EQA – Environmental quality / Qualité de l'Environnement / Qualità ambientale, ***24 (2017) 1-13***

PEDOSTRATIGRAPHY, GEOARCHAEOLOGY AND QUATERNARY RESEARCH

Claudio Bini (1)*, Mohammad Wahsha (2)

(1) Dipartimento di Scienze Ambientali, Università Ca' Foscari Venezia, Italy
(2) Marine Science Station, The Jordan University, Aqaba Branch, Jordan

* Corresponding authour Email: bini@unive.it

Abstract

Soil has been currently studied with reference to its primary functions and economic value, in terms of biomass production, agriculture fertility, environmental filter, genic reserve, organic carbon sink. Besides primary functions, attention has been deserved to soils as stratigraphic records and privileged archives of archaeological or palethnological findings, and of paleogeographic, paleo-environmental and paleoclimatic features, i.e. as cultural container. Numerous examples of pedostratigraphic sections, soil landscapes and, more generally, cultural landscapes are available in current literature. Most of them are paleosols, or are related to archaeological sites, and therefore are historical records of natural and human events, source of information and knowledge: in a sole word, soils are actual cultural heritage. In this paper some study cases are proposed in order to overcome the balk between pedology, archaeology and environmental conditions.

Introduction

Soil is a fundamental resource for humanity, as declared more than forty years ago in the European Soil Chart (European Council, 1972), and plays major functions, both biological (biomass producer, ecological filter, genic reserve, habitat for plants and animals, including humans) and abiological (physical substrate for infrastructures, source of inert materials, cultural and historical sink).Therefore, its conservation and sustainable use is a major concern for decision makers and Public Authorities, as suggested by the European Union (2002).

More recently, attention has been paid to soils as stratigraphic records and privileged archives of palethnological, paleontological and archaeological findings (Bini, 2002; Bini and Gaballo, 2005), i. e. as cultural heritage, not easily valuable in economic terms, but with important scientific, didactic and even technical relapses. Particularly concerning the relationships between pedology and archaeology, there is still an unexplored balk to examine (Frink, 2003). To the archaeologist, soil is the matrix defining spatial relations between artifacts. Soil is the material used in constructing monumental architecture. Soil is the media within which past human activities, life itself, took place. Yet, as stressed by Jenny (1941, 1989), and is well appreciated by the pedologists, the soil is a living entity, a dynamic system evolving along trajectories constrained by the five factors of soil

DOI: 10.6092/issn.2281-4485/7275

formation (climate, organisms, relief, parent material, time). Since the time dependent processes leading to the soil development are of millennial or million scale, the time scales involved in soil formation are incompatible with the archaeologist's research that is focused into cultural changes which are at decadal or century level.

Archaeological soil research

Before the relationship between soil science and archaeological science can realize its full potential, it is necessary to overcome the balk that frustrates mutual consilience, and the view of soils as an expression of genetic and diagenic processes, coeval through time (Frink, 2003). The descriptive approach, normal to pedological analyses, fails to capture these coeval processes. What is needed is a "physiological" approach that explores those processes fundamental to all soils (e.g. weathering, leaching, pedoturbation, organic matter dynamics), and their specific and measurable effects on cultural material.

Archaeological soils are often far too complex in nature and origin; however, this complexity that results from natural geological, edaphic and culturally-induced processes can yield information and insights into archaeology, that no other discipline can access. Soils should be tackled through "environmental and archaeological profiling", so that interpretations are robust enough to withstand both experimental testing and holistic archaeological analysis (Macphail, 2003).

The chief elements required for such sustainable interpretations are:

1. A sampling regime that is focused on the archaeological questions, but within a budget that allows lateral and other control sampling;
2. Sampling should be *exactly* complemented by sampling for other disciplines (e.g. mineralogy, geochemistry, palynology);
3. Laboratory studies that flexibly combine morphological, micromorphological, microchemical and bulk analytical techniques;
4. Characterisation and identification of fabrics, pedofeatures, and anthropogenic inclusions in soil thin sections;
5. Development of independent interpretations that can be tested both within the soil database and against findings from archaeological feature analysis and artefact recovery, with the final product being the development of consensus interpretations.

Examination and analysis of soil samples from trenches excavated at archaeological sites make it possible to identify old settlements and the overlying cultural layers, which consist of remains of prehistoric sites, both shelters and open sites (Bini and Pilli, 2001), floor and walls of historical buildings, burial and open areas (Bini et al., 1978, 1985; Bini and Gaballo, 2005), devoted to human activities (cultivation, working, metallurgy, etc.). Also paleoclimate and palenvironmental conditions of archaeological sites could be inferred from soil properties (Bini, 1999, 2002).

With few exceptions, natural soils have distinct O, A, and B horizons, which provide evidence that this "soil profile" formed on a relatively stable location, and evolved on, within and concurrently with its landscape. By examining and analysing a soil profile and its position in the landscape, it is possible to achieve information about the succession of natural events that took place at a given site. In this sense, the oldest, more or less well preserved soils, genetically related to previous conditions of climate and morphology (*paleosols*), are of particular relevance and considerable scientific interest, since they comprehend, in a more or less explicit manner, the soil-landscape evolutionary memory, in spatial-temporal continuity/contiguity. It is something like a "phylogenesis" that drives soil evolution from soil profile to soil sequences and soil landscape. Some study cases may contribute to better understand these relationships.

Study cases

Petra/al-Wu' Aira Castle (Jordan)

During the Crusader period (XII-XIII centuries), a network of fortified sites was constructed in the Near East, extending from Syria to the South of Jordan (Fig. 1), likely having a more strategic-logistic rather than military function. Indeed, the control of the caravan routes along the main arteries of the region seems to have been the base for the location of the settlements in the territory.

Figure 1
Schematic map of the Middle-East region with indication of Christian fortresses from Syria to south Jordan.

The fortifications were set up few years after Jerusalem had dropped in 1099, in order to protect the eastern side of the Latin Kingdom of Jerusalem and to preserve the entire pre-desert fertile area (Vannini, 2007).

In the area surrounding Petra (Jordan), five fortresses were built in the first fifteen years of the XII century and abandoned after 1187; al-Wu'Aira castle is one of these fortresses. It is located in a strategic position to control the main access roads

DOI: 10.6092/issn.2281-4485/7275

to the bottom of the Petra valley and to assure reciprocal visibility among the forts for quick mutual defense.

The site. The Crusader castle of al-Wu'Aira was located on the summit of a rocky hill (Jabel Wu'Aira). The entire settlement area presents a quadrangular shape (Fig. 2); it was defended by a double curtain of walls and included a number of squared towers and an inner citadel (Vannini & Tonghini, 1997).

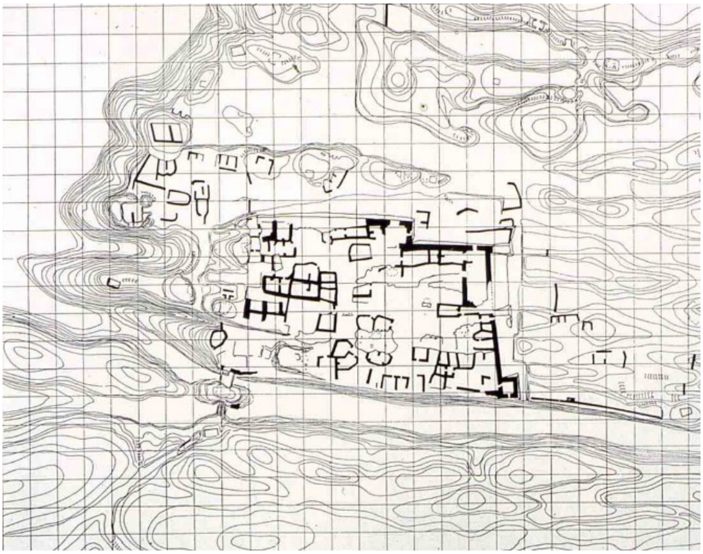

Figure 2
Location of the archaeological area of al-Wu'Aira castle.

Geologically, the area is characterized by a rugged arenaceous-calcareous rock forming irregularly shaped domes which create level disparities, gorges, crevices or peculiar hollows, delimiting deep narrow wadis. Several aggradational and erosional phases, caused by climatic fluctuations, are known in the area for the Late Pleistocene and Early Holocene (Goldberg, 1986). Holocene geomorphic changes in the area are prevalently represented by alternating sequences of wadi alluviation and erosion (Goldberg and Bar-Yosef, 1990). The complex morphology of the area allowed the utilization of natural shelters by early men from the Neolithic, probably during the 6th and perhaps the 5th millennia Before Christ (BC). The 4th millennium BC (Bronze Age) saw the greatest human impact on the environment, with increased deforestation and overgrazing. Afterwards, during the Iron Age (1200-580 BC) deposition re-occurred, evidenced by angular, poorly sorted gravels and sands elevated from abandoned hill slopes. Finally, during the late Roman, Byzantine and early Arabic periods, the climate appears to have improved, although much of the alluvial accumulation may have resulted from agricultural activities (Mariotti et al., 2008; Bruins, 1990).
Surface findings and stratigraphic excavations carried out by the archaeological mission of the University of Florence since 1995 highlighted the main phases of the settlement in the area. Man occurrence dates back from at least the medium Bronze age (5000 BP), but there is evidence for masonry and structure adaption in

the late Roman, Byzantine and early Arabic periods, when the climate appears to have improved (Goldberg and Bar-Yosef, 1990); subsequent transformations occurred during the Nabatean and the Crusader period (1116-1188), with re-use or adaption of the ruins of the castle by Bedouins, though ephemeral, in most recent times (Bini & Bertocci, 1997).

Past and present climate and vegetation. During the Quaternary, several climatic fluctuations occurred in almost the entire area of Jordan and adjacent countries (Horowitz, 1992; Horowitz & Gat, 1984). Some periods must have been considerably more humid than the present day (Horowitz & Gat, 1984). Other periods must have been very dry, and correspond to desert phases. As a consequence, the vegetation cover changed several times before reaching the present status. During the last glacial period, there was a great expansion of forests, with maximum diffusion in the area between 14,000 and 10,000 years BP (Van Zeist & Bottema, 1982). Later on, the climate became drier; as a consequence, the forest vegetation began to retreat towards the present day condition. However, the forest cover reduction recorded in the last 5000 years is imputable also to human activity (Van Zeist, 1985; Bottema & Woldring, 1990).

Today, the climate is characterized by semi-desert conditions, with mean annual precipitation of 150 mm and occasional rainfall in winter. Frequent winter floods cause erosion in wadis as well as do winds on geomorphic surfaces. Soils are typically sandy, shallow, grey, carbonate-rich, as also observed in Wadi Araba (Jenny et al., 1990). The vegetation cover is very scarce (<10%), with mostly irano-turanian steppe and arboreal components represented by evergreen oak, particularly by *Quercus calliprinos* Webb. (Mariotti et al., 2008).

Pedostratigraphy. Five stratigraphic sections were excavated at sites corresponding to different archaeological units of the castle area. These units conform to a limited time-span, ranging from about 1000 AD to the present day.

All the profiles showed generally uniform physico-chemical characteristics, derived from the parent rocks in the surrounding uplands. They are characterized by weak pedogenic alteration, have a single grain structure with very weak consistency in the sandy layers and a subangular blocky structure in the loamy layers, sub-alkaline reaction, little organic C and P. The data recorded are consistent with disturbed, archaeologically related deposits that have undergone some pedogenic reworking, particularly recognisable in thin sections (Fig. 3).

Pedogenic features such as corrosion, aggregation, caps and coatings point to short-term pedogenesis (one thousand years) of reworked soil material, with the formation of weakly developed Arenosols (Wahsha et al., 2016).

With regard to plant history, the highest number of Mediterranean trees and shrubby plants occurs in the most ancient levels. This suggests that the dominant vegetation in the area was previously of Mediterranean type, the best represented species being evergreen oaks (e.g. *Q. calliprinos*)*,* and *Pistacia*.; afterwards, vegetation was strongly impoverished, at least in southern Jordan and around Petra.

Indeed, palynological analyses have shown the presence of a degraded Mediterranean forest or a forest-steppe during the Roman and Byzantine occupation of Petra, and a later further degradation towards a steppe vegetation.

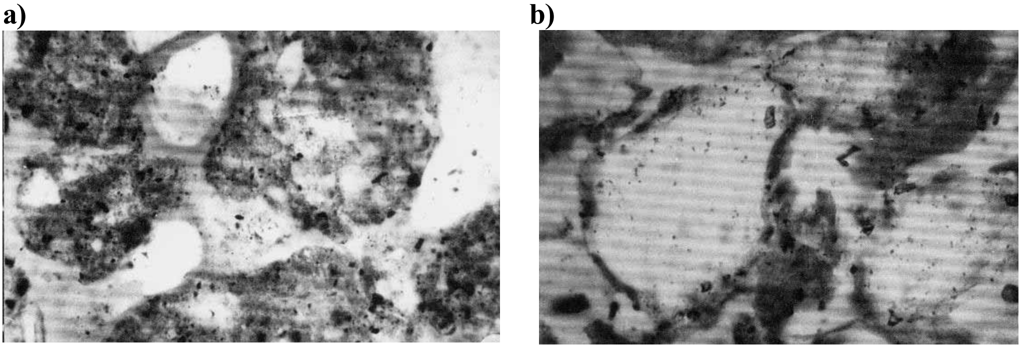

Figure 3. *Micrographs of selected samples from pedostratigraphic sections (adapted from Wahsha et al., 2016).*
a: Limpid yellow-brown clay coatings bridging and bordering dusty dark brown plasmic material (64x).
b: Loose quartz grains bordered by pale brown, limpid clay films and papules (64x).

The decrease in Mediterranean flora elements coincides with the introduction of cultivated Cerealia of the *Avena-Triticum* group (Mariotti et al., 2008). This cultivation extended over a brief interval and can be related to the Crusader settlement in the area (AD 1165-1189).

The landscape surrounding the castle appears to have remained quite similar in its global delineation since the Medieval Age up today, and is consistent with the steppe vegetation of the Mediterranean region.

The Venice lagoon (Italy)

The origin and evolution of the Venice Lagoon is closely controlled by variations in relative sea level, controlled by the combined effects of eustacy, isostasy, and subsidence. Alluvial deposits forming the Venetian paleoplain and underlying the Venice Lagoon document past environmental changes related to climate and changing sea level; they date from the Last Glacial Maximum (LGM) and were deposited during the phase of sea level lowstand (Donnici et al., 2011). These alluvial deposits were buried by lagoon sediments caused by the marine ingression in the Venetian area during the Middle Holocene, culminating in the Late Holocene sea level highstand phase (Correggiari, Roveri, & Trincardi, 1996). Within the alluvial sequence, the uppermost deposits are consolidated and much harder and more resistant to deformation than the underlying deposits. Due to its resistance, this layer found in Venice and in the surrounding area is known as "caranto" (from *caris*, a late Latin word meaning stone). Different opinions have been expressed concerning the origin and the real extent of this layer. Due to its geotechnical features, Matteotti (1962) defined the caranto as overconsolidated clay. Based on macroscopic observation, Gatto and Previatello (1974) called this layer a paleosol and described it as 1–3m thick, compacted, and mottled with carbonate nodules. More recently, based on geomorphological evidence, Fontana, Mozzi, and Bondesan (2008) interpret the submerged and outcropping caranto layer as a continuous pedogenic surface. On the inner margin of the central lagoon, the caranto layer is mineralogically associated with the Pleistocene Brenta River sedimentary system (Mozzi et al., 2003): deactivation of the Brenta sedimentary system, surface stability, and pedogenesis resulted in the formation of the caranto.

Recent investigation of sediment cores extracted within the city of Venice and its lagoon allowed to carry out pedological, micromorphological, paleoecological, and chronological analyses of subsurface deposits (Donnici et al., 2011). Fifteen sediment cores were analyzed in this study. Eight selected sediment cores containing the caranto layer are located in the city; other cores were collected in the inner margin of the lagoon, in the northern lagoon, and in the littoral. The stratigraphy of each core was described and samples were collected from selected key layers, that is, caranto and adjacent layers. Four sedimentary facies were identified based on morphological and lithological properties within the cores:

Facies F (Fluvial Plain). The deepest sediments in the cores, reaching a maximum depth of -16.5 m, are massive grey silt interlayered with coarsening upward sequences of silty clay, silt, sandy silt, and fine micaceous sand. A peat layer at -11.40 m dates 19,400 ±120 ^{14}C yr B.P.

These sediments were deposited during the LGM and are interpreted as floodplain deposits. Sandy bodies with tractive structures are related to river channel deposits. Peaty layers within the floodplain sequence indicate periodic diminished sedimentation in the flood basins and the formation of swamps dominated by organic sedimentation.

Facies W (Weathered Alluvium). This is a sequence of fine-textured alluvial deposits that contain abundant redoximorphic iron mottles and calcareous nodules. These sediments are also highly compacted, measured as unconfined compressive strength with a pocket penetrometer. Facies W has a maximum thickness of 2–3 m. Mineralogical composition consists of poorly sorted, subrounded to subangular detrital grains of calcite, dolomite, quartz, feldspar, mica, chlorite, and rock fragments. These grains are supported by a clay-rich matrix of the same composition. Particle size ranges from silty clay loam to sandy loam in the upper part, and to loamy sand in the bottom part. The uppermost part of this facies (about 1m thick) contains abundant (30%) centimetric (1–1.5 cm in size) yellowish (10YR6/6–5Y5/6) mottles indicative of redoxymorphic conditions (Fig. 4). Also present are hypocoatings of calcareous material, calcareous impregnations, calcite infillings in some elongated pores, and hard calcite nodules, a few millimeters to centimeters in size, randomly distributed at different depths and sometimes reaching 10–15% by volume.

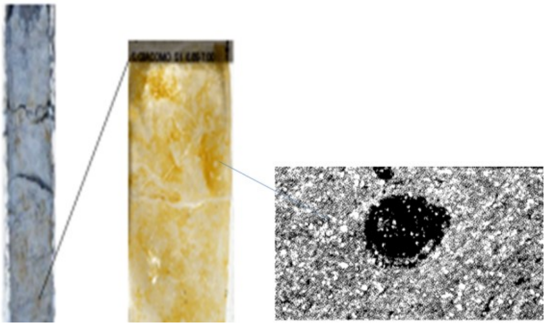

Figure 4
Redoximorphic features and an iron nodule with clay rim in closed-porphyric matrix from the 2BCg caranto horizon in the Porto Marghera core (adapted from Mozzi et al., 2003).

The upper layers of Facies W contain plant fibers dated between 9173 ± 81 ^{14}C yr B.P. and 5755± 55 ^{14}C yr B.P. All together, the physical and chemical characteristics of Facies W make it consistent with the widely recognized caranto layer, and the ^{14}C dating of organogenic content indicates a latest Pleistocene to middle Holocene period of reduced alluvial deposition.

Facies P (Palustrine). A sharp stratigraphic contact separates the top of Facies W from overlying dark greenish grey (5Y4/1–5Y6/1) clay and silt with small vegetal inclusions. This facies is characterized by fine texture, soft to slightly firm consistency, and is decalcified and subacid. Organic matter is mostly dispersed. These deposits have a vughy microstructure, and the coarse fraction consists of subangular/subrounded quartz grains, weathered feldspars, and rock fragments. The fine fraction is fine silty with both single-spaced porphyric crystallitic and reticulated striated b-fabric. Pedofeatures are weakly represented and consist of ferruginous impregnations and rare calcareous impregnations. Physical and chemical properties of these sediments are indicative of deposits related to freshwater marshes and swamps preceding the Middle Holocene marine ingression.

Facies L (Lagoon Sediments). A sharp stratigraphic contact separates Facies P from overlying grey (5Y6/1) and dark grey (5Y4/1) silt and silty clay, containing mollusk shells and vegetal remains. The thickness of Facies L varies from 1 to 2m near the continental margin of the lagoon to 5–6m in the eastern Venice area. Physical features indicate a soft consistency with low values of shear strength and unconfined compressive strength. The microstructure of these materials is extremely porous and contains many large fragments of lagoon mollusk shells. These sediments are indicative of intertidal and subtidal mud flats. Facies L documents lagoonal environments related to the Middle Holocene marine ingression and the following marine highstand.

Depositional Environments since the LGM

During the last glacial maximum (LGM), when alpine climate in northern Italy was cold continental (Serandrei-Barbero et al., 2005; Pini, Ravazzi, & Donegana, 2009; Donnici et al., 2011), glaciers and rivers supplied large amounts of clastic sediments, and the Venetian Plain experienced a period of major aggradation.

The aggradation phase was followed by fanhead trenching at the Brenta valley mouth in the piedmont area after 14,500 ^{14}C yr B.P. (Fontana, Mozzi, & Bondesan, 2008), that is, 18,000 cal. yr B.P. Deposits described as Facies W represent the uppermost, altered part of the alluvial sequence (Facies F) and correspond to what is locally called caranto. Palustrine deposition (Facies P) above the caranto horizons, locally topping the alluvial sequence, represents low-energy flood and pond deposits in the coastal plain just preceding the marine ingression (Canali et al., 2007).

When aggradation of the Venetian Plain stopped, climate was mild and humid (Vescovi et al., 2007). The development of soils with caranto features outcropping in the Venetian Plain (Giandon et al., 2001; Mozzi et al., 2003; Mozzi, 2005) and in the Po Plain (Cremaschi, 1987; Marchetti, 2002) is related to the warm and relatively humid climate during Early and Middle Holocene. Post-glacial climate enhanced local calcification, resulting in the pedogenetic formation of calcareous nodules at depth within the alluvial sequence. Micromorphology clearly indicates that secondary calcite precipitated within biogenic pores (burrows) during an emersion phase. Calcification appears to have been the primary pedogenic process in the formation of the caranto. Collectively, the macro- and microfeatures of the samples analyzed in this study point to a pedogenic alteration of exposed fluvial sediments, with formation of a set of ACk horizons overlying consolidated Ck horizons (Fig. 5), similar to calcisols observed today in agricultural soils of the mainland (Giandon et al., 2001).

Figure 5
Laminated calcareous crust, calcite infillings and iron segregation in a silty-clayey matrix from the Ckg caranto horizon in the S. Giacomo core.

Since the development of a soil takes place where there is a balance between deposition and erosion, pedogenesis is a pulsating phenomenon that occurs during periods of prevailing stability (biostasy), and is arrested during periods of prevailing instability (resistasy). Weathering of alluvial parent materials deposited in the Venice area after the deactivation of the Brenta River system was time-transgressive, and different surfaces became stabilized at different times. Therefore, calcification was diachronic within a mosaic of alluvial surfaces. Soil formation may occur quickly under relatively warm, moist climate, and it is plausible that 2–3 meters of alluvium (Facies F) was altered within 10,000 years.

The caranto is thus a paleosol that extends under the Venetian Lagoon and is physically continuous with Latest Pleistocene calcisols developed into alluvial

DOI: 10.6092/issn.2281-4485/7275

deposits on the mainland. Whereas mainland calcisols represent continuous pedogenesis since the LGM, soil formation within the facies W has been interrupted by Holocene marine transgression since ca. 6000 cal. yr B.P.

In conclusion, the stratigraphic study of the cores, has enabled to define and date the sequence of events occurred in the Late Quaternary in the central sector of the Lagoon of Venice and in the landward margins. Sediment weathering and soil formation should have occurred during the last 20,000 years, as a result of changing environmental conditions, which determined the general evolution of the Central and Northern Venice lagoon area, outlined as follows.

Deposition of fluvial sediments, mainly as overbank fines with sandy channel bodies, during the Last Glacial Maximum.

Repeated episodes of alluvial sedimentation, with some phases of emersion and, hence, oxidation (mottling). From these events originated the *caranto*, i. e. a discontinuous layer interpreted as a pedogenic C_k horizon, with age ranging between approximately 14,500 and 5,700 years BP.

Sea level raising and formation of large fresh and salty marshes (before 4,500 BP).

Salt water ingression and lagoon formation (after 4,500 BP).

Although not synchronous in the area, this unconformity is a significant stratigraphic marker for the Pleistocene-Holocene boundary. In this perspective, depth to *caranto* at different sites, allows reconstruction of the continental paleo-surface, and its evolution.

Conclusions

Our results and other recent investigations on paleosols, submerged and archaeological soils, corroborate the idea that the climatic and environmental variations occurred during the Quaternary interglacial periods cover only 10% of the last 750000 years (i.e. since the Brunhes/Matuyama magnetic inversion); conversely, interstadial periods assume increasing importance with respect to time elapsed. Short- and long-term correlations among palaeoclimatic, palaeomagnetic, palaeoenvironmental conditions, palynology and soils are now available for Middle and Late Pleistocene and Early Holocene. Therefore, soils may be useful pedostratigraphic units in Quaternary deposits correlation studies.

In this perspective, major scientific importance is assigned to those soils which represent palaeoenvironmental records (i.e.paleosols), or that are custom of archaeological and palethnological records, and that make the soil itself an actual "cultural container", historical record of natural and human events, source of information and knowledge: in a sole word, soil is an actual "cultural heritage".

Cultural heritage is an important economic resource for countries where one of the major attractions is the unique composition of the landscape, like Italy. The role played by the soil in this ambit is generally little considered, whereas the spectacular scenery is universally appreciated.

Numerous initiatives have been developed in the last years to corroborate the image of soil as cultural heritage, in conjunction with the other land resources. Attention has been devoted to prehistoric and historical settlements, medieval mining, soil and wine production, greenways, trekking walks. Other initiatives concern medieval pilgrim roads through Roman churches, Napoleonic itineraries, sites of historical wars.

All these initiatives point to the valorisation of natural and cultural land resources, including soil, in a territory where cultural heritage represents a valuable tool for enhancing tourist fluxes.

References

AL-EISAWI D. (1985) Vegetation of Jordan. In: Hadidi A. Studies in the history and archaeology of Jordan. II. Ministry of Archaeology. Amman: 45-57.

BINI C., CIUFFI G., PAOLI P. (1978) Osservazioni geopedologiche e paleobotaniche sulla natura e sulle caratteristiche ambientali dei depositi rinvenuti nello scavo archeologico del Palazzo Pretorio di Prato. Ricerche di archeologia altomedievale e medievale, 2-3, 279-295.

BINI C., CIUFFI G., PAOLI P. (1985) Analisi geopedologica e paleobotanica: tentativo di ricostruzione ambientale. In "L'antico palazzo dei Vescovi a Pistoia. II - Indagini archeologiche" (a cura di G. Vannini), pp. 481-528. Leo Olschki editore, Firenze.

BINI M., BERTOCCI S. (1997) The Survey of Al-Wu'aira: A contribution to the knowledge of the Crusader castles in Jordan. Ann. Dept. Antiq. Jordan 41:403-414.

BINI C. (1999) I siti paleolitici: pedostratigrafia e paleopedologia. In Sardegna Paleolitica. Studi sul più antico popolamento dell'isola, a cura di F. Martini. Edizioni Centro Stampa 2P, Firenze, p. 35-42.

BINI C., PILLI A. (2001) Aspetti pedologici e paleoambientali del sito mesolitico Putia I (Bz). Ladinia, 23:5-14.

BINI C. (2002) L'analisi pedostratigrafica e paleoambientale nel contesto archeologico. In Fortuna e declino di una società feudale valdarnese. Il Poggio della Regina. (A cura di G. Vannini), 205-228. Società Editrice Fiorentina. Firenze.

BINI C., GABALLO S. (2005) Paleosols vs Anthrosols. A case study in the Temperino mine archaeological area (Campiglia M.ma, Southern Tuscany, Italy). Proc. Int. Conf. "Paleosols: memory of ancient landscapes and living bodies of present ecosystems", 36-37, Firenze.

BOTTEMA S., WOLDRING H. (1990) Anthropogenic indicators in the pollen record of eastern Mediterranean. In: Bottema S., Entjie-Nieborg G, Van Zeist W. (Eds), Man's role in the shaping of the Eastern Mediterranean Landscape: 231-264.

BRUINS H.J. (1990) The impact of man and climate on the Central Negev and NE Sinai. In: Man's role in the shaping of the eastern Mediterranean landscape. Bottema, Entjes-Nieborg and Van Zeist (eds), 87-99.

CANALI G., CAPRARO L., DONNICI S., RIZZETTO F., SERANDREI-BARBERO R., TOSI L. (2007) Vegetational and environmental changes in the eastern Venetian coastal plain (northern Italy) over the past 80,000 years. Palaeogeography, Palaeoclimatology, Palaeoecology, 253:300–316.

CORREGGIARI A., ROVERI M., TRINCARDI F. (1996). Late Pleistocene and Holocene evolution of the north Adriatic Sea. Il Quaternario, 9:697–704.

CREMASCHI M. (1987). Paleosols and vetusols in the central Po plain (northern Italy): A study in Quaternary geology and soil development. Milan: Unicopli.

DONNICI S., SERANDREI-BARBERO R., BINI C., BONARDI M., LEZZIERO A. (2011) The Caranto Paleosol and Its Role in the Early Urbanization of Venice. Geoarchaeology: An International Journal, 26(4):514–543.

EUROPEAN COUNCIL (1972) European Chart of Soil. Brussels.

EUROPEAN UNION (2002) Comm. N° 179: "Towards a thematic strategy for soil protection". U.E. Comm., Division XII, Brussels.

FONTANA A., MOZZI P., BONDESAN A. (2008) Alluvial megafans in the Venetian-Friulian Plain (northeastern Italy): Evidence of sedimentary and erosive phases during Late Pleistocene and Holocene. Quaternary International, 189:71–90.

FRINK D.S. (2003) Examination of the unexplored balk between pedology and archaeology. Proc. II Int. Congress "Soils and Archaeology", Pisa.

GATTO P., PREVIATELLO P. (1974) Significato stratigrafico, comportamento meccanico e distribuzione nella laguna di Venezia di un'argilla sovraconsolidata nota come "caranto." Report No. 67. Venezia: Consiglio Nazionale delle Ricerche, Istituto per lo Studio Dinamica Grandi Masse.

GIANDON P., GARLATO A., MOZZI P., RAGAZZI F., VINCI I. (2001) La carta dei suoli del Bacino Scolante in Laguna di Venezia. Bollettino della Società Italiana di Scienze del Suolo, 50:273–282.

GOLDBERG, P. (1986) Late Quaternary environmental history of the southern Levant. Geoarchaeology,1:224-244.

GOLDBERG P., BAR-YOSEF O. (1990) The effect of man on geomorphological processes based upon evidence from the Levant and adjacent areas. In: Man's role in the shaping of the eastern Mediterranean landscape. Bottema, Entjes-Nieborg and Van Zeist (eds), 71-86.

HOROWITZ A., GAT J.R.. (1984) Floral and isotopic indications for possible summer rains in Israel during wetter climates. Pollen et Spores, 26(1):61-68.

HOROWITZ A. (1992) Palinology of arid lands. Elsevier, N.Y., 341-389.

JENNY H. (1941) Factors of soil formation. Mc Graw- Hill, N.Y.

JENNY H. (1989) The soil resource. Springer Verlag, N.Y.

JENNY M., SMETTAN U., FACKLAM-MONIAK M. (1990) Soil-vegetation relationship at several arid microsites in the Wadi Araba (Jordan). Vegetatio, 89:149-164.

LAMBECK K., ANTONIOLI F., PURCELL A., SILENZI S. (2004) Sea-level change along the Italian coast for the past 10,000 yr. Quaternary Science Reviews, 23:1567–1598.

MACPHAIL R.I. (2003) Attaining robust interpretations of archaeological "soils": examples from rural and urban contexts. Proc. II Int. Congress "Soils and Archaeology", Pisa.

MARCHETTI M. (2002) Environmental changes in the central Po plain (northern Italy) due to fluvial modifications and men's activity. Geomorphology, 44:361–373.

MARIOTTI LIPPI M., MORI SECCI M., BINI C. (2008) Archaeobotany in the Crusader castle of al-Wu'Aira (Petra, Jordan). Webbia, 63(1):69-79.

MATTEOTTI G. (1962) Sulle caratteristiche dell'argilla precompressa esistente nel sottosuolo di Venezia-Marghera. Notiziario dell'Ordine degli Ingegneri della Provincia di Padova, 6:1–15.

MOZZI P. (2005) Alluvial plain formation during the Late Quaternary between the southern Alpine margin and the Lagoon of Venice (northern Italy). Geografia Fisica e Dinamica Quaternaria, 7:219–230.

MOZZI P., BINI C., ZILOCCHI L., BECATTINI R., MARIOTTI LIPPI M. (2003) Stratigraphy, palaeopedology and paynology of Late Pleistocene and Holocene deposits in the landward sector of the lagoon of Venice (Italy), in relation to the Caranto Level. Il Quaternario, 16:197–214.

PINI R., RAVAZZI C., DONEGANA M. (2009) Pollen stratigraphy, vegetation and climate history of the last 215 ka in the Azzano Decimo core (plain of Friuli, north-eastern Italy). Quaternary Science Reviews, 28:1268–1290.

SERANDREI-BARBERO R., BERTOLDI R., CANALI G., DONNICI S., LEZZIERO A. (2005). Paleoclimatic record of the past 20000 years in Venice (northern Italy): Biostratigraphic evidences and chronology. Quaternary International, 140–141:37–52.

VAN ZEIST W., BOTTEMA S. (1982) Vegetational History of the Eastern Mediterranean and the Near East during the last 20.000 years. In: Bintliff J.L., Van Zeist W. (Eds.), Paleoclimates. Paleoenvironments and Human Communities in the Eastern Mediterranean Region in Later Prehistory. Bar Int. Series 133:277-323.

VAN ZEIST W. (1985) Past and present environments of the Jordan Valley. In: Hadidi A. Ed.), Studies in the history and archaeology of Jordan. Ministry of Archaeology. Amman: 199-204.

VANNINI G., TONGHINI C. (1997) Medieval Petra: settlements of the Crusader and Ayyubid period. In: Bikai P.M., Egan V. (Eds.), Archaeology in Jordan. American Journal of Archaeology, 101:534-535.

VANNINI G. (2007) Il ruolo di Petra "Medievale" e la Rinascita di una frontiera. In: Vannini G. (Ed.), "Archeologia dell'insediamento Crociato-Ayyubide in Transgiordania: Progetto Shawbak". Biblioteca Di Archeologia Medievale, 21:12-21.

VESCOVI E., RAVAZZI C., ARPENTI E., FINSINGER W., PINI R., VALSECCHI V., WICK L., AMMANN B., TINNER W. (2007) Interaction between climate and vegetation during the Lateglacial period as recorded by lake and mire sediment archives in Northern Italy and Southern Switzerland. Quaternary Science Reviews, 26:1650–1669.

WAHSHA M., AL-JAWASREH R., MARIOTTI LIPPI M., AL-TAWAHA M., BINI C. (2016) Pedostratigraphical records of al-Wu'Aira castle (Petra, Jordan). Fresenius Environmental Bulletin, 25(12):5347-5353.

DOI: 10.6092/issn.2281-4485/7275