Cultural soilscapes

E. C. WELLS

Department of Anthropology, University of South Florida, Tampa, Florida 33620, USA
(e-mail: cwells@cas.usf.edu)

Abstract: While soil is normally studied as the outcome of natural geological and chemical processes, soil research by archaeologists, geographers and other social scientists focuses on the human behavioural dimensions of soil formation. As a result, 'cultural soilscape' is an analytical concept common to both Earth and social sciences that encourages a more holistic, transdisciplinary approach to studying soil formation processes. This paper introduces the concept of cultural soilscape and reviews important archaeological work on this theme over the past decade.

Soil is usually considered to be the product of numerous intersecting natural processes, including those associated with the erosion of geological materials, topography, climate, living organisms and time. Recently, social scientists – but especially archaeologists and geographers – have proposed that 'culture' (learned and shared knowledge and beliefs that produce, and are produced by, human behaviour) should be added to this list, and that soil should be understood and studied as a product of social forces as much as natural ones (see Wagstaff 1987). Indeed, soil surveyors and pedologists have long recognized that physical, biological and chemical properties of soil may be altered significantly as a direct result of human activity. It is not surprising, then, that recent approaches to soil morphology and related research consider the *cultural soilscape*, which can be defined as a given area of the Earth's surface that is the result of spatially and temporally variable geomorphic, pedogenic and cultural processes. As the physical embodiment of human/environment relationships, the cultural soilscape is an important analytical domain, because it reveals the consequences of the complex and multilayered dialectic between human behaviour and soil bodies over long periods. In this paper, I review the varied ways in which geo-archaeologists and soil scientists have collaborated to study cultural soilscapes over the past few decades. In doing so, I hope to convince the reader that transdisciplinary studies of ancient, recent and contemporary cultural soilscapes provide unique, but complementary, datasets with which to model soil formation processes.

The cultural soilscape as an analytical domain

Since its inception as a scientific discipline nearly a century ago, archaeology has concerned itself with the study of human impacts on the manufacture, use and discard of material culture, that is, artifacts and the technologies developed to adapt to societies' changing circumstances over time (Binford 1962; Clarke 1968). The fundamental analytical unit was considered to be the prehistoric site – an area of human settlement or activity composed of artifacts and features as well as other evidence for human behaviour. Very recently, however, the goal of archaeology has shifted to understanding landscapes and entire regions in the past, rather than a single site, and to read the history of human activity all the way up to the global scale (Anschuetz *et al*. 2001). As a result, archaeologists have drawn theoretical and methodological insights from other social and natural sciences to study the use, management and meaning of landscapes (Butzer 1982).

The convergence of different disciplinary approaches for landscape research is not unique to archaeology. Many social and natural scientific disciplines have independently come to the conclusion that landscapes have cultural characteristics in addition to natural ones (e.g. Cosgrove 1984; Jackson 1994). The concept of landscape, then, can be understood as a composite of all factors and features that constitute the visual and perceived impact of an anthropogenic environment upon the human senses (e.g. Bender 1992; Bradley 1998). In other words, landscapes are the physical and spatial manifestations of the relationship between humans and their environment (Marquardt & Crumley 1987). For studying landscapes as

From: Frossard, E., Blum, W. E. H. & Warkentin, B. P. (eds) 2006. *Function of Soils for Human Societies and the Environment.* Geological Society, London, Special Publications, **266**, 125–132.
0305–8719/06/$15

social and natural phenomena, it is clear that geology, pedology and other Earth sciences must play a central role. Indeed, these varied strands have combined to form new, transdisciplinary approaches to landscape research, such as geo-archaeology and historical ecology, which focus on the physical evidence for human/environment relations over very long time spans, on the order of hundreds or thousands of years (e.g. Davidson & Shackley 1976; Stein & Farrand 1985; Collins *et al*. 1990; Holliday 1992; Crumley 1994; Kirch & Hunt 1997; Ashmore & Knapp 1999).

Central to these new approaches is an appreciation of cultural soilscapes. While functioning soil is formed through the physical disintegration and chemical decomposition of rocks through weathering and subsequent arrangement by biological and chemical agents, the cultural soilscape is formed through these processes plus human behavioural variables acting to disturb and displace soil. In this way, the concept of cultural soilscape is more inclusive than the generic term, anthrosol (soil modified by human activity), because it encompasses not only the materials that can be perceived and used as resources by humans (for growing food, raising buildings and earthworks, and so on) but also other humans and the social and historical frameworks imposed by people upon their physical surroundings (e.g. Waters & Ravesloot 2001). Hence, the concept of cultural soilscape is appropriate for understanding the ways in which humans modify their physical environment at the landscape scale (versus the pedon scale for anthrosols), as well as the ways in which the physical environment shapes human behaviour. To be sure, cultural soilscapes are rarely shaped by a single person. Instead, they materialize a palimpsest of many individual ideas, beliefs and practices. In this way, cultural soilscapes are historically contingent on local patterns and processes, and act as reservoirs of shared ecological knowledge and its manifestation in the soil record.

Archaeology and soil memory in the study of cultural soilscapes

Since culture and soil 'coevolve' alongside one another, studies of cultural soilscapes necessarily employ diachronic, integrated, and multi-perspective approaches, which juxtapose archaeological, historical and ethnological studies with research in the Earth sciences. By providing unique and compelling arguments about long-term patterns of land use, archaeology occupies an important niche within the intellectual and scientific world, because it provides information at a scale and resolution that makes it suitable for studies of human/soil dynamics (van der Leeuw & Redman 2002). For archaeologists, the extent to which soils trap and preserve human impacts is critical for studying cultural soilscapes. Over the past decade, soil science has come to play an essential role in archaeologists' toolkits, since many human actions result in physical changes to soils as well as in the deposition of a range of chemical compounds (see Scudder *et al*. 1996). Recent technological advancements in analytical methods and instrumentation have made detecting and studying these impacts relatively quick and inexpensive; thus, this line of research is becoming standard practice in many archaeological investigations. Indeed, when combined with archaeology, cultural soilscapes often can be studied with the most basic tools of pedology: soil morphology, particle-size distribution analysis, pH, clay mineralogy, and patterns of chemical element accumulation (see Holliday 2004).

In archaeological studies of cultural soilscapes, the core concept is 'soil memory', that is, how soils encode the physical, biological and chemical effects of different human activities. These effects can include modification to soil structure (often leading to compaction), soil reaction (pH), aeration and water drainage, nutrient cycling and soil organism activity, soil temperature regimes, as well as the addition of anthropogenic materials and other contaminants. These effects, in turn, may influence other soil properties, for example, water infiltration and permeability, water-holding capacity, and root penetrability. Studying changes to the physical structure and composition of soils has long been an integral part of archaeological research (e.g. Cornwall 1958; Limbrey 1975; Courty *et al*. 1989; Feller *et al*. 2003). Much less is known about the chemistry of anthrosols composing cultural soilscapes that developed prior to the Industrial Revolution, even though the chemical effects of modern human activities on soils have been well studied (see McBride 1994; Sparks 2003).

A good deal of information on the chemistry of ancient anthrosols has come from geochemical applications in archaeology. For example, early work by European geographers (e.g. Arrhenius 1929, 1931) revealed high concentrations of soil phosphate in areas of ancient human occupation, which can be explained by the observation that human activities involving the deposition of refuse and organic waste increase the amount of phosphorus and other elements (mainly calcium, carbon, and nitrogen) in soils. Once deposited, phosphorus ions attach to iron, aluminum or calcium ions to form relatively stable chemical compounds that can be detected and quantified with appropriate techniques (see Eidt 1985; Wild 1986). The basic idea is that the surfaces of certain soil particles, particularly clays, hold ions carrying a negative charge (anions) that act like magnets to attract positive ions (cations). Cations – including those from calcium, magnesium and potassium – generated by human activities become attached to the soil particles in a process known as cation exchange. Since these compounds are rapidly fixed to the mineral surfaces of sediments, they tend to remain stable and immobile (resistant to horizontal and vertical migration) for very long periods. To establish the quantity and distribution of chemicals that have accumulated on the surfaces of sediment grains as a result of human activity, one compares the concentrations of elements in anthrosols to those of soils unaffected by human settlement and land use.

The work of European geographers and others in the early twentieth century (reviewed in Proudfoot 1976; Bakkevig 1980; Bethell & Máté 1989; Craddock *et al.* 1986) developed an impressive array of techniques for measuring available soil phosphate (using mild-acid extraction procedures) and total soil phosphate (using strong-acid digestion procedures) as a means to prospect for archaeological sites. More recent studies (e.g. Coultas *et al.* 1993; Dunning 1993; Schuldenrein 1990; Sullivan 2000) have improved some of these methods, but employ them using more human-centred perspectives, by viewing patterns of phosphate deposition as a measure of the ways in which humans interfere with phosphorus cycling in ecosystems. In addition, researchers have begun to examine the implications of elements other than phosphorus for site formation processes (e.g. Linderholm & Lundberg 1994; Middleton & Price 1996; Entwistle *et al.* 2000*b*; Wells 2004).

Recent exemplary research at macro-, meso-, and micro-scales

The manner by which humans mould cultural soilscapes is studied in archaeology at three nested spatial scales: macro-, meso-, and micro-scales. The first concerns large portions of the soilscape, including resource catchment zones and agricultural field systems. The second deals with mid-level spatial domains, such as garden plots and landscapes between settlements. The third level relates to localized patterns of land use among households and communities, for instance, food preparation or consumption areas and formal spaces for public gatherings.

Macro- and meso-scale approaches to cultural soilscapes tend to focus on studying human ecodynamics, plant-subsistence strategies and habitat variation, by pooling information from settlement and demography along with climate reconstructions (oxygen isotope studies of lake sediment cores) and land-use history (phosphate changes across soil strata). For example, work by Cowgill (1961; Cowgill & Hutchinson 1966) in the mid-1960s showed how soil chemical analysis of lake sediment cores in the Guatemalan Petén rainforest can be used to investigate the effects of intensive cultivation of the region's soils prior to the sixteenth century. Cowgill and her colleagues found that widespread cultivation accelerated soil erosion, which resulted in the accumulation of thick, clay-rich, gleyed deposits in Petén lakes. Not long after this work, another study, by Provan (1971, 1973) in the early 1970s, applied chemical analyses to anthrosols from Bjellandsøynæ, an Early Iron Age farm site in Norway. By investigating exchangeable sodium, potassium, calcium, magnesium, organic carbon, total phosphorus and total nitrogen, Provan observed that the distribution of brown podsols correlated with cultivated parcels of land, while iron-humus podsols signalled undisturbed soils.

Aside from these isolated cases, however, only since the mid-1970s has soil chemistry played a major role in archaeological research concerned with reconstructing past agricultural practices. At first, these studies were largely limited to research on enrichment and depletion of certain plant macronutrients, namely phosphorus, nitrogen, and potassium, over time. More recently, however, soil chemistry has been incorporated into large, multidisciplinary projects that combine archaeological survey and excavation with physical and chemical analysis of sediments and palynology. For example, Dunning (1993, 1996; Dunning & Beach 1994, 2000; Dunning *et al.* 1997, 1998), Fedick (1995, 1996; Fedick *et al.* 2000; Fedick & Morrison 2004), and others (e.g. Pope *et al.* 1996; Wingard 1996; Beach 1998; Rosenmeier *et al.* 2002) examine anthrosols produced by the pre-Hispanic Maya peoples of Central America to answer questions about the nature and variability in agricultural practices and how these practices allowed the Maya to adapt to a complex mosaic of microenvironmental variations in soil since at least 1000 BC. Previous studies in this region show that the Maya developed creative agrotechnologies to deal with soil variation in their karstic environment, farming on drained fields to stabilize surface hydrology and improve the soil characteristics of the plant-root zone (Pohl *et al.* 1990; Pope & Dahlin 1989; see also Turner & Harrison 1983). By combining archaeology, pedology and geomorphology to investigate the ways in which highly fertile and effectively irrigated agricultural fields were created and maintained, this research provides key information on the environmental parameters of cultural adaptation to tropical soilscapes.

In addition to elemental studies, analysis of stable carbon isotope ratios (i.e. $^{13}C/^{12}C$ ratios) has become particularly important to prehistoric agricultural studies because of the characteristic isotopic signatures of C3 and C4 plants (Nordt 2001). Corn, for instance, is a C4 plant enriched in ^{13}C relative to most other cultivated and wild plants. As a result, distinctive carbon isotope signatures produced by ancient corn crop residues can be preserved in the humic component of soil organic matter: humus extracted from buried A-horizons of soils that were likely used for the cultivation of corn is enriched in ^{13}C. These kinds of studies have been used to trace the spread of maize agriculture at Caracol in the tropical forests of Belize (e.g. Webb *et al.* 2004) and to reconstruct manuring and other soil fertility enhancing activities at Orkney in northern Scotland (e.g. Simpson *et al.* 1997, 1998; Bull *et al.* 1999).

Work on micro-scale cultural soilscapes is a relatively recent development, and is largely concerned with reconstructing the types and locations of certain domestic activities. For example, phosphate deposition is associated with the preparation and consumption of foods and beverages; sodium and potassium compounds are generated by the production of wood ash in hearths and kilns; iron oxide and mercuric sulphide are accumulated in soils through the use of hematite and cinnabar used as pigments in burials and caches; and iron and titanium oxides from microphenocrysts embedded in volcanic glass are deposited in soils as a result of obsidian tool manufacture and use (e.g. Middleton & Price 1996; James 1999; Vizcaíno & Cañabate 1999; Wells *et al.* 2000; Scudder 2001; Knudson *et al.* 2004; Middleton 2004; Wells 2004; Cook *et al.* 2005; Marwick 2005; Sampietro & Vattuone 2005). This work builds on earlier studies (e.g. Cook & Heizer 1965; Heidenreich & Konrad 1973) that explored the possible geochemical pathways of a range of different elements and compounds in anthrosols at archaeological sites in North America. By mapping the distribution of certain combinations of elements across archaeological sites, these studies were able to determine the precise locations of human settlement within broader landscapes, as well as human activities within archaeological sites.

Two sets of micro-scale studies exemplify current research on cultural soilscapes. First, Entwistle and colleagues (Entwistle & Abrahams 1997; Entwistle *et al.* 1998, 2000*a*, *b*) study the impacts of arable cultivation and animal husbandry on soil development and characteristics at historical farm sites on the islands of northwestern Scotland. They combine historical archaeological research (in which written records can be correlated with archaeological finds to confirm the locations and functions of certain features) with physical and geochemical studies of soils to investigate land-use patterns, with the greater goal of distinguishing habitation and cultivation areas. They find that the spatial covariance of certain major elements or rare-earth elements and trace metals corresponds to activity loci. For example, calcium and strontium signatures are found in cultivated soils that were enriched with shell sand and bone or fish remains to enhance soil fertility, while agricultural plots that exhausted soil fertility and nutrient capacity contain soils with significantly depleted concentrations of zinc, nickel, magnesium and copper. In contrast, habitation zones are enriched in potassium, thorium, rubidium and caesium. While it is unclear which specific human activities resulted in the deposition of these chemical elements, the signatures are nonetheless useful for studying spatial patterns of activity loci in the past, which may help model site form and function.

The second example involves reconstructing daily practices in pre-Hispanic residential sectors of Piedras Negras, Guatemala, and Cerén, El Salvador. Here, Terry and colleagues (Terry *et al.* 2000, 2004; Wells *et al.* 2000; Parnell *et al.* 2001, 2002*a*, 2002*b*) focus on phosphorus and heavy metals (namely copper, iron, mercury, manganese, lead and zinc) to infer specific activities for different kinds of architecture and features. For example, they find that interior spaces in residential buildings contain soils enriched in phosphorus, which they interpret as evidence for the preparation and consumption of meals. On the other hand, they interpret low phosphate signatures surrounding building exteriors as possible evidence for ancient roof drip-lines in which rainwater presumably would have washed away organic debris enriched in phosphors. Areas of craft production involving the use or application of pigments are marked by combinations of heavy metals, with broad, linear patterns of copper and manganese concentrations possibly indicating directions of sweeping and related cleaning activities. Heavy metals also are found in association with plaster fragments at the bases of walls along the exterior façades of buildings, suggesting that some walls may have been painted in antiquity. Finally, they use soil chemistry to create typologies for different kinds of refuse deposits, including those that contain high amounts of organic matter versus those that contain craft production debris. Knowing the spatial distribution of contrasting refuse types across a site, in addition to the types and locations of activities that produced this refuse, may help in reconstructing ancient domestic activity patterns.

Future directions

Future developments in the archaeological study of cultural soilscapes inevitably will depend on ethno-archaeological research aimed at linking soil chemical signatures of modern (observable) human activities with those of prehistoric peoples in archaeological sites, to understand the cultural pathways by which elements and compounds are deposited in soils. This work has largely just begun (e.g. Barba & Ortiz Butrón 1992; Barba *et al*. 1995; Middleton & Price 1996; Fernández *et al*. 2002; Wells & Urban 2002; Terry *et al*. 2004), but the results show great promise. When these kinds of human-centred investigations are combined with broader landscape approaches, it will be possible to study and understand cultural soilscapes in a far more detailed manner than has been the case. For example, more sensitive and flexible frameworks for classifying, mapping, and studying soils can be created. Soil taxonomy was developed in the mid-1970s in the US to characterize soil variation by measuring certain quantifiable properties, including diagnostic horizons and soil moisture and temperature. However, it has been pointed out that this taxonomy creates classes that are only partially related to landform (Young & Hammer 2000), possibly because cultural impacts are not considered. Sandor (1992), who considers the cultural soilscape, has worked closely with indigenous communities to develop folk typologies for soil classes, some of which crosscut those described using traditional soil taxonomy. While these kinds of classification approaches are not widely applicable, they strongly suggest that human use and perception of cultural soilscapes have important consequences for understanding soil formation processes.

References

ANSCHUETZ, K.F., WILSHUSEN, R.H. & SCHEICK, C.L. 2001. An archaeology of landscapes: perspectives and directions. *Journal of Archaeological Research*, **9**, 157–211.

ARRHENIUS, O. 1929. Die Phosphatfrage. *Zeitschrift für Pflanzenernährung. Düngung und Bodenkunde*, **10**, 185–194.

ARRHENIUS, O. 1931. Die Bodenanalyse im dienst der archäologie. *Zeitschrift für Pflanzenernährung. Düngung und Bodenkunde*, **10**, 427–439.

ASHMORE, W. & KNAPP, A.B. (eds) 1999. *The Archaeologies of Landscape: Contemporary Perspectives*. Blackwell, Oxford, UK.

BAKKEVIG, S. 1980. Phosphate analysis in archaeology – problems and recent progress. *Norwegian Archaeological Review*, **13**, 73–100.

BARBA, L. & ORTIZ BUTRÓN, A. 1992. Análisis químico de pisos de ocupación: Un caso etnográfico en Tlaxcala, México. *Latin American Antiquity*, **3**, 63–82.

BARBA, L., PIERREBOURG, F. D. TREJO, C., ORTIZ BUTRÓN, A. & LINK, K. 1995. Activités humaines reflétées dans les sols s'unités d'habitation contemporaine et préhispanique de Yucatan (Mexique): études chimiques, ethnoarchéologiques et archéologiques. *Revue d'Archéométrie*, **19**, 79–95.

BEACH, T. 1998. Soil constraints on northwest Yucatán, Mexico: pedo-archaeology and Maya subsistence at Chunchucmil. *Geoarchaeology: an International Journal*, **13**, 759–791.

BENDER, B. 1992. Theorizing landscape and the prehistoric landscapes of Stonehenge. *Man*, **27**, 735–755.

BETHELL, P. & MÁTÉ, I. 1989. The use of soil phosphate analysis in archaeology: a critique. *In*: HENDERSON, J. (ed.) *Scientific Analysis in Archaeology and Its Interpretation*. Institute of Archaeology, University of California, Los Angeles, 1–29.

BINFORD, L.R. 1962. Archaeology as anthropology. *American Antiquity*, **28**, 217–225.

BRADLEY, R. 1998. *The Significance of Monuments: on The Shaping of Human Experience in Neolithic and Bronze Age Europe*. Routledge, London, UK.

BULL, I.D., SIMPSON, I.A., VAN BERGEN, P.F. & EVERSHED, R.P. 1999. Muck 'n' molecules: organic geochemical methods for detecting ancient manuring. *Antiquity*, **73**, 86–96.

BUTZER, K.W. 1982. *Archaeology as Human Ecology: Method and Theory for a Contextual Approach*. Cambridge University Press, Cambridge, UK.

CLARKE, D.L. 1968. *Analytical Archaeology*. Methuen, London, UK.

COLLINS, M.E., CARTER, B.J., GLADFELTER, B.G. & SOUTHARD, R.J. (eds) 1990. *Pedological Perspectives in Archaeological Research*. Soil Science Society of America, Madison, Wisconsin, Special Publications, **44**.

COOK, S.F. & HEIZER, R.F. 1965. *Studies on the Chemical Analysis of Archaeological Sites*.

University of California, Berkeley, Publications in Anthropology, **2**.

Cook, S.R. Clarke, A.S. & Fulford, M.G. 2005. Soil geochemistry and detection of early Roman precious metal and copper alloy working at the Roman town of *Calleva Atrebatum* (Silchester, Hampshire, UK). *Journal of Archaeological Science*, **32**, 805–812.

Cornwall, I.W. 1958. *Soils for the Archaeologist*. Phoenix House, London, UK.

Cosgrove, D.E. 1984. *Social Formation and Symbolic Landscape*. University of Wisconsin Press, Madison.

Coultas, C.L., Collins, M.E. & Chase, A.F. 1993. Effect of ancient Maya agriculture on terraced soils of Caracol, Belize. *In*: Foss, J.E., Timpson, M.E. & Morris, M.W. (eds) *Proceedings of the First International Conference on Pedo-Archaeology*. University of Tennessee, Knoxville, 191–201.

Courty, M.-A., Goldberg, P. & Macphail, R.I. 1989. *Soils and Micromorphology in Archaeology*. Cambridge University Press, Cambridge, UK.

Cowgill, U.M. 1961. Soil fertility and the ancient Maya. *Transactions of the Connecticut Academy of Arts and Sciences*, **42**, 1–56.

Cowgill, U.M. & Hutchinson, G.E. 1966. A general account of the basin and the chemistry and mineralogy of the sediment cores. *In*: Cowgill, U.M., Goulden, C.E., Hutchinson, G.E., Patrick, R., Racek, A.A. & Tsukada, M. (eds) *The History of Laguna Petenxil*. Connecticut Academy of Arts and Sciences, Hartford, Memoirs, **17**, 2–62.

Craddock, P.T., Gurney, D.A., Pryor, F. & Hugs, M. 1986. The application of phosphate analysis to the location and interpretation of archaeological sites. *Archaeological Journal*, **142**, 361–376.

Crumley, C.L. (ed.) 1994. *Historical Ecology: Cultural Knowledge and Changing Landscapes*. School of American Research Press, Santa Fe, New Mexico.

Davidson, D.A. & Shackley, M.L. (eds) 1976. *Geoarchaeology: Earth Science and the Past*. Duckworth, London, UK.

Dunning, N.P. 1993. Ancient Maya anthrosols: soil phosphate testing and land use. *In*: Foss, J.E., Timpson, M.E. & Morris, M.W. (eds) *Proceedings of the First International Conference on Pedo-Archaeology*. University of Tennessee, Knoxville, Special Publications, **93–03**, 203–211.

Dunning, N.P. 1996. A reexamination of regional variability in the prehistoric agricultural landscape. *In*: Fedick, S.L. (ed.) *The Managed Mosaic: Ancient Maya Agriculture and Resource Use*. University of Utah Press, Salt Lake City, 53–68.

Dunning, N.P. & Beach, T. 1994. Soil erosion, slope management, and ancient terracing in the Maya lowlands. *Latin American Antiquity*, **5**, 51–69.

Dunning, N.P. & Beach, T. 2000. Stability and instability in prehispanic Maya landscapes. *In*: Lentz, D.L. (ed.) *Imperfect Balance: Landscape Transformations in the Precolumbian Americas*. Columbia University Press, New York, 179–202.

Dunning, N.P., Beach, T. & Rue, D.J. 1997. The paleoecology and ancient settlement of the Petexbatún region, Guatemala. *Ancient Mesoamerica*, **8**, 255–266.

Dunning, N.P., Rue, D.J., Beach, T., Covich, A. & Traverse, A. 1998. Human–environment interactions in a tropical watershed: the paleoecology of Laguna Tamarandito, El Petén, Guatemala. *Journal of Field Archaeology*, **25**, 139–151.

Eidt, R.C. 1985. Theoretical and practical considerations in the analysis of anthrosols. *In*: Rapp, G. & Gifford, J.A. (eds) *Archaeological Geology*. Yale University Press, New Haven, Connecticut, 155–190.

Entwistle, J.A. & Abrahams, P.W. 1997. Multi-elemental analysis of soils and sediments from Scottish historical sites: the potential of inductively coupled plasma–mass spectrometry for rapid site investigation. *Journal of Archaeological Science*, **24**, 407–416.

Entwistle, J.A., Abrahams, P.W. & Dodgshon, R.A. 1998. Multi-elemental analysis of soils from Scottish historical sites: interpreting land-use history through the physical and geochemical analysis of soil. *Journal of Archaeological Science*, **25**, 53–68.

Entwistle, J.A., Abrahams, P.W. & Dodgshon, R.A. 2000*a*. The geoarchaeological significance and spatial variability of a range of physical and chemical soil properties from a former habitation site, Isle of Skye. *Journal of Archaeological Science*, **27**, 287–303.

Entwistle, J.A., Dodgshon, R.A. & Abrahams, P.W. 2000*b*. An investigation of former land-use activity through the physical and chemical analysis of soils from the Isle of Lewis, Outer Hebrides. *Archaeological Prospection*, **7**, 171–188.

Fedick, S.L. 1995. Land evaluation and ancient Maya land use in the Upper Belize River area, Belize, Central America. *Latin American Antiquity*, **6**, 16–34.

Fedick, S.L. 1996. An interpretive kaleidoscope: alternative perspectives on ancient agricultural landscapes of the Maya lowlands. *In*: Fedick, S.L. (ed.) *The Managed Mosaic: Ancient Maya Agriculture and Resource Use*. University of Utah Press, Salt Lake City, 107–131.

Fedick, S.L. & Morrison, B.A. 2004. Ancient use and manipulation of landscape in the Yalahau region of the northern Maya lowlands. *Agriculture and Human Values*, **21**, 207–219.

Fedick, S.L., Morrison, B.A., Andersen, B.J., Boucher, S., Acosta, J.C. & Mathews, J.P. 2000. Wetland manipulation in the Yalahau region of the northern Maya lowlands. *Journal of Field Archaeology*, **27**, 131–152.

Feller, C., Brown, G.G., Blanchart, E., Deleporte, P. & Chernyanskii, S.S. 2003. Charles Darwin, earthworms and the natural sciences: various lessons from the past to the future. *Agriculture, Ecosystems and Environment*, **99**, 29–49.

Fernández, F.G., Terry, R.E., Inomata, T. & Eberl, M. 2002. An ethnoarchaeological study of chemical residues in the floors and soils of Q'eqchi' Maya houses at Las Pozas, Guatemala.

Geoarchaeology: an International Journal, **17**, 487–519.

Heidenreich, C.E. & Konrad, V.A. 1973. Soil analysis at the Robitaille site, part 2: a method useful in determining the location of long house patterns. *Ontario Archaeology*, **20**, 33–62.

Holliday, V.T. 1992. *Soils in Archaeology: Landscape Evolution and Human Occupation*. Smithsonian Institution Press, Washington, DC.

Holliday, V.T. 2004. *Soils in Archaeological Research*. Oxford University Press, Oxford, UK.

Jackson, J.B. 1994. *A Sense of Place, a Sense of Time*. Yale University Press, New Haven, Connecticut.

James, P. 1999. Soil variability in the area of an archaeological site near Sparta, Greece. *Journal of Archaeological Science*, **26**, 1273–1288.

Kirch, P.V. & Hunt, T.L. (eds) 1997. *Historical Ecology in the Pacific Islands: Prehistoric Environmental and Landscape Change*. Yale University Press, New Haven, Connecticut.

Knudson, K.J., Frink, L., Hoffman, B. & Price, T.D. 2004. Chemical characterization of Arctic soils: activity area analysis in contemporary Yupik fish camps using ICP–AES. *Journal of Archaeological Science*, **31**, 443–456.

Limbrey, S. 1975. *Soil Science and Archaeology*. Academic Press, London, UK.

Linderholm, J. & Lundberg, E. 1994. Chemical characterization of various archaeological soil samples using main and trace elements determined by inductively coupled plasma atomic emission spectrometry. *Journal of Archaeological Science*, **21**, 303–314.

McBride, M.B. 1994. *Environmental Chemistry of Soils*. Oxford University Press, Oxford, UK.

Marquardt, W.H. & Crumley, C.L. 1987. Theoretical issues in the analysis of spatial patterning. *In*: Crumley, C.L. & Marquardt, W.H. (eds) *Regional Dynamics: Burgundian Landscapes in Historical Perspective*. Academic Press, San Diego, California, 1–18.

Marwick, B. 2005. Element concentrations and magnetic susceptibility of anthrosols: indicators of prehistoric human occupation in the inland Pilbara, western Australia. *Journal of Archaeological Science*, **32**, 1357–1368.

Middleton, W.D. 2004. Identifying chemical activity residues on prehistoric house floors: a methodology and rationale for multi-elemental characterization of a mild acid extract of anthropogenic sediments. *Archaeometry*, **46**, 47–65.

Middleton, W.D. & Price, T.D. 1996. Identification of activity areas by multi-elemental characterization of sediments from modern and archaeological house floors using inductively coupled plasma–atomic emission spectroscopy. *Journal of Archaeological Science*, **23**, 673–687.

Nordt, L.C. 2001. Stable C and O isotopes in soils: applications for archaeological research. *In*: Goldberg, P., Holliday, V. & Ferring, R. (eds) *Earth Sciences and Archaeology*. Plenum Press, New York, 419–445.

Parnell, J.J., Terry, R.E. & Golden, C. 2001. Using in-field phosphate testing to rapidly identify middens at Piedras Negras, Guatemala. *Geoarchaeology: an International Journal*, **16**, 855–873.

Parnell, J.J., Terry, R.E. & Nelson, Z. 2002*a*. Soil chemical analysis applied as an interpretive tool for ancient human activities in Piedras Negras, Guatemala. *Journal of Archaeological Science*, **29**, 379–404.

Parnell, J.J., Terry, R.E. & Sheets, P. 2002*b*. Soil chemical analysis of ancient activities in Cerén, El Salvador: a case study of a rapidly abandoned site. *Latin American Antiquity*, **13**, 331–342.

Pohl, M.D., Bloom, P.R. & Pope, K.O. 1990. Interpretation of wetland farming in northern Belize: excavations at San Antonio, Río Hondo. *In*: Pohl, M.D. (ed.) *Ancient Maya Wetland Agriculture: Excavations on Albion Island, Northern Belize*. Westview Press, Boulder, Colorado, 187–237.

Pope, K.O. & Dahlin, B.H. 1989. Ancient Maya wetland agriculture: new insights from ecological and remote sensing research. *Journal of Field Archaeology*, **16**, 87–106.

Pope, K.O., Pohl, M.D. & Jacob, J.S. 1996. Formation of ancient Maya wetland fields: natural and anthropogenic processes. *In*: Fedick, S.L. (ed.) *The Managed Mosaic: Ancient Maya Agriculture and Resource Use*. University of Utah Press, Salt Lake City, 165–176.

Proudfoot, B. 1976. The analysis and interpretation of soil phosphorus in archaeological contexts. *In*: Shakley, M.L. (ed.) *Geoarchaeology*. Duckworth, London, UK, 93–113.

Provan, D.M.J. 1971. Soil phosphate analysis as a tool in archaeology. *Norwegian Archaeological Review*, **4**, 37–50.

Provan, D.M.J. 1973. The soils of an Iron Age farm site: Bjellandsøynæ, S.W. Norway. *Norwegian Archaeological Review*, **6**, 30–41.

Rosenmeier, M.F., Hodell, D.A., Brenner, M., Curtis, J.H. & Guilderson, T.P. 2002. A 4000-year lacustrine record of environmental change in the southern Maya lowlands, Petén, Guatemala. *Quaternary Research*, **57**, 183–190.

Sampietro, M.M. & Vattuone, M.A. 2005. Reconstruction of activity areas at a formative household in northwest Argentina. *Geoarchaeology: an International Journal*, **20**, 337–354.

Sandor, J.A. 1992. Long-term effects of prehistoric agriculture on soils: examples from New Mexico and Peru. *In*: Holliday, V.T. (ed.) *Soils in Archaeology: Landscape Evolution and Human Occupation*. Smithsonian Institution Press, Washington, DC, 217–245.

Schuldenrein, J. 1990. Geochemistry, phosphate fractionation and the detection of activity areas at prehistoric North American sites. *In*: Collins, M.E., Carter, B.J., Gladfelter, B.G. & Southard, R.J. (eds) *Pedological Perspectives in Archaeology Research Proceedings*. Soil Science Society of America, Madison, Wisconsin, Special Publications, **44**, 107–132.

Scudder, S.J. 2001. Soil resources and anthropogenic changes at the Tibes site, Ponce, Puerto Rico. *Caribbean Journal of Science*, **37**, 30–40.

SCUDDER, S.J., FOSS, J.E. & COLLINS, M.E. 1996. Soil science and archaeology. *In*: SPARKS, D.L. (ed.) *Advances in Agronomy*. Academic Press, New York, 1–76.

SIMPSON, I.A., BOL, R., DOCKRILL, S.L., PETZKE, K.-J. & EVERSHED, R.P. 1997. Compound-specific $\delta^{15}N$ amino acid signals in palaeosols as indicators of early land use: a preliminary study. *Archaeological Prospection*, **4**, 147–152.

SIMPSON, I.A., DOCKRILL, S.J., BULL, I.D. & EVERSHED, R.P. 1998. Early anthropogenic soil formation at Tofts Ness, Sanday, Orkney. *Journal of Archaeological Science*, **25**, 727–746.

SPARKS, D.L. 2003. *Environmental Soil Chemistry*. Academic Press, New York, Second Edition.

STEIN, J.K. & FARRAND, W.R. (eds) 1985. *Archaeological Sediments in Context*. University of Maine, Orono.

SULLIVAN, A.P. 2000. Effects of small-scale prehistoric runoff agriculture on soil fertility: the developing picture from upland terraces in the American Southwest. *Geoarchaeology: an International Journal*, **15**, 291–313.

TERRY, R.E., FERNÁNDEZ, F.G., PARNELL, J.J. & INOMATA, T. 2004. The story in the floors: chemical signatures of ancient and modern Maya activities at Aguateca, Guatemala. *Journal of Archaeological Science*, **31**, 1237–1250.

TERRY, R.E., HARDIN, P.J., HOUSTON, S.D., NELSON, S.D., JACKSON, M.W., CARR, J. & PARNELL, J.J. 2000. Quantitative phosphorus measurement: a field test procedure for archaeological site analysis at Piedras Negras, Guatemala. *Geoarchaeology: an International Journal*, **15**, 151–166.

TURNER II, B.L. & HARRISON, P.D. (eds) 1983. *Pulltrouser Swamp: Ancient Maya Habitat, Agriculture, and Settlement in Northern Belize*. University of Texas Press, Austin.

VAN DER LEEUW, S. & REDMAN, C.L. 2002. Placing archaeology at the center of socio-natural studies. *American Antiquity*, **67**, 597–605.

VIZCAÍNO, A.S. & CAÑABATE, M.L. 1999. Identification of activity areas by soil phosphorus and organic matter analysis in two rooms of the Iberian sanctuary 'Cerro El Pajarillo.' *Geoarchaeology: an International Journal*, **14**, 47–62.

WAGSTAFF, J.M. 1987. *Landscape and Culture: Geographical and Archaeological Perspectives*. Basil Blackwell, London, UK.

WATERS, M.R. & RAVESLOOT, J.C. 2001. Landscape changes and the cultural evolution of the Hohokam along the Middle Gila River and other river valleys in south-central Arizona. *American Antiquity*, **66**, 285–299.

WEBB, E.A., SCHWARCZ, H.P. & HEALY, P.F. 2004. Detection of ancient maize agriculture in the Maya lowlands using the stable carbon isotope compositions of soil organic matter: evidence from Caracol, Belize. *Journal of Archaeological Science*, **31**, 1039–1052.

WELLS, E.C. 2004. Investigating activity patterns in prehispanic plazas: weak acid-extraction ICP/AES analysis of anthrosols at Classic period El Coyote, northwest Honduras. *Archaeometry*, **46**, 67–84.

WELLS, E.C. & URBAN, P.A. 2002. An ethnoarchaeological perspective on the material and chemical residues of communal feasting at El Coyote, northwest Honduras. *In*: VANDIVER, P., GOODWAY, M. & MASS, J. (eds) *Materials Issues in Art and Archaeology VI*. Materials Research Society, Warrendale, Pennsylvania, 193–198.

WELLS, E.C., TERRY, R.E., PARNELL, J.J., HARDIN, P.J., JACKSON, M.W. & HOUSTON, S.D. 2000. Chemical analyses of ancient anthrosols in residential areas at Piedras Negras, Guatemala. *Journal of Archaeological Science*, **27**, 449–462.

WILD, A. 1986. The retention of phosphate by soil: a review. *Journal of Soil Science*, **1**, 221–238.

WINGARD, J.D. 1996. Interactions between demographic processes and soil resources in the Copán Valley, Honduras. *In*: FEDICK, S.L. (ed.) *The Managed Mosaic: Ancient Maya Agriculture and Resource Use*. University of Utah Press, Salt Lake City, 207–235.

YOUNG, F.J. & HAMMER, R.D. 2000. Defining geographic soil bodies by landscape position, soil taxonomy, and cluster analysis. *Soil Science Society of America Journal*, **64**, 989–998.