**Principles of Ichnoarchaeology: new frontiers for studying past times**

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**SUMMARY - Principles of Ichnoarchaeology: new frontiers for studying past times** - Since its origins, Archaeology has evolved by interaction with other disciplines, and, in particular, the Earth Sciences have provided major tools for archaeological analysis. Among the branches of Earth Sciences, ichnology represents a new, promising field for application in Archaeology. The present work explores the application of ichnological methods and themes in Archaeology, as Ichnoarchaeology. Despite case studies on archaeological traces, a uniform, consistent approach has been lacking. As a consequence, archaeologists are still not taking full advantage of traces. This study aims to establish a basis for a coherent, uniform framework by presenting the major themes of Ichnoarchaeology through state-of-the-art case studies. It demonstrates the potential for the study of archaeological traces, and encourages collaboration among scientists of different fields to deepen the knowledge of our cultural heritage.

**Key words**: ichnology, Archaeology, ichnoarchaeology, geoarchaeology, traces

**Parole chiave**: Icnologia, Archeologia, Icnoarcheologia, Geoarcheologia, tracce

1. **INTRODUCTION**

1.1 **Scientific Archaeology**

“...The islanders, too, were great pirates. These islanders were Carians and Phoenicians, by whom most of the islands were colonised, as was proved by the following fact. During the purification of Delos by Athens in this war all the graves in the island were taken up, and it was found that above half their inmates were Carians: they were identified by the fashion of the arms buried with them, and by the method of interment”

(Thucydides, The Peloponnesian War, I, 8)

Thucydides (Vth century B.C.) reports one of the first examples of archaeological analysis: in his “The Peloponnesian War”, the author reconstructed an historical scenario by interpreting ancient weapons buried in the ground. Thucydides himself alluded to this approach using the term ἀρχαιολογία, “speech or research about ancient things”.

Since Thucydides’ times, Archaeology has evolved by incessant interaction with other disciplines. Branches of Earth Sciences have played a fundamental role, Archaeology greatly benefiting from interactions with Geochemistry, Geophysics, Palaeontology, Palynology, Pedology, Sedimentology and Stratigraphy.

Among the branches of Earth Sciences, Ichnology represent a relatively new field with promise for application in...
Archaeology. This study focuses on the application of ichnological methods and themes in Archaeology, a discipline termed Ichnoarchaeology.

1.2. Archaeology and Ichnology

Archaeology (from Greek ἀρχαιολογία, ἀρχαῖος “ancient” and λόγος “speech”) was considered for a long time a branch of History, although during the 20th century it developed its own identity. At present, Archaeology is regarded as the discipline aiming to reconstruct ancient human civilisations and cultures through the analysis and documentation of physical evidence found in the soil (structures, artefacts, biological or human remains) (after Bianchi & Bandinelli 1976; Pallottino 1980; Strazzulla 1996: 33-82).

The archaeologist’s physical evidence has significant analogies with the cornerstone of Ichnology, i.e. traces. In fact Ichnology (from Greek ἰχνος “trace” and λόγος “speech”) is regarded as the study of fossil and recent traces, which can be considered as biogenically-produced sedimentary structures (Frey 1973). Recently, Bertling et al. (2006) refined Frey’s (1973) approach and defined a trace (fossil) as “a morphologically recurrent structure resulting from the life activity of an individual organism (or homotypic organisms) modifying the substrate” (after Blackwelder 1967; Frey 1973; ICZN 1999: Glossary). However, it must be pointed out that the definition of trace is still debated (i.e. Skolithos listserver 2003).

It is not possible to trace a sharp limit between Archaeology and Ichnology. Although the end-terms are clear (e.g. minoan vase= Archaeology; Zoophycos= Ichnology), there are many other items falling within a wide grey zone (Fig. 1).

Bivalve borings on an ancient temple typify the grey zone. Such borings are classic ichnological items, although they can provide archaeological information (i.e. relationship between civilisation and sea-level fluctuations; Section 2.2). Archaeological coprolites also fall within the grey zone. These biodepositional traces provide archaeologists with information on the palaeoenvironment of archaeological sites (i.e. palaeovegetation and palaeoclimate), and the diet and palaeopathology of ancient civilisations (e.g. Panagiotakopulu 1999; González-Samperiz et al. 2003).

This work is aiming to inspect how ichnological methods and themes can find application in Archaeology.

1.3. Methods

Few archaeological studies have explicitly mentioned Ichnology. Some of the major examples concern insect borings in bison bones (West & Hasiotis 2007) and archaeological mammal traces (Higgs 2001; Hasiotis et al. 2007). Jean-Michel Geneste included Ichnology in his workshop about the archaeological study of the Chauvet-Pont d’Arc Cave (see also García 2005).

From these few examples it would appear that archaeological traces have been rarely considered. In reality, however, traces have been commonly studied in Archaeology, but, in most cases, they have been not referred as Ichnology. Archaeologists have often dealt with traces: burrows (e.g. Giacobini 1992; Pierce 1992), borings (in lithic substrates: e.g. Mohrange et al. 2006; in xylic substrates:

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Fig. 1 - Ichnoarchaeology represents the transitional zone between ichnology and archaeology.

Fig. 1 - L’icnoarcheologia rappresenta la zona transizionale tra icnologia e archeologia.
1. Potential of Ichnoarchaeology. The existing studies on archaeological traces show the potential of ichnoarchaeology in addressing archaeological problems which are not solvable using conventional methods.

2. Archaelogical traces and ichnologists. Most studies on archaeological traces have not been authored by “traditional” ichnologists. In fact, experts on archaeological traces are more often linked with other disciplines (Archaeology, biology, soil science, etc) and they do not regard themselves as “ichnologists”.

3. Lack of a uniform approach. A uniform, systematic approach has been lacking in the study of archaeological traces.

The aforementioned points require a multidisciplinary approach to the subject in order to portray coherently the study of archaeological traces (points 1, 2) and to place them in a consistent, uniform framework (3). Consequently, experts in various fields – Ichnology, Archaeology, biology, restoration, soil science, anthropology - were invited to share their experience on archaelogical traces. The philosophy of the resulting paper presents the major themes of Ichnoarchaeology through state-of-the-art case studies. The experts, co-ordinated by the senior authors (Baucon and Privitera), wrote specific sections of the paper (Bonaccossi and Canci, section 2.2; Laborel, Mohrange, Marriner, Laborel-Deguen, section 3.2; Kyriazi, section 3.3; Neto de Carvalho, sections 3.4, 4).

This is the first step to propose a uniform, systematic approach to the study of archaeological traces.

2. BIOTURBATIONAL STRUCTURES

2.1. Introduction

Bioturbational structures include some of the most representative traces of Palaeoichnology, such as burrows and footprints. However, these structures are some of the most problematic in Ichnoarchaeology because of preservational issues. In most of archeological cases diagenetic processes have acted for insufficient time to enhance these traces. As a consequence, it is often difficult to recognise distinct burrows/footprints at archaeological sites. Nevertheless, there are some recurrent diagenetic and sedimentological conditions that facilitate the fine-quality preservation of bioturbational structures in archaeological context. These are illustrated by two sites: Aquileia (Italy, Roman Age) and Qatna (Syria, Bronze Age).

2.2. Artificial substrates vs natural substrates: the imprinted bricks of Aquileia

Although archaeological footprints are uncommon on natural substrates, they have been reported from several sites around the world (Tab. 1).

The occurrence of footprints is intimately linked with the geotechnological properties of the substrate during the trace-making process. Allen (1997) made use of neoichnological observations and indentation experiments to analyse an ichnoarchaeological site on the Severn Estuary (Great Britain), where a diverse ichnofauna of Flandrian Interglacial to post Roman times has been found (Tab.1). Diagenesis also plays a role as the occurrence of archeological footprints is generally linked to relatively prolonged and/or fast diagenesis. For these reasons, archaeological footprints are more difficult to distinguish in very recent deposits (e.g. Classical Antiquity and Middle Ages sites).

However, there is a particular kind of substrate – bricks - where archaeological footprints are abundantly reported, even from the middle Ages. Bricks (and tiles) represent an optimal substrate to preserve traces because of their:

- Geotechnical properties. Bricks consist of clay-rich sediment and, before drying, have a reasonable degree of moisture; therefore, they are usually highly susceptible to trace-making.
- Open-air drying. Usually, the brick-making process includes sun-drying. During this phase, bricks are stocked over vast open-air surfaces; consequently, animals have good possibilities to leave footprints on the drying bricks.
- Fast diagenesis. The drying phase causes rapid induration of the bricks; in some cases sun-drying constitutes the last phase of the brick-making process (e.g. during Neolithic times), although commonly sun-dried bricks are subsequently fired. For instance, in Roman times, Vitruvium referred only to sun-dried bricks, while buildings made of fired bricks were reported from Silla’s Age (1st century B.C.; Adam 2003). Sun drying and firing processes are analogous to rapid diagenesis, which can lead to optimal preservation of footprints.
- Resistance and abundance. Bricks and tiles have been commonly used throughout antiquity, and they constitute a very resistant material, giving footprints on bricks a high preservation potential.

The study of imprinted bricks (Fig. 2) can give important information for interpreting archaeological site. The most basic information concerns the faunal components present. For example, Higgins (2001) studied abundant and well-preserved material from various Roman and Medieval sites in England. By examining the imprinted bricks, he was able to identify various tracemakers (dogs, cats, birds, mustelids, sheep/goats, cattle, pigs, horses). Because the tracemaker is usually a mammal, it can be identified with a high degree of confidence. However, some caus
tion must be given to the interpretation of bricks: unlikely most trace fossils, imprinted bricks are commonly transported. Therefore, when analysing imprinted bricks, it must be kept in mind that the ichnofauna always refers to the place of production of the bricks. In this regard, ichnological data could be useful to find the place of brick production when this is unknown (i.e. by determining if the ichnoassociation is urban or rural).

Footprints can also give information on palaeoenvironments: some mammals are very sensitive as regards environmental setting (e.g. beavers are associated with streams and lakes bordered by trees; otters occur near river courses; squirrels are usually found within coniferous woods or mixed coniferous/deciduous woods; red fox is an environment crossing species, but it is usually associated with mixed woodland/open country; see Stokes & Stokes 1986).

Even though imprinted bricks offer important information, we must not consider them as dei ex machina to solve

<table>
<thead>
<tr>
<th>Reference</th>
<th>Tracemakers</th>
<th>Age</th>
<th>Location</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gonzalez et al. (1996) and Roberts et al. (1996)</td>
<td>Aurochs, red deer, roe deer, crane, human footprints</td>
<td>3500 years</td>
<td>United Kingdom</td>
<td></td>
</tr>
<tr>
<td>Belperio &amp; Fotheringham (1990)</td>
<td>Emu, kangaroo and human footprints</td>
<td>5000 years</td>
<td>Australia</td>
<td></td>
</tr>
<tr>
<td>Watson et al. 2005; Willey et al. 2005</td>
<td>Human footprints</td>
<td>5400 years</td>
<td>North America</td>
<td>Cave setting</td>
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<tr>
<td>Politis &amp; Bayon (1995)</td>
<td>Sea mammal and human traces</td>
<td>7100 years</td>
<td>Argentina</td>
<td></td>
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<tr>
<td>Allen (1997)</td>
<td>Deer, auroch, domesticated cattle, sheep/goat, horse, wolf/dog, human footprints</td>
<td>from Flandrian Interglacial to post-Roman times</td>
<td>United Kingdom</td>
<td></td>
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<tr>
<td>Tongiorgi &amp; Lamboglia (1963); Lockley (1999)</td>
<td>Human footprints; cave bear footprints and scratch marks</td>
<td>Palaeolithic</td>
<td>Italy</td>
<td>Cave setting</td>
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<tr>
<td>Vallois (1930)</td>
<td>Human footprints</td>
<td>Palaeolithic</td>
<td>France</td>
<td>Cave setting</td>
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<tr>
<td>Mountain (1966)</td>
<td>Human, hyaena and bird tracks</td>
<td>Pleistocene</td>
<td>South Africa</td>
<td></td>
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<tr>
<td>University of Haifa (2007)</td>
<td>Human footprint</td>
<td>Roman times</td>
<td>Israel</td>
<td>Roman soldier sandal print</td>
</tr>
</tbody>
</table>

Fig. 2 - Imprinted bricks. a. Roman brick with dog’s footprint. Aquileia, Italy. b. Medieval brick with track; arrow points to the second footprint of the track (partially preserved). The footprints show features typical of canine producers (rounded morphology, relatively small size) but the presence of claw marks are indicative of dog-like producer (cats usually retreat claws during locomotion). Monte Naone, Italy. Courtesy of Sebi Arena.

Fig. 2 - Laterizi improntati. Scala 1 cm. a. Laterizio romano con impronta di cane. Aquileia, Italia. b. Laterizio medievale con impronta, possibilmente di cane. Monte Naone, Italia. Per gentile concessione di Sebi Arena.
all the archaeozoological problems of a certain site. In fact it must be kept in mind that imprinted bricks do not record the total biodiversity. For instance, Baucon et al. (in prep.) studied the Roman site of Aquileia (Italy) and gave evidence that the imprinted bricks (Fig. 3) suggested a much poorer fauna than the skeletal remains.

Footprints on natural substrates: dynamics of 2000 B.C. pottery manufacture revealed by ichnoarchaeological evidence (Qatna Acropolis, Syria)

As mentioned, preservation of footprints on natural substrates requires appropriate geotechnical and diagenetic conditions, which are not always associated with the archaeological context. Nevertheless, when present, archaeozoological footprints can provide precious information, usually not determinable with other methods (see Allen 1997; Huddart et al. 1999; Webb et al. 2006). Archaeological footprints on natural substrates (Fig. 4) are not transported and therefore provide a vital source of spatial and temporal data that can help in the understanding of the social behaviours of past civilisations. For instance, human footprints have revealed the structure of the groups frequenting caves, and, in some cases, ritual behaviours have been inferred (see the discussion in Lockley 1999 and Tongiorgi & Lamboglia 1963 about the Toirano, Tuc d’Audoubert, Chauvet, Niaux caves). In addition, footprints can be also a useful tool for determining land use and economical issues. Moreover, archaeolog-
Archaeological footprints can give behavioural (direction of travel, gait, speed) and palaeopathologic information (diseases and injuries), as well as data on the individuals (sex, age) and environment. Some of the aforementioned points are demonstrated in table 2, which take into account two case studies from the literature:

The utility of archaeological footprints is demonstrated by a recently discovered site: the trampled surface of Qatna (Bronze Age) provides information on zoological, ethnozoological, anthropological and social features.

Archaeological excavations conducted by an Italo-Syrian expedition at Mishrifeh, ancient Qatna (Central Western Syria), discovered a large pottery workshop on the summit of the site’s acropolis. The ceramic manufacturing area was built at the beginning of the second millennium BC as a small production area, reached its maximum extension during the Middle Bronze Age II (c. 1800-1600 BC), and was abandoned in the following Late Bronze Age I (c. 1600-1400 BC).

During its last centuries of activity, the ceramic man-

Tab. 2 - The table summarizes two ichnoarchaeological studies and shows the potential of archaeological footprints in various fields. 

<table>
<thead>
<tr>
<th>Information revealed by archaeological footprints</th>
<th>Taxonomic information</th>
<th>Behavioural information</th>
<th>Spatio-temporal information</th>
<th>Environmental reconstitution</th>
<th>Land use and economical issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severn Estuary (Allen 1997; Flandrian Interglacial- Roman times).</td>
<td>Ichnoarchaeological footprints gives the taxonomic position of the animal.</td>
<td>Ichnoarchaeological footprints can reveal the producer’s behavior, direction of travel, gait, speed, age and health.</td>
<td>The ichnoassemblages reveal the gradual displacement of wild species (e. g. deer) by domesticated animals as the degree of human intervention in the area increased.</td>
<td>Substrate properties are understood from footprints</td>
<td>The ichnoassemblages give precise spatial information on the impact of humans on environment: data on domestication, management of natural areas, distribution of animal populations on the margins of the estuary. Footprints analysis reveal far more about the spatio-temporal distribution of the fauna than the known skeletal remains.</td>
</tr>
<tr>
<td>Sefton coast (Huddart et al. 1999; Neolithic-Bronze Age).</td>
<td></td>
<td>Huddart et al. (1999) hypothesized palaeopathological issues from human footprints (e.g., missing/fused toes, bursitis – showing congenital bunions - and arthritis). Even though the specific case remains to be verified, it is conceivable that footprints can reveal paleopathologic issues.</td>
<td></td>
<td></td>
<td>From ichnological, geological and archaeological data it is possible to infer that the Sefton coast was being used for access, as the inland was extensively wooded or too wet for easy movement. The coast was probably used for a combination of hunting/gathering while cattle grazing occurred on the dunes slacks at various time periods.</td>
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</table>
Manufacturing workshop was subdivided to different specialised sectors. In these sectors the clay was levigated, mixed with temper and kneaded; the vessels were thrown on the wheel, dried on specially built surfaces, fired in kilns and finally stacked before transportation to their final destinations.

During the archaeological excavations an exceptional discovery was made in the northern part of the workshop. On the surface of a trodden floor located between two platforms (equipped with kilns and other installations) dozens of human and equine footprints were preserved (Fig. 5).

The horse footprints are particularly interesting since they represent one of the earliest archaeological attestations of this animal in Syria. The archaeological context suggests that horses were used to transport the pottery manufactured in this area. In fact, horse footprints are associated with rounded impressions, probably formed by jars. As a consequence of the previous point, horse footprints assume an important ethnozoological value. The Qatna footprints give evidence that the horse, generally used in war or as a prestige animal by the urban elites, was also employed as a beast of burden in the Middle Bronze Age II.

As above mentioned, the horse hoof prints were associated with a series of round imprints adjoining the mud platforms. These structures might be related to the presence on the floor of jars fired in the adjacent kilns. Moreover, the rounded impressions – together with other ichnological and archaeological evidence – suggest that this area was a passageway for personnel operating in this part of the workshop, a surface for drying the pottery, and for cooling and storing the pots after firing and before transport to their final destination.

The analysis of the human footprints brings to light the following points:
- morphological analysis of footprints shows that the producers were either adults or children working in the pottery manufacturing area;
- workers were not barefooted but wore simple sandals, probably consisting of a sole fastened to the foot by a strap or a fabric band.

The analysis of the Qatna footprints is still underway. The trampled surface represents an exceptional (and large) database of anthropological information about the physical characteristics of the Qatna population during this period (Fig. 6). Its study will make it possible to estimate the stature and sex of the people working in the ceramic production area, which will be combined with the anthropological evidence recovered from the contemporary necropolis located under the Royal Palace to reconstruct the physical type of the ancient inhabitants of Qatna.

Fig. 5 - The Qatna archaeological site. a. Female terracotta figurine with a miniature bowl, Middle Bronze Age I. Operation J. b. Pottery drying surface with imprints, pottery production area, 17th century B.C. Operation J. c. Detail of one of the pottery drying surfaces with imprints of the sandals of the craftsmen, horse hoofs and jar bases, pottery production area, Operation J, 17th century B.C.

Fig. 6 - Trampled layers. a. Plan of the pottery drying surface (part). b. Footprints that permitted reconstruction of the dynamics (direction of passage, age of the workers, horses as beasts of burden) of the 17th century B.C. site.

Fig. 6 - Livelli con impronte. a. Mappa dell’area di produzione ceramica (parte). b. Le impronte hanno permesso di ricostruire le dinamiche (direzioni di passaggio, età dei lavoratori, cavalli come bestie da soma) del sito del XVII secolo a.C.
2.3. Archaeological burrows and bioturbation

In Palaeoichnology, burrows are among the most studied structures as they can provide precise behavioural and palaeoenvironmental information. Nevertheless, archaeological burrows have received little attention compared to vertebrate footprints. This fact is partly due to the difficulty of examining the three-dimensional structure of archaeological burrows: diagenetical enhancement is usually lacking in archaeological deposits.

Despite these difficulties, archaeological burrows deserve more attention as they can provide useful information for archaeological analysis (e.g. Jeske & Kuznar 2001 on the Archaeology and canine digging behaviour; Boceck 1986 on rodent burrowing behaviour in archaeological sites; see also Laza 2001 on insects).

Burrows, as well as the other kinds of traces, can be syn-depositional or post-depositional:
- syn-depositional traces include the Qatna trampled layer whose traces are environmentally related to the Bronze Age where they occur;
- post-depositional traces would include the burrows of a modern badger disrupting a Palaeolithic site. See figure 7.

For instance, Giacobini (1992) reported some examples of syn-depositional traces in various Palaeolithic sites.

The combined analysis of borings (animal gnaw marks; human chop marks) and marmot burrows opens a vivid window into human-animal interactions during Palaeolithic times showing:
- bioerosional marks on marmot bones that demonstrate skinning, disarticulation and filleting. As a consequence it is possible to infer that humans hunted and dismembered marmots;
- the presence of burrows proves that marmots frequented shelters and caves as intrusive animals. The identity of the tracemaker has been determined because, in some cases, articulated skeletons of marmots have been found in the burrows.

Bioturbation is not just a post-depositional phenomenon that mixes an already buried site but, in many cases, represents a mechanism for artefact burial. Darwin (1896) observed that earthworm activity often led to the rapid burial of artefacts. As Balek (2002) noted, the burial of an artefact can often be explained by the combined processes of (1) within-soil burrowing and (2) translocation of small particles from depth to the surface. These processes have been confirmed by the observations of Johnson et al. (2005) of upward biotransfers (ejection of fine soil particles onto the surface) and biomixing (mixing within the soil) as major biodynamic processes in the soil.

As mentioned above, bioturbation is fundamentally a post-depositional process, although there is a tendency in Archaeology to consider that artefacts within the same level are contemporaneous. This is compromised by the action of burrowing animals which can drastically mix the stratigraphy of an archaeological site. For instance, Araujo & Marcelino (2003) simulated an archaeological deposit in a controlled manner and quantified the bioturbation by armadillos. The results of the experiment demonstrated that armadillos significantly displace artefacts (vertically and horizontally) and are capable of mixing cultural horizons positioned at least 20 cm apart.

Such experiments show the importance of bioturbation as a post-depositional process, either in continental (e.g. Canti 2003) and marine environments (see Shaffer et al. 1997 and Stewart 1999 for observations on bioturbation of submerged archaeological sites). The position of artefacts in soils is a crucial element in the interpretation of archaeological sites, although it must be recognised that completely undisturbed archaeological sites are uncommon.

For these reasons, bioturbation is often viewed as an obstacle impeding a “correct” interpretation of past civilisations. Nevertheless, we propose a more positive approach to post-depositional bioturbation. In fact, evidence of bioturbation may inform about the formation of archaeological sites (after Fowler et al. 2004). According to the biodynamic approach of Johnson et al. (2005), the effects of bioturbation are, in a certain degree, predictable. Morin (2006) followed a similar approach and argued that the vertical distribution of archaeological artefacts is predictable in bioturbated contexts. Moreover, Morin (2006) proposed a detailed model.
to characterise the stratigraphic evolution in bioturbated archaeological sites, which aims to quantify the stratigraphic noise related to bioturbation.

In conclusion, bioturbation is a primary element to take into consideration when studying archaeological sites.

3. BIOEROSIONAL STRUCTURES

3.1. Introduction

Bioerosional traces are structures excavated mechanically or biochemically by organisms into rigid substrates (Pemberton et al. 2001). Bioerosional structures are quite common at archaeological sites, and show a wide behavioural and palaeoenvironmental range. In particular, the following rigid substrates are particularly common in archaeological contexts: rocks (i.e. Laborel & Laborel-Deguen 1994), wood (i.e. Fozzati & Scanferla, 2002) and bone (i.e. Kierdorf 1994).

These substrates are considered below using case studies: borings in ancient Mediterranean harbours (rocky substrates), insect borings in wood substrates and therapeutic bioerosion of bone substrates.

3.2. Bioerosional ichnofabrics in ancient Mediterranean harbours

3.2.1. Introduction

The frontispiece of Lyell’s “Principles of Geology” (Lyell 1830) represents one of the first applications of ichnology to Archaeology (Fig. 8). Lyell described and illustrated borings in the Roman market of Pozzuoli as an evidence of sea-level variations in historic times. In spite of Lyell’s work, the study of biological indicators of recent sea-level variations is a relatively recent discipline (Flemming 1969). Bioerosional structures have been widely considered in “traditional” Ichnology (e.g. Bromley & D’Alessandro 1984, 1989; Simon et al. 1984), and have recently found application in the archaeological study of harbours and other littoral structures (Laborel & Laborel-Deguen 1994; Papageorgiou et al. 1993; Morhange et al. 1996, 1998, 2001, 2006; for a detailed bibliography see Marriner & Morhange 2007).

Bioerosional structures on lithified substrates typically have a high preservation potential; consequently they are often found in archaeological contexts, where they are useful for tracing variations of local sea-level. Such bioindicators have been used in a number of studies, either on natural shorelines (e.g. Laborel et al. 1994; Pirazzoli et al. 1982), or on ancient harbours affected by recent tectonic changes in sea-level (Morhange et al. 1996, 1998, 2001, 2006; Stiros et al. 1996).

The Mediterranean Sea represents an amazing open-air laboratory for the study of bioerosional structures in an archaeological context. Mediterranean coastlines have been colonised by flourishing civilisations since before Phoenician times, and its biodiversity includes numerous boring taxa.

3.2.2. The biological bases

The combined action of erosional and constructional agents controls the morphology of rocky shores: bioconstructional agents (e.g. calcareous algae, bivalves and gastropods; see Laborel 1986) may be counterbalanced by bioerosional agents (i.e. pholadid bivalves, sea-urchins, polychaetes) (Dalongeville et al. 1994).

On the rocky shores of the Western Mediterranean, bioerosional and bioconstructional agents show a very well-defined vertical pattern. In fact, the littoral environmental constraints lead to a precise spatial distribution of fauna and flora (see the detailed studies of Peres & Picard 1964, as well as the broadly similar scheme of Stephenson & Stephenson 1949).

The biological zonation of the Western Mediterranean
Sea includes three principal zones, from the land seawards (Fig. 9; see also Fig. 10a).

1. Littoral fringe: wetted by surf and colonized by endolithic Cyanobacteria.

2. Midlittoral zone: periodically submerged by waves and tides, displaying a pattern of parallel algal belts, with biomass and species diversity increasing seaward. On limestone, the main eroding elements are Cyanobacteria and limpets which shape the tidal notch and erosional bench. Bioconstructional elements such as the coralline rhodophyte *Lithophyllum lichenoides* may also be important sea-level markers.

3. Infralittoral (sublittoral) zone: ranging from mean sea-level (MSL) down to a depth of 25-35m, this zone is densely populated by brown sea-weeds and its narrow upper fringe bears cemented gastropod molluscs (*Dendropoma petraeum*, *Vermetus triqueter*) and bivalves (*Chama*). Lower down in the infralittoral zone, the main erosional agents are boring sponges *Cliona* spp. (Rutzler 1975; Spencer 1992), annelids (*Polydora* and related species), sea-urchins (*Paracentrotus*) and rock-boring bivalves, mainly *Lithophaga lithophaga*. Vermetid gastropods and coralline algae protect the rock against bioerosion and, under favorable conditions may build reef-like rims and platforms which are very precise sea-level markers (Laborel & Laborel-Deguen 1994; Morhange et al. 1998). In protected harbours, zonation is somewhat simplified as the open-water, high-energy fauna generally does not develop; in these cases the main bioconstructors are usually cirripeds (*Balanus*) and oysters, while the main bioeroder are polychaetes. On wooden elements such as posts, infralittoral bioerosion is represented mainly by terebratulid bivalves and polychaetes (Fig. 10b).

3.2.3. Bioerosional ichnofabrics in Ichnoarchaeology

The distribution of bioerosional-bioconstructional agents gives data on a number of different topics.

- **Air/water interface**: The borderline between marine and subaerial forms corresponds to the air/water interface gives an accurate indication of the past sea-level. This separation line is generally well marked by the abrupt disappearing of macrorobors, even in protected harbours (Fig. 11; see also Laborel et al. 2003).

- **Periodic sea-level fluctuations**: Periodical oscillations
of sea level can be inferred by the study of ichnofabrics and/or by cross-cutting relationships between bioerosional and bioconstructional forms. For instance, the superposition of infralittoral on midlittoral forms shows a sea-level rise. An example is given in figure 12, where sea-urchin and Lithophaga borings are dissecting an older vermetid rim, indicating a slight rise of sea-level after the formation of the rim (Thomme-ret et al. 1981).

- Duration of sea-level fluctuations. The duration of a transgressive event may be deduced from the size of the bioerosional forms. For instance, some years are requi-
red before Lithophaga produces a bioerosional ichnofabric. The mean diameter of Lithophaga borings depends on the age of the animals and reaches its maximum value after a long time, often more than fifty years (Kleemann 1973). As a consequence, the measurement of Lithophaga borings allows an indirect estimation of the transgressive event.

- Physical properties of the environment. The degree of opening of a harbour may be deduced from the fixed fauna, but also from the bioerosional ichnofabric. Dominance of annelid tubes is generally associated with semi-closed or even brackish environments, whereas an open water, high energy environment is characterised by an ichnoassociation dominated by clionid, echinoid and Lithophaga borings (respectively corresponding to the ichnogenera Entobia, cf. Circolites, Gastrochaenolites). For example, the marble columns of the Roman market in Pozzuoli are bored by wide Lithophaga burrows, up to an altitude of +7 metres, therefore indicating a prolonged stay in open sea water (Fig. 11). The bases of the mentioned columns – as well as smaller pillars – are coated by encrusting annelid tubes, consequently indicating that the open water environment was later replaced by a brackish one.

3.3. European wood-boring organisms and the conservation of archaeological artefacts

3.3.1. Introduction

Wood is one of the most commonly used materials because of its favourable properties: it is durable, light, easily decorated, easy to work, burns, floats, looks attractive, and makes a noise under strain. It has been used since the appearance of humankind and it is inconceivable to imagine the cultural evolution of the European civilisations without it.

Wood is destroyed by several biological and physico-chemical factors causing anisotropic dimensional alteration, chemical alterations, cracking, discouloration, growth rings and bark detachment, lessening of mechanical strength, surface decay, and several other modifications of physical properties. Among biological factors, boring organisms are a prominent in damaging archaeological wood. In fact borings strongly influence the preservation of xylic artefacts and, consequently, the quality of the archaeological information.

A general overview of the problem is given here, focusing on the following points using European case studies:

1. types of borings affecting archaeological wood;

Fig. 12 - Ichnofabric analysis to determine late Holocene shoreline changes. Falasarna (Crete), after Aloisi et al. (1978). 1. Erosional notch, with superimposed infralittoral perforations. 2. Eroded vermetid (Dendropoma) rim, marking the contemporary sea-level. 3. Sea-urchin rasping dissecting the vermetid rim Lithophaga holes, contemporary of 3. In conclusion, the ichnofabric analysis indicates a relative sea-level change related to neotectonics.
3.3.2. Wood-boring organisms of Europe

Several taxa are known to bore wood, either in marine or continental environments. In the marine realm certain bivalves and crustaceans are a major treat for submerged wood artefacts. Archaeological wood is particularly affected by boring organisms: Fozzati & Scanferla (2002) presented evidence that xylophagous animals (Teredo, Limnoria, Chelura) preferentially attack archaeological wood.

In the continental realm, insects are regarded as the major group of animals damaging wood. Insects attack wood for shelter, food and laying eggs, and in some cases they cooperate with micro-organisms such as bacteria and fungi to transform cellulose and lignin to more easily digestible products. The principal orders of xylophagous insects are Coleoptera (“beetles”) and Isoptera (“termites”). Termites are a social group of insects mainly distributed in tropical and subtropical regions (among 26-32 °C and 70-90% relative humidity; Unger et al., 2001). In tropical regions they represent a major threat for wood artefacts, while in the most of Europe they are a secondary pest (termites are only present in the southernmost part of Europe).

For these reasons, Coleoptera will be taken into particular account. The life cycle of wood-boring Coleoptera includes different ontogenetic stages, which are always associated with characteristic traces (Fig. 13).

1. **Tunnel systems.** Wood-boring coleopterans usually choose cracks to lay eggs, which will develop into larvae. Larvae are responsible for intricate tunnel systems, derived from their feeding activity. These structures are the most damaging for wood artefacts.

2. **Faecal pellet.** These are products of digestion, in some cases diagnostic of the tracemaker (see Tab. 3).

3. **Wood dust.** Freshly pulverised wood is often one of the more conspicuous traces of the activity of wood-boring insects.

4. **Pupal chambers.** Just before pupation, the larva enlarges the diameter of a section of a tunnel. During the pupal stage, the insect limits its movements and completes metamorphosis in the pupal chamber.

5. **Exit holes.** When the adult emerges, it leaves characteristic exit holes which are typical of each species. According to Korozi (1997: 19), the life cycle of Mediterranean insects lasts from 1-10 years, depending on the insect, wood type and environment. Generally speaking, wood-boring coleopterans favour high temperatures and low RH (Relative Humidity) levels. Most are very adaptive, but cannot withstand extreme conditions. Table 3 lists the most common European wood-boring organisms, with particular account to their traces.

Fig. 13 - Commonest traces produced by wood-boring coleopterans (based on the genus Anobium).

Fig. 13 - Principali tracce prodotte da coleotteri perforatori (basato sul genere Anobium).
Tab. 3 - Major wood-boring organisms of Europe. Based on Unger et al. (2001), SIS disinfections (pers. com.)

<table>
<thead>
<tr>
<th>Fam.</th>
<th>Species</th>
<th>Associated traces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insecta, Order Coleoptera</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anobiidae</td>
<td>Anobium punctatum</td>
<td>The female lays eggs in the cracks of the wood (or in the exit holes of previous generations); when the insects become adults, they swarm producing the characteristic exit holes (round, 1-2 mm in diameter). The galleries are tortuous with thick debris mixed with excrements. In hardwood the galleries are irregular and partially filled with cigar-shaped faecal pellets.</td>
</tr>
<tr>
<td>Xestobium rufivillosum</td>
<td></td>
<td>The galleries are meandering, and the exit holes are usually numerous, circular (2, 5-4 mm diameter). Faecal pellets large and lens-shaped. A special feature is the brown discoloration of the wood, derived from the simultaneous attack by decay fungi. This species is named death watch beetle for the ticking sound produced to attract mates; this sound is produced by hitting the forehead on the gallery floor.</td>
</tr>
<tr>
<td>Nicobium castaneum</td>
<td></td>
<td>Galleries follow fiber direction and exit holes are 1.3-3 mm in diameter. Pupa cocoons are made of faecal pellets and placed near the exit hole. Nicobium hirtum is widespread in Japan, where it causes significant damages to temples.</td>
</tr>
<tr>
<td>Oligomerus ptilinoides</td>
<td></td>
<td>The boring morphology is very similar to Nicobium castaneum.</td>
</tr>
<tr>
<td>Cerambycidae</td>
<td>Hylotrupes bajulus</td>
<td>The larva is up to 25 mm long, and makes large (more than 1 cm long) straight and curvy tunnels, extending close to the wood surface. The galleries are usually grooved and stuffed with fine and abundant wood-dust mixed with cylindrical-shaped excrete. Due to the size of the larvae, the mechanical resistance of the wooden structures is seriously compromised. The exit holes are elliptical and present rich and fine debris.</td>
</tr>
<tr>
<td>Veranombycidae</td>
<td>Hesperophanes cinereus</td>
<td>The larvae cause serious damage: they affect structural and mechanical properties of the wood, up to the extent of making it impossible to diagnose their presence. The exit holes are oval, 6-10 mm in diameter.</td>
</tr>
<tr>
<td>Neoclytus acuminatus</td>
<td></td>
<td>Winding galleries, often parallel to the bark. Circular exit holes.</td>
</tr>
<tr>
<td>Phymatodes testaceus</td>
<td></td>
<td>The larvae produce abundant granular debris, and the exit holes are elliptical with a diameter of 5-7 mm.</td>
</tr>
<tr>
<td>Lycidae</td>
<td>Lycus brunneus</td>
<td>Its tunnels are stuffed with wood-dust and the exit holes are round, 0.8-2mm in diameter. The galleries are meandering with rectilinear traits. The galleries, 1-2 mm wide, are similar to those of Anobium punctatum but they can be distinguished for the frass: Lycus brunneus is associated with extremely fine and light coloured frass, not forming fecal pellets. Hence the common name “powder post beetle”.</td>
</tr>
<tr>
<td>Bivalvia, Teredinidae</td>
<td>Teredo navalis</td>
<td>Clavate borings, 6-8 mm in diameter. Characteristically the boring walls have carbonate linings. Teredo has a worm-like body (hence the common name shipworm).</td>
</tr>
<tr>
<td>Crust. Limnidae</td>
<td>Limnoria lignorum</td>
<td>Limnoria (“gribble”, a crustacean) produces winding tunnels, which are usually narrow (1 mm diameter) and shallow (not more than 20 mm deep).</td>
</tr>
</tbody>
</table>
Anobium punctatum is especially widespread in zones influenced by marine climate and significant humidity. Its presence is reported from in Europe, but it has been introduced also into North America, South Africa, South Australia and New Zealand. It attacks broadleaves and conifers, and especially the sapwood. The larva is capable of using very poor, weathered and dry wood. Even if the wood is seriously attacked, it does not fully lose its resistance and its structure is always recognisable.

The optimum development of the larvae occurs at 22-25 °C and 80% RH. It is rare in mountainous regions. This species lives in wood already degraded by fungi, not perfectly dry. It feeds on broadleaves, such as oak, elm, walnut, splinter, poplar and willow.

It colonises nearly every wooden object present in poorly ventilated and very hot environments. It damages paper too.

It is a typical Mediterranean species occurring in poorly ventilated and hot environments.

It lives in discreetly elevated temperatures (28-30 °C), usually occurring in house interiors and roof beams. It is associated with conifers, such as redwood, fir, larch and pine.

This species prefers broadleaves, such as turkey oak, acacia, beech, poplar, walnut and chestnut.

It is a widely diffused species attacking furniture made of broadleaves.

It attacks broadleaves, especially oak.

It is diffused especially in the tropics, but it has been introduced into Europe, North America, Australia and Japan with the commerce of tropical wood. It is associated with 10-16% RH and 20 °C temperature. It attacks very porous woods with a moisture content of around 15%.

_Teredo_ usually attacks shipwrecks in salty water and most often associated with warm and temperate waters.

_Limnoria_ usually occurs in cold and temperate waters.
3.3.3. Conservation and restoration of bored wood: case studies

In this contribution, three case studies are considered to explain some of the most common treatments for bored wood.

- Agricultural tool (property of the Natural History Museum of Lesvos). This tool, dragged by animals, was used to separate cereal seeds. All of its surfaces were seriously damaged by the attack of at least three different types of wood-borers, as evidenced by the several types of exit holes and tunnels (Fig. 14).

- Greek orthodox icon (private collection of Mr. Tsarbopoulos, Athens). This magnificent piece of history and art has been seriously damaged by larvae. The biogenic structures include tunnels which partly collapsed, causing the structural damaging of the paint. Exit holes were also present on the sides of the object. Freshly pulverised wood and faeces indicated the presence of living insects in several areas (Fig. 15).

- Greco-Roman mummy (property of the Museum of Egyptian Archaeology of Turin). Even though the artifact is constituted by composite materials, it represents a very interesting case study regarding boring insects. In fact the mummy has been attacked by very aggressive organisms; the delicate nature of the artifact required special disinfection techniques (developed by SIS Disinfestazioni in collaboration with the Museum of Egyptian Archaeology of Turin, Italy).

Typically, wooden artefacts undergo several stages of treatment: cleaning, disinfection, adhesion, consolidation, filling, and in the case of waterlogged wood, desalination and drying.

If boring organisms are still present, disinfection is important. For the disinfection of dry wooden objects, several methods are used, among which are the application of toxic substances, microwaves, heat and creation of anoxic environments (i.e. Xavier-Rowe et al. 2000). Chemicals have been used to disinfect two of the listed objects, the agricultural tool and the icon. As regards the agricultural tool, a chemical agent (Cuprinol) was injected into the exit holes, and subsequently brushed on the object’s surfaces. The Greek-orthodox icon (Fig. 16) underwent to a similar treatment: after removing mechanically excrements and pulverized wood, the artifact was injected and impregnated with chemicals (Wood Shield).

Sometimes, the disinfection of boring insects requires more elaborate treatments. The combined use of anoxic environments with inert gases (argon and nitrogen) has been described by Valentin et al. (1992: pp. 165-167). Similar techniques have been used on the described Greco-Roman mummy infested by insects (Fig. 17).
Fig. 15 - Greek orthodox icon damaged by insect borings. a. This Greek orthodox icon of folk art presents numerous problems created by wood borers. The tunnels are so close to the painted surface that paint has fallen into the gaps, resulting in loss of painted surfaces. This is evident in the upper part of the icon, around St. John’s head, and mostly on the lower part of the icon, the wood underneath St. George (on the left corner), the face of St. Charalambs (in the centre) and less in the area of St. Demetrios (on the right corner). b. The coloured surface has collapsed and was lost due to the existence of wood borer tunnels underneath it, resulting to the loss of nearly half of St. Charalabos’s face. A crack runs across all of the saint’s body, indicating the existence of a tunnel. In the areas where the paint has been lost, wood dust and woodbore excrement can be seen.

Fig. 15 - Icona ortodossa danneggiata da insetti perforatori. a. Quest’icona greca presenta numerosi danni procurati da insetti perforatori. I tunnel sono così vicini alla superficie dipinta che la pittura è collassata nei vuoti, producendo una perdita delle superfici pitturate. b. La superficie dipinta è collassata e quasi metà del viso di San Charalabos è stata distrutta a causa dei tunnels. Nelle aree dove la pittura è stata danneggiata, si osservano escrementi e segatura.

Fig. 16 - Restoration of bored Greek icon. a. Mechanical cleaning of pulverised wood and excrement, with the aid of a scalpel. b. Consolidation of the back of the icon by injecting Paraloid B72 40% v/v in acetone. The tunnels were quite long and very close to the surface. Injecting acrylic resin into one hole resulted in the oozing out of the material from another spot, along the length of the underlying tunnel. This may be observed by the inlined dots of acrylic resin in this photograph.

Fig. 16 - Restauro dell’icona greca perforata. a. Pulizia meccanica da segatura e escrementi, effettuata con l’aiuto di uno scalpello. b. Consolidamento della parte posteriore dell’icona tramite l’iniezione di Paraloid B72 40% v/v in acetone. I tunnel sono estesi e vicini alla superficie. L’iniezione di resina in un foro di uscita è sgorgata da un’altra apertura, dopo aver attraversato un tunnel. Questo fatto è dimostrato dalle gocce di resina allineate.
Propanone (C₃H₆O) has been applied to the agricultural tool to lay their eggs. Since certain insects use exit holes of previous generations to facilitate reasons but also as a means of prevention and control, conservators (including coleopterans and molluscs) can be precise indicators of sea-levels.

Insect traces could constitute a very proficient ichnoarchaeological tool as wood-boring insects are very selective about environment. The palaeoenvironmental value of insects has been already tested in Archaeology (e.g. Kenward 2006), and ichnologists previously described borings in fossil wood (e.g. ichnogenera *Dekosichnus*, *Palaeohuprestus*, *Palaeoipidus*, *Palaeoscoylytus*, *Xylonichnus*; see also Genise 1993, 1999). As a consequence, it appears manifest that archaeologists, conservators, entomologists and ichnologists have to be encouraged in collaborating to better understand our cultural heritage.

The limits of Ichnoarchaeology revealed by trepanation

In the introductory part of the paper we discussed the difficulty of finding a discrete boundary between Archaeology and Ichnology. In fact these disciplines are separated by a wide grey zone, which comprises also human-produced structures. The archaeological record registers numerous human traces, such as footprints (i.e. Allen 1997) and coprolites (i.e. Bryant 1974). It is also known that humans are responsible for a number of bioerosional structures (i.e. gnaw marks, Landt 2007). Nevertheless, predation is not the only behaviour producing modifications of bone substrates: humans have produced various modifications of osteological substrates for surgical, religious or mystical purposes (MacCurdy 1905, Ford 1937, Piggott 1940, Stewart 1958, Rytel 1962, Lisowski 1967, 1988, Figueiredo 2002).

Since prehistoric times, human skulls have been object of these kind of modifications, which are found in archaeological deposits from all ages and areas: Europe (e.g. Genna 1930; Castiglioni 1941), Africa (Hilton-Simpson 1913; Forgue 1938; Oakley & et al. 1959), pre-Colombian America (Verano 1979; Tiesler Blos 1999), India (Sankhyan & Weber 2000) and Australia (Webb 1988). Two main categories are recognised:

- sincipital marks (trepanation *sensu lato*): superficial scrappings resulting from therapeutic or ornamental activities at the scalp level;
- craniectomies (trepanation *sensu stricto*): complete re-

3.3.4. Future scenarios: wood borings as a palaeoenvironmental tool

Hitherto, borings have been only considered as causes of damages to archaeological wood. We conclude this contribution with a novel approach: wood borings could constitute an additional source of information for the archaeologist. Taking in mind the preference of wood borers for precise environmental conditions (Tab. 3), wood borings could express the environmental history of a particular artefact. Structures such as exit holes and tunnels could provide valuable information for the archaeologist, such as climate (temperature, humidity) and bathymetry. Such an approach was partly anticipated by Oevering et al. (2001) who noted that wood-borers (including coleopterans and molluscs) can be precise indicators of sea-levels.

After disinfestation, the wood can be consolidated with epoxy, acrylic or wax fillers that may vary in viscosity, according to the needs of the object (see also Schniewind & Kronkright 1984: pp146-150).

Insect tunnels and exit holes are filled for static and aesthetic reasons but also as a means of preventive conservation, since certain insects use exit holes of previous generations to lay their eggs.

Acrylic thermoplastic resin (Paraloid B72 40% v/v in propanone - C₃H₆O) has been applied to the agricultural tool and the Greek icon to fill exit holes and tunnels. The artistic value of the icon required some attention for restoration. The destroyed wooden surface on the back was filled with a warm mixture of beeswax, chalk and acrylic colours, while the destroyed areas on the front were filled with a warm mixture of beeswax and chalk, later retouched with acrylic colours and varnished.

Preventative conservation is vital in ensuring that wooden objects are maintained in optimal condition. RH (Relative Humidity) should be less than 70% and temperature should be 20-25 °C. In some cases conservators create a microclimate to enclose very fragile objects. The rooms where wooden objects are kept should be monitored for the presence of wood borers. This is often done using insect traps. Child and Pinninger (1994: pp 129-131) provide guidelines on effective monitoring strategies, and note some of the limitations of the methodology.
moval of areas of the cranial bone, resulting in a borehole. In many cases craniectomies were not responsible for the death of the patient (Kurth & Rohrer-Ertl 1981).

The question naturally arises: is trepanation a kind of bioerosion?

Trepanation (Fig. 18) is the intentional process of perforating the skull of a living (or recently deceased) person (after Pahl 1993). Moreover, the word trepanation comes from the Greek term “trypanein” which means “to bore”.

Therefore, it is evident that trepanation can be associated with bioerosion which is, by definition, the process where animals, plants and microbes sculpt or penetrate surfaces of hard substrates (Bromley 1994). As a consequence, one could point to Ichnology as the optimal discipline to study trepanation. However, it is manifest that “traditional” ichnological methods show important limitations in this field. In fact other disciplines (e.g. forensic medicine, anthropology) play a much more important role in the study of this phenomenon.

From this example, a problematical aspect of Ichnoarchaeology emerges. A great part of human-related structures can be considered as traces (e.g. rock art, stone tools, graves; see Hasiotis et al. 2007), although the traditional methods of Ichnology do not find application to all of them.

4. ICHNOLOGICAL HIEROPHANIES

4.1. Rocks, cultural landscapes, and Ichnology

Rocks have been part of the human cultural landscape since Palaeolithic times (Bradley 2000). They have been referential landmarks in a cognitive cartography which often defined day-life activities and environmental interactions. In many cases they have been linked with the divinatory and the magic.

In such cases rocks represent hierophanies, that are supposed to be manifestations of the sacred: according to Eliade’s (1959) observations, hierophanies mirror “something of a wholly different order, a reality that does not belong to our world, in objects that are an integral part of our natural ‘profane’ world”.

Archaeologists are extremely interested in geological hierophanies. In fact “sacred rocks” provide precious insights into the religious beliefs of a civilization.
There are many examples of geological hierophanies. Uluru (Ayers Rock, Australia) is a monumental example of hierophany for Aboriginal people. Sacred rocks are found worldwide, in many cultures of the past and of the present; some other major examples are Ej Khad (Mongolia), Macchu Picchu’s sacred rock (Peru), and the Meotoiwa Wedded Rocks (Japan).

Curiously, archaeologists themselves are frequently responsible for the creation of new hierophanies. For instance the Pedra Redonda (Rounded Stone, Portugal) village developed around a large, rounded ammonite. Archaeologists erroneously interpreted the fossil as religious rock art depicting magic alignments (Silva 2001).

Among geological hierophanies, there are many ichnological ones (“ichnohierophanies”), which are also found in an archaeological context. For instance, slabs with fossil footprints were collected by Indians; they brought these slabs - named “uki stones” by the Iroquois – to their villages for religious purposes (Mayor 2007). In the Rio do Peixe area of Brazil has been found a petroglyph associated with a dinosaur footprint (Leonardi & Carvalho 2000; Fig. 19). The Aztecs used the toponomastic term Temacpalco, which means “Impression of the Hands”; this fact is linked with an ancient Aztec legend, which tells of Quetzalcoatl - the Feathered Serpent God – leaving hand-prints in the rock (Mayor 2007). In Spain, peasants and shepherds from La Rioja Ba- ja attributed dinosaur footprints to the horse shoes of Saint Thomas (Sanz 1999).

From the few examples cited above, it is possible to categorize ichnohierophanies (Tab. 4) into five socio-cultural groups: cultural, morphological, artistic, scientific and composite.

This contribution aims to show some major examples of ichnohierophanies, particularly from Portugal and Spain.

<table>
<thead>
<tr>
<th>Ichnohierophanies</th>
<th>Definition</th>
<th>Examples</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultural</td>
<td>Trace fossils interpreted as manifestation of supernatural realities.</td>
<td>At Cabo Espichel (Portugal) a religious pilgrimage is related to sauropod trackways. The legend tells that the footprints were left by a mule carrying Our Lady.</td>
<td>This kind of ichnohierophanies are not connected with the scientific method (as happens for scientific ichnohierophanies), but they are associated with popular beliefs and religion.</td>
</tr>
<tr>
<td>Morphologic</td>
<td>Abiotic structures interpreted as ichnological traces of supernatural.</td>
<td>At Monte Sant’Elia (Stromboli, Italy) are found rounded depressions interpreted as Devil’s footprints.</td>
<td>This kind of hierophany is usually linked with geomorphological features (i.e. karstic structures)</td>
</tr>
<tr>
<td>Anthropic</td>
<td>Human-produced structures associated either with ichnology or supernatural.</td>
<td>At Bohuslän (Sweden) there are Bronze Age carvings depicting boats and footprints, probably linked with the cult of the netherworld (Bradley, 1997).</td>
<td>These kinds of symbols are linked to the supernatural by human intervention. For instance, ritual podomorphs are not a direct manifestation of the supernatural (as happens for cultural/morphologic ichnohierophanies) but they actually reflect worshipping of the supernatural. Thus, these kinds of symbols correspond to an extended meaning of hierophany.</td>
</tr>
<tr>
<td>Scientific</td>
<td>Ichnohierophanies resulting from the erroneous scientific interpretation of the ichnological record.</td>
<td>The “Bicha Pintada” (“painted snake”) of Milreu (Portugal) has been interpreted by archaeologists as a petroglyph. According to this interpretation, the “Bicha pintada” would be produced by Celtic tribes as a symbol of ophiolitic rituals. In reality it is a trace fossil (Cruziana).</td>
<td>Probably the most of ichnohierophanies are composite, as cultures continuously superimpose their beliefs.</td>
</tr>
<tr>
<td>Composite</td>
<td>Superposition of different ichnohierophanies.</td>
<td>The podomorphs of Ifanes (Portugal) are actually rock art, but popular culture successively interpreted them as footsteps of Saint Joseph, Our Lady and Jesus.</td>
<td></td>
</tr>
</tbody>
</table>

Tab. 4 - Classification of ichnohierophanies.  
Tab. 4 - Classificazione delle icnoierofanie.
4.2. “Admire Our Lady climbing the rock” and other cultural ichnohierophanies

In popular culture trace fossils have been interpreted as the manifestation of supernatural realities. For instance, huge footprints in rocks have been often connected to the supernatural capabilities of extraordinary creatures/divinities; according to Eliade’s (1959) terminology, this fact represents a “kratophany” (hierophany in which the experience of power dominates). The structures known as “Ciamapa te del Diavolo” (“Devil’s footprints”, Italy) are an example of a kratophanic interpretation: an ancient legend interprets the footprints as produced by the Devil who has the supernatural power of walking on lava. The “Devil’s Footprints” are actually hominid trackways preserved in ash deposits (Mietto et al. 2003). Other examples from classical antiquity often interpret fossil footprints as produced by Hercules. For instance, this interpretation is reported by Herodotus (as regards ancient Moldavia, 450 years BC) and Diodorus (1st century BC, Sicily; Mayor & Sarjeant 2001).

Apart from kratophanic interpretations, there are several other examples showing that humans associated trace fossils with supernatural realities (“cultural ichnohierophanies”). As mentioned above, fossil footprints were collected for religious purposes by the Iroquois (Mayor 2007) and petroglyphs are associated with dinosaur footprints in Brazil (Leonardi & Carvalho 2000) and North America (Mayor 2007). Iberian Neolithic tribes have been also inspired by fossil medusoid impressions (see below).

An astounding cultural ichnohierophany comes from Cabo Espichel (Western Portugal). This case is quite recent but shows clearly the archaeological value of ichnohierophanies and the anthropological basis of “sacred trace fossils” (Fig. 20).
Inside the Memory Chapel at Cabo Espichel is an 18th century *azulejo* (a painted, glazed ceramic tilework) depicting the miracle of Our Lady of Mule’s Stone (Fig 20a). This *azulejo* shows a set of footprints intersecting a huge sea-cliff; a mule is carrying the Virgin Mary over the trackway (Fig. 20b).

The tilework refers to an ancient legend dealing with Our Lady. According to the legend, the Virgin Mary came from the sea on the back of a mule which left its footprints on the sea-cliffs. This legend is associated with an important Christian ritual observed for many centuries. On the summit of Cabo Espichel is a sanctuary where the ritual is celebrated in a very popular annual pilgrimage (even the Portuguese Royal Family have participated in this ceremony since the 18th century).

The legend is linked with the palaeontological treasure preserved on the crags projecting on the ocean (nowadays a protected Natural Monument). In fact, on the same cliff depicted in the *azulejo* (Fig. 20c), are two parallel and overlapping sets of fossil trackways (*Brontopodus*); one set produced by adult sauropods, the other by juveniles (Lockley et al. 1994a, 1994b; Fig. 20d). Fishermen were probably astonished by the enormous size of the footprints (almost 1 m in diameter) and, more than 800 years ago, this has fuelled their devotion.

4.3. “Virgin of the Footprint”: medieval ichnohierophanies from Portugal

There are many natural phenomena (weathering pits, gnamma, potholes) interpreted as traces of extraordinary creatures such as saints or demons (morphological ichnohierophanies). Such ichnohierophanies are present in cultures from all over the world. To cite a few examples, a granite boulder is named “Devil’s Foot Rock” after a colonial legend telling of a squaw being chased by the devil (Rhode Island). Foot-like depressions in the ground (more than one metre in diameter) are interpreted as the footprints of the giant Mo-su, leaving his trace on his way across the Pacific to Fiji (Samoa Island). At Monte Sant’Elia (Stromboli, Italy) there are rounded depressions interpreted as Devil’s Footprints.

In Portugal, the “Virgin of the Footprint” ichnohierophany recurs in various areas (Fig. 21). One of the most interesting examples is represented by the “footprints” of the Virgin Mary from Nazaré. Nazaré itself demonstrates the potential role of ichnohierophanies in Archaeology. In fact the cultural and economic development of Nazaré is deeply connected with the miracle of the knight D. Fiuss Roupinho (revealed in the 17th century by Bernardo de Brito). The legend takes place in the forests of Sítio (“The Place”) and tells of a knight who was hunting when he encountered an enormous deer. The deer was the devil, trying to attract the knight to a high cliff. When the demoniac deer jumped from the steep cliff, the Virgin Mary immobilized the knight’s horse by penetrating its hind legs into the rock. In the sanctuary of Sítio there is an *azulejo* (glazed tilework) depicting the miracle (Fig 21a).

The weathered limestone bed (Turonian) with the “footprints” is sacralized by the “Memory Chapel” (built in 1377); here thousands of pilgrims and tourists try to find the horseshoe prints of the legend (Fig. 21b). This legend was developed through years of “religious Archaeology” trying to establish a link between the natural landscape and some fossilized bones (found in a nearby pre-historic cave). Possibly, the monks tried to find morphological analogies with the footprints of Cabo Espichel (“Pedra da Mua”), which were –

![Image 1](image1.png)

**Fig. 21 - “Virgin of the Footprint” ichnohierophanies.** a. The legend of Nazaré is exposed in the glazed tiles (18th century) of the Sítio sanctuary. This *azulejo* shows the slab where Roupinho’s horse was blocked by the divine intervention of Virgin Mary. b. The limestone layer with the “footprints” of Roupinho’s horse: differential weathering of the limestone is partly due to the ichnofabric. c. “Our Lady of the Jump” sanctuary. In this river gorge some potholes are interpreted as the devil’s landing site. d. Weathering pits in quartzites interpreted as Mary’s footprints and stick prints near the Senhora da Candosa sanctuary.

**Fig. 21 - Le ichnoierofanie della “Vergine delle Impronte”.** a. Il santuario di Sítio preserva alcuni *azulejos* che raccontano della leggenda di Nazaré. b. Lo strato con le “impronte” del cavallo di Roupinho. c. Il santuario di “Nostra Signora del Salto”. d. Il santuario di Senhora de Candosa.
at that time - one of the most famous sanctuaries in Portugal. Indeed, the cretaceous limestones of Nazaré commonly contain “depressions” and “pits”, which originated by karstification and weathering of nodular limestones. The texture is partly related with the ichnofabric, often dominated by *Rhizocorallium* and *Thalassinoides* (Fig. 21b).

Similar ichnoverhierophanies occur all over Portugal; for instance the miracle of “Our Lady of the Jump” (spread in northern Portugal) is based on the devil that crossed the river gorge by jumping (Fig. 21c). Two parallel potholes are interpreted as the landing imprints of the devil. According to another legend, the Virgin Mary of Candosa also crossed the Ceira River gorge. Indeed some “pits” formed by weathering of Ordovician quartzites are interpreted as the imprints of the stick of the Virgin Mary (Fig. 21d).

In Benedita (north of Lisbon) there is a weathered slab of bioturbated limestone (Upper Jurassic) associated with the Virgin Mary. According to the legend, the inhabitants dedicated a fountain to the Virgin Mary, who imprinted her feet as a sign of gratitude.

### 4.4. Solar medusae in the House of the Written Stone

Mayoral *et al.* (2004) described an impressive geomonument presenting 90 impressions of hydromedusae (from the lowermost Cambrian). The locality, known as “Casa de la Piedra Escrita” (*The House of the Written Stone*; Constata, Spain), corresponds to the oldest unquestionable record of jellyfishes (Mayoral *et al.* 2004; Fig. 22). Although the impressions are not ichnoveros, they show the interaction between biogenic structures (mortichnia?) and past civilizations.

In fact the medusoid impressions were inspirational entities for Neolithic people. Some specimens of *Cordubia gigantea* were pitted and rasped in order to highlight their morphology. Moreover, some petroglyphs found in the surroundings seem to replicate the biogenic impressions.

Probably, the sun-like morphology of *Cordubia* is the base of the fascination for these structures. Solar petroglyphs have been often interpreted as sacred/mystic symbols, although it is difficult to confirm this interpretation for *Cordubia*. Nevertheless, “Casa de la Piedra Escrita” shows the interaction between humans and fossil biogenic structures.

In conclusion, the “House of the Written Stone” demonstrates that past civilizations were attracted by peculiar biogenic morphologies in the rocks; the fascination was so pronounced that Neolithic tribes reproduced and highlighted the morphology of *Cordubia*.

Similar anthropologic bases are shared by other archaeological cases. Native Americans and African tribes (Mayor & Sarjeant 2001) used to transpose “sacred footprints” from the consecration space (the tracksite) to other environments. For instance, Palaeo-Indians depicted tridacny footprints in correspondence of dinosaur tracksites and transposed these iconographies to granite landscapes (see Mayor & Sarjeant 2001). In Lesotho, Bushmen depicted in cave paintings not only the Iguanadontid footprints but also their rather accurate conception of the creatures that made them (Mayor 2001).

The association of tracksites and petroglyphs shows the fascination for traces and their probable sacralization. Accordingly, the replication of fossil traces reveals a process of cultural transfer, where ichnological morphologies were transported to new geographies and different geologies.

### 4.5. Anthropic ichnoverhierophanies

The previous paragraph concluded with some examples of anthropic reproduction of ichnological features. Such cases represent not only cultural ichnoverhierophanies (they reflect a supernatural interpretation of actual trace fossils) but also anthropic ichnoverhierophanies.

Anthropic ichnoverhierophanies are well represented by some Bronze and Iron Age sites. For instance, at Bohuslän (Sweden) several carvings depict boats and footprints, and they are probably linked with the cult of the netherworld (Bradley 1997).

One of the best examples of anthropic ichnoverhierophany comes from Asia. A recurrent symbol of buddhism is consti-
tuted by “Buddhapaada”, which means “Buddha’s footprint” in Sanskrit. Buddhapaada are known at least from the 1st century B.C. (see Motoji 1992) and they usually consist of artificial engravements symbolizing the presence of Buddha. Frequently they are finely decorated and there are also ancient poems dedicated to these symbols (i.e. “The Buddha’s Footprint Stone Poems” described by Mills 1960).

Carved footprints are also present in numerous Bronze and Iron Age sites, from various parts of Europe: northwestern Iberia, Canary Islands, France, Scandinavia and the Italian Alps (Zurla, Capo di Ponte, Valcamonica; Coimbra 2004). Many Christian sanctuaries were built close to these symbols and became destinations of pilgrimage. Such cultural superpositions are found near the village of Ifanes (Northern Portugal) where numerous prehistoric podomorphs have been reinterpreted by Christian popular culture. In fact the Ifanes podomorphs are traditionally worshipped as the footprints left by Saint Joseph, the Virgin Mary and Jesus during their escape to Egypt (Coimbra 2004). Ichnoarchaeological methods have revealed that the producers outlined their own feet to produce the carvings (Neto De Carvalho & Baucon 2008).

More ichnological symbols come from Portugal. In the village of Barreiro de Besteiros there is a rock art monument of national importance, the Alagoa rock (Fig. 23). More than 110 podomorphs are carved in the rock (Gomes & Monteiro 1977; Fig. 23).

A problematic aspect of the Alagoa rock concerns the technique used for carving the petroglyph. The use of ichnoarchaeological methods confirmed the hypothesis about the production of the petroglyphs. In fact the carvings reveal features in common with natural ichnoassociations (in particular size disparities and feet proportionality). Therefore, real feet were used as models for the rock art: the authors outlined their own feet with a pointed tool. Moreover, ichnoarchaeological analysis revealed individuals of different ages: children, teenagers and adults all participated in the creative process, bare-footed or wearing simple sandals.

4.6. Reading the trace fossil alphabet: written stones and other mistakes

Scientific ichnoliterographies are modern-day hieroglyphies derived from the erroneous interpretation of trace fossils. In several cases archaeologists failed to interpret trace fossils, similarly to illiterate peasants deciphering an alien alphabet. Under a misleading anthropocentric light, fossilised behavioural patterns became expressions of past civilisations. Two paradigmatic examples from Portugal show the importance of Ichnoarchaeology to avoid such erroneous interpretations of the past.

“Bicha Pintada” – which means Painted Snake – is a winding concave structure found on the top of a quartzite bed in the Ribeira de Codes Valley. Archaeologists interpreted the “Bicha Pintada” as a totemic symbol dating back to the 5th century B.C. (Fig. 24c). According to this interpretation, the structures were carved by a Celtic tribe celebrating ophiolatric rituals (Oliveira 1959; Félix 1969). This discovery raised significant clamour: recently the “Bicha Pintada” has been regarded as the largest Iberian (and probably European) serpentiform petroglyph ever found. Moreover, its occurrence would be associated with a rock carving sanctuary dating from the Final Copper or Iron Age (Gomes 1999). Under this interpretation the “Bicha Pintada” became a notorious element of the Portuguese cultural patrimony, although a Celtic origin of this structure lacks archaeological basis (Neto De Carvalho et al. 1999).

In fact its genesis is biological (not artistic) and much more remote: “Bicha Pintada” dates back to Lower Ordovician. Unquestionable ichnologic evidence (Neto De Carvalho & Cachão 2005) shows that “Bicha Pintada” is not a petroglyph but a burrow produced by trilobite feeding activity.

In France the trace fossil *Cruziana*, popularly known as *Pas-de-boueufs* or Monument druidique, is also part of popular mythology (Deslongchamps 1856; Fauvel 1868; Morière 1879). Its importance is implicit in the slab with *Pas-de-boueufs* of Vaudobin (Trun), considered an historical monument for the associated legend but more recently reinterpreted as a layer with trilobite trace fossils (Durand 1985). *Cruziana* is not the only ichnogenus to have misled archaeologists. At a place known as “Penas Escravidas” (Written Stones) in the Barreiras Brancas range (not far from Rio de Onor village, Portugal) are curly, winding, looping structures in the rocks (Medeiros 1950). These structures resemble alphabetical inscriptions (Figs 24a, 24b) and, for this reason, they were considered rock art by Santos Junior (1940).
This interpretation is completely incorrect; in fact the curly structures correspond to the ichnospecies *Daedalus halli*. What seems to be written scrawls are dense associations of these trace fossils sectioned by the bedding plane (in the type of preservation called *Humilis*). The trace corresponds to the helicoidal displacement of thin, subvertical burrows in a shallow marine environment (Lower Ordovician). It has relevance to a complex ethological pattern which is still problematic nowadays (Seilacher 2000). The “Sun Clock” from Marra das Três Senhoras (another locality in the Barreiras Brancas range; Alves 1935: 827-828, Fig. 80) is probably also a scientific ichnohierophany associated with the misinterpretation of *Daedalus*.

5. **CONCLUSIONS**

This contribution has considered the archaeological implications of the major themes of ichnology.

- **Bioturbational structures**: Archaeological footprints are an important source of information and they are usually associated with recurrent diagenetical scenarios. The case studies demonstrate that footprints can provide fundamental information that are often unobtainable using other methods. For instance, footprints can reveal behavioural information (speed, gait, etc.), data on the individuals (sex, age), identification of the faunal assemblages, palaeopathological issues, structure of the human groups, dynamics of ritual behaviours, land use and economical issues.

- Burrows are difficult to discern in an archaeological context because of insufficient diagenesis; nevertheless, when they are determinable, they offer an important source of palaeoenvironmental and behavioural information. Burrows are related to another important aspect of Ichnoarchaeology, bioturbation. Bioturbation is not just a process that mixes an already buried site, but represents in itself a mechanism for artifact burial. For these reasons, the mechanics of bioturbation are important to an understanding of the formation of particular archaeological sites.

- **Bioerosional structures**: Borings in lithic substrates play an important role in Ichnoarchaeology. In fact they can provide precise details on the dynamics of littoral establishments. For instance, the study of bioerosional ichnofabrics can answer many questions, such as:
What was the mean sea level? How long did the transgressive event last? What were the periodical fluctuations of relative sea-level? Was it a restricted harbour or an open one?

- Archaeological borings occur also in xylic substrates. In fact wood-borers are a major phenomenon to consider during the restoration of artefacts. It is important to understand their mechanics to correctly preserve the archaeological information. Wood-borings are not only an obstacle for the archaeological interpretation, but they can also represent new palaeoenvironmental tools as wood-borings are usually produced by environmentally-sensitive organisms; therefore, the morphological study of wood-borings can provide precious palaeoenvironmental information.

- Borings in bone substrates play an important role in permitting reconstruction animal-animal interactions (humans included). Among borings on bone substrates, trepanation constitutes a peculiar case which is problematical with respect to the boundary between Archaeology and Ichnology.

- *Ichnohierophanies*. Trace-related symbols have a strong archaeoanthropologic value. In this study a new term, “ichnohierophany”, for ichnological symbols related to the sacred supernatural. In several cases, trace fossils have been interpreted as manifestations of supernatural entities (cultural ichnohierophanies). In other cases, abiotic structures have been misunderstood as ichnological traces of the supernatural. There are also human-produced structures associated either with Archaeology or supernatural (anthropic ichnohierophanies). The interpretation of these symbols requires a certain degree of ichnological knowledge: for instance, there are several cases in which archaeologists have interpreted trace fossils as petroglyphs (scientific ichnohierophanies).

- *Further themes*: This study considered only marginally coprolites and gnaw marks, which are important traces to take into consideration in Archaeology (e.g. Marquardt 1974).

- *Further directions*: This work establishes a base for a consistent, uniform approach to the study of archaeological traces. In order to reach this aim, archaeologists are encouraged to collaborate with ichnologists (and related experts) during research. Therefore, the next step is providing a theoretical approach based on “traditional” Ichnology.

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Part I
Invertebrate Ichnology