Chapter 2
Formation and Properties of Urban Soils

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Abstract Urban soils form by the same overall set of processes that are involved in the formation of all soils. In this chapter we combine two general approaches to understanding soil formation, the first based on state factors and the second on soil fluxes. We review the soil properties used for identification and classification. The concepts of anthroposequences and urbanisation gradients are introduced, and the soil groups important for urban environments, Anthrosols and Technosols, are described. Changes in geomorphology caused by urbanisation, such as modification of hydrology and landforms created by additions of removal of material, are discussed. Specific examples of soils in modified urban environments, such as reclaimed coastal land, landfills, and constructed wetlands, are presented. Finally, this chapter explores the archaeological landforms and soil properties present in historical and contemporary cities, and the range of chemical, physical, and biological archaeological information stored in urban soils.

Keywords Soil formation · Pedogenesis · Urban soils · Geomorphology · Anthropogenic landforms · Archaeology · Soil properties · Technosols

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Some of what you could learn from this chapter:

- The basics of soil formation processes (pedogenesis) and soil classification as it applies to urban soils
- How landforms in urban environments have been modified
- The ways in which urban soils differ from (or resemble) non-urban soils
- The types of archaeological information preserved by soils and how archaeological information can be obtained from soils

2.1 Introduction to Urban Pedology and Pedogenesis

The processes which result in formation of urban soils from their parent materials can be understood using the conceptual frameworks used for soil formation in general. As a result, this chapter will first present and discuss the basics of the main concepts involved when considering soil formation in any environment.

McKenzie et al. (2004) summarise the two main approaches to understanding *pedogenesis*, or soil formation: first, the *state factor* approach, where observable soil properties reflect the environment during soil formation (including climate, organisms, parent material, relief, and time), and second, what we will call the *soil fluxes* approach, involving additions and losses to and from soil systems and transformations and translocations of materials within the soil environment. It is most useful to have an understanding of both approaches in order to have a complete understanding of soil formation.

2.1.1 State Factors and Soil Formation

The **state factor** approach to understanding soil properties and formation was most likely first developed in the late 1800s by the Russian scientist Vasily Dokuchaev (Evtuhov 2006). Dokuchaev viewed a soil as an independent environmental compartment, which has properties reflecting the combined influence of subsoils, climate, flora and fauna, geological age, and relief in the same location. This concept was developed further by several scientists and became a foundational idea in soil science following publication of *Factors of Soil Formation* by American scientist Hans Jenny (Jenny 1941). A common way of expressing the state factor model of soil formation is in the so-called clorpt equation (Eq. 2.1):

$$\text{soil properties}, S = f\left(\text{cl,o,r,p,t,}\ldots\right) \tag{2.1}$$

where $f(\ )$ represents 'a function of'; cl = climate, o = organisms, r = relief (topography/altitude), p = parent material, t = time, … = any other factors (e.g. localised phenomena such as fire).

The scale of the *clorpt* factors is similar to the scale of observation for difference in soil properties. For example, when considering difference on soil profiles on a continental scale, we would consider large-scale differences in factors such as basin- or craton-scale differences in geological parent material, global climatic zones such as those in the Köppen-Geiger climate classification (Kottek et al. 2006), and large-scale relief such as mountain belts. In contrast, for an urban ecosystem, we would need to consider smaller-scale phenomena such as urban microclimates (e.g. an urban heat island), changes in parent material over short distances as a result of human disturbance, and smaller-scale relief such as individual hillslopes or excavations.

2.1.2 Soil Fluxes and Soil Formation

The **soil fluxes** approach to understanding soil formation and properties is derived from Simonson (1959) in which the focus is on the processes occurring in the soil itself. In this approach (called the 'process-systems' model by Schaetzl and Anderson 2005), the observable properties of a soil profile represent the balance of additions to or losses from soil, as well as translocations and transformations of material within soil. If the balance between additions, losses, translocations, and transformations differs, then the resulting soil profile will have different properties. The soil fluxes approach implies a more dynamic view of soils, since the processes involved are common to all soils, but the relative degree to which they occur affects the soil properties which can be observed at any point in time. For example, continued additions of material to a soil environment, such as net accumulation of organic matter, will ultimately result in a different soil profile.

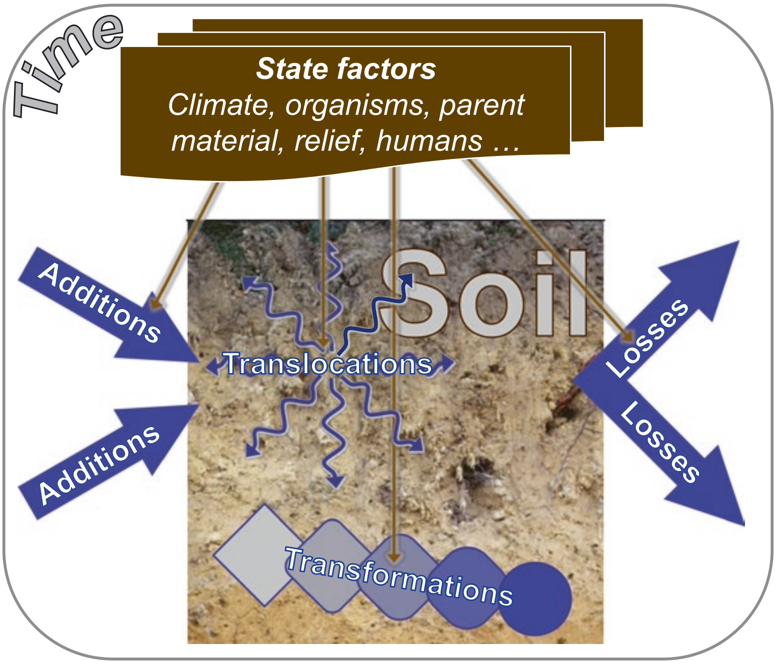

Fig. 2.1 A two-way conceptual approach to soil formation, showing the state factors in *italic text* and the soil fluxes in **bold text**. The state factors affect the relative amounts and types of soil fluxes. Time is shown as a separate overarching state factor since the other state factors are not constant but vary with time

A soil's properties reflect the relative sizes of *soil fluxes*: additions, losses, translocations, and transformations of material; however, this approach alone is not enough to fully understand soil formation and the resulting soil properties. A combination of both approaches described here is more satisfying, in that it is the *state factors* that affect the sizes and types of soil fluxes that occur. We have tried to show this combined model of soil formation graphically in Fig. 2.1, which also treats time as a special factor because it is a dimension that all other factors and fluxes operate in. The unique combination of time, state factors, and fluxes results in different observable properties in a soil profile, and a list of the types of soil properties considered important in discriminating different types of soils appears in Box 2.1. Most these properties are important for other purposes as well, since they affect the ability of soils to perform critical environmental functions such as supplying water and nutrients to plants or modifying the behaviour and toxicity of pollutants. We will address these soil functions in detail in Chaps. 4, 5, 6, 7 and 8.

Box 2.1: Soil Properties Used to Identify Different Soil Types and Classify Soils

All of the soil properties below are controlled by the effects of the state factors on soil fluxes.

Horizons – these are the approximately horizontal, layer-like features in soil caused by pedogenesis. Soils differ in the types, thicknesses, colour, etc. of horizons and other properties (see below), whether or not there is distinct contrast between horizons, whether horizons are well-developed, and so on.

Soil organic matter – concentration of soil organic carbon, depth(s) of accumulation.

Soil texture – measured by the relative amounts of sand (0.05–2 mm), silt (2 μm–0.05 mm), or clay-sized (<2 μm) grains or particles in the *fine earth* (<2 mm) fraction of soils.

Mineral types – especially type of clay but also carbonate minerals, iron oxides, silica, or presence/absence of disordered minerals, volcanic glasses, gypsum, etc.

Exchangeable cations and soil pH – some soil materials (especially clay minerals and organic matter) carry negative electrostatic charge which is balanced by the dominant cations in soil. The relative concentrations of these cations (H^+, Al^{3+}, Na^+, Mg^{2+}, K^+, Ca^{2+}) are related in part to soil pH.

Soluble salt content – a few minerals (salts) dissolve easily in water, and, if salts are abundant in soil, the result is high concentrations of salts in soil pore water. Such a soil would be considered saline.

Climate- and/or hydrology-controlled features – frozen subsoils, extremely leached horizon(s), saturation with water, arid-zone soils, desert pavements.

Presence of rock-like materials – stoniness and composition of rock fragments, cementation within or between stony components.

Degree of weathering or alteration – how different the soil material(s) are from the parent material.

Human modification – such as mixing by cultivation, presence of anthropogenic artefacts.

2.1.3 *Pedogenesis of Urban Soils*

A combined state factor-soil fluxes approach makes sense in urban systems if the effects of human activity are simply included in the ‘organisms’ state factor. Some soil scientists, however, consider anthropogenic effects as a separate state factor (e.g. Amundson and Jenny 1991). Even though inclusion of a human state factor is not restricted to urban environments, this is a useful approach to take given the great importance of human modification in cities. The impact of humans can also change some other state factors affecting soil formation, for example, by introducing new plant and animal species, creating new landforms and, more recently, modifying local and global climates.

In some environments, the state factor approach can be understood more easily by carefully choosing soils in locations which allow us to isolate the effects of a single factor on soil formation and properties. This leads to the concept of *soil sequences*, in which a series of geographically separated soils show a gradient in only one state factor, with the other state factors being approximately constant throughout the soils’ development. The most commonly studied of these is probably the *toposequence*, where the changing state factor is **relief**, such as a sequence of soils from the top to bottom of a hillslope. A detailed discussion of soil sequences (e.g. toposequences, chronosequences, climosequences) is not within the scope of this book, but readers are referred to excellent discussions of this topic in Schaetzl and Anderson (2005) and White (2006). It is possible, however, to make an analogy between the more commonly studied soil sequences and soil sequences where the state factor that changes is predominantly the human factor. This type of soil sequence, an *anthroposequence*, has been studied along urban to rural gradients, showing changes in several soil properties from the rural-urban fringe to the urban core (Pouyat et al. 1995). In many cases the changes in soil properties along an urban-rural gradient represent additions of substances to soils by human activity (Figs. 2.2 and 2.3).

The existence of soil sequences along urbanisation gradients means that there is effectively a continuum of urban effects related to urbanisation. A question then emerges: do truly urban soils exist? The best answer to this question is probably

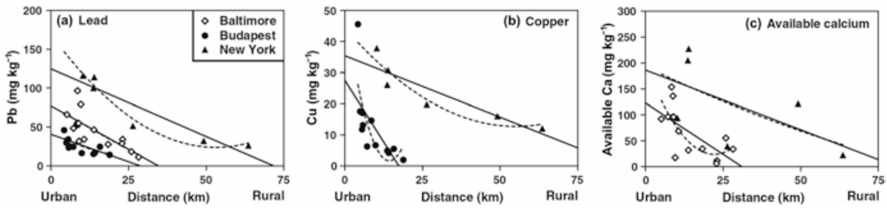

Fig. 2.2 An example of a soil anthroposequence shown by gradients in soil properties: (**a**) lead concentration, (**b**) copper concentration, and (**c**) available calcium concentration, in relation to distance from urban centres (from Pouyat et al. (2008); used with permission from Springer). ‘Available calcium’ refers to Ca extracted from soil using dilute acid solutions

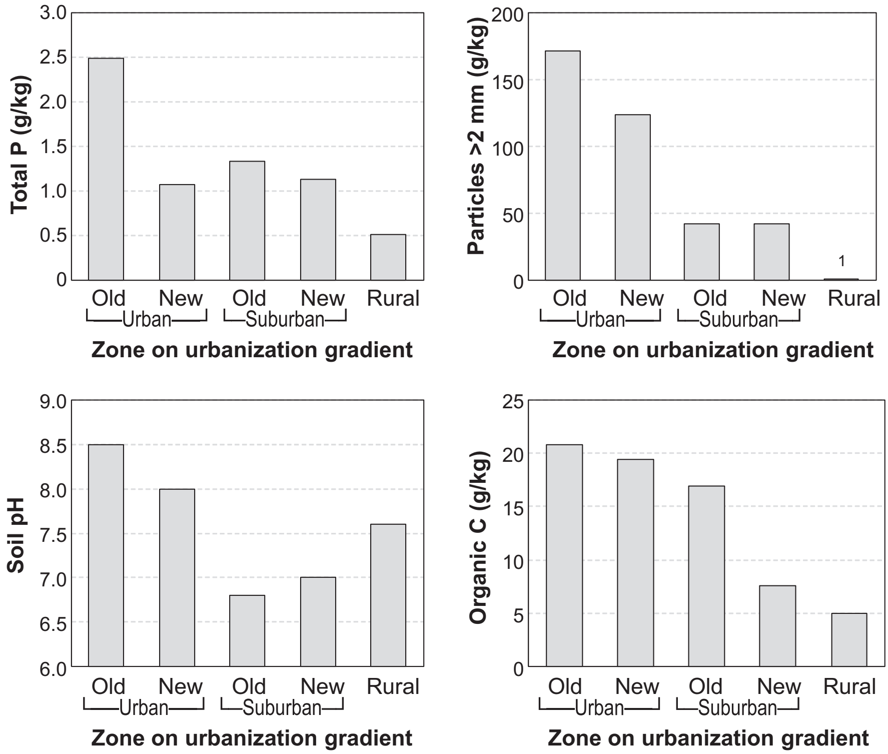

Fig. 2.3 Differences in soil properties along an urbanisation gradient. (Redrawn from data in Table 1 in Zhang (2004))

provided by soil classification schemes. There are numerous soil classification schemes in use, which can be confusing, so we will use examples from the most widely used international soil classification system, the International Union of Soil Sciences' 'World Reference Base for Soil Resources' (IUSS Working Group WRB 2014). Soil classification schemes are most often hierarchical; that is, they classify soils into broad categories based on diagnostic soil properties such as the existence of a certain type of *horizon*. If we assume that an urban soil must reflect human influence on its formation, then two groups of soils in the World Reference Base, called *Anthrosols* or *Technosols* (IUSS Working Group WRB 2014), are the most likely candidates.

Another framework for understanding urban soils is that of Soils of Urban, Industrial, Traffic, Mining, and Military Areas (SUITMAs) as proposed by Morel and Heinrich (2008). The SUITMA concept considers urban soils together with other soils having significant anthropogenic influence on their formation but which are not necessarily located in cities.

The *Anthrosol* soil group mainly relates to the effects of long-term cultivation on soil formation. The historical association of urban areas with fertile soils and food production that we covered in Chap. 1 makes it likely that many urban soils are also (former) Anthrosols. However, Anthrosols clearly also occur in non-urban environments, so they are not unique to urban areas. The *Technosol* soil group is characterised by the presence of materials which have been manufactured or relocated by humans, so Technosols would therefore seem to more obviously represent urban soils. Of course, Technosols are also present in non-urban environments; for example, in remote areas, the deep *regolith* or rock materials ('spoils') displaced by mining activities can form the substrate on which a soil develops (Rossiter 2007). Consequently, like Anthrosols, Technosols are also not unique to urban environments. Box 2.2 contains a summary of the criteria used to identify anthropogenic soils in different environments, with examples from three soil classification schemes.

The lack of uniqueness of the World Reference Base's two anthropogenic Reference Soil Groups to urban environments does not mean that soil classification schemes are inadequate tools for describing or defining urban soils. Another great advantage of a soil classification is that it provides a structured conceptual framework for describing and understanding soil properties and soil formation. In the World Reference Base, the concepts that help us to understand soils are encapsulated in the principal and supplementary qualifier terms. For example, a 'garbic Technosol' identifies a soil with ≥20% artefacts in the upper 1 m, with the artefacts composed of or containing anthropogenic organic waste materials (i.e. garbage, which inspires the term 'garbic'). The qualifiers can be used to identify human features in non-anthropogenic Reference Soil Groups as well; for example, the suffix 'transportic' is used to indicate natural soil material which has been moved (transported) by humans to another location (for more explanation see Rossiter 2007). Similarly, the presence of artefacts below the 20% threshold required for classification as a Technosol can be important, so the qualifier 'technic' can be appended to many of the Reference Soil Groups.

The concepts summarised in soil classifications such as the World Reference Base can therefore help us with the identification and description of soil environments consisting of both natural materials affected by urban phenomena and natural processes acting on urban materials. The emphasis, in many soil classifications, on horizons as the primary diagnostic criterion (i.e. macroscale phenomena) means that more subtle effects may be missed. Even when the classification can be based on soil composition rather than a diagnostic horizon, the thresholds imposed by soil classification schemes may not allow informative terms to be used within the classification. For example:

- The World Reference Base requires anthropogenic horizons to be at least 50 cm thick for the soil to be an Anthrosol.
- The World Reference Base requires artefacts to comprise ≥20% of soil volume for the classification of Technosol to be applied or 10–20% artefacts by volume to use the 'technic' qualifier.
- The Australian Soil Classification (Isbell 1996) requires additions of anthropogenic material ≥30 cm deep or that soil features reflecting natural pedogenesis have been erased by human activity, for some suborders of Anthroposols.

Box 2.2: Examples of Diagnostic Properties of Anthropogenic Soils in Soil Classifications.

Classification	Highest-level category	Criteria for highest category	Subcategories and criteria
World Reference Base of the International Union of Soil Sciences (IUSS Working Group WRB 2014)	*Anthrosols* (reference soil groups)	Various types of horizon ≥50 cm deep created by activities related to cultivation	*Hydragric* – paddy soils *Irragric* – irrigated soils *Hortic* – fertilisation and organic residues *Plaggic* – manure and sod application *Pretic* – charcoal, artefacts *Terric* – added mineral material and deep cultivation
(as above)	*Technosols*(reference soil groups)	Primarily, ≥20% by volume of artefacts in upper 1 m or with a geomembrane or hard, consolidated layer of industrial origin	*Ekranic* – hard material ≤5 cm from surface *Linic* – low permeability geomembrane ≤1 m from surface *Urbic* – ≥20 cm layer with ≥20% vol. rubble/refuse *Spolic* – ≥20 cm layer with ≥20% vol. industrial waste *Garbic* – ≥20 cm layer with ≥20% vol. organic waste *Cryic* – permanent ice in upper 2 m *Isolatic* – soil on a hard manufactured surface, e.g. roof, pots *Leptic* – hard continuous layer ≤1 m from surface *Subaquatic* – permanently submerged *Tidalic* – affected by tidal water *Reductic* – reducing conditions in top 1 m *Hyperskeletic* – < 20% vol. fine earth
Australian Soil Classification (Isbell and National Committee on Soil and Terrain 2016)	*Anthroposols* (soil orders)	'Profound modification' from human activity including truncation, burial, and creation of new parent materials. Burial depth ≥ 30 cm; removal of natural pedological features	*Fusic* – ≥0.3 m with ≥20% ash material from burnt peat *Cumulic* – ≥0.3 m human deposited material, e.g. middens, mill mud *Hortic* – incorporation of organic residues to remove natural pedological features *Garbic* – soil underlain by landfill of mainly organic refuse *Urbic* – soil underlain by landfill of mainly manufactured mineral refuse *Dredgic* – soils on mineral material dredged from marine/aquatic sediments *Spolic* – soils on material transported by humans *Scalpic* – soils on land surfaces with pre-existing soil truncated by humans
US soil taxonomy (Soil Survey Staff 2014)	(none)	(none)	Recognises multiple *anthropic epipedons* = surface soil layers derived from human alteration or transportation of soil material, which exist on landforms or disturbed areas created by humans

In many cases, human modification of soils changes their properties but not to the extent that they then meet the requirements for classification as anthropogenic soils or even anthropogenic subcategories of natural soils. Such human modifications, such as additions of new material from construction debris, street dusts, or other waste materials, can significantly change the chemical, physical, and biological properties of the soil environment (Jim 1998; Lehmann and Stahr 2007; Pouyat et al. 2007; Taylor et al. 2010; Wei and Yang 2010; Rate 2018).

2.2 Soil-Related Changes in Urban Geomorphology

Numerous changes are made to landforms in urban areas as cities evolve; many of these geomorphological changes create a more convenient environment for urban infrastructure such as buildings, roads, and below-ground pipe/cable networks. In addition, 'new' land suitable for urban use may be generated by reclamation of inland water bodies or, especially, on coasts.

2.2.1 Modification of Surface Hydrology

From a hydrological perspective, the changes in geomorphology due to urbanisation have been well-documented. Ehrenfeld (2000) reviews the changes in hydrology and wetland geomorphology caused by direct modification such as infilling or drainage but also from other changes to the urban hydrological environment including the following: covering of land surfaces with impermeable layers, stream modification, and flow regulation. Clearly the infilling of wetland basins (see the example in Fig. 2.4) represents a geomorphological change (in land elevation and slope modification), and the wetlands themselves change in form due to processes like increased erosion (Ehrenfeld 2000). Similarly, Paul and Meyer (2001) review the changes to urban stream hydrology and geomorphology; in urban environments, stream channels may be filled in or converted to surface or below-ground artificial drains (see the example in Fig. 2.5). This removal of natural drainage channels, together with large proportions of impervious land surfaces, has profound effects on urban hydrology and geomorphology (we will address some of the hydrological issues in Chap. 5). The effect of geomorphological changes on urban soils is less well documented. Soils developed on landforms created by human activity are included within various soil classification schemes (see Box 2.1 above), but there do not seem to be any systematic studies of how soil properties are affected, despite the known coupling of soil properties with hydrology (e.g. Schaetzl and Anderson 2005). The relationship between geomorphology and hydrology is not one-sided. As described above, changes in geomorphology strongly affect hydrology, and the converse is also true: hydrological changes affect geomorphology (i.e. landforms and soils), leading to complex feedbacks.

Fig. 2.4 Infill of lakes and wetlands in the central metropolitan area of Perth, Western Australia (−31.951 S, 115.86 E), shown by an overlay of a map from 1838 (State Library of Western Australia) on an aerial photograph from 2016 (Mapbox 2019)

Drainage of land, and groundwater extraction, in urban areas is also known to have caused land subsidence (Brown and Nicholls 2015), due to reduction of the effective stress of groundwater pressure (Galloway and Burbey 2011). Groundwater extraction also changes soil chemical properties, because it changes water-filled pores into air-filled pores. For example, Salmon et al. (2014) describe formation of acid sulphate soils when groundwater levels decreased by ca. 3 m between 2000 and 2010, resulting in entry of atmospheric oxygen into subsoils and consequent oxidation of sulphide minerals. For an understanding of soils in urban environments, then, a knowledge of landform changes that affect hydrology is essential.

2.2.2 *Coastal Land Reclamation*

Changes in geomorphology caused by human activity also include new landforms created by coastal reclamation; not all urban landform changes involve surface sealing and altered drainage. In coastal reclamation, land is 'reclaimed' from coastal fringing (e.g. saltmarsh), tidal, and even permanently submerged coastal water environments. There are two main types of coastal reclamation: (1) excluding marine and tidal water from salt-affected coastal land by constructing physical barriers such as dykes and installing artificial drainage (Li et al. 2014) and (2) creating new land by filling in submerged marine environments with imported soil- or sediment-like material (El Banna and Frihy 2009; Semmens et al. 2011).

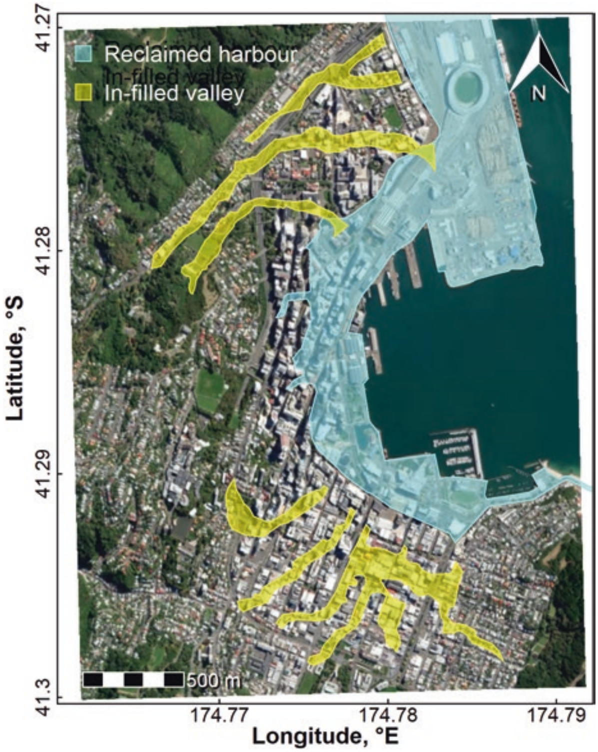

Fig. 2.5 Aerial photograph map of Wellington, New Zealand (−41.285 S, 174.775 E), showing areas of reclaimed land in former stream valleys (yellow) and harbour margins (pale blue). Base map from Mapbox (2019); overlays based on a map in Semmens et al. (2011)

From a soil science perspective, the first type of reclamation is most relevant, since the resulting soils allowed multiple land uses, including agriculture or horticulture. There is a long history of such reclaimed-land soils, which are often called 'polders', from the reclamation of low-lying coastal land in Northeastern Europe and South-East Asia. Some partially urbanised examples include Noordoostpolder 52.72 N, 5.76 E in the Netherlands and the large Bắc Hưng Hải polder near Hanoi in Vietnam 21.01 N, 105.90 E. (Coordinates are provided so the locations can be viewed in Google Earth or similar software or web mapping service; e.g. in Google Earth, remove the non-numeric information and search for '52.72, 5.76'). Pons and van der Molen (1973) investigated the properties of soils developed within 1000-year-old polders in the Netherlands. These centuries-old Netherlands polder soils have undergone a process of physical, chemical, and biological changes culminating in formation of distinct soil types at the higher order of soil classification schemes (USA), depending on the composition of the original sediment (parent material). In many cases, even several centuries of pedogenesis resulted in changes mainly in the surface soils, with deeper subsoils remaining similar to the original submerged sediments.

In many cases, construction of new land by filling in (reclamation type 2; see Fig. 2.5) has been performed because there was insufficient space, especially on flat land, for building development, so much of the new land area is ultimately occupied by infrastructure leaving minimal actual soil exposed at the surface (Jim 1998). There would appear to have been very few studies of soils developed from materials used to fill in marine or freshwater submerged environments, despite this being a common practice worldwide over time frames which are long enough for some pedogenic alteration to occur (Brown 1970; Bowler et al. 1995; Semmens et al. 2011). Some examples of infill of submerged harbour or estuarine environments are in Perth, Scotland (56.395 N, −3.43 W); Wellington, New Zealand (−41.27 S, 174.785 E, Fig. 2.5); and Rio de Janeiro, Brazil (−22.895 S, −43.19 W).

2.2.3 Other Built-up Landforms

These include the 'positive landforms' of Brown (1970) and various 'constructional anthropogenic landforms' listed in the USA soil taxonomy (Soil Survey Staff 2014), ranging in scale from middens (a few metres) to artificial islands (up to kilometres). Some examples of these are discussed separately below.

Archaeological mounds. Large mounds of soil-forming material constructed by human activity (intentional or unintentional) are known from early periods in the history of humanity. The city of Adria in Northern Italy is the site of a large mound, up to 5 m high and 20 ha in areal extent, caused by cumulative additions of urban material over an approximately 700-year period (Corrò and Mozzi 2017, 45.052 N, 12.057 E). Numerous other examples of anthropogenic mounds exist in ancient urban or pre-urban areas worldwide, for example, in Amazonia (Roosevelt 2013) and the Middle East (Faust and Katz 2015). Not only do these mounds represent new parent materials for soil formation, but they also have the potential to modify local hydrology.

Waste stockpiles and landfills. Human activities, especially those in urban environments, produce large quantities of waste material. Despite efforts to reduce the size of waste streams, considerable quantities of waste from cities require disposal (Grimm et al. 2008) and are disposed of into landfills or (temporarily) in mounded landforms, commonly on land reserved for these purposes (Cherubini et al. 2009). Soils forming on these landforms are the urbic, garbic, or spolic Technosols of the World Reference Base classification (IUSS Working Group WRB 2014). Figure 2.6 shows an example of a mounded landfill in an urban industrial zone which has been landscaped into public open space. Occasionally, stockpiled material is soil placed in temporary mounds during urban development, which is intended to be replaced or removed at project completion.

Land-disposed dredge spoils. Material removed by dredging from submerged freshwater or marine sediments, or *dredge spoil*, has historically been disposed of onto land (Almeida et al. 2001). Land disposal still occasionally occurs, despite a large body of evidence showing that the spoils commonly contain sulphide minerals

Fig. 2.6 A landfill mound in the Homebush Bay area (western Sydney, Australia −33.8454 S, 151.0559 E). (Image date April 2016; used with permission from funambulator (2016))

such as pyrite which oxidise under non-submerged conditions to form acid sulphate soils (Morse 1994; Borma et al. 2003; Clark and McConchie 2004). Land disposal of dredge spoils can form large elevated landforms; examples include South Yunderup, Western Australia (−32.59 S, 115.782 E; see Fig. 2.7). Soils developed on dredge spoil are classified as spolic Technosols in the WRB (IUSS Working Group WRB 2014) and, specifically, as dredgic Anthroposols in the Australian Soil Classification (Isbell and National Committee on Soil and Terrain 2016).

2.2.4 Landforms Modified by Removal of Material

The construction of urban infrastructure commonly requires levelling of land on various scales, from creating a flat base for house foundations to much larger-scale modifications such as road, railway, and canal cuttings (Fig. 2.8) – or even complete removal of hills (Brown 1970) (Fig. 2.9). In addition, the 'negative landforms' identified by Brown (1970) include excavations made for other purposes, such as quarries (Fig. 2.8) or stormwater compensation basins (Appleyard 1993). Numerous other excavated landforms are listed in the USA soil taxonomy (Soil Survey Staff

Fig. 2.7 South Yunderup, Western Australia (−32.59 S, 115.782 E), showing a large area of dredge spoil in the foreground (with diagonal fill pattern) which has acidified due to the oxidation of pyrite and other sulphide minerals contained in the original estuarine sediment. (Photograph by Chris Yanicki (2017), used with permission)

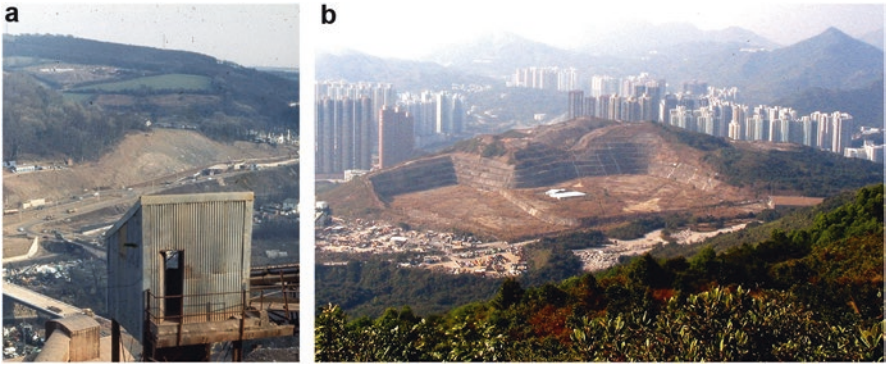

Fig. 2.8 (**a**) A large road cutting in Tongwynlais in South Wales (51.533 N, −3.253 W) in 1971 (public domain image from Gillham 2017); (**b**) Pak Shing Kok quarry landform in urban Hong Kong (22.308 N, 114.271 E). (Public domain image from 2008 by Martin Ng)

2014), in which they are called ‘destructional anthropogenic landforms’. Like the positive anthropogenic landforms described in Sect. 2.2.3, excavations will affect local hydrology, and there is the potential for new soils to form on excavated surfaces. Such soils are not considered explicitly in the World Reference Base classification but would be considered scalpic Anthroposols in the Australian system (Isbell and National Committee on Soil and Terrain 2016) (Box 2.1).

Fig. 2.9 Landscape truncation by complete removal of 'Denny Hill' in Seattle, USA (47.61 N, 122.33 W), in approximately 1910; public domain image by Shakespeare at https://commons.wikimedia.org/w/index.php?curid=16477653

2.3 Characteristics of Urban and Anthropogenic Soils

It would be practically impossible to describe all the possible variations of urban soils. This section will discuss common features of soils in urban environments, with specific examples of soils in some important urban contexts.

2.3.1 Urban Soils with Minimal Modification

It is difficult, if not impossible, to identify soils in urbanised areas which have no changes resulting from human activity. Recognition of minimally modified soils is, however, important in the context of understanding the various impacts on urban soils. For example, in some regulatory frameworks (e.g. National Environment Protection Council 2013), *background concentrations* of potential contaminants are required for a full assessment of their potential environmental impacts. In many urban areas, soils having negligible human modification are rare but may exist in nature reserves or on undeveloped peri-urban land. These soils would not be defined as anthropogenic soils and may still contain traces of anthropogenic materials if deposition of airborne dusts or aerosols is locally significant.

2.3.2 Distinctive Properties of Soils in Urban Environments

We will deal with many of the soil properties encountered in urban environments in later chapters and in the sections below, but we should be aware of them at this stage as well.

Some of the diagnostic properties of Anthrosols and Technosols, which include many urban soils, are presented in Box 2.2: relatively high artefact content ('artefacts' can be imported soil-like material), *geomembranes* or industrial hard layers, rubble/refuse, industrial waste, organic waste, deep enrichment with organic matter and/or nutrients, and so on. These 'classification-based' properties encompass properties such as impermeable surface cover and many of the consequences of modifying urban geomorphology.

As mentioned, however, many of the characteristics of urban soils relate to addition of material below the thresholds required for soil classifications – for example, the threshold for artefacts in a Technosol is quite high, at 20% by volume. Of the numerous human additions, the most troubling are of contaminants, the very wide range of substances that, directly or indirectly, can have adverse effects on organisms including humans. These substances include nutrients (N, P, etc.), trace elements, asbestos, radionuclides, (micro)plastics, manufactured nanoparticles, and other inorganic contaminants like cyanide (see Chap. 6). Organic contaminants are also of great concern, including hydrocarbons, chlorinated organic compounds, pesticides, endocrine disrupting chemicals, various pharmaceuticals, and many more (see Chap. 7).

Biological contamination is also possible; urban activities may introduce pathogens into soils, and it is in the biology of soils that concerning declines may be observed rather than additions, in the form of individual species decline or loss of biodiversity. Chapter 8 discusses the biological properties which are relevant in urban soil environments.

2.3.3 Coastal Reclaimed Soils

The formation and properties of polder soils have been reviewed by Li et al. (2014), who use the term 'coastal reclaimed soils'. Some consistent properties are observed for coastal reclaimed soils; they tend to be wet soils, with finer texture and better structure than the original sediments. Chemical soil fertility generally improves with time since reclamation of coastal soils, as soil organic matter accumulates; a major constraint to their use in plant production is the residual salinity from their tidal or marine origins, with formation of acid sulphate soils occurring if the parent sediments contained pyrite or other sulphide minerals. In general, more favourable soil properties were established in coastal reclaimed soils in South-East Asia than in North America or Europe (Li et al. 2014).

2.3.4 Soils on Landfills

Soils developed on landfill materials would fall within the garbic or spolic Technosol classifications of the WRB (IUSS Working Group WRB 2014). Landfills are commonly constructed with an overlying clean soil material, however; depending on the depth of surface fill, non-anthropogenic soil groups or orders may be more relevant. The type of waste material (e.g. construction waste, organic wastes, or mixtures of different waste types) disposed of in the landfill structure affects the subsequent soil-forming processes.

Early soil development on landfill materials has been shown to be associated with compaction, as the newly deposited waste and cover materials settle, increasing the density and reducing porosity and maximum water storage (Tifafi et al. 2017). Settling on landfills containing organic waste may also reflect decreases in volume due to decomposition of putrescible organic waste material (Oakley and Jimenez 2012). The land elevation may also decrease due to the mass of overlying landfill compacting the underlying soil or sediment (El-Fadel and Khoury 2000).

One of the almost universal properties of landfills is that they contain contaminants; the actual contaminants present depend on the types of waste that have been disposed of. Soils that develop on landfills may also therefore be contaminated, depending on the properties and thickness of the clean cover material. The types of contaminants present in landfills are extremely diverse and include metals, excess nutrients, hydrocarbons, volatile organic compounds, pesticides, pathogens and other microorganisms, microplastics, and asbestos (Department of Environment and Conservation 2009; Plant et al. 2014). The details of contaminant behaviour in urban soils will be discussed from a chemical perspective in Chaps. 6 and 7 and in the context of soil biology in Chap. 8.

Landfills used to dispose of organic wastes commonly generate methane, as a product of *anoxic* decomposition of organic matter. The methane is emitted from the surface soil layers, regardless of whether clean soil overlies waste material (Blume 1989). Methane is a greenhouse gas (Bellucci et al. 2012) and also represents a safety or health hazard due to its flammability or if landfill gas enters closed buildings with poor air exchange (US EPA 2017).

2.3.5 Soils on Dredge Spoils and Coastal Acid Sulphate Soils

Soils developed on dredged materials are included in the categories of spolic Technosols in the World Reference Base (IUSS Working Group WRB 2014) or dredgic Anthroposols in the Australian Soil Classification (Isbell and National Committee on Soil and Terrain 2016). Coastal acid sulphate soils (CASS) developed from land drainage are not necessarily categorised as anthropogenic soils, being classified instead in other soil groups such as gleysols in the WRB or hydrosols in Australia.

In urban and other environments, drainage of coastal soils is common (Brady 1974). The formation of acid sulphate soils from drainage of coastal soils or land disposal of dredge spoils is a well-known phenomenon (Morse 1994; Dent and Pons 1995). The acidification process is commonly associated with increased mobility and potential bioavailability of iron, aluminium, sulphur, and trace elements, including potentially toxic metals and metalloids such as As, Cd, Co, Cr, Cu, Mn, Mo, Ni, Pb, and Zn (e.g. Sohlenius and Öborn 2004). The metal(loid) contaminants released by acid sulphate oxidation may then be lost from the soil system and enter other environments such as water and aquatic sediments (Huerta-Diaz et al. 1993; Gröger et al. 2011). Chapter 6 will address the geochemical processes and properties in acid sulphate soils in more detail.

Acidification of estuarine soils to form acid sulphate soils creates a soil environment that is not conducive to plant growth, due to toxicity of aluminium and other ions released under acidic conditions. The lack of plant cover on the soil surface commonly results in the generation of dust end export of potentially contaminated soil material into the atmosphere and other environments (Ljung et al. 2010). In addition, the salinity of acid sulphate environments, related to the estuarine or marine origin of the original sediments and to the production of soluble salts during acid sulphate oxidation, also suppresses plant growth (Fanning 1990).

2.3.6 Soil-Like Materials

Natural and constructed wetlands. Water bodies which are relatively shallow overlie sediments or *wetland soils*, which have many of the characteristics of *upland soils*. Wetlands of various types, including shallow and/or seasonal water bodies, are present in many urban environments worldwide. A key feature of wetland soils is their different oxidation-reduction chemistry, driven by the restriction of oxygen supply in water-filled pores and the consumption of oxygen and other electron acceptors by microorganisms (Gambrell 1994). The wet conditions promote storage rather than decomposition of organic matter, so that wetlands may be important for carbon storage in urban environments (Pouyat et al. 2006; Vepraskas and Vaughan 2016). The other main differences in wetland soils are related to changes in the form of iron, such that the reduced form (Fe^{2+}) predominates (giving paler 'gleyed' colours), and, if the supply of sulphur (e.g. as atmospheric sulphate) is great enough, accumulation of sulphides (mineral phases containing S^{2-} or S_2^{2-}) (Vepraskas et al. 2016). The sulphide phases formed under anoxic conditions incorporate trace elements along with iron, and so wetland soils can accumulate trace element contaminants in immobile forms. In constructed wetlands and infiltration basins, the soils most likely develop into subaquatic Technosols, according to the IUSS World Reference Base classification (IUSS Working Group WRB 2014).

Many urban wetlands have been drained and/or infilled during development. The wetland sediments may persist in drained conditions or beneath the imported fill materials, with associated risks of acid sulphate soil development, especially if the local hydrology changes towards drier conditions.

Infiltration basin sediments. Stormwater drainage networks are important infrastructure in urban environments and are very necessary due to the generally high proportion of impermeable surface cover which increases run-off. The constrained channels of stormwater drains (particularly open drains), however, have the potential to increase the risk of flooding. A flood control measure that can be applied is the inclusion of *infiltration basins* – high-volume sections of drains which are typically much deeper and wider than the drain itself – along the lines of stormwater drainage. Also called compensating basins or detention basins, these are designed to fill with storm water during flood events and thereby reduce the risk of flooding; an additional benefit is groundwater recharge while water exists above the base level of the infiltration basin.

The sediments in infiltration basins may be actual soils (e.g. public open space in natural landscape depressions), deliberately excavated basins, or natural lakes/ponds included in the stormwater drainage network. If permanently or seasonally submerged, they bear many of the properties of soils in natural and constructed wetlands. In some cases where the infiltration basin is dry for most of the year (e.g. empty basins in sandy soils with buried pipework to carry base flow), they may most resemble upland soils.

Green roofs. The use of roof spaces on urban buildings to create 'green roofs' (Fig. 2.10) is a practice which is increasing in frequency, since it offers benefits to the urban environment such as cooling through shading and evapotranspiration, or acting as storm water buffers. A green roof typically has an imported, constructed soil substrate composed of the following (from the surface to deeper layers): optional mulch, soil-like growing medium, filter membrane, drainage layer, waterproof/root-excluding membrane, thermal insulation, vapour control, and structural roof support. In the world reference base classification, they are included in isolatic Technosols (IUSS Working Group WRB 2014). Few studies have explicitly considered ongoing formation processes in soil materials on green roofs, probably as their installation in contemporary cities is a recent phenomenon, so there is not yet a consensus on soil-forming pathways. Bouzouidja et al. (2018) show that the properties of soils on green roofs evolve relatively rapidly with time. Over a 4-year period, concurrent with development of the vegetation, eluviation of fine particles, increases

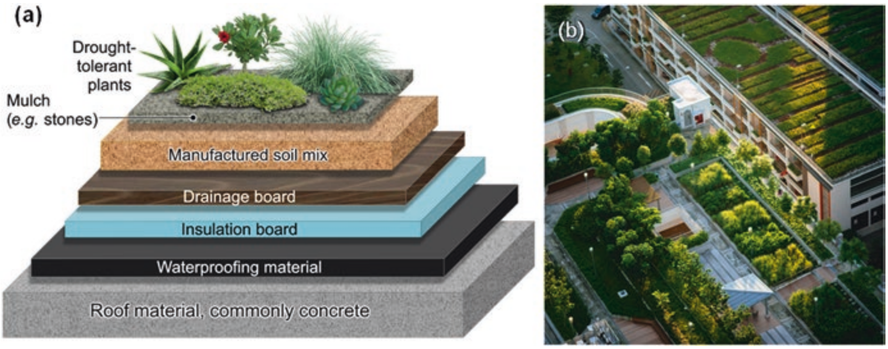

Fig. 2.10 (**a**) Layers in a typical manufactured green roof construction; (**b**) aerial view of green roofs in Singapore. (Public domain image by chuttersnap on unsplash.com/photos/IfmqOuOkaOA)

Fig. 2.11 Accumulation of road dust and other debris in an urban environment in Perth, Western Australia. If left undisturbed, such deposits provide incipient parent materials for soil and associated organisms. (Photograph by Andrew W. Rate; entire ruler for scale is 15.8 cm long)

in macro- and microporosity (at the expense of mesopores), decrease in organic carbon content, and increase in nitrogen content, all occurred. In contrast, Schrader and Böning (2006) measured greater organic carbon and N contents, but lower pH, in the soil of older (compared with younger) green roofs. Regardless of constructed or ongoing soil formation, however, a green roof environment would need continuing intensive management to preserve ecosystem functions.

Street dusts. Dust accumulating on impervious urban surfaces (Fig. 2.11) is normally transient but may persist for long enough in some microenvironments that plants can establish on dust accumulations. The source of the dust may in fact be soil particles which become resuspended in air by wind (De Miguel et al. 1997). Dusts from within urban environments or from remote sources are also known to represent pedogenetic additions to urban soils. To our knowledge, researchers have not yet investigated pedogenesis where the main parent material is any type of urban dust.

2.4 Archaeological Features of Urban Soils

The soils and landforms of cities contain clues to their history; cities remain in one place for a long time, and humans leave behind many traces of their habitation which accumulate over time. These clues may take the form of evidence of past landscape modification by humans, physical soil components such as anthropogenic artefacts, chemical signatures such as accumulation of nutrients or contaminants, or particular microfossils related to human modification of ecosystems. In some case the archaeological heritage in cities is of great cultural and historical value and takes precedence over urban development. For example, 'rescue archaeology', the retrieval of artefacts accidentally excavated during development construction, was common in many municipalities until urban planning procedures began considering archaeological issues explicitly.

2.4.1 Archaeological Anthropogenic Landforms

Cities evolve most obviously by changes in lateral extent, usually to cover more land area (see Chap. 1), but urban development may also involve creation or destruction of landforms (see Sect. 2.2 above), which cause vertical changes in urban landscapes. For example, Faust and Katz (2015) studied the Bronze to early Iron Age urbanisation of Tel 'Eton in contemporary Israel, showing from archaeological strata on a large mound landform that multiple phases of urbanisation had occurred from ca. 2000 to 300 BC. Corrò and Mozzi (2017) analysed buried urban strata and showed a history of elevation change in Adria, Italy, dating back to the sixth century BC. In contrast, the presence of archaeological artefacts can help to constrain a time frame for natural soil- or landscape-forming events (see Völkel et al. 2012).

As discussed in Chap. 1, the location of ancient settlements is also related to geomorphology and the quality of soils. The location of the ancient Tel 'Eton city is thought to reflect both its proximity to fertile alluvial soils and geomorphologically controlled transport and trade routes (Faust and Katz 2015).

2.4.2 The Soil 'Cultural Layer'

The concept of a *cultural layer* in soils, an anthropogenic soil horizon which contains artefacts derived from human occupation and disposal of materials, has been used in the context of stratigraphic excavation in archaeology since the early twentieth century (Browman and Givens 1996). Cultural layers are commonly found in urban soils, commonly as anthropogenic horizon(s) superimposed above natural soils. The underlying natural soils are sometimes truncated (their upper layers removed) by excavation or erosion. Alexandrovskaya and Alexandrovskiy (2000) describe cultural layers from the fifteenth century and younger in the city of Moscow, Russia, which are typically 2–5 m and can be up to 20 m deep. Naturally, such large volumes of soil material derived from human activities contain many artefacts such as construction and food wastes, metal and ceramic objects, remains of cooking fires, and so on. Organic materials can be preserved in the anoxic conditions created by saturation of soil. Both Alexandrovskaya and Alexandrovskiy (2000) and Zhang et al. (2005) in urban soils of Nanjing, China, also found urban soil cultural layers to be enriched in organic matter, nutrients, and metals. The soil cultural layers in Nanjing spanned five Chinese dynasties across 2–6 m of anthropogenic horizons

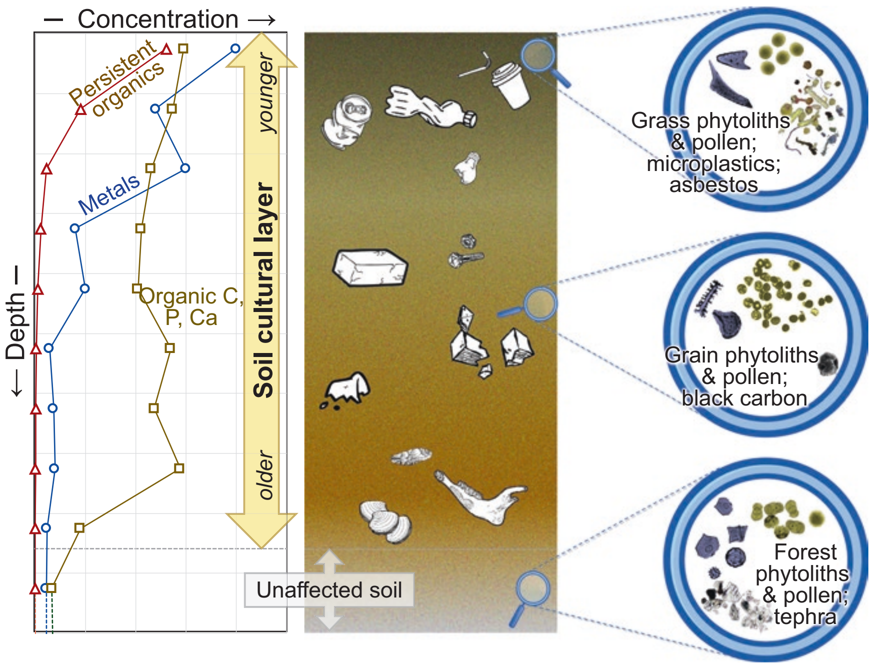

Fig. 2.12 Schematic of an idealised series of superimposed soil cultural layers. Different artefacts (anthropogenic and biological) are found in each layer depending on its age. (Graphic by Andrew W. Rate)

and had greater concentrations of Cu, Pb, and Zn than the underlying 'background' soils, similar to the Moscow soils which had also become enriched in arsenic since the seventeenth century. In general, we would expect to find different artefacts, microfossils, and chemical composition in soil cultural layers of different ages, and this is shown in idealised form in Fig. 2.12.

Evidence of patterns of human habitation and activities has also been deduced from much thinner soil layers. For example, information on human activities in ancient urban structures in both Songo Mnara in Tanzania (fourteenth to sixteenth centuries, Sulas and Madella 2012) and Brussels, Belgium (twelfth to eighteenth centuries, Devos et al. 2013), was obtained using soil micromorphology, with both chemical analyses and identification of *phytoliths*. In both of these studies, soil layers or features on the millimetre scale or smaller were identified, such as the coatings around larger soil grains, and the artefacts were the phytoliths of plant species cultivated by humans. Similar information can be generated by analysis of other microfossils in soils, such as pollen grains, or diatoms which can indicate the use of irrigation (Sánchez-Pérez et al. 2013) (Table 2.1).

Table 2.1 Types of archaeological information available from analysis of urban soils

Target of analysis	Soil material analysed	Information obtained	Reference(s)
Artefact content	Cultural layers	Age of urban habitation; types of human activities	Alexandrovskaya and Alexandrovskiy (2000)
Organic carbon content	Soil profile	Location of cultural layer; land use; activities in and around buildings, etc.	Lehmann et al. (2003) and Mazurek et al. (2016)
Nutrient (esp. P) content	Soil profile, surface soil	Type and location of human activities (e.g. cooking)	Alexandrovskaya and Alexandrovskiy (2000), Wells et al. (2000), and Mazurek et al. (2016)
Other major elements	Soil profile, surface soil	Type and location of human activities (e.g. fireplaces, buildings, roads)	Wilson et al. (2005)
Trace elements	Soil profile, surface soil	Type and location of human activities (e.g. smelting); provenance of artefacts	Wilson et al. (2005, 2007), Hellemans et al. (2014), and Sylvester et al. (2017)
Organic compounds	Cultural layers, soil profile, grave sites	Individual human behaviour and activities (e.g. diet, health); soil redox conditions	Pickering et al. (2018)
Phytoliths	Cultural layers, soil profile	Diet	Vuorela et al. (1996)
Other microfossils: pollen, diatoms, ostracods	Cultural layers, soil profile, lake sediments	Sedimentary history, irrigation, erosion, diet	Vuorela and Hiekkanen (1991), Shen et al. (2006), and Fleury et al. (2014)

2.4.3 Archaeological Information from Major Elements

Enrichment of urban soils with major elements (i.e. the more common chemical elements in the Earth's crust or in biological systems, such as C, N, P, K, S, Ca, or Fe) is a common phenomenon, since there are many human activities which can lead to increases in concentrations. Waste disposal sites such as food waste middens result in enrichment of soil with carbon, phosphorus, and calcium (from artefacts such as shells and bones; see Fig. 2.13); similar enrichments have been attributed to the use of manures as fertilisers (Entwistle et al. 1998; Davidson et al. 2006; Sánchez-Pérez et al. 2013). Greater concentrations of calcium and associated elements may also be associated with the previous locations of hearths or cooking fires (Wilson et al. 2005). Human burial sites may also become enriched in major elements such as phosphorus (Pickering et al. 2018) or calcium (Ottaway and Matthews 1988).

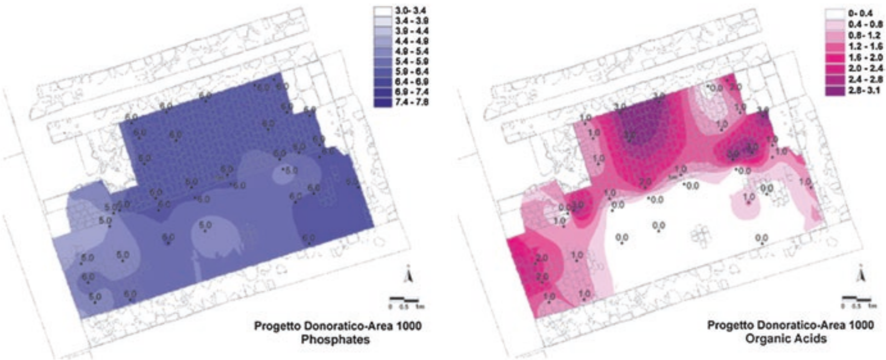

Fig. 2.13 Distributions of phosphate (left) and organic fatty acids (right) in soil materials on the former floor of Donoratico medieval castle in Central Tuscany, Italy. (From Middleton et al. 2010 and used with permission from Springer)

2.4.4 Archaeological Information from Trace Elements

The concentrations, and depth-wise and spatial distributions, of trace elements in urban soils can provide substantial information on (pre)historical human behaviour and activities. Ottaway and Matthews (1988) found that different trace elements were enriched (relative to the underlying unaffected soil) in different patterns in a soil profile, depending on the age of the anthropogenic stratum sampled (see also Fig. 2.14). They were able to relate enrichment of trace elements to the period of occupation: for example, early Neolithic samples (ca. 7000 years old) showed minimal enrichment, whereas late Neolithic and Eneolithic samples (5000–5500 years old) showed enrichment of Cu and Zn. Enriched strontium (Sr) was related to the period of human occupation in general, with greater Sr concentrations in more recent medieval samples (Ottaway and Matthews 1988).

Trace element concentrations, especially of multiple elements, can also yield information about the function of different areas at archaeological sites. Wilson et al. (2005) showed that the concentrations of Ba, Cu, Sr, and Zn in surface soils could be used to discriminate areas such as fields, gardens, middens, byres, houses, and hearths. The Roman urbanisation of Calleva Atrebatum in Hampshire, UK (first century BC to fifth century AD), was studied by Sylvester et al. (2018), who showed that the entire historical city area was enriched in multiple elements, particularly gold and silver, relative to background soils. Localised high values of individual element concentrations or multi-element indices at Calleva Atrebatum were attributed to metal extraction activities such as smelting and cupellation. In a more recent context, Rate (2018) used multi-element signatures to delineate zones on an urban site which related spatially and logically to nineteenth- and twentieth-century land uses or contamination sources such as market gardening, dumping of glass waste, road traffic, and stormwater drainage.

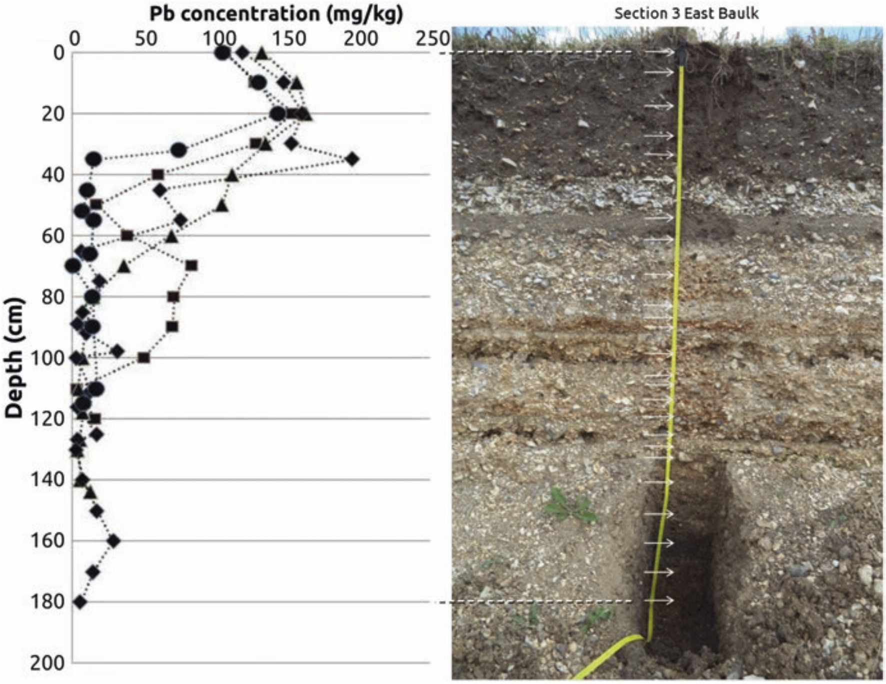

Fig. 2.14 Depth profile of soil lead (Pb) concentrations at Calleva Atrebatum in Hampshire, UK, which was occupied from the first century BC to the fifth century AD. (From Sylvester 2017, based on original work by Dr Chris Speed at the University of Reading)

The trace element signatures (comprising the concentrations of a suite of elements by which materials can be discriminated) of some anthropogenic items can yield information on the origins of these artefacts found in cultural layers of urban soils and therefore to infer patterns of commerce or migration (Hellemans et al. 2014).

2.4.5 Archaeological Information from Other Chemical Substances

More recently, organic chemical signatures have been used as archaeological tracers. For example, various organic fatty acids (see Fig. 2.13) have the potential to provide information about food residues, manures, or sacrificial rituals and distinguish location based on these activities or materials (Middleton et al. 2010). In addition, Zou et al. (2010) found that (1) polycyclic aromatic hydrocarbons (PAHs) could be used to indicate the presence and location of ancient fires; (2) PAH-like biomarkers such as the terpenoid organic compounds, cadalene and simonellite, were indicators of natural plant communities.

2.4.6 Archaeological Information from Geophysical Techniques

The most widely used geophysical techniques for characterising surface soils are electrical conductivity/resistivity-based techniques, measurement of variations in local magnetic field (magnetometry), and ground-penetrating radar (Herz and Garrison 1998). Such techniques, with appropriate signal processing and numerical analysis, provide potentially powerful tools for assessing subsurface soil environments in a non-invasive and non-destructive manner.

Magnetic measurements are possibly the most commonly used geophysical method in archaeology: for example, Boschi (2012) described the use of magnetic gradiometry (i.e. measurements of magnetic field gradient) to delineate various buildings in the fifth-century AD town of Classe in Northeast Italy (44.395 N, 12.219 E). Similarly, Cella and Fedi (2015 #160; see Fig. 2.15) used derivative magnetic gradiometry to obtain details of the buried ruins of buildings at the Torre Galli archaeological site in Calabria, Southern Italy (38.641 N, 15.939 E). *Magnetic susceptibility* measurements have also provided archaeological information (Fleisher and Sulas 2015).

The ability of subsurface layers to conduct (or resist) an electrical current has also been used to provide archaeological information. The simplest implementation is using an electromagnetic induction device which measures bulk soil electrical conductivity (Benech and Marmet 1999). More detailed archaeological data can be

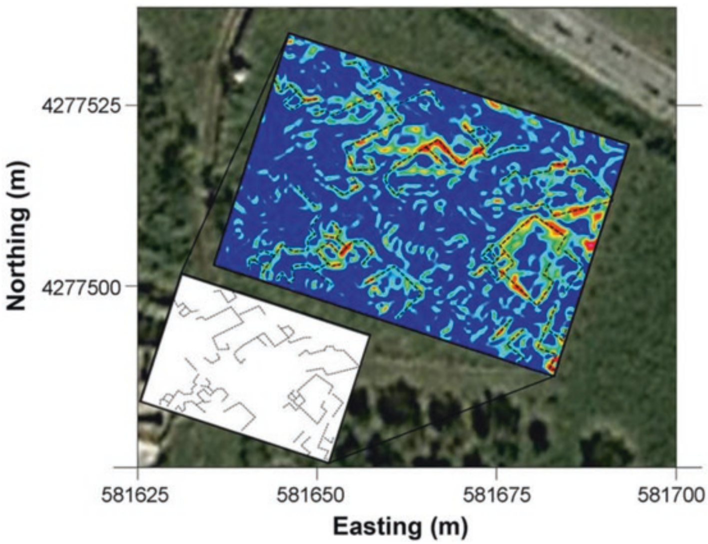

Fig. 2.15 An example of the use of soil magnetic measurements for geoarchaeology, from Cella and Fedi (2015). The large oblique rectangle on the map shows a mathematically processed magnetic field gradient of the soil, which is used to infer the historical location of walls of dwellings. (Used with permission from Springer)

acquired using electrical resistance tomography to create 2D or 3D images of the subsurface (De Giorgi and Leucci 2017).

Two- and three-dimensional images of subsurface archaeological structures can also be obtained using ground-penetrating radar (GPR). For example, Millaire and Eastaugh (2014) used GPR successfully to delineate walls and other structures in three dimensions (to a depth of 40 cm) in the pre-Hispanic city of Gallinazo, Peru (100 BC–AD 700).

2.4.7 Archaeological Information from Soil Microbial Properties

The microbial properties of soil such as microbial biomass, fungal biomass, and respiration rate have been found to vary between locations having historical human modification (Bronze Age; sixteenth to tenth century BC) and reference sites and within ancient anthropogenic soils themselves (Peters et al. 2014). Using more advanced DNA-based, phospholipid fatty acid profiling and substrate-based diversity techniques, Margesin et al. (2017) studied soils at Monte Iato in Western Sicily (occupied during the eighth to sixth centuries BC). The microbial analyses of the Monte Iato soils showed that the soil microbial community varied between anthropogenically modified soils in terms of both functional, physiological, and genetic diversity.

2.5 Additional Reading

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2.6 Summary

- The processes of soil formation are similar for urban soils and non-urban soils. Both can be described by a combination of a state factor model and a soil fluxes approach. In urban soil environments, however, we can define soil *anthropose-*

quences (or urbanisation gradients), where the state factor that changes is predominantly the human factor.

- Soil classification provides a structured conceptual framework for describing and understanding soil properties and soil formation. Soil classification schemes such as the World Reference Base include specific categories for soils modified by humans, which include urban soils. The most relevant broad category is that of the Technosols, soils which contain materials which have been manufactured or relocated by humans, such as impermeable surfaces, various waste materials, or geomembranes.
- The landforms in urban environments have been modified profoundly by human activity since ancient times. Wetlands, valleys, and even near-shore marine environments have been filled in to flatten or extend usable land. Streams and rivers have been straightened or forced into artificial channels, even underground, and land may subside due to groundwater extraction. Mounds have been created to store wastes, move solid-earth material to different locations, or have grown as successive layers of urbanisation are built superimposed on one another. Conversely, elevated landforms such as hills have been cut through for transportation routes or even removed completely.
- Urban soils differ from non-urban soils when there have been substantial landform or land cover changes or when significant amounts of various materials and substances have been added. Some specific examples of distinctive soils which have been modified by humans and which occur in urban environments include reclaimed coastal soils, soils on landfills, and acid sulphate soils. Urban environments may require a widening of our usual concepts of soils to include wetland and drainage basin soils, green roofs, and soils developed from anthropogenic dusts.
- In an archaeological context, we can identify a *cultural layer* in many urban soils, an anthropogenic soil horizon which contains artefacts derived from human occupation and disposal of materials. The superposition of multiple cultural layers can be derived from separate phases of historical urban development. Soil cultural layers are also commonly enriched in carbon, nutrient elements such as phosphorus, and various organic marker compounds, from use and disposal of organic materials such as foodstuffs and manures. Urban soils may also become enriched in trace elements from early times, reflecting extraction and use of metals and associated elements. The physical presence of artefacts and building ruins in soils can be ascertained using a range of geophysical techniques. Finally, the chemical and physical changes due to human activity can be reflected in changes in soil microbial abundance and diversity.

2.7 Questions

2.7.1 Checking Your Understanding

1. What are the parameters in the state factor 'c-l-o-r-p-t' equation, and how does each one affect the material fluxes in, and therefore the properties of, soils? Which parameters are affected by urbanisation?
2. What would be the requirements for a landscape transect over which to measure soil properties on an anthroposequence?
3. How would we determine if a particular urban soil was a Technosol? What are the various subcategories of Technosols?
4. Choose an urban geomorphological change (e.g. valley filling, redirection of drainage networks, or large-scale excavation) and summarise the effects you would expect the changed landforms to have on the resulting soils.
5. Make a table which lists the type of changes we see in urban environments in separate rows in the first column, with biological, chemical, and physical effects on soils identified in the next three columns for each type of change.
6. How could we use archaeological soil information to determine layers of different ages (e.g. differentiating pre-industrial from post-industrial and distinguishing pre-urban from urbanised)?

2.7.2 Thinking About the Issues

7. Is an anthroposequence a useful way of thinking about urban soils, in the same way as a more traditional toposequence or chronosequence? If so, why or, if not, why not?
8. As well as acid sulphate soils forming in excavated dredge spoils and on drained coastal land, what other urban practices might result in the formation of acid sulphate soils?
9. What processes or events might confuse, mask, or erase archaeological information in urban soils?

2.7.3 Contemplating Urban Soils Creatively

10. If we were able to travel forward through time for 5000 years, what might we find in our urban soils?

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