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Palaeosol nomenclature and classification for South Africa: A new perspective

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ABSTRACT

Despite being well renowned for prominent palaeosols, there is no documented attempt at appraising the suitability of existing palaeosol nomenclature and classification systems for palaeosols from South Africa, even in the wake of increasing scientific awareness of the applicability of palaeosol-based proxies for palaeoenvironmental and palaeoclimatic reconstructions. In this study, selected palaeosols from five prominent sites in South Africa were classified using the landmark system of Mack et al. (1993) and the most recent classification system proposed by Krasilinikov and Calderón (2006). Sequel to field identification and description of the diagnostic horizons, the palaeosols were analysed using routine laboratory procedures for properties including particle size distribution, pH, calcium carbonate content, colour, elemental geochemistry, clay mineralogy and micromorphology for detailed characterisation and classification. The palaeosols qualified as ferric Calsisols, calcic Gleysol, concretionary Argillisol, ochric Calsisol and ochric Protosol using Mack et al. system; and Infracalsisol, Infraluvisol, Infraplinthisol and Infracambisol by Krasilinikov and Calderón system. Plinthite was quite prominent in the red palaeosol. We, therefore, suggest that another term be coined in the two systems to take care of palaeosols with outstanding preserved plinthic horizons. The complex nature of palaeosols and after burial alterations brings about a lot of changes which would have to be addressed by the international palaeopedology community in order to enhance communication and exchange of knowledge and formulation of relevant theories amongst scientists. Future studies of palaeosol classification in the region would benefit from a more robust and improved unified global classification scheme which would address the loopholes of the existing systems.

1. Introduction

Palaeosol is soil that formed on a landscape of the geological past. It carries the imprints of the pedogenic factors that are no longer operational in the present. In some cases, palaeosols could be found not preserved as complete and undisturbed profiles but features such as truncations, stone lines and superimposed allochtonous materials on genetic horizons can detect such discontinuities (Fedoroff et al., 2010; Eze and Meadows 2014a). Palaeosols are commonly classified into three major types on the basis of their position in a stratigraphic section and in the landscape namely buried, relict and exhumed soils (Birkeland, 1999). Buried soils are those which were not affected by later pedogenesis since the time they formed because they got buried by younger sediments. Non-buried or relict soils are at the land surface since the time of their initial formation and they may or may not have acquired their properties sometime in the past whereas exhumed soils were formerly buried but then exposed to current pedogenesis. Modern soil is, on the other hand, will be used in this manuscript to mean soils having properties from the presently operational soil-forming factors.

In principle, classification is an orderly way of grouping objects based on similarity of observable and/or measurable attributes, thereby improving systemisation of knowledge and enhancing communication. Classification opens new lines of research and allows for exchange of knowledge amongst stake holders. Unlike other fields of the Earth sciences including pedology, sedimentology, palaeontology, etc. which have well organised and, in some cases, universally accepted systems of classification, palaeopedology is still struggling in this area, as compared to its other aspects (Imbellone, 2011). Although there are numerous classification systems available for modern soils, the major topical challenge of palaeopedology has been the development and adoption of a unified classification system for palaeosols across the globe. Palaeopedologists strongly emphasize the need to not use classification schemes designed for modern soils for palaeosols for the following reasons: i) these systems do not focus on the limitations of palaeosols since they are not directly the object of study. For example, the definition of soils by Soil Survey Staff (1999) as "natural body comprised of solids (minerals and organic matter), liquid, and gases that occurs on the land surface, occupies space, and is characterized by one or both of the following: horizons, or layers, that are distinguishable from the initial

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material as a result of additions, losses, transfers, and transformations of energy and matter or the ability to support rooted plants in a natural environment" lends more credence to this; ii) higher order categories of modern classification uses climate information and this cannot be obtained from palaeoclimate models for palaeosols either for a palaeo geological unit or time frame (Imbellone, 2011).

Since there is no documented study aimed at reviewing or providing palaeosol classification systems in South Africa, palaeosol nomenclature has been incongruous. For example, Smith (1990) classified alluvial palaeosols of the Permian lower Beaufort in the south western Karoo basins after USDA *Soil Taxonomy* – a system much criticised since it takes climatic parameters into consideration, specifically Aridisols and Gelisols at the order level. The major limitation associated with IUSS-WRB, USDA *Soil Taxonomy* and South Africa Soil Classification System is that they are based on a large number of modern diagnostic soil properties such as cation exchange capacity (CEC), moisture content, organic matter content, bulk density, pH, base saturation, argillic horizons, thickness of horizons and compaction that are not, in all cases, preserved in palaeosols (Yaalon, 1971; Retallack 2001). In palaeosols, estimation of surface diagenetically altered horizons would be near impossible due to loss of organic matter by erosion and decomposition.

Several approaches have been applied globally for classification of soils and palaeosols, but none is generally endorsed by the palaeopedology community due to the inherent shortfalls in their formation concepts and definitions. In South Africa, the three most popular systems of modern soil classification systems include: World Reference Base (WRB-ISRIC-IUSS, 1998), USDA *Soil Taxonomy* (1999) and South African Soil Classification System (SCWG, 1991). The ISRIC-IUSS WRB system is used more internationally and, unlike USDA *Soil Taxonomy*, does not explicitly utilise climatic information in its classification. Since the works of Land Type Survey of South Africa and Van der Merwe (1940) – the all-inclusive accounts of soils of South Africa - soil classification has evolved remarkably in the country leading to the development of a South African Soil Classification System (SCWG, 1991). The South African soil classification system has two hierarchical elements: form and family to date, 73 forms and 400 families have been identified. To further improve communication via effective classification, Fey (2010) created and mapped these soils into 14 groups based on identification of diagnostic horizons as defined by the South Africa Soil Classification Working Group (1991). ISRIC-IUSS WRB and South African soil groups therefore have something in common – they both use modern diagnostic horizons and properties in their classification. Correlation with ISRIC-IUSS WRB proves that 25 out of 32 reference groups are present and represented in the 14 South African soil groups (Fey, 2010).

Notable classification systems developed for palaeosols include: i) the classification of Duchaufour (1982) which lays emphasis on pedogenic processes operating under certain environmental conditions rather than properties, a particular attribute that makes it suitable for both modern soils and palaeosols; ii) the landmark palaeosol-specific taxonomy of Mack et al. (1993). It is a hierarchical system that draws fundamentally from six observable pedogenic features or processes: organic matter content, horizonation, redox conditions, in situ mineral alteration, illuviation of insoluble minerals and accumulation of soluble minerals. The major drawback of this system as argued by Retallack (1993) is that since it is specifically meant for palaeosols, it could weaken communication between palaeopedologists and soil scientists. Other systems include those by Nettleton et al. (1998), later modified in Nettleton et al. (2000), Retallack (2001) and a recent system proposed by Krasilnikov and Calderon (2006). A very comprehensive review of the strengths and weaknesses of these systems is extensively presented in the work of Imbellone (2011).

There has been increasing awareness especially in the last decade about the reliability of palaeosol-based proxies for palaeoenvironmental and palaeoclimatic reconstruction (Retallack, 2014). In South Africa, palaeosols have been studied for inferences of palaeoclimates and palaeoenvironments (e.g. Botha and Fedoroff, 1995; Watanabe et al., 2000; Eze, 2013). Climate variables spanning precipitation, temperature and palaeo $p\text{CO}_2$ composition have been successfully reconstructed using palaeosol based proxies. It is against this backdrop that the need for a unified palaeosol classification system has become pressing so as to facilitate communication amongst scientists, in the same way as the universally-adopted binomial Linnaean system of plants and animal taxonomy works. In South Africa, however, there has been no previous attempt at classifying palaeosols despite their being widely distributed and that it is the locus of one of the world's oldest palaeosols (2.6 Gb ya) (Watanabe et al., 2000), being a cradle of humankind and single largest fossil hominin in Africa (McCarthy and Rubidge, 2013; Berger et al., 2015). In this paper, classification of selected palaeosols from five locations in South Africa using the well-known system proposed by Mack et al. (1993) and a recent system of Krasilnikov and Calderon (2006) were evaluated for their suitability. The study further highlights the need for a universal classification and nomenclature system for palaeosols.

2. Geographical and geological setting

Five palaeosol profiles were described, viz two at Langebaanweg Fossil Park (LBW) and one each at Koeberg, Glenhof road at the Cape Peninsula and Goukamma (Fig. 1). The Fossil Park is located approximately 120 km north of Cape Town and the exposed palaeosol profile is situated at latitude 32°57.784″ S and longitude 18°06.367″ E approximately 30 m above sea level. The local geology of LBW comprises Late Neogene Varswater formation (Fm) of the Sandveld group overlain by the Springfontyn Formation and calcareous aeolian deposit of the Langebaan formation (Fm) and Varswater formation (Roberts et al., 2011).

The exposed palaeosol at Koeberg is in a coastal cliff which lies north of Cape Town on the west coast at 33°37′15.0″ S and 18°23′27.0″ E, some 200 m northwest of the Koeberg nuclear power plant. Koeberg lies within the so-called winter rainfall zone (Chase and Meadows 2007) and today receives around 372 mm precipitation annually.

The palaeosol at Glenhof road represents a soil-geomorphic unit and is located near the foot of the iconic Devil's Peak (a prominent projection of the Table Mountain), formed of Palaeozoic Cape Supergroup rock. The amount and spatial distribution of rainfall in the region is strongly variable and strongly influenced by topography, although the mean annual precipitation and temperature for the location are 1300 mm and 17.3 °C respectively (Harris et al., 2010). The site is underlain at depth by deeply weathered meta-sedimentary strata of the Neoproterozoic Tygerberg Formation of the Malmesbury Group. The meta-sedimentary strata originally comprised deep water marine mudrock and are mantled by relatively thin deposits composed of alluvial river terrace material (Kantey and Templer Pty, 2008).

The palaeosol section at Goukamma Nature Reserve is exposed on the seaward side of a dune barrier a few kilometres east of Sedgefield between 34°02′48″ S, 22°50′20″ E and 34°02′53″ S, 22°50′43″ E. Goukamma receives precipitation all year round from a combination of both winter cyclonic and tropical easterly flow activity (Weather Bureau, 1986). Both Koeberg and Goukamma are underlain by strata of established aeolian sedimentary patterns which were established in the Late Tertiary and persisted into the Quaternary (Roberts et al., 2009, Bateman et al., 2011).

3. Materials and methods

3.1. Field sampling

Undisturbed hand samples were then taken from each horizon of the palaeosol profiles. These samples were specifically marked for thin section preparation. More representative samples were also collected and bagged for further laboratory investigations. In the field, colour