach is more quantitative than in the classification of Mack et al. (1993), so that the paleoenvironmental conditions of paleosols can be inferred more accurately, but it is also more difficult to apply as it needs large amount of analytical information. The following evidences are considered: indirect lithified soil properties, hardening, weatherable mineral content in the sand and silt fractions, CEC to clay ratio, total analysis of fine-earth fraction and clay mineralogy.

The system utilizes the prefix "*krypto*" (Greek "*kryptos*": hidden or covered) to indicate that the soil is buried by a younger soil or by a potential soil parent material. It is applied to the following orders modified from Soil Taxonomy: *Kryptohistosols, Kryptospodosols, Kryptandisols, Kryptoxisols, Kryptovertisols, Kryptaridisols*.

Other buried paleosols are indicated by the following formative elements:

- "*evolv*", indicates that a soil could develop further if the climate is appropriate: for example, some of the soils of the Figure 1 could be classified as *Kryptevolvisols.*
- "*eld*", to indicate a soil which reached the maximum evolution of its primary (weatherable) minerals: *Krypteldisols*;
- "*addend*", for the soils that do not fit in another class: *Kryptaddendosols*.

Later, in order to include all types of paleosols (buried, relict, exhumed and lithified) Nettleton et al. (2000) modified the original classification. They proposed a classification system based on properties linked to genetic processes, using morphological properties resistant to alteration, such as: horizonation, soil fabric, root and worm casts, and redoximorphic features. Field and micromorphologic properties, degree of weathering and proportion of resistant minerals are used as criteria for orders; chemical total analyses give indirect measure of base saturation and clay mineralogy. The indirect criteria are used to classify modified or lithified paleosols during or after the burial.

Two new orders and the suborders (*buried, relict, lithified* and *exhumed*) are added. Paleosol taxa names are clearly separated from those of the modern soil. The prescript *paleo-* is used at the order level and the following adjectives are used at the suborder level: *kryptic* for buried; *enduric* for relict, *lithic* for lithified and *emergent* for exhumed. When the prefix *krypt-* is replaced with *paleo-* in the name of the order, eleven categories are established: *Paleohistosols, Paleospodosols, Paleoandisols, Paleooxisols, Paleovertisols, Paleoaridisols, Paleoeldisols, Paleomollisols, Paleoevolvisols* (soils of Figure 1), *Paleoinceptisols* and *Paleoaddendosols*. Also, less formal modifiers can be applied to suborders to indicate physical characteristics (*accretionary, buried, complete, truncated, welded*, *carbonate-enriched, unleached, gleyed, oxidized*), origin of the parent material (*residual, alluvial, colluvial, eolian, pyroclastic*) and extension of the paleosol (*extensive, inextensive*).

A recently proposed classification which uses the ideas, definitions, and criteria worked out by the WRB (FAO-ISRIC-IUSS, 1998) has been adapted for buried paleosols (Krasilnikov et al., 2006), Figure 4. Only relatively stable properties are used: texture, structure, mineralogical composition and related cation exchange capacity, etc. It is mainly applicable to buried paleosols of Recent to Cenozoic ages because it uses properties and pedological processes tentatively related to modern soils, without climatic requirements. It would not be applicable to lithified paleosols where diagenesis would have altered most of the pedogenic characteristics, and the few that could be detected would be insufficient to classify a paleosol.

In addition, exhumed soils or polygenetic surface paleosols could be classified as modern soils without any reference to their history (Figures 4, a and f). Soils buried within two meters of the surface, which are affected by present pedogenetic processes, can be classified as surface soils (Figures 4 b and c). These soils are called *"pedocomplexes"* or *"welded soils"* and receive the prefix *"Thapto-"* before other modifiers in the WRB. The prefix can be applied to both complete and truncated paleosol profiles, either starting below 2 m from the surface (Figure 4 e) or 50 cm from the surface and separated from the ground soil by a layer of sediment without any evidence of pedogenesis (Figure 4 d).

Dynamic properties that can be altered by diagenesis are not considered in the first level of abstraction, and the definition of many diagnostic horizons of the WRB was modified. The prefix "*infra-*" is used for modified diagnostic horizons and properties and reference groups of buried paleosols. The number of proposed units is less than for surface soils in the WRB. Modifiers reflecting dynamic properties in the WRB are allowed; for the second level of abstraction of buried paleosols the prefixes "*pedo-"* for properties pedogenetically acquired and *“dia-”* for properties generated by post-burial processes are tentatively recommended; if the origin of the property is unknown, no modifier is used.

The proposed classes at the higher level are 25: *Infrahistosols, Archaeosols, Infraleptosols, Infraanthrosols, Infracryosols, Infravertisols, Infrafluvisols, Infragleysols, Infraandosols, Infrapodzols, Infraplinthosols, Infraferralsols, Infrasolonetz, Infraplanosols, Negrosols, Infragypsisols, Infradurisols, Infracalcisols, Infraglossisols, Infraluvisols, Infranitisols, Infralixisols, Infraarenosols, Infracambisols, Ochrisols.*

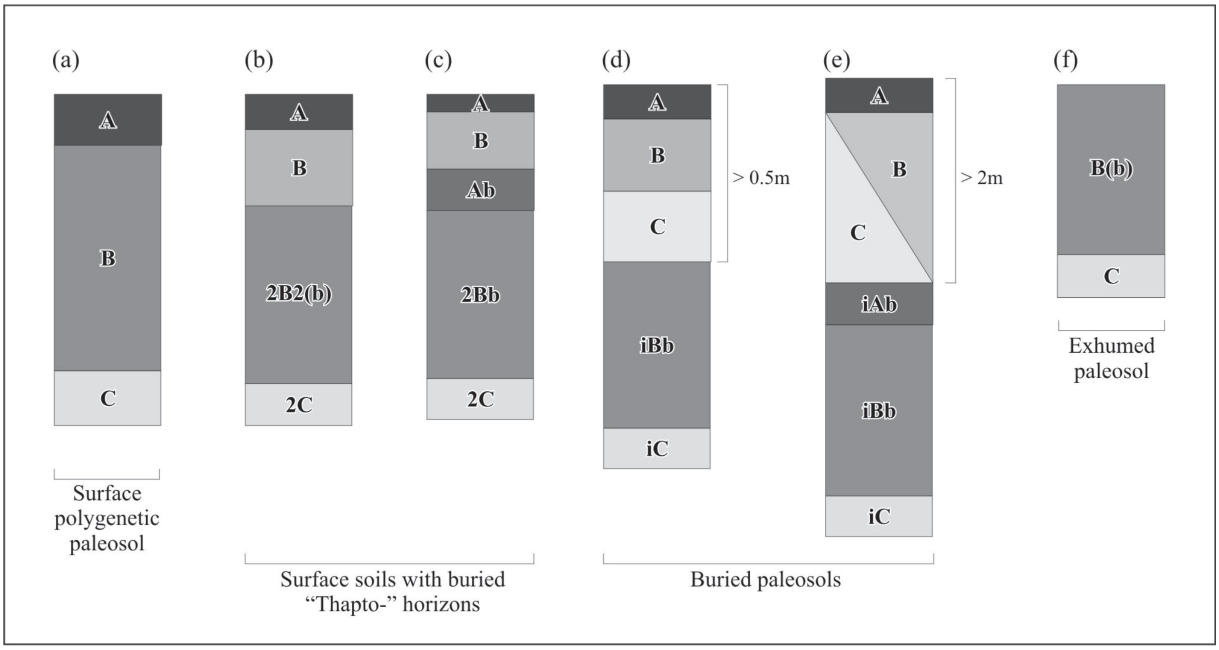

FIGURE 4. Various types of paleosols: (a) surface poligenetic paleosol; (b) welded buried paleosol; (c) complete buried paleosol at shallow depth; (d) buried paleosol isolated from the surface soil by a sediment layer; (e) deeply buried paleosol; (f) exhumed paleosol. The prefix *“i”* indicates isolated or *“infra-”* horizons. Modified from Krasilnikov and Calderón, 2006.

FINAL REMARKS

The success of a classification is achieved by its applicability in a given discipline. In the case of paleosol classifications, and beyond their specifications, none of them had a massive acceptance among paleopedologists, possibly due to the complexity of the object of classification and/or the possibility of paleoclimatic inferences to be made from a set of less rigidly structured but equally indicative features, and/or the need for further research. A comparison of different classifications is shown in Table 1.

In Argentina, the greater bulk of information refers to buried paleosols. There seems to be a tendency to classify paleosols according to the discipline of origin. If genesis and classification aspects are studied from a pedological approach, Soil Taxonomy (2006) is used. If paleosols are used as proxy records of paleoclimatic conditions or as stratigraphic markers from a geological approach, field and micromorphologic characteristics are described in detail, sometimes ignoring the classification of the paleosol or tentatively using an order of Soil Taxonomy, as Retallack (2001) suggests or, in a few cases, using the system of Mack et al. (1993). Although Pazos and Moscatelli (1998) propose the use of WRB in Argentina, this system is very little applied, either to modern soils or paleosols (Giménez, this issue). Nettleton et al. (2000) and Krasilnikov et al. (2006) classifications are not yet applied in Argentina, probably because they are very recent. Additional detailed studies on paleosol classification are needed in Argentina to begin testing and comparing the application of the different modern soil classifications to paleosol sections.

TABLE 1. Different systems mentioned in the text. Systems for modern soils are included as references. There are no horizontal relationship in the names of the classes.

MODERN SOILS		PALEOSOLS				
WRB 2006	**ST 2006**	**Mack et al., 1993 B, E, R**	**Nettleton et al., 1998 B**	**Nettleton et al., 2000 B, E, R**	**Retallack, 2001 B, E, R,**	Krasilnikov & Calderón, 2006 **B**
32 classes	**12 classes**	**9 classes**	**9 classes**	**11 classes**	**12 classes**	**25 classes**
Anthrosol	Histosol	Histosol	Kryptohistosol	Paleohistosol	Histosol	Infrahistosol
Histosol	Entisol	Protosol	Kryptovertisol	Paleoinceptisol	Entisol	Archaeosol
Technosol	Inceptisol	Vertisol	Kryptospodosol	Paleovertisol	Inceptisol	Infraleptosol
Cryosol	Vertisol	Gleysol	Kryptoxisol	Paleomollisol	Vertisol	Infraanthrosol
Leptosol	Alfisol	Calcisol	Kryptoandisol	Paleospodosol	Alfisol	Infracryosol
Vertisol	Ultisol	Gypsisol	Kryptoaridisol	Paleooxisol	Ultisol	Infravertisol
Fluvisol	Spodosol	Argillisol	Kryptoeldisol	Paleoandisol	Spodosol	Infrafluvisol
Solonetz	Oxisol	Spodosol	Kryptoevolvisol	Paleoaridisol	Oxisol	Infragleysol
Solonchak	Andisol	Oxisol	Kryptoaddendosol	Paleoeldisol	Andisol	Infraandosol
Gleysol	Aridisol			Paleoevolvisol	Aridisol	Infragypsisol
Andosol	Mollisol			Paleoaddendosol	Mollisol	Infrapodzol
Podzol	Gelisol				Gelisol	Infraplinthosol
Plinthosol						Infraferralsol
Nitisol						Infrasolonetz
Ferralsol						Infraplanosol
Planosol						Negrosol
Stagnosol						Infradurisol
Chernozem						Infracalcisol
Kastanozem						Infraglossisol
Phaeozem						Infraluvisol
Gypsisol						Infranitisol
Durisol						Infralixisol
Calcisol						Infraarenosol
Albeluvisol						Infracambisol
Alisol						Ochrisol
Acrisol						
Luvisol						
Lixisol						
Umbrisol						
Arenosol						
Cambisol						
Regosol						

B: buried, E: exhumed, R: relict

BIBLIOGRAPHIC REFERENCES

1. BRONGER, A. & CATT, A. Paleosols: Problems of definition, recognition and interpretation. In: BRONGER, A. & CATT, J.A. (Eds.), **Paleopedology. Nature and application of paleosol**. Catena Supplement 16, p. 1-7, 1989.
2. BRONGER, A. & CATT, A. Summary outline and recommendations on paleopedological issues. **Quaternary International**, v. 51/52, n. 7/8, p. 5-6, 1998.
3. BUURMAN, P. Classification of paleosols - a comment. **Quaternary International**, v. 51/52, n. 7/8, p. 17-33, 1998.
4. CUMBA, A. & IMBELLONE, P. Micromorphology of paleosols at the continental border of the Buenos Aires Province. Argentina. **Revista Mexicana de Ciencias Geológicas**, v. 21, n. 1, p. 18-29, 2004.
5. DAN, J. & YAALON, D.H. Pedomorphic forms and pedomorphic surfaces. In: INTERNATIONAL CONGRESS OF SOIL SCIENCES, 9, 1968, Adelaide. **Transactions...** Adelaide, v. 4, p. 577-584, 1968.
6. DAMS, D.E. & HOLLIDAY, V.T. Soil Taxonomy and

paleoenvironmental reconstruction: a critical commentary. **Quaternary International**, v. 51/52, n. 7/8, p. 109-114, 1998.
7. DUCHAUFOUR, P. **Pedology**. London: Allen and Unwin, 448 p., 1982.
8. FAO-ISRIC, ISSS. **World Reference Base for Soil Resources**. World Soil Resources Report. Rome, 84 p., 1998.
9. GIMENEZ, J.E. The World Reference Base for Soil Resources (WRB) and its application to some soils of Argentina. **Geociências**, This issue.
10. GUO, Z.; FEDOROFF, N.; LIV, D. Micromorphology of loess-paleosol sequence of the last 130 Ka in China and paleoclimatic events. **Science in China,** (Series D), v. 39, n. 5, p. 468-477, 1996.
11. IMBELLONE, P. & GIMÉNEZ, J. Parent materials, buried soils and fragipans in northwesten Buenos Aires province. **Quaternary International**, v. 51-52, n. 7/8, p. 115-126, 1998.
12. IMBELLONE, P.; GIMÉNEZ, J.; CUMBA, A. Suelos con "fragipan" de la pampa arenosa. In: CONGRESO GEOLÓGICO ARGENTINO, 16, 2005, La Plata. **Actas...** La Plata, v. 5, p. 65-72, 2005.
13. IMBELLONE, P.; GIMÉNEZ, J.; PANIGATTI, J.L. **Suelos de la Región Pampeana. Procesos de formación**. Buenos Aires: Ediciones INTA, 320 p., 2010.
14. INTA. **Mapa de Suelos de la Provincia de Buenos Aires**. Escala 1:500.000. CIRN. Instituto de Evaluación de Tierras. Buenos Aires, 525 p., 1989.
15. KRASILNIKOV, P. & GARCÍA CALDERÓN, N. A WRB-bases buried paleosol classification. **Quaternary International**, v. 156-157, Special issue, p. 176-188, 2006.
16. KRAUS, M. Paleosols in clastic sedimentary rocks: their geologic applications. **Earth Science Reviews**, v. 47, p. 41-70, 1999.
17. KRAUS, M. & GWINN, B. Facies and facies architecture of Paleogene floodplain deposits, Willwood Formation, Bighorn Basin, Wyoming, USA. **Sedimentary Geology**, v. 114, p. 33-54, 1997.
18. KRAUSE, J.M. & BELLOSI, E.S. Paleosols from the Koluel Kaike Formation (Lower-Middle Eocene) in the South-central Chubut, Argentina. A preliminary analysis. In: CONGRESO LATINOAMERICANO DE SEDIMENTOLOGIA, 4 y REUNIÓN ARGENTINA DE SEDIMENTOLOGÍA, 11, 2006, Bariloche. **Actas...** Bariloche, p. 125, 2006.
19. MACK, G. & JAMES, W. Paleoclimate and global distribution of paleosols. **The Journal of Geology,** v. 102, p. 360-366, 1994.
20. MACK, G.; COLE, D.; GIORDANO, T.; SCHAAL W.; BARCELOS J. Paleoclimatic controls on stable oxygen and carbon isotopes in caliche of the Abo Formation (Permian), south-central new Mexico, U.S.A. **Journal of Sedimentary Petrology**, v. 61, n. 4, p. 458-472, 1991.
21. MACK, G.; JAMES, W.; MONGER, H. Classification of paleosols. **Geological Society of America Bulletin**, v. 105, p. 129-136, 1993.
22. NETTLETON, W.; BRASHER, B.; BENHAM, E.; AHRENS, R. A classification system for buried paleosols. **Quaternary International**, v. 51/52, n. 7/8, p. 175-183, 1998.
23. NETTLETON, W.D.; OLSON, C.G.; WYSOCKI, D.A. Paleosol classification: problems and solutions. **Catena**, v. 41, p. 61-92, 2000.
24. PAZOS, M.S. & MOSCATELLI, G. The WRB applied to Pampean Soils, Argentina. In: WORLD CONGRESS OF SOIL SCIENCE, 16, 1998, Montpellier, France. **Proceedings...** Montpellier, Simposium 42, CD-ROM, 1998.
25. RETALLACK, G. A paleopedological approach to the interpretation of terrestrial sedimentary rocks: the mid Tertiary fossil soils of Badlands National Park, South Dakota. **Geological Society American Bulletin**, v. 94, p. 823-840, 1983.
26. RETALLACK, G. Classification of paleosols: Discusión and reply. **Geological Society of America Bulletin**, v. 105, p. 1635-1637, 1993.
27. RETALLACK, G. Core concept of paleopedology. **Quaternary International**, v. 51/52, n. 7/8, p. 203-212, 1998.
28. RETALLACK, G. **Soils of the Past**. London, Blackwell Science Ltd. Second edition, 404 p., 2001.
29. RUHE, R. Geomorphic surfaces and the nature of soils. **Soil Science**, v. 82, p. 441-445, 1956.
30. RUHE, R. & OLSON, C. Soil welding. **Soil Science**, v. 130, p. 132-139, 1980.
31. SCHIAVO, H.; BECKER, A.; CANTÚ, M. Caracterización y génesis de los fragipanes de la depresión de Curapaligüe, Dto. Saenz Peña, Córdoba. **Ciencia del Suelo**, v. 13, p. 28-34, 1995.
32. SOIL SURVEY STAFF. Soil Taxonomy. A Basic System of Soil Classification for Making and Interpreting Soil Surveys. Wisconsin: **Agriculture Handbook** nº 436. Second edition, 869 p., 1999.
33. SOIL SURVEY STAFF. **Claves para la Taxonomía de Suelos**. Departamento de Suelos de los Estados Unidos. Décima edición, 331 p., 2006.
34. SOLLEIRO-REBOLLEDO, E.; MACIAS, J.A.; GAMA-CASTRO, J.; SEDOV, S.; SUTERAHITSKY, L. Quaternary pedostratigraphy of the Nevado de Toluca volcano. **Revista Mexicana de Ciencias Geológicas**, v. 21, n. 1, p. 101-109, 2004.
35. YAALON, D.H. Soil Forming processes in time and space. In: YAALON, D.H. (Ed.), **Paleopedology**. Jerusalem, Israel University Press, p. 29-39, 1971.
36. ZÁRATE, M. & IMBELLONE, P. Problems and concepts of Paleopedology in Argentina. **Quaternary International**, v. 51/52, n. 7/8, p. 28-30, 1998.

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