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beyond the theme

# The contribution of geosciences to the study of European *Dark Earths*: a review

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Since the early 1980s the study of "Dark Earths" has been a research field in which geoscientists have collaborated with archaeologists. After a brief overview of the origin of the expression "Dark Earth" and of its wide chronological spectrum, the article describes the analytical methods of geosciences most commonly employed in its study. Four case studies from Italy, Belgium and France are presented to provide an overview of the range of natural and anthropic processes involved in dark earth formation.
**Keywords**: Dark Earth, urban geoarchaeology, soil analyses

*Fin dai primi anni Ottanta lo studio delle "Terre Nere" si è avvalso della collaborazione tra Scienze della Terra ed archeologia. Dopo una disamina dell'origine del termine, e dell'ampio spettro cronologico delle Terre Nere, l'articolo presenta una rassegna dei metodi analitici comunemente utilizzati in tale contesto. Vengono poi illustrati quattro casi di studio da Italia, Belgio e Francia, che permettono di apprezzare la gamma di processi naturali ed attività antropiche coinvolte nella formazione delle Terre Nere.*
***Keywords**: Terre Nere, geoarcheologia urbana, analisi del suolo*

## 1. Introduction

According to Macphail, Galinié and Verhaeghe (2003), the terms "made earth" and "dark made earth" were introduced by Norman and Reader (1912) to indicate poorly stratified archaeological deposits in London separating Roman stratigraphic units from medieval and post-medieval ones. In France, archaeological deposits with similar characteristics dating from the "carlovingian" period were labelled as *terre noire* by Th. Vacquer since the middle of the 19$^{th}$ century, as mentioned by Guyard (1993). The original use and early diffusion of the expression "Dark Earth" is a product of British

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urban archaeology (see Carver 1987; Yule 1990; Macphail, Galinié, Verhaeghe 2003). During the "Rescue" excavations in London in the 1970s and 1980s, numerous Dark Earth deposits were encountered throughout the City, sealing the latest Roman strata (Yule 1990). These deposits appeared to "embody" the gap in archaeological and historical knowledge that spanned between the Late Roman period and the end of the first millennium AD (Macphail 1981; Macphail, Linderholm 2004; Loveluck 2004). More specifically, it was within the discussion about the end of the Antique city and the reduction of commercial activity and population density in late Roman towns in the 4$^{th}$-5$^{th}$ century AD that Dark Earths became object of archaeological and historical research (Galinié 2004; Yule 1990).

During the 1980s, the discussion on Dark Earths (*Terre Nere*) entered the Italian archaeological debate, following the diffusion of medieval archaeology in cities in the northern part of the country, where maps of archaeological risk were being prepared (Gelichi 1999). In Italy, Dark Earths were mainly dealt with in the framework of the studies concerning the continuity of life in Roman cities in the period from the 5$^{th}$ century AD onward (Brogiolo, Cremaschi, Gelichi 1988; Brogiolo 2011).

With the renovation of ancient town centres, Dark Earth were excavated in France since the early 1970s, for instance in Metz (Verdel 1986) and in Lyon (Arlaud *et alii* 2001). The "problème des terres noires" and its historical implication was brought to light by a team of archaeologists and geoarchaeologist taking part in excavations in Paris, Tours and Noyon (Cammas *et alii* 1995), followed by several scholars (Galinié 2002; Fondrillon 2007; Jaffrot 2008; Borderie 2011). Since 2002, Dark Earth was quoted as a priority by the National Committee of Archaeological Research (CNRA 2004).

In Belgium, the study of Dark Earths (*Terres Noires*, *Zwarte Lagen*) entered the archaeological debate in the 1990s, following a series of rescue excavations in the centre of several cities. These studies reopened the discussion on the origins of several medieval cities (e.g. Brussels, Antwerp, Aalst) (Degraeve *et alii* 2010; Wouters 2011; Devos *et alii* 2012).

It must be stressed that the term Dark Earth is not found in any of the soil classification systems, such as the World Reference Base of FAO (WRB 2007) or the American Soil Taxonomy (Soil Survey Staff 2003). Dark Earth is currently preferred to other terms present in older literature such as "dark layers", "black layers", "black earth", "made earth", or "dark made earth" (see Macphail, Galinié, Verhaeghe 2003; Yule 1990; Brogiolo 2011). Confusion should be avoided with "Amazionian Dark Earth", a form of man-made soil found in association with former indigenous settlements in the Amazon basin (see Lehmann *et alii* 2004), and with the dark-colored "chernozemic soils" of central Europe (see for example Gerlach *et alii* 2006; WRB 2007). In European urban archaeological contexts, Dark Earth indicates dark-colored, poorly stratified units, often formed over several centuries, frequently rich in anthropogenic remains (brick, mortar, tile, charcoal, bone, pottery, etc.). More specifically, it is often used to define units situated in between stratified deposits of antique cities (between the 1st and the 3rd-5th century AD) and medieval ones (from the 11th-12th century AD onwards). A more detailed discussion of the definition of "Dark Earth" can be found in Galinié (2004), Devos *et alii* (2009) and Fondrillon (2009).

## 2. The analytical methods of geosciences in Dark Earth research

The study of Dark Earths has been a field for the integration between earth scientists and archaeologists since the early 1980s, with the work of soil specialist R.I. Macphail on sites in London, Southwark, Carlisle, and York (Macphail 1981; 1983). His involvement continued in 1982-1984 at a number of Dark Earth sites in Britain, where soil micromorphology and physicochemical analyses were chosen as new effective methods to investigate these heterogeneous deposits (Macphail, Courty 1985). Also in Italian medieval archaeology, since the late 1980s, the study of Dark Earths and urban stratigraphy included the contribution of earth scientists employing soil micromorphology and soil physicochemical analyses (see for example Brogiolo, Cremaschi, Gelichi 1988; Cremaschi 1992). In France, an interdisciplinary "best practice" for the analysis of Dark Earth linking historians, archaeologists and geoscientists was advocated in 1995 by Cammas *et alii*. In Brussels, a protocol involving soil micromorphology, physico-chemical analyses and botanical studies (pollen, phytoliths and seeds) has been systematically employed since the beginning of the 21st century (Devos *et alii* 2012).

In the following lines we provide a presentation of the analytical methods of earth sciences that, according to a review of recent literature (see Table 1), have most often been used in Dark Earth studies. They consist largely of physical and chemical analyses that are routinely employed in soil science (see Louwagie, Langohr 2000). These were transferred into "archaeological soil" studies, predominantly without specific adaptations of the methods to archaeology.

Tab. 1 (pp. 148-150). List of sites where earth science analytical methods were employed in contexts defined as "Dark Earths" in Europe. [1] Chronology: expressed as "century AD" except where otherwise specified. [2] Physicochemical analyses, key to abbreviations: OC = organic carbon; N = nitrogen; PSA = Particle size analysis; BC = basic cations; CEC = cation exchange capacity; HM = heavy metals; MS = magnetic susceptibility.

| Site Name | Country | Chronology[1] | Physicochemical analyses[2] | | | | | | | | | | Micro morphology | References |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | OC | N | pH | PSA | BC | CEC | $P_2O_5$ | $CaCO_3$ | HM | MS | | |
| Sint-Jozefscollege, Aalst | Belgium | $5^{th}/6^{th}$ - $11^{th}$ | | | | | | | | | | | x | Devos 2012a |
| Burchtsite, Antwerp | Belgium | Late Roman - $9^{th}$ | | | | x | | | | | | | x | Wouters 2011; Devos 2012b; Devos *et alii* (in preparation) |
| Hôtel d'Hoogstraeten, Brussels | Belgium | $10^{th}$-$12^{th}$ & $16^{th}$-$17^{th}$ | x | x | x | x | x | x | x | | x | | x | Devos *et alii* 2011a; Devos *et alii* 2012 |
| Place de la Vieille-Halle-aux-Blés, Brussels | Belgium | $10^{th}$-$12^{th}$ | x | x | x | | x | x | | | | | x | Devos *et alii* 2007b; Devos *et alii* 2012 |
| Impasse du Papier, Brussels | Belgium | $10^{th}$-$14^{th}$ | x | x | x | x | x | x | x | | | | x | Devos *et alii* 2011a; Devos *et alii* 2012 |
| Treurenberg, Brussels | Belgium | $11^{th}$-$13^{th}$ | x | x | x | x | x | x | x | | x | | x | Devos *et alii* 2007a; Devos *et alii* 2012 |
| Pauvres Claires, Brussels | Belgium | Late Medieval | | | | | | | | | | | x | Devos *et alii* 2012 |
| rue de Dinant, Brussels | Belgium | $12^{th}$-$13^{th}$ | x | x | x | x | x | x | x | x | | | x | Devos *et alii* 2009 |
| Emile Braunplein, Ghent | Belgium | $10^{th}$-$12^{th}$ | | | | | | | | | | | x | Ervynck *et alii* 1999 |
| Courage's brewery, Southwark | UK | $2^{nd}$- late $4^{th}$ | x | | | x | | | x | x | | x | x | Macphail 1994; Macphail 2003; Macphail, Linderholm 2004 |
| Culver Street, Colchester | UK | post 59 AD - late $1^{st}$ | x | | | x | | | | x | | | x | Macphail 1994 |
| Whittington Avenue, London | UK | post 59 AD - late $1^{st}$ | x | | | x | | | | x | | x | x | Macphail 1994 |
| Southwark Street, Southwark | UK | post $2^{nd}$ | x | x | | x | x | | | | | | x | Macphail 1994 |
| St Thomas Street, Southwark | UK | post $3^{rd}$ | x | x | | x | x | | | | | | x | Macphail 1994 |
| Rangoon Street, London | UK | $4^{th}$-$11^{th}$ | x | x | | | | | | | | | x | Macphail 1994 |
| Jubilee Hall, Covent Garden, London | UK | Middle Saxon | x | | | | | | | x | | | x | Macphail 1994 |
| Winchester Palace, Southwark | UK | $2^{nd}$-$3^{rd}$ | | | | | | | | | | | x | Macphail 1994 |
| St Bartholomews Hospital, London | UK | $2^{nd}$-$4^{th}$ | | | | | | | | | | | x | Macphail 1994 |

| Site Name | Country | Chronology[1] | Physicochemical analyses[2] | | | | | | | | | | Micro morphology | References |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | OC | N | pH | PSA | BC | CEC | $P_2O_5$ | $CaCO_3$ | HM | MS | | |
| Deansway, Worcester | UK | 4th-9th | x | | | | | | x | | | x | x | Macphail 1994; Macphail 2003; Macphail, Linderholm 2004 |
| GPO/St. Paul Cathedral, London | UK | ca. 4th | | | | | | | | | | | x | Macphail 1994 |
| Paul Street, Exeter | UK | Late Roman-Late Medieval | | | | | | | | | | | x | Macphail, Coury 1985 |
| 7-11 Bishopsgate | UK | 2nd-4th | x | | | | | | x | | | x | x | Macphail, Linderholm 2004 |
| Colchester House, London | UK | 2nd-4th | x | | | | | | x | | | x | x | Macphail, Linderholm 2004 |
| No. 1 Poultry, London | UK | 5th ? - 11th | x | | | | | | x | | | x | x | Macphail, Linderholm 2004 |
| Beer Cart Lane, Canterbury | UK | ? | x | | | | | | x | | | x | x | Macphail, Linderholm 2004 |
| Elms Farm, Heybridge | UK | 1st BC- 1st AD | x | | | | | | x | | | x | x | Macphail, Linderholm 2004 |
| Scole, Norfolk | UK | Late Roman | x | | | | | | x | | | x | x | Macphail, Linderholm 2004 |
| Pevensey Castle, Sussex | UK | 5th-14th | x | | | | | | x | | | x | x | Macphail, Linderholm 2004; Fulford, Rippon 2011 |
| Guildhall, London | UK | mid 3rd ? - 11th | x | | | | | | x | | x | x | x | Macphail *et alii* 2004; Macphail *et alii* 2007a |
| Northgate House, Winchester | UK | Late Roman | x | | | | | | x | | x | x | x | Macphail, Crowther 2011 |
| Gloucester, Tanners Hall | UK | 5th-11th | x | | x | | | | | | | | x | Macphail 1983 |
| Whitefriars, Norwich | UK | late 11th-early 12th | x | | x | | | | | | | | x | Macphail 1983 |
| Keasy Lane | UK | post 2nd-3rd | x | | x | | | | x | | | | x | Macphail 1983 |
| No. 1 Poultry | UK | 5th?-11th | x | | | | | | x | | | x | x | Macphail *et alii* 2004 |
| Magdeburg Cathedral | Germany | Ottonian-12/13th | x | | | | | | x | | x | x | x | Macphail *et alii* 2007b |
| Ferrara, Piazzetta Castello | Italy | 14th-15th | | | | | | | | | | | x | Cremaschi 1992 |
| Firenze, Uffizi Gallery Complex | Italy | 7th-11th | x | x | x | x | x | x | x | x | | | x | Nicosia *et alii* 1992 |
| Brenzone, Verona | Italy | 6th-7th | | | | | | | | | | | x | This article; Bruno, Tremolada 2011 |
| RU2, Amiens | France | 4th-10th | | | | | | | | | | | x | Gebhardt 1997 |
| Palais de Justice, Besançon | France | Medieval | | | | | | | | | | | x | Cammas 2004 |

| Site Name | Country | Chronology[1] | Physicochemical analyses[2] | | | | | | | | | | Micro morphology | References |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | OC | N | pH | PSA | BC | CEC | $P_2O_5$ | $CaCO_3$ | HM | MS | | |
| Vieux Château, Château-Thierry | France | 4th-9th | x | x | | | | | | x | | | x | David 2004 |
| Sainte-Chrétienne, Metz | France | 4th-14th | x | x | | | | | x | x | x | x | x | Gebhardt 1997; Borderie 2011; Augry *et alii* in press |
| Ilot-Turmel, Metz | France | 4th-13th | | | | | | | | | | | x | Gebhardt 1997; Gébus, Gama 2004 |
| Pierre Hardie, Metz | France | 4th-12th | | | | | | | | | | | x | Gebhardt 1997; Gébus, Gama 2004 |
| Boulevard Saint-Michel, Paris | France | 4th-13th | | | | | | | | | | | x | Cammas 2000 |
| Rue Monsieur-le-Prince, Paris | France | 3rd-19th | | | | | | | | | | | x | Cammas 2000 |
| Collège de France, Paris | France | post 4th | x | x | | x | | | x | x | | | x | Cammas 2000; Cammas 2004 |
| Cloître Cathédral, Noyon | France | 4th-13th | x | x | | x | | | x | x | | x | x | Borderie 2011 |
| Rue de l'évêché, Noyon | France | 4th-13th | x | x | | x | | | x | x | | x | x | Borderie 2011 |
| Sq. Grospiron, Noyon | France | 4th-12th | x | x | | x | | | x | x | | x | x | Borderie 2011 |
| Pl. A. Briand, Noyon | France | 4th-12nd | x | x | | x | | | x | x | | x | x | Borderie 2011 |
| Grenier d'abondance, Strasbourg | France | Early Medieval | | | | | | | | | | | x | Cammas 2004 |
| Sainte-Marie, Strasbourg | France | Early Medieval | | | | | | | | | | | x | Cammas 2004 |
| Saint-Julien, Tours | France | 4th-12th | x | | | x | | | | x | | | x | Fondrillon 2007 |
| Rue Franche, Bayeux | France | 4th-13th | x | x | | | | | x | x | | x | x | Schutz et alii in press |
| La Chapelle, Beauvais | France | 4th-11th | x | x | | x | | | x | x | | x | x | Borderie 2011 |
| Galerie nationale de la tapisserie, Beauvais | France | 4th-13th | x | x | | x | | | x | x | | x | x | Borderie 2011 |
| Musée départemental, Beauvais | France | 4th-12th | x | x | | x | | | x | x | | x | | Borderie 2011 |
| Cloître Cathédral, Beauvais | France | 4th-12th | x | x | | x | | | x | x | | x | | Borderie 2011 |

### *2.1. Soil Micromorphology*

Soil micromorphology can be defined simply as the microscopic study of soils (see Kemp 1997; Stoops 2003). This technique involves the analysis of undisturbed soil samples by means of thin sections, microscope slides on which a thin (20-30 micron-thick; with 1 micron or "μm" equaling 1/1000 mm) slice of soil material has been mounted after being consolidated in resin (Benyarku, Stoops 2005). By virtue of deriving from an undisturbed soil sample, e.g. a monolith or a block, thin sections allow us to observe all of the soil components (aggregates, voids, mineral grains, anthropic inclusions, post-depositional features, etc.) exactly as they occur in their natural setting. Soil micromorphology was first developed in the 1930s by the German soil scientist W.L. Kubiëna (Kubiëna 1938), who applied it to the study of mechanisms of soil formation. The technique was only later applied to archaeological research by I. Cornwall in the 1950s (Cornwall 1958), but it was not until the 1970s and 1980s that it became a widespread tool in archaeology (see Courty, Goldberg, Macphail 1989; Macphail, Courty, Goldberg 1990).

As mentioned above, soil micromorphology was employed since the earliest earth scientific studies of Dark Earths (Macphail 1981; 1983; Macphail, Courty 1985), and has since then been one of the main analytical tools in this research topic (see tab. 1). Soil micromorphology allows us to decipher the palimpsest of natural processes and anthropic activities responsible for Dark Earth formation, as will be made clear by the examples in chapter 3.

### *2.2. Particle size analysis*

Particle size analysis (or granulometry or grain size analysis) consists in the determination of the percentages of sand, silt, clay and gravel that make up a given sample. These are normally measured by means of a laser granulometer or by a combination of sieving (sand fraction) and of "pipette" method (silt and clay), a procedure that exploits the direct relationship between the settling velocity of particles in water and their size. Particle size analysis is commonly employed in soil science to evaluate the physical fertility of soils. More importantly, it informs us on the origin of the sediments that compose a given stratigraphic unit or horizon (alluvial, aeolian, anthropic etc.), and allows us to detect lithological discontinuities. Particle size analysis of Dark Earths often reveals that they contain roughly equal amounts of sand silt and clay, tending therefore towards loamy textures. This is due to the fact that materials with different size classes are mixed and reworked in Dark Earth by human activities (e.g. digging, cultivation, dumping, quarrying etc.) and by the activity of burrowing soil fauna (see Moinerau 1970; Macphail, Linderholm 2004).

Once the different percentages of sand silts and clay are available, a particle size similarity index can be calculated (Langohr, Scoppa, Van Wambeke 1976). This index expresses the degree of similarity in the sedimentary composition of two samples. It can be used to detect discontinuities (e.g. erosion, artificial cuts, change of sedimentation style etc.) within a sequence or to reveal a common genetic "root" in the sediments making up different units. For example, at the Biblioteca Magliabechiana site in Firenze (Italy) this index highlighted the great internal homogeneity of Dark Earth units sampled across different profiles, and showed that these formed by homogenization and reworking of local alluvium (Nicosia 2006; see also Nicosia *et alii* 2012). Thus, specific heterogeneities in particle size give information on the role played by the local sediments in Dark Earth formation and can highlight differences between Dark Earths occurring in different towns, as showed for example by Borderie (2011).

### *2.3. Organic carbon and nitrogen*

Organic carbon constitutes about two thirds of soil's total organic matter. According Nelson and Sommers (1982) and Stein (1984) organic matter consists in "plant, animal, and microbial residues, fresh and at all stages of decomposition, humus, and inert carbon forms such as charcoal, coal, and graphite". The amount of organic matter in the soil influences its chemical and physical fertility. In order to determine this amount, two methods are more often employed. The first one is the method of Walkley and Black (1934), in which chromic acid is used to oxidize organic carbon forms. According to Skjemstad and Taylor (1999), this method is efficient in recovering carbon present in the soil as charcoal, a common constituent of Dark Earths. The second method is loss on ignition (LOI): in it, the weight loss calculated from before and after a sample is burned at 500°C represents the organic matter originally present in the sample (Holliday, Stein 1989). If evaluated in strict agronomic terms, the amount of organic matter in most European Dark Earth would be considered low or even very low. Nevertheless, compared to the units that occur below or above them in stratigraphic sequences (backfill, rubble units, colluvial or alluvial layers etc.), Dark Earths often exhibit a relative increase in organic matter content (Borderie *et alii* in press-b). This is mostly due to the survival to decomposition of recalcitrant fractions of organic matter, representing only a portion of the whole amount originally present in Dark Earth. This organic matter is originated from the decay of vegetal matter, dead organisms and, in significant amount, it derives from anthropic activities. These include the discard of domestic waste, the input to the soil of human and animal excrements, the decay of structures and artifacts in perishable material, manuring and other agricultural practices etc.

The ratio between carbon and nitrogen (the latter measured by a procedure known as "Kjeldhal method" – see Kjeldahl 1883, Pauwels *et alii* 1992) is used to evaluate the dynamics of the nutrition chain operating in the soil. These dynamics are important because they are at the base of the speed and of the mode in which organic matter is decomposed. In general, European Dark Earths are often characterized by a low C/N ratio, close or lower than the reference value of 12 (see Lozet, Mathieu 1997, Baize 2000). This evidence indicates an advanced stage of the decomposition of humus in Dark Earth (see Devos *et alii* 2009), and has been used to substantiate the hypothesis that in sites in Brussels part of Dark Earths results from agricultural practices (Devos *et alii* 2007).

### *2.4. Calcium carbonate*

Calcium carbonate ($CaCO_3$) can be present in soils and sediments as both a primary constituent and as a secondary neoformation. It is important in soils as it affects both their chemical and physical fertility, especially for its buffering effect, which maintains the soil pH on high values. Calcium carbonate is normally determined by measuring the amount of $CO_2$ liberated by the reaction with HCl (see Pauwels *et alii* 1992, Baize 2000). In leaching climates, where the water reaching the soil as precipitations is more abundant than the water leaving due to evaporation and transpiration, calcium carbonate is gradually leached out of the system. This leads to a progressive acidification of soils, which implies a loss of fertility. The latter can be restored by adding calcareous material to the soil (marl, ashes, mortar fragments, etc.), a technique employed in ancient and modern agriculture and known as "liming" or "chaulage" (see Devos *et alii* 2011a).

The process of weathering of calcareous material under leaching climate conditions is at the base of the "para-Rendzina model" of Dark Earth formation proposed by Macphail (1994; see also Macphail Galinié, Verhaeghe 2003). Para-Rendzina is a term of the French soil classification system that designates soils formed on calcareous parent material, which, once weathered, liberates in the soil large quantities of sand-sized particles (Duchaufour 1983). Similarly, in the model proposed by Macphail (1994) for Dark Earths, the calcareous parent material which is weathered consists of mortar and plaster fragments derived from destruction, robbing and decay of buildings and monuments. Upon weathering, these fragments release the sand particles they contain. This model is itself derived from a study of the shallow soils that formed on construction rubble and characterized by a ruderal vegetation cover in post-Second World War Berlin (Sukopp, Blume, Kunick 1979). According to these models, it appears that a key role in the formation of Dark Earths is played by processes of weathering and soil formation acting on materials accumulated in response to human activities (dumping, construction, quarrying, digging, ground-levelling etc.).

### *2.5. Phosphorus*

In the last few decades, there has been an exponential increase in the application of phosphorus analyses for archaeological purposes (Holliday, Gartner 2007; Devos *et alii* 2011b). The method is based on the assumption that human activities like manuring, harvesting, storage, preparation, cooking, burial practices and stabling can lead to phosphorus accumulation in the soil (Proudfoot 1976; Holliday, Gartner 2007). A major issue is the application of a rather wide variety of methods to measure phosphorus concentrations in the soil (see Holliday, Gartner 2007; Devos *et alii* 2011b). A first group of analyses measures the total phosphorus concentration, a second group the concentration of organic and inorganic phosphorus, a third group the concentration of plant-available and plant non-available phosphorus and a fourth group (the fractionation method) measures different types fractions of phosphorus (see Devos *et alii* 2011b). As each method measures a different type of phosphorus, the data should be accompanied by a text that clearly explains the applied method.

Phosphorus analyses have been mainly applied in the study of Dark Earth to reveal post depositional accumulation of phosphorus (see Macphail, Linderholm 2004), the accumulation of bone, ash, organic matter and coprolites during Dark Earth formation (see Devos *et alii*, 2009) or phosphorus already present in the soil before Dark Earth formation (see Macphail, Linderholm 2004).

### *2.6. Other analytical methods*

Cation exchange capacity (CEC) is an important parameter in the evaluation of soil fertility. As can be observed in Table 1, it was also often employed in Dark Earth studies. The CEC of a soil corresponds to a quantification of the sites where cations - nutrients that plants can uptake from the soil ($Ca^{2+}$, $Mg^{2+}$, etc.) - can be stored or "adsorbed" onto the soil exchange complex, which is mostly made up by clays and organic matter. The analysis of "basic cations" determines how much of the exchange complex is occupied by a group of cations that are particularly important for plant nutrition ($Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, and $K^{+}$).

The pH of the soil expresses the concentration of $H^{+}$ ions in the soil solution, which ultimately determines whether a soil is acid, neutral or alkaline. Soil pH is typically buffered on alkaline values of 8 or higher by the presence of calcium carbonate or lime (see above). The latter can be of natural origin (e.g. limestone), but in Dark Earths is often anthropic, as in the case of mortar or ashes. pH regulates nutrient availability and the main reactions and processes in soils, and is therefore a precious – and relatively inexpensive – parameter to study soil formation.

High concentrations of heavy metal in soils, such as zinc (Zn), lead (Pb), copper (Cu), cadmium (Cd), are indicators of specific geochemical environments or are the results of human craft activities (Baize, Deslais, Saby 2008, Nriagu 1983). The transformation of minerals and the recycling of materials can release large quantity of particles in the atmosphere and fallout is recorded in sediments (Sterckemann *et alii* 2006). Heavy metal concentrations have been occasionally measured within the Dark Earth units and very high amounts of lead – more than 1800 mg/kg – were measured in Metz (Borderie 2011; Augry *et alii* in press) This anthropogenic concentration of lead in Dark Earth, even where no lead artefacts were found, can be a strong indicator of craft activities in the post-Antique period.

Care should indeed be taken in interpreting the results of these analyses, as well as of most chemical analyses presented here. Post-occupation changes in the soil (e.g. due to leaching, acidification, re-carbonation etc.) can in fact strongly modify its chemical characteristics. If this were the case, the chemical fertility and acidity measured today would differ significantly from those of Dark Earth in the past. This can be avoided only if the latter is well sealed by later sediments, being cut-off from interaction with soil forming processes.

## 3. Geosciences and Dark Earths: examples and case studies

### *3.1. The Uffizi gallery complex in Florence (central Italy, fig. 1)*

Rescue archaeological excavations were carried out in 2005-2006 under the Biblioteca Magliabechiana in Florence, which is part of the famous Uffizi gallery complex (see Cantini *et alii* 2009; Nicosia *et alii*

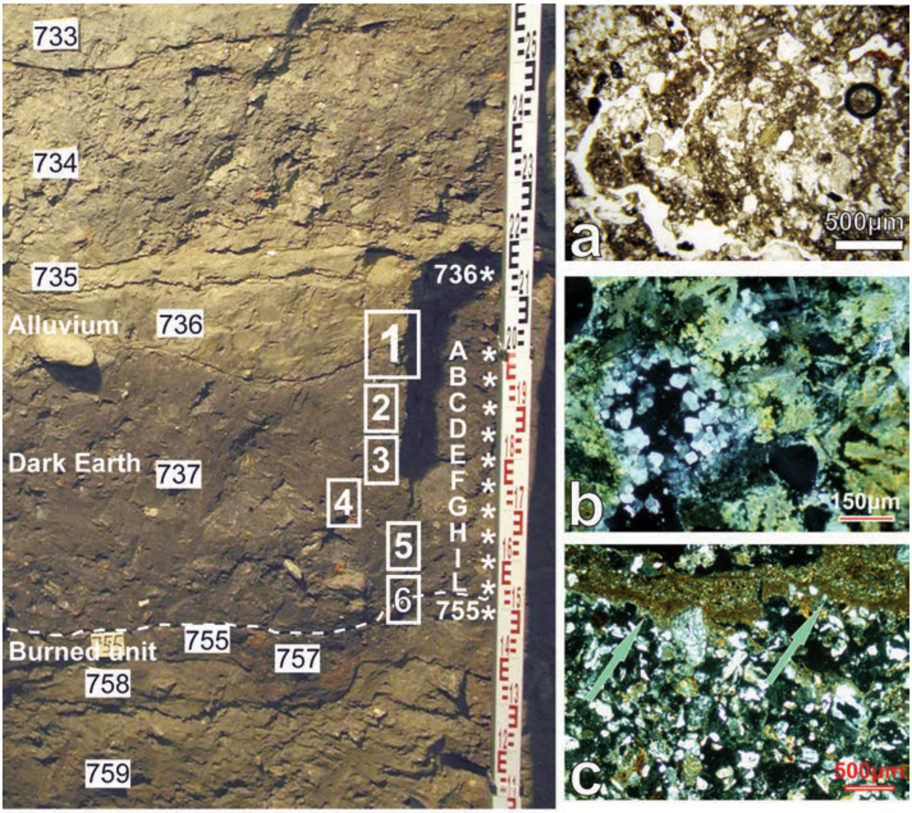


Fig. 1. Firenze, Uffizi gallery complex (see Nicosia *et alii* 2012). Example of a Dark Earth sequence, comprising from bottom to top: a unit composed of burned structural remains (Unit 755); a ca. 50 cm-thick Dark Earth unit representing the interval between 7th and 11th century AD. This unit derives from manure production or "night-soiling" at the base (marked also by higher phosphate content – see tab. 2), and from domestic waste discard, with episodic input of alluvium in the top part (Unit 737); an alluvial silty clay loam layer from the Arno river (Unit 736; possibly the large magnitude flood of 1177 AD). Rectangles indicate the position of thin sections whereas the asterisks indicate samples for physicochemical analyses.
a) Dark Earth, thin section 2 (20x, plane polarized light). The curved distribution of the fine earth is a passage feature by burrowing soil fauna. Homogenization by bioturbation is one of the main processes responsible for Dark Earth formation.
b) Dark Earth, thin section 5 (100x, cross polarized light). Ash aggregate containing calcite crystals. Ash and other domestic residues were often mixed with human and animal fecal material to obtain manure, a practice known as "night-soiling".
c) Dark Earth, thin section 6 (20x, cross polarized light). A thin crust of clay and silt formed at depth (arrows) testifies to the periodic input of alluvium during Dark Earth formation. The crust rests on a weathered mortar fragment.

| Sample | Def.[1] | Depth[2] cm | Sand % | Silt % | Clay % | Class[3] (USDA) | Org C % | N % | C/N | pH $H_2O$ | pH KCl | $CaCO_3$ % | Tot. $P_2O_5$ ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **US736** | *All* | - | 10.0 | 58.5 | 31.5 | SiCL | 0.43 | - | - | 8.2 | 7.0 | 5.6 | - |
| **A** | *DE* | 0-10 | 34.6 | 41.4 | 23.8 | L | 0.48 | 0.078 | 6.2 | 8.1 | 6.9 | - | 606 |
| **B** | *DE* | 10-15 | 44.3 | 34.9 | 20.7 | L | 0.79 | 0.081 | 9.7 | 8.0 | 7.0 | 2.2 | 605 |
| **C** | *DE* | 15-20 | 44.4 | 34.1 | 21.4 | L | 0.90 | 0.084 | 10.7 | 8.0 | 7.0 | - | 775 |
| **D** | *DE* | 20-25 | 44.9 | 33.7 | 21.3 | L | 0.95 | 0.112 | 8.5 | 8.0 | 7.2 | 1.9 | 801 |
| **E** | *DE* | 25-30 | 45.6 | 32.9 | 21.3 | L | 0.86 | 0.081 | 10.6 | 8.0 | 7.1 | - | 662 |
| **F** | *DE* | 30-35 | 46.3 | 32.6 | 21.0 | L | 0.83 | 0.081 | 10.2 | 8.3 | 7.1 | 2.3 | 589 |
| **G** | *DE* | 35-40 | 44.7 | 32.6 | 21.2 | L | 0.74 | 0.080 | 9.2 | 8.2 | 7.0 | - | 704 |
| **H** | *DE* | 40-45 | 46.4 | 33.0 | 20.5 | L | 0.82 | 0.076 | 10.8 | 8.3 | 7.0 | 1.9 | 662 |
| **I** | *DE* | 45-50 | 43.5 | 32.7 | 23.7 | L | 1.25 | 0.086 | 14.5 | 8.0 | 7.0 | - | 927 |
| **L** | *DE* | 50-55 | 46.9 | 30.7 | 22.6 | L | 0.92 | 0.075 | 12.3 | 8.1 | 7.1 | 5.1 | 965 |
| **US755** | *BU* | - | 48.3 | 27.2 | 24.5 | L | 0.61 | 0.061 | 10.0 | 8.0 | 7.0 | 2.4 | 390 |

Tab. 2. Uffizi gallery complex, Florence. Selected physicochemical analyses on the profile shown in Figure 1. [1] Def. = Definition: All = alluvium; DE = Dark Earth; BU = Burned Unit; [2] Depth from upper boundary of Dark Earth. [3] Textural classes according to Soil Survey Staff (2003): SiCL = Silty clay loam; L = Loam. The particle size analyses highlight the great internal homogeneity of Dark Earth, with all samples containing similar proportions of sand, silt and clay, resulting in a uniform loamy texture throughout. The alluvial sediments deposited by the Arno flood of 4th November 1177 display a markedly different texture. Note the increase in organic carbon in Dark Earth with respect to the alluvial layer (US 736) and to the unit below, made up by burned structural remains (US 755). The low C/N ratio, below the reference value of 12, testifies to the advanced stage of the decomposition of humus and to vigorous biological activity. The Dark Earth pH is buffered to values around 8.0-8.3 by the presence of carbonates, predominantly of anthropic origin (mortar fragments, ashes). The relative increase in total phosphate ($P_2O_5$) in the samples I and L (7th century AD Dark Earth phase) derives from the input of faecal material linked to practices of manure production or "night-soiling".

2012). The excavation brought to light thick Dark Earths sandwiched between alluvial layers deposited during the floods of the nearby Arno river. Soil analyses proved that an early phase of Dark Earth formation, radiocarbon dated to the 7th century AD (see Fedi *et alii* 2007), was linked to the accumulation of manure or "night-soil". This practice fits well with an area used for urban agricultural or horticultural practices (see Davidson *et alii* 2006). Dark Earth formation was accompanied by wet environmental conditions, with periodic inundations of the nearby Arno river, as also confirmed by geomorphological and archaeological data. Alluvial sediments were most likely deposited periodically and reworked by faunal activity (small rodents, earthworms, etc.) within the Dark Earth deposit. This process, known as bioturbation, is of fundamental importance in Dark Earth formation, as it is responsible for its great internal homogeneity and lack of recognizable stratification. Human activities, such as digging, trampling, backfilling and ground levelling, also contributed to the reworking. A period of non-deposition and abandonment followed the phase of Dark Earth formation of the 7th century, marked also by a lower ceramic density recorded during excavations. Such a period is also highlighted by a gap of ca. 250 years between the base and the top part of the Dark Earth interval, inferred from the available radiocarbon dates (Fedi *et alii* 2007; Nicosia *et alii* 2012). The resumption of Dark Earth formation in the 10th to early 11th century AD was marked by the dumping of domestic waste. These activities indicate that the area was again inhabited, and that the conditions were favourable for strong biological activity to resume. Archaeological excavations exposed postholes and scatters of construction rubble that could be linked to buildings built with perishable materials, dated to the 11th century. Towards the end of the second period of Dark Earth formation, the environment shows another transition towards wetter conditions in a context characterized by the gradual decrease in human presence. The wet conditions culminated with the deposition of the alluvial layer that covers the sequence, most likely corresponding to the major flood of November 4th 1177 AD.

### *3.2. Castelletto di Brenzone (Verona, northeastern Italy, fig. 2)*

The site of Castelletto di Brenzone, on the Eastern shores of the Garda Lake, is an interesting case study concerning the re-use of Roman buildings during the early medieval period. In particular, at Brenzone ca. 30 cm of Dark Earth-like deposits formed directly on the robbed structural remains of a Roman villa (see Bruno, Tremolada 2011). Artefacts

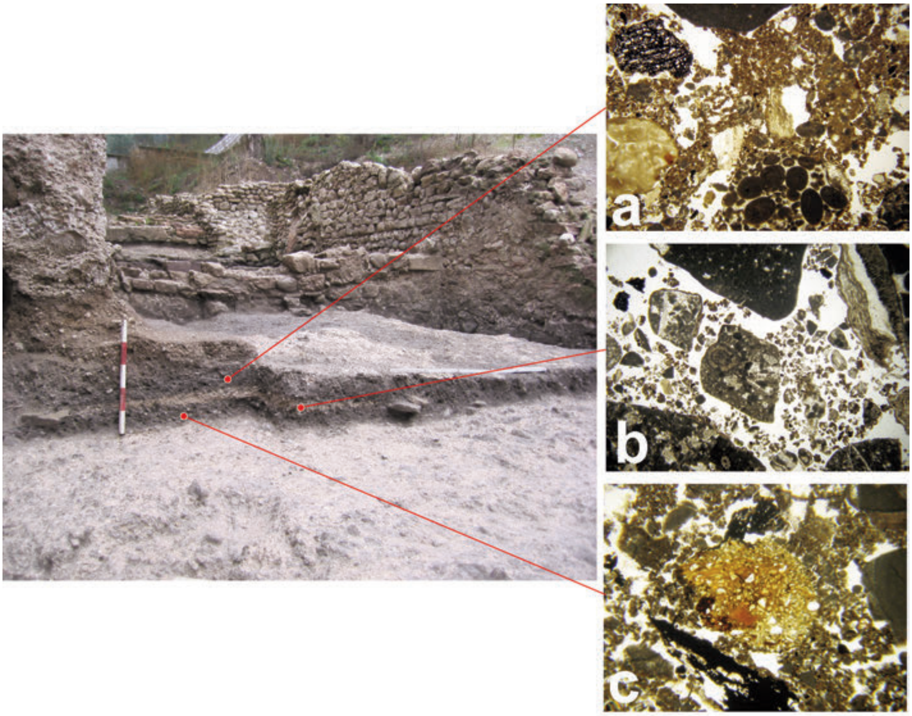


Fig. 2. Castelletto di Brenzone (Verona). Example of 6th-7th century AD Dark Earth formed directly on a robbed Roman floor.
a) Dark Earth (20x, plane polarized light, frame width 4.5 mm). Mixture of soil material, limestone fragments, charcoal, mortar, all strongly homogenized by soil fauna.
b) Dark Earth (20x, plane polarized light, frame width 4.5 mm). One of the levels of coarse sand and gravel that occur within Dark Earth. These might derive from periodic sweeping of the domestic areas. Note strong bioturbation occurring in the space between coarse clasts.
c) Dark Earth (20x, plane polarized light, frame width 1 mm). Allochtonous soil fragment reddened by burning. These aggregates, and the presence of ashes and abundant charcoal, testify to the functioning and maintenance during the phases of re-use of the Roman villa.

found in these deposits allowed to ascribe them to the late 6th – 7th century AD (Bruno, Tremolada 2011). The microstratigraphic study, carried out by means of thin sections, revealed that these deposits formed primarily as the outcome of domestic activities and trampling. They are in fact mainly composed of wood ash, in which charcoal, burned sediment aggregates, mortar, brick and pottery fragments and bones are dispersed. Indicators of animal gathering (dung, secondary phosphates, etc.) and of artisan activities (slags, metal fragments, high-temperature burning by-products) are absent. Mm-thick levels of coarse sands and gravels are interfingered within the domestic deposits. These could correspond to small backfill episodes done in order to "restore" the trampling surface, or could be as well a residual lag deposit left after raking. The absence of microscopic indicators of surface slaking (a process caused by the impact of raindrops on the soil surface – see Courty *et alii* 1989) and of puddling suggests that while the deposit was forming the aggrading surface was roofed or anyway covered. The microstratigraphic studies hence allowed us to infer that, after a span of time impossible to quantify following the robbing of the Roman villa, its remaining structures were squatted at least since the late 6$^{th}$-7$^{th}$ century AD. The change in the mode of use of space is reflected by a change in the style of sedimentation, witnessed by the formation of Dark Earth-like deposits.

### *3.3. Rue de Dinant, Bruxelles (Belgium, fig. 3)*

The geoarchaeological study of Dark Earth units in the centre of town dating from the 10$^{th}$-13$^{th}$ century AD, the period where historians place the earliest urbanization of Brussels, allowed to identify a series of activities related to soil exploitation (silt extraction, quarrying), and agriculture (crop growth, pasture, etc.). These identifications raise a lot of questions on the dynamics of the early developments of Brussels (see Vannieuwenhuyze *et alii* 2012; Devos *et alii* 2012).

One example is the rescue excavation by the Direction of Monuments and Sites of the Brussels Capital Region of site of rue the Dinant (see Devos *et alii* 2009). During this intervention thick Dark Earths have been discovered covering an important part of the site. Artefacts found within them allowed to ascribe them to the 11$^{th}$-12$^{th}$ century. In the northern part of the site, clay/loam extraction pits truncated the Dark Earth. In the southern part, remains of the 13$^{th}$ century rampart of the first city wall covered the Dark Earth.

Micromorphological study, combined with physicochemical analyses and phytolith study, revealed that the Dark Earth in the southern part was probably the result of the addition of soil sods that got bioturbated by faunal activity and thus homogenized, probably due to pastoral activities (US 638). Later on the surface was put into agriculture, with the addition of lots of manure and domestic waste to enhance soil fertility (US 631) (see fig. 3). The northern part of the site showed a somewhat different sequence of long lasting agriculture (see Devos *et alii* 2009).

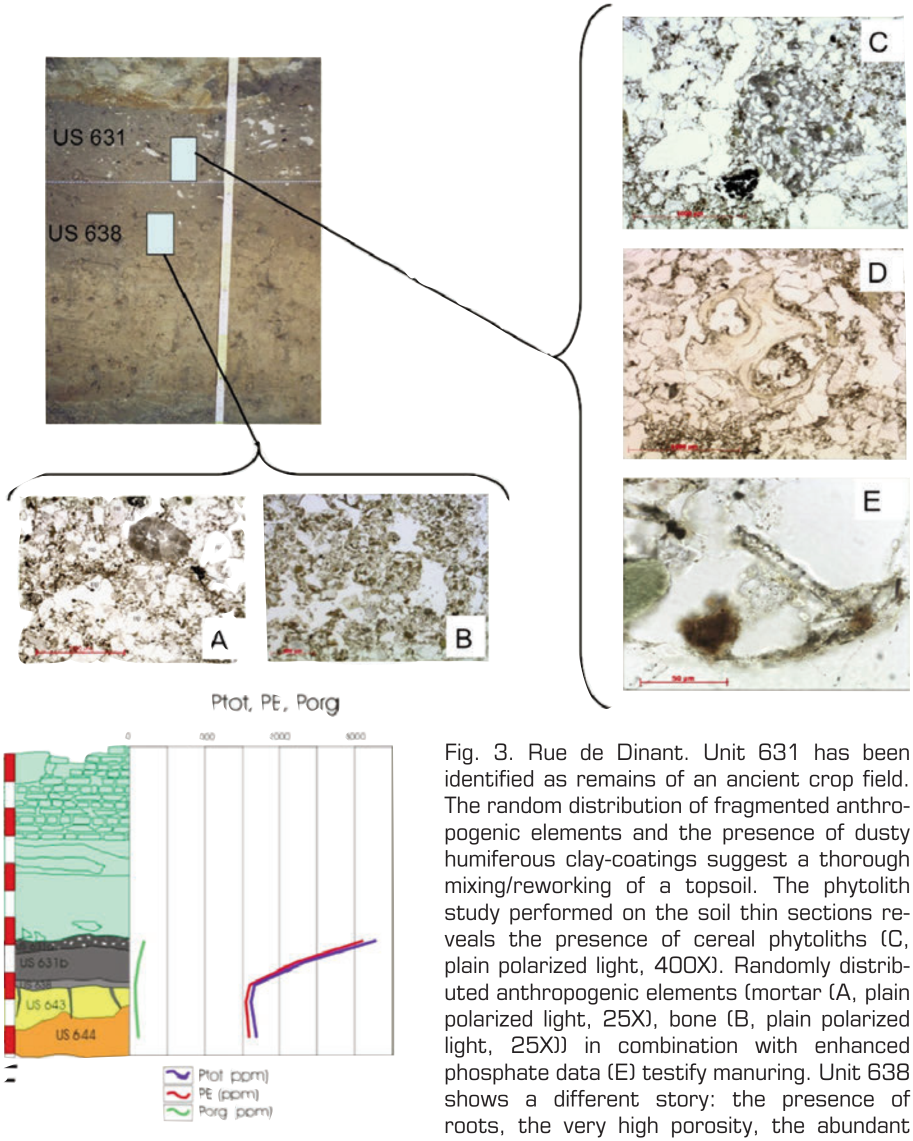


Fig. 3. Rue de Dinant. Unit 631 has been identified as remains of an ancient crop field. The random distribution of fragmented anthropogenic elements and the presence of dusty humiferous clay-coatings suggest a thorough mixing/reworking of a topsoil. The phytolith study performed on the soil thin sections reveals the presence of cereal phytoliths (C, plain polarized light, 400X). Randomly distributed anthropogenic elements (mortar (A, plain polarized light, 25X), bone (B, plain polarized light, 25X)) in combination with enhanced phosphate data (E) testify manuring. Unit 638 shows a different story: the presence of roots, the very high porosity, the abundant excremental organo-mineral micro-aggregates and the presence of sparitic biospheroids (D, plain polarized light, 25X) point to heavy bioturbation by plant roots and earthworms. In combination with the absence of cereal phytoliths this unit is probably testifying old pasture land.

### 3.4. Rue de l'Évêché, Noyon (France, fig. 4)

Excavations at rue de l'Évêché, in Noyon, exposed 0.80 m of Dark Earth resting above late Antique deposits and cut by 12th century pits (Desachy 1999). Noyon is located on a sandy colluvial fan in the flood-plain of the Versette, on a clayey and carbonated substrate. The site is situated in the very centre of the Antique and Medieval town, within the city walls, at the crossing of the two main streets. Dark Earth of rue de l'Évêché is very homogenous and no stratification was observed *in situ*. Thus, in addition to the usual micromorphological and chemical observation, systematic counting on thin sections was used in order to spot any vertical heterogeneity. The results revealed that Dark Earth are formed by successive surface and sub-surface horizons, partially bioturbated by

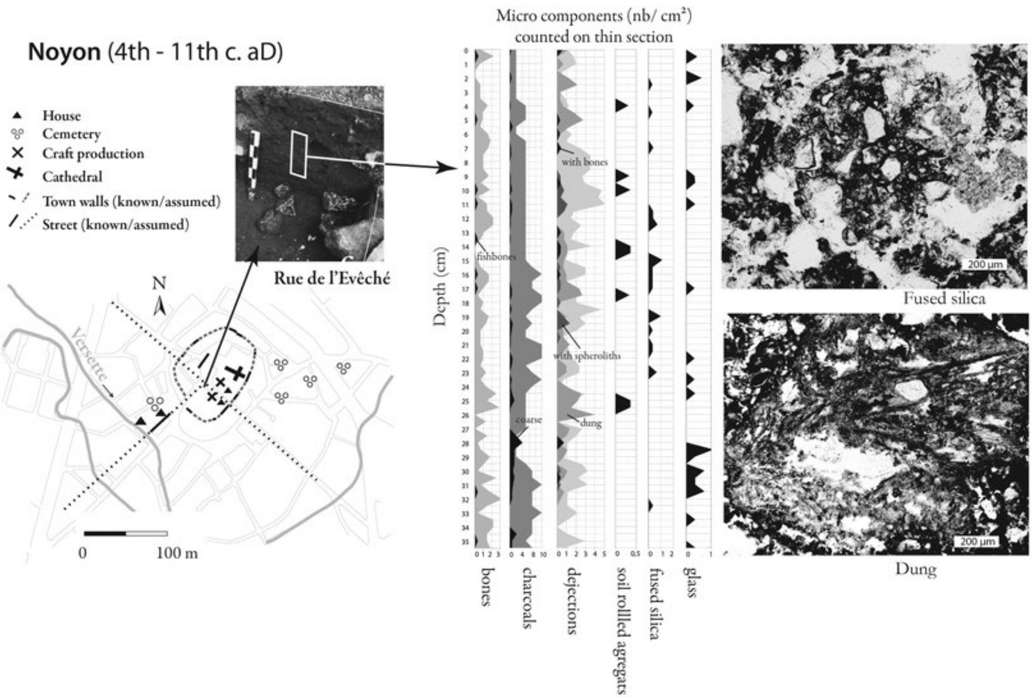


Fig. 4. Noyon, rue de l'Évêché (from Borderie in press). The systematic counting on thin section every 5 mm shows the vertical succession of dejections (dung and phosphatic aggregates with bones or spherulites) and fused materials (silica and glass). The concentration of phosphatic materials can be linked with the high phosphorus measured by chemical methods (see tab. 3).

| Dark Earth | LOI 550°C % | Corg % | Ntot % | C/N | OM % | $CaCO_3$ % | Fe % | P inorg. ppm | P tot ppm | P org ppm | MS $10^{-8} kg^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5.56 | 1.97 | 0.12 | 15.8 | 3.4 | 12.8 | 0.084 | 27913 | 28417 | 504 | 82.41 |

Tab. 3. Noyon, rue de l'Évêché (from Borderie in press). In this carbonated context, Dark Earth is rather rich in organic matter, characterised by very high phosphorus (Ptot). The low organic phosphorus (Porg) shows the degree of mineralisation of the components and the important contribution of faecal material.

*enchytraeïds* and earthworms and weathered by percolations, indicating an outdoor space. Nevertheless, microscopic component such as bone, glass and charcoal fragments, many dejections, fused silica and rolled aggregates, are well preserved, (Borderie 2011). This can indicate that sediments accumulated rapidly and were trampled. The combination of these different refuses suggests that domestic waste was disposed in this area (Borderie *et alii* in press-a). Thin section counting clearly shows vertical concentrations of dung and of fused material such as glass and silica (fig. 4**)**, indicating the use of this area for herbivore gathering and, alternatively, craft activities.

Combined with other studies in Noyon (Lacroix 2004, Borderie 2011, Borderie in press), the geoarchaeological analyses of Dark Earth give new data on the early Middle Ages town life, showing that Dark Earth can be linked with human dwelling and not with abandonment.

## 4. Geosciences in Dark Earth research: a balance and future perspectives

Observing the chronology column in Table 1, it is clear that Dark Earths occur over a wide and very variable time range. Moreover, their presence is not limited to urban contexts, as several "rural" Dark Earths are reported in literature, and not necessarily where a previous Roman-age occupation exists (see Loveluck 2004; Nicosia, Devos *submitted*). Furthermore, as shown by the examples in chapter 3, a wide variety of anthropic and natural processes are involved in Dark Earth formation, ruling out any univocal interpretation. Shall we therefore conclude that Dark Earths simply do not exist as a valid archaeological research theme? This would deny the actual evidence that, in archaeological contexts characterized by intense human dwelling, deposits that are dark-colored and somewhat enigmatic did form across Europe. It is at this point that the contribution of the methods of geosciences becomes paramount. These are in fact able to "see through" the dark of Dark Earth, revealing that many different interpretations, in terms of human agency, environmental conditions, use of space, and post-depositional processes are possible. The authors of this article therefore agree with scholars such as Galinié (2004) and Loveluck (2004), who think that Dark Earth should be regarded as a "concept d'attente", as a case of well-established archaeological field jargon that does not imply an univocal classification or, worse, interpretation.

Before the application of geoscience methods to Dark Earths in the early 1980s, these deposits were regarded as generic "abandonment soils", gardens, backfill or even as alluvium (see Yule 1990). The analyses performed in the following 30 years did not completely rule out these interpretations, but contributed to add some complexity to aprioristic formulations. We now know that each site has a story of its own, deriving from a complex interplay of human activities and sin- and post-depositional natural processes. Especially thanks to soil micromorphology, it is well established that the accumulation of waste deriving from domestic activities, from cess and latrines, from construction, destruction and robbing of buildings, from artisan processes, etc. constitutes the parent material at the base of Dark Earth formation. We know that a contribution to the vertical accretion of Dark Earths can come from natural sedimentation, especially in sites located in active alluvial contexts (see Nicosia *et alii* 2012; Cremaschi, Nicosia 2010). The important role of weathering of construction material and of soil forming processes has also been established by the approach based on geosciences. In particular, the activity of soil fauna such as rodents, beetles, ants, and earthworms has proven to be a key process in Dark Earth formation. The latter results in the masking of the original stratigraphy, by erasing boundaries and sedimentary structures, and can cause the random distribution of natural and anthropogenic components within the deposit. The traces of specific land utilization types have also been revealed by analyses at a number of sites. These include, for example, domestic occupation, craft activities, circulation areas, the gathering of animals, the presence of grassland, pastures or of abandoned areas characterized by a ruderal vegetation, agricultural and horticultural activities, etc.

Where do we go from here? Although soil micromorphology and physicochemical analyses have proven powerful in elucidating the cultural activities associated with Dark Earth, their combination with other analytical methods constitutes a main research trend for the future. Specifically, thin section study can be coupled with instrumental analyses (e.g., electron microprobe, SEM/EDS), phytolith analysis, micro-archaeology, pollen and macro-remain studies and spatial analysis of artifact distribution. Future study should include research on the origin and evolution of the organic matter in Dark Earth, especially of pyrogenic organic matter. Charcoal, charred vegetal material and soot are in fact main components of Dark Earth, and are at the base of its peculiar dark appearance. Collaboration between soil micromorphologists and pedo-anthracologists – specialists in determining the origin and taphonomy of charcoal in soils – could therefore yield important results.

Moreover, the understanding of Dark Earths and, more broadly, of urban stratigraphy cannot be separated from the wider environmental framework. This is especially true for cities located in alluvial settings, where rivers shape the city's topography, are key to its economy and rule settlement choices (see Heimdahl 2005; Cremaschi, Nicosia 2010; Nicosia *et alii* 2012; Nicosia *et alii* in prep.). The behaviour of rivers is in itself linked to wider processes such as neo-tectonics and climate change, implying the need to investigate at a broader scale. An example is the phase of severe river avulsion that led to rapid and conspicuous sedimentation in northern and central Italy between the 5$^{th}$ and 8$^{th}$ century AD (see Fontana *et alii* 2012; Pasquinucci, Menchelli, Genovesi 2012), a period of time that saw the formation of Dark Earths in many cities. This phase of geomorphic instability, which contrasts with the stability of the Roman period, is linked by Fontana *et alii* (2012) to climatic causes, and potentially coincides with the "deluge" mentioned by the Longobard historian Paul the Deacon. This is just one of the many examples showing that beside improvements in analytical methods and inter-disciplinary research, geoscientists involved in Dark Earth studies will need to integrate their findings in a wider geomorphological and palaeo-environmental picture.

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