2

PEDOLOGICAL PERSPECTIVE

Concepts and facts

Michel Brossard and Jeanne Brancier

Introduction: the soil system

Soils form a continuous cover on continents at the confluence of atmosphere, biosphere and geosphere. Soil is a complex mixture of mineral and organic particles, resulting from weathering of parent rock material and biogeochemical processes acting over time. Soils can be young, for example, on recent volcanic or sedimentary deposits, but they can also be the cumulative result of centuries and millennia, such as neotropical ferralsols on old lithology (Gardi *et al.* 2014). In addition, they are three-dimensionally organised on kilometric, hectometric, metric, centimetric and micrometric scales.

The finest levels of organisation (from nanometres to centimetres) concern clay particles, hydroxides, intraelement porosity, organic matter (OM), bacteria and hyphae and the association of these components in microaggregates. This 'soil fabric' (see Chapter 3), described by micromorphological approaches, plays an essential role in soil functioning and in the acquisition of features whose evolution over time can be studied. But previous studies have also provided a robust set of arguments for the analysis of physical and geochemical properties of soils (see Pansu and Gautheyrou 2006, and Chapter 4). For all these detailed approaches, a coherent sampling strategy relies on a macromorphological (from decametric to centimetric scales) description of horizons and their vertical stratification (the 'solum'). The highest description level is that of the catena (the chain of soils along land cover), from hectometre to kilometre. Since its origins (Milne 1947), the concept of catena has evolved. It is now generally considered a continuous mantle of soils, even if the observed soils are the result of different clay formations, weathering stages and/or different parent materials (Brabant 1991; van Wambeke 1992). The catena and toposequences representations allow a global understanding of the distribution of soils in space.

Soils and the past

Geoarchaeology is the part of environmental archaeology that consists of a blending of archaeology with soil science, and is concerned with studying soils and sediments present on archaeological sites. It aims to make the soils talk and to reveal the invisible of the history (Cammas 2015; Cammas and Wattez 2009).

Indeed, soils can register over time the environmental and human-induced changes, and thus become an archive, called 'soil memory' (Brochier 2002; Pomel 2008). However, current environmental conditions do not always allow these archives to be read and interpreted. Then, the main issue in a possible archaeological context is to distinguish geological temporalities from pedological ones before starting an actual pedoarchaeological study (Schwartz 2012).

Within the *anthrosols* class of the World Referential Base (IUSS 2014), the particular category of archaeological soils is recognised by certain national classifications. For example, the French soil reference (Baize and Girard 2008) describes *archaeological anthroposols* as soils modified to a thickness of more than 50 cm and containing more than 20% (by volume) of artefacts (pottery fragments, charcoal, etc.); the US Soil Taxonomy qualifies them as *anthreps*, based on the diagnostic horizon thickness (USDA 1998). Recently, Brancier *et al.* (2018) proposed some changes in the definition of archaeological anthroposols by including micromorphological and geochemical features, therefore enhancing the need for a robust geoarchaeology.

Soil as an open system and soil features

Soils are continuously submitted to matter and energy fluxes, so that organic and inorganic materials are weathered, transformed and disappear. Water infiltration solubilises the elements and transfers them to the water table and streams. Although some can be brought in by sedimentation and colluvium, as well as by wind, most of the soil's mineral elements are inherited from the weathering front, i.e. the volume of soil above the bedrock. Some, such as quartz, are hardly weathered, while others (e.g. micas) are transformed into clays or even rapidly dissolved (e.g. feldspars). The sandy fraction of soils (i.e. particles from 50 µm to 2000 µm) is inherited from the parent material. Thus, the physical characterisation of the solum (see Chapter 4) and its horizons provides direct information on soil origin and can confirm any discontinuities observed in the sequence of horizons.

With regard to the evolution of the solid mineral phase during soil development, the 'young minerals' are found in the deepest, weathering layers (saprolite), while older ones are generally near the surface (Allard *et al.* 2018). This apparent paradox is probably not unrelated to the large confusion made between layer, soil layer, horizon and sediment. In our approach, the term sediment is used in its geoscience meaning: 'solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, or ice, and has come to rest on the earth surface' (Gregorich *et al.* 2002). Soil layers, or horizons, are units of iso-functioning and should not be considered chronostratigraphic units.

This emphasises the need for a robust description of soils, sites and anthropogenic features in the overall geopedological context (Schwartz 2012).

OM is also continuously transformed by bacteria, fungi and soil microfauna and macrofauna. It is also transported by solubilisation and physically by soil macrofauna (geophagous earthworms, ants, termites). The latter process is called bioturbation. Depending on biogeochemical and physical conditions, OM can form specific complexes with cations and clay minerals. The vertical and lateral redistribution of OM reveals in some soils peculiar pedogenic processes (e.g. Duchaufour *et al.* 2018; Hartemink and McSweeney 2017). Bioturbation can displace a large volume of materials (Boulet *et al.* 1995; Brossard *et al.* 2007), including small archaeological artefacts, and is one of the phenomena that promote the transformation of structure and porosity (Brossard *et al.* 2012). Under tropical conditions this bioturbation is one of the reasons why soil horizons are poorly expressed macroscopically, for example, in ferralsols. Soil macrofauna also exerts a granulometric sorting. Chapter 14 illustrates the particular rôle of macrofauna bioturbation in ancient earthworks.

If we consider soils as open systems and their constituents are in transition, then how to approach archives and chronologies?

Lamotte and Marliac (1989) presented a topographic organisation of sedimentary and anthropogenic materials and the relationships between soil constituents, anthropic features, structures and processes resulting from descriptions and analysis. The detection of anthropogenic material requires a spatial description of soil cover and the relationships between horizons. The latter clearly reveals the position of natural soil horizons relative to the anthropogenic material used to build a mound. It also delineates the two systems: the natural soil and the archaeological anthroposol. Soil constituents (the clay fraction <2 μm and sand) are observed in all the structures. The hardpan (a soil layer hardened by cementation of soil particles with OM or minerals) is not a human construction but can be distinguished by micromorphology from hard blocks, which are 'adobe' residues.

The volcanic deposits of Mount Pelée (Martinique, French West Indies) are an example of particular complexity. Quantin *et al.* (1991) studied soil development on dacito-andesitic pyroclasts. They showed that on the deposit dated 1670 yr BP, the weathered horizon reached a depth of 30 to 50 cm. From top to bottom of the profile, the median particle size decreases from approximately 2 mm in the youngest soil (48 yr BP) to 0.2 mm in the oldest one (1670 yr BP). On the contrary, the mass of secondary products increases from 1–2% (48 yr BP) to approximately 10% (1670 yr BP). Seventy per cent of the secondary products (neoformed) were found in particles finer than 20 μm. These products have a high content of aluminium and are composed mainly of allophanic compounds, and small amounts of clay minerals have been detected, mainly microspherical halloysite. Thus, for the pedo-archaeological approach, it has been necessary to consider the fact that pedogenic processes, which are very young here, promote the thickness of the soil horizon and a continuous modification of the nature of the mineral phase. The latter is continuous because a younger deposit covered the oldest pumice stone deposit and brought back new products. Brancier *et al.* (2018), through a rigorous micromorphological study, showed that soil formation results from the juxtaposition of natural pedogenic processes and pre-Columbian anthropogenic action on one of the pumice deposits.

The distribution of OM also illustrates our point. We know that OM comes mainly from above- and below-ground plant biomass. Biomass decomposition processes promote the construction of the upper organo-mineral soil layer. In general, the distribution of carbon concentration in the soil decreases with depth. For example, the top 0.5 m of French Guianan soils contain more or less 70% of the carbon stock in the first metre of soil. This upper OM is the most recent, and the older one is redistributed in deeper layers, in which there is a continuous mixture of recent inputs (from litter and roots) and 'old' OM. Therefore, the chronological distribution of soil OM is not random. In fact, in a given layer, the apparent age of OM seems constant over time because the OM is continuously renewed. Meanwhile, the charcoal in the same horizon is ageing.

The nature of the carbon source (i.e. the vegetation type) has a signature. If the vegetation type is stable over time, the isotopic signature $\delta^{13}C$ will be fairly constant in soil profiles, and slight variations in $\delta^{13}C$ patterns will be explainable by minor changes in vegetation and/or pedogenic processes (Freycon *et al.* 2010). But it is difficult to link the variations of $\delta^{13}C$ to OM age. Thus, the age of charcoal alone does not prove that the volume of soil where it was found is a layer built by past human activities. Moreover, the origin and distribution of charcoal in the soil are not always due to human action. The processes leading to their incorporation into the soil are complex and, to be conclusive, their presence must be linked to that of archaeological remains.

Water dynamics and hydromorphy

Lowland soils have long been of great interest to human societies because they are usually fertile. Their position in the catena leads to successive deposits of sediments, which are transformed in pedogenic horizons, generally under conditions of poor drainage, i.e. excessive moisture. Depending on water dynamics, exogenous water input and the depth of the water table, these soils can have a large gradation of hydromorphic features. Due to the saturation of porosity by water over time, they display characteristic reddish/brownish/yellowish colour in the uppermost horizons and greyish/bluish colour in the deeper ones.

The interest of these soils from a pedoarchaeological point of view is that hydromorphy preserves OM and other features. However, the main problem is to account for the heterogeneity of the deposits transformed by pedogenic processes in order to distinguish anthropogenic effects. Cumulative effects are not always clear. For example, the current groundwater dynamics may be different from what it was when human activities developed. Pedological work must be supported by systematic surveys and light detection and ranging (LiDAR) or infrared techniques in order to detect past earthworks intended for water control, but also any three-dimensional structure that appears as a rupture in the soil cover. At the pit scale, a deep organic layer is not necessarily anthropogenic. Most often, it is an ancient upper layer that has been covered by post-sedimentary deposits. The past 'way of water' is also generally different from that of today. Field survey with augers in large areas allows us to describe these horizons, their extension and their association with other diagnostics horizons.

Even if soil water saturation tends to preserve past features, soil functioning can affect some of them. Huisman *et al.* (2017) measured and characterised biological decay processes and chemical and mineralogical modifications of bones in wetland soils. They pointed out that the alternation of wet and dry conditions resulted in the dissolution of some of the bone mineral and the formation of Ca-Fe(III) phosphates and that the mechanism 'apparently ended when the bone-rich layer became permanently waterlogged and anoxic'. One of their conclusions was that variations in redox conditions keep chemical, mineralogical and biological processes active. In other words, the open soil system is active and incorporates the bone-rich layer.

Other recent approaches

Diffuse reflectance spectroscopy in the visible and near infrared (Vis-NIR) has been used in soil science in recent decades (Stenberg *et al.* 2010). This methodology appears interesting for the recognition of vegetation signatures in soils (Ertlen *et al.* 2015).

We stressed the importance of matter transfer, as human activities can strongly impact these processes by increasing soil erosion. In the study of the dynamics of mineral transfers, the use of inorganic elements is constantly evolving. Meteoric ^{10}Be, ^{137}Cs and ^{210}Pb have been widely used in the last decades, due to their contrasting half-lives and input histories: ^{10}Be allows us to investigate the millennial timescale, while ^{137}Cs and $^{210}Pb_{(xs)}$ give access to the decadal one (de Tombeur *et al.* 2020).

Conclusive words

Although the main issue is to identify and interpret past occupation patterns, the effect of prolonged and/or spatially extended human activity must be considered (Figure 2.1).

The main questions, including hypotheses, must be identified in the field. Fieldwork is essential for the description of the site solum, the definition of sampling strategy and a first choice of analyses to be conducted. Although the costs of analyses are generally lower than for detailed field approaches, the analytical phase is not routine. It involves a discussion depending on the soil types, the nature of the features measured and may sometimes require a large set of methods, such as geochemical and mineralogical analyses (Pansu and Gautheyrou 2006; Baize 2018, and Chapter 4).

In addition, identification and inventories are specific issues for which it is necessary to create reference collections of soil samples. The first is in micromorphology (Chapter 3) and concerns soil features and the various anthropogenic artefacts. The second is to allow future analyses with new techniques or to carry out verifications or analytical corrections.

The features we observe today are the integrative result of mechanisms that occur over time. In a pedoarchaeological approach, the only way to ensure that the

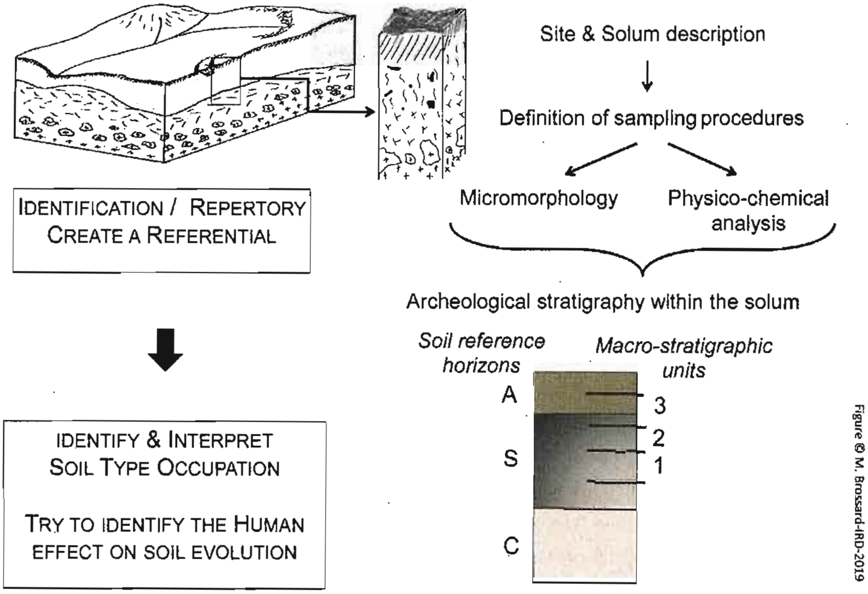

FIGURE 2.1 The pedological perspective, when it comes to past human activities: from reality to interpretation and concepts

traits are the results of human actions is to conduct iterative prospecting, from the field to the microscope and geochemical approaches.

Acknowledgements

JB benefited from an 'Investissement d'Avenir' grant managed by the Agence Nationale de la Recherche (Labex CEBA ANR-10-LABX-25–01).

References

Allard, T., Gautheronb, C., Bressan Riffel, S., Balan, E., Fernandes Soares, B., Pinna-Jamme, R., Derycke, A., Morina, G., Taitson Buenoe, G., and do Nascimento, N., 2018. Combined dating of goethites and kaolinites from ferruginous duricrusts. Deciphering the Late Neogene erosion history of Central Amazonia. *Chemical Geology*, 479, 136–150.

Baize, D., 2018. *Guide des analyses en pédologie*. Versailles: Quæ.

Baize, D. and Girard, M-C., eds., 2008. *Référentiel Pédologique*. Versailles: Quae.

Boulet, R., Pessenda, L.C.R., Telles, E.C.C., and Melfi, A.J., 1995. Une évaluation de la vitesse de l'accumulation superficielle de matière par la faune du sol à partir de la datation des charbons et de l'humine du sol: exemple des latosols des versants du lac Campestre, Salitre, Minas Gerais, Brésil. *Comptes Rendus de l'Académie des Sciences de Paris. Série 2a*, 320 (4), 287–294.

Brabant, P., 1991. *Le sol des forêts claires du Cameroun: exemple d'étude d'un site représentatif en vue de la cartographie des sols et de l'évaluation des terres*. Paris: ORSTOM.

Brancier, J., Cammas, C., Todisco, D., Jégouzo, A., Romon, T., and van den Bel, M., 2018. Origine, caractérisation et modes d'occupation des Anthroposols Précolombiens : Approche micromorphologique comparée de deux sites en Martinique et Guyane Française. *Géomorphologie : Relief, Processus, Environnement*, 24 (3), 301–319.

Brochier, J.E., 2002. Les sédiments anthropiques. Méthodes d'étude et perspectives. *In:* J.-C. Miskovski, ed. *Géologie de la Préhistoire : Méthodes, Techniques, Applications*. Paris: Géopré, 453–477.

Brossard, M., Fregonezi, G.A.D., Guimaraes, M.D., Medina, C.D., Pasini, A., Vilela, L., and Ayarza, M.A., 2012. Analysis of an illustrative interaction between structural features and earthworm populations in Brazilian ferralsols. *Comptes Rendus Geoscience*, 344 (1), 41–49.

Brossard, M., López-Hernández, D., Lepage, M., and Leprun, J.-C., 2007. Nutrient storage in soils and nests of mould-building *Trinervitermes* termites in Central Burkina Faso: consequences for soil fertility. *Biology and Fertility of Soils*, 43, 437–447.

Cammas, C., 2015. *L'anthropisation des systèmes pédo-sédimentaires aux périodes protohistoriques et historiques : Une recherche sur les sols urbains (Géoarchéologie et Micromorphologie)*. Paris: AgroParisTech.

Cammas, C. and Wattez, J., 2009. L'approche micromorphologique : méthode et application aux stratigraphies archéologiques. *In:* J.-P. Bravard, C. Cammas, P. Nehlig, P. Poupet, P.-G. Salvador, and J. Wattez, eds. *La géologie, les sciences de la terre appliquées à l'archéologie*. Paris: Errance-Actes Sud, 181–216.

de Tombeur F., Cornu S., Bourlès D., Duvivier A., Pupier J., Team ASTER, Brossard M., and Evrard O., 2020. ^{10}Be, ^{137}Cs and $^{210}Pb_{xs}$ in soils: impact of physico-chemical characteristics. *Geoderma*, 367, 114242.

Duchaufour, P., Faivre, P., Poulenard, J., and Gury, M. 2018. *Introduction à la science du sol*. 7e éd. Paris: Dunod.

Ertlen, D., Schwartz, D., Brunet, D., Trendel, J.M., Adam, P., and Schaeffer, P., 2015. Qualitative near infrared spectroscopy, a new tool to recognize past vegetation signature in soil organic matter. *Soil Biology and Biochemistry*, 82, 127–134.

Freycon, V., Krencker, M., Schwartz, D., Nasi, R., and Bonal, D., 2010. The impact of climate changes during the Holocene on vegetation in northern French Guiana. *Quaternary Research*, 73, 220–225.

Gardi, C., Angelini, M., Barceló, S., Comerma, J., Cruz Gaistardo, C., Encina Rojas, A., Jones, A., Krasilnikov, P., Mendonça Santos Brefin, M.L., Montanarella, L., Muñiz Ugarte, O., Schad, P., Vara Rodríguez, M.I., and Vargas, R., eds., 2014. *Atlas de suelos de América Latina y el Caribe*. Luxembourg: Comisión Europea.

Gregorich, E.G., Turchenek, L.W., Carter, M.R., and Angers, D.A., 2002. *Soil and Environmental Science Dictionary*. New York: CRC Press.

Hartemink, A.E. and McSweeney, K., 2017. *Soil Carbon*. Berlin: Springer.

Huisman, H., Ismail-Meyer, K., Sageidet, B.M., and Joosten, I., 2017. Micromorphological indicators for degradation processes in archaeological bone from temperate European wetland sites. *Journal of Archaeological Science*, 85, 13–29.

IUSS Working Group WRB, 2015. *World reference base for soil resources 2014. International soil classification system for naming soils and creating legends for soil maps, update 2015. World soil resources reports No. 106*. Rome: FAO.

Lamotte, M. and Marliac, A., 1989. Des structures complexes résultant de processus naturels et anthropiques: exemples du tertre de Mongossi au Nord-Cameroun. *Bulletin de la Société Préhistorique Française*, 10 (12), 420–428.

Milne, G., 1947. A soil reconnaissance journey through parts of Tanganyika territory. *Journal of Ecology*, 35, 192–269.

Pansu, M. and Gautheyrou, J., 2006. *Handbook of Soil Analysis: Mineralogical, Organic and Inorganic Methods*. Berlin: Springer.

Pomel, S., 2008. *La mémoire des sols*. Bordeaux: Presses universitaires de Bordeaux.

Quantin, P., Balesdent, J., Bouleau, A., Delaune, M., and Feller, C., 1991. Premiers stades d'altération de ponces volcaniques en climat tropical humide (Montagne Pelée, Martinique). *Geoderma*, 50 (1–2), 125–148.

Schwartz, D., 2012. Les temps du sol: interprétations temporelles de l'archivage pédologique dans les approches paléoenvironnementalistes et géoarchéologiques. *Étude et Gestion des Sols*, 19 (1), 51–66.

Stenberg, B., Viscarra Rossel, R.A., Mouazem, A.M., and Wetterlind, J., 2010. Visible and near infrared spectroscopy in soil science. *In:* D.L. Sparks, ed. *Advances in Agronomy*. Burlington, MA: Academic Press, 163–215.

USDA, 1998. *Keys to Soil Taxonomy*. 8th ed. Washington, DC: Natural Resources Conservation Service.

van Wambeke, A., 1992. *Soils of the Tropics: Properties and Appraisal*. New York: McGraw Hill.

Brossard Michel, Brancier J.

Pedological perspective : concepts and facts.

In Odonne G. (ed.), Molino Jean-François (ed.). Methods in historical ecology : insights from Amazonia.

New York (USA) : Routledge, 2021, 17-24.

(New Frontiers in Historical Ecology). ISBN 978-0-367-18221-2