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FROM MICRO TO MACRO SPATIAL DYNAMICS IN THE VILLAGGIO DELLE MACINE BETWEEN XIX-XVI CENTURY BC

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by
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A Pier e alla mia famiglia, le mie insostituibili colonne portanti

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1 AN INTRODUCTION TO ARCHAEOLOGICAL EXPLANATION

***Where** did social action happen?*

This is one of the main research questions in archaeology. With a historical text more or less contemporary with the ancient social action being studied, the historian can hear the direct perspectives of people from when the social action was originally performed. She can interrogate a text about what happened and the past will spring into her awareness. In textual based history, the past is perceived because knowledge about the human behaviour is available in the same context, albeit through the filter of some textual narrative contemporaneous with the event described. Feedback and feed-forward control has then a real sense, because when there is access to a narration of the past, the historian is capable of evaluating the solution of historical problems, and perceiving errors when the explanation did not correspond to the perception of the past. In contrast, we as prehistorian archaeologists are not able to fully read the past, as we do not possess any preserved narration nor any direct witness describing past events. We cannot see in the present what was performed in the past, nor why or when. We do not have descriptions of past facts, or explanations of motivations, intentions, and goals. We can only examine some incomplete and probably altered *effects* of social activity performed in the past, but these are *actual* observations and do not know a priori how they are connected with what happened some time ago. This places in the position of criminal investigators. Just as there are many different possibilities for catching a criminal, so there are many different possibilities for discovering past actions and where they were supposed to have occurred. Like criminal investigators, historians look for a ´smoking gun`: “a trace that unambiguously discriminates one hypothesis from among a set of currently available hypotheses as providing “the best explanation” of the traces thus far observed” (Cleland 2002: 481).

Nevertheless, even in those circumstances, the past can be transferred, partially, to the present with consideration of a trajectory of ordered modifications that material elements have experienced from the moment of their origin, i.e. from social action in the past, to the past to the moment of archaeological observation. Michael Leyton (1992) has argued that a trajectory of changes, a history, can be described as a discontinuous sequence composed of a minimal set of distinguishable actions. We are assuming that anything we can see, the “materiality” of the world, has been transformed or modified from its original (bio-geological) aspect as a consequence of human action or a further bio-geological process. Transformation means changing an object internally, making evident its essence and altering it. Human experience is shaped by material and non-material things humans transform into products.

Taking this into account, we must also analyse the variability manifested in the data through a diachronic perspective, in order to reconstruct the site biography (Brück 1999: 145-6). Taking this into account, we must also analyse the variability manifested in the data through a diachronic perspective, in order to reconstruct the site biography (Brück 1999: 145-6). The objects, houses and settlements could not be fully understood if considered as static entities in time and space, and if processes and cycles of production, consumption and discard are looked as a whole. Not only do objects change throughout their existence, but they often have the capability of accumulating histories, so that the present significance of an object derives from the events to which it is connected (Kopytoff 1986; Gosden & Marshall 1999: 170). Through this approach, almost every tile of the object/house/settlement's biographical puzzle can be reassembled and, consequently, inferences about past societies can be drawn (Chapman & Gaydarska 2007).

Therefore, we may assume that we can use perceived variation in shape, size, texture, composition and spatio-temporal location values to "run time backwards" and explain how those variations were caused. We may describe a trajectory of changes by imposing a temporal 'slicing' on archaeologically perceived discontinuities (Barceló 2009). The intention for such a slicing will be to visually represent the transitions between events. In this way, archaeologists can simulate the actual occurrences of events in a historical sequence. Such a trajectory of events would be "explanatory" because the same occurrence of an event within the trajectory, and its spatio-temporal relationship with the preceding and successive event, would serve as the *explanandum* of what happened in the past (García 2015).

Explaining the past in the present is therefore a gradual task that proceeds from the general to the specific and that guides, constrains and overlaps with the derivation of a causal explanation from the visual input acquired at the archaeological site and at the laboratory. The overall explanatory process is thus broken down into the extraction of a number of different observable physical properties (low-level analysis), followed by a final decision based on these properties (high-level analysis). Low-level processes typically concern the extraction of relevant features (form and frequency, shape and composition) characterizing the individuality of each archaeological event (Figure 1).

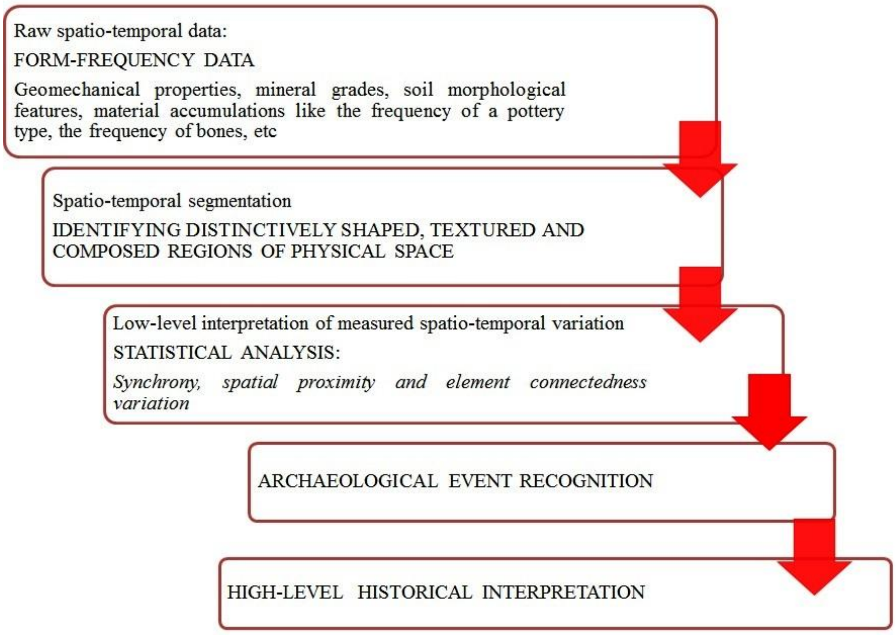

Figure 1 The process of "dissecting" and interpret archaeological event.

Careful examination shows that not every observed low-level feature is the consequence of something produced in the past. Many changes of natural and social reality affect the object externally without changing it internally. Subsequent level of processing are needed to represent higher-level correlations that arise when archaeological events are finally categorized. Events themselves are higher-level entities, integrated in historical trajectories, which should be constructed using mechanisms that are more complex.

1.2 The nature of spatial problems in Archaeology

1.2.1 Introduction and preliminary definitions

“Physical space” can be defined as a container of actions and people: it exists independently of social action because it was generated before its actual occurrence, as a joint effect of human and natural processes. Hence, space affects social action in the same way social action affects space. We produce ‘containers’ where future people will act, in the same way as past people created containers for our own actions and activity (Bradley 1991; Bender 1993; Barrett 1994; Tilley 1994; McGlade 1995, 1997). In this way, we can argue that space is thus the representation of social organization that reflects a true planning strategy (Cattani 2015: 97).

Humans modify physical space and in turn physical space constrains human behaviour. We excavate pits, accumulate sediments, build walls, and hoard artefacts when producing garbage and we may determine the social exclusivity of a place by defining, for instance, property rights (Gatrell 1983: 136-146; Gosden 1994; Thomas 1996; Gilchrist 1999; Ashmore 2000; Robin 2002: 248; Harvey 2007: 102). Consequently, physical space should be considered as a dynamic entity which is constantly changing (Barceló 2005; Barceló & Maximiano 2012). Indeed, space consists of structures and devices that, as long as they exist as socially meaningful entities, are active as agents in the prosecution of social action (Santos 2000: 35). This view was shared and enhanced during the 1960s by the Radical Geography school of thought: authors such as Peet (1977), Harvey (1971, 1976, 1982), Olsson (1974), Lefebvre (1969, 1971, 1991) and Soja (1989, 1996, 2001) among others built up their analysis of social actions referring to the sphere of production, distribution, consumption and reproduction. Following those scholars, we assume space is not simply a passive "backdrop for action, but is socially constructed and constitutive of social relations" (Johnson 1989; Blanton 1994; Parker-Pearson & Richards 1994; Yaeger & Canuto 2000; Robin & Rotschild 2002: 161).

The dense web of interactions between people, producing things and space, is not only affected materially by social action, but symbolically by human cognition. Experiential and phenomenological understanding of space should be taken into account in order to better reconstruct everyday human interaction with physical space that may constrain social action. This approach is widespread in disciplines such as human geography, anthropology (Harvey 1989, 1996; Ingold 1993, 2000; Dear 2001) and archaeology (Shanks & Tilley 1987; Hodder 1990; Tilley 1994; Llobera 1996; Bender et al. 1997; Thomas 2000; Bender 2001; Preucel & Meskell 2004; Briz et al. 2012; Estevez & Clemente 2012). We do not only ‘see’ ground surface that contains us, we experience it, we speak about it, we try to understand how it affects our activity and consequently fill it with meanings and symbolism (Tilley 1994: 23; Preucel & Meskell 2004: 220). Consequently, there is never a single landscape but always many landscapes. “Landscapes are an outcome of the practices of identity formation since people create their sense of identity through engaging and re-engaging, appropriating and contesting the sedimented pasts that make up the landscape” (Preucel & Meskell 2004: 220).

Space is such a general and abstract concept, that it should be analytically deconstructed. The easiest way is by distinguishing different spatial scales, from the micro-scale (the immediate ground surface in which we act) to the macro-scale (the landscape in which the micro-level space is included). If the micro-space is where individual acts, the macro-space is where communities interact (Brück & Goodmann 1999; Schmader & Graham 2015: 25-26). At the highest spatial levels, an archaeological site may be defined as a node of more concentrated human activity within a larger area over which activities were conducted in the past. This assumption allows distinguishing analytically human settlements from other landscape features. Although the consequences of human activity may be scattered all over huge areas (“landscapes”), archaeological sites are places where such archaeological material evidence is found in higher quantities and frequencies than the areas surrounding them (Carman 2000).

At the lowest spatial levels, physical space appears to be differentiated into activity areas which can be defined as “sites” within a site, where a relatively limited set of tasks were performed, with a restricted set of artefacts (and ecofacts) (Kent 1990:1; Kroll & Price 1991:1-3; Rigaud & Simek 1991: 200; Schmader & Graham 2015: 25-26).

Whether we shift “up-scale” away from the site to the landscape or “down-scale” from the site to the activity area, our goal as archaeologists is always to study past cultural and non-cultural materials (artefacts, ecofacts, sediments and features) that have survived into the present day as a result of individual discards, depositions and post-depositional alterations occurred so far. . If we could observe how human action generated in each place a certain amount of individualized material consequences, we could get information on some characteristics of such activities, behaviours, shares and reasons that determine changes in population density of the archaeological observables. The archaeological record and its constituent objects vary in a number of physical dimensions and this variability reflects both traces of past human activities and traces of non-cultural processes that have acted upon the record. Principal dimensions of variability are formal (physical) properties of objects, quantities of objects, disposition of objects in space and co-occurrence (relational association) of objects (Rathje & Schiffer 1982: 64-5; Hodder 2001). Consequently, the general form of archaeological spatial problems can be expressed in the following question:

“*where* did social agents perform their actions and work processes?”

Although recent postmodern perspectives celebrate plurality and indeterminacy (Harvey 1989: 9; Hassan 1995:131f; Eagleton 2003:13; Fahlander 2012: 110), we follow here an approach based on the principle of causality, asking

“*why* have those archaeological materials been found *here* and not *elsewhere*?”

Studying causality does not necessarily mean employing traditional processual archaeology. The idea of spatial cause can be defined as the way an entity is placed at a distinctive location. That is to say, we are interested in inferring how human actions and/or natural processes produced the effective location of some material element somewhere. Throughout this research we will ask questions like:

Why are *those* pottery fragments where we have found them? Why have *those* animal bone fragments been found near *those* lithic tools? Why does the location of *those* wooden posts seem to be aligned with the location of those other structures?

We will solve the spatial *why*-questions in terms of *how* humans performed actions in the past. It is easy to see then that the concept of the mechanism becomes the heart of such causal explanation. Obviously, the word “mechanism” is here a catch-all term for how social intentions, goals and behaviours are causally connected (Bechtel & Richardson 1993; Craver 2001; Machamer et al. 2000; Darden 2002; Glennan 2002; Ylikoski 2011). No matter how long or complicated the causal process is, it can be called a mechanism if its description answers the question "*how* did the cause bring about the effect?". Clearly, nothing is gained if such an explanatory mechanism is reduced to linking some *x* occurred somewhere, while some *y* also occurred nearby (where *x* and *y* refer to different acts, events or processes). Such descriptive chains of events, even if true, are not explanations but they are something to be explained. Statistical regularities don't explain, but require explanation by appeal to the activities of individual entities and collections of entities. An important aspect of our way of understanding spatial causality is that we need to pay attention to the flux of ongoing activities, to focus on the unfolding of real activity in a real setting.

The task of explaining the spatiality of a social event therefore involves the description of the various causal chains linking all the elements implicated (once those elements have been appropriately described and separated) in constituting a social fact. This also means identifying relevant elements between which causal relationships exist, and determining their nature. Spatial causal relations should therefore be rooted in all the effective actions clearly responsible for any single event, even though these are constrained by their environment and the manner in which such action is institutionally organized and "structured".

It is important to take into consideration that "location" is a property of events, but it is not a *cause* itself. Of course, there is a sense in which physical space can determine the placement of different activities: given that we stand on the ground when we act, the nature of such surface affects what we do and the way we do. However, as we have already argued, this surface is also the result of human activity at a time prior to the action being studied. Spatial and temporal locations of any event are a consequence of other social acts, which limit, constrain, and in some cases, determine future actions. An action can generate the reproduction of similar actions around it, or it can prevent any other similar action in the same vicinity. Some of the actions performed in the vicinity of the location increase chances of one type of action and decrease chances of others. Therefore, the real cause should be explained in terms of the *influence* an action performed in some time interval at a location has over all actions performed in the proximity at the same or later moment, and this influence can be described in terms of probability **(**Barceló 2005; Barceló & Maximiano 2012). In this sense, a definition of *distance* as the difference between the values of any property between two (or more) spatial/temporal locations (Gatrell 1983) is a key concept. The concept of distance is seen as a causal mechanism, because we usually assume that "everything is related to everything else, but near things are more related than distant things" (Tobler 1970).

Location itself can only be understood in functional terms, that is, according to what is performed at each place and at each moment. This is a consequence of the fact that social actions are performed in an intrinsically better or worse spatial/temporal location for some purposes, because of their position relative to some other location for another action or a reproduction of the same action (Barceló & Pallares 1998; Barceló 2002). Our objective should be then to analyse where, when and why a social action varies from one (temporal-spatial) location to another. In considering social actions as *practiced* by human actors in reference to other human actors, we assume social action has purpose in the minds of the people involved in the action or causal process. Any account of spatial causality should emphasize human motivation and purposefulness (Leont'ev 1974; Engeström 1987, 1999; Nardi 1996; Zinchenko 1996; Davydov 1999) because social activity is shaped first and foremost by a subject's intention; in fact humans are able to distinguish one activity from another only by virtue of their differing motivations or intentions.

As such, we will only understand spatial causality when distinguishing subjects, needs, motivations, goals, actions and operations (behaviour), together with mediating mechanisms (signs, tools, rules, community, and division of labour). A subject is a person or group engaged in an activity. An intention or motivation is held by the subject and explains activity, giving it a specific direction. Each motivation is an object, material or ideal, that satisfies a need. Activities are realised as individual and cooperative actions, or chains and networks of such actions that are related to each other by the same overall object and motivation. Activities are oriented to motivations, that is, the reasons that are impelling by themselves. For their part, actions consist of chains of operations, which are well-defined behaviours used as solutions to conditions faced during the performing of an action. Actions are processes functionally subordinated to activities; they are directed at specific conscious goals. Actions are realised through operations that are the result of knowledge or skill, and depend on the conditions under which the action is being carried out.

One social need or motivation may be realised using different actions, depending on the situation. On the other hand, the same action can be associated to different motivations, in which case the action will have a diverse meaning in the context of each motivation. For instance, if the activity is "building a house", the goal will be "fixing the roofing", the skill can be hammering, or making bricks or cutting wood. The frontier between intentional activity and operational behaviour is blurred. Intentions can be transformed in the course of an activity; they are not immutable structures. People's motivation for an activity can be changed and so it becomes an action, and an action can become an operation when the goal changes.

Motivation for an activity can be lost and so it becomes an action, and an action can become an operation when the goal changes. The motivation for one activity may become the goal of another activity, as a result of which the latter is transformed into some integral activity. Therefore, it is impossible to make a general classification of what an activity is, what an action is and so forth, because the definition depends on the subject or object in a particular set of circumstances.

Since social activity is not relative to one individual but to a distributed collection of interacting people and the consequences of their actions, we will not study how social activities took place by understanding intentions or motivations of individual agents alone, no matter how detailed the knowledge of those individuals might be. To capture the *teleological* or purposive aspect of behaviour, we should investigate collective action, that is, why different people made the same action, or different actions at the same place and at the same time. Our research goal should be to explain the sources or causes of that spatial variability, and not exactly the inner *intentions* of individual action.

It is therefore important to distinguish between:

- social actions themselves, which are processes and mechanisms capable of transforming reality;
- causal interactions, which are events whereby the effect of a social action has induced a transformation by virtue of its own invariant change-relating capability;
- the result of an action, as the state of affairs that has to be obtained for that action to have been carried out;
- the consequence of an action, as a further state of affairs that has been brought about by the attempt to carry out the action.

In one sense, causal interactions are the factors explaining why a social action was performed at a specific time and place, that is to say, its motivation or reason. On the other hand, the result of an action is conceptually linked to a causal interaction, whereas consequence is contingently related to the action, and should be independent to the event in which the action was performed.

1.2.2. The nature of archaeological spatial problems

From an explanatory point of view, it is desirable to predict the distribution of archaeological entities on the basis of social, economic and cultural parameters that are believed to be the causal driving forces for their distribution and abundance. Pielou (1977) noted an important distinction between the terms “dispersal” and “dispersion” in ecology that is very relevant for the present discussion. While “dispersal” is a process, such as the movement of individual organisms, “dispersion” is the spatial arrangement that results. The same should be true in the social sciences: human behaviour implies the *dispersal* of some material items, direct or indirect, the conscious or unconscious consequence of behaviour, and its result is then a *dispersion* of discarded objects. We can define an observed dispersion of archaeological materials in terms of the arrangement of the consequences of some human behaviour across the Earth's surface, and a graphical display of such an arrangement is an important tool, because it may summarise raw data directly, or may reflect the outcome of more sophisticated data analysis.

Can we predict “dispersal” from “dispersion”? In natural populations, through the observation of the spatial distribution of individuals, you can sometimes acquire information on some behavioural characteristics of species and reasons that determine temporal changes in the observed spatial pattern, at different time moments. It is not so easy when we consider the relationship between dispersal and dispersion of material data as a product of human behaviour. The problem is that any form of dispersion can be the result of many different dispersal mechanisms: actions, both social and individual, and even natural, enacted there up to that time. In archaeology it is usual to predict where people lived and worked (the “dispersal”) from the known dispersion of sites, where evidence of residential and labour activities have been found. In this case, “dispersal” is viewed as a social decision that should be inferred from the evidence observed in a sample of sites where that decision was made effective. When we are predicting the location of a new “possible” archaeological settlement based on a sample of previously known sites whose location is known (Kohler & Parker 1986: 400), we are in fact reconstructing the spatial behaviour around the social decision to occupy a particular place.

Following this definition, Verhagen and Whitley (2012) suggest that we can only speak about predictive models if they result in a quantitative estimate of the probability of encountering archaeological remains outside the locations where they have already been discovered in the past. This kind of predictive model is routinely used to obtain an assessment of site density in an area that might either be facing a direct threat of disturbance, or in a planning zone where policies on Cultural Resource Management need to be determined. They can also be seen as interesting sources of information when preparing for survey: a predictive model can be used to determine which areas are more likely to produce archaeological sites and which are less likely to do so, distinguishing between high- and low-potential zones (Judge & Sebastian 1988; Deeben et al. 1997; Kamermans & Wansleeben 1999; van Leusen & Kamermans 2005; Whitley

2005; Burns et al. 2008; Kamermans et al. 2009; Verhagen 2007; van Leusen et al. 2011; Verhagen & Whitley 2012; Casarotto 2015; Pizziolo & Sarti 2015).

In standard archaeological predictive modelling, what is predicted is the location of the site according to what we know about the physical space that contains a plurality of sites. The decision that biased preferences for some particular locations over others is reconstructed in terms of the influence landscape features may have had on the particular location that has been documented. This form of modelling usually compares known site data, within a controlled survey area, with "environmental" datasets like distance to water, soil type and slope, and then extrapolates the correlations found to areas where no site information is available, usually by means of logistic regression (Kvamme 1990; Verhagen 2006; Finke et al. 2008; Goodchild 2006; Carleton et al. 2012; Harrower 2013; Deravignone et al. 2015). The variables analysed and used for prediction are obviously thought to have some relation to site location preference and, in recent times, more attention is paid to ideas of how people may have used and perceived landscape in the past (Parcero Oubiña et al. 1998; Llobera 2001; Whitley 2003, 2004, 2005; Fleming 2006; Harris 2006; Lock & Harris 2006; Gosden et al. 2007; Lock & Faustoferri 2008; Lock 2009; Roymans et al. 2009; Llobera et al. 2011; Llobera 2012; Rennell 2012; Balla et al. 2013). This recent emphasis on social and cognitive issues is a direct answer to the criticism that there is no actual way of predicting the location of all archaeological sites (Wheatley 2004; Holdaway & Fanning 2008; see discussion in McEwan 2012; Verhagen & Whitley 2012; Verhagen et al. 2012).

We can ask ourselves if the same can be true at lower spatial scales: can we predict where social agents did something (dispersal) from the observed distribution of artefacts, tools and discarded material at the *intra*-site scale? Environmental or topographic information that may have had some relation to settlement location preference is of low interest here. We need a different causal mechanism to understand the location of individualised actions, even if they were practiced collectively, within a site. What explains the location of residence, production and ideological practice within a landscape or territory does not explain the placement of particular activities of residence, production and ideological practice within a settlement. Since only very few archaeological functional categories have been studied in detail in terms of their dynamic responses to micro-spatial location, static distribution modelling often remains the only approach for studying possible consequences of a human intentionality on artefact distribution.

We may assume that the probability a social action occurred at a specific location was related to the frequency of its material effects (the archaeological record) at nearby locations. Archaeologists traditionally have drawn their inferences about past behaviour at the intra-site scale from dense, spatially discrete aggregations of artefacts, bones, features, and debris (Hodder & Orton 1976; Rick 1976; Binford 1978; Simek & Larick 1983; Carr 1984; Hietala 1984; Simek 1984; Binford 1987; Djindjian 1988, 1999; Cribb & Minnegal 1989; Kintigh 1990; Blankholm 1991; Gregg et al. 1991; Rigaud & Simek 1991; Grier & Savelle 1994; Marean & Bertino 1994; Quesada et al. 1994; Kolb & Snead 1997; Wandsnider 1996; Fontana 1998; Logan & Hill 2001; Vaquero & Pastó 2001; Tardieu 2002; Fenu et al. 2003; Peretto 2003; D'Andrea & Gallotti 2004; Holdaway et al. 2004; Orton 2004; Peeters 2004; Berger et al. 2005; Pizziolo & Sarti 2005; Keeler 2007; Anderson & Burke 2008; Katsianis et al. 2008; Pizziolo & Viti 2008; Vaquero 2008; Ying et al. 2011; De Reu et al. 2012; Gallotti et al. 2011, 2012; Milek 2012; Winiger et al. 2012; Alberti 2013; Aprile 2013; Henry et al. 2014; Oron & Goren-Inbar 2014; Gopher et al. 2015; Assaf et al. 2015; Jayalath et al 2015; Martínez-Moreno et al. 2015; Ullah et al. 2015). When we are in face of a spatio-temporally determined accumulation of archaeological observables it seems obvious to think in quantitative terms, and hence of the apparent intensity, importance or abundance of actions that generated such accumulation in the past. Depositional events are then usually referred as accumulation or aggregation episodes, in which the probability that a social action occurs is related to its dimensions. In other words, the more frequent refuse materials at a specific place (location), the higher the probability that a social action was performed in the vicinity of that place. In general, the intuition of archaeologists led to believe that, if the abundance of archaeologically evidenced actions is different in different places, there is a chance that in the past the intensity or frequency of the action was greater in certain places or at certain time intervals. This characterization of archaeological formation processes in terms of *accumulation* has led to the idea of a direct relationship among the population size at a site, the site occupation time span, and the amount of material discarded by its inhabitants, as if the number of artefacts increase directly with a settlement's occupation span (see discussion in Varien & Mills 1997; Varien & Potter 1997; Varien & Ortman 2005).

Consequently, it is easy to understand that some of the most useful tools in archaeology to estimate the past use and function of place rely on the analysis of count data about artefact frequency. If this assumption is correct, then the probability of inferring distinctive locations of particular social actions would be determined by the *intensity* of the social activity performed at that place and moment. Then, assuming that the abundance of archaeological observables at some particular place is a function of the number of times a particular action was performed at that location, we would say that the area where we have found more things, or where their density values are higher and more continuous than in others, was the most likely place where a social action was performed. Obviously, the assumption is just a simple explanation of the quantity of materials found at some particular place; it does not give explanation of the causal nature of the deposition nor of what happened there.

1.2.3. From count data to spatial probabilities

Assuming that the place where the more archaeological observables have been identified in the present is the specific location where some activity took place in the past, it would be useful transform the counts of discarded artefacts into a measure of the occurrence of some activity. *Probability* is such a measure because it usually means the chance or the likelihood of occurrence of an event. When the event is impossible, the probability of that event occurring is 0, while when the event is sure, the probability of that event occurring is 1, and all other events will have a probability between 0 and 1.

The spatial density of the material effects of the activity *x* at the place *y* may be interpreted as a function of the probability that an action was performed at that spatial location. In agreement with the most usual definition of probability, we may assume then that the consequences of an action, having being performed in the past, would be the more probable the more times the activity was repeated at the same place, i.e. the more "frequent" the activity was at that place. If the frequency of the action in the past is related to the abundance of its remains in the present, then variations in the number of observed archaeological elements at different places can be used as a key to estimate the probability the action was performed in some of those places. It is most likely that the action was carried out where material evidence is more abundant (Barceló & Maximiano 2012). Areas where the spatial frequency is the highest can be defined as *attraction* points for material consequences. The underlying idea is that changes in the probability of the "prior" (performance of action during the past) determine changes in the probability value of the "posterior" (the material effects recovered in the archaeological record) (Achino et al. 2016: 725). However, having to infer the cause ("prior") from its results ("posterior") in a probabilistic way, we have to rebuild the real frequency that was generated in the past by the action. When the frequency of an archaeological feature at some locations increases, the probability that the social action was performed in its neighbourhood will converge towards the relative frequency at adjacent locations. If action *A* took place at location *l* and at time *t*, it should be related to the occurrence of observed material evidence around that location that was generated at time *t*, and also with material consequences located elsewhere, and at *t-1* and *t+1*, to explain ***why*** *A* took place, ***where*** it took place, ***there and then***, as opposed to another location and time (Barceló 2005; Barceló & Maximiano 2012).

In any case, we cannot model directly the probability of the occurrence of any activity itself, but the activity of "disposal" and "discarding". Depositional events are accumulation or aggregation episodes during which useless material elements (objects without any utilitarian or symbolic function and not reused) travel through several storage and transportation steps, i.e. discard or refuse. This definition should be applied both to the discard of tools after usage and also to the discard of waste after consumption. This latter activity usually involves a physical reduction in the item being consumed, while usage is usually associated with wear and tear and not reduction. In this sense, a depositional event is not a single fact: it is the result of a collection of elements from one or many sources, the transport of that material by any competent agent or groups of agents, and the deposition of elements whenever and wherever the competency of the transporting agent is reduced, and where a suitable basin is located (Stein 1987).

Predicting the probability that a particular activity may have occurred at a specific location from the abundance of material remains of that activity, we are asking about the activity of discard, and not about the probability of the primary action. This question can only be answered when there is an attested degree of spatial correlation between primary activities (usage/consumption), secondary refuse and discard. Sometimes refuse was produced and thus located at the same place of the primary action, where original objects were used, or the activity of discard was carried out in a secondary area, whose particular location was chosen after use and/or consumption (for more detail see chapter 2). For instance, butchery may generate a series of discarded materials (bones). Their quantity does not inform us about the place where someone carried out the activity, but tells us about the action of refuse itself. Spatial patterns of waste hardly provide information about primary actions, but they can be explained in terms of the formation and deformation of such refuse, which are the result of social motivations (Douglas 1966; Drackner 2005; Reno 2014). The actual location of discarded material evidence is therefore a consequence of the social and cultural motivation causing refuse formation, rather than a mechanical sub-product of use or consumption.

To infer the cause, i.e. the social action performed at a particular place ("dispersal"), from the effect, i.e. the variability in the observed spatial frequencies of material items measured at a finite set of locations ("dispersion"), we have to rebuild the real frequency of evidence that was generated in the past by the social action (Barceló & Maximiano 2012). The basic assumption is that archaeologists know the near-complete list of all tools and objects that prehistoric inhabitants of the studied settlement had at their disposal; artefacts in that list can be characterised through the proportion of times that each object would be found at some location of infinite spatial extension and temporal duration.

We can estimate, up to a certain point, the quantity of tools and other artefacts that were produced and/or used in the past, and later discarded. As first highlighted by Nelson's and Cook's work (published for the first time in Schiffer 1975: 840), the amount of discarded material (in particular, tableware pottery) can be seen as a function of the length of site occupation, the size of the group that inhabited the site and the rate at which specific artefacts were discarded (Varien & Ortman 2005: 132-133). Furthermore, in the 1970s, Schiffer formalised the study of these interactions with a formula known as the "discard equation" or "Cook's law":

$$T_i = S_i * t / L$$

where T_i is the total discard of an artefact type at location *i*; S_i is the number of artefacts of a given category in use at *i*; *t* is the length of time over which the discard took place at *i*; and *L* is the use-life of the artefact type (Hildebrand 1978; Deal 1983; Mills 1989; Pauketat 1989; Lightfoot 1992; Varien & Potter 1997; Hildebrand & Hagstrum 1999; McKee 1999; Gallivan 2002; Varien & Ortman 2005; McKee 2007; Sullivan 2008; Rosenwig 2009; Schiffer 2010; Surovell 2012; Achino & Capuzzo 2015: 67-8). We have slightly modified the original formulation to include a reference to the place where discard was supposed to have been performed. It is important to take into account that this equation refers to very well-defined archaeological categories of findings, for which use-life is known. Given the amount of economic, social, cultural and cognitive motivations around the decision to discard an artefact after its productive life, we should create very restricted categories related to the kind of categorizations that prehistoric agents would have used in reality their real lives.

As suggested by Porčić (2012), one needs to know the values of these variables in order to project T_i, and use it to calculate actual probabilities. However, if the goal is to project a structure of the accumulated assemblage, in terms of relative frequencies of artefact classes, then one only needs to know the average use-life of each class. Indeed, relative frequencies of classes in the accumulated assemblage will remain constant through time and relative frequencies of *S* for each class can be determined from the available house inventories. In that way, the only thing which is needed is the use-life value for each functional class, or the temporal duration of the actual deposit; the problem is that we can rarely properly measure that time interval. The only thing which we are aware of, and is measurable, is the sediment volume resulting from the various depositional processes acting over an apparently unknown period of time. This time interval can be definable if the natural process of deposition (e.g. accumulation of sediment by wind) is known, but again, it is not always possible: sometimes, for example, the sedimentary matrix is the result of the collapse of a wall at a point in time, or an accumulation of anthropogenic depositions (as garbage). Obviously, with a minimum number of 30 properly measured radiocarbon estimates per depositional contexts we could have a reliable measure of the involved time span, but this is not commonly the case.

To estimate the probability of a particular dispersal mechanism from an observed dispersion of discarded elements, we should estimate the number of artefacts belonging to a single given and well-defined category in use at any given point in time, at each possible location (S_i) from the total number of discarded elements at *i* (T_i):

$$S_i = T_i * L / t$$

When the use-life of the artefact type and the temporal duration of the observation unit are the same, both terms can be eliminated and **then**, and **only then**:

$$S_i = T_i$$

This favourable condition occurs when the artefact has a duration in life more or less equivalent to the life of a person (estimated, according to common sense, at ca. 20 years); thus, the maximum precision in temporal terms is associated to a time-span which includes just one generation (also around 20 years).

1.2.4. Scalar fields and spatial gradients

Spatial probabilities can be best analysed using *scalar fields* to investigate spatial variation in the probability of an action occurred, be it a primary action, secondary refuse or post-depositional alteration (Camara et al. 2014). In general, a *field* is a quantity that can be specified everywhere in space as a function of position. In our case, we deal with physical spaces only. Hence, a field will be defined as a function between an independent variable D (in our case the probability of occurrence) and the x, y and z coordinates, corresponding to every location in a 3D space. The scalar field exists in all points of space and at any moment of time, while the scalar is its value at a certain location and at a certain time. We require the representation of spatial distributions to be coordinate-independent, meaning that any two observers, using the same units, will agree on the value of the scalar field at the same absolute point in space, regardless of their respective points of origin.

Scalar fields can be represented mathematically as functions. We should define the function for the specific location of interest, and the function returns the value of the probability of occurrence at that location. Probability estimations are characteristically *continuous* because values belonging to the set can take on ANY value within a finite or infinite interval. More formally, we can define the continuity of the spatial function as follows: an infinitely small increment of the independent variable x always produces an infinitely small change $f(x+\alpha)-f(x)$ of the dependent variable y. Thus, f defined on a real interval I is continuous if and only if for all x infinitely close to a, the value $f(x)$ is infinitely close to $f(a)$, at every point of I. The trouble is that spatial frequencies, as calculated in the previous section, are discrete measures because they are specific to discrete areas (i) where density has been calculated.

To convert discrete measures of spatial frequencies at some locations into a continuous measure of probability of occurrence for the studied area, we can "interpolate" a global function to known data points. Spatial interpolation is the process of using points with known values to estimate corresponding values at other unknown points. For example, to make a scalar field for the probability of refuse of materials of certain archaeological categories, we do not have enough evenly spread spatial frequencies to cover the entire studied area. Spatial interpolation can estimate the spatial probability at locations without recorded data, by using known spatial frequencies at nearby well-excavated sampling units. This type of interpolated surface can be called a statistical surface.

Given the location of archaeological evidence, the purpose of any spatial interpolation method is to predict the value of the dependent variable at any imaginable spatio-temporal coordinate. The result is an interpolated manifold (usually a surface), which can be understood as a probabilistic map for the placement of social actions performed in the past. In such a map, nearer things appear to be more related than distant things (Tobler's law) (Tobler 1970), because the synchronicity of social actions states that, all else being equal, activities that occur at the same time will tend to increase the joint frequency of their effects. In other words, in locations spatially and temporally close together, we would expect to have relatively similar spatial frequencies, and those further apart to have relatively larger differences.

For instance, supposing that we know the presence or absence of all archaeological categories related to a settlement from a single period of time, then spatial-temporal interpolation would estimate the probability of human settlement at unsampled locations and times. Ideally, instead of predicting for each location (x,y) a single value $f'(x,y)$ or this value plus a variance $\sigma'(x,y)$, it would be interesting to estimate the probability density of the value $f(x,y)$. Given a sample of observed frequencies at known locations, what we would need to generalize is a non-linear function that may represent the probability density function of the social action in its original spatial modality. In other words, we are trying to calculate the probability density function of finding archaeological evidences $Pr[f(x,y) \geq th]$ for a fixed critical threshold th and for any location (x,y) of any archaeological evidence. Obviously, the ability to interpolate accurately depends ultimately on the availability of data commensurate with the particular target scale of output.

Interpolation has been utilised in archaeology since the 1970s (Hodder & Orton 1976; Kvamme 1990; Kvamme 1995; Wheatley & Gillings 2003; Neiman 1997; Robinson & Zubrow 1999 among the firsts). The most common application has traditionally been for the creation of digital elevation models (Conolly & Lake 2006), but the technique can also be applied to model a continuous distribution of cultural data, such as artefact densities or event horizons (e.g. Gkiasta et al. 2003) derived from sampled locations. The apparent complexity in archaeological spatial datasets arises from such spatial heterogeneity, insofar as the densities of different phenomena (e.g., artefacts, settlements, field walls etc.) vary widely over space and, moreover, relationships that hold true in one area of a landscape may not hold true in another. To complicate things further, cultural (and natural) phenomena often also exhibit spatial anisotropy: the measurements of a given phenomenon may not vary equally evenly in all directions, but may have trends that are directionally dependent (e.g. the frequency of artefacts may decrease evenly in one direction, but more chaotically in another) (more details are provided in Chapter 4). This complexity does not, however, mean that spatially heterogeneous and anisotropic phenomena are unable to be investigated quantitatively. In fact, as we here show, formal spatial analysis can yield a much deeper understanding of the structure of a dataset and its spatial variability.

In archaeology, inductive and correlative predictive modelling aims to predict archaeological characteristics of places from their non-archaeological, usually environmental, characteristics (Kvamme 1990; Wheatley 2004). Analysing statistical properties of locations in which sites occur usually generates a classification rule that determines the archaeological characteristics of locations for which archaeological properties are not known. We are suggesting going further, using the characteristics of spatial process as predicted on the basis of the statistical properties of locations in which archaeological observables occur, to infer the original placement of each action. Several things, however, argue strongly for the need for further critical debate of those methods. D. Wheatley (2004) suggests that, although much has been written about the theoretical issues surrounding explanatory spatial predictive modelling, rather less attention has been directed to the reasons why their expectations are not always fulfilled.

Kriging or Gaussian process regression is a method of interpolation for which interpolated values are modelled by a Gaussian process governed by prior covariances (Oliver & Webster 1990; Cressie 1990; Neal 1996; Williams & Rasmissen 1996; Williams 1998; Banerjee et al.

2008; Stein 2012 among others). This is a procedure based on the assumption that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. The kriging tool fits a mathematical function to a specified number of points, or all points within a specified radius, to determine the output value for each location. According to these suitable assumptions, the interpolation method gives the best linear unbiased prediction of intermediate values.

The basic idea is to predict the value of a function at a given point by computing a weighted average of the known values of the function in the neighbourhood of the point. The procedure starts with a prior distribution taking the form of a Gaussian process: *N* samples from a function will be normally distributed, where the covariance between any two samples is the covariance (or kernel) function of the Gaussian process evaluated at the spatial location of two points. A set of values is then observed, each value associated with a spatial location. Now, a new value can be predicted at any new spatial location, by combining the Gaussian prior with a Gaussian likelihood function for each of the observed values. The resulting posterior distribution is also Gaussian, with a mean and covariance that can be simply computed from observed values, their variance, and the kernel matrix derived from the prior.

The general formula is formed as a weighted sum of the data:

$$\hat{Z}(s_0) = \sum_{i=1}^{N} Z(s_i)$$

where:

$Z(s_i)$ = the measured value at the *i*th location

λ_i = an unknown weight for the measured value at the *i*th location

s_0= the prediction location

N = the number of measured values

The weights, λ_i, are based not only on the distance between measured points and the prediction location but also on the overall spatial arrangement of measured points. To use the spatial arrangement in the weights, the spatial autocorrelation must be quantified. Thus, in ordinary kriging, the weight, λ_i, depends on a fitted model to the measured points, the distance to the prediction location, and the spatial relationships among the measured values around the prediction location.

To make a prediction with the kriging interpolation method, two tasks are necessary:

- Uncover the dependency rules.
- Make the predictions.

To realise these two tasks, we should go through a two-step process:

1. calculating covariance functions to estimate the statistical dependence.
2. predicting the unknown values.

Once the autocorrelation value is known for particular variables in a defined area, using interpolation methods it is possible to create a prediction about values assumed by these variables in other sectors located at a known distance, that have not yet been sampled. The purpose is to generate a grid of data values from an existing set using two-dimensional spatial interpolation methods. Grid generation is typically a process based on weighted averages of values at nearby points. The assumption is that each grid cell or intersection is likely to be similar to other values in its neighbourhood. In the case of kriging, weights are based on the distance between measured points, prediction locations, and overall spatial arrangement among measured points. Kriging is unique among interpolation methods in that it provides an easy method for characterising the variance, or the precision, of predictions (Burrough & McDonnell 1998; De Smith et al. 2009) (for more details see Chapter 4).

In any case, scalar fields calculated using interpolation and related methods only maximise available information from often sparsely distributed data. As such, it does not solve the archaeological problem of inferring the original location of social action, nor why materials are where they are, but gives us some information about the spatial modality of social action based on the spread and density of its material effects. Given that any collective social action is intentional and goal-directed by definition, the spatial distribution of material consequences of such actions also reveals some aspect of that intentionality. Thus, by interpolation we are looking for some characteristics of the spatial process that generated observed locations. In other words, the main objective should be the correlation of different social actions:

- how the spatial distribution of an action has an influence over the spatial distribution of other(s) action(s),
- how the spatial distribution of an action has an influence over the temporal displacement of other(s) action(s).

The main assumption is that the spatial and temporal location of human action is a consequence of other, both human and bio-geological events, which limit, constrain, and in some cases, determine future actions. Therefore, we are looking for the "influence" an activity performed at a location has over all material evidence observed in the proximity. Such action *x* can generate the reproduction of similar (actions x_1, x_2, x_3….) around it, or it can prevent any other similar activity in the same vicinity. Some of actions performed in the vicinity of the location increase the probability of an action and decrease the probability of others.

Discontinuity detection is essentially the operation of distinguishing significant local changes among spatially sampled values of some physical properties. Hoffman and Richards (1984) have proposed that a good rule of thumb is to divide the data array into components at *maximal concavities*, which mathematically speaking, are the local minima of curvature. Formally, such a discontinuity in spatial probabilities of the social action is defined as an observable edge in the first derivative of the mathematical function that describes archaeological frequencies over space. We can use spatio-temporal gradients of the frequency of social effects to define limits and intensity of an attraction field, which represents how the action has modified physical space around it.

A "spatial gradient" in the data array is a formal way to represent the direction assumed by the maximum rate of change of the perceived size of dependent values, and a scalar measurement of this rate (Sonka et al. 1993; Maximiano 2007; Barceló 2008; Barceló et al. 2009; Barceló et al.

2015: 37). This spatial gradient describes the modification of the density and the size of archaeologically measured values such that regularity patterns in spatial variation can be determined, which implies a similarity in neighbour regions, as described in Tobler's Law (Tobler 1970). The gradient is calculated by finding the position of maximum slope in its intensity function, i.e. a graph of the value of the dependent variable as a function of space. First-order differential operators compute variation levels of such intensity function, and the spatial gradient can be estimated by detecting the maximum in the first derivative of the mathematical function in relation to the intensity function. A more economical algorithm would be to detect zero-crossings of the second derivative of the mathematical function in relation to the intensity function. The second derivative of a function is just the slope of its previously calculated first derivative. The second derivative, thus, computes "the slope of the slope" of the original spatial probability; in such a function, the position of the interfacial boundary corresponds to the zero value between a highly positive and a highly negative value. Then, the intensity profile of spatial frequencies can be graphed as a curve in which the x axis is the spatial dimension and the y axis corresponds to the dependent variable (for instance, the quantity of some archaeological material at each sampled location). Likewise, the directivity of such a probability gradient (or "aspect" of the scalar field) is simply the polar angle described by the two orthogonal partial derivatives. Peaks are the most probable locations of single accumulations. Directivity inferences allow us to understand the relationship between neighbour accumulations and how some parts of the space were "cleaned," suggesting the most probable location of residence activities (more technical details appear in Chapter 4).

Each identified spatial gradient constitutes a localised event in space and time, be it an individual, a collective action, or a series of actions, and develops together with its environment as a complex network of dialectical relationships at multiple levels, conditioning the performance of the action and successive others performed in the neighbourhood. It materialises a complex field of attraction, radiation, repulsion and cooperation around this activity, producing the necessary energy for the functioning and even the existence of the social system. It is easy to see that in those circumstances, a deterministic model is an oversimplification of the spatial process.

1.2.5. Multivariate spatial prediction

Up to now we have discussed how to predict the place where an action took place in the past, on the basis of the *spatial probabilities* for that action[1]. In archaeology, these spatial probabilities should be estimated *in the present* from the count of preserved material consequences of the studied action. Nevertheless, it does not necessarily mean that the place where the action was performed in the past is exactly the place where archaeological remains are the more abundant.

In the previous section we have given a short introduction regarding how to transform spatially distributed count data of archaeological observations into a model of spatial probabilities. In most cases, however, such a probabilistic map is not enough to solve the archaeological spatial problem because the place where an action was performed cannot be predicted from the sole remains of that action. What cannot be predicted for an isolated category, can be estimated for the repeated association of categories that recurrently appear at the same place. For instance, it is hardly possible to know the place where a meal took place from the spatial pattern of animal bones that were discarded during the meal. It is even more difficult if we do not know if bones were discarded after meat acquisition, during butchery or cooking, or after consumption.

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[1] For an ecological application of the same principle see Cabeza et al. 2004; Saracco et al. 2010

However, if we have enough evidence of the spatial distribution of hunting equipment, of butchery conditions, cooking elements and the furniture necessary for meat consumption, a comparison of all those spatial distributions will give us some clues as to where the meal took place.

The problem exceeds classical spatial regression methods because we are trying to compare different dependent variables, as the abundance of different archaeological observables (z_1) and the probability of occurrence of different activities (z_2) through a fixed disposition of two independent variables, x and y, which are the spatial coordinates of the abundance or probability measurements. We should consider that the relationship between these two (or more) dependent variables may - or may not - be constant across space; if this relation varies within spatial context, violating the principle of stationarity, spatial non-stationarity takes place. This means that "the global correlation statistics (such as Pearson's r) could be inaccurate estimates of explanatory strength and that global models of the dependence of one spatial variable on another are likely, at the very least, to miss important local patterning, but also run the far more serious risk of mixing the effects of local relationships and producing an entirely spurious, mis-specified model (a manifestation of what is known as Simpson's Paradox)" (Bevan & Conolly 2009: 11).

As an example, the relationship between the abundance of bone sherds (*bs*) and fragments of a lithic industry (*li*) across a specific settlement area is considered. The set of defined counts against the other may indicate that where high quantities of the bone shards are found, so too are high quantities of lithic artefacts, according to a covarying relationship. However, the measured strength and the statistical significance of this relationship may vary spatially and might even be entirely different in one part of the study area than in another. What, in fact, we wish to understand is not simply whether *bs* and *li* covary, but also in what spatial locations, at what scales and in what local ways they covary. A simple solution would be provided by the map algebra approach, a cell-by-cell combination of raster data layers, stacked on top of each other and overlapping the scalar fields of each dependent variable, we look for coincidences. A simple operation, like addition or multiplication, is applied to each raster cell location. Map algebra generates a new raster output based on the math-like expression (Tomlin 1990; Wheatley & Gillings 2003; Kjenstad 2013).

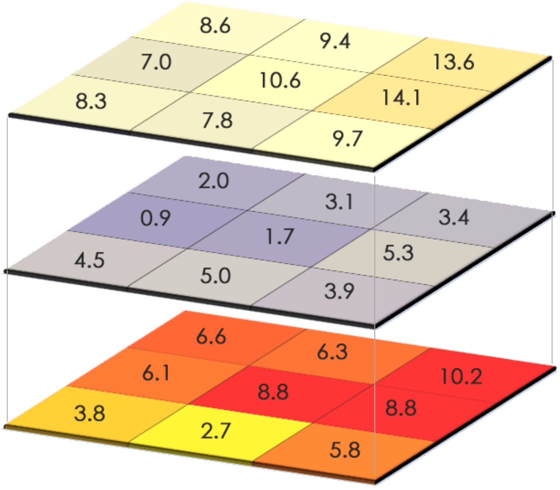


Figure 2 Example of Algebra Map (from: http://gisgeography.com/map-algebra-global-zonal-focal-local/)

Depending on the spatial neighbourhood, map algebra operations can be categorized into four classes: local, focal, global, and zonal. “Local” operations work on individual raster cells, which are equivalent to the sampling units we have used in fieldwork for converting count data into spatial frequencies. “Focal” operations work on cells and their neighbours, whereas “global” operations work on the entire scalar field. Finally, “zonal” operations work on areas of cells that share the same value. The input and output for each operator being a map, the operators can be combined into a procedure or script to perform complex tasks. In our case, comparing the probability of occurrence of different actions at the same place, through the use of boolean or relational operators, we can be faced with two different scenarios: we can either identify where all refuse activities, related with the same primary activity, occurred around the same area, or how they vary more than expected spatially if the activity was performed intentionally at a fixed location. Modern extensions of the map algebra principle allow making this comparison with reference to time phases (Frank 2005; Mennis & Tomlin 2005; Schmitz et al. 2013).

A difficulty with the standard map algebra approach is that the limitations of usual boolean operators requires reduction of the number of dependent variables and makes comparisons of very few archaeological categories at a time. An alternative is the method presented in chapter 4: a spatially unconstrained Correspondence Analysis, in which scalar fields are considered as spatial contingency tables, and where the ultrametric chi-squared distances between all cells and grids, can be factored in a reduced number of factors, and those factors can be spatially represented in an *x, y* graph.

In any case, classical map algebra or spatially unconstrained Correspondence Analysis are procedures that deal with grids and cells, that is, with discrete visualizations of a scalar field, which is essentially a continuous representation of bi-dimensional arrays of real numbers. Then, if the geometric equivalent of a scalar field is a statistical surface, we can also present the problem of multidimensional spatial prediction in terms of statistical surfaces multiple non-linear correlation.

Different methods exist for surface correlation or comparison in digital image studies, employing tracking and image registration techniques for accurate 3D measurements of changes in images. This is often used to measure deformation, displacement and strain, but it is widely applied in many areas of science and engineering. Commonly, Digital Image Correlation relies on finding the maximum of the correlation array between pixel intensity array subsets on two or more corresponding images, which gives the integer translational shift between them. In our case, it would be possible to measure the degree of coincidence between the probability of occurrence of the same activity, as estimated using different data sets of archaeological refuse materials. The two-dimensional discrete cross correlation r_{ij} can be defined in several ways, one possibility being:

$$r_{ij}=\frac{\sum m \sum n[f(m+i,n+j)-f][g\,(m,n)-\overline{g}]}{\sqrt{\sum m \sum n\left[f(m,n)-\overline{f}\right]}^{2} \sum m \sum n[g(m,n)-\overline{g}]^{2}}$$

Here *f(m, n)* is the probability of occurrence at a point *(m, n)* in the scalar field of activity *f*, and *g (m, n)* is the probability of occurrence at a point (*m*, *n*) in the scalar field of activity *g*. $\overline{f}$ and $\overline{g}$ are mean values of the intensity matrices *f* and *g*, respectively (adapted from Schreier et al. 2009).

In summary, our task is to find the common spatial structure in a given set of archaeological variables, under the assumption that structure that is common across many individual instances of the same cause-effect relationship, must be definitive of that group. That is to say, when a thing of certain sort *A* has been found to be spatially associated with a thing of a certain other sort *B*, and has never been found dissociated from a thing of the sort *B*, the greater the number of cases in which *A* and *B* have been found spatially associated, the greater the probability that they were spatially related, because they were causally connected. The presence of communalities implies a high level of "regularity" in the data, meaning that certain locations will be more probable than others (Zytkow & Baker 1991: 34). A remaining question is how the location differences among the effects of cause *C* have determined or conditioned differences among effects of cause *B*. This property has also been called *location inertia*: it is a time-lag effect that activities experience in the adjustment to new spatial influences (Wheeler et al. 1998). In other words, changes in the probability that a social action has been performed at a location, and at a distance from the place of another action, should determine changes in the probability of the spatial variability of material effects, i.e. the archaeological record, not only of the same action, but also of other actions performed at the same place during different time intervals. The spatio-temporal variability of such an "influence" is what we call the dynamics of the socially configured relational space.

1.2.6. The Implicit problems of spatial prediction at the Intra-site scale

The probability an activity took place somewhere in the past cannot always be estimated in terms of the abundance and density of material consequences of that activity. We can mention five basic difficulties, at least: 1) the problem of raw count data, 2) the problem of fragmentation, 3) the problem of categorization, 4) the problem of empty areas, and 5) the problem of post-depositional alteration.

1.2.6.1. The problem of raw count data

The number of archaeological observables (count data) is not necessarily indicative of the number of events that happened in the past. Observing, for example, four lithic flakes of a particular common type at four different spatial locations (x,y_1, x,y_2,….x,y_4), they can be understood as four different events, or as a single related event if all those were synchronous; indeed, they could be the material consequence of a single lithic manufacturing act, as production scraps, or the result of four consecutive working acts, with the same raw material. If depositional events occurred independently in different locations in space and time, archaeologists can calculate the frequency of the event in question. In contrast, if different events of the same kind occurred simultaneously (i.e. non-independently) at the same place, the number of elements will not be related to the number of events per unit of time (frequency). In this way we can distinguish between *count data* and spatio-temporal *frequencies*. We should refer to "count" as a list of observations, and "frequency" as the calculation of the number of times a certain event took place, based on observed counts, but also taking into consideration the length of the time interval over which the event was repeated (Lindsey 1995).

In an ideal prehistoric settlement that fully complies with the Pompeii premise, i.e. that is completely preserved as it was during its deposition (more details in Chapter 2), the number of posts associated with pile-dwelling structures are *counts of those objects*. The number of independent *k* pile-dwellings, e.g. houses, is the frequency of the building events that took place in the past. The key to understanding the difference between counts and frequencies is that to calculate the frequency with which an event repeatedly occurred in the past, we count the number of times that the event happened within a specific time interval. We call the particular interval of time and/or space, within which some related events took place, a "period". A count of 1350 fragments of any material may seem a lot, but if we assume duration of 300 years, a frequency of 4.5 items per year would be enough for obtaining what seemed so high a value. The frequency is calculated by dividing the count of observables by the time interval length, in this case 1350/300 being 4.5 remains per year.

Furthermore, the importance of converting count data into spatio-temporal frequencies resides in the fact that mathematical operations such as scalar fields, gradients and statistical surface correlation can only be done with estimates of probability of occurrence. Probabilities are in fact "frequency ratios", and not mere counts of data. A spatial probability is the limiting value of the frequency ratio, as the number of repetitions, and if it becomes infinitely large is called probability of the event A.

$$P(A) = \frac{\text{Number of actual observations } (i) \text{ where } S \text{ is present}}{\text{Total number of observations}}$$

Those probability estimates depend on density measures, and hence on the election of the sampling unit. As a basic principle, the more limited the space-time reference units (*i*), and more circumscribed in time (*t*), the more reliable will be the estimation of spatial probabilities. This circumscription seems relatively easy in the case of spatial excavation units, where we use equally-sized spatial sampling units organised into a grid. When instead of excavation units we have well-delimited activity areas generated in the past (built space units), we can calculate the centroid of a polygon or the mean centre of a set of points.

1.2.6.2. The problem of fragmentation

One of the main problems archaeologists can face when quantifying archaeological evidence is that in 99.99% of cases, remains of the past archaeologically observed in the present are fragmented, and in 99.99% of those cases we have not been able to retrieve all fragments of the original artefacts that once existed. Only in some very specific cases, again as when the archaeological context complies with the Pompeii premise, what we have observed at the scale of the single fragment can be generalized to the entire object the fragment comes from. For example, the isotopic composition of a fragment of human bone can be generalised to the individual. On the other hand, affirming that a whole vessel (not seen) had no decoration in the past because the fragment observed in the present does not, is a serious error of interpretation, based on the confusion that 1 fragment equals 1 whole artefact.

Furthermore, the dispersal mechanism of fragments after breakage, for instance, is significatively different to the dispersal of discarded tools (Pandolfi & Ortiz 1998, Curran et al. 2000, Repetto et al. 2000, Rena et al. 2004, Shubash et al. 2008). When a vessel is broken, the shard scatter follows the physics of the impact, which in many aspects is entirely random (Brownian motion). Refuse and discard are constrained by the agent's motivation to act in one way or another, according to their cultural definition of "garbage". Additionally, fragmentation is usually the result of a post-depositional action or event. Hence, what we observe in the fragment may have nothing to do with the way an original artefact was produced, used or consumed. Therefore, a mere count of remains is usually a bad estimate of the abundance of a particular attribute, because what it generally describes is the post-depositional fragmentation and does not mirror the refuse's formation or the original activity.

Therefore, we cannot always assume that "the higher the number of similar fragments of some undefined archaeological object, the more frequent the material consequences of the action having produced those remains, and therefore the higher the relevance of such an activity". If we identified 300 chert flakes in the present, how many cores were worked in the past? If you have excavated the remains of four hearths, how many of them were contemporary and how many households existed? There is no simple solution to these problems because a solution will depends on the number of flakes that have been extracted from a core, the nature of household activities, and so on.

One solution may be estimating the minimum number of individuals (NMI) that could have generated an observed amount of remains with the same feature or intent. It is relatively easy in archaeozoology and forensic archaeology, since the shape of animal or human bone, and its laterality, are previously known (Lyman 2008; Grayson 1984). This approach should further be applied to all archaeological domains, estimating the minimum number of vessels from the count of identified fragments (Orton 1993; Orton & Tyers 1992; Baxter & Cool 1996; Arcelin & Tuffreau-Libre 1998; Bellanger et al. 2006; Chapman & Gaydarska 2007; Felgate et al. 2013), or the number of lithic tools from flakes and other remains (Shott 2000, Andrefsky 2007, Shott & Olson 2015; Jayez & Nasab 2016). A problem in estimating the minimum number of individuals is the difference between whole objects and parts of composite objects. For instance, pile-dwellings are formed by wooden posts and beams, vegetal elements and, in some cases, stones. How many houses, and of which size, can be reconstructed from an observed amount of beams, posts or vegetal elements? There is no simple solution to this problem, except being extremely careful in estimating the minimum number of "individuals" per event.

1.2.6.3. The problem of categorisation

To count observables, we should be able to distinguish what is similar from what is different. We may say, for instance, that there are 20 thick fragments of "red" pottery, 15 thin fragments of "reddish" vessels and 5 fragments of decorated pots. What does it mean here "thick", "thin", "red", "reddish", "decorated"? What one archaeologist defines and then counts as an instance of "thick", another can count as an instance of "thin". Archaeologists can differentiate analytically between categories that were not differentiated in the past, and hence, their spatial dispersion could have been unconsciously biased. Most of our "archaeological types" are subjective evaluations of what seems similar to an archaeologist according to his/her previous experience. Consequently, there can be as many different counts as there are different ways of categorising the archaeological observations. Furthermore, the categories we use to count the number of instances probably have nothing to do with the category used by social agents in the past. A "bell beaker" pot with "international" decoration is something archaeologists identify in the present, and probably had nothing to do with the cultural and/or functional category used in the past by the original makers and users of these artefacts. Archaeological types are analytic distinctions made by archaeologists for practical purposes (assumed synchronicity and "cultural" origin) that are hardly ever related with what past agents categorised when producing or using tools and other elements. As a general principle, we should use the most restricted functional or productive categories, instead of very general stylistic types; those functional or productive definitions should be made according to objective quantitative properties determining or constraining the use. We should count the number of objects that were produced in the same way with the same intention.

This is the classical emic/etic distinction. The "emic" approach investigates how local people think; how they perceive and categorize the world, their rules for behaviour, what has meaning for them, and how they imagine and explain things. The "etic" is a scientist-oriented approach shifting the focus from local observations, categories, explanations and interpretations to those of the researcher (Harris 1976). Using etic categories to classify archaeological observables and estimate counts of the original emic categories is probably wrong because of the difficulties that arise in relating the two confidently. However, emic knowledge from the past is probably out of our range, and we are constrained to build etic knowledge in terms of generalizations about human behaviour that are considered universally true, and commonly links cultural practices to factors of interest to the researcher, such as economic or ecological conditions, that cultural insiders may not consider very relevant.

1.2.6.4. The problem of empty areas

We hardly ever have the chance to excavate all the physical space where human action occurred. We are very lucky if we can "observe" even 5% of the original extension of what once was a settlement. The obvious technical, funding and human restrictions on excavating all sites, make us insist on documenting findings and to set aside emptiness. Nevertheless, it is obvious that in order to understand what generated a spatial distribution, we need to differentiate locations where the archaeological category is present from where it is absent, with the idea that places where we have not found anything in the present (although archaeologically investigated) would also be empty places in the past.

A common feature of archaeological spatial datasets is their tendency to contain many zero values. However, places with zero counts are not always "empty places". Because of the lack of coherent archaeological sampling procedures, unsampled places are valued with a zero. *Zero inflation* appears in datasets due to the excess of empty places, caused by false-zero observations because of sampling or observer errors in the course of data collection. Empty sampling units can be the result of incorrect surveying, bad preservation, or caused by strong historical effects that leads to the absence of archaeological data in particular areas. Second stage collections at finer resolution can make clear that, in some cases, zeros are false negatives, arising from rapid observation time and disguising a range of low counts that would be identifiable if surveyors were to search for longer (Bevan & Conolly 2009). A zero count may also have occurred simply by chance because the action that happened in the past does not saturate the entire suitable area with its material consequences (e.g. because of the small probability of leaving archaeological evidence or its bad preservation).

The presence of zero inflation as a result of false zeros may or may not violate distributional assumptions, but will lead to uncertainty regarding parameter estimates. Hence, it would be no longer possible to determine whether a difference in the number of individuals surveyed over time and space is because of a change in the size of the population, or due to a change in the detection probability of individuals. Regardless of causes of the aggregation, its occurrence leads to difficulties both in sampling and analysis. Statistical inference based on such data are likely to be inefficient or wrong, unless careful thought is given to how these zeros arose and how best to model them (Martin et al. 2005). As a general rule, it should be evident that we have to explore the entire area that we presume to study spatially. In some cases, count data from previously unsampled and unobserved areas can be estimated using interpolation methods (see section 2.4 in this chapter). However, the more exhaustive the spatial sampling is, the better the chance of inferring original dispersal from an observed dispersion of data.

Krakker and colleagues (Krakker et al. 1983; see also Kintigh 1988; Shott 1987, 1989, 1998; Shott et al. 1989, 2000; 2008) argued that the likelihood of an archaeological find within a given survey area is the product of three probabilities: A) the probability that an archaeologist unearths what is buried (which is a function of the excavation area size and the archaeological intervention layout), B) the probability that an artefact contained in the sampled area would be detected by the archaeologist (which, among other things, depends on whether or not the depositional unit contents are screened, the size and composition of the artefact, and the nature of the sediment), and C) the probability that the archaeologically sampled area contained any artefacts. In these terms, the detection probability of an individual artefact can be determined using the following equation (Verhagen et al. 2013):

$$D = 1 - e^{-AdW}$$

where:

- D = detection probability;
- e = the base of natural logarithms (2.711828);
- A = the area of the sampling unit;
- d = the density of artefacts per area unit;
- W = the observation probability, i.e. the probability that an artefact will be recognized as such when it is recovered.

If we are willing to assume that artefacts on a site are distributed randomly in two dimensions with a given density, we can calculate the probability that something occurred at a particular place. However, in order to estimate such probability, we need to know how the density of artefacts varies across a site. The average and the shape of density distribution determine the amount of observables at any point on the site. Whether or not something happened at some particular place is identified by the refuse that this event generated at that time. Thus, we must know: (1) the average density of artefacts of that particular category over a studied area, (2) the shape of site's density function, and (3) the distance between surveyed area and the most probable location of the original activity. If the distribution is regular enough, simply any location on the site has the same probability of yielding artefacts. In contrast, for symmetrical distributions, the probability of locating artefacts is much lower at the edge of the site than it is near the centre (Kintigh 1988).

Therefore, survey and archaeological excavation should follow strict rules for sampling and observation (Orton 2007). Archaeologists should be: A)aware that the probability that the count of artefacts or fragments within a spatial unit is proportional to the intensity erosion that has affected that unit and the time the spatial unit was affected by erosion, B)aware that the probability that some archaeological material is detected by a surveyor should be independent of previous detections made by this surveyor or others, C)aware of the rate at which the archaeological feature was likely present in the past.

1.2.6.5. The problem of post-depositional alteration

In previous pages, we have stressed the possibilities for making inferences about past behaviour from dense, spatially discrete aggregations of artefacts, bones, features and debris. The problem is that we cannot necessarily assume that the main agent responsible for creating such aggregates was *only* human behaviour. Archaeologically observed aggregation of materials may not reflect past human social action but, rather, post-depositional processes. According to various scholars (Thomas 1983; Aldenderfer 1987: 98), an archaeological observation must be seen as both the product of human behaviour and post-depositional forces that have modified the structure, the content and often also the location of archaeological artefacts. Indeed the possibility to identify random patterning does not seem so strange. Loss, discard, reuse, decay, and archaeological recovery are numbered among diverse formation processes that in a sense mediate between past behaviours of interest and their surviving traces (more about this in Chapters 2 and 3). Archaeological assemblages should be regarded as aggregates of individual elements, which interact with various agents of modification in statistical fashion, with considerable potential for variation the traces they ultimately may show.

Most post-depositional processes make archaeological assemblages lower in element densities, more homogeneous in their internal density, less distinct in their boundaries, and more similar (or at least skewed) in composition and so, in general, more amorphous. These processes have the effect of disordering artefact patterning in the archaeological record and increasing entropy. Furthermore, some may increase the degree of patterning of artefact disturbances towards natural arrangements (Ascher 1968; Carr 1984). Consequently, determining whether various frequencies of items in an assemblage or deposit have resulted from undisturbed deposition, differential distribution, or differential preservation is the problem we have to solve to understand the spatial causality of observed dispersions (Brain 1981; Lyman 1987, Mameli et al. 2002). Cowgill (1970) proposed a preliminary solution, arguing we have to recognize three basic populations (in the statistical sense): 1)events in the past, 2)material consequences created and deposited by those events and 3)artefacts that remain and are found by archaeologists ("physical finds").

By stressing discontinuities, Cowgill argues for viewing formation process as agents of bias within a sampling framework. Initially, material items are organized in the archaeological record in a way coherent with the resource management strategies and social practices that generated them. Once the location of social action was left, those remains were subject to bio-geological forces, which produce a new material arrangement. This new patterning of social material remains is opposite to the original pattern, and consequently increases entropy (dises-organization, chaos, and ambiguity), until the original patterning become unrecognisable. Each population is then a potentially biased sample drawn from the previous population, although also this is, itself, a potentially biased sample. We may view these discontinuities as sampling biases, since what we recover and observe does not proportionately represent each aspect of the antecedent behaviour. From our dialectic point of view, transformations in the original patterning of activity sets are not the simple results of accumulation processes, whether considering low entropy sets (e.g. primary depositions) to higher entropy patterns (e.g. disturbed deposits). They are, rather, non-linear quantitative changes which, beyond a threshold, produce a qualitative transformation. The depositional process may be thought of as a mathematical set, organised according to structural transformations, operating upon a previously structured set. In this sense, the occurrence of specific formation process is determined by concrete causative variables. This means that, depending on the degree of entropy, the transformed archaeological set is not necessarily a random sample of the original population. Hence, the difference between a depositional and an activity set is based on a deep qualitative discontinuity generated by the aggregate of minor quantitative modifications (Estevez 2000; Mameli et al. 2002).

The actual combination of post-depositional alterations, related to causal processes, that could have given rise to specific deposits is nearly infinite and so one cannot expect to find many simple correspondences between *a priori* lists of evidence and the characteristics of specific deposits. Material subtraction may appear differently presented, in proportion to robustness, under a given destructive regime. Survival may be correlated with the compactness of the material, expressed as specific gravity (Brain 1980). There are many both natural and social actions or processes potentially acting during or after a primary cause (Hassan 1987; Marciniak 1999). Even primary causes themselves act with different intensities in different contexts, in such a way that effects may *seem* unrelated to causes. The main point is not the recovery of the "social action direct effect" by reversing the formation process of "depositional sets" (for more detail see chapter 2 and for definitions, see Carr 1984; Schiffer 1987; Urbancyk 1986). Rather, attention should be drawn to the dynamic life history of archaeological remains and processes of different temporal frequency acting on the ultimate position, content, and pattern of such observables. This perspective provides a strong antidote to the simplistic "reconstruction of culture" by "correcting" for apparent disturbances or distortions.

The archaeological record as it appears in the present should be understood as a palimpsest: it is the material result of multiple depositional processes that have been acting through time. In order to reconstruct the most likely original deposition, we should go backwards to original activities carried out at a site during its occupation, analysing potential effects of different deformation processes (post-depositional disturbances and taphonomic effects) that occurred after the site's abandonment. Biasing effects may have strongly altered the surface of the deposit, affecting the preservation status of finds as well as their spatial distribution. Different reasons and modalities of abandonment may also influence the preservation of evidence.

Therefore, the possibility of inferring dispersal in the past from the observation of the dispersion of archaeological traces in the present is affected by uncertainty. Archaeologists cannot guarantee that the particular abundance of material items configuring the archaeological record reflects completely the sequence of social events unfolded over the time. Therefore these interpretative processes are assumed to be stochastic since they provide the reconstruction of probabilistic scenarios. For instance, in archaeozoological contexts, the aggregation of quantitative modifications made on a carcass (in content and spatial distribution) can produce a qualitative relevant change (a bone assemblage). Scavenging should be considered as a sequence of modifications which convert an animal carcass into a disintegrated set of bones. It is no more an animal, but it contains some distorted elements of what once was, in a palimpsest. Given the probabilistic nature of causal relationships, we cannot assert that "survival parts of a skeleton will follow an entirely predictable pattern if the destructive influences are known" (Brain 1980: 117). That means that simple documentation of frequencies of disarticulated and articulated joints in an assemblage may not permit the inferential identification of social action before/after/in absence of subtraction by scavenging. Nevertheless, the fact that we cannot *predict* the degree an artefact assemblage has been altered post-depositionally does not mean we cannot analyse a series of archaeological observations as a by-product of a set of social actions altered by other processes (or the reproduction of the same actions at the same place).

2 *THE FORMATION - DEFORMATION PROCESSES OF THE ARCHAEOLOGICAL RECORD*

2.1 Introduction

The archaeological record, as it is, represents the contemporary material evidence left over from past dynamic behaviour.
Can this evidence enable archaeologists to reconstruct the lifestyles of past societies, as the activities carried out, the patterns of frequentation and its general complexity? How far can archaeologists adopt the application of a “Pompeii hypothesis”, i.e. that this evidence is the material result of a fixed picture of the past as it was at the moment of its final deposition?

According to Ascher (1961) what archaeologists dig up are not "*the remains of a once living community stopped, as it were, at a point in time*" (1961: 324); instead, it is the result of disturbance processes, sources of distortion in the archaeological record, acting from the site abandonment until its recovery by archaeologists. Steward and Seltzer (1938) argued that archaeological evidence is not always indicative of past phenomena and that the knowledge of different roles played by objects in several systems may not only contribute to an understanding of cultural processes but could even modify historic and taxonomic assumptions. Therefore, a Pompeii premise appears scarcely applicable in archaeology due to the refractory nature of the deposit: it mainly enables us to reconstruct past societies in a probabilistic and limited way (Taylor 1948: 143; Smith 1955; Leach 1973: 768; Sullivan 1978: 186).
The unobservable past, however, is not unknowable (Aron 1958: 12; Spaulding 1968: 37; Fritz 1972), but the difficulties lie in the inadequacies of theories and methodologies to reconstruct the past (Binford 1968a; Sullivan 1978: 186). The limited arguments are based on questionable inferences about activities carried out at the site, derived from the simple occurrence of remote material remains produced in the past. According to Binford (1981: 198) the mismatch of the archaeological record to the Pompeii premise does not make our understanding of the past impossible: “the limitations lie in our methodological naiveté, in our lack of principles determining the relevance of archaeological remains to propositions regarding processes and events of the past” (Binford 1981: 198). Following Ascher’s assumptions (1968), Krause & Thorne (1971: 246) highlighted that the archaeological deposit could be modified and the internal debris could be transported by numerous chemical, biological and mechanical processes. This issue, clarified by some authors (Binford 1968b: 2; 1981: 199-200), was initially formalised by Schiffer (1972).

Cultural (anthropogenic) and non-cultural (natural) components have influenced and disturbed the archaeological record (Binford 1968b: 2; Schiffer 1972:156; Binford 1981: 199-200). The explanation of variability in non-cultural domain usually incorporates the laws of sciences such as chemistry, physics and geology (Hole & Heizer 1969; Schiffer 1972; 1987). Natural action and anthropic agents result in differentiated arrangements of material evidence (Ascher 1968:46-47; 52). However, both natural and cultural factors impinge on remains to such a degree that the archaeological record is rarely a direct reflection of past behaviour (Figures 3A and 3B). Instead, it can be defined as a contemporary phenomenon created through deformation processes (Foley 1981a: 157). Although material evidence and its contexts may have existed for centuries or even millennia, observations, knowledge and inference about those are as contemporary as the archaeologists who do the observing (Foley 1981a: 157).

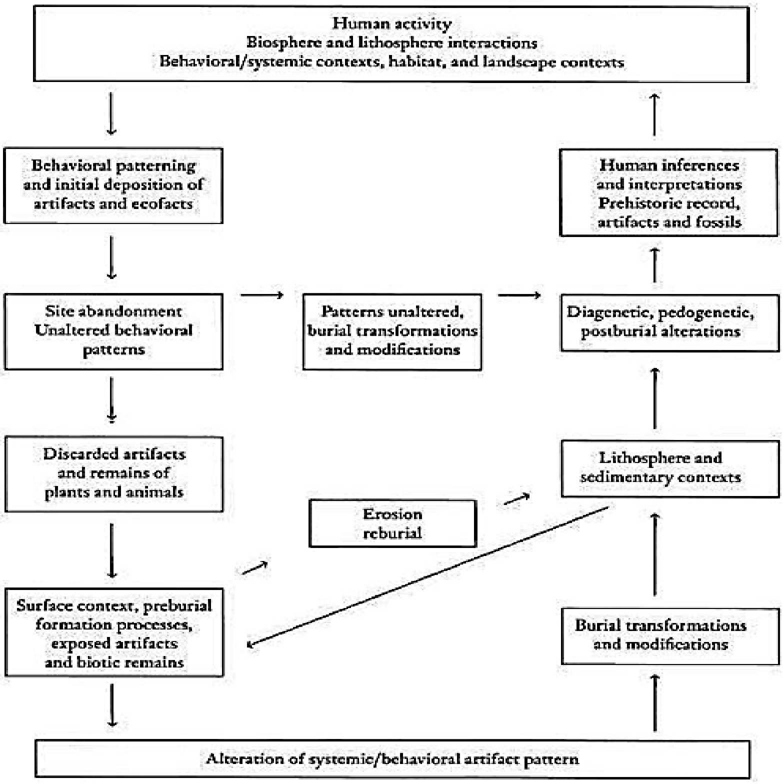


Figure 3A The figure shows the effects of human-environmental interactions on the archaeological record (from Hill & Rapp 2006: 61, Figure 3.1).

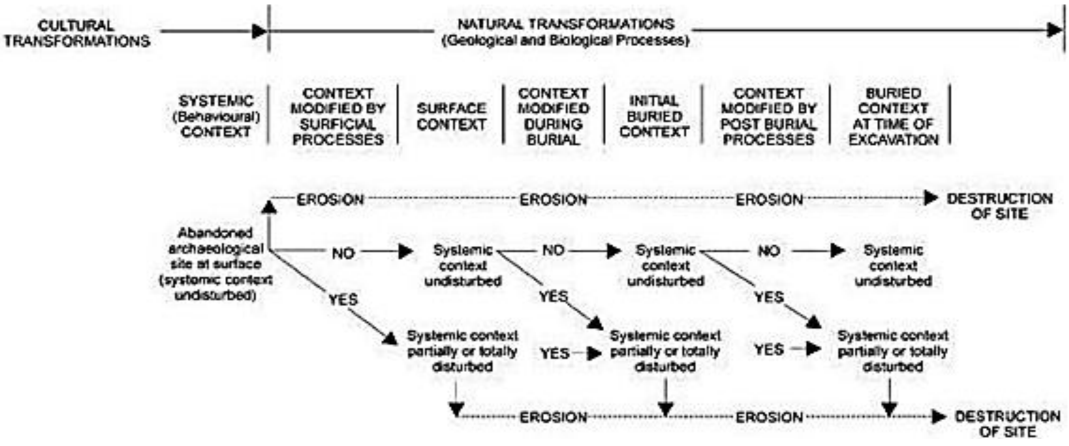


Figure 3B A flow-chart for site formation (from Kelly & Thomas 2013: 108).

As such, the archaeological record is not a fixed and immutable entity but an incomplete and distorted reflection of the past, resulting from a combination of human behaviours and forces of nature. The cultural and natural formation processes often work together or in sequence in complex ways (Ellis 2000: 40). Cultural formation processes (also called "c-transforms" as discussed in Schiffer 1987) produced the original archaeological context (deposition of artefacts and ecofacts) and any subsequent cultural modifications in the record (reuse, discard, abandonment, re-accumulation and cultural disturbance). The non-cultural formation processes ("n-transforms") are responsible for what decays and what is preserved, for the collapse of structures and the accumulation of sediments, for a host of disturbances ranging from earthquakes to earthworms and for the deposition of ecofacts relevant for inferring past environmental conditions (Schiffer 1987:7).

The majority of formation processes operate between the past behaviours of interest and their surviving traces. The archaeologist is thus forced to investigate formation processes themselves, assessing and correcting for their many effects (Kristiansen 1985; Schiffer 1987: 7). The stratigraphic sequence of a settlement (Harris 1979; Carandini 1996) is defined by the material consequences of these processes: primary and secondary deposition, abandonment and reoccupation. In attempting to reconstruct past activities the archaeologist has to track down the different phases which each fragment went through from their primary to their final deposition (Ruiz Rodriguez & Molinos 1991: 133). When the site was eventually abandoned, successive human behaviours and natural forces could cause modification either to their condition or their spatial locations that, nevertheless, would remain in their original archaeological context. These changes are defined as "disturbance" or "post-depositional" processes (Wood & Johnson 1978; Villa 1982; Schiffer 1987; Ellis 2000: 41; Estevez 2000). An animal and human-conducted post-depositional process as trampling could involve walking across the ground surface causing the disturbance of materials on and immediately below the surface. The artefacts and ecofacts, affected by damage, such as breakage, can be moved vertically into and out of the subsurface, or horizontally across the surface (later displacement). Furthermore, an outstanding role is played by the study of taphonomy, first introduced by Efremov (1940) in zoology. This discipline has transformed our reading of the archaeological record from a merely result of anthropic actions to a complex system of interactions beginning at the time of site occupation and continuing throughout the depositional and erosional processes, until its discovery, recovery and analysis (Gifford 1980, 1981; Schiffer 1983; Ellis 2000; Muckle 2006; Lucas 2012). Taphonomy is helpful in identifying natural as well as cultural sources of bias in accumulation, preservation, collection and identification of the faunal material. This includes transport of bones by biological, geological or cultural agencies, either inside or outside the archaeological sites, as well as their breakage due to scavengers, soil acidity, weathering and mechanical destruction (Johnson 2004: 61).

In order to reconstruct the past, scholars have argued for defining a “zero status” for the record as it has been subjected to the transformations which involve the intra-depositional processes; they start from the first depositional phase and end with the last site occupation (Rodriguez & Molinos 1991: 134).

Thus, pre-depositional and depositional process, as well as intra-depositional processes and post-depositional processes together make the archaeological record. In this case study, the archaeological record embodies the accumulation process which took place on the abandonment plan of the Villaggio delle Macine. The archaeological inferences are built on what is preserved of past repeated events/actions carried out at the site during its last life phase and abandonment, partially mediated by the subsequent post-depositional processes. Their observable material consequences are fragments of past, that can be imagined as a shattered mirror, that probabilistically reflects the past: the combined effects of all depositional and post-depositional processes have created and influenced the archaeological record. Consequently, in constructing meaningful inferences, archaeologists need a well-developed theoretical framework which takes into account the complex network based on these natural and cultural processes (Shott 1998; 2006; Schiffer 2010). In this chapter, these processes are first analysed separately, following the suggestions of Stein (1987: 339), in a brief discussion that highlights the importance of an interdisciplinary and combined approach, proposed through appling selected useful discipline specific techniques (geoarchaeology and paleoecology, ethnoarchaeology, taphonomy and fragmentation studies).

Since a deeper and fully comprehensive discussion of these issues goes beyond our purposes, we recommend reading the appropriate texts (see in next pages for more details). Instead, the issue of settlement abandonment is then widely explored, being the core of this analysis. Some models and approaches proposed by scholars during recent decades will be discussed from an ethnographical and an archaeological perspective. These case-studies combine a wide range of geographical areas and time periods, identifying archaeological patterns which provided useful results for modelling the analysis of the abandonment plan under study.

The different stages of the formation-deformation trajectory covered by the archaeological deposits will be followed, from the systemic to the archaeological context. In the most straightforward scenario, human activity imposes patterns and then physical (geologic and biologic) processes influence these or impose additional ones upon the material consequences of the past actions. The starting point is represented by the complex amalgam of processes included in the so-called “zero status”, specifically illustrated through the following example.

2.2 The “zero status”: a methodology

The material consequences of each natural and/or human action or process performed during the formation of the record and the associated stratigraphy (Harris 1979; Carandini 1996; Renfrew & Bahn 2000) form the “zero status*”* (Leonardi 1982: 112). All the single depositional actions which occur during the site occupation (intra-depositional processes) and abandonment contributes to this status (Ruiz Rodriguez & Molinos 1991: 134-6).

For instance, during the building of a wall, firstly a hole might be dug necessary raw material, a clay. Then material relocation occurs, from the original place (i.e. the clay supply area) to the depositional basin (a place of clay use). Raw bricks are created using the clay and the wall is built up. As such, the provision of raw material, its rearrangement and the building of the wall, are all involved in the deposit formation as contributory causes of its subsequent transformation (Leonardi 1982; 1991: 23).

In a later phase which is still part of the occupation, the original project may have been changed and what was built previously was altered, not necessarily by the same people, reducing the height of wall.

After that, a flood softens the raw clay and erodes away the material consequences of previous human action.

The strong rain leaches the wall, destroying the brick structure and erasing the traces of the pit used for clay extraction. Finally, the atmospheric agents (mainly the wind) carry and homogenize what had already been washed by natural agents (Figure 4).

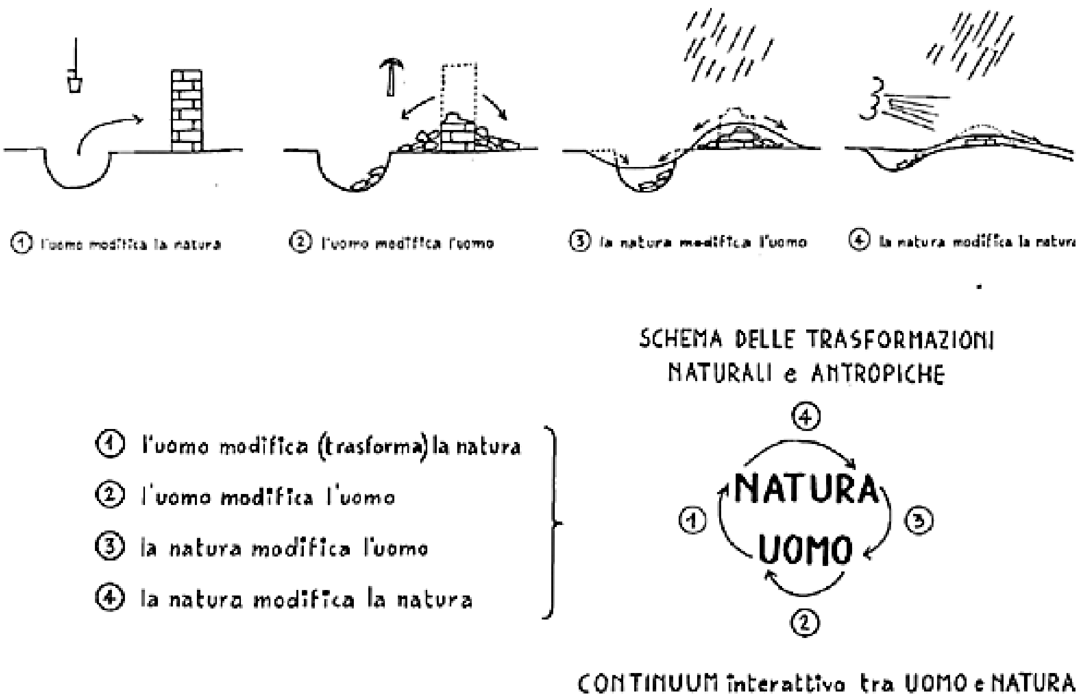


Figure 4 The relations between the actions which involve the formation of archaeological stratigraphy (from Leonardi 1982: 102, Figure 3).

The formation of sedimentary deposits (the occupation plan where the wall is lodged) and its stratigraphy is hence the resulting product of several actions (the pit excavation, the transport of its content in a depositional basin and the wall-building) while each following natural or human actions leads to a modification of the archaeological record in the making.

Usually this occurs through a transformation (as in the case of human interaction with the wall) or through material displacement (as result of the atmospheric agents). In particular, the second option necessarily requires a form of transportation, either a) something is removed from one place to bring it to a different location (human action); b) something is transported from one place to another (water or wind action), or c) something moves from one location to another, especially due to other natural forces as gravity.

Because of its nature, any relocation results initially in negative evidence (absence of the previously deposited material, the traces of removed material) and, after the transport, a positive evidence (the added material). Conversely, if the transformation is related to a material modification caused by natural or human agents and carried out without an external transfer or displacement, this evidence can be defined "neutral", because the objects undergo only a single reworking. In summary, each provision implies a removal and each removal follows a contribution, while the transformations are the result of reworking without material transport (Figure 5).

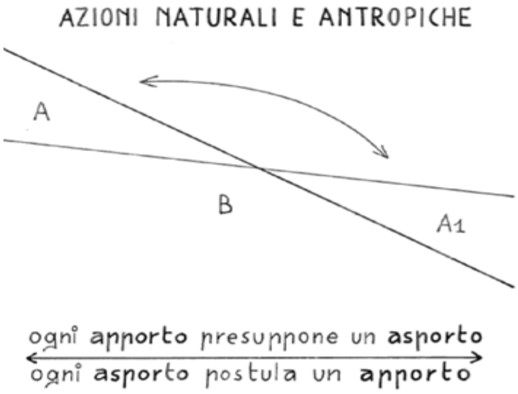


Figure 5 Each natural or anthropic provision implies a removal and each removal follows a contribution (from Leonardi 1982: 103, Figure 4).

After this phase of use, the plan of the occupation site, which is still being created as a result of the intra-depositional processes, hosts the last process which belongs to the so-called zero status: the abandonment. During such a stage, the community abandons the site, taken away what can still be useful and leaving behind useless, cumbersome and impractical artefacts. As such, the zero status is the combined evidence of the depositional processes (the building of wall), the intra-depositional process (the partial destruction of wall) and the abandonment. The derived occupation plan will show traces of activity areas that went through some changes, the material consequences of human and natural actions which took place (Figure 6). This complicates understanding the archaeological record formation, since the traces of the depositional processes accumulate and sometimes are interfered with by those of the abandonment (Leonardi 1991: 37).

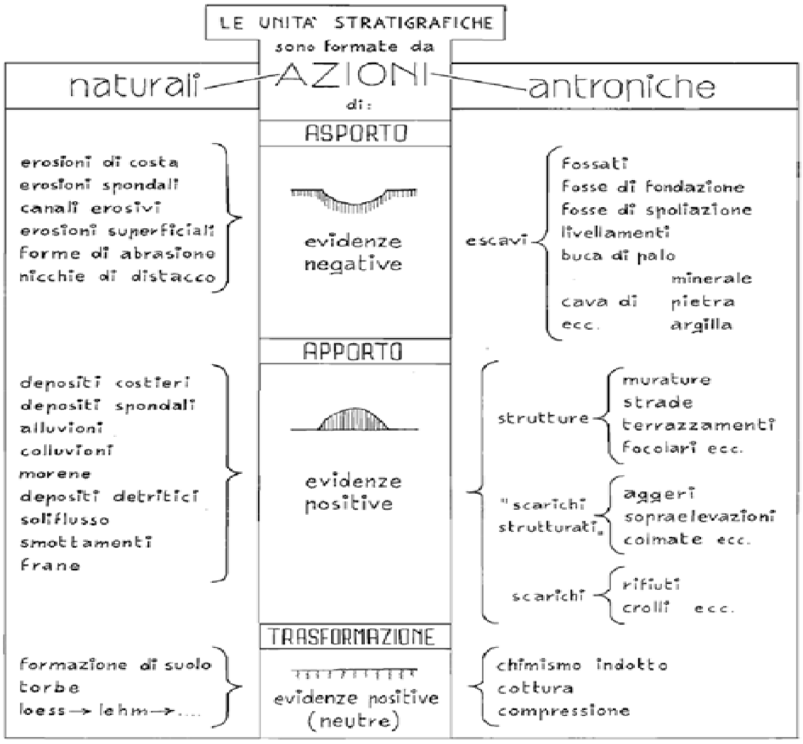


Figure 6 Explanatory scheme of the correspondence between natural and anthropic actions/processes (from Leonardi 1982: 106, Figure 7).

In some cases the material consequences of the abandonment could be easily distinguishable, such as when a sudden abandonment occurred. When, instead, people leave a site without haste, the clear understanding of each action in a more general chronological sequence is more complicated. The model of micro-spatial analysis requires an interdisciplinary approach: pedological investigations and sediment analyses permit us to recognize the chronological sequence of activities which did not leave easily distinguished traces on stratigraphy (Figure 7).
The smallest portion of the archaeological record, the sediment, recognized as an important unit of analysis in obtaining a suitable understanding of site formation processes, represents the starting point.

Figure 7 The dynamic framework of the archaeological deposition (from Leonardi 1991: 25, Figure 5).

2.2.1 The natural formation processes

The basic natural deposit, over which the archaeological record (items and structures) lies, consists of sedimentary particles which represent the smallest analysis portion of the non-cultural formation process or N transforms (Schiffer 1972: 156; 1976: 15-16; 1987:7; 2010: 42).

These processes of the natural environment impinge upon and modify cultural observables, influencing the survival of the archaeological record, both in a depositional and post-depositional scale. Natural materials are incorporated with archaeological deposits in many ways; local geological and geochemical processes can form new objects (e.g. concretions), move earth (in erosion and soil formation), dissolve archaeological evidence (e.g. bone phosphate) and deposit materials (e.g. manganese oxide) during the deposition. Interpreting the archaeological record associated with specific depositional settings relies on evaluating what types of destructive and preservative processes prevailed.

Where weathering and erosion were dominant processes, the spatial arrangement and composition of sites will have been modified. Destruction by weathering or rearrangement by erosion and redeposition will remove some or most of the patterns imposed by the systemic human behavioural context and introduce other geological and biological structures. The archaeological deposit is a three dimensional unit: it is distinguished on the basis of the observable changes in some physical and chemical properties (Schiffer 1983, 1987) and is composed by a collection of mineral or rock particles (the sediments). These may come from different sources (pottery as well as charcoal fragments, rock, bone or seed), be of diverse ages or be transported by diverse agents. Only through an appropriate analysis of the particles' attributes will an interpretation of the processes responsible for the sediment formation be discernible (Stein 1987: 340). According to Stein (1987: 341-42) the attributes observed in modern situations are correlated with the depositional processes responsible for their creation; these descriptions are good predictors of the processes carried out in the past because they were related by laws of physics and chemistry which operate uniformly through time and space. For instance, the presence of clay is an indicator of a low-velocity or zero-velocity transport agent; as the velocity of a transport agent decreases, the competence also decreases. In contrast, biological behaviours (as actions of an individual) are not predictable: their daily actions do not adhere to clear laws for how individual creatures behaved in the past (Stein 1987: 343). Furthermore, in any deposit of clastic sediments the characteristics of particles are influenced by the environment of deposition. Modification of a landscape can be caused by a whole variety of natural processes, from the greatest natural destabilizing processes to a state of equilibrium (Butzer 1982; French 2003: 8). Soil faunal activity may selectively destroy one type of artefact or environmental data over another, changing and/or biasing the archaeological record that is recovered by archaeologists (Bell et al. 1996). Natural formation processes involve depositional as well as post-depositional stages and the following section is devoted to the analysis of the former, pinpointing the formation of the natural environment which will hold the archaeological record.

2.2.1.1 The natural pre-depositional formation processes: soils and sediments

Sediments are defined as "*those materials deposited at the earth's surface under low temperatures and pressures*" (Goldberg & MacPhail 2006:11, quoting Pettijohn 1975): they create three dimensional sedimentary bodies (deposits) which are subsequently modified in characteristic ways.

Since sediments are so ubiquitous in archaeological sites, it is necessary to have at least a working knowledge of some of these characteristics in order to share this descriptive information. The parameters that we observe in sediments commonly reflect – either individually or collectively – the history of the deposit, including its origin, transport and the nature of the locale where it was deposited, that is, its environment of deposition (Goldberg & MacPhail 2006:11). The sediments can be classified into three basic types (clastic, chemical and organic) of which the first is the most abundant. They are composed of rock fragments or soil material that reflect a history of erosion, transport and deposition by agents such as wind (e.g. sand dunes), running water (e.g. streams, beaches) and gravity (e.g. landslides, slumps, colluvium).

Typical examples of clastic sediments are sand, silt, clay and their lithified results (sandstones, siltstones and shale respectively); furthermore, volcaniclastic debris (such as volcanic ash, blocks, bombs and pyroclastic flow debris) are also considered as clastic sediments (Fisher & Schmincke 1984). The chemical sediments are "*those produced by direct precipitation from solution*" (Goldberg & MacPhail 2006:13); typical examples are the precipitated minerals, as halite (table salt), gypsum (calcium sulphate), calcite or aragonite (both forms of calcium carbonate) derived from strong evaporation of lakes in semi-arid areas or from sheets of calcium carbonate (e.g. travertine or flowstone) in cave environments.

The biological sediments are composed mostly of organic materials, especially plant matter; peats or organic rich clays in swampy areas and depressions are characteristic examples. For archaeologists, sediments are the enclosing medium and the environment for the physical and chemical remains that comprise archaeological sites (Krumbein & Sloss 1963; Bullard 1970; Dowman 1970:5; Blat et al 1972; Shackley 1975: 6; Rathje & Schiffer 1982: 130; Wittlesey et al 1982: 28; Stein 1985; Stein 1987: 339; French 2003: 36; Goldberg & Macphail 2006). Finally, the attributes of sediments such as texture and colour, provide evidence on the nature of the environment at the time of sediment deposition and soil formation. Early studies of archaeological sediments, relying upon these characteristics, were directed toward paleoenvironmental reconstruction (Stein 1985). The specific constituents of a sediment, such as mineral types, also provide information about its origin(s) (Schiffer 1987: 224).

In addition, soils are deposits of organic/inorganic material (animal, mineral and organic constituents) differentiated into horizons of variable depth which differ from the material below in morphology, physical make-up, chemical properties and composition, and biological characteristics altered in situ through time (Joffe 1949; Bullard 1970; Shackley 1981: 257; Schiffer 1987:201; Banning 2000: 243; French 2003: 35; Holliday 2004).

Firstly, several of these factors mainly influence the soil indirectly: 1) climate, 2) organism, 3) relief or topography, 4) parent material and 5) time (Jenny 1941; Bunting 1967; Fitzpatrick 1986; French 2003: 36-37; Holliday 2004: 261; Goldberg & Macphail 2006: 43). The climate (1) locally and seasonally affects temperature and rainfall, which in turn influences soil development and type (Bunting 1967). Temperature determines humidity, evaporation, microclimates, length and intensity of the growing season and the type of vegetation able to grow. Rainfall affects most other factors, such as the amount and type of vegetation and the amount of leaching and removal of nutrients or bases from the soil (French 2003: 37).

In contrast, the living organisms (2) affect the physical structure of the soil directly (Bunting 1967). They are responsible for mixing, commination, aeration and the formation of humus-clay complexes which tend to give soil stability. Different types of organism are found in different soil conditions, for example earthworms in basic conditions and fungi in acidic conditions (French 2003: 36). Furthermore, the physical and chemical weathering processes which create the soil, also affect the relief (3) and drainage characteristics of the landscape. Mechanical effects and transformations such as transport, redeposition of soil by erosion agencies (frost shattering, wind and water abrasion) and the disruptive effects of plants and animals (rooting and burrowing) are sources of physical alteration (Bunting 1967; Limbrey 1975; French 2003: 39). The relief also affect many soil properties such as the depth or loss of soils on slopes and in valleys (exposed ridges and uplands, eroding slopes, colluvial footslopes, and boggy valleys) as well as the moisture gradient, amount and variety of vegetation, altitude and aspect, soil water run-off and filtration (Bunting 1967).

The spatial variability within a given soil type is caused by the parent material (4) (type of rock or substrate) which provides its basic constituent. Finally the time (5) represents the medium through which all these changes took place; indeed, the soils can be considered as a complete ecosystem: it is a dynamic and open system comprising the living and non-living parts of the soil environment acting as a unit (Odum 1963; Sheals 1969; Birkeland 1974; Mandel & Bettis 2001; French 2003: 38).

Although archaeologists use the terms soils and sediment synonymously, it is important to distinguish between them (Butzer 1971; Balme & Paterson 2006: 50; Goldberg & Macphail 2006). The concepts are quite different, and misunderstandings arise in archaeology over use and misuse of the terms and, especially, the underpinning concepts. Soils are made up of particles of broken rocks and organic materials. Their formation (pedogenesis) results from biological, physical and chemical processes on the parent rock: the elements may become hydrated or leached, and biological activity, whether involving bacteria or larger plants and soil animals, mixes organic matter with mineral material. The sum total is the initiation of soil horizon formation, called horizonation (soil materials being differentiated as profiles which have horizons). Indeed, the soils within specific archaeological contexts are evidence of variable past situations which form and mature gradually; they took acted on a essentially stable, extant and exposed substrate. Therefore a soil forming episode is often termed a period of "stability" ("stasis"). The soil's cyclic history of development can also be interrupted many times (Shackley 1981: 18-19; Balme & Paterson 2006: 50; Goldberg & MacPhail 2006: 27).

In contrast, sediments are made up of particles that are the result of the breaking down of naturally occurring minerals by weathering. Indeed, a sediment has a dynamic history which encompasses erosion, transport and deposition over a landscape or area (e.g. glacial till, Aeolian loess, beach sand). Therefore, an archaeological deposit is clearly a sediment and not a soil, with a source (e.g. a combustion feature) and a mode of deposition (e.g. dumping, accumulation of stabling waste). Like any sediment, an archaeological deposit itself may have accumulated through sedimentary processes (geogenic and/or pedogenic in character) and may have been affected by post-depositional processes which destroyed original layering and transformed or completely removed some easily weatherable materials, such as wood ash (Weiner et al. 1995; Goldberg & MacPhail 2006: 27).

In sum, sediments and soils constitute the natural context which held and retained archaeological observables. The reasonable identification and analysis of the processes which govern their formation can inform about the history of both materials and site itself, the agents and environment in which human behaviours that defined the site were carried out (Shackley 1981: 262). Furthermore, this evidence is essential in helping to reconstruct both past environmental events and changes (Goudie 1993; French 2003: 35). In terms of process, artefacts can be considered as sedimentary particles accumulated both mechanically or chemically: from a geo-archaeological perspective they are a special kind of geologic and bio-stratigraphic deposit which contribute to the final character of the archaeological record. They consist of sediments that contain the remains or traces of past life, "*either due to the presence of objects modified by people or the remnants of materials – rocks, plants or animals- used by humans in the past*" (Rapp & Hill 2006: 25). Because the same principles apply to sedimentary settings containing artefacts or other archaeological features, archaeologists need to understand sedimentological concepts. These form the basis for better evaluations of the environmental contexts of sites and the conditions that affect the final archaeological record. Sediments and soils even provide even a systematic framework useful to describe the deposits associated with artefacts where the results of human behaviours are held in the c-transforms (Rapp & Hill 2006: 25).

2.2.2 Cultural formation processes

Some macro cultural processes are involved in the formation of the archaeological record, starting from the deposition stage (Willey & Mc Gimsey 1954; Schiffer 1987: 47). This stage has been the most widely recognized of those resulting from human behaviour and it occurs when materials move from systemic context into archaeological context (Schiffer 1987; Kelly & Thomas 2013: 39). This deposition process consists of discard of broken, worn-out and obsolete items (Schiffer 1972, 1977, 1996), accidental loss (Fehon & Scholtz 1978; Schiffer 1996: 76-9), ritual deposition, such as "disposal of the dead and their accompaniments, caching of artefacts when a structure is dedicated, and placing offerings at a shrine" (Silberman & Bauer 1996: 132). An artefact may have several functions (utilitarian or symbolic) and can become part of the archaeological context for different reasons but through the same deposition process, the discarding, that involves several storage and transportation steps (Schiffer 1987: 47). In the case of symbolic objects they can be discarded either because they become obsolete or they can be reused and deposited "with a ceremonial fanfare" (Schiffer 1987: 48). Conversely, the utilitarian objects are usually discarded only when they cannot perform their techno-functions for irreparable change (breakage, use-wear, deterioration). Other factors leading to the conclusion of artefacts' life-uses include, for instance, that some objects could be designed for only one or very few uses in ceremonial occasions or still-serviceable artefacts could be discarded because they belonged to a larger object that got broken.

Several artefacts and ecofacts are not designed to be used but are the wasted material results of activities; for instance, chipping stones generates large amounts of debris, most of which quickly became part of the archaeological context. The artefacts judged defective during manufacture are useful for archaeologists as they provide a reliable guide to reconstructing the activities performed at the site during the past, and, furthermore, they helpfully replace the absent finished products removed after (or for) their use (Callahan 1973: 55). After an artefact, facility or structure has served in one set of activities the reuse processes can take place. Common instances of reuse are recycling (which involves some manufacture), secondary use (no remanufacture) and lateral cycling (a change in user only).

A further cultural process occurs when, along with the artefacts, the activity area, structure or entire settlement is transformed into archaeological contexts: the abandonment. Such transformation may be a normal occurrence, as well as a strategic choice of the inhabitants, or it can be caused by an unanticipated catastrophe, such as a mudslide or an earthquake that destroys a village. The site abandonment can sometimes represent only a moment of stationarity because the artefacts, once deposited, do not always remain in the archaeological context. Indeed, disturbance and reclamation processes are the reverse of cultural deposition, transforming cultural materials from an archaeological to a systemic context.

2.2.2.1 The first cultural deposition process: use and discard

However obvious it might seem, the first cultural deposition process is represented by the site's occupation itself: when a community starts to live in a particular location, it firstly deals with providing all suitable structures and tools which ease the inhabitants' stay. Then, such tools – artefacts- transition through three main phases characterizing their life-cycle: utilization, deposition and residuality. The utilization is understood as the fulfilment of the object's purpose during one or more events of use, while the deposition is its transition from the living culture to archaeological context and the residuality is the artefact's passive stay in an archaeological context (Kuna 2015: 282).

The final activities during the discard process leave traces on the archaeological record. This involves several types of refuse being deposited during the past, which become part of an archaeological context distinct from the previous "behavioural" one (according to the definitions employed in Schiffer 1976, 1987, 2010; Rathje & Murphy 1992; Shott 1998: 17-19; Kuna 2015).

The creation of waste material is a unavoidable process that occurs naturally when an organism interacts with its environment (Pichtel 2005; O'Brien 2008; Havliček 2015: 47). Refuse is broadly defined as unwanted material; it is discarded when it ceases to be used as intended, when it becomes deformed, put aside, forgotten, abandoned, and so forth (Neustupný 2011). In fact, discard is initiated in a number of ways, depending on the intended functions of items. They may have lost their technological functions by breakage, use-wear or other forms of deterioration. Other items might continue to perform well technically, while losing their ideological or sociological functions by going out of style or by no longer symbolizing the social positions of the users.

Once discard is initiated, items travel complex pathways before reaching their final resting places in the archaeological record. All artefacts discarded at their locations of use are called primary refuses, while those discarded elsewhere are the secondary refuses; these types are closely related because very often the first over time becomes part of the second category. Hence, in activity areas used repeatedly, the accumulation of discarded items would eventually interfere with continued activity performance. Through a periodical clean-up of the areas, the discarded items are removed and deposited elsewhere, especially in a spatially removed location such as midden, toft, landfill, abandoned structures or cemetery (Schiffer 1972, 1977, 1987, 1996; Rathje & Murphy 1992; Rossignol & Wandsnider 1992); this depletion process produces the formation of the secondary refuse.

Among others (Schiffer 1972; South 1977; O'Connell 1979; Murray 1980; Beck & Hill 2004), Gould (1978) carried out an ethno-archaeological study of the Western Desert aborigines of Australia: he examined the amounts of lithic raw material that was selected, used and ultimately discarded as primary refuse by an aborigine man over an average year. Gould noticed that within ethnographic habitation campsites, all quarried stone tools were made, used and subsequently disposed directly in and around the immediate vicinity of windbreak or shelter. Furthermore, at specific localities, low on the scale of archaeological visibility and dispersed over certain parts of the landscape, chopper-planes are left where they were used: here the base of any mulga tree shows a scar on its trunk to indicate removal of a slab of wood. Flake-knives are also left where they were used in butchering and dividing meat, after a successful hunt (Gould 1978: 823).

McKellar proposed that waste items below a certain dimension should become primary refuse irrespective of the availability of methods for their disposal as secondary refuse (McKellar 1983: 1). This hypothesis, partially anticipated by Schiffer (1976: 188), was confirmed in a variety of ethno-archaeological settings and has achieved the standing of a general principle. An example of this can be seen in the artefacts placed on the sand floors remaining after the original floors rotted within the homes at Brunswick Town, North Carolina. In this context, a far higher number of whole objects were recovered in the sand layer than in adjacent midden deposits (South 1979: 75): these refuse are called "primary *de facto* refuse" (South 1977: 297, 1979:75).

In the transition from the systemic to the archaeological context, the refuse more often appears to follow the model of the secondary refuse disposal (Cameron & Tomka 1993), whereas primary refuse appears much less represented. This has been systematically examined by Hayden and Cannon (1983: 154) at four highland Maya communities; they distinguished the refuse between two types: the first, the causal refuse, identifies refuse with little value or hindrance potential such as plant remains, bones, ashes and small inorganic remains. They are usually discarded in the toft area, which is located just outside the structure and patio; it is used for maintenance-storage activities and discard of refuse (Hayden & Cannon 1983: 126). The second, the clutter refuse, identifies objects which were only potentially recyclable, such as broken ceramics or broken axe heads. During their last phase of life the objects could go through several stages of discard. In the first stage the refuse is placed in what Deal (1983) has called "provisional discard" areas: these are located within the house, along walls, in corners or under beds, or in the toft areas of the house, along outside walls, fences or hedges. During this first stage the artefacts could break up from some attritional processes (such as accidental breakage, weathering, caprices of children's play behaviour, the effect of animal activities and retrieval of select pieces). When the refuse becomes a nuisance, the women assemble and dump it in sectors with little practical use (such as community dumps or pits), which constitute their final disposal stage.

Concerning these first categories of refuses (primary and secondary ones) recently Kuna highlighted that, in his opinion, they have rarely identified with certainty in archaeological contexts ““*since they usually consist of just the lower parts of settlement pits without any traces of the original activity surfaces (hence, primary refuse can hardly be expected) and with rare instance of deliberate dumping (secondary refuse)”* (Kuna 2015: 279). In response to this issue, he proposed the concepts of tertiary refuse and internal and external residues as categories explaining the manner in which the settlement assemblages could have formed. In particular, those objects that represent still functioning parts of an activity area, such as a dump or an active refuse area, are defined as tertiary refuse; to be included in this category, artefacts should have found their way into their place of deposition only together with the material of the layer in which they were originally deposited as refuse (Kuna 2015: 281). When they are simply natural elements of the surrounding environment – lacking a functional role of refuse – they are labelled as residue (see the definition of residual in Nováček 2003). The internal residues are material accumulated in the cultural layer during the existence of the activity area, while the external residues are the remnants from the preceding and succeeding periods (Kuna 2015: 281) (Figure 8).

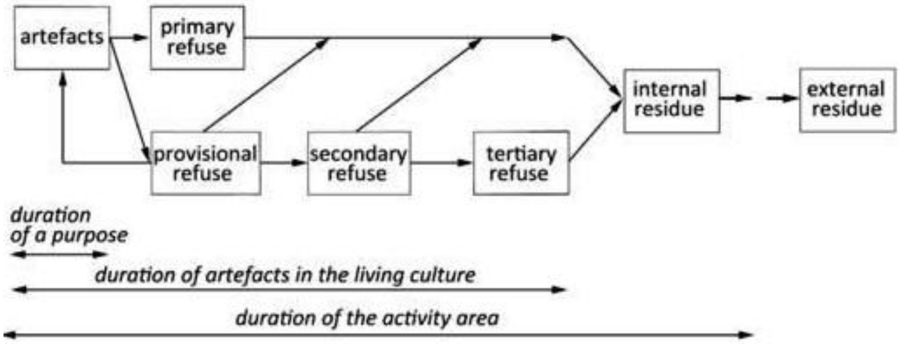


Figure 8 The different categories of refuse identified by Kuna (from Kuna 2015: 281, figure 22.1).

The last two types of refuse (the abandonment and *de facto* refuse disposal) are part of the further deposition process: the abandonment (see the next paragraph for more details).

When the refuse are characterised by very small dimensions, they are described as micro-refuse (also known as micro-artefact, micro debris and micro-remains). Such refuse can inform on the activities of individuals and small groups, especially within households or small campsites since they facilitate small-scale reconstruction (Fladmark 1982; Rosen 1986; Hull 1987; Dunnell & Stein 1989; Vance 1995; Ullah 2005; Ames 2012; Ullah et al. 2015).

Recently, Havlíček described examples of material and waste management on select Upper Palaeolithic and Mesolithic sites (as Poggenwisch and Borneck, Pincevent, Dolní Věstonice, Molodova, Telmanskaya, Pushkari, Mezin, Kostenki I, Buren, Kašov, Pinceventve and Molí del Salt) (for the detailed bibliography see Havlíček 2015: 50-56); the re-examination of this evidence enables him to draw some conclusions. Although every situation is unique and corresponds to the given natural and cultural conditions, a certain regularity in the waste management during the past can be assumed: a large number of stone artefacts and bone shreds are found near hearths, the former being left where tools were produced whereas the latter are used, amongst other things, as fuel. Organic waste, at least in the case of shell middens (e.g. at Ertebølle, Denmark (Gutiérrez-Zugasti et al. 2011), was deposited in one specific place. He further pinpointed that examining ethnological parallels, direct similarities can be found between the lifestyle of Palaeolithic and Mesolithic cultures and the indigeneous peoples who inhabit taiga and tundra areas today, probably because both cultures are linked by a way of life and the related adaptations to environmental conditions (Jelínek 1977). Similar refuse patterning, which centre the activities on the hearths, has been identified by Sakaguchi in the pinniped hunting camp of Hamanaka 2 site on Rebun Island, Hokkaido, Japan, dated to the Dobayashi New Phase (ca. 1450 cal BC-1300 cal BC) (Sakaguchi 2007), here cited only as an example.

Before completing this analysis of refuse disposal types, we return to call attention on the discard equation, or Cook's Law, previously introduced and analysed in Chapter 1. As aforementioned, this law has been used by archaeologists to estimate systemic quantities such as the number of cooking pots from a site in a given time-span and, from these data, population size (Cook 1972), occupation span (Varien & Mills 1997; Varien & Potter 1997) and artefact use-life (De Boer 1974; David 1972). Because the basic discard equation is a statistical law, subject to variation in, for instance, the standard deviations and skewness of use-life and systemic number (Shott & Sillitoe 2004), it should be judiciously. In assigning values to the independent variables, such as use-life, one can employ correlates derived from comparative ethnographic and ethnoarchaeological studies (e.g. Shott 1989, 1996) but, again, judiciously. As has been noted elsewhere (McGuire & Schiffer 1982) the largest source of variation in applications of Cook's law is usually in estimating T_D from archaeological samples (Sullivan 2008; Schiffer 2010).

An important next step in this direction was the discovery of Duckfoot, a small residential site located in southwestern Colorado (Varien & Lightfoot 1989; Lightfoot 1994; 1993; 1992). This is a well-preserved and well-dated site that has been almost completely excavated. The chance to accurately study each stratigraphic unit enabled archaeologists to develop accumulation rates of materials over very short periods of time (annual time-span) and consequently they measured the occupation span of site. The modality and pattern of site and region frequentation as well as the population estimations can be hypothetically reconstructed through comparison with data from other excavated sites. The variability in the duration of occupation among sites within a region or between regions is an indication of different land use strategies; the changes in occupation span provide a way of measuring the degree of sedentism, itself an important variable in interpreting changes in social complexity (Ames 1981:799; Price & Brown 1985; Pauketat 1989; Kelly 1992; Varien & Mills 1997: 143; Gallivan 2002).

2.3 The settlement abandonment

The abandonment of places starts and causes a set of processes involving the deposition of artefacts: the somewhat common and significant outcome of these processes is the creation of *de facto* refuse. This consists of items, facilities and structures which are often still useful but that nevertheless enter archaeological context because they are left at the abandonment place (Schiffer 1972). Items that are not left behind are subject to curate behaviour, the removal of materials during the process of abandonment for continued use elsewhere. Some abandoned places are as small as individual limited-activity areas and isolated households, whereas others cover entire settlements and even entire regions. The causes of abandonment also range widely and include the depletion of resources, the deterioration of materials, the emergence of diverse social pressures, and environmental changes (Ellis 2000: 41). Numerous factors influence the nature of *de facto* refuse formation and curate behaviour at any particular place, including, among others, the rate of abandonment, the means of available transport, the distance to the next settlement, the formal characteristics of the items involved, and the perceived value of the items. Archaeologists have to decipher the precise degrees of impact these variables have under different circumstances (Schiffer 1972; 1987; Baker 1975; Murray 1980; Stevenson 1982).

2.3.1 The different settlement abandonment modes

During the abandonment phase, the inhabitants leave the site carrying required supplies with them, as well as raw materials, most portable items of potential future use or value (functional, personal, monetary, aesthetic or other), or with high replacement costs (Stevenson 1982: 5). The removal and transport elsewhere of the artefacts occurred through curation behaviour (Hayden 1976; Schiffer 1985, 1996: 90-6; Tomka 1993; Nash 1996; Shott 1996) which changes their ratio and patterns of spatial distribution (Schiffer 1985).

The items that are left at the abandonment place are probably difficult to transport, easy to replace and have a little residual utility. Through the last discard process, they become part of the archaeological record (Ascher 1968; Schiffer 1972: 6; Baker 1975: 1): the creation of *de facto* refuse seems to be a somewhat common and significant outcome of abandonment. The tools, facilities, structures and other cultural materials, although still usable or reusable, are left behind when an activity area is abandoned (Schiffer 1972; Schiffer 1996: 89-97). *De facto* refuse deposition and curation behaviour are two sides of the same coin: whereas the former represents an accretion process, the latter is a depletion process (Schiffer & LaMotta 1999; Allison 2012). A floor assemblage composed entirely of bulky, broken and fairly ubiquitous objects is therefore one likely to have been heavily depleted by curation processes, and would not provide a representative household inventory (Stevenson 1982). Hence, the nature of *de facto* refuse formation and the curation behaviour at any particular place represent a reflexive image of the conditions under which the abandonment occurred (the site abandonment modes) while also providing a glimpse of past society itself (Stevenson 1982; Schiffer 1972, 1976).

Some variables, such as distance to the next site, means of available transportation and season of movement may determine, in part, whether cultural materials will be curated or deposited as refuse during abandonment (Schiffer 1972, 1976). Where distance to the next site is appreciable or transport is limited to what people can carry, heavy objects and stationary facilities will tend to become refuse (Schiffer 1976:33). At the same time, season of movement may influence what is left behind at a site if subsistence-settlement systems are seasonally dependent. According to various authors (Longacre & Ayres 1968; Schiffer 1972, 1976, 1985; Lange & Rydberg 1972; Bonnichsen 1973; Robbins 1973; Baker 1975; Stevenson 1982; Cameron 1991; Joyce & Johannssen 1993; Kent 1993; Allison 2012), a structure, activity area (semi-micro scale) or entire settlement (micro scale) whose floor assemblage includes many portable, valuable and/or usable objects and a relatively great numbers of elements in manufacture, use and maintenance processes, is typically inferred to have undergone a rapid, unplanned abandonment. In contrast, an assemblage that appears to be highly depleted by curation, that is to say characterized by only large and/or broken objects, while only few artefacts and features in processes of manufacture, use, or maintenance, is usually ascribed to a slow, planned abandonment.

Scholars have strongly supported these theoretical assumptions through archaeological and ethnoarchaeological examples. In particular Stevenson analyzed two different gold rush sites: the Mush Creek population appears to have emigrated in a planned or gradual manner with no intention of returning, while Bullion Creek was abandoned more rapidly and in an unplanned way with most people intending to come back. According to the theoretical hypothesis, the *de facto* refuse are poorly documented at Mush Creek, whereas a considerable amount of it was recovered at Bullion Creek. In particular, at the latter, 29% of objects were under or intended for construction, 49.6% were in use or in functional condition and all were found within activity areas. The inverse condition had resulted when the Mush Creek site was abandoned: the majority of artefacts were identified as secondary refuse (above all broken or exhausted items) and none were found within any identifiable activity areas (Stevenson 1982: 241-242). These data could confirm the hypothesis of the orderly arrangement of *de facto* refuse proximal to an identified activity area, reflecting the anticipated return to the area; conversely, the random arrangement of *de facto* refuse, outside particular areas, may suggest more permanent abandonment.

Furthermore, when a return to a site after abandonment is planned, the inhabitants would begin to store, cache and prepare most functional and valuable items not required for immediate use, so that they might be reused on their return.

For instance, Baker (1975:11) analyzing the abandonment of some quarry pits and trenches identified in Garland Country, focused on hammerstones. They were used during the activities of lithic raw material extraction, refinement and tool manufacture and finally they seem to have been used for pulverizing plant material. Since all the hammerstones were found whole, in an orderly grouping, still usable for stone working activities, Baker considered them as deposited through storage processes. As such, although the site was abandoned he explained their grouping was the result of an attempt to protection through relocation. If a common quarry area was revisited intermittently by several social groups upon termination of procurement activities, specialists might store their quarry tools inconspicuously to avoid their loss through pilfering; storage for protection might also occur if a particular type of hammerstone was uncommon or related to the upkeep of items. In addition, since some tools left unprotected might deteriorate and become unserviceable for later use, their intentional burial in the ground may be due to particular ground's properties; conversely, ground moisture absorption may have rendered tools more suitable to certain activities. In addition, storage behaviour could ensure their future retrieval, in particular if they were buried within their activity areas.

Through analysis of archaeological and ethnographic data gathered on abandonment, archaeologists obtain a deeper knowledge and understanding of this past phenomenon. Behaviours such as curation or caching of tools, dismantling of structures, and the interruption of normal disposal patterns (Schiffer 1987:89-98; Cameron & Tomka 1993: 3) leave “fossil records” in the archaeological deposit. These enable identifying the different types of occupation and abandonment (Tomka 1989), as planned or unplanned (Baker 1975; Stevenson 1982, 1985) and even seasonal, episodic or permanent ones.

Each of these scenarios involves different occupation strategies: as Kent suggests (Kent 1993:65), when we plan to stay at a camp for a short period of time (seasonally or occasionally) the material consequences left in the archaeological record should consist of smaller artefact inventories, often less bulky and durable; instead, when a site is permanently occupied the community puts more effort into site construction and camp maintenance activities. According to this example (Kent 1993: 67) considered on a macro scale (the region), the different mobility patterns could be inferred also from the material evidence produced by the abandonment process. Highly nomadic groups should have a different material inventory from sedentary groups and nomadic settlement patterns influence the visibility of foragers in the archaeological record. This assumption was taken to the extreme level by Brooks and Yellen (1987). They addressed this issue among the !Kung, affirming that the sites abandoned under planned condition and with the intention of returning are the only archaeologically recognizable ones, because those permanently abandoned were simply invisible in the archaeological record. We cannot interpret this assumption as an absolute truth applicable to all archaeological case-studies -or the *a priori* condition- but rather as a condition that should be verified archaeologically every time. Hence, if we use material culture in our models of abandonment, we must firstly take into account the gross levels of mobility, such as nomadism versus sedentism (Kent 1993:67).

Furthermore, when interpreting the material remains at settlement sites, it is crucial for archaeologists to consider the nature of site abandonment. Stevenson (1982) has shown that material patterning at sites with evidence for rapid, unplanned abandonment should closely reflect the activities performed during site use (Joyce & Johannessen 1996: 138, 151). The same condition occurs when the abandonment results from warfare or natural disasters; in this case the abandonment may be hurried and unplanned and cultural material may be left where it was used. Alternatively, as in the case of La Concha, an abandoned single-family household compound in rural Mexico, a gradual, planned abandonment has a much more variable effect on material patterning at domestic sites: indeed, according to Ascher (1968) most artefacts and usable building material can be scavenged and reused. Nevertheless, these studies suggest that, through an ethnoarchaeological approach, archaeologists can associate abandonment activities and their material consequences with the causes of abandonment, noting some correlations. For instance, catastrophic abandonment resulting from warfare or natural disasters may be hurried and unplanned, and cultural material may be left where it was used. Alternatively, as in the case of a dilapidated structure in an active village with abandonment as slower and planned affair, may involve the scavenging and reuse of most artefacts and usable building material (Ascher 1968). In addition, the causes of abandonment range widely and can include the depletion of resources, the deterioration of materials, the emergence of diverse social pressures and environmental changes (Ellis 2000: 41).

2.3.2 The causes of settlement abandonment

When the environmental changes in a given settlement or settlement region occur, its inhabitants, even if they are able to adapt themselves to the diversity, can shift from a position of increase and stability to one of instability and rapid decline (Mc Leman 2011: S 108). The settlement abandonment can represent the terminal result of acute population decline at a given location: it appears likely that when conditions changed for the better or for the worse, populations responded by changing their mode of living. During some time periods and in some areas, when the population has to cope with these changes for the worse, they choose diverse subsistence strategies. Different groups model their lifestyle according to sedentary strategies and agriculture, whereas others prefer following models of hunting and gathering, as some ethnographic studies which analysed the relationships between hunter-gatherers demonstrated (Gulliver 1955; Macquet 1961; Wimberly & Rogers 1977; Stuart & Gauthier 1981; Upham 1984: 251). In addition to diseases or natural catastrophes (flood, earthquake, etc.), a wide range of causes can be recognized, such as ritual reasons, warfare and conflict among social groups and finally structural decay (Cameron 1990: 28; 1991: 156-157). Structure abandonment in some cases has been examined using cross-cultural ethnography and ethnoarchaeological data primarily from villages (Gould & Watson 1982; Wylie 1985; Cameron 1991: 156-157). The ritual abandonments can result in enriched floor assemblages that can be easily confused with abundant *de facto* refuse. Clearly, failure to acknowledge and identify these processes can severely bias inferences (Allison 2012). In the New World some ethnographic examples suggest that many indigenous peoples living in mud-and-brush pit structures are reported to have burned their houses upon abandonment, usually as a result of the death of one or more of the occupants. Ethnographers commonly report that some portion of the deceased’s material possessions, among other objects, were destroyed within a house when it was burned. This behaviour represents one of the most likely alternatives for abandonment activities carried out among some pit structures located in the Four Corners Region of the American Southwest, during the late BMIII/PI (Cameron 1991: 35); in this case, ethnographic evidence suggests that burning might be the result of ritual activities, such as the burning of a house after the death of the owner, or as a response to structure deterioration.

For the latter cause in particular, two different models have been identified by scholars according to a permanent or a short site occupation. McGuire and Schiffer (1983) have suggested that the form and use-life of structures and their subsequent abandonment are largely the result of a trade-off between the costs of building a structure and the costs of maintaining it. The longer builders plan to use a structure, the more effort they will expend in construction, the longer the structure should last. This hypothesis suggests that anticipating longer occupation should result in less frequent structure abandonment, because use-life has been increased through improved quality of construction. Ample ethnographic evidence supports McGuire and Schiffer’s (1983) suggestion that when settlements are intended to be occupied for only a short time, energy expenditure is minimal. As the length of expected habitation increases, energy invested in construction also increases (Cameron 1990: 158). Furthermore, in the case studies analyzed by Schwerdtfeger, the structure locations were considered “permanent” and the frequency of structure abandonment depends to a large degree on durability of construction material. The structures in these cases are indeed abandoned as the result of decay, death of the owner or divorce of a wife occupying a hut (Stevenson 1982: 86-88; Cameron 1991: 159).

Finally, assuming that we could observe the settlement structures in a point of time closely next to their abandonment, we would be able to recognize the material evidence of this behavioural system. Instead, when the structure is recovered by archaeologists, the traces of subsequent changes caused by those so-called disturbance phenomena are identifiable. In this context, these changes can be defined as post-abandonment processes.

2.4 The post-abandonment processes

The life history of a structure, activity area, or settlement does not end with its abandonment. Many processes of accretion and depletion can alter the assemblages in the post-abandonment stage: the reuse of structure, for habitation or other purposes, may introduce a new set of primary, secondary and provisional depositional processes, possibly obscuring all traces of earlier occupations (Schiffer 1985, 1996: 28, 40-4; Rothschild et al. 1993). In addition, the abandoned structures are often used as rubbish dumps, leading to accumulations of refuse varying in depth, quantity and artefact content (Allison 2012).

However, as Walker has suggested (1995a, 1995b; Walker et al 1995; Lightfoot 1993; Wilshuen 1986), the types of objects deposited secondarily in an abandoned structure may not be totally random with respect to the functions of that structure in its habitation stage; the possible interrelationship of depositional modes in the habitation, abandonment and post-abandonment phases of a structure is another area that requires far more archaeological and ethnoarchaeological research. Structural collapse can also introduce objects into room floors, primarily through the deposition of objects used as construction materials, e.g. chinking fragments of artefacts in adobe (Schiffer 1985, 1996). Finally, a slew of cultural and non-cultural processes can remove objects from room floors after abandonment. Scavenging (Gorecki 1985), collecting, and a wide range of cultural and non-cultural disturbance processes, including faunal-and-floral-turbation, organic decay, pot hunting and archaeological excavation, deplete archaeological deposits and further transform house floor assemblages.

2.5 The post-depositional processes

When a site is abandoned, two scenarios can occur: 1) the site is not re-occupied after its abandonment, 2) the site is re-occupied and a new plan is created.

In both cases, the recently created archaeological context (the zero status) is altered by transformations subsequent to the deposition, i.e. the post-depositional changes. These changes get different meanings and definitions, depending on the specific reference case. For instance, a site inhabited during the prehistory, is frequented again during the Roman age and the building of a Roman logline cuts the prehistoric deposit. This action can be interpreted in two ways: it represents "positive" evidence for its chronological phase (Roman), but also a disturbance of the previous prehistoric archaeological record. For this reason the post-depositional processes have to be defined as "dynamic" processes: they influence the distribution, preservation and visibility of material consequences of past action. The removal of the earliest deposit is directly linked to the actions of accumulation of the subsequent archaeological materials which overlie the previous remains (as the case of the Roman logline).

In contrast, if the site is abandoned during the prehistoric age and it is not re-occupied, the post-depositional processes can be defined as "transformative": they modify the already formed deposit without the addition or removal of significant amount of material. These processes can be defined as “passive” because they destroy or alter the previous archaeological record, without complying with the law of superposition and, on the contrary, they act independently. Human post-depositional transformations are quite limited, but notably there is compression (from trampling (Schiffer 1987: 126-129) or any other action which produces the same effect), and the material change of state due to the heat (Leonardi 1991). In addition, the anthropic traces of plowing (Schiffer 1987: 129-132) represent an exception to these "negative" type of layers: they directly inform about a layer which has to be considered as an artefact, resulting from naturally and anthropically induced processes (Leonardi 1991: 38).

The natural post-depositional transformations, on the other hand, constitute a wide separate branch. This includes chemical and biological processes which involve also plants and animals. As with the human actions, they act on already formed deposits and provide us with “negative” data from an archaeological and anthropic perspective: they can reveal the absence of human activities, for example if a stratigraphy is formed also by a layer which contained only phyto-bio actions, absence of human occupation involving a break in the sedimentation occurs.
Furthermore, during formation, the features of the material already deposited into the soil may be altered, with some valuable data masked and sometimes destroyed. This large family of processes is known as “pedoturbation”, i.e. the mixing of soils and sediments (Wood & Johnson 1978: 317; Schiffer 1987: 206). Once deposited, sediments can also be transported and re-deposited by non-cultural processes within sites, depending on the local topography, nature of the sediments and prevalence of flowing water (Schiffer 1987: 202). Even on the micro scale, graviturbation processes can lead to downslope movement and mixing of sediments principally under the influence of gravity, without the aid of the flowing medium of transport such as air, water or glacier ice (Wood & Johnson 1978: 346; Schiffer 1987: 216). Animals and plants can play an outstanding role in the disturbance processes (on faunalturbation *cf.* (Thorp 1949; Heath 1965; Wood & Johnson 1978: 327; Hole 1981; Johnson 1990; Johnson & Watson-Stegner 1990; Holliday 2004: 271) as referenced in Schiffer 1987: 207; Leigh 2001: 283; *cf.* on floralturbation (Pyddoke 1961; Schiffer 1987: 216). These collective post-depositional processes are further divided in the categories of natural and cultural disturbance (Muckle 2006: 83). The first can be analysed on three major scales, depending on their effects: artefact, site and region. Clearly this division is only artificial and used by scholars as a useful educational tool to facilitate the processes’ understanding (Schiffer 1987; Ellis 2000: 43; French 2003; Goldberg & MacPhail 2006; Schiffer 2010; Beck 2012: 649): however, according to Schiffer (1987; 2010) although they have effects at more than one scale, this organization remains useful.

2.5.1 The natural post-depositional processes

Alternatively known as non-cultural disturbance processes or N-transforms, natural disturbance processes include a wide range of activities that may alter the patterning of material record. Non-cultural formation processes are the chemical, physical and biological processes of the natural environment that impinge upon and modify cultural materials, in systemic and archaeological contexts.

2.5.1.1 The natural post-depositional processes: the artefact scale

These natural processes include environmental processes such as deterioration, decay, alteration and modification, which take effect at the artefact scale. They can occur at any time during an artefact's life history and involve a change in physical properties such as colour, surface texture, light reflectance, weight, shape, chemical composition and even hardness or tensile strength (Schiffer 2010: 43). The environmental factors of deterioration are traditionally grouped by their mode of action as physical, chemical and biological agents (Figures 9 and 10). The first two groups are active in most environments and the ubiquitous one is water; in streams and at the seashore artefacts are tumbled and abraded, and natural rocks and shells are fractured in ways that sometimes mimic human modification (Schiffer 2010: 44). Water also promotes changes in porous and hygroscopic materials. For example, alternate wetting and drying of wood causes cracking along the grain. Through freeze-thaw cycles, water elongates cracks in rocks and concrete, and erodes the surface of porous rock and brick. Nevertheless, some post-depositional physical accumulations can be helpful in archaeological interpretations. For instance, artefacts lying within sediments can become encrusted with secondary carbonates. The carbonates coating the artefacts can be dated. Since the carbonates were formed after the artefacts were deposited within the sediments, the age of the carbonate provides a minimum constraining age for the artefact (Rapp & Hill 2006: 28).

Figure 9 Free-thaw processes have caused these construction bricks in Ouray, Colorado, to break apart (from Schiffer 1987: 183, Figure 7.6).

Figure 10 Beetle exit on a juniper fencepost, near St. John's, Arizona (from Schiffer 1987: 198, Figure 7.9).

Chemical agents and their reactions are promoted by water and oxygen contained in the atmosphere. The rate of chemical reaction (as oxidation of organic materials and corrosion of some metals) increases with rising temperature and the highly reactive compounds in the natural soils favour the changes; acid condition, for example, dissolve bone and basic conditions promote the breakdown of glass (Klein & Cruz-Uribe 1984; Schiffer 1987; Marean 1991; Child 1995; Schiffer 2010). Many archaeological deposits also contain a high concentration of salts contributed by wood ash and the deterioration of other cultural materials.

Finally, biological agents are living organisms such as bacteria, fungi, insects and other animals which in most cases damage organic matter through chemical and/or physical means. Bacteria also play a role in the corrosion of the metals, especially in marine environments. Moisture content is usually the most important factor influencing the activity of bacteria, fungi and insects. Bacteria, for example, need a water-saturated substrate, whereas fungi require somewhat less moisture. Beetles and some termites have even less stringent moisture requirements. These agents influence even the location of the artefacts, their spatial distribution and movement in the deposit, impacting analysis at the two broader scales, semi-macro (site) and macro (region).

2.5.1.2 The natural post-depositional processes: the site scale

After the deposition stage, a variety of changes can occur within an archaeological sediment. *"Such alterations are superimposed on the original make-up of the sediments and its constituents"* (Rapp & Hill 2006: 28). Schiffer (1987) provides a comprehensive discussion of natural site formation processes, which are summarized by Stein (2001) and quoted, among others, by Holliday (2004). Nash and Petraglia (1987) and Goldberg and Whitbread (1993) also provide a number of case-studies of natural formation processes identified at archaeological sites.

Since soil formation represents the alteration of rock and sediment, pedogenesis is an important natural process in the formation of archaeological sites. The other relevant weathering processes involved in site formation are grouped as "diagenetic alterations"."Diagenesis" refers to all chemical, physical and biologic changes undergone by a sediment after its initial deposition, exclusive of surficial alterations (weathering) and metamorphism (Bates & Jackson 1980: 171).

Retallack (1990: 129) includes pedogenesis as a kind of diagenesis, and Caple (2001: 588) refers to the interaction of the burial environment and archaeological evidence as diagenesis, grouping a variety of weathering processes that can include pedogenesis. However, most specialists clearly differentiate diagenetic from pedogenic processes (e.g. Schaetzl & Sorenson 1987; Catt 1990: 65, 1998) although many diagenetic processes are similar to pedogenic ones and distinguishing between them may be difficult (Catt 1998).

Post-depositional effects result not only in the wholesale removal of fundamental parts of the archaeological record (e.g., bones) but even modify textures, colours, and other aspects of the deposits which in turn hinder recognition of the original depositional characteristics and associated stratigraphic relationships (Figures 11 and 12). Such hardening can also hinder the excavation and recovery of artefacts (Rapp & Hill 2006: 28).

Figure 11 Site of Wilson-Leonard, south central Texas showing stratigraphic sequence of deposits that span from Early Palaeo-Indian at the base (c. 11300 BP) up to Late Prehistoric at the top (c.1000 BP). The sequence here consists of fluvial gravels at the base that are overlain by interfingering cienega, organic rich silty clays (IcI), overbank silts (Isi), stony colluvial and alluvial silts (II) that become successively rich in organic matter and rocks (IIIa, IIIc), while a more geogenic, less anthropogenic silt (IIIb) separates these last two organic-rich layers (from Goldberg & MacPhail 2008: 2015, Figure 6).

Figure 12 Middle Palaeolithic anthropogenic deposits about 50 ka from the West wall of Kebara Cave, Mount Carmel, Israel. The bulk of the deposits are intact combustion features comprised of ashes and organic-rich layers (from Goldberg and MacPhail 2008: 2015, Figure 7).

In contrast, diagenetic processes can involve cementation of deposits by carbonate derived from groundwater, or iron precipitation/dissolution, resulting in concomitant formation of secondary minerals, that include phosphates carbonates, sulfates, and nitrates (Figures 13 and 14). In aqueous solutions, these substances infiltrate and lithify deposits. This lithification can slow later weathering, contributing to the preservation of archaeological sites (Rapp & Hill 2006: 28).

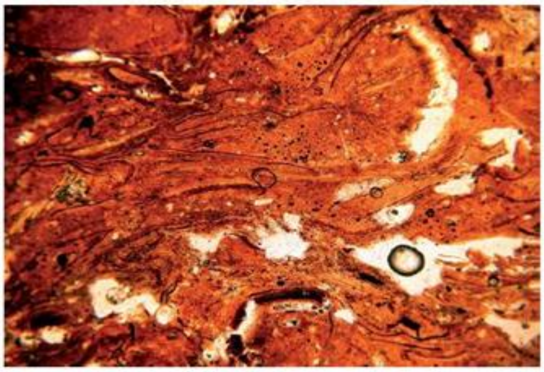


Figure 13 Photomicrograph of thin section M80 (from a medieval pit fill, Spitalfields, London). This illustrates the presence of calcium phosphate cemented human cess pit (latrine waste) within which are embedded plant fragments probably relict of the ingestion of vegetables (from Goldberg & MacPhail 2008: 2015, Figure 4).

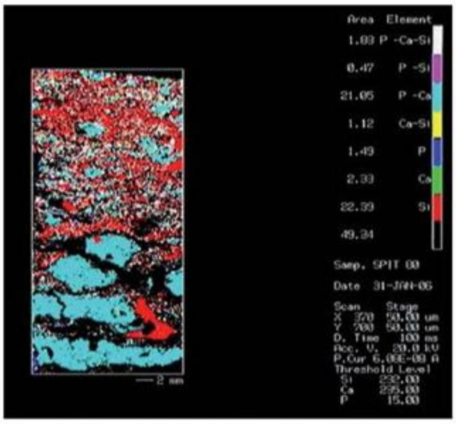
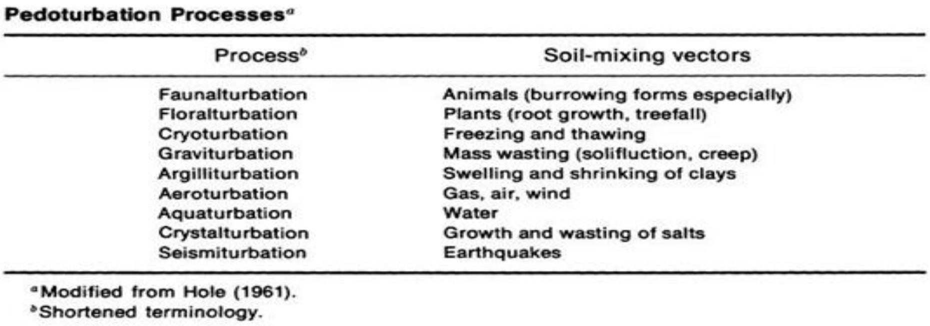


Figure 14 Microprobe map of a part of thin section M80 (combinations of the elements Ca, P and Si) (from Goldberg & MacPhail 2008: 2015, Figure 5).

A succinct summary of soil forming processes that is particularly apropos in the context of archaeological site formation is provided by Buol (Buol et al. 1997: 132): *"Pedogenic processes include gains and losses of materials from a soil body in accordance with the degradational, aggradational, or intermediate geomorphic character of the site, as well as translocations within a soil body".* In an expressly archaeological context, Schiffer (1987: 199-220) categorized many of these pedogenic processes, which can be related to disturbances of soils and sediments. Together they are called "pedoturbation". This term was introduced firstly by Hole (1961) who listed and defined nine processes of pedoturbation that cause soil mixing (Figure 15). They have been summarized and examined in detail by several scholars (Buol et al. 1973:89, 94; Wood & Johnson 1978: 319; Schiffer 1987: 224; Ellis 2000: 43; Holliday 2004: 261; Schiffer 2010: 46; Beck 2012: 649) and here we will provide only a summary analysis.



Pedoturbation Processes[a]

Process[b]	Soil-mixing vectors
Faunalturbation	Animals (burrowing forms especially)
Floralturbation	Plants (root growth, treefall)
Cryoturbation	Freezing and thawing
Graviturbation	Mass wasting (solifluction, creep)
Argilliturbation	Swelling and shrinking of clays
Aeroturbation	Gas, air, wind
Aquaturbation	Water
Crystalturbation	Growth and wasting of salts
Seismiturbation	Earthquakes

[a] Modified from Hole (1961).
[b] Shortened terminology.

Figure 15 Schematic graph of the main pedoturbation processes (from Wood and Johnson 1978: 318, table 9.1).

"Faunalturbation" includes all of the various animal impacts on the archaeological record. The most pronounced result, brought about by the actions of numerous burrowing animals, is the vertical mixing of soils and sediments. Less significant, though generally still important, is the lateral displacement of artefacts that results from animals on the surface. The burrowing activities of a wide range of animals (particularly ants, termites, worms, crayfish, earthworms, badgers and small mammals) can also very effectively mix or churn a soil or archaeological site (Thorp 1949; Heath 1965; Wood and Johnson 1978; Stein 1983; Johnson 1990; Johnson & Watson-Stegner 1990; Holliday 2004: 271; references in Leigh 2001: 283, Figure 10.4; Schiffer 1987:232-235; Schiffer 2010: 46). However, the patterning and intensity of such redistributions will undoubtedly vary considerably between species, sites and regions. Animals can produce distinct *krotovina* (in-filled animal burrows) while the effects of gophers and other burrowing animals upon archaeological sites can produce the homogeneization of cultural deposits (Stein 1983; Erlandson 1984) (Figure 16).

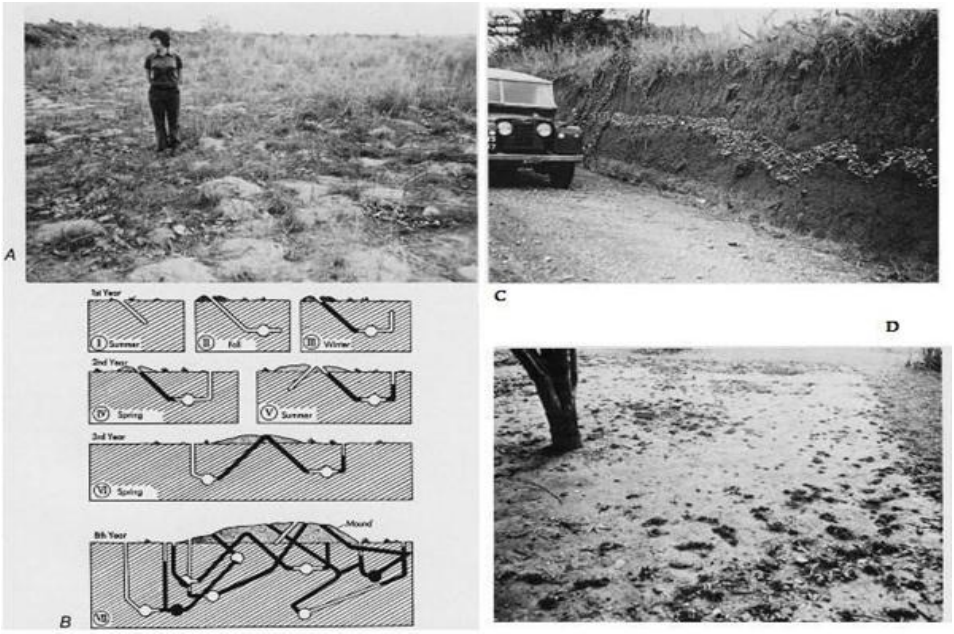


Figure 16 Example of faunalturbation from Wood and Johnson 1978. A) Rodent (gopher) burrow mounds, Canadian River Valley, west Texas; B) Evolution of a ground squirrel burrow and mound (both p. 320 Figure 9.1) C) Stone line in a tropical soil due to activity of termites in Africa (p. 325, Figure 9.4) D) Earthworm middens built during January thaw, 1973, in east-central Illinois (p. 327, Figure 9.5 A).

Plants can also alter the archaeological record ("floralturbation"): root growth, trees fall and vegetation cause soil disturbance (Pyddoke 1961; Wood & Johnson 1978: 328-333; Schiffer

1987: 235-237; Ellis 2000: 43; Kelly & Thomas 2013: 71). Tree-fall processes, for instance, can contribute to redeposition on the surface of site materials that adhered to the roots. This process leads to mixing and instances of inverted horizons; further accumulation of both larger artefacts and unmodified stone sometimes forming pavements on the surface. The nature of surface vegetation has numerous, important impacts on site visibility and, while not a formation process per se, is nevertheless an important influence on survey and excavation sampling strategies (Figure 17).

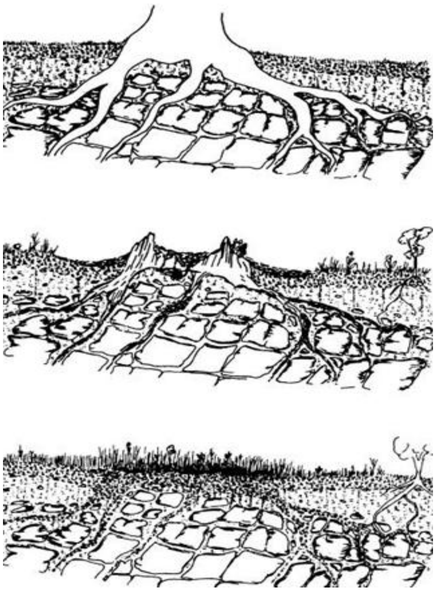


Figure 17 A three-stage diagram showing the formation of root casts (from Wood & Johnson 1978: 330, Figure 9.6).

The formation of stone pavements, involutions or frost heaving, mass displacement, frost cracking, frost sorting, and patterned ground are the widespread effects of the freeze-thaw processes that mix soil (Washburn 1973) and are called “cryoturbation”. They include those impacts on the archaeological record that result from freezing and thawing of the subsurface. The material consequences of the freeze-thaw processes were tested by Hilton (2003) in attempt to identify the post-depositional redistribution: The laboratory and field experiments have shown that the closer to the ground surface a buried object is positioned, the more rapidly it will move upward as a result of the freezing process (also discussed in Corte 1962, 1966; Johnson et al 1977; Johnson & Hansen 1974; Wood & Johnson 1978). If abandoned materials are swiftly buried, the potential for movement due to needle ice formation (and other agents) diminishes accordingly. For this reason it is important that archaeologists attempt to gauge the rate of deposition for a given stratigraphic context. Where the overburden is determined to have accumulated rapidly, post-depositional disturbance of the deposits due to cryoturbation may be less pronounced (Hilton 2003: 196-7, Figure 18). The obtained data enables prediction of the degree of disturbance that can be expected for archaeological sites subjected to cyclic freezing and thawing.

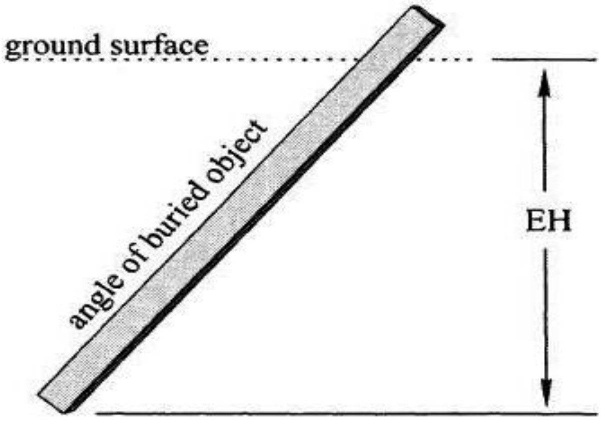


Figure 18 The effective height (EH) of an object plays a major role governing the rate at which it is ejected out of the ground because of alternating freezing and thawing (From Hilton 2003: 170, Figure 2).

In general, the probable occurrence of pedoturbation processes can be predicted on the basis of environmental parameters. “Argilliturbation”, the opening and closing of large cracks in the ground (swelling and shrinking of clay), occurs in regions having heavy clay soils subjected to wet-dry cycles, because it is caused by changing amounts of moisture in the subsurface (Wood & Johnson 1978: 352-58; Schiffer 2010: 46). Such soils are called vertisols and are commonly referred to as "self-swallowing” soils (Oakes & Thorp 1951). They are extensive in the seasonally wet and dry tropics and sub-tropics, where they are variously called black cotton soils, regur, tirs and dark Clay soils of warm regions (Oakes & Thorp 1951; Dudal 1963, 1965). They also occur in the middle latitudes where conditions permit (Figures 19 and 20).

Another soil mixing process is related to the amount of moisture: “Crystalturbation”. It is common to sub-humid lands of the world and there are two principal ways in which it occurs. First, precipitating solutions gradually form crystals in the soil which increase the distance between soil particles and objects. An example is when caliche (calcium carbonate) intermittently precipitates in soil over a long period of time, eventually engulfing the soil as a calcic or petrocalcic horizon (Wood & Johnson 1978: 362-365, Figure 21). Other crystals that form may be other calcium carbonate variants (tufa, travertine), sodium carbonate, sodium chloride (common salt, halite), calcium sulfate (gypsum), or silicon dioxide (quartz), plus other compounds, such as iron, and aluminium (Gile et al. 1966, 1969:281, 1975:325). Crystalturbation also occurs through repeated cracking, re-solution and reprecipitation of salts in soil. Such processes lead to the development of patterned ground, amazingly similar to that formed by frost action: sorted circles, sorted and non-sorted polygons, sorted and non-sorted nets, sorted steps and stripes, salt wedges, heaved stones and other heaved objects (Hunt & Washburn 1960; Malde 1964:14; Hunt 1975:55-65; Wood & Johnson 1978: 362) (Figure 22).

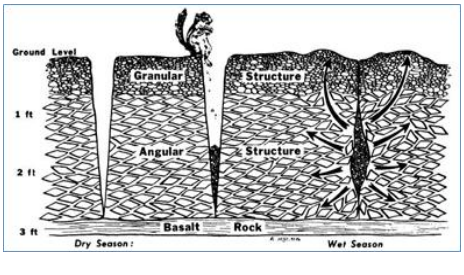


Figure 19 Sketch illustrating wetting (swelling) and drying (shrinking) cycles of vertisols (from Wood & Johnson 1978: 355, Figure 9.20).

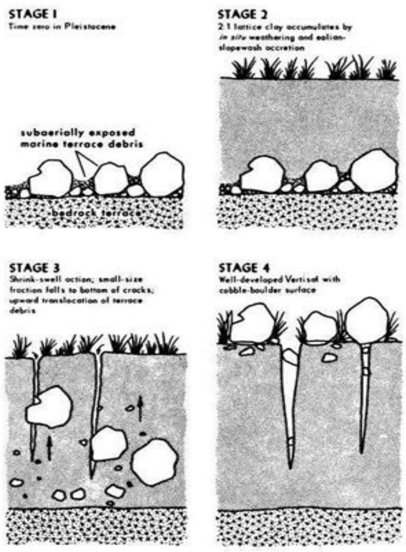


Figure 20 Hypothetical model of seasonal shrink-swell process and evolution of vertisols and stone pavements (from Wood & Johnson 1978: 357-258, Figure 9.22).

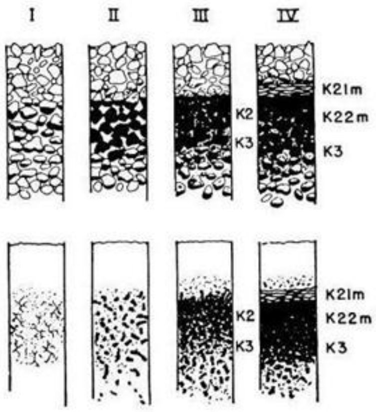


Figure 21 Diagram of stages of caliche accumulations in gravelly (top) and non-gravelly (bottom) parent materials. Carbonate accumulations are indicated in black (from Wood & Johnson 1978: 363, Figure 9.27).

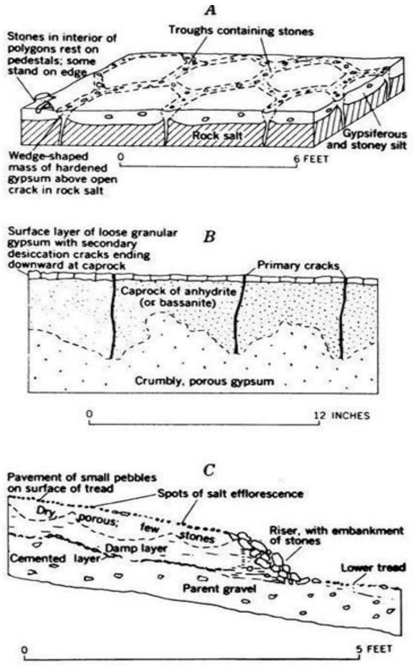


Figure 22 Sketch and cross sections of group patterns in Death Valley, California. A) Diagram of sorted polygons above a layer of rock salt. B) Cross section of nonsorted polygons in anhydrite caprock on gypsum. C) Cross section of sorted step (terracette) (from Wood & Johnson 1978: 365, Figure 9.30).

“Graviturbation”, in turn, consists of all of those impacts that are the direct and exclusive result of gravity; it is the mixing and movement of soil and rock debris downslope, including subsidence, without the aid of the flowing medium of transport such as air, water, or glacier ice. It includes a host of different processes, all of significance to archaeologists and others concerned with pedoturbation (Wood & Johnson 1978: 346; Ellis 2000: 43; Holliday 2004). Wood and Johnson (1978: 346-347) list the individual graviturbation processes under slow or rapid movement. The former are more subtle processes but, in the long term, are of equal if not greater archaeological importance. In contrast, those considered rapid movements are self-evident and where they occur they have great archaeological implications. The remaining types of pedoturbation listed by Hole (aeroturbation, aquaturbation and seismiturbation) can considered to mainly act at the third scale of analysis: the region.

2.5.1.3 The pedoturbation processes in a regional analysis scale

The regional archaeological record is defined as *"a more or less continuous distribution of artifacts over the land surface with highly variable density characteristics"* (Dunnell & Dancey 1983:272). However, even the artefacts not visible on the ground's surface, obscured by sediments, water, vegetation, and later occupations should compose the regional record (Foley 1981b). The observables and sites on this scale interact with the environment, producing a range of effects which depend on the nature of processes involved, principally physical and biological agents, as a result of climatic and geological factors.

Climate in this context is regarded as mainly consisting of temperature, precipitation and wind patterns. Geology includes the minerals, rocks and landforms of a region as well as some of the purely geological processes, shaping them (Evans 1978:2). Together, climate and geology determine specific precipitation regimes, types of storms and prevailing winds, erosion and sedimentation patterns, and influence vegetation and faunal associations in ecosystems (Schiffer 1987:235).

Regional environmental processes affect, in particular, the accessibility, visibility and distribution of the artefacts and sites in the regional archaeological record. Water and wind have extraordinary impact on the surface of the landscape under ordinary conditions over sufficient periods of time (Ellis 2000:43). For instance, "Aeoturbation" (the aeolian process) produces the erosion of soils and sediments (Pye 1995; Goldberg & MacPhail 2006) (Figure 23); the wind may sculpt entire exposures of bedrock resulting in the formation of yardangs, elongated hills which parallel the prevailing wind direction (Figure 24). From an archaeological perspective, wind erosion may play an important role in the integrity of the assemblages. The principal risk is the effect of deflation in which fine grained material is blown away leaving a lag deposit of heavier, stony objects. Consequently, artefacts originally contained in different deposits from successive occupations can be found together within the same 'assemblage' after the finer interstitial material has been removed. Deflation surfaces are common and are particularly important in Old World settings, where time depth provides the opportunity for repeated and longtime deflation. A great number of sites in Egypt (and Sinai), Israel and Jordan have been surveyed and excavated over the past several years and many show signs of deflation (Wendorf & Schild 1980; Goring-Morris 1987; Schiffer 1987; French 2003; Goldberg & MacPhail 2006: 122; Schiffer 2010: 49).

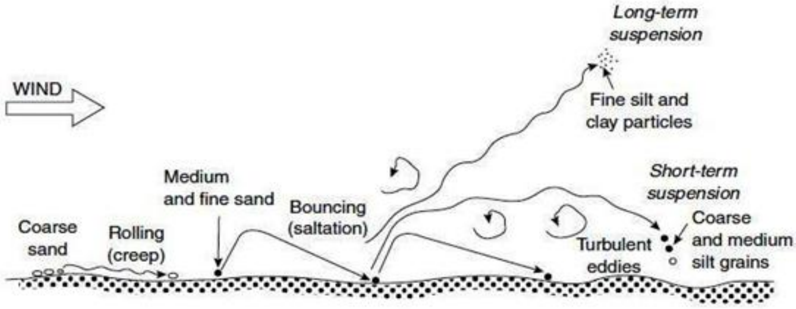


Figure 23 Schematic view of aeolian transport of sedimentary grains (from Goldberg & MacPhail 2006: 121, Figure 6.3).

Figure 24 A large yardang in the western desert of Egypt, north of the Kharga Oasis (from Goldberg & MacPhail 2006: 121, Figure 6.4 C.

Furthermore, Wood and Johnson (1978: 359) highlight that with term “aeroturbation” Hole (1961:376) would indicate also the soil gas which disturbs the fabric of the soil. However, the same authors affirm that aside from the marginally relevant studies cited by Hole, the only situation they know where aeroturbation by soil gas may be an important archaeological mixing process is in the formation of desert pavement and the underlying vesicular layer (Wood & Johnson 1978: 358-359).

Similar erosional effects produced by the Aeolian processes can be caused by hydrological disturbance processes. In this case, when the rainwater reaches the ground as rain or snowmelt, it can seep into the ground or run off. In the first case, “Aquaturbation” occurs, i.e. when water under pressure disturbs the soil (Figure 25) (Hole 1961; Wood & Johnson 1978: 360-363). In almost all environments, rainwater pursues different courses to varying degrees, depending on precipitation patterns, evaporation rates, vegetation, and the nature of the terrain and substrate e.g. slope, permeability (Butzer 1976; Schiffer 1987: 268; Goldberg & MacPhail 2006: 73).

When the water runs off in river valleys on hillsides it is responsible for laying down colluvial or slopewash deposits, sometimes burying sites under many meters of sediments (Schiffer 2010: 51). Where watercourses emerge from foothills or mountains onto flatter land, their velocity decreases, and so they deposit sediment in landforms known as alluvial fans. These lands commonly develop in arid or semi-arid areas where rainfall is intermittent. Alluvial deposition even occurs where rivers flood and the grade falls off sharply. Overbank flooding can lay down meters of sediment on floodplains (Turnbaugh 1978; Schiffer 2010: 51). Sites located on landforms susceptible to erosion will undergo more damage than others in the region.

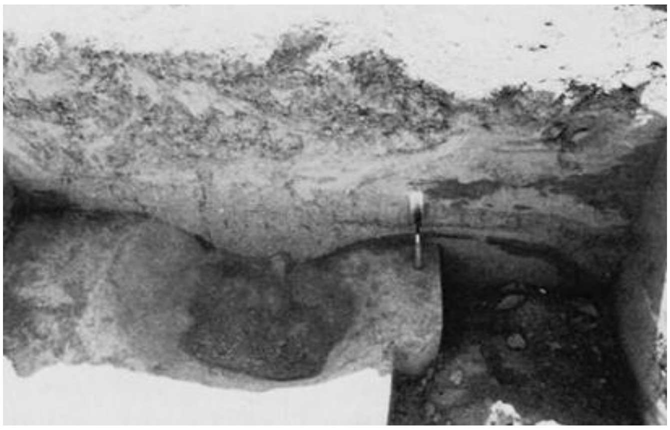


Figure 25 Involutions (flame-structures) caused by aquaturbation, Dutton Site, eastern Colorado. The site is low-lying and poorly drained, and surface freezing pressures ultimately caused deformation of the saturated soil (from Wood & Johnson 1978).

In practical terms, erosion can be expected where water moves quickly over barren and loosely consolidated sediment. On steep, unprotected slopes, rainwater constantly removes the smaller particles, and brisk flows transport larger ones as well. As with wind, water erosion can remove enough of the smaller soil particles to deflate a site. If the process continues for long time periods, only the larger artefacts will remain, resting on bedrock. Conceivably, large numbers of upland sherd-and-lithic scatters were more substantial sites before erosion, perhaps exhibiting far more variability in feature content than is now the case. Conversely, artefacts removed by erosion may end up on the surface in downstream areas.

Nevertheless, we also have to take into account the faculties of fluvial systems to preserve the context of archaeological sites and remains (Ferring 1986, 2001; Needham & Macklin 1992; Brown 1997; Howard et al. 2003; Goldberg & MacPhail 2006: 72). Low energy inundations of

flood plains away from the higher energy channels provide a favourable potential for preserving artefacts and features near to their original depositional contexts. The French sites of La Verberie (Audouze & Enloe 1997) and Pincevent (Leroi-Gourhan & Brézillon 1972) are noted for their evident preservation of the physical integrity and therefore palaeoanthropological fidelity of the remains. The greatest concentrations of hand axes occur at the probable spring fed “waterhole” at the early hominid site of Boxgrove, United Kingdom (Roberts et al. 1994).
Finally, dramatic, even cataclysmic events of regional scale occasionally occur: hurricanes, earthquakes and volcanic eruptions (Ellis 2000: 43). “Seismiturbation” (Wood & Johnson 1978: 366-369) consist of the soil moving caused by earthquake as well as volcanic action. Among the effects is the production of cracks, usually accompanied by lateral or vertical motion of the earth; such cracks may fill with sand or other waterborne sediments and they may be quite conspicuous. Some examples from south eastern Missouri and adjoining areas, produced by the New Madrid earthquake of 1811 and successive years are illustrated in Figures 26 and 27.

The effects of storm and volcanic eruptions are analyzed by Schiffer (Schiffer 1987: 233-234, 236-238). Storms in particular have drastic impacts on ongoing communities and are, unfortunately, a recurrent phenomenon in particular regions. They impact sites and settlements and their effects are brought about by the action of wind and water. These agents work similarly, in that their potential to damage structures and to move materials is a function of their velocity: the strong winds of a tornado ravage wooden structures and can even transport cars, and swiftly flowing flood waters can remove part of a site or settlement. Whereas, in contrast, weak winds and sluggish water displace only small and lightweight particles. Subsequent research in the hurricanes field has been carried out in attempt to understand the frequency and intensity of these phenomena during prehistory, through palaeo-tempestological evidence of hurricane horizons in sediment profiles taken by coring at coastal sites (Gischler et al. 2008; Woodruff et al. 2008; Keegan et al. 2013: 51). However, more information is still needed on the long.term effects of the less destructive processes. For instance, little is known about how the role of wind in the deterioration of structures in archaeological context or the cumulative impacts of ordinary rainfall on the distribution of surface artefacts (Schiffer 1987: 233).

On the one hand, volcanism, the final disturbance process, can in some ways be considered as the most invasive phenomenon. On the other, it ensures the best preservation: catastrophic abandonment and burial at Pompeii has become a yardstick of legendary proportions for assessing the evidence surviving elsewhere (see Binford 1981; Schiffer 1985). It is not the only key example as indeed, another entire prehistoric Mesoamerican village was buried similarly in volcanic ash, the so-called Ceren site (Sheets et al. 1979; Sheets 1983a, 1983b, 2002).
In conclusion, the effects of environment on the remnants of myriad activities and settlement systems can be swift and dramatic or slow and subtle, from a site buried at once in the volcanic ash of a cataclysmic eruption, to another gradually obscured over millennia by the gentle fall of pine needles. Regardless of the specific processes involved, the interaction of archaeological remains with the regional environment poses challenges and opportunities for the archaeologist: although these processes may have provoked the destruction or obscured the visibility of entire sites, they can also reveal long-buried sites and lay down evidence of past environmental processes crucial for understanding cultural adaptations (Butzer 1971, 1982; Evans 1978; Gladfelter 1981; Shackley 1981; Schiffer 1987). However, in attempt to understand the formation of the archaeological record, archaeologists also have to take into account the cultural post-depositional processes which played an essential role.

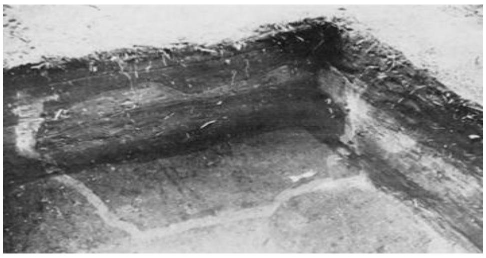


Figure 26 Fault trace (light-colored sinuous zone) at the Zebree Site, Arkansas. Note how it curves around the pit outline at lower right (from Wood & Johnson 1978: 367, Figure 9.31).

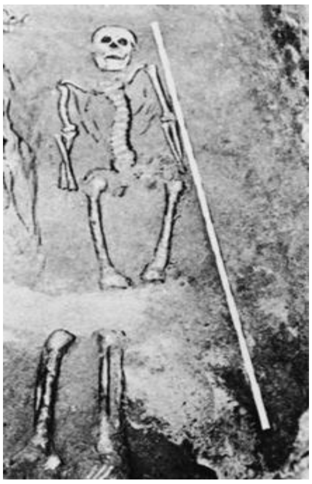


Figure 27 Burial 19 at the Campbell Site, a Mississippian Cemetery in Pemiscot County, southastern Missouri, showing sand-filled cracks and displacement of the lower extremities, probably a result of the New Madrid earthquake (from Wood & Johnson 1978: 367, Figure 9.32).

2.5.2 The cultural post-depositional processes

Also known as C-transforms, cultural disturbance processes include a wide range of activities that may alter the patterning of the material record. Two major kinds of processes are identified by scholars: reclamation and disturbance. Both can cause the spatial rearrangement of artefacts and ecofacts and, sometimes, even their complete disappearance.

2.5.2.1 The cultural post-depositional processes: reclamation

When an archaeological site is abandoned, two possible scenarios can occur: the site is reoccupied and sporadically attended or is completely and definitely abandoned. In the first case the most widespread post-depositional cultural process in play is called reclamation, transforming artefacts from archaeological context back to the systemic context. When a site is re-occupied by a different group, the process of reclaiming artefacts and structure from the archaeological deposits previously occupied by other communities is termed “salvage” (Foley 1981a: 157; Schiffer 1987: 104; 2010: 38). The new occupants, reusing building materials and even entire structure, for many purposes, essentially salvage them. For instance, some communities reuse shell middens, as quarries for raw materials (Baker 1975; Ceci 1984). The proximity to a resource in limited distribution, such as a natural shelter, a reliable spring, arable land, or a location along an important trail or trade route can determine this choice. Schiffer quoted the example of Ventana Cave which provides shelter from the desert heat and contains a spring; it was reoccupied countless times by Paleoindian, Archaic, Hohokam, and historic Papago peoples (Haury 1950; Schiffer 1987: 104).

"Scavenging" occurs when the accumulations of artefacts, usually secondary refuse, previously deposited, are again exploited by said or new inhabitants (Ascher 1968; Foley 1981a: 157; Schiffer 1987: 106; Ellis 2000: 41; Schiffer 2010: 38). One of the first ethno-archaeological accounts of scavenging was furnished by Ascher (1968) who, in an important and influential article, briefly described how the Seri Indians of Sonora, Mexico, reclaimed deposited items. He attributes this great intensity of scavenging and cycling of materials to the general conditions of environmental scarcity under which the Seri lived (Foley 1981a: 157; Schiffer 1987: 109). A wide variety of deposited items and other material remains are deemed valuable enough to reclaim in this manner and the greater the value, the greater the effort invested.

The general rates of scavenging are primarily determined by the relative availability of necessary or desired items within systemic context; the scarceness of economic or political power as well as the condition of living in marginal environments can cause a stronger scavenging practice. Inter-site reclamation processes, the immediate transfer of materials from an archaeological site to an occupied settlement elsewhere, have been attested, as well as inter-site collecting and pothunting behaviours (Schiffer 1976: 36; Foley 1981a: 157; Schiffer 1987: 114; Schiffer 1995: 10; Ellis 2000: 41; Schiffer 2010: 38). The inter-site process involves the movement of value and available archaeological items from one site to another where they are scarce. The available means of transport influence what and how much is collected: large and heavy objects are ignored unless the energy to move them is available. The pothunting process, also defined as treasure hunting (Ellis 2000: 41), requires the excavation and the transport of subsurface materials and thus is regulated by the ease of removing items from the ground. Generally, among treasure hunters of equal technological level, the deeper and more firmly embedded object are the less they are subject to removal. When technological sophistication increases, the available energy for excavation rises so that the likelihood and extent of treasure hunting are likely to increase as well (Ellis 2000: 42).

Pothunting is among the most rampant and culturally acceptable forms of context destruction (Layton & Wallace 2006:60). In general, this process involves the removal of portable antiquities from their context, whether pottery, lithic or metalwork. It is still a pastime done individually, in groups or with family members, at least in developed countries. Naturally, the cumulative impacts of collecting and pothunting are influenced by the size and depth of a site's deposits. The absolute quantity of artefacts removed from a large and deep site is potentially greater than from a small surface scatter. The severest artefact drains occur at shallow sites subjected to ploughing. This latter activity renews the surface by bringing up formerly buried objects, making them visible to collectors. Persistent collecting at such sites leaves behind a biased and depleted artefact inventory (Schiffer 1987: 116-117).

Consequently, cultural depositions are the result of accumulative processes (e.g. artefact manufacture and discard) as well as subtractive processes (e.g. artefact scavenging and recycling) interacting with the surrounding environment (Goodyear et al. 1979). Through the reuse and movement of materials from place to place, a community can trigger pervasive processes which modify the landscape (Foley 1981a: 157). As shown in pothunting, these post-depositional processes involve both the horizontal (from one site to another or from one area to another within the same site) and the vertical movement of archaeological observables which is the meeting point between reclamation and disturbance processes.

2.5.2.2 The cultural post-depositional processes: the disturbance

Various human behaviours cause changes in either the condition or the location of archaeological artefacts and ecofacts: these are grouped into the disturbance processes and have been the *foci* of investigations by a number of archaeologists. Resulting disturbances include the vertical and horizontal movements of objects respectively into and out of the subsurface or across the surface (later displacement) and even their breakage or other damage. Can the reclamation processes, mentioned above, also be considered the results of disturbance processes? The choice of separating the former from the latter is due to the intrinsic value of the disturbance assumption. It is related to how objects are finally discarded and grouped in an archaeological context while, in contrast, reclamation processes lead to the return of objects from the archaeological context to the systemic context. Consequently, reclamation can be only partially considered as a disturbance process. Trampling and ploughing are the widespread cultural post-depositional processes which disturb the archaeological record. Trampling involves walking across the ground surface, by humans and animals, and disturb materials on and immediately below the surface (Gifford & Behrensmeyer 1977; Yellen 1977: 103; Rowlett & Robins 1982; Villa 1982; Schiffer 1987: 126; Gifford-Gonzalez et al. 1985; Nielsen 1991; McBrearty et al. 1998; Schiffer 2010: 39). The cumulative effect of trampling depends upon 1) the physical properties and abundance of artefacts on the surface, 2) the frequency, intensity and duration of trampling, and 3) the penetrability of the substrate.

Ground surfaces exhibit varying degrees of penetrability; trampling displaces artefacts downward in soft, easily penetrated substrates (such as sand) and moves them laterally on low-penetrability substrate (such as dry clay) (Ellis 2000: 42; Schiffer 2010: 39). According to some scholars (Gifford & Behrensmeyer 1977; Yellen 1977: 103), trampling of occupation debris scattered over the sandy surface of contemporary hunter and gatherer campsites caused migration of the smaller elements into the earth. Experimental observations by Stockton (1973) even suggest that trampled material will sort itself according to size, with the larger pieces occurring on or close to the surface while small objects may be pushed down to a depth of about 10 cm. Alternatively, this size effect may be due to scavenging and reuse of large, older artefacts by later inhabitants of the same site (Baker 1978; Villa 1982:279). Lateral displacements of trampled artefacts produce distributional patterns that can be mistaken for activity areas (Figure 28). The flow of relatively small objects from places of heavy trampling to nearby zones of lower trampling sometimes forms artefact concentrations called “woogleys” which are common along walls of structures and in proximity to features, such as fences and paths (Schiffer 1987: 127; Schiffer 2010: 40).

In addition, frangible artefacts, as bone and low fired ceramics, deposited on hard surfaces tend to be broken into smaller pieces and abraded. Chipped stone, on the other hand, is likely to suffer mainly from abrasion on all surfaces and micro-flaking. These effects on formal properties render it relatively easy to identify heavily trampled artefacts.

Similar to trampling, plowing results in both the vertical and the horizontal displacement of objects, as well as their deterioration. It is the churning of the soil brought about by the agricultural activities, usually mechanical, though sometimes resulting from the use of animals.

It disturbs materials on and below the surface to a depth of a few feet. Vertical size-sorting of materials is likely and lateral displacement tends to be in the direction of ploughing activities. The deterioration of objects can be extreme. The major factor influencing the nature of ploughing disturbances is the intensity of field preparation. Generally, the more intensive the ploughing, the greater the impact (Ellis 2000: 42). In some areas of intensive agriculture, nearly every site has been plough, usually many times.

Figure 28 Sandy "surfaces" in very arid places create occupation zones, such as this extramural activity in Tulor Ayllu, Chile (from Schiffer 1987: 128, Figure 6.4).

In documenting the massive effects of modern agriculture on sites, archaeologists sometimes lose sight of the great antiquity of many cultivation practices and overlook the impacts of cultivation in non-state societies. In many non-industrial societies people do cultivate previously occupied areas. For example, Heider (1967) reports that the Dani of Highland New Guinea put gardens into former habitation areas, disturbing cultural deposits. The Maori also sometimes garden in earlier deposits; in the case of the field illustrated in Figure 28, the cultivation had disturbed a shell midden (Schiffer 1987: 129-130).

Consideration of the mechanisms which involve the formation of the archaeological record leads to the conclusion that all variables and processes that govern the observable data-set have to be taken into account. The information on prehistoric population flows through these variables, from the stage of raw material extraction for artefact manufacture, to their definitive discard and the post-depositional factors that alter its distribution (Foley 1981a: 166, Figure 29). This deeper consideration of the most relevant natural and cultural processes involved in the formation and deformation of the archaeological record enables us to reach an heightened knowledge of their widespread features and consequences. Can archaeologists carry out an overall analysis, separating out these effects from the true archaeological signature?

Figure 28 Shell middens, North Island, New Zealand. A) No evidence of major cultural disturbance, B) Extensive cultural disturbance by Maori cultivation (from Schiffer 1987: 130, Figure. 6.5).

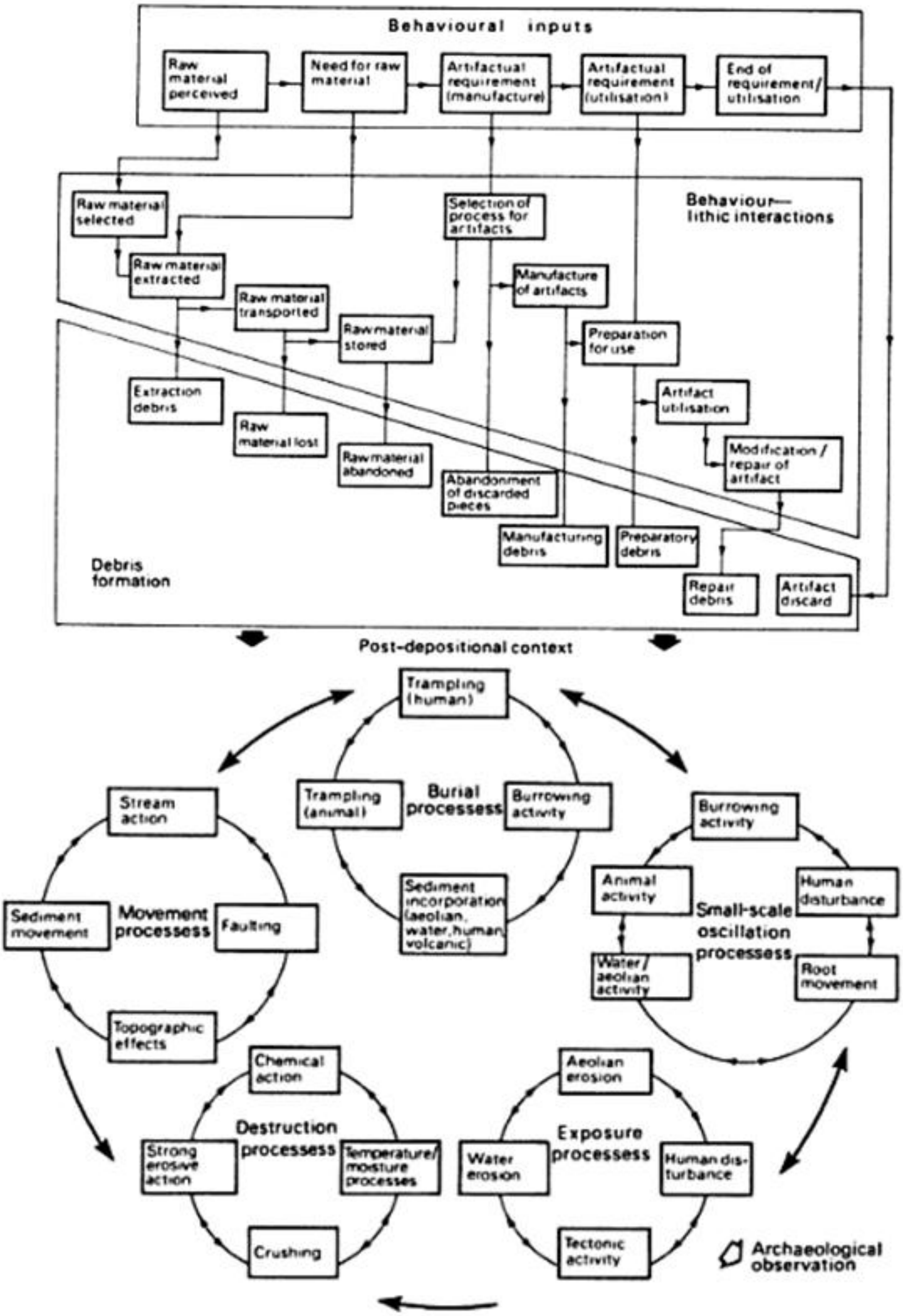


Figure 29 Flow chart of artefact dynamics (from Foley 1981a: 166, Figure 6.5).

2.6 The natural and cultural formation processes: "there is strength in numbers"

"*Although the processes of archaeological and geological sedimentation are, generally, subject to different causes, and although man is much more involved in the first type of deposition than in the second, it seems that the two processes are subject to similar rules and axioms* (Gasche & Tunca 1983: 326)".

During the past decades, several scholars have emphasized the issues in identifying the effects of formation processes, consequently offering guidelines to overcome them (e.g. Butzer 1971, 1982; Schiffer 1976, 1983, 1987, 2010; Wood & Johnson 1978; Gifford 1981; Gladfelter 1981; Stein 1987, 2001). These approaches are anchored on the consideration that natural processes can be inferred in principle because they have predictable physical effects related to the laws that govern them. These processes and their effects are relevant initial assumptions for understanding the formation of specific deposits. However, the use of these summaries as the primary and only source for evaluating site formation (Nash & Petraglia 1984: 189) implies the overlooking of several critical factors (Nash &Petraglia 1987: 190).

Archaeologists have often operated with the belief that the analysis of formation processes, by isolating and explicitly defining their features, examines the fundamental nature of the interface between the archaeological record and the environmental and physiographic matrix, within which it is embedded (Foley 1981a; Wandsnider 1989; Rossignol & Wandsnider 1992: 7). As Butzer emphasized "*people and animals are geomorphic agents that produce a specific range of archaeological sediments that require special attention and interpretation*" (Butzer 1982: 78). We cannot divide the study of man from the study of his environment, their mutual interaction and the tangible evidence of such interaction.

Archaeologists have often operated with the belief that the effects of specific natural processes can be readily identified and separated from those generated by cultural activities. Since anthropogenic processes can affect the soil development at any time and over brief to long periods, it is not possible to separate out those processes linked by the same depositional event. The archaeological record therefore represents a complex amalgam of inputs originating from a diverse array of cultural and natural processes (Nash & Petraglia 1987: 187).

Furthermore, in order to interpret the properties displayed by an archaeological context, the post-depositional conditions that affect the record at the level of the artefact, site and region must also be understood (Schiffer 1987). Effects such as size reduction and sorting, damage patterns and disorganization enable investigators to appreciate the past agencies that were responsible for the complex arrangements of cultural and environmental materials (deposits) observed today (Schiffer 1987: 265, 302).

Archaeological data are made of structural information, artefacts and ecofacts linked by complex factors which can never be fully understood. "*Archaeology is, after all, human palaeoecology in its truest sense, from the very first appearance of man (itself a controversial point) to yesterday*" (Shackley 1981: vii). The archaeological record has in a large part been shaped by the same processes (in particular during its post-depositional phases) that have modelled the landscape (Albanese 1978; Butzer 1982; Thompson & Bettis 1982; Davidson 1985; Schiffer 1987; Waters 1992; Bettis 1995; Mandel 1995; Waters & Kuehn 1996: 484). Once people abandon the site, the geomorphic conditions characterizing the landscape determine whether it is initially preserved or destroyed. If the landscape is stable (i.e. if it is characterized by negligible erosion or deposition) an archaeological site may remain at the surface without becoming either buried or eroded. However, if the site is situated in an area that is, or that becomes, subject to erosional conditions, all or part of it will be destroyed. Similarly, if the site is situated in an area of active deposition, which could also begin after abandonment, it will be buried (Walters & Kuehn 1996: 484). As with the geological sequences, the archaeological record is determined by the number, magnitude, duration, areal extent and timing of periods of deposition, erosion and stability; they work in concert to preserve, arrange and fragment the evidence of human activity on the landscape (Walters & Kuehn 1996: 485).

The degree of geological processes affecting the archaeological sample varies within and between regions and must be evaluated on a case-by-case basis (Walters & Kuehn 1996: 495). To deal with these issues the geoarchaeological studies have assumed a increasing value and role. They provide the framework needed to determine the potentially preserved portion and the loss and fragmentation of the original archaeological record (Walters & Kuehn 1996: 495). The outstanding knowledge gained from taphonomy, ethnoarchaeology and experimental archaeology importantly contributes to understanding the distinctive sediments retrieved by archaeologist and the processes that caused their formation (Schiffer 1987: 265).

2.7 The identification and analysis of formation and deformation processes

During the last few decades archaeological research has in part focused on explaining how the record was formed, so-called “formation theory”. This covers a set of approaches that address the archaeological formation processes (Shott 1998: 311; Lucas 2012: 74). According to these approaches, the archaeological record is an end point, “*as the future of a past present*” (Lucas 2012: 74). With the rare exception of a quick and complete burial as in Pompeii, archaeologists usually recover a very biased subset of material culture. It is not unreasonable to imagine that for every complete pottery vessel or arrowhead in an archaeological site, there are probably a thousand or more pieces of potsherds or lithic debitage (Cowgill 1970). Thus, what is retrieved is not necessarily an accurate reflection of what originally existed. However, in an attempt to interpret most exhaustively the material consequences of the past actions composing the archaeological record, the analysis has to start from the smallest portion of archaeological record: the sediment (Shackley 1981: 5).

According to Stein (1987: 375), a useful approach to decipher depositional histories would be to treat the record (in its entirety) as a “sedimentological deposit” composed of individual sedimentary natural and cultural elements that impart their own set of attributes on the deposit. An archaeological sediment may be defined as directly or indirectly related to past human activity (Shackley 1975: 6). It includes artefacts and ecofacts added to archaeological record through cultural or natural environmental processes (Pyddoke 1961: 76-78; Shackley 1981; Schiffer 1987: 290). Some of these items, as evidence facilitating paleoenvironmental reconstruction, enable to infer the non-cultural formation processes that acted on a deposit (Gifford 1981) and allow to compare the relative contributions of cultural and non-cultural deposition (Brieur 1977; Schiffer 1987: 9). Amongst them, we can name insects (Shackley 1981), vertebrate remains (e.g. bones, hair feathers), plant parts and seeds, pollen (Bryant & Holloway 1983; Moore & Collinson 1991; Bennet & Willis 2001), phytoliths (Pearsall & Piperno 1988; Lentfer & Boyd 1998; 1999; Pearsall 2000; Piperno 2006) and other plant crystals

(Brochier 1983; Rovner 1983), land snail shells (Evans 1972; Bobrowsky 1984), various concretions, nesting materials (of birds, rodents, and insects) and humus. All the single elements of the archaeological record have to be taken into account when reconstructing the past.

Although formation processes are highly varied and their potential combinations seemingly infinite, c-transforms, n-transforms and the environmental/landscape constituents enable to sorting the more or less likely possibilities for the cases at hand (Schiffer 2010: 55). In reconstructing the most probabilistic picture of the past, what available tools do archaeologists hold? A multidisciplinary approach based on different contributions seems the most suitable to encode the formation and deformation processes of the archaeological record. Although the issue of modelling these processes will be addressed in next chapters, an introductive analysis of this approach is required here, to provide a complete overview.

2.7.1 How to codify the formation and deformation archaeological processes: geoarchaeology and palaeoecology

In codifying the processes involved in the formation of archaeological deposit, several questions have to be asked: where do the items that compose the deposit come from? How did they reach the site? How long did it take? What happened afterwards? (Shackley 1981: 5, 12). It is also common practice to give estimate of the formation rate of deposits within complex stratigraphic sequences and in some cases this may be possible, but it is vital to know the source of the deposit (Shackley 1981: 5).

Environmental archaeology can represent the most suitable interpretive strategy: it is concerned with the physical and biological elements and relationships that impinge on the activities of people in the past (Dincauze 2000: xxiv). Although definitions may vary, environmental archaeologists consider human activities in the past within their environmental contexts and apply techniques and interpretations derived from the biological and geophysical sciences to archaeological issues. Thus, the term "environmental archaeology" regards the "*application of concepts and methods of geosciences to archaeological research*", especially geoarchaeological and palaeoecological analyses (Waters 1992: 3). The term geoarchaeology seems to have been coined by Butzer in 1973 and it formed a key part of his influential book "Archaeology as Human Ecology" (1982).

The basic principles, methods and knowledge of geoarchaeology were essentially adopted from the earth and soil sciences applicable to the study of artefacts and the depositional – and post-depositional processes involved in the creation of the archaeological record (Matthews et al 1997; Rapp & Hill 1998: 1-2; Ellis 2000: 239; Stein 2001; Lucas 2012: 85). Hence, geoarchaeology is the result of the combined study of archaeological and geomorphological records and the recognition of how natural and human-induced processes alter the landscapes. Goearchaeology has manifold aims: it is useful to construct integrated models of human-environmental systems and interrogate the nature, sequence and causes of human versus natural impacts on the landscape. It is really only one major strand of environmental archaeology, which generally needs the collaborative and corroborative support of several other sets of data, but a good understanding of it is essential for reading landscapes (French 2003: 35).

Sciences such as climatology (Lamb 1995; Burroughs 2005), geochemistry (Thompson & Oldfield 1986; Spark 1995; Pollard & Heron 1996), geochronology (Walker 2005), geology

(Brown 1997; Rapp & Hill 1998; Williams et al 1998; Garrison 2003; Golberg & Machpail 2006), geomorphology (Butzer 1971; Tricart & Cailleux 1972; Thron 1988; Schumm 1991; Summerfield 1991; Dincauze 2000; French 2003:47ff; Denham 2008; French 2013) and pedology (Limbrey 1975; Courty et al. 1989; Barham & MacPhail 1995) belong to the general definition of geoarchaeology. These disciplines can focus on the stratigraphy either at a single site or compare results from multiple sites across a landscape. They are also useful to disentangle site formation processes, thereby enabling the reconstruction of depositional (sedimentary) and pedogenic (soil formation) processes through time, with particular reference to archaeological evidence of past practices and differentiating post-formation and post-burial transformation.

Micromorphology, for instance, examines the composition and fabric of soils and sediments, through thin-section petrography (among others Matthews et al. 1997: 281, French 2003; Goldberg & MacPhail 2006. Such studies can reveal 1) the origin and environment of sediment depositions, 2) land-use practices, 3) anthropogenic materials and features, such as ash, mud bricks, mortar, cremations, floors, and micro-artefacts, 4) whether clays are inherited from mud brick or introduced secondarily by soil-forming processes, 5) vegetational cover, 6) post-depositional processes, including diagenesis and soil formation, and 7) the context of burning (determining the fuel, the temperature, and possibly even the purpose) (Ellis 2000: 239).

Distinct stages in the development of each stratigraphic unit and archaeological context are differentiated into a) original deposition represented by inherited sedimentary stratification, b) pedogenic alteration of the sediment and, potentially, the formation of archaeologically significant palaeosols and deposits, c) pedogenic transformations of context prior to and after burial (Barham 1995: 161; Denham 2008: 470).

The second category of analyses identified as an integral part of “environmental archaeology” is palaeoecology, the study of former environments, including the materials and processes of their formation, the ecosystems that they supported and the temporal fluctuations in the relationships between biological organisms. It is an important mechanism for exploring the evolution of, and oscillations in, our constantly changing environments, and for the comprehension of changes and the agents that drive these changes. Palaeobiological evidence, in the form of fauna and flora, is probably the most effective and direct means that can be used to reconstruct past environmental conditions; it can include material as diverse as pollen grains, insect remains, glacial sediments and tree rings (Bell & Walker 1992). In palaeoecological investigations, as with all studies into the past, the evidence is fragmentary and only elements of it survive.

The palaeobiological record comprises of traces or remains of former living organisms preserved as fossils or subfossils. Armstrong and Brasier (2005) consider any dead organism that is vulnerable to the natural processes of sedimentation and erosion to be a fossil, irrespective of the way it is preserved or how it died. In the late 8th century, James Hutton introduced this concept within his theory of earth (Craig 1987) and over the last few decades this has certainly been the case, with the scientific rigour of classical uniformitarianism’ as proposed by Gould (1965). This can reconcile some of the recent challenges to the philosophy within its framework (Lowe & Walker 1997; Clarke 2012: 539). Sciences such as archaeobotany (Pearsall & Piperno 1988; Jacomet & Kreuz 1999; Pearsall 2000; Wilkinson & Stevens 2003; Jacomet 2005; Jacomet 2007; Van de Veen 2007; Jacomet 2013), palaeoclimatology (Birks & Birks 1980; Digerfeldt 1988; Haas et al. 1998; Magny 1993, 2004, 2005, 2013), dendrochronology (Huber 1964, 1967; Fletcher 1978; Becker et al. 1985; Kaenel

& Schweingruber 1995; Fasani & Martinelli 1996; Billamboz 2003, 2005, 2013), archaeoentomology (Osborne 1988; Brayshay & Dinnin 1999; Smith 2002; Whitehouse 2006; Elias 2010) and archaeozoology (Davis 1987; Reitz & Wing 1996; Schibler & Jacomet 1999; O'Connor 2000; Rowley-Conwy 2004; Schibler 2005) can be considered part of palaeoecology.

The main focus of archaeobotanical research is the study of past people-plant relationships. This includes a reconstruction of the diet, subsistence, agricultural strategies, the social and cultural role of food and the exploitation of the environment in which people and their animals dwelt. The accuracy of archaeobotanical reconstructions, however, depends on the quality of the botanical data recovered from excavations. The first responsibility for an archaeobotanist is, therefore, to consider all the factors that influence the making of the record (e.g. taphonomy), i.e. the study of the processes that lead to the incorporation of fossil assemblages into a sediment (Jacomet 2005) and it has to take into account as tool for the multidisciplinary approach here proposed.

A combination of both geoarchaeological and biological analyses enables more complex interpretations of landscape change. For instance phytolith, pollen and charcoal (macro and micro) studies can be used to reconstruct burning and vegetation histories for the landscape that can be compared to sedimentation and soil formation histories (Canti 1995: 186).

2.7.2 How to codify the formation and deformation archaeological processes: the taphonomic approach

Taphonomy is an interpretational perspective based on the study of formation processes that affect the final spatial pattern and compositional character of the archaeological record. Because archaeological materials are part of sedimentary deposits governed by geomorphic and sedimentologic processes, these disturb also the interpretation of artefacts and ecofacts within them. The landscape context plays a critical role in human behaviour because it impacts the visibility, preservation, location and features of artefacts which become part of the archaeological record (Rapp & Hill 2006: 60).

The word "taphonomy" was coined by the Russian palaeontologist Efremov (1940) and it was originally applied to fossil biotic remains in the study of fossil record. In archaeology, taphonomy has expanded from paleontology's traditional concern with bones to include plant remains and artefacts. It involves the analysis of processes which govern the movement of objects from a living dynamic context (the human behaviour) to a static accumulation or assemblage of materials (the archaeological context) (Rapp & Hill 2006: 62; Kelly & Thomas 2013: 119). In following this perspective, taphonomy taught us how to read the archaeological record as a complex series of interactions, beginning at the time of human activity, through depositional and erosional processes, to discovery, recovery and analysis by archaeologists (Johnson 2004: 61; Rapp & Hill 2006: 16, 60).

Taphonomic biases, the processes which change the archaeological record (such as erosion or weathering for example), represent the material consequences of a general assumption according to some authors : *"the longer something is in existence, the more chances it has to be removed from the archaeological record by taphonomic processes, thereby causing over-representation of recent events relative to older events"* (Surovell et al. 2009: 1715; see also Surovell & Brantigham 2007). This assumption has been introduced earlier by Ascher (1968) through the “time’s arrow”: according to this concept, the quantity and quality of evidence that can survive in the archaeological record reduces over time. Our potential knowledge of the past is directly related to the state of preservation, which is conditioned by the time elapsed since the cultural deposition occurred. In this perspective, old sites are condemned to contain less information than recent ones because they have suffered more disturbances and therefore fewer artefacts can remain.

This point of view needs to be explored, taking into account some important clarifications (Schiffer 1987:8-11); the site and artefacts degradation is not linked to the passage of time *per se* but is caused by different formation processes which impact on the degree of site preservation. Indeed, the deposits must be evaluated for their information potential (or limitations) on a case-by-case basis. Adopting this perspective, some authors (Surovell & Brantigham 2007; Surovell et al. 2009) highlighted this issue by comparing archaeological, paleontological, and geologic temporal frequency distributions, all characterized by similar distributions, and since that time, they have come across additional examples (Anderson et al. 1997; Kirch 1998: 288; ; Johnson 2006: 136–137; Johnstone et al 2006; Thorndycraft & Benito 2006; Ugan & Byers 2007, 2008; Hiscock 2008: 228–239). They proposed methods for correcting taphonomic bias in an attempt to extract demographic signals from archaeological temporal frequency distributions. This model, here only briefly introduced as a methodological approach addressing the issue of archaeological taphonomy, will be analysed in detail in the following chapters; its pertinence and usefulness in our case study will be proven.

While taphonomic approach showed their advantages initially as applied to plant and faunal remains (Voorhies 1969; Berhrensmeyer 1975; Binford 1978, 1981, 1984; Brain 1981; Boaz 1982; Gifford-Gonzalez 1985; Haynes 1991; Lyman 1994; McBrearty et al. 1998; Schiffer 1983), it has since been implemented even for other artefact classes. Schiffer (1972, 1976), Wood and Johnson (1978) and Rowlett and Robbins (1982: 73-74) have reviewed in detail the major mechanisms and natural processes which involve post-depositional movement. Furthermore, vertical size-sorting of artefacts has been reviewed by Baker (1978), while Rick (1976) has considered their downslope movement and Oman (1979) has explored size-sorting in this kind of movement. Sirainen (1977) postulated the vertical descent of stone artefacts, whereas Harris (1979:93-7) generalized that such migrants may go either up or down without leaving detectable traces in the soil.

Villa (1982) proposed the study of conjoinable pieces (especially bone and lithic fragments) to test the presence and extent of stratigraphic disturbances that have not left clear, macroscopic traces in archaeological sediments and which have, therefore, few chances of being recognized. The refitting studies (Schick 1986, 1987; Pigeot 1987; Cziesla et al. 1990; Hofman & Enloe 1992; Sellet 1993; Schlanger 1996; Shott 2003; Hofman & Ryan 2013) offer an important way of dealing with this issue: indeed, it represents an analytical tool which informs about the many variables affecting the characteristics of assemblages such as the taphonomic processes. Hence, the ways in which an assemblage refits as a larger pattern speaks to the diachronic dynamics of site formation, spanning this entire duration and linking a single location with many places on the landscape (McCall 2006: 121-123). Even the study of intensive pottery refitting and conjoining obtain important clues about cultural and non-cultural formation processes and provide useful interpretations of the material objects themselves (Chapman & Gaydarska 2007: 82).

In an early study of the consequences of the formation processes on ceramic assemblage variability, Robert Burgh (1959) showed how refitting studies enable archaeologists to assess the reliability of chronological inferences. According to him, refitting fragments from the same objects retrieved in different contexts dated them to the same time span or stratigraphic phase. This assumption could be applied to both horizontal refits, within the same horizon, or to vertical refits linking different strata, and became a basic tool for taphonomic investigation (Larson & Ingbar 1992). Although they clarified that the refitted objects cannot be completely and absolutely useful as chronological and/or stratigraphic markers, most authors continue in this way (for example see the contributions to Hofman & Enloe 1992).

Chapman agreed this assumption (2007: 84) and introduced another. In producing a summary of the known refitting studies carried out during recent decades in his 2007 book, he pointed out that, although the study of formation processes through fragment re-fitting had produced a mix of significant results and predictable findings, a question remained unanswered: where are the missing fragments, the fragment orphans? If the results of analyses establishing the possible impact of taphonomic issues (including post-depositional degradation and erosion) and also the use of chamotte and the practice of manuring were not able to explain the absence of 80-90% of the site's vessel population, it was necessary a hypothetical explanation, more related to deliberate social practice (Chapman & Gaydarska 2007:111). Three possible practices were identified and proposed: 1) fragment curation in an off-site location, 2)enchained relations between sites, with fragments taken off the site, 3) the introduction of fragments onto the site from another one where the greater part of the vessel has been deposited.

All of these explanations were based on a common assumption: the majority of these orphan fragments belonged to whole vessels that had developed enchained relations across the landscape; these fragments could indeed have been re-fitted to others from the same objects that were deposited elsewhere. Chapman and Gaydarska commented: "*It is hard to resist the conclusion that fragment dispersion across the landscape was one of the important social practices through which enchained relations were maintained at the local and sometimes wider level"* (2007:111). However, such research showed that the documentation of fragment dispersion raised interesting problems and issues as despite the inter- and -intra-site re-fitting analysis: the conjoint object was still often incomplete, suggesting an even more complex object biography which archaeologists, until now, could not completely decode. There are tantalising hints that, after the break, fragments followed separate biographical pathways before they were re-united, often in a burial. The exact movement of the fragments during their deposition are in most cases unknown, the exception being in lithic refitting, when micro-sequencing can be determined. Hence, do archaeologists have to throw in the towel? They have to accept "new challenges".

2.7.3 How to codify the formation and deformation archaeological processes: ethnoarchaeology and experimentalism

To better understand the natural and behavioural processes that form and deform the archaeological record, the analysis has to start with the material consequences of the actions carried out during the past, namely the artefacts and their extended biographies. Each single stage of the artefacts' life, from their manufacture, use-life, through their initial break and the subsequent reuse, to their final deposition constitute this biography. Furthermore, if these objects have been reused their "history" must include also a wider range of persons and locations with whom they were associated. All remains, with their different biographies, included in an individual context, need to be harmonised into an overall interpretation (Chapman & Gaydarska 2007: 77). In this perspective, the comparison with sensitive ethnoarchaeological studies and experimental approach (Trigger 1989; Kenoyer et al. 1991; Rossignol & Wandsnider 1992: 7; Earle 2008: 199-200) have a key role, in differentiating the value of things within their extended depositional contexts.

From the combination of ethnology and experimentation, derived the increasingly common practice of "ethnoarchaeology" which involves the collection of ethnographic information to address specific archaeological issues (Earle 2008: 199-200). This discipline is an actualistic approach that explores anthropogenic impact on archaeological matrices in light of systemic intra-site and inter-site patterns of human behaviour over space and through time (Rossignol & Wandsnider 1992: 7; David & Kramer 2001: 94 e sgg). Sullivan (1989), among others, carried out a refitting study of pottery fragments recovered at Site 17, a small Kayenta Anasazi settlement, located south of the Grand Canyon. He noted that broken pottery, even when damaged beyond repair, was stored in a variety of contexts (floors, roofs and exterior areas). The materials probably represented potential technological solutions to the problems of daily household life (DeBoer & Lathrap 1979: 127). According to Hayden and Cannon (1983: 131) "*the fragments might be useful for something*". This suggestion is entirely reasonable (Sullivan 1989: 111-112) since fragments possess properties, such as durability, impermeability and resistance to fire are rarely duplicated by products of the natural environment. This position was also evidenced in previous ethnoarchaeological studies (for example those of Stanislawski about the Hopi potters (1977: 221-4). He showed that many of them collected, stockpiled and re-used both prehistoric and modern Hopi potsherds in their homes. They used these fragments with many purposes, since they were inserted in the frames of the house (on the door, window, walls or bread ovens), or used in shrines with sacral purposes (for divining the future and averting the bad luck of a pot breaking during firing). They could also be useful as commodity of exchange or as temper for other fragments or templates.

Ethnoarchaeology represents a means to investigate modern site formation processes: might this serve as a model for archaeological sites, as argued by Yellen (1971) and Binford (1978a)? It can be, in a hypothetical way, if certain conditions are met. Although most ethnoarchaeological studies rely on direct ethnographic observations (the systemic context) or a time-period immediately following discard or abandonment (e.g. Gould 1968; Yellen 1977; Binford 1978a-b; Hayden & Cannon 1983), some scholars (Schiffer 1976; Gorecki 1985: 175) highlighted that studies often erroneously gave little consideration to post-depositional processes, despite an increased awareness of their importance during those decades (Schiffer 1972, 1976; Wood & Johnson 1978; Gifford 1980; Vila 1982 (see the subchapter 2.3).

Gorecki (1985: 175) proposed for ethnoarchaeologists "*to move another methodological step further by completing their ethnoarchaeological observation with the "archaeology of their ethnographies*". Some scholars had done this, with the example cited by Gorecki being Hayden and Cannon (1983) who carried out among the Maya Highlanders in an attempt to resolve to their refuse disposal behaviour. This "post-mortem" analysis of ethnographic contemporary sites can be used as a tool to answer specific question related to artefact deterioration and the long-term visibility of sites. In this perspective, ethnoarchaeology enables reconstructing a wide range of physical processes (from sedimentation, to weathering, to the properties of worked materials), the taphonomy of bones and other debris, the manufacture and use of specific technologies, their resulting wear and distribution, and, finally, patterns of refuse discard. In this last case, ethnoarchaeology has greatly assisted archaeologists to effect a broader linkage of past and present.

The ethnoarchaeological approach showed potential for understanding the abandonment behaviour as well. During the 1970s, the key role played by abandonment in the formation of the archaeological record was recognized (Cameron & Tomka 1996: 3).

Although all purely archaeological sites have been abandoned, not all structures or settlements were abandoned in the same way. As established above, in order to interpret the archaeological record accurately archaeologists must investigate also this process and, according to some authors (Schiffer 1987, 1996; Cameron & Tomka 1993; La Motta & Schiffer 1999), a combination of ethnographical, ethnoarchaeological and archaeological data from a wide range of geographic areas and time periods seems to be needed to understand the effect of abandonment on archaeological patterns.

2.8 Discussion

The archaeological record consists of an amalgam of formation and deformation processes. Throughout this chapter, a thorough overview of the different stages involving the creation of deposits has been carried out. Through a complete analysis, starting from the soil within the artefacts are deposited and ends analyzing the post depositional changes, two types of processes with two different natures can be distinguished: firstly, the so-called cultural transformation/activity that involves human behaviour (c-transforms), and secondly, the processes that impinge upon and modify cultural materials due to environment called n-transforms.

Loss, discard, reuse, decay and archaeological recovery are numbered among the diverse processes that in a sense mediate between the past behaviours of interest and their surviving traces (Meadow 1976; Hassan 1987; Schiffer 1987; Mameli et al. 2002). The occurrence of chemical, physical and biological effects can alter the physical attributes of items, disorder their patterning and finally modify their accumulated frequency within or among spatial units. For instance, even if the total amount of objects found together in a recovery unit would indicate that the items were used in some common activities, when archaeologists infer that assumption we have to take into account that it cannot be based exclusively on this simple association. Hence, in this context the need of a deep knowledge of taphonomic bias and post-depositional processes appears crucial. Against a heuristic model, the summary of natural and cultural processes plays a key role in order to reshape our perspective of formation processes and increase our understanding of the complex deposit under study. Only if we know this combination of processes which first created the record, their features and spatial location, can we also evaluate and control the results of that bias as the transformation of assemblages in more amorphous ways and the increasing of their entropy.

Structure abandonment in some cases is examined using cross-cultural ethnography and ethnoarchaeological data primarily from villages. Although they provide reasonable analogies with prehistoric episodes of structure abandonment in settlements of a similar nature, their direct application in archaeology can be simplistic and inaccurate. Nevertheless, some authors forcefully argue that the use of analogy, acknowledged or not, forms the basis for most archaeological interpretation. Archaeologists have been invited to systematize the entire sequence of relevant processes, in reconstructing the past. In this perspective, even the process of settlement abandonment has to be taken into account since different kinds of abandonment leave different effects and traces on archaeological material patterning. They can inform us about the lifestyle of the site's inhabitants such as their occupation strategy within the landscape (suggesting models of mobility or sedentism) while the different modes and causes of settlement abandonment can even inform about environmental changes (earthquakes, hurricanes and volcanic phenomena) that occurred during the past. After site abandonment, the altered and accumulated material consequences of some actions enter into the archaeological context; although they should be recovered as the site's surface, the post-abandonment processes may change their features and spatial patterns.

Some important steps toward a better contextualization of formation processes and understanding some of the factors conditioning the variability of the archaeological record have been taken thanks to this multidisciplinary approach. It requires the integration of disciplines such as taphonomy, geoarchaeology and environmental archaeology, among others. The great potential of this synergetic collaboration was identified in obtaining the best results within archaeological research: some applications to different case-studies have proved their utility to solve archaeological issues. Together with geoarchaeological and soil analyses, palaeoenvironmental studies are essential, along with palynological research and good dating, for the creation of long-term landscape developmental histories and for evidence of the human role in shaping landscapes over time (French 2013: 555). The presence of ethnoarchaeological, ethnographic and ethnohistorical studies side-by-side with archaeological analyses offers yet another example of the positive complementarities of these sub-disciplines. Once the general framework is established, we will closely analyse the study focus of this thesis: the abandonment plan of lakeside settlements.

"Where there is water there is life!" People's interaction with wetlands is a global phenomenon, which is not restricted to specific periods. Archaeological evidence of this interaction spans from the dawn of humankind to the present and it can be found in the most unthinkable places (Menotti & O'Sullivan 2013: 7). Our research, during the next chapter, will focus on the analysis of the lake dwelling context, i.e. the formation processes which involve this natural environment. The first step to achieve this knowledge is represented by an exhaustive understanding of the natural environment that embraced the archaeological record and the depositional and post-depositional processes which could have altered its features. A deeper summary of the studies carried out on lakeside settlements will enable selecting the best framework for analysing the accumulated observables that composed the abandonment plan under study.

3 THE LAKE-DWELLING PHENOMENON: FORMATION AND DEFORMATION PROCESSES

3.1. Introduction: diversity and variety of wetland archaeology

Humans have always been fascinated by water regardless of its forms, either as sea, rivers, lakes or simple marshy ponds (Pétrequin 1984: 30-31). We have been linked to these features, in a way or another, since the dawn of humanity. Indeed, a large number of well-known early hominid sites occurred in wetland environments: in Europe sites of the Early Palaeolithic such as Torralba in Spain, Boxgrove in England and Bilzingsleben in Germany are associated with wetlands (Coles 2004b: 183-184). Swamps, playas, marshes and bottomlands have been among most attractive areas on the landscape during the prehistory, because of their resource diversity, productivity and reliability (Niering 1985: 29; Forman & Godron 1986; Nicholas 1988: 268-269; Nicholas 2003: 262). Different needs (as subsistence, in terms of food procurement through water and primary resources), and sheer necessity (such as defence), or more elaborated socio-economic aspects (such as logistic reasons, linked to settlements) or beliefs (Menotti 2012: 27; Menotti & O'Sullivan 2013: 31) might have probably driven the interaction between people and wetland.

It is difficult to estimate exactly when this relationship started to become more systematic: however, people probably began to settle into humid environments and to fully connect their everyday-lives to that particular ecosystem in relatively recent times. Although we are aware of sporadic episodes of wetland occupation and exploitation in the Holocene, particularly in the Mesolithic, such as at Starr Carr, in England (Clark 1954; Coles 2004a), a few sites on Feder Lake, in southern Germany (Schlichtherle 2004) and some cases in Lithuania (Menotti et al. 2005), the large-scale settling of lacustrine environments did not occur until the Neolithic (Menotti 2004: 2). As time elapses, people-wetland interaction becomes more and more complex: it encompasses elements both sacred and profane (Menotti & O'Sullivan 2013: 29) such as the "bog bodies" (Menotti 2004: 11), a widespread variety of objects, as war booties at Skedemosse, Sweden (Larsson 1998; Menotti 2012: 16) and the open-set proposed by Jennings (2014: 117-129).

Furthermore, this environment could own manifold benefits as the presence of harvesting resource and the opportunity of install settlements and even defensive sites (Coles & Coles 1989, 1996; Nicholas 1998; Nicholas 2003: 262). The variety of activities carried out within and between the wetland and resulting material consequences of such activities, reflect the variability of wetland ecosystem itself. In fact, edges of lakes, rivers, marshes, fens, coastal and estuarine saltmarshes, peatbogs and mires come to be chosen as settling areas and they are even penetrated and explored more systematically. The wide spatial dimension of these archaeological discoveries, from quite all over the world, and their spread across a very large time-span (since the beginning of the Holocene to nowadays), confirm the importance of wetland exploitation.

These environments vary widely in their location, topography, climate, water regimes and geomorphological features, vegetation and wildlife from place to place, from tundra regions to the tropics and over every continent of the Earth. However, notable wetlands are especially attested in Europe, Americas, Africa, Middle East, Asia and Oceania (Pétrequin 1984: 45-49).

After a summarised overview of the common features and stages of formation that characterise the most widespread wetland ecosystems, this chapter will focus on the lakeside settlement: its

formation and deformation processes are deepen explored to better contextualise and understanding our case study, the site of Villaggio delle Macine, that falls into this category.
The more sites were discovered, the more it became evident that the location of these settlements is mainly related to environmental morphology, without necessarily following a specific construction style (cf. Menotti & O'Sullivan 2013: 12, figure 3.7.1). The supposed uniqueness of lacustrine villages as a construction built only on stilts in a permanently wet environment, particularly referred to the Alpine-Circum region (Keller's theory), had given way to other possible choices: houses built on the ground, houses with slightly raised floors or houses on piles (true lake-dwellings), according to the subsequent scholarly theories (theories of Reinerth, Paret and Vogt).
A new type of lake-dwellings in peat deposits and marshes was identified and the further discovery of key archaeological sites such as Egolzwil 3 (Vogt 1951), Zug-Sumpf (Speck 1955) and Fiavé (Perini 1975) definitely closed the *Pfahlbauproblem* discussion (Menotti 2001: 20). This last site shows all types of lake-dwellings, from the classic Keller's pile-settlements to the land-built villages described by Paret. The lay-out of Fiavé lacustrine dwellings consists of three zones and it follows a chronological occupation pattern which goes from the Neolithic to the beginning of the Late Bronze Age. This example pinpointed that the building structure depended upon the morphology of environment and how the lake-dwelling was built over a long time-span.

3.1.1 Lake-Dwellings: "triumph and tragedy" of the Pompeii hypothesis

The variability which characterises different wetland environments is even reflected by the wide richness and variety of archaeological observables recovered there; this environment ensures a very good preservation of inorganic as much as organic (specially flora and fauna) remains, as its main strengths (Pétrequin 1984: 24-26). These findings enable archaeologists to reconstruct palaeonvironmental as well as socio-economic aspects of ancient communities, but they even trigger an invaluable multidisciplinary collaboration between a myriad of different disciplines. From the three most inseparable ones (archaeobotany, archeozoology and geoarchaeology) a number of scientific analyses, from sedimentology to palynology and in some cases even microbiology, come to aid of the lake-dwelling research. Furthermore, the large amount of well-preserved timber found in waterlogged contexts has also contributed to the development of one of the most precise dating techniques in archaeology, i.e. dendrochronology. This dating method can be used symbiotically with the radiocarbon dates, showing its suitability in calibrating this last dates (Reimer et al. 2004; Menotti 2012: 19). The results obtained from the individual discipline, in the framework of multidisciplinary research, can serve as proof or disproof of the other disciplines' outcomes. This synergetic effort ensures higher precision and accuracy of achieved results (Menotti 2004: 19).

Thus, the potential offered by archaeological research in wetland ecosystem includes: 1) the reconstruction of landscape models through the analysis of environmental available data; 2) economic evidence of both plants and fauna that may provide precise details of land use, food procurement, preparation and consumption; 3) stratified living and working surfaces on settlement sites and other structures; 4) wooden structural elements recognisable as parts of individually identifiable buildings; 5) they enable dating precision to the year and to the season, creating the possibility of observing the realities of relationship both internal and external; 6) complete artefacts, with handles, bindings and ornamentation rather than only inorganic parts; 7) wholly organic objects as wood, fabric and skin probably otherwise unknown in the archaeological record; and finally 8) patterns of cultural and socio-economic aspects of those prehistoric wetland communities.

According to these "triumphant"conditions (Coles' perspective, Coles & Coles 1989, 1996), are the wetland archaeological contexts reflecting a "Pompeii premise", i.e. are they a fixed picture of the past as it was at the moment of its last deposition? (more detail in Chapter 2, 2.1). This condition is not be considered as an absolute assumption because of the potential interference of several biases factors. Shell middens, coastal and river estuarine wetland environments, provided a useful example of this circumstance. They are concentrated deposits of shells accumulated as food remains and subject to complex formation/deformation processes. In this context, what could seem to be an original accumulation of shells and other marine resources may be produced by natural agents (Bailey 1975: 52; Bailey et al. 1994; Stiner 1994: 177, 182; Bailey & Flamming 2008: 7). As in this case, the luckily occurrence of a "Pompeii premise" in our archaeological record has to be case-by-case tested, avoiding counterproductive conclusions. The possibility that archaeological evidence will eventually come to light as it was originally formed depends essentially on deformation- post-depositional processes. Together with preservation processes, they start soon after the object or the site is abandoned (Schiffer 1987). It is known that organic materials are usually better preserved in waterlogged environments because they are effectively sealed in anaerobic conditions, which prevent artefacts from decaying. However, it is important to point out that various wetland environments, from peat bogs to marshes, would be "deformed" by post-depositional processes in a broad variety of ways that is not limited to the erosive processes but embraces a wide range of disturbances, i.e. the "tragedies". This chapter is focused on an overview of the formation and deformation processes that produced and changed the archaeological record in wetland -and in particular lacustrine- contexts. Several archaeological, ethnographical and experimental case studies, from all over the world and across the prehistory, are described to provide a practical perspective.

3.2. The pre-depositional status

3.2.1 The first natural formation process

Exploring formation processes that generated the archaeological record, the content (archaeological observables) as well as the container (environmental setting) have to be analysed. Traces of past activities are hence accumulated in specific landscape and material consequences embraced into the archaeological layer -sediment; it can be defined as the result of natural pre-depositional formation process that took place before the people chose to interact with the surrounding environment and exploit it. The identification and interpretation of distinctive bodies showed by sediment revealed different processes which during the past may operate not necessarily at the same rate or over the same time intervals and spatial locations. The bulk of inclusions may derive from animals and plants living in or on sediments subsequent to deposition (remnant); others may be elements of communities that were carried along with the sediments, finally coming to rest far from their native habitats (re-deposited). The remnant (autochthonous) fossils belong normally to times following the subaerial depositional event itself. Their environmental signals must be evaluated for their chronological relationships to the depositional event and to the archaeological event under investigation.

Naturally re-deposited (allochthonous) materials belong to earlier times and distant space in relation to any deposit that contains them. As elements of sedimentary history, they represent environmental conditions as source; they may consequently either complement or contradict the autochthonous evidence. How much time and space separates them from the deposit itself is to be determined in each case (Dincauze 2001: 272). Wetland ecosystems, such as mires, bog, fens, marshes and swamps represent our depositional environments and are intermediate between subaerial and subaqueous environments. Although listing all possible wetland ecosystems is not among the aims of this chapter, main features of most common wet environments where archaeological record is usually formed are highlighted with a brief overview. The lacustrine wetland contexts will be analysed more in detail.

3.2.2. The wetland ecosystems: features and formation

Wetlands, as the link between land and water, are some of the most productive ecosystems in the world. They are often found at the interface of terrestrial ecosystems (such as upland forests and grasslands) and aquatic systems (such as lakes, rivers, and estuaries) (Butzer 1971; Shackley 1981; Mitsch & Gosselink 1993, 2000, 2007; Dincauze 2000; French 2003; Goldberg & MacPhail 2006) (Figure 30). Some are isolated from deep-water habitats and are maintained entirely by groundwater and precipitation. Even though they show structural and functional overlap and physical interface with terrestrial and aquatic systems, wetlands are different from these other ecosystems in so many respects that they must be considered as a distinctive class (Figure 31).

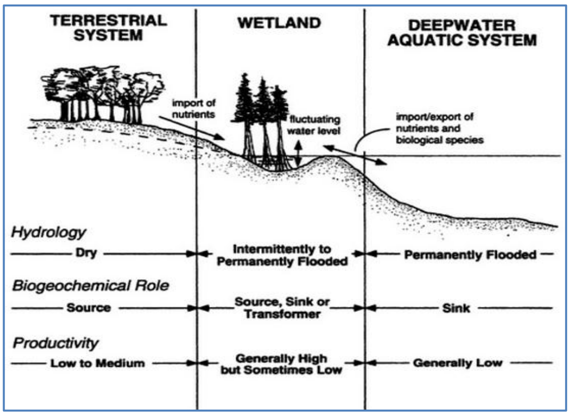


Figure 30 Wetland can be part of a continuum between terrestrial and deepwater aquatic systems (from Mitsch & Gosselink, 1993, figure 2.1A).

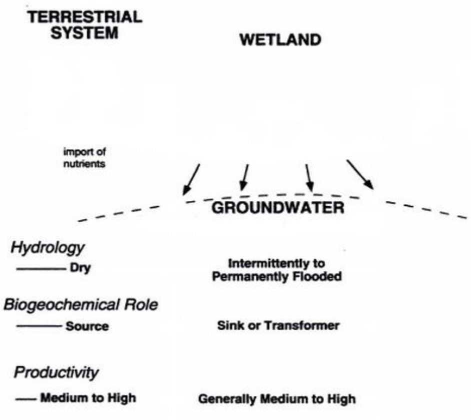


Figure 31 Isolated from connections with water bodies (from Mitsch & Gosselink 1993, figure 2.1B).

Wetland sites are characterised by several common features: all have shallow water or saturated soil where accumulated organic plant material are decomposed slowly. Hence, this ecosystem supports biota such as a variety of plants and animals adapted to the saturated wet conditions (hydrophytes), while an absence of flooding-intolerant biota is attested. Wetlands are characterised by the presence of water, either at the surface or within the root zone and often have unique soil conditions that, as mentioned above, differ from adjacent uplands. Although climate and geomorphology define the degree to which wetlands can exist, the starting point is the hydrology. This feature, in turn, affects and defines physical and chemical wetland properties (such as nutrient availability, pH and environment, including soils), which determines what and how much biota, including vegetation, is found in the wetland (Figure 32) (Retallack 1990; Mitsch & Gosselink 1993, 2000, 2007).

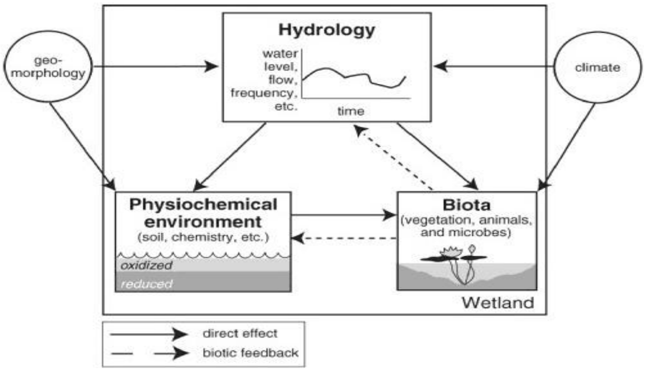


Figure 32 The three-component basis of a wetland definition: hydrology, physiochemical environment and biota. Note that these three components are not independent and that there is a significant feedback from the biota.

The general definition of wetland includes multiple ecosystems (Figure 33); although some types of formation processes are the same in all cases, more specific peculiarities can still be individually detected. In the pursuit of our goal, the processes which took place in the formation of wetland contexts settled during prehistory are highlighted.

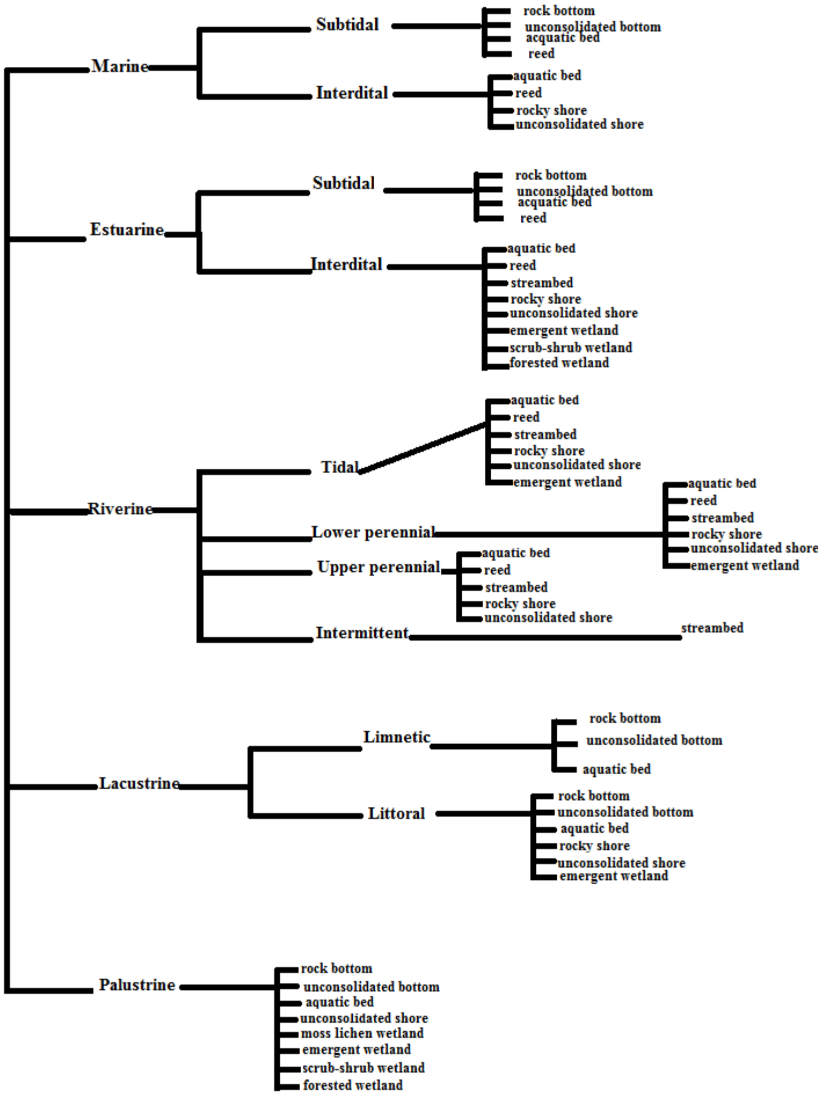


Figure 33 Hierarchy of wetlands and deepwater habitats in the US wetland classification (redrawing, from Cowardin et al. 1979), showing system, subsystems and classes.

The term "peat" is generically used for any wetland that has at some point accumulated partially decayed plant matter because of incomplete decomposition. The result can be an in-filled lake (terrestrialisation) or a process of waterlogging less wet mineral soils (paludification) (Dierßen 2003; Menotti 2012: 11) (Figure 34). Peat formation is even favoured by factors that reduce metabolic activity of micro-organisms, such as water saturation in the uppermost peat layers (the unsatured zone defined as acrotelm) especially in eutrophic areas. Peatlands are adapted to the extreme conditions of high water and low oxygen content of toxic elements and low availability of plant nutrients.

Their water chemistry varies from alkaline to acidic. Peats occur in all continents, from the tropical to the boreal and Arctic zones, from the sea level to high alpine conditions (Joosten & Clarke 2002). Many terms have been used to describe peat-forming wetlands, particularly in Europe (Verhoeven 1992; Glooschenko et al. 1993). For instance, the term "mire" refers to any peat-accumulating wetland, either bogs and fens. The slow decomposition of mosses, especially species of *Sphagnum* growing in acidic groundwater pools or shallow ponds, creates the classic bogs (Maltby & Barker 2009: 45). Fens are boggy landscapes formed in alkaline or neutral groundwater; they receive some drainage from surrounding areas and usually support marsh-like vegetation (herbaceous and woody plant species). Carrs are variants supporting woody swamp vegetation in addition to peat. A type of bog that differs from the raised is the blanket bog. In them, the drainage of water (especially on hills and mountains) is impeded by leaching and iron pan formation, which results in the formation and coverage of peat (usually moss and heather) over an originally “dry” surface (Hammond 1981; Maltby 2009; Menotti 2012: 11).

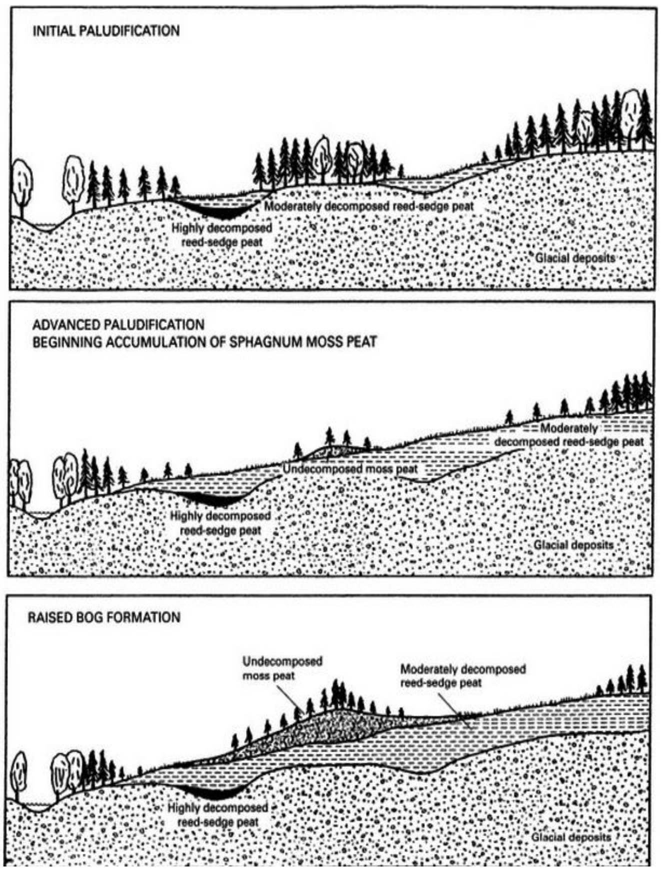


Figure 34 Stages in paludification of a northern landscape (from: Minnesota DNR 1987).

Other wetland contexts are bottomlands that consist of lowlands along rivers; in most cases they are located on alluvial and periodically flooded floodplains. The process of wetland development in river floodplains can be summarised as follows: marine transgression (during periods of sea-level rise) results in an impeded run-off of the river’s tributaries as the hydraulic gradient is reduced. This impeded run-off results in more frequent and increased longevity of overbank floodings and rising groundwater tables. This, in turn, favours the growth of species that tolerate a high groundwater table, especially Alnus (alder) in areas which previously were typically meadows (within the river floodplains) or deciduous forests (on higher ground). The high groundwater table and frequent floods inhibit the humidification of plant material, resulting in the development of floodplain peats or mires. Where the floodplains are unconstrained, a landward expansion of the (floodplain) mires is observed, during marine transgression. On the side of the river or estuary, reed swamps, saltmarsh and mudbanks may develop, resulting in peat and clastic sediments, overlying the basal peats. In periods of marine regression, a seaward expansion of the floodplain mire can be observed, resulting in an intercalated or upper peat. Furthermore, fresh or saltwater wetlands characterised by emergent herbaceous vegetation adapted to waterlogged soils are marshes. They occur in areas that are frequently or continuously inundated with water and they are most often associated with mineral soils that do not accumulate peat (Maltby & Barker 2009: 44-45). When marshes are dominated by wood vegetation (in particular trees and shrubs in North America and Phragmites in Europe), they are defined as swamps. These are terrestrial habitats formed where woody vegetation alternates with stretches of open water (Sharitz & Mitsch 1993; Dincauze 2001: 314; Maltby & Barker 2009: 44-45). Furthermore, along low-lying coastlines, deposit of salt marsh and other swamplands are attested; they are very similar to those of mudflat and lagoonal deposits. The latter includes coarse (fine sand) as well as fine (silt and clay) laminae, with some laminae rich in detrital organic matter (Goldberg & MacPhail 2006: 161). During their formation, the deposits of salt marsh and other swamplands have been affected by subaerial weathering, biological activity, surface and channel water flow.

There are also the lacustrine environments, often located in interfacing areas between wet and dry conditions. Lakes are closed bodies of standing water that vary considerably in size. The basins where they are formed have numerous origins, including volcanic and meteorite craters, glacial depressions left by decaying ice (kettles) or retreating ice (moraines), alluvial floodplains (oxbows and avulsed channels) or karstic depressions (sinkholes) (Goldberg & Macphail 2006: 112). Generally, lakes are categorised as either open or closed; the former, exorheic, have an outlet and consequently remain fresh, without concentrations of salts. They tend to be stable and have shorelines with short-range fluctuations in lake level.

The latter (endorheic) on the other hand have not outflow and dissolved solutes are concentrated; they are unstable and subjected to large inter-and intra-annual fluctuations in volume and position of the shoreline. The formation of lacustrine sediments is characterised by several phases. Clay and silty sediments are transported into the lake from streams: much of the coarser load is dropped there along the margins, while the finer material is carried in suspension by the combined action of currents-winds and they eventually settle to the bottom. At the same time, wind-induced waves and currents may also redistribute coarser materials around the coastal margins (Nichols 1999; Goldberg & MacPhail 2006: 112). The lacustrine deposits include evaporites (usually gypsum or salts), calcareous beds (including chalk), marls, silts and clays, sands and organic matters (Butzer 1971: 185-7). Evaporites consist mainly of gypsum (calcium sulphate) and other salts such as sodium, magnesium and potassium chlorides or sulphates. Such beds frequently indicate desiccation or lake shrinkage during the dry season or long-term reduction of a larger lake to a lagoon or salt pan, while lacustrine chalks usually indicate fluctuation of oxygen content. Freshwater marl sedimentation is commonly confined to comparatively small water bodies and the lime content included in the lake deposits may be derived by plant or inorganic agencies. This brief explanation of the most exploited wetland ecosystems is suitable to clarify the main features of depositional contexts and landscape settings in which traces of past activities have been attested, from the dawn of civilisation. A selection of some case studies, e.g. archaeological settlements retrieved in lakeshore, will be introduced, to reconstruct all the tiles of our archaeological record - “puzzle”, starting from the first pre-depositional status.

3.2.3. The pre-depositional status of wetland lacustrine archaeological contexts

Among the multiplicity of wetland ecosystems, our research is focused on pile-dwellings - lakeside contexts. In the figure 6, a model of the most widespread geological layers of some morenic south-alpine italian lakeside environments is summarised (Leonardi & Balista 1996: 201) (Figure 35)[2].

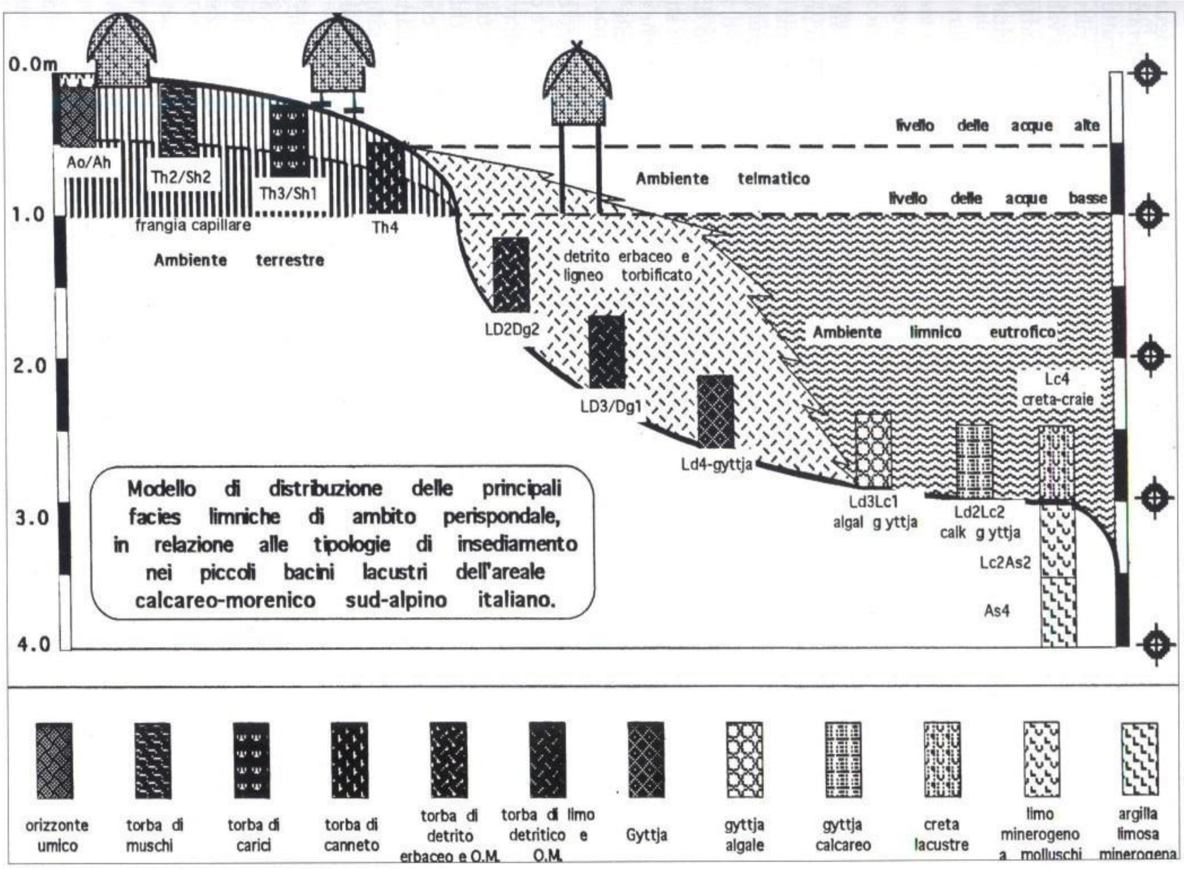


Figure 35 Lakeside settlements: stratigraphic model with related sedimentary facies (from Leonardi & Balista 1996: 201, figure 3) (drawing by Balista).

The majority of these archaeological contexts seemed to be settled during the past imposing on a similar natural pre-depositional layer defined as lake marl stratum or silty-clay gyttja. This layer, composed by carbonates (silty carbonate mud, micrite), is formed by limnic precipitation in many lakes of the temperate zone, where the water depth ranges between 0.5 and 12 m (Muckle 1942; Schindler 1976; Brochier 1983; Ismail-Meyer et al. 2013: 321). In particular, in some archaeological sites in the Circum-Alpine region, the laminated micrite is deposited on the lake bottom as carbonate mud, formed by seasonal natural processes (Platt & Wright 1991; Freyter & Verrecchia 2002). Depending on the geomorphological situation of the riparian zone and the hinterland, changing amounts of fluvial sands can be added to the lake marl (Ismail-Meyer et al 2013: 321). The sediment often shows alternating sequences of denser micrite and looser sandy laminations, containing more algal remains and molluscs; amounts of fluvial sands can be added to the lake marl depending on the geomorphological situation of the hintherland (Figure 36).

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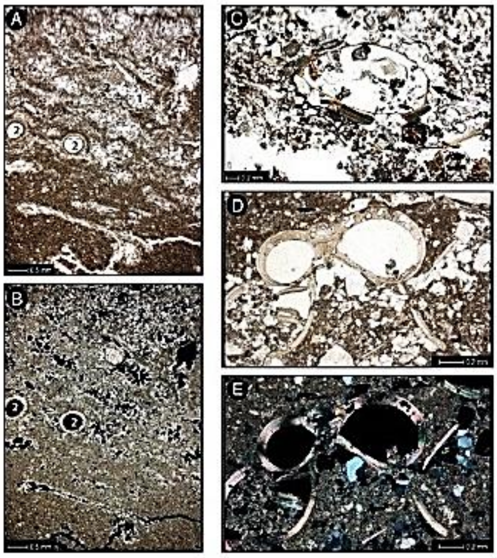
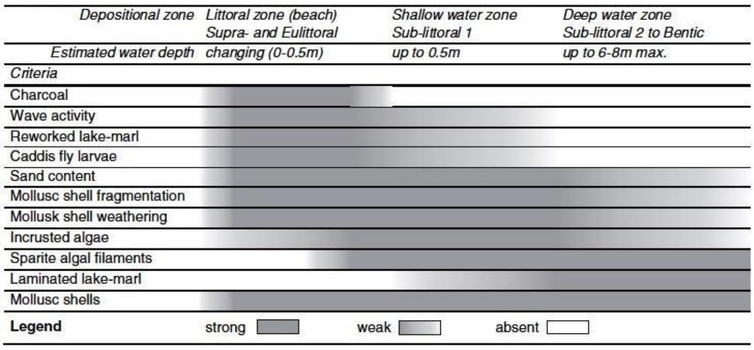
[2] In this article, the authors analysed the sites of Fiavè, Ledro, Lucone, Polada, Lavagnone, Barche di Solferino, Bande di Cavriana, Castellaro Lagusello, Cisano, Cascina di Sona, Cavaion, Lagazzi del Vho, Canar, Arquà and Fimon (p.202)



(A) Stratified, carbonate rich lake marl with cross-section through stems of chara-algae (1) and oogonia (2). Zug-Riedmatt M96, plane polarized light (PPL).
(B) Same as (A), the chara stems (1) and carbonate rim of the oogonia (2) are easily recognizable, cross-polarized light (XPL).
(C) Cross-section through a caddis fly larva (arrow), with adherent sand grains. Arbon-Bleiche 3 M1036, PPL.
(D) Weathered mollusc shells in a sandy lake marl. Risch-Aabach M4, PPL.
(E) Same as (D), XPL.

Figure 36 Micromorphological analyses on the lake marl (from Ismail-Meyer et al. 2013: 327, figure 7).

Thanks to detailed results of micromorphological analyses applied to some Neolithic lakeshore settlements (such as Arbon-Bleiche 3; Cham-Eslen; Zug-Riedmatt; Risch-Aabach; Stansstad-Kehrsiten; Lobsigesee; from Ismail-Meyer et al. 2013), specific depositional environment can be recognised in the littoral zone. The currents and wave action cause reworking, reprocessing and sorting of lake marl: in particular, formation below the wave base in calm sub-littoral conditions produced finely laminated lake marl (sub-littoral 2 to bentic), whereas reworking by waves in shallow waters produced homogeneous layers of lake marl, with fragmented mollusc shells and algal filaments (sub-littoral 1) (Figure 37) (Brochier 1983, 1989; Pétrequin & Magny 1986; Ostendorp 1990a; Ismail-Meyer & Rentzel 2004; Digerfeldt et al. 2007; Ismail-Meyer et al. 2013: 321).



Depositional zone	Littoral zone (beach) Supra- and Eulittoral	Shallow water zone Sub-littoral 1	Deep water zone Sub-littoral 2 to Bentic
Estimated water depth	changing (0-0.5m)	up to 0.5m	up to 6-8m max.
Criteria			
Charcoal	▓	☐	☐
Wave activity	▓	▒	☐
Reworked lake-marl	▓	▒	☐
Caddis fly larvae	▓	▒	☐
Sand content	▓	▓	▒
Mollusc shell fragmentation	▓	▓	▒
Mollusk shell weathering	▓	▓	▒
Incrusted algae	▒	▓	▒
Sparite algal filaments	☐	▓	▓
Laminated lake-marl	☐	▒	▓
Mollusc shells	▓	▓	▓
Legend	strong ▓	weak ▒	absent ☐

Figure 37 Division of depositional environments and their recognition from the characteristics of lake marl (from Ismail-Meyer et al 2013: 326, table III).

After the removal of finer particles, sand became enriched and a lag deposit was formed. At Constance lake (e.g. Arbon-Bleiche 3, Hornstaad and Allensbach), a leaching of the fine matrix during the Neolithic period took place and consequently sandy beach deposits were formed (Ostendorp 1990a, 1990b; Ismail-Meyer & Rentzel 2004; Ismail-Meyer et al. 2013: 321). In addition, wave erosion prevents a further accumulation in the littoral zone, leading to the progradation of the shoreline and the formation of a flat surface that can expand toward the lake centre with time (Magny 1978; Pétrequin & Magny 1986; Platt & Wright 1991; Magny 1992a). The same pre-depositional natural sediment is attested at some European lake-side settlements:

among those, some are included into the Circum-Alpine region (such as the Alpenquai lake-dwelling on Zurich Lake (Wiemann et al. 2012: 66), in central Italy (such as at the Mezzano Lake, Lazio, Central Italy (homogeneous and laminated gyttia with interbedded layers of turbidites) (Sadori et al. 2004: 5) and some North-European archaeological contexts (such as the sites 1 and 2 recovered at the Luokesas Lake (Moletai District of Eastern Lithuania) (Figures 38 and 39) (Menotti et al. 2005: 385,397; Lewis 2007: 33,3 6, 47-8; Prenckénaité 2014).

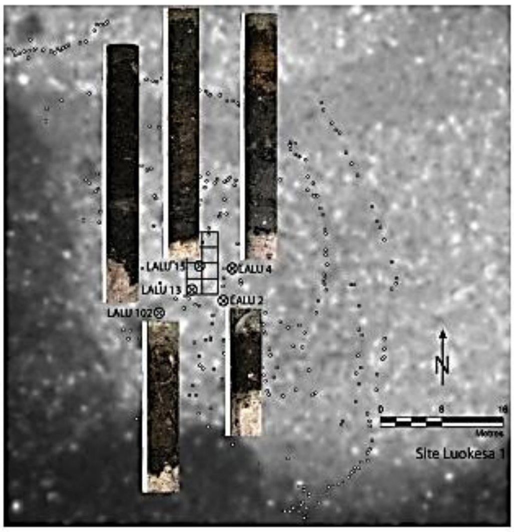


Fig. 9

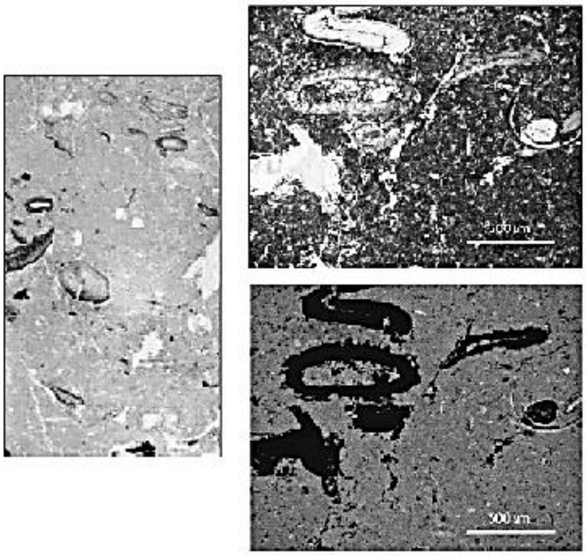


Fig. 10

Figure 38 Lake marl platform (light grey) with the site L1, the piles (dots), the measurement grid for the excavation and the micromorphologically analysed profile columns (crosses) with photographs of the opened columns included (Pranckénaité & Pollmann).
Figure 39 Thin section images from Luokesas Lake L2, S3. Typical fabric of the lake marl (grey micritic fabric and plant remains) (from Lewis 2007: 41, figure 5).

Among the French archaeological settlements, at the sites of Chindrieux and Tresserve, located on the eastern shore of Bourget Lake (Savoie, France), the basal layer is represented by a lake marl unit (Gauthier & Richard 2009: 112, 114). In Slovenia, three archaeological pile-dwellings recovered at the Ljubjansko barje (Ger. Das Laibacher Moor, situated in central Slovenia, near the capital Ljubljana) show a sedimentary sequence that starts with a layer of lake marl (Melik 1946; Tancik 1965; Verbič & Horvat 2009).

In particular, at the site Resnikov Prekop, this lake marl or gyttja is predominated by a carbonate-rich sediments, composed especially by homogeneous grey clay, snail and bivalve shells (Turk & Velušček 2013: 186). The same depositional layer characterises the Blatna Brezovica and Stare Gmajne that show a lower concentration of carbonate sediment (Turk & Velušček 2013: 187). In Italy, across the shore of the Lucone Lake - a former lake in the western amphitheatre system of the Garda Lake - pile-dwelling settlements from the Early-Middle Bronze Age are attested. According to the data derived from one core (LUC-1 of 7 m length, recovered at a distance of only 100 m from one settlement), the basal sediment consisted of silty clay characterised by high percentages of non-carbonate minerals and increasing organic matter[3]. This layer is followed by a dark silty gyttja alternated with a clay gyttja (Valsecchi et

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[3] Although these stratigraphical data derived from the core, located at 100 m from the settlement A, we can consider these data valid also for the settlement's basal sediment, as another core (LUC-2) confirmed the results of the first one.

al. 2006: 99-113). Moreover, a similar natural basal layer characterised the site of Ledro I, located in the Ledro Lake, on the southern slope of the Alps, at c. 6 km north of Garda Lake. In particular, Ledro I is located on the southeastern shore, just west of an area occupied by Middle Bronze Age lake-dwellings in the outlet area (Magny et al. 2009: 577). The basal deposit is formed by a pebble beach layer, typical of the lake-shore sedimentation; a carbonate lake-marl layer finally overlaid the morainic deposits (Magny et al. 2009: 580) (Figure 40).

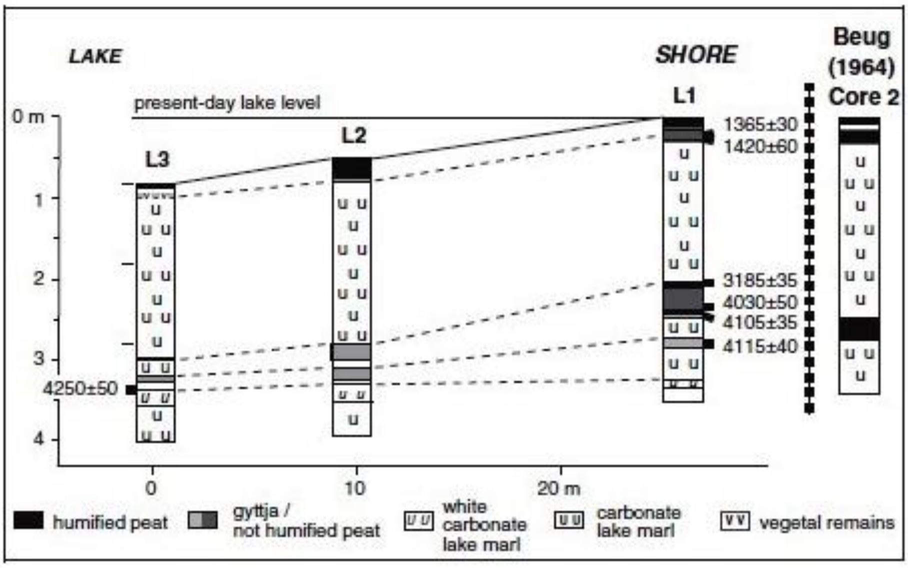

Figure 40 Core transect established on Ledro I. On the right the lithostratigraphic profile of core 2 pollen analysed by Beug (1964) is shown (from Magny et al 2009: 576, figure 1).

At the site of La Draga, on the edge of Banyoles Lake (Girona, Spain), the base level of the stratigraphic sequence consists of carbonate sands of bioclastic origin (Level IX) (Palomo et al. 2014: 62). Other lakeside settlements are characterised by different natural basal deposits produced by the combined action of different lake formation processes and environmental settings. At the site of Dispilio, located on the southern shore of Orestias Lake (Kastoria, northern Greece) (Hourmouziades 1996; Menotti 2004), the lacustrine sediments of the pre-occupation show relatively deep-lake sedimentary environments (bluish muds and sands). Furthermore, discrete horizons of olive gray sediment associated with root casts, organic staining and decayed organic matter are attested, indicating falls in lake level (Karkanas et al. 2011: 84, 107). At the site of Ballyarnet, on the edge of Ballyarnet Lake (4 km to the north-west of Derry city, Ireland) some archaeological remains of a lake-settlement were retrieved. In this case, a peat deposit rich in glacial clay characterised the basal natural sediment (Ó Néill et al. 2007: 42-44). In the pile-dwelling of San Savino (San Savino site 2), located on the shore of Trasimeno Lake (Magione, Perugia, Central Italy) (Angelini et al. 2012), the peat deposit, recovered below the anthropic layer, is a grey-greenish silty sediment with shells (Angelini et al. 2012: 6).

Furthermore, a number of prehistoric settlements, for instance in Italy, were built along the rivers (e.g. Isolone del Mincio (Piccoli & Peroni 1992; Aspes 1997), San Pietro Canàr (Balista & Bellintani 1998), Lagona at Poggiomarino (Albore Livadie 2005; Albore Livadie et al. 2008; Cicirelli et al. 2008) or lagoons (e.g. Stagno at Livorno (Zanini & Martinelli 2005; Giachi et al. 2010). Focusing on river settlements, at the site of Lagona (Poggiomarino), the recent stratigraphic analysis are located on the right bank of a wide deviation drawn by the current

Sarno River. Here, a salty clay base layer (SU 7347) has been identified. This sediment, typical of a fluvial-lacustrine environment, is characterised by an extremely low-energy hydrological regime and rich on aquatic flora and shells. It has been extended horizontally and has been recovered from some of the site's trenches (Figure 41).

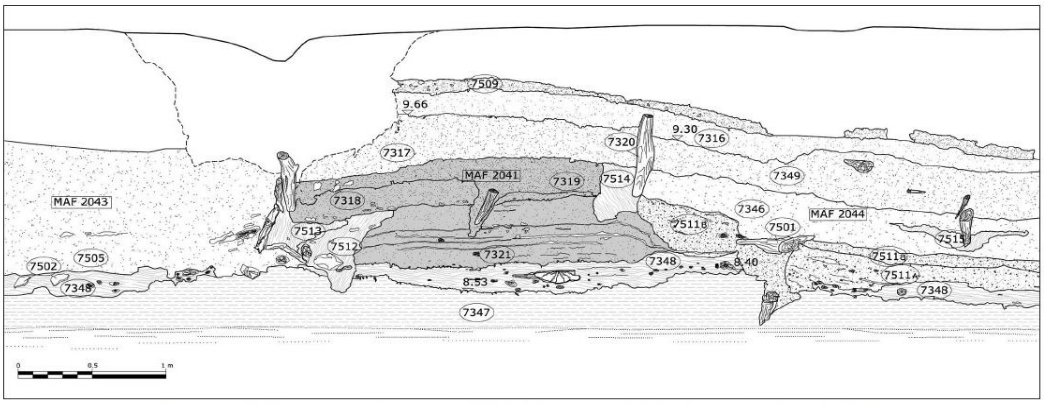

Figure 41 Site’s trench: stratigraphic section with highlighted the different layers (from Albore Livadie et al 2008: 16, figure 5).

At the site of San Pietro Canàr, anthropogenic deposits overlapped a base sequence of peat deposits which were covered in alluvial sediments (Balista & Bellintani 1998). Regarding the lagoons, the site of Stagno constitutes a useful case: this pile-dwelling is located near the city of Livorno, about 7 km from the present coastline, at the southernmost limit of an ancient swamp. The archaeological deposit consisted of clayey layers alternated with organic clay banks; at the bottom, in the sector C (Ia), a homogeneous level with shells indicates the former presence of a brackish lagoon (SU 118 and 114). A lagoonal level sealed the deposit, suggesting that the natural environment preceding the pile-dwelling settlement was re-established after its abandonment (Giachi et al. 2010: 1261). Similarly, many lake-dwelling-like settlements have been discovered in marsh and fen-lands, the *Moorsidlungen* (e.g. Gachnang-Niederwil Egelsee (Hasenfratz & Casparie 2006), and Wasserburg-Buchau (Reinerth 1928; Kimmig 1992).

The outstanding case of *Terramare* settlements of Po Valley deserves finally a particular mention; the “*palafitte a secco*” are settlements surrounded by a moat and an earthen rampart (among others Bernabò Brea & Mutti 1994; Bernabò Brea et al. 1997; Pearce 1998; Cremaschi et al. 2006; Nicosia et al. 2011: 280-92; Menotti 2012: 155). These sites have been identified both south of Po river (Emilia-Romagna) (Cremaschi 1997; Cremaschi et al. 2006) and north of that river, in lower Venetian plain and southern Lombardy (Balista et al. 1998; Cremaschi et al. 2006; Nicosia et al. 2011: 280). At Fondo Paviani, the base of the archaeological sequence is characterised by peat deposits, covered by alluvial sediment. They culminated with a clay-textured horizon (5Bw), the substratum which embraced archaeological deposit (Figures 42 A-B) (Nicosia et al. 2011: 283).

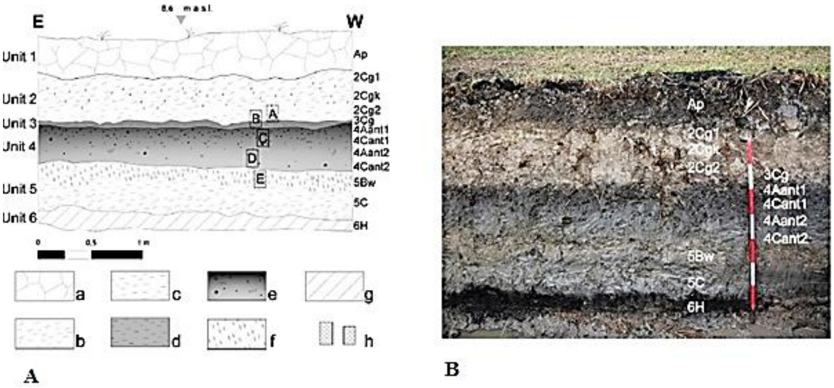

Figure 42A Fondo Paviani. Profile 1, with indication of main litho-stratigraphic units (left) and pedogenic horizons (right). a) Present-day plough horizon. b)Silty clays. c)Clays. d)Organic clays. e)Bronze Age anthropogenic deposits. f)Olive-brown concretions. g)Peat. h)Thin sections (from Nicosia et al. 2011: 283, figure 4); Figure 42B Fondo Paviani. Profile 1, with indication of the pedogenic horizons (from Nicosia et al. 2011: 283, figure 5).

During this stage -as in the later phases of formation processes - lake levels start to change due to climatic fluctuations which occurred during the Holocene (Magny 1978; Magny et al. 2004, 2009; Menotti 2001, 2004, 2012). Such fluctuations have been documented in some cases using accurate micromorphological analyses. These showed that the lake level decreased, enabling the emersion of lake marl that formed a hard compact surface (Schurrenberger et al. 2003): above this layer, flat surfaces were formed. At some Neolithic lakeside settlements a rather good preservation of pollen and mollusc shells could hint to a short hiatus (presumably a few weeks) that occurred just before the settlement was founded (Magny 1978; Wallace 1999; Ismail-Meyer 2010; Ismail-Meyer et al. 2013: 325).

3.3. The intra-depositional phase

A lake- or pile-dwelling, is essentially a form of settlement construction adapted to specific humid and damp water environments. Although the conscious choice of inhabit wetland locations was made for various possible reasons, it had advantages as well as disadvantages. Several factors, including the potential ease of construction and life, have been suggested to justify the occupation of the lakeshore (Barfield 1994: 132; Coles & Coles 1992; Pétrequin 1984: 321; Pétrequin & Bailly 2004; Menotti & Pranckenaite 2008; Pydyn & Gackowski 2011: 134; Menotti 2012, 2013). However, according to Jennings' perspective, concept of "ease" are entirely subjective and the extent to which these factors influenced the choice to occupy wetland environments is uncertain (Jenning 2014: 81). Hence, humid settlements are characterised by specific problems, such as the poor preservation of agricultural products and health difficulties, that are not encountered in the inland (Horden & Purcell 2000: ch. VI. 5; Walsh 2014: 80-81); furthermore, unpredictable lake—level fluctuations may affect the lifespan of settlements and houses (Ebersbach 2012: 285).

Defensive aspects could partially motivate the occupation, although this may have been true only in some situations. For instance, while certain sites show indications of a defensive function (such as Wasserburg-Buchau (Reinerth 1928; Kimmig W 1992; Billamboz 2009), Siedlung-Forschner (Menotti 2001: 130; Siedlungsarchäologie im Alpenvorland XI 2009), and Greifensee-Böschen (Eberschweiler et al. 2007), others do not appear particularly defensive in nature (such as Hauterive-Champréveyres (Benkert & Egger 1986; Rychner-Faraggi 1993), Ürschhausen-Horn (Gollnisch-Moos 1999), Zurich-Alpenquai (Viollier et al. 1924; Mäder 2001) and Cortaillod-Est (Arnold 1990a) (Jennings 2014: 81).

It is also possible that lake-settlements were occupied to access and control trade routes, particularly where water features constituted natural crossroads; in these contexts, models, peoples and objects seem to have moved during the past.

Interaction between human communities and environment as well as the preference for specific features of the landscape have certainly influenced the choice of where to locate settlements; people could take advantage of availability of agriculturally productive land, the presence of rich wetland resources, such as fish, waterfowl and climatically favourable conditions (Vogt & Guyan 1977; Pydyn 2010; Menotti 2012: 104-106). During the Neolithic Age, when the lake levels were low and flat moraine shoals near the shore could easily be utilised as "empty platforms", some lake-dwellings in the Circum-Alpine region started to be settled (Magny 1978; Magny 1993; Monnier et al. 1991; Ismail-Meyer et al. 2013: 324). A similar phenomenon occurred in Northern Europe (such as in the case of the settlements at Valgjärv Lake (Koorküla, Estonia) where the settlers found a favourable place on a peninsula in the lake, which was later covered by water (Selirand 1986; Roio 2007: 27). These areas were probably ideal locations to erect settlements so close to (or even in) the water (Hasenfratz & Gross-Klee 2005; Ismail-Meyer et al. 2013: 318).

Furthermore, previous occupation of similar sites could influence the subsequent choice of inhabit dwellings, according to the "cultural memory" perspective (Jennings 2014: 80)[4]; for instance, this is the case of the lakeside settlements reoccupied during the Bronze Age and Early Iron Age at the Circum-Alpine region, after a first Neolithic occupation. As firstly quoted by Schlanger (Schlanger 1992: 92) and improved by Cameron (1993), lakeside dwellings are, in some extent, "persistent places": the long-term occupation of this region had a complex alternated trajectory of occupancy and abandonment, a sequence of social decisions and dispositions that is attested in such life histories of places (Crumley 1995: 1177).

Although the majority of lake-dwelling settlements coincide with periods of favourable climate, lakeshores were even settled despite evidence of climate deterioration (Menotti 2009: 63). During a colder and damper climatic period, for instance, the lake-settlements in the south-eastern Baltic region (transition period between the Late Bronze and Early Iron Age) were occupied (such as the Luokesa sites (Pranckėnaitė 2012, 2014); however, they were inhabited in nearly all cases for only short periods of probably a few decades (Gackowski 2000; Pydyn 2000; Pranckėnaitė 2014: 342).

While these factors, as climate and environmental morphology, enabled lake-dwellers to occupy the proximity of the lakes, negative influence on the economy has been detected, looking at crop failures; this emerged for instance in the already mentioned communities of Lithuania of the 1st millennium BC, where livestock farming remained an especially important part of the economy compared to agriculture (Luchtanas 1992; Daugnora & Girinkas 2004; Pranckénaité 2014: 342). This condition has been caused in particular by the alternation of cold and wet summers (Pfister 2001; Menotti 2009: 63). Other reasons behind human occupation of wetland environments and lake-dwellings largely remain unknown (Jennings 2014: 80).

The choice to settle a landscape activates several cultural formation processes that start from the organisation of space: a package of "structural or architectural elements" (Ellison 1975: 292-307, 1981: 417-21; Barrett et al. 1991; Brück 1999: 145) were built as immovable form of material culture (Brück 1999; Gerritsen 2003, 2008; Jennings 2012a; Arnoldussen 2013; Jennings 2014: 88).

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[4] For the relation place/landscape memory see Van Dyke & Alcock 2003: 5, suggested by Jennings 2014: 80.

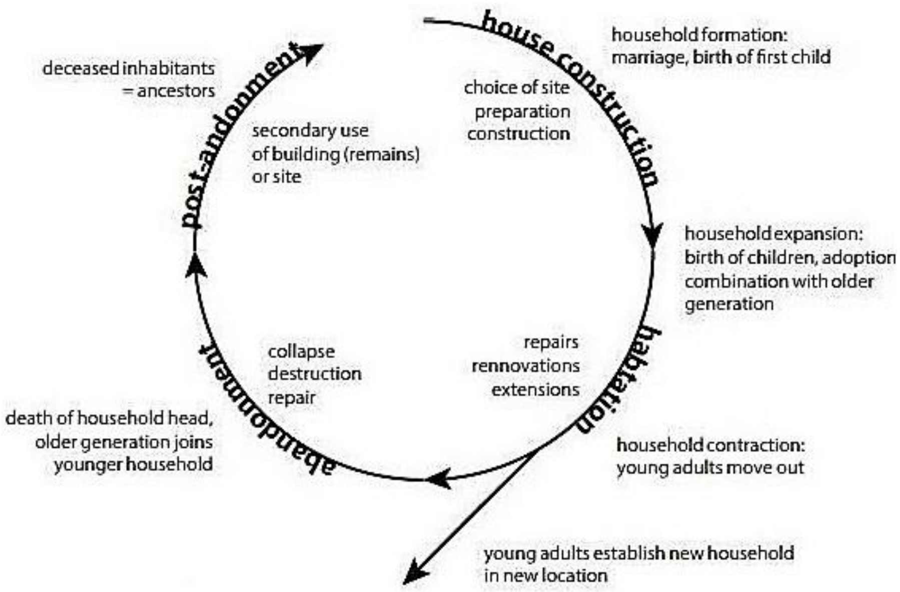


Figure 43 The potential biography of a single-phase farmstead (in northern Europe) (from Jennings 2014, figure 5.5).

Through the analysis of different houses' life-cycles, such as the planning, the construction process, the occupation period (which includes all renovation, expansion and/or internal modification) and the final abandonment, their biography can be reconstructed (figure 14), in a micro-scale (single house) and in a macro perspective (whole the settlement). In the following sections, explanatory examples will be provided. However, given the breadth of the topic and the large amount of existing data, these example are not to be considered as fully exhaustive by any means.

3.3.1 The first anthropogenic intra-depositional process: the biography of houses in wetland context

Once the choice to settle in a wetland landscape was made, the community needed to adapt the natural setting for them to successfully live in. They could modify flora mainly in three ways: 1) introducing or favouring edible plants, 2) opening up woods for animal husbandry and, at the same time, 3) using natural resources such as wood for heating, building or producing metals. Each of these scenarios would produce a characteristic vegetation pattern, whose traces should be found in the pollen and micro-charcoal record (Sadori et al. 2004: 11). Some changes in natural settings could involve the decision of building a settlement: the manifold use of wood implies a decrease of their presence in the environment due to the clearance of forests. This phenomenon is frequently followed by high values of anthropogenic indicators such as cultivated crops, new plant species, anthropogenic taxa and finally the enormous increase in microscopic and macroscopic charcoal concentration. This panorama is widespread in these case studies: a strong reduction of forest cover was observed in coincidence with the establishment of Late Neolithic pile-dwellings (such as Palù di Livenza, Northern Italy (Pini 2004) and Bronze Age settlements (Northern Italy: among others Terramare of Tabina di Magreta (Bertolani Marchetti et al. 1988), Montale (Mercuri et al. 2006), Poviglio Santa Rosa (Cremaschi et al. 2006) and the pile-dwellings of Lucone (Tinner et al. 2006; Valsecchi et al. 2006), Ledro (zone LB3 during the Bronze Age) (Magny et al. 2009), Lavagnone (De Marinis et al. 2005); Central Italy: for instance the pile-dwelling of San Savino (Trasimeno Lake)

(Angelini et al. 2013) and Mezzano (Sadori et al. 2004). The cultural process of deforestation is also attested, during the Early Bronze Age, at ZH-Mozartstrasse (Menotti 2001: 101), as well as at Bodman-Schachen 1 (Liese-Kleiber 1985,1987; Rösch 1987, 1990a, 1990b, 1993, 1996; Frank 1989); during the Late Bronze Age the clearance was attested also at the site of Zurich-Alpenquai, as indicated by the presence of extended cleared areas and of grassland in pollen and macro-remains retrieved in the cultural layers of phase B (Jacomet & Brombacher 2009; Wiemann et al. 2012:80). Nevertheless, aridity crises could even cause a natural deforestation, such as in the case of some Central Italy Bronze Age contexts: the 3800 varve years BP were characterised by this phenomenon well-known in many pollen diagrams from central Italy. This climate change could cause the human's local presence in the Mezzano Lake (Sadori et al. 2004: 16) between 3700 and 3500 years BP.

The spatial arrangement of buildings might be decided during this stage: as majority of settlements have been only partially excavated, analyses related to the use of space are quite limited (Schlichtherle 2004; Ebersbach 2012: 291; Menotti 2012: 149). However, some general observations can be elaborated on the base of available data. The orientation of houses seems to follow patterns that have been varying across time and regions. For instance, Neolithic and Bronze Age settlements in northern Europe and Scandinavia differ considerably from those in the Circum-Alpine region (Menotti 2012: 149). The latter settlements tend to be more clustered and follow a regularised plan o semi-regular arrangement, such as settlements around Feder Lake, at Hauterive-Champréveyres and Cortaillod-Est (Menotti 2004; Primas 2008: 39), as well as the sites of Mozartstrasse and Kleiner-Hafner (Menotti 2004). Lake-dwellings on Constance Lake were erected along a road leading to the waterfront. While these Bronze Age settlements were constructed in rows, those of Federsee Lake (such as Siedlung Forschner and Wasserburg-Buchau) displayed conglomerates of buildings with small clusters separated from each other and all constrained by a surrounding palisade (Jennings 2014: 90). This latter structure may probably have been built so that the settlement did not appear particularly defensive in nature, or in order to impose a limit on the potential settlement size through the erection of perimeter palisades and fences. Massive and/or protective palisades were also attested at the French lakeside settlements (such as Clairvaux and Chalain (in particular Chalain 19) (Pétrequin 1991; Pétrequin 1997; Pétrequin et al. 1999), in Slovenia (such as Maharski prekop where the settlement was protected by a double enclosure (Bregant 1974, 1975, 1996; Čufar et al. 2010: 2037; Turk & Velušček 2013), at north-European wetland villages (as for instance Biskupin (Billamboz 2004), in some Italian lakeside dwellings (Lavagnone 2 (De Marinis 2000: 103), Fiavé 6 (Marzatico 2004: 87) and Terramare (such as, for instance, at Villaggio Grande of Terramara di Santa Rosa Poviglio, (Cremaschi 2010: 36) at Fondo Paviani, where a quadrangular earthen rampart surrounded the settlement (Nicosia et al. 2011: 281). At Greifensee-Böchen a surrounding palisade and "hedgehog-like" structure would have acted as both defensive measures and windbreaks.

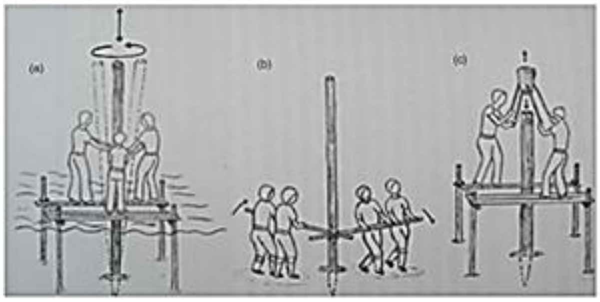
Village expansion also involved the construction of some structures outside the surrounding palisade but within the hedgehog structure (Jennings 2014: 85). The settlements of Siedlung-Forschner stood out, as the 15 houses were protected by a massive wooden wall nearby them and a long and robust palisade a few metres outside the wall (Ckeefer 1985, 1986, 1990; Torke 1987, 1989, 1990). The wooden fences, surrounding the site L1 of Luokesas, were not very solid and strong, although their height and type of construction remains unclear; this means that the purpose of defense was not of high priority, as the structure would most likely be aimed at preventing livestock from escaping (Pranckėnaitė 2012, 2014: 346, 351).

Some fences were finally constructed along with settlements and they seemed to be easily and readily moved, disassembled and erected again, as at Suzt-Lattrigen (Ebersbach 2012: 290, 292, figure 17.5). Their defensive features differ widely, from semi-circular structures built with thin sticks to real palisades. Archaeological evidence indicates that Bronze Age settlements might have been more often fortified than Neolithic ones (Ebersbach 2012: 290-1). The sites where these defensive structures were not attested are in some cases referred to as “open” settlements, such as Ürschhausen-Horn (Primas 2008: 39; Jennings 2014: 91). Throughout high-precision dating of posts reconstruction of the whole settlement’s development can be obtained: in response to a usual pattern one or two houses started in a given place, followed by few additional built in the next year. After two or three years a sudden increase of another ten or more new buildings can be seen, with some more houses being built in the adjacent areas. This pattern is attested, among others sites, at Arbon-Bleiche, Greifensee and Sutz-Lattrigen (Ebersbach 2012: 291).

The architecture of houses also varies across time and space, due to environmental and technological factors as well as cultural and regional reasons. As mentioned above, the natural pre-depositional layer consisted mainly of lake marl sediments; available on various glacial and morainic lakes, they are often in a liquid state, retaining thixosotropic characteristics similar to that of quicksand (Menotti 2012: 297). Wooden piles of buildings got easily cutted into this type of sediments, since they are relatively solid until the vibrations of penetrating object liquefy them. This condition facilitated the penetration of object itself and sediments stabilised again once the vibration stopped. When the dry surface is removed or wetted with additional water, the entire process of driving a wooden pile 2-3 metres into the lake marl takes no more than ten minutes (Monnier et al. 1991:34, Schöber 1997: 86; Menotti & Pranckenaite 2008: 3; Menotti 2012: 298). This process can be even faster if sediments are particularly soft and inundated, such as in the eastern Baltic Sea region; there piles were driven up to 4.5 metres into the lacustrine sediment, such as at pile settlements on Luokesas Lake (Menotti et al. 2005: 385; Menotti & Pranckenaite 2008) and in other European lakeside dwellings (such as at Fiavé (Perini 1987: 80).

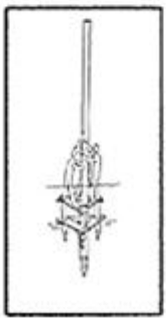
Although there are various methods of driving wooden piles into the ground (figure 44A), the most common one is the rotate-lift-and-drop technique, as confirmed by experimental analyses based on material evidence recovered at the lake-dwelling settlement on Luokesas Lake (Lithuania) (figures 44B 1-2-3).

44A



44B.1

44B.2



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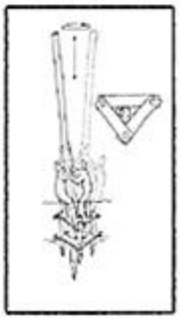

Figure 44A Three techniques of driving wooden piles into the ground lake marl: a)the rotate-lift-and-drop technique; b)the rotation technique; c)the wooden mallet technique (drawings: Olenka Dmytryk) (from Menotti 2012: 299, figure 7.13); Figure 44B.1 The pile in vertical position with three people standing on the movable wooden structure, ready to begin driving it into the lake marl (Photo: E. Pranckenaite) (from Menotti & Prankenaite 2008: 7, figure 15a). Figure 44B.2 Schematic illustration of the beginning of the experiment (three people standing on the movable structure, ready to begin driving the pile in the lake-marl – the lake water is about as high as the structure (drawning: B Pollmann) (from Menotti & Prankenaite 2008: 7, figure 15b). Figure 44B.3 Schematic illustration of the process of driving the pile into the lake marl (conical rotation, uplifting and dropping of the pile (Drawing: B. Pollmann) (from Menotti & Prankenaite 2008: 7, figure 16).

This was the technique mainly used in the lake-dwelling tradition of the Circum-Alpine region, during the Neolithic and Bronze Age. On the contrary, in the case of peat sediments, driving wooden piles is a much harder task. Piles cannot usually be driven into the peat more than 1 metre-deep, even with the help of an initially excavated posthole (Menotti 2012: 297). It is therefore not surprising that the majority of houses found in peatbog environments (or shrinking lakes) were built directly on the ground (Schlichtherle 1997a, 2002, 2004; Schlichtherle & Strobel 1999; Menotti 2012).

The process of adaptation to the environment involves also the choice of house architecture and its construction. For instance, while in a semi-wet marshland environment the community could choose between a pile-dwelling and a ground floor house, lakeshores could be only settled with pile-dwellings. These ancient architectural traditions of house construction are still adopted among present-day cultural groups: one of the best example is the pile-dwelling of Ganvié, on Nokouè Lake (Benin, Africa) (Pétrequin 1997). Here, people still live in traditional wooden houses, especially constructed on stilts. The resemblance of these modern settlements on stilts to the prehistoric European pile-dwellings of the Circum-Alpine regions is striking (Figure 45).

Figure 45 Contemporary pile-dwellings at Ganvié on Nokoue lake, Benin (Photograph: P. Pétrequin) (from Menotti 2012: 62, figure 2.5; Pétrequin 1997, figure 128).

Diverse building techniques and house architecture have been characterising the European lake-dwelling tradition. Thanks to extensive excavations and a long history of research in some European regions, especially the Circum-Alpine region, a good understanding of a variety of construction techniques utilised in moor- and lake-dwellings is available (Menotti 2012: 132; Jennings 2014: 80). Three widespread models have proposed during past decades regarding methods of construction employed in lakeside dwellings (the *Pfahlbauproblem*), with Keller (Keller & Heierli 1854), Reinerth (Reinerth 1932), Vogt (Vogt 1955) and Paret (Paret 1958) as authors. The "reconciliation" between these views was possible (Seifert 1996: 168-83; Benkert et al. 1998; Menotti 2001b: 324-6, 2012: 132-139; Jennings 2014: 81), even since their combination was attested in some archaeological contexts. This can also occur in the same settlement during different chronologies and according to change of environmental conditions, as lake-level fluctuations.

Lake-dwelling architectural types (pile-dwelling and ground floor houses) involve several construction techniques, which may vary according to their geographical location, chronology and the surrounding environmental conditions (Menotti 2012: 136). Different approaches were used to the foundation of buildings in order to compensate for marshy ground and topographic undulation: compact homogeneous loam floors could be laid directly on the ground with surrounding timber lintels. At the site of Lobsigesee and Cham-Eslen, they seem to have been connected to the perimeter of the houses. At Arbon Bleiche 3 they are combined with anthropogenic components (such as micro charcoal, ashes, fine organic material, charred macro remains and/or artefacts) (Ismail-Meyer & Rentzel 2004; Ismail-Meyer et al. 2013: 327). In other cases, grid-work timbers could be placed within the surrounding lintel structure to provide extra support for the floor (Jennings 2014: 83-4). At Greifensee-Böschen various degrees of stabilising methods were utilised: timbers or beams were secured together at their overlapping ends with treenails or binding. They limited the amount of movement that could occur within the structure itself. Furthermore, guiding piles were driven into the ground through pre-cut timber boards that served as weight spreaders for the above building structure (Jennings 2014: 85-6). For instance, the foundation of Fiavé 6, along the bank and on the bed of the Carera Lake, consisted of vertically pierced boards, i.e boards with holes for the allocation of the tie slats. They served to hold a grid foundation on the lake bottom and lay at right angles to each other, in order to distribute the weight of the huts that stood above in a regular manner (Marzatico 2004: 87-89). In other cases (such as in Austria, at the three settlements of Schärfling, Misling 2 and Weyregg-Landunfssteg) the compensation for the instability of the lake floor is realised through log frameworks, used as foundations of huts (Offenberger 1981; Ruttkay et al. 2004: 51). Here, this framework is fastened to the lake floor with pegs. Other settlements displayed houses built on foundation frames and with floorings of perpendicularly set crossbeams, as in the French Jura (Chalain Lake) (Pétrequin 1991; Pétrequin & Bailly 2004: 36-45). In Northern Italy a further quite widespread building technique is known, the *bonifica* (Figure 46): this structure, built on the ground, could be stratified in one or more layers composed by vegetal elements and small wooden beams, according to environmental conditions.

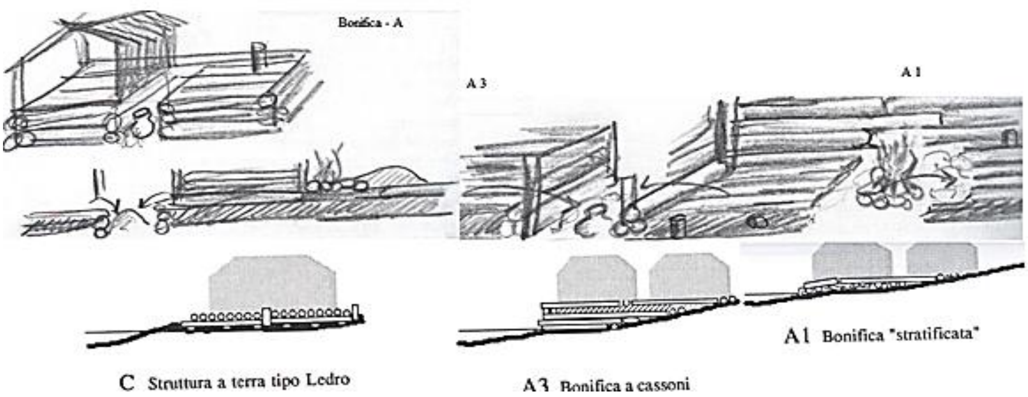

Figure 46 Examples of some depositional and sedimentary models, related to different features of structures (from Balista & Leonardi 1996: 204-213, figure 4).

It is attested in some sectors of lakeside settlements as the exclusive building technique (such as at Isolino Virginia (Baioni et al 2005; Ledro (scavi 1980-83), Lavagnone, Arquà (Balista & Leonardi 1996: 215-222), whereas in others it is also combined with pile-dwelling structures, as at Barche di Solferino, in the south-western sector of site (excavations of Zorzi and Nicolussi (Zorzi & Nicolussi 1938) and Bande di Cavriana (Balista & Leonardi 1996: 215, 219). Moreover, for the northern Alpine region some scholars proposed a division between construction methods employed in western and the eastern part of the region and between the Upper Swabia and Constance Lake (figures 47A-B).

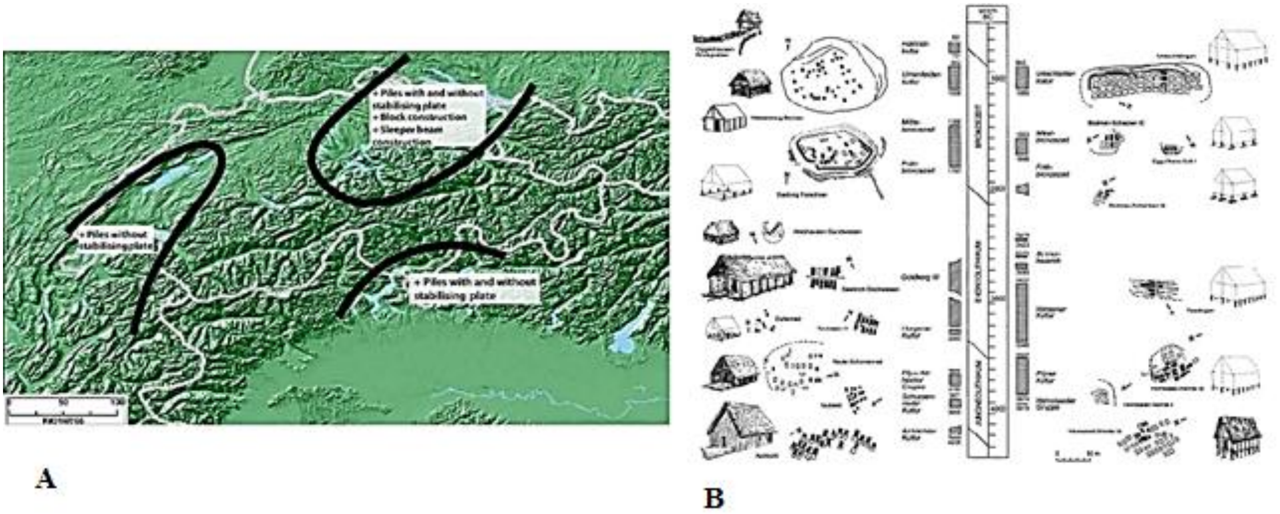

Figure 47A Distribution of different lake-dwelling construction methods in Switzerland during the Neolithic and Bronze Age (from Jennings 2014: 81, figure 5.1; Seifert 1996, figure 194) Figure 47B Cultural groups in the wetland communities of Upper Swabia (left) and Constance Lake (right). Dating, settlement plans and typical houses. Drawing: A. Kalkowski (from Menotti 2004: 28, figure 2.3).

Houses found at Neuchâtel Lake (Geneva, Biel, Murten and Bourget) were constructed using piles driven into the ground and sediment which supported superstructures above the ground (Arnold 1990: 66-79). In some lake-settlements of western Switzerland, such as at Cortaillod-Est, the three-aisle construction type was adopted, with four rows of posts (two wall posts and two internal posts) supporting the roof of the building, which measured up to 15.5 x 6 metres in width (figure 48). This three aisle plan cannot be observed in the eastern Switzerland (Seifert 1996: 168); houses were usually two-aisled with three rows of posts, the middle one being the ridge post row.

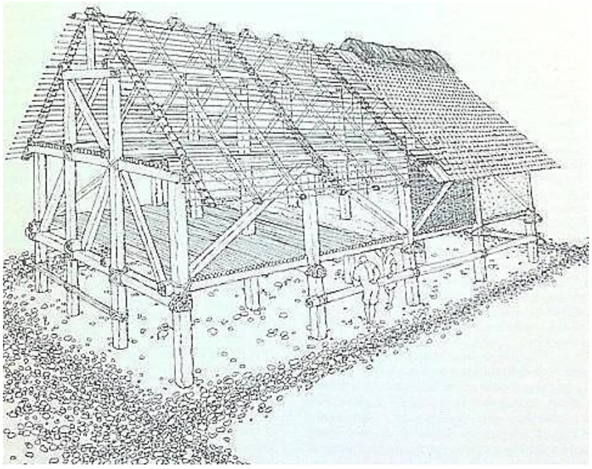

Figure 48 Reconstruction of house from Cortaillod-Est (from Arnold 1990: 79, figure 69).

In the eastern part of the northern Alpine region, a variety of construction techniques has been identified, including piles driven into the ground through a stabilising plate (Pfahlschue); this perforated plate technique was used throughout the lake-dwelling tradition from the Neolithic to the Late Bronze Age (Ebersbach 2012: 28; Menotti 2012: 136, figure 4.5b). Posts used as the main frame of houses at the Arbon Bleiche 2 seem to have been either directly rammed into the ground or inserted into a *Pfahlschue* or perforated base plate (Menotti 2001b: 104); for instance, in the sector A of Lavagnone, the Early Bronze Age (IB) dwellings rested on typical perforated wooden base plates (Figure 49). A construction method called *Schwellenbau* (sleeper beam construction) is attested between Constance Lake and Sempach Lake: piles were driven into the ground through boards or planks (Gross et al. 1987: 67; Seifert 1996: 168-71; Benkert et al. 1998: 199; Jennings 2014: 81); they provided stabilisation and support for buildings' posts and formed the bases and foundations of walls.

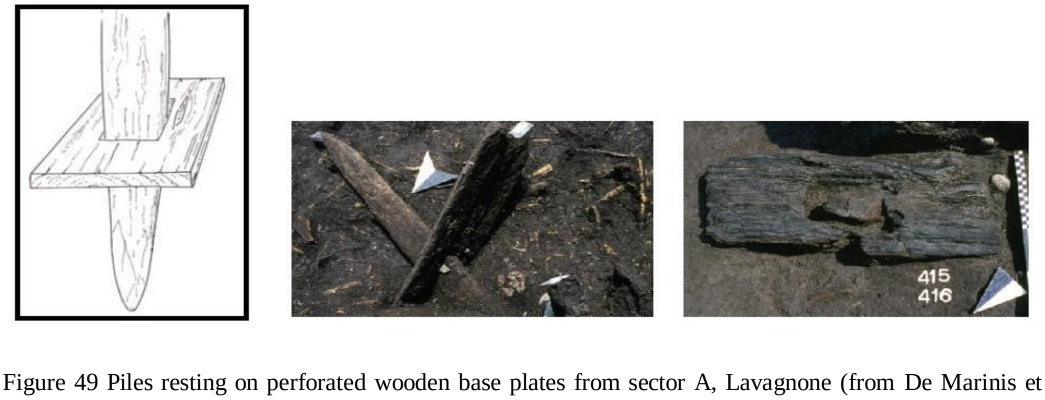

Figure 49 Piles resting on perforated wooden base plates from sector A, Lavagnone (from De Marinis et al. 2005: 225, figure 5).

At the site of Zug-Sumpf buildings related to an older occupation phase (Seifert 1996: 46-53; Jennings 2014: 83) were constructed using the *Schwellenbau* and *Pfahlschue* techniques. Instead, more recent buildings were constructed using the block technique (Seifert 1996: 128-38). This block construction method, *Blockbau*, was common to the lake-settlements east and west of Constance Lake during the Late Bronze Age; this has been recognised at the settlement of Greifensee-Böschen (Greifen Lake, Switzerland) (Eberschweiler 1990a; Eberschweiler et al. 2007) and at Ürsch-hausen-Horn, Nussbaum Lake, Switzerland (Gollnisch-Moos 1999). This technique consisted of layering round timbers on top of each other that intersected and overlapped at building corners with notches or recesses, allowing timbers to sit flush against each other (Menotti 2012: 134; Jennings 2014: 81). The block-building technique was also attested in the terrace houses of the fortified lacustrine settlement of Biskupin, in Poland, dated to the Iron Age (Menotti 2012: 144, Menotti & O'Sullivan 2013). A combination of various construction techniques is attested here, where block-construction, mortise and tenon joints were identified (Figure 50).

Figure 50 Schematic reconstruction of the Late Bronze Age house of Greinfesee-Böschen, Greifen lake, Switzerland (from Menotti 2012: 137, figure 4.6).

The most elaborate foundation system involved the raising of buildings on platforms constructed in a simple blockbau technique, with the insertion of floor timbers at an intermediary level of the structure (Gollnisch-Moos 1999: 21-71). Across the shore of the Lake Zurich, at the Early Bronze Age ZH-Mozartstrasse lake-dwelling, wooden structures consisted of two superimposed groups of dwellings built on ground-joists. Both groups were directly built on the lake marl although, in the case of the second group, houses were also constructed on the old floor of the first. A plausible hypothesis about the function of such a massive and elevated floor is that it was built to protect dwellings from a possible lake level increase (Menotti 2001a: 100). Thanks to the well-preserved wooden structures it has been possible to attempt a fairly accurate reconstruction of houses (Gross & Diggelmann 1987; Menotti 2001b: 99) (Figure 51).

Furthermore, the Neolithic Egolzwil settlement provided an example of the packwerk technique where foundations have been created by packing assorted timber in a regularised cross-hatch pattern (Speack 1981b: 109-10; Wyss 1983; Jennings 2014: 83). At the site of Hunte 1 (Dümmer Lake, Central Germany), three types of architecture can be distinguished in chronological order. The first and the oldest consisted of a peculiar polygonal hut, whereas the second and third are rectangular buildings varying in size. While the first two types seem to have been built directly on the ground, the third type could have been slightly elevated on stilts floors (Kossian 2007; Menotti 2012: 139). Although wetland house remains in Poland are not numerous, three regions showed distinction in terms of house architecture; in the Wielkopolska region a prevalence of vertical pile constructions is noted, while in the others (Masurian and Pomerania) houses seem to have been built on large platforms – not on stilts – constructed on top of artificially built islands in the water near the lake-shore (Menotti 2012: 140). Similarly, the Poggiomarino settlement was built in a marshy riverine environment (on the bank of the River Sarno, central Italy): a series of artificial islets with houses on top were constructed (Pruneti 2002; Castaldo et al. 2008; Cicirelli & Albore Livadie 2008). A comparable structural model has been recognised in England, Scotland and Ireland where lake islands were made up and used for habitation, the Crannogs (O'Sullivan 1997, 1998; Cavers 2006; Henderson 2007).

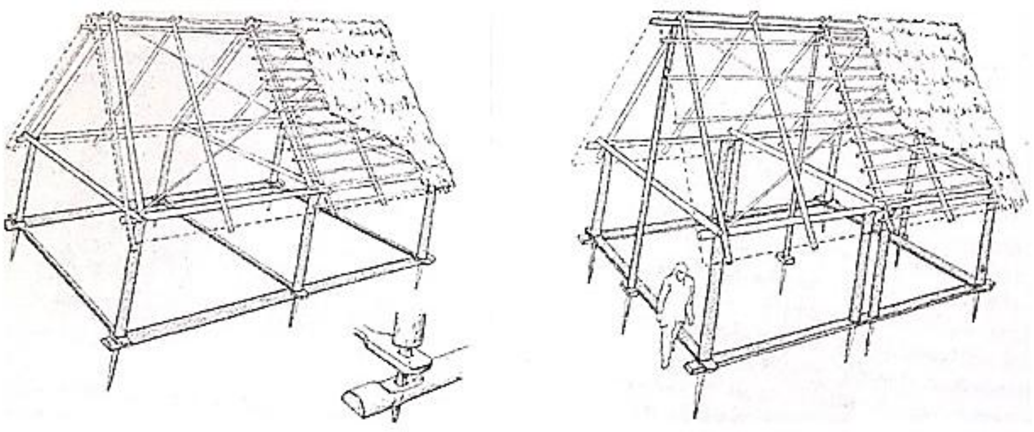

Figure 51 An attempted reconstruction at EBA houses at ZH-Mozartstrasse (after Gross & Digelmann 1987a:67; from Menotti 2001b:99, figure 3.16).

Fens should also be included in this overview: they consist of drowned landscapes, overcome by wetland conditions only from the Neolithic onwards and occasionally an earthwork. It had once stood on the former land surface that became engulfed by peat, to be revealed many centuries later, when drainage and ploughing caused the peat to shrink and waste away (Coles 2004a: 101). Two basic methods of constructions have generally been suggested for fens. The first, the Packwerk model, consists of an artificial mound being built up, characterised by layers of material with one or more structures built upon; the second model shows a free-standing platform; there is evidence for both approaches in all countries (Henderson and Sands 2013: 274). These models are most readily identified in later Bronze Age Irish sites, which seem to present a greater range of constructional forms (O'Sullivan 1998: 69-96). For instance, at the Late Bronze Age phases of Ballinderry Crannog N 2, Ireland, both free-standing and Packwerk approaches are clearly found (Newman 1997: 97; Cavers 2006: 391). The primary construction of the Early Iron Age site of Oakbank crannog in Scotland seems to have been firstly free-standing and only subsequently becoming more of a Packwerk mound (Dixon 2004).

This overview cannot be exhaustive without the analysis of Terramare: as already mentioned, they can be defined as mainly quadrangular settlements surrounded by an embankment and ditch into which waters of a nearby river or natural canal were re-routed. Thus, apart from performing a defensive function, earthworks also functioned as containing walls and as means to redistribute the water resources, as it has been attested, for instance, at Castello del Tartaro and in various other Terramare, including Santa Rosa and Redù (Modena) (Cardarelli 2010: 450). Generally, houses of the Circum-Alpine region and the Mediterranean (such as Dispilo

(Hormouziades 1996) were similar in shape to Terramare, as they were rectangular[5]. However, their size may still vary according to place and time. A standard pile-dwelling would normally not exceed 4 x 10 metres (such as Hornstaad- Hörnle 1A, Arbon-Bleiche 3 (4 x 8 metres), Poggiomarino settlement (3-3.5 x 10-12 metres) and they could be smaller (such as some on-platforms houses found at Moltajny (Poland) (3.2 x 3.5 metres) (Pydyn 2007: 325-7) and in Austria (at Schärfling, Misling 2 and Weyregg-Landunfssteg with houses of averaged 3-4 metres in length (Offenberger 1981; Ruttkay et al. 2004: 51).

However, at Federsee a longhouse (e.g. Seekirch-Stockwiesen) built directly on the ground would easily reach 5 x 15 metres (Schlichtherle 2004; Menotti 2012: 130); evidence of elongated pile-dwellings have been found at Humudu and Majiabang in China and in Japan where the Jomon rectangular houses of Ondashi reached 5 x 10 meters (Menotti 2012: 139). Across the Zurich Lake (in particular at ZH-Mozartstrasse), the size of the houses range between 5 and 6 metres in length and 3 metres in width, with the only exception of houses 5, 6 and 9 in group b which are one third larger than the others (Menotti 2001: 100). Similarly, the dwellings with recognisable dimensions of the Arbon-Bleiche 2 had, according to Hochuli (1994), an approximate length of 4.5-6 metres and a width of 3.5-4.5 metres. In Britain and Scotland the shape of houses was circular (such as at Glastonbury or at crannogs). The majority of Neolithic lacustrine settlements out from the Circum-Alpine region such as La Marmotta (Bracciano Lake, Lazio, central Italy) (Fugazzola Delpino & Mineo 1995; Fugazzola Delpino 1998; Fugazzola Delpino & Pessina 1999; Fugazzola Delpino 2002) and La Draga (Girona, Catalonia, Spain) (Bosch et al. 2006; Palomo et al. 2014) seem to have been built directly on the ground. The floor of the latter type was usually made of various strata of round-wood, bark, twigs, plaster and it was sometimes covered in clay (Figure 52).

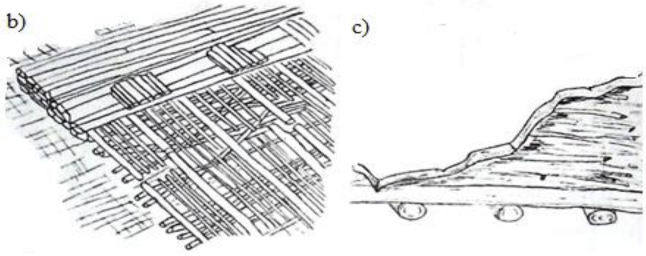

Figure 52 Different kinds of lake-dwelling house floors: b)multi-layered roundwood floor build directly on the ground; c)wooden floor paved with clay (Drawing: Olenka Dmytryk) (from Menotti 2012: 134, figure 4.3).

At the sector D of La Draga and in particular in the Level VII (the oldest phase of occupation corresponds to the level of collapsed wood), posts ending in a fork into which a plank was fitted in a clearly original position were documented. This association seemed to define a wooden structure that would separate the wet ground level from the level activity. This element is a direct archaeological evidence of use of wooden structures erected above ground level (Palomo et al. 2014: 65). Moreover, for the second phase of the site's occupation, the presence of travertine blocks attested the construction of a paved surface (Structure 252) which extends over the entire sector D (Palomo 2014: 62): this structure was documented in Sectors B and C still on top of the collapsed wooden level. Furthermore, the elevated floor of pile-dwellings consisted

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[5] Nevertheless, at the site of Fimon (Northern Italy) the distribution of some posts has suggested a sub-circular or oval shape of the houses) (Lioy 1876).

of half-split small logs or planks but they too were sometimes paved with a stratum of clay (the latter model was found at Fiavé 6 (Perini 1987). At ZH-Mozartstrasse lake-dwellings, floors were mainly built of beech (Menotti, 2001: 100) (Figure 53).

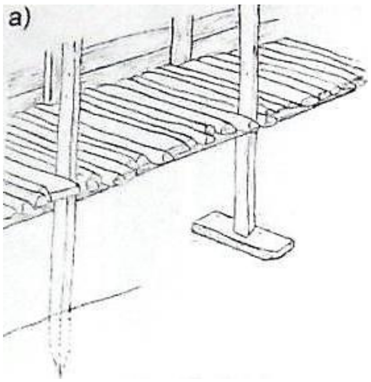

Figure 53 Different kinds of lake-dwelling house floors: elevated floor of a pile-dwelling (from Menotti 2012: 134, figure 4.3).

The Bronze Age lakeside dwellings displayed a coexistence of different building typologies, with a remarkable capacity of adaptation to varying geomorphologic conditions, as attested for instance at Fiavé. There, in the Fiavé 6 settlement, dwelling structures in water on "individual piles" as well as ground-foundation structures were found. The habitation level would have consisted of a raised platform constructed of joists, planks and branches; joists were set in notches and slots in the tops of piles, which clearly had a supporting function. Piles, driven into the lake-bed without any elements strengthening the bottoms of them, carried the weight of the superstructure on saddles and slots and transmitted this weight together with the horizontal pressure, into the marl bed (Perini 1987: 81). A similar technique was employed at the site of Stagno (Livorno, Italy), in the area C. The remains of this structure consist of seven vertical elements (120 cm long and 30 cm in diameter), with a long point (50 cm ca) carved to facilitate insertion into the ground. Some of these vertical elements are still preserved in situ, planks passing through rectangular openings in the upper part. Perpendicularly to these planks, spars of 350 cm maximum length and 10 cm ca diameter, were placed horizontally. Some small vertical poles were even found and are supposed to have functioned as further side-supports for horizontal elements. On the whole, the structure appears to have been a well-anchored rectangular building with a peculiar level of small branches laid down in a compact manner, likely intended as a floor (Zanini 1997; Giachi et al. 2010: 1262). The same house construction technique was found at Lavagnone (Lavagnone 3), where upper parts of piles support the superstructure on brackets, differently from Fiavé (Perini 1987: 82). Recently, a relation between the construction methods of Fiavé 6 and those of the Early Bronze Age site at Bodman-Schachen in the western area of Constance Lake has been proposed by Köninger and Schlichtherle (Köninger & Schlichtherle 2001: 45; Menotti 2004: 89).

In two Polish regions (Masurian and Pomerania) two different ways of preparing the ground for the on-platforms houses have been identified: a) the *Fascinenbau* (the area was prepared with irregular timber and brushwood) and b) the *Packwerkbau* (different strata of roundwood were used in order to construct a large platform which was the base layer of houses) (Menotti 2012: 140-141). At the site L1 of Luokesa architectural remains correspond to those of the artificially built wooden platforms in Poland (Gackowski 1995; Hayedeck 1909; Pranckènaitè 2014), but L1 has been identified as a pile-dwelling such as few Polish examples (Polanowo 12 and Powidz 16) (Pydyn & Rembisz 2010; Pranckènaitè 2014: 348). The site is composed of buildings with raised floors, with cultural deposits accumulated below (Ismail-Meyer 2014; Heitz-Weniger 2014; Pollmann 2014). The construction technique of walls varies considerably, from simple half-split, vertically set small logs to block-construction or wattle-and-daub panels (Pétrequin 1984; Menotti 2012: 134) (Figure 54).

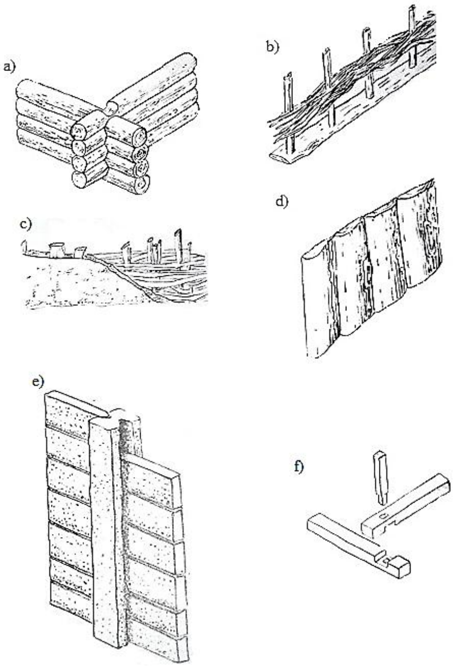

Figure 54 Different kinds of lake-dwelling walls: a)Block-construction; b)Wattle; c)Wattle and daub; d)Split roundwood; e)Plank-pillar; f)Plank-pillar with mortise and tenon joints (Drawings: Olenka Dmytryk) (from Menotti 2012: 135, figure 4.4).

At the lakeside settlement of La Draga, preliminary data related to the construction techniques are available, although analyses of some elements retrieved in the sector D are still in progress. For instance, small calibre branches interwoven between them to form a lattice may have constituted parts of the walls; this type of construction technique is well-known ethnographically, where interlaced branches are then covered with clay. However, clay remnants were not associated with these elements at La Draga (Palomo et al. 2014: 64). At MZ-Mozartstrasse the walls were mainly built of oak (Menotti 2001: 100), such as at some contexts from the Slovenian region (Čufar et al 2010), whereas at San Savino site they are of *fagus*. At this site and at the Terramare of Montale (Mercuri et al 2006: 53) the oak was used for pile supporting framework and roofs; traditionally, roofs are difficult to reconstruct as are usually not preserved. Wooden shingles were probably used more often, as straw and reed are thought not to have been available in sufficient quantities in Neolithic periods (Jacomet 1997: 285). Also bark or combinations of different materials might have been used; houses with a ridge post row have surely had a gabled roof with its angle, depending on the covering: straw and red need steep gradients to let the rain drip off easily, while shingles can also be secured to low gradient roofs (Figure 25). A steep, high raising roof could easily have been used as a second attic. Notched log ladders indicate the use of construction elements high above the ground (Ebersbach 2013: 287). At the Arbon Bleiche 3 and Fiavé 6 the roof was made of reeds or wooden shingles and in some cases also bark from different species of trees were attested; at ZH-Mozarstrasse they were mainly built of ash (Menotti 2001: 100). As main cultural processes, e.g. the decision, planning and the settlement construction process have been summarised, this analysis will now address the occupation of houses and the material evidence of living floors.

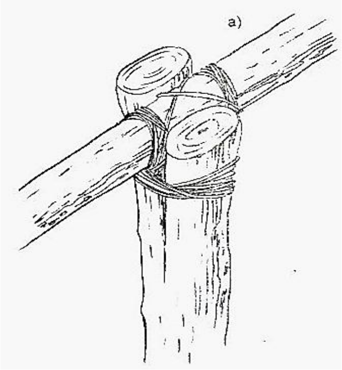

Figure 55 The twin-pile building technique: a) long piles supporting the roof (Drawings: Olenka Dmytryk) (Menotti 2012: 137, figure 4.7).

3.3.2 The living floors of lake-side settlements

Activities undertaken in the stage of habitation of a settlement are primarily related to the maintenance of "commensal" unit, including food processing, preparation and consumption, sleeping, manufacture and maintenance of tools/artefacts and the consequent maintenance of specific activity areas (Rathje & Schiffer 1982: 46; LaMotta & Schiffer 1999: 21). At the lakeside settlements, such everyday activities took place indifferently in most of structures (*Allzweckhäuser*) (Ebersbach 2013: 289). Sometimes, smaller buildings existed in, between or behind normal houses that were interpreted mainly as granaries or storage buildings; a late Bronze Age storehouse has been found at Wasserburg Buchau (Menotti 2004: 29).

However, in most cases, size and position of houses are insufficient criteria to identify different functions: for instance at Greifensee no differences between big, central and smaller buildings alongside fences have been identified. Very few special houses, identifiable as workshops, have been found in most recent years, in particular in Bronze and Iron Age buildings, mainly related to metalworking (Hochuli et al. 1998: 206-7; Müller et al. 1999: 146-9). According to Ebersbach (Seifert 1996; Ebersbach 2002; 2013) the existence of stables, barns or workshops as separate buildings has not as yet been proved in any Neolithic wetland settlement of the Alpine ridge, although this is often stated in older publications. Nowadays no structures in wetland sites around the Alps could be interpreted as elite houses (e.g. houses of special wealth, size, building material or furnishing) or religious and/or political communal buildings or market places (Seifert 1996: 123-5; Ebersbach 2013: 290; Menotti & O'Sullivan 2013). Very few special structures recently have recognised and labelled as "cult houses" (Schlichtherle 2006; Honegger 2007)[6]: although their architecture does not differ much from other buildings of a settlement, they displayed certain artefact categories, special decoration of walls or particular orientation. At the site of Marin-Les Piécettes (Neuchâtel Lake), a central building was erected on an artificial little hill, with an unusual high number of posts and absence of artefact categories like stone, bone and antler tools (Honegger 2001; Loser & Maytain 2007). In the settlement of Reute, one house of bigger size and different orientation also showed a special distribution of artefacts (Mainberger 1998). At Luwigshafen house walls with painted decoration and modelled breasts occurred, alongside high-quality textiles, fishnets and anthropomorphic pottery

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[6] As highlighted by some authors, their possible meaning or function remains open to discussion (Ebersbach 2013; Jennings 2014)

(Schlichtherle 2006). Two oldest buildings of Greifensee, constructed in a central position and with a technology differing from the other, could show a special meaning; here, artefact categories such as food processing and textile production tools as well as low densities of remains were absent (Eberschweiler et al. 2007; Ebersbach 2013: 289). At ZH-Mozartstrasse an Early Bronze Age packwerkbau platform of 200 m^2 was found; some hypothetical functions have been suggested, such as central village place, a workshop, a herding or cult space (Gross et al. 1987: 70-74; Jenning 2014: 81).

Since lakeside settlement buildings with a certain special function are very rare, most of these structures seem to have been devoted to domestic practices. Material residues of these activities can make their way into the archaeological record through three major depositional processes, as already mentioned in the chapter 2. Primary deposition is the accretion process by which objects enter the archaeological record at their location of use, either through discard as “primary” refuse (Schiffer 1972, 1977, 1996) or through accidental deposition as “loss” refuse (Fehon & Schlotz 1978; Schiffer 1996: 76-9). Determining which objects could directly enter the archaeological record, an understanding of how the living floor of an ancient house was formed and consequently its penetrability is required (LaMotta & Schiffer 1999: 21). For instance, in the case of an elevated floor (a floor on stilts that can be made of round wood or planks and sometimes coated with clay), some of refuse consisting of numerous potsherds, animal bones, seeds and wood fragments could accidentally fall during the occupation of the structure, forming a dump; the underlying organic marl could have surrounded them. At Fiavé (horizon 6) complete pots of various dimensions, after settling upright or horizontally on the organic marl between the piles, had subsequently been fragmented by the weight of overlying deposits (Figure 56A). At Lucone di Polpenazze, in the excavated area A from the Early Bronze Age layers, some quite entire vessels recovered in the organic marl (layers G-H-I) probably fell down from aerial substructures of pile-dwellings (Baioni et al. 2007: 86). Elevated floors and the close proximity of houses in some prehistoric lacustrine villages of the Circum-Alpine region have always intrigued scholars as to where the daily waste was discarded. In order to shed more light on this issue, few experiments on refuse discarding have been performed (Menotti 2012: 315). Thanks to these reconstructions, the presence of a rubbish flap on the house floor has been hypothesised, since discarded waste was discovered underneath the elevated floor (Leuzinger 2000; Jacomet et al. 2004), such as at Arbon-Bleiche 3 (experimental reconstruction) (Figure 56B).

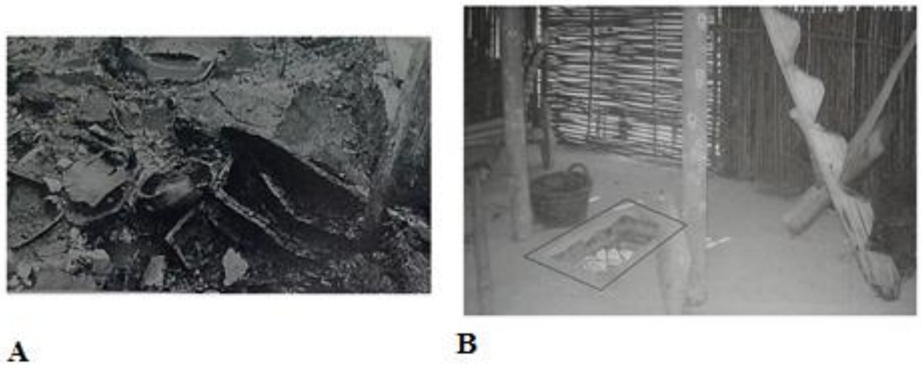

Figure 56A) Fiavé: detail of one of the dumps of refuse among the piles (from Perini 1987: 80, figure 5.6). Figure 56B) A rubbish flap (rectangle) reproduced in the Arbon-Bleiche 3 experimental house (n. 23) constructed at the Pfahlbaumuseum, Unteruhldingen, Germany (from Menotti 2012: 316, figure 7.24).

The concentration of poppy seeds found inside one of the Chalain station 3 house might confirm this scenario (Baudais et al. 1997: 703; Jacomet and Brombacher 2005), since the disposal could have been realised through a sort of trap-door in the floor. Furthermore, according to the reproduction of Unteruhldingen's houses (Constance Lake, Germany), lake-dwellers would discard their rubbish either at the back or the front of the house, depending on the location of the main street in relation to the house entrance (Krauss et al. 1999; Ebersbach 2013: 314) (Figure 57). According to Arbogast (Arbogast et al. 1997) in the rear of houses an empty space was presumably more "private". Usually, there one or more fireplaces and sometimes also ovens were built into houses. Around the fireplace, all kinds of daily domestic activity have been identified, but only few remains survived, trampled into the floor; bigger remains have either been burnt or cleaned out. Thanks to experimental reconstruction of Chalain houses, more light was shed on the living conditions inside the house. For instance, a study of fireplace smoke in the house without a chimney was carried out: although it seems incredible, it was understood that the first 1,5 metres above the floor inside the house would not be engulfed by smoke, which would concentrate only in the upper roof. Moreover, some advantages have been recognised, as the preservation of the thatch and the maintenance of the interior free of flies and mosquitoes in the summer and maybe even mice in winter (Monnier et al. 1991:20; Menotti 2012: 315). Detailed analysis of refuse patterns inside, below and around houses of Chalain showed also a more public space near the door, oriented towards the next open space, where rubbish heaps were often accumulated (Monnier et al. 1991; Menotti 2012: 315). As highlighted by ethnographic research (Murray 1980; Hayden & Cannon 1983), at most activity areas as well as at domestic spaces practices of refuse's cleaning up are periodically documented, with their spatial relocation elsewhere.

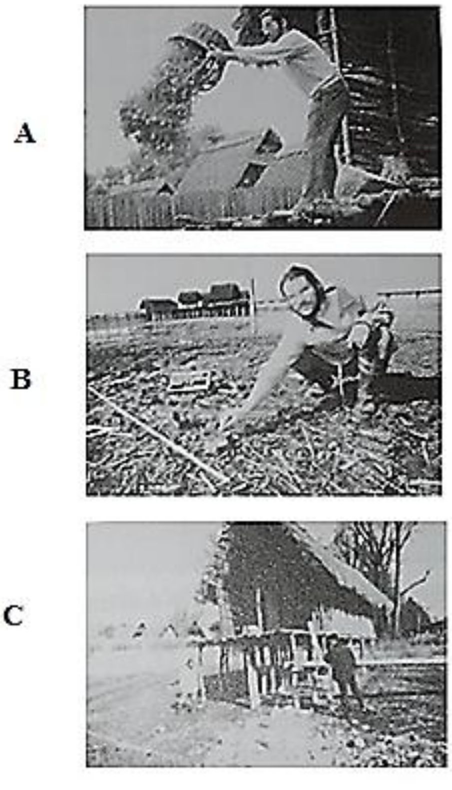

Figure 57 Depositional patterns of discarded rubbish, experimentally recorded at Unteruhldingen, Constance Lake, Germany: a)discarding process; b and c) recording process (from Menotti 2012: 315, figure 7.23).

As above mentioned , also in the pile-dwelling context, any remaining primary refuse most likely includes objects that had a low potential for hindering on-going activities, especially objects small enough to escape cleaning technology (McKellar 1983; Tani 1995; Schiffer 1996: 66-7). The process of refuse cleaning up from the house floor or activity areas and its deposition in a spatially removed location (such in some middens, tofts, landfills and abandoned structures) (Schiffer 1972, 1977, 1996; see also Rathje & Murphy 1992) could display the depletion process or "secondary deposition". Hence, at lakeside settlements refuse were predominantly accumulated outside houses forming dumps, probably in order to even keep a healthy environment. For instance, in the sector D of Lucone a dump area, constituted of organic finds, fragments of pots and charcoals was found in the Early Bronze Age layers (Baioni et al. 2006: 90). In the synchronic layers of sector B of Lavagnone, waste dumps were found, serving as evidence of settlement activity (De Marinis et al. 2005: 223). At Isolino Virginia, in the layers of the third occupation phase a shallow ditch was found and interpreted as dump (Baioni et al. 2005: 211).

At Hornstaad Hörne IA, on Constance Lake, the rubbish was especially thrown out houses. Remains of flax seemed to be concentrated only in a few places in the AH3 sector, in the organic layer 206, where rubbish zones of two houses overlap (Maier 2001, 70 Abb. 54). Flax remains were therefore not deposited everywhere in the settlement, but rather they were concentrated in certain places where other rubbish was also deposited; same observations were made on layer J at the site of Zürich AKAD/Pressehaus by Jacomet (1981, 137). On the contrary, at the much more recent site of Arbon TG Bleiche 3, flax remains were much more common and were found everywhere (Maier 2001: 79; Jacomet & Brombacher 2005).

A rubbish heap in the back part of one house (C) was found at Chalain station 3 (Baudais et al. 1997: 725 ff), containing halzenut shells, carbonised cereal chaff, bones and artefacts. Charcoal and ashes were most likely formed close to hearths due to cooking; they were periodically removed and dumped in other locations, as confirmed by the density of plant remains. They were much lower near hearth structures, where dwellers cleaned regularly and rubbish was deposited in areas between houses (Jacomet & Brombacher 2005: 80). In the mire site Alleshausen/Hartöschle, Maier found large amounts of carbonised cereals in the zone of the oven, suggesting that this was used for the handling and cooking of cereals. Concentrations of silver fir twigs were found at Horgen ZH Scheller in cultural layers inside houses; they were used as filling or insulation material (Favre 2002: 160; Eberli et al. 2002b: 208). During settlement phases, horizontally complex deposits of variable compositions have accumulated, containing large amounts of preserved organic material (such as sand, carbonate mud, and some clay aggregates) as well as various types of biogenic remains (architectural elements as, among other, timbers, roof shingles, collapsed walls) and a multitude of artefacts and ecofacts (Röder et al. 2013: 16). Well-preserved organic remains are imbedded in this organic matrix, which also contains pottery and stone tools, charcoal, ashes, bones (including fish bones), loam aggregates, clods of lake marl and different dung remains, such as at Arbon-Bleiche 3 (Ismail-Meyer et al. 2013: 329). Organic remains accumulated on floors may be interpreted as waste from food processing and cooking (fruits, seeds, bones of wild and domestic animals, fish scales and bones, charcoals, and ashes), fuel (wood, bark, and twigs), and insulation (twigs, mosses, and bark residues) against humidity, wood working activities, animal stabling and other daily life activities (Ismail-Meyer et al. 2013: 335).

"Special" accumulation referred to particular activity areas or practices are even documented; for instance, at Lobisgesee, very thin lenses of decalcified clay was interpreted as raw material deposits, due to their strong similarities with the matrix of ceramic sheds: they proved the production of ceramics in the living areas (Ismail-Meyer et al. 2013: 327) (Figure 58).

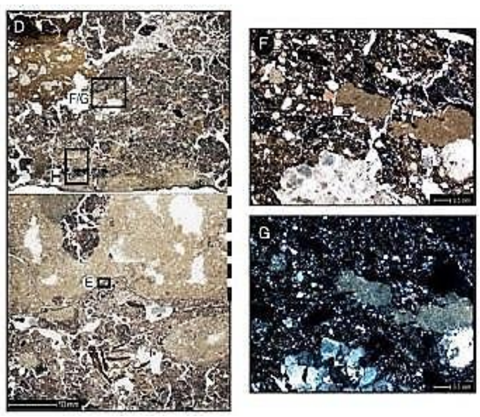

Figure 58 Charcoal rich occupation deposit containing unburnt clay (center) and crushed granitic temper (base), indicating pottery manufacturing within a roofed area. Lobsigesee M6, PPL (from Ismail-Meyer et al. 2013: 328, figures 8 D, F, G).

The distribution of pottery along the outside of buildings following breakage demonstrated by some ethnographic studies (e.g. Hayden & Cannon 198; Deal 1985) is confirmed in some lakeside settlement contexts: for example, at the settlement of Ürschhausen-Horn, ceramics were placed in such spatial location fragments of individual vessels were dispersed among several structures (Gollnisch-Moos 1999; Nagy 1999; Jennings 2014: 85). The activity of fireplace cleaning probably produced thick ash layers accumulated as a midden and found next to a house, at Stansstad-Kehrsisten (Ismail-Meyer et al. 2013: 330). Furthermore, the high presence of specific refuse categories in some houses might suggest specialised practices: for instance, at Arbon-Bleiche 3 high proportions of wild animal bones in two houses were attributed to specialised hunting (labelled hunter houses) (Deschler-Erb/Marti-Grädel 2004b: 232, 251) implying professional hunting (Röder et al. 2013: 25). At the site of Zurich-Alpenquai the high quantity of hazel twigs into the reduction horizon 1.1 (Q651) could be interpreted as a storage brought into the settlement during spring as food for humans and livestock; anyway, the layer could be also a dung layer (Wiemann et al. 2012: 73).

Other special activities such as butchering have been attested in some contexts such as Horgen (Zurich Lake) and Sipplingen (Constance Lake) (Menotti 2012). Furthermore, small wattle constructions were identified in some lakeside settlements; they could be used as enclosures for small ruminants. Leafy branches and mistletoe can be regarded as fodder for livestock that very likely resided within settlements, at least temporarily (Ismail-Meyer & Rentzel 2004; Ismail-Meyer 2010). Areas with dung layers interpreted as cattle stands have been found in settlements, located predominantly outside houses. However, rare finds of animal faeces in, under or between some houses document the presence of animals inside settlements and even within a house (e.g. Pestenacker, House 1: Schönfeld 1991). At Arbon-Bleiche 3, coprolites can be attributed to ovicaprids (sheep/goat), cattle and less frequently carnivores/omnivores (dogs or foxes and pigs), small rodents, possibly field mouse and humans (Le Bailly & Bouchet 2004; Le Bailly et al. 2003; Courty et al. 1991) (Figure 59).

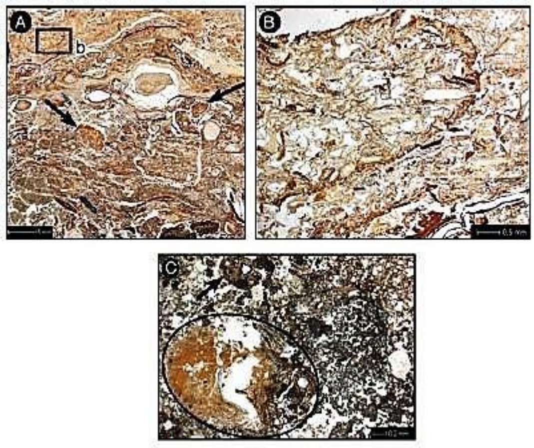

Figure 59 a-b) Dung rich stabling deposit, with droppings of sheep/goat (arrows in the central part). The black rectangle marks the position of the detail Figure 9B. Arbon-Bleiche 3 M1030, thin section scan. c) Concentration of burnt coprolites withmelted phytoliths. The brown phosphaticmatrix of a carnivore coprolite turns into carbonate to the right side (circle). A further possible burned coprolite shows a bubbly structure (arrow). Cham-Eslen M665, PPL (from Ismail-Meyer et al. 2013: 330, figure 9A, B, C).

At the site L1 of Luokesas beside dung remains very few animal bones, mostly of sheep, goat and pigs were found, showing that livestock was kept at the site (Pranckenaite 2012, 2014: 348). In the mire site of Seekirch-Stockwiesen in the Federsee region, rubbish heaps including dung and human coprolite-zones were found beside houses (Maier 2004, 91-95). One of coprolites investigated at Arbon Bleiche 3 appeared to be of human origin because its composition differed markedly from the ruminant coprolites and showed similarities with plant remains found in pot-crusts (Kühn & Hadorn 2004; Martínez Straumann 2004). It was composed of many bone fragments and remains of cultivated plants. There was a lot of cereal pollen and bran, remains of linseed and some apple-pericarps (Jacomet & Brombacher 2005: 80).

At Arbon-Bleiche 3 the combined results of micromorphology, the analysis of botanical macro remains and pollen studies showed that the ruins of a house were probably reused as a stand for cattle and sheep/goats in particular during the winter, as only dung dated to this season was found (Ismail-Meyer & Rentzel 2004; Courty et al. 1991; Akeret & Rentzel 2001; Kühn & Hadorn 2004; Haas 2004). The same data, obtained from combined archaeobotanical investigations of sheep/goat pellets, seeds, fruits, vegetative plant material and twigs could be identified at the site of Fiavé Carera, in the Early/Middle Bronze Age layers (sounding 3, zone 4, stratigraphic units 3/12 and 3/20). It can clearly be shown that animals were kept inside the settlement area during winter/early spring (Karg 1996: 93).

The third major depositional process occurring during the habitation phase is provisional discard; in this stage, broken or worn-out objects are not discarded *per se*, but are stored or cached with the expectation that they will serve a useful purpose later (Hayden & Cannon 1983; Deal 1985; Schiffer 1996: 99; LaMotta & Schiffer 1999: 21-22). An additional contributor to provisional refuse is functionally obsolete items-broken or still usable- that are nonetheless retained instead of discarded. Can we attribute this “nostalgia effect” (Gould 1987: 149), e.g. the decision to keep items that took part in earlier activities in their own lives, to the potential re-use of timber (over repairs, expansion and/or internal modification of houses during the occupation or from other settlements)? Sometimes old items acquire a renovated function as a part of displays (Schiffer 1996: ch. 3). The construction of pile-dwellings would have required high amounts of timber that would have been used for construction of the superstructure. They may have constituted a significant and readily available timber resource which, in light of the current dendrochronological evidence, does not appear to have been extensively utilised (Jennings 2014: 104). Timbers of the initial pioneer construction have been reused at for instance the settlement Conjux-Le Port 3 (Billaud 2011) and at Hauterive-Champréveyres, where evidence indicates that piles were occasionally removed and possibly reworked (Pillonel 2007:70). This re-use of timbers, coupled with the splitting of them to produce multiple piles from single logs, may indicate an over exploitation of the surrounding forest resources, leading to a reduced availability of suitable size trees; this condition was attested also at Cortaillod-Est (Arnold 1986). The material evidence of these structural changes and expansions can be found in anthropogenic layers: small aggregates of unburnt clay characterised by organic temper might be the only evidence of wall construction of raised houses, as in Arbon-Bleiche 3 and Standssad-Kehrsiten (Cammas 2003). Differently, accumulations of branches, wood, bark, moss, mistletoe, leaves and pine needles might derive from the preparation of timber for construction/re-construction activities and they could also be insolation material for the floor (Pétrequin 1997b). Furthermore, the presence of clustered burnt loam fragments most likely indicate demolition and/or renovations of hearths (Ismail-Meyer et al. 2013: 327). The renovation or reconstruction practices are often caused by environmental as well cultural processes: both fire events and water level variations have influenced occupational strategies carried out during the past by wetland dwellers; in some cases they have caused even the lakeside settlements' abandonment.

3.3.3 Fire events as expression of natural process as well as anthropogenic activity

During the sites occupation phase, intentional (Chabanuk 2008) as well as accidental wooden house conflagrations happened quite often. These events have frequently occurred, in particular during dry phases, such as in the summer, with major sources of combustion being human activities and lightning (Van der Valk 2006; Lindsay 2010). Large amounts of ash were produced by surface vegetation of a peat which have easily been washed away by rain (Charman 2009; Lindsay 2010). Micromorphological analyses of building structures in some lakeside settlements have shown traces of combustion, confirming that fire management was fairly problematic, especially during dry phases. At the site of Cham-Eslen (Zug Lake) traces of conflagrations have been found in organic layers, as burnt plant material, ashes and melted phytoliths (Figure 60); layers of charcoals were rather rare, as they are easily dislocated (Macphail et al. 2010).

Figure 60 The site of Cham-Eslen: e) scanned thin sections and description of micromorphological phases and their possible reconstruction. The small rectangle marks the position of the Figure 3F. f)detail of a burned clay aggregate with melted quartz grains (arrows) and gray ashes at the bottom (Pictures by Kantonsarchäologie Zug, Switzerland, and K. Ismail-Meyer) (from Ismail-Meyer et al. 2013: 322, figures 3E-F).

At Arbon-Bleiche 3 and Stansstad-Kehrsiten the formation of fire debris from raised wooden dwellings were always associated with the collapse, tilt and displacement of affected structures (Hochuli et al. 1998). This has led to the formation of heterogeneous accumulations of burned daub aggregates, containing charcoal and ashes (Ismail-Meyer et al. 2013: 333). Since the distinction between a structure purposely set on fire and one burnt accidentally is extremely difficult, some house-burning experiments have been carried out, in order to help the reconstruction task of archaeologists. In Denmark during the 1960s a replica of a full-scale Iron Age house was set on fire and the entire destruction process was thoroughly recorded (Hansen 1966; Neilsen 1966); the data obtained were corroborated by an unplanned conflagration that accidentally destroyed two large, full-scale LBK houses replicas at the Archeo-Centre in Netherlands (Flamman 2004; Menotti 2012: 315-6). Following a careful consideration of remains from both experiments (the planned and the accidental fires), archaeologists came to some conclusions: first of all, they recognised how easily and quickly even a quite large house can be destroyed by fire and, second, that even with a careful pre-and post-conflagration recording of data, the remaining archaeological evidence is very limited. Then, these experiments showed how construction elements and techniques of a house have direct implications on the way the house burns and collapses and their deep analysis can facilitate the full reconstruction of building techniques and material used; nevertheless, in most cases, also the experimental reconstruction shed less light on the different manner in which conflagrations took place during the past.

At the site of Zurich-Alpenquai a fire event was recognised in the cultural layer of phase B (layer 2.1): it contained little organic material, chunks of loam, wood, a relatively large amount of charcoal but also burned pottery and a clay-ash mixture on top of the layer. These latter suggested the presence of a burning event (Künzler Wagner 2005: 14).

At the site of Dispilo (Karkanas et al. 2011: 109) differences could be observed in the level of the destruction layer: these have probably to be attributed to the taphonomic history of burnt houses. Indeed, not all of them collapsed at the same time after the burning episode. Some of them may have fallen *en masse*, giving the impression of *in situ* wooden structures on the ground. However, sedimentary features clearly show that these structures had fallen into the water, as suggested by timber pieces which were half-burnt, burned only on the outer surface or on one side.

Among other possible causes of the building or the whole settlement renovation some environmental changes can be listed: water level variations are likely to have triggered the decision of building certain house models rather than others. In addition, sometimes the lake level may have forced dwellers to abandon their houses, or it may have only indirectly influenced their lifestyle, through negative impact on the subsistence and economy (e.g. crop failure).

3.3.4 Natural intra-depositional processes

3.3.5 Lake-level fluctuations

Climate is not stable in time. It is understood that long term as well as short term variations in climatic conditions might have influenced human occupational patterns in prehistoric and also more recent times (Menotti 2001a: 117). The reconstruction of past lake-level fluctuations is carried out through the study of sediments accumulated in lacustrine basins; the recognition of the water depth of past deposition environment and thus the definition of bathymetric markers are needed. In order to reconstruct past changes in lake levels of the sub-Alpine area, two methods have been used (Magny 2004: 135). The first, established by Digerfeldt (1988) and used by botanists, is based on changes in the distribution of lake vegetation. Macrophytic vegetation is largely determined by water depth, resulting in a characteristic zonation of emergent, floating-leaved and submerged vegetation from the shore to the deep water. Changes in vegetal macrofossil assemblages in a sediment core can be assumed to reflect variations in the water depth at the core site. The second method, developed by sedimentologists (Brochier & Joos 1982; Moulin 1991; Magny 1992, 2004), is based on a combination of multiple parameters, including changes in sediment texture (coarser deposits correspond to near-shore areas), lithology (organic deposits often characterise shallow water) and assemblages of various carbonate concretion morphotypes. Since modern studies have revealed that differences between these latter characterised specific zonation from the shore to the deep water, changes in their relative frequency can provide indications of past lake-level fluctuations. Other markers can also be used to reconstruct past variations in water-levels, for instance diatom, chironomid or oxygen-isotope analysis (Berglund 1986; Magny 2004: 135). Lakes' hydrological balance is delicate, since climate alterations involving an increase in humidity and higher percentage of precipitation could have influenced this equilibrium, causing water levels to fluctuate (Menotti 2001a: 119). However, not all lakes react in the same way to climatic oscillations. An important role is played, according to Magny (1992, 2004, 2009 among others), by the sensitivity of lakes, mainly linked to the ratio of the catchment area to the lake area. The geological as well as morphological structure of the basin area, in addition to natural origins of lakes, the size and the length of their inlets and outlets, influence the intensity of a transgression. As a result, it is possible that during same climatic variations one lake records lesser or weaker transgressions than another lake situated nearby (Figure 61). For instance, despite Constance Lake and Zurich Lake form part of the same microenvironment and have similar geological origins, their response to hydrologic changes due to climate is not totally equivalent. This is mainly because of their difference in size and the extent of their catchment areas (Menotti 2001a: 122).

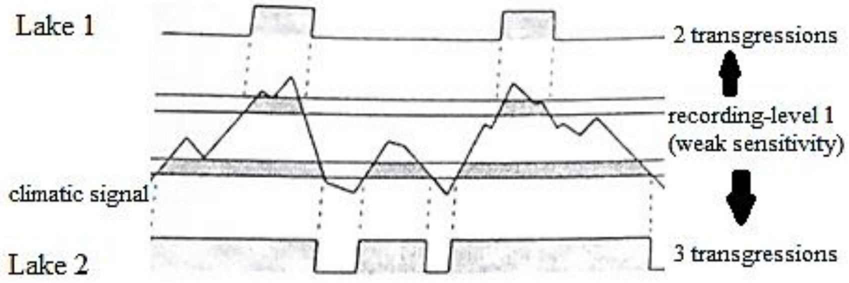

Figure 61 two different levels of transgressions according to the sensitivity of the lakes (after Magny 1992: 328; from Menotti 2001a: 122, figure 9.4.1.1).

Furthermore, Magny (Magny 2001: 135) suggests that only synchronous changes in several lakes within a region can testify to their climatic origin. In order to reconstruct Holocene water-level fluctuations in a large number of lakes, possible correlations between variations in climate and the history of Neolithic and Bronze Age lake-shore villages have been tested. The data, from 29 lakes in a mid-European region composed of the Jura Mountains, the northern French Pre-Alps and the Swiss Plateau, indicate that the whole Holocene period was punctuated by alternate higher and lower lake level phases (Figure 62). Testing its climatic significance and implications, this mid-European lake level record is compared with three other palaeoenvironmental records and also atmospheric residual ^{14}C variations' diagram. In effect, since an attempt of correlating some of the French Jura lake levels fluctuations with the variation of the atmospheric ^{14}C content of the past 10,000 years has successfully been made by Magny (1995), the important role played by the solar activity has been recognised. In figure 30 close correlations appear between the mid-European lake level record and the other proxy data (Magny 1999, 2004: 138). They display synchronicities with paleoenvironmental and archaeological data from these and also other European countries (van Geel & Renssen 1998). Magny (1995, 2004; Menotti 2009: 62) shows that there is a plausible correlation between climate and lake-dwelling occupational patterns (Figure 63).

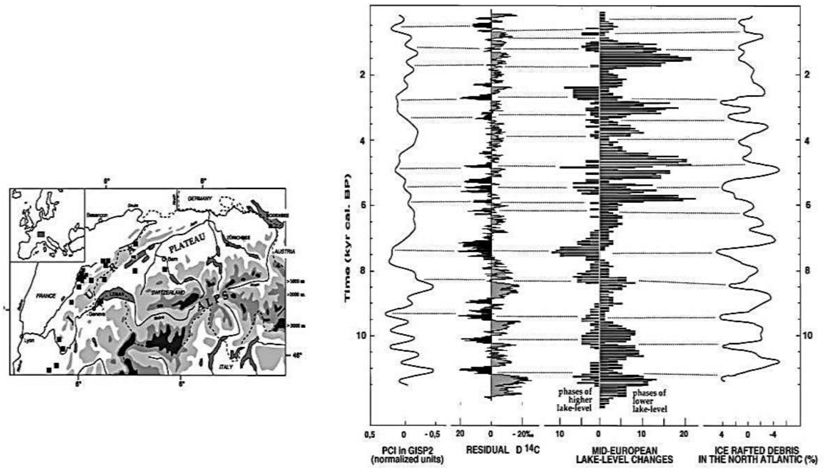

Figure 62 Panel 1 (left): geographical location of the records presented in the lower panel. Panel 2 (right): comparison between the Holocene record of the atmospheric ^{14}C variations (Stuiver et al 1998) and the Mid-European lake-level fluctuations (after Magny 2003; from Magny 2004: 136, figure 9.2).

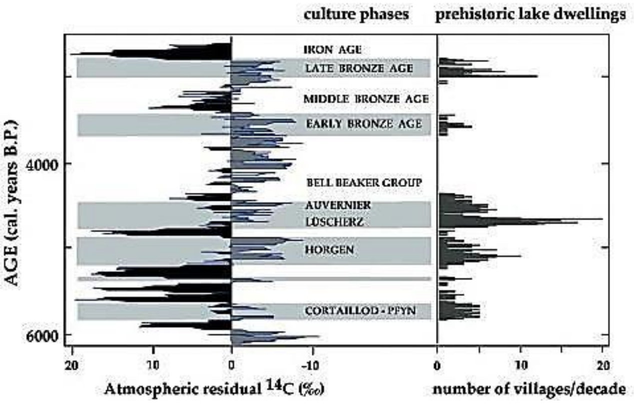

Figure 63 Correlation between atmospheric residual ^{14}C variations (+unfavourable climatic conditions; -favourable climatic conditions) and lakeshore settlement occupations in the western part of the Circum-Alpine region (Menotti 2009: 62, figure 1; after Magny 2004: 139, figure 9.3).

Pétrequin and Bailly (2004), on the other hand, argue that the relationship between climate and lakeshore occupation does not always work. There are in fact periods when climatic conditions in the lacustrine environment were favourable, but lakeshores were not settled. For instance, short-term deteriorations in the climate during the first half of the 37th and 36th centuries BC had little impact on lakeshore occupation. On the contrary, in the 34th century BC some lakes, in particular in the western part of Switzerland, continued to be occupied, despite climate deteriorations (Menotti 2009: 62). During the Neolithic, in addition to one occupational gap that occurred over 3400-3250 BC, other interruptions due to transgression of lake levels have occurred in the entire northern Alpine region, displaying a more regional nature. Despite these local discrepancies, all occupations followed a general pattern, which matches with environmental factors and in particular with climatic conditions (Magny 1992). The situation was slightly different during the Bronze Age and a sharp distinction has also to be made between the northern and the southern parts of the Alps. In the former, two main occupational gaps have occurred during the 24th-18th centuries BC and between the 15th-12th centuries BC. Since during the Early Bronze Age the northern as well as the southern part of the Alps were characterised by stable and favourable climatic conditions without indications of deterioration, this first gap in the northern region was indeed mainly due to cultural factors that have not affected, for instance, northern Italy and Slovenia, were lakeshores were kept on being occupied (Menotti 2001a: 119). On the contrary, towards the Middle Bronze Age climate started to deteriorate in both regions although this condition has reached the southern Alpine area at least one century later and its impact on lacustrine settlements occupation patterns was not so drastic. Some lakes are known as the most sensitive in northern Circum-Alpine region such as Constance and Zurich Lakes. At the former, normal seasonal level-fluctuations vary as much as three metres between winter (the lowest) and early summer and/or early autumn (the highest). This natural phenomenon has also been witnessed on less sensitive lakes and even on shrinking morainic lakes such as Feder Lake (Siedlung-Forschner) in Germany (Schlichtherle & Wahlster 1986) and the former Carera Lake (Fiavé) in Italy (Perini 1987). Although not all sites were affected in the same way by water transgression, the extent of its influence on lacustrine settlements could depend also on the typology and the location of dwellings (Menotti 2001a, b; 2009). Indeed, it has influenced the way houses were constructed - reconstructed (Pétrequin 1984; Menotti 2001b: 319). A variety of house types, developed throughout the lake-dwelling tradition in the Circum-Alpine region, was ranging from houses on stilts on shores of highly dynamic lakes (with marked seasonal lake-level fluctuations, e.g. Constance Lake), to dwellings constructed directly on the ground (but nevertheless carefully insulated, e.g. Feder Lake) in wetland environments less prone to periodical floods (Menotti 2001a, 2004b; Schlichtherle 2004; Menotti 2012: 119). Furthermore, since the cyclic nature of fluctuations have threatened lake dwellers, they have taken some measures to protect the house and settlements. For instance, during the Early Bronze Age phases of occupation at the lacustrine settlement of ZH-Mozartstrasse, houses were constructed directly on the soft ground with a single-layered wooden floor; in particular, a thick multiple-layered structure, which elevated the living floor by several centimetres, was found in a house built during the last phase of settlement occupation, probably in order to protect houses against rising lake levels (Gross 1987b; Gollnisch & Seifert 1998; Menotti 2001a: 100). Nonetheless, these water-level transgressions have influenced and damaged occupational layers of dwellings. Generally water fluctuations could quickly inundate and covered by fine-grained deeper water deposits (lake marl), or, if the water had risen slowly, its effects can be destructive (e.g. erosion can be caused by wave action) (Goldberg & Macphail 2006: 114). Flooding of lakeside settlements due to surface flow have caused erosional processes within anthropogenic accumulations (Jacomet et al. 2004) (Figure 64).

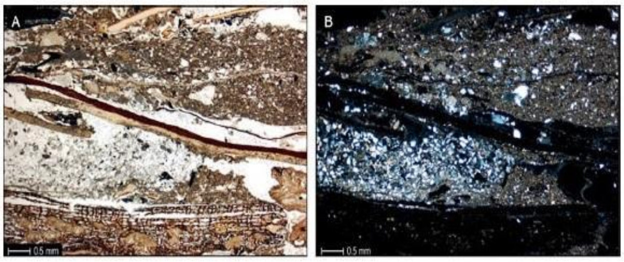

Figure 64 a) Sorted sand deposit on a top of an erosion surface as a consequence of a sandy inwash from the hintherland. Note also the homogeneous transgression deposit in the upper section. Arbon-Bleiche 3 M1036, PPl. b)same as A, XPL (from Ismail-Meyer et al. 2013: 328, figures 8A-B).

Micromorphological investigation showed that the uppermost parts of organic cultural layers were more affected by flooding, according to the acrotelm-catotelm model. The loose acrotel of organic accumulations was faster eroded, while the dense, waterlogged "catotelm" was not affected by the flooding and remained in situ; otherwise, a general homogenization of anthropogenic sequences would have been the consequence (Ismail-Meyer et al. 2013: 332). There are several micromorphological features which indicate flooding in the archaeological record, such as reworked layers containing a micrite matrix, or big amounts of well-sorted fine sands, possibly mixed up with organic detritus and micro-charcoal. Archaeological deposits that do not contain any freshwater indicators (such as, for instance, mollusc shells) can be considered as in situ, whether they contain fragile components, as wood ashes or well-preserved coprolites (Huber & Ismail-Meyer 2012). This could be the case of Cham-Eslen (Zug Lake): there sedimentological and micromorphological studies indicated that the single house found was built as a ground-level construction on the top of a small island. Lake flooding led to erosion and reworking of anthropogenic sediments, but in the central part of the building archaeological sediments could be considered as in situ (Huber 2009; Huber & Ismail-Meyer 2012; Ismail-Meyer et al. 2013: 332). At the pile-dwelling of Mezzano, lake changes in level and extension occurred in several periods; the positive hydrological balance of the lake was able to flood the nearby flat area, as occurred before and after the Bronze Age. The running water during one or more phases of low lake level produced an erosional surface which was recognised (Sadori et al. 2004: 8-9). Furthermore, archaeological evidence of lake-level fluctuations within the sites can be find also as spreads of objects which were washed out by the flood itself. For instance, at Siedlung-Forschner on Feder Lake (south Germany) a large quantity of artefacts such as pottery, wooden tools and also animal bones was found out of its original place. They were piled up against the internal side of the village palisade, due to the action of severe flood which moved the objects until they became trapped against the fence (Schlichtherle & Washlster 1986; Menotti 2001a: 100). At Arbon-Bleiche 2, on Lake Constance, a large quantity of wooden planks were discovered in sector L, deposited there by a major flood which occurred at the end of the 16th century BC. Since the level of water in the Early Bronze Age is known (ca 392 m a.s.l) and the village of Arbon-Bleiche 2 was located at about 396 m a.s.l., the lake level had to raise quite considerably in this period. These examples show that lacustrine communities were taking measures to face the natural phenomenon of lake fluctuations. For instance, during the Late Bronze Age, at Ürschhausen-Horn, among others, some architectural attempts to combat rising humidity were realised (Gollnisch-Moos 1999; Jennings 2014: 135). Unfortunately, those solutions have in some cases only been temporary, since the severity of flood could prevail and the exodus from the lakes became, in some cases, inevitable. Thus, the variability of lake level could affect not only the intra-depositional formation of the archaeological deposit but it could be also considered among the reasons that have caused the abandonment of lakeside settlements. Fire events - conflagrations can be listed among intra-depositional processes as well as the likely reasons for the site abandonment, due to their polyvalent nature and their repetitiveness during the past.

3.4. The lakeside settlement abandonment: introduction

At a certain time-span during the occupation of a village inhabitants decided to abandon the settlement. This is defined as "the process whereby a place, an activity area, structure or entire settlement is transformed to archaeological context"(Schiffer 1987: 89; Schiffer & LaMotta 1999: 22; Cameron 2006: 28). It can occur on an increasingly inclusive scale, as abandonment of a structure or activity area, a large portion or even the entire settlement, a local area or a large region. It has also a temporal component, since it can be a temporary, long term or permanent phenomenon. Each spatial and temporal dimension has different consequences for the formation of the archaeological record. During the abandonment it can be assumed that residents will remove the most useful and portable objects, according to several conditioning factors (Stevenson 1982; Deal 1985; Schiffer 1985; LaMotta & Schiffer 1999; Cameron 2006: 28; Schiffer et al. 2010). Different modes of abandonment (e.g. see Longacre & Ayres 1968; Lange & Rydberg 1972; Schiffer 1972, 1976, 1985; Bonnichsen 1973; Robbins 1973; Baker 1975; Stevenson 1982; Cameron 1991; Joyce & Johannessen 1993; Kent 1993) could produce peculiar material evidence. During an unplanned and quick abandonment many valuable and usable objects may be left where they were used, forming the *de facto* refuse (Schiffer 1996: 89-97); consequently, they could be removed for use elsewhere according to curate behaviours. These processes are two sides of the same coin, since the former is an accretion process, while the latter a depletion activity (LaMotta & Schiffer 1999: 22). Investigating the chosen mode of abandonment, the complex situation that involves the formation of lakeside settlements has to be highlighted. A chain-like sequence of site construction, abandonment, renovation/reconstruction and further final abandonment characterises these contexts, rather than a simple single linear sequence of events (Jennings 2012: 16). For instance, when a conflagration event has destroyed the settlement, this might be quickly followed by a site rebuilding directly above the previous (e.g. Wasserburg-Buchau, Federsee Lake, Germany (Billamboz 2006) or in the proximity of the original (e.g. the Neolithic settlement of Sutz-Lattrigen-Rütte (Biel Lake, Switzerland) (Hafner & Suter 2004: 23; Jennings 2012: 16). At Lucone di Polpenazze, sounding D, the occurrence of a sudden fire event is testified by the burnt elevated remains of the house and a unique partially burned beam of groundwater ("trave di falda") was found; the site was immediately (after one year, dated through dendrochronology) restored through the planting of new poles (Baioni et al. 2005: 89-90), then the material evidence produced during the abandonment has been absorbed simultaneously into the reconstruction layer. On the contrary, when the site would be re-occupied after years, decades or even centuries (such as the abandonment of Early Bronze Age settlements in the northern Alpine region with a subsequent return during the Late Bronze Age, similarly to Ürschhausen-Horn and Oggeslshausen-Bruckgraben, or not re-occupied at all (as Greifensee-Böschen (Eberschweiler et al. 2007), the material consequences of the abandonment could be partially preserved on the archaeological record. However, this evidence could probably be mixed up and even deformed by post-depositional processes. When an increase of water lake level has occurred after the abandonment, the plan has been sealed and preserved in an underwater condition (such as at Arbon Bleiche 3). The conscious decision of leaving the site, as a temporal strategy or as a definite choice, was triggered by cultural as well as natural factors. In accounting for the entirety of abandonment pictures, a straightforward multi-causal explanation is required, associated with an approach that takes into account the differences involved by peculiar strategies of abandonment in a micro scale as well as in a macro dimension.

3.4.1 Different abandonment modes in the lakeside settlements context

The abandonment of lakeside settlements often conveys images of catastrophe, mass migration and environmental crisis (Menotti 2001b: 145); nonetheless, to correctly explore and interpret the complexity of abandonment processes a focus on the its causes is not exhaustive. An important role is played by the articulation between human behaviour at the time of abandonment and the resulting patterns in the archaeological record. They also hinge upon the different modes and strategies followed by inhabitants during their exodus.

The short-term abandonment seems to be a quite widespread phenomenon in lakeside settlements, probably linked to changing climatic conditions; these variations could force inhabitants to settle shallower areas where they less likely experienced inundation in the event of lake water rise (Menotti 2001b, 2003, 2004; Jennings 2014: 22). Some settlements, for instance Unteruhldingen-Stollenwiesen (Schöbel 1992), Cortaillod-Est/Cortalloid-Plage/Cortaillod-Les Esserts (Arnold et al. 1986) and Auvernier-Nord (Arnold 1983) were re-occupied but underwent a spatial shift and were gradually moved with each phase of re-occupation and new building activity. The Zurich-Mozartstrasse site shows cultural occupation over 24 centuries between the Neolithic and the Late Bronze Age, with at least 15 phases of occupation and hiatuses (Gross et al. 1987; Conscience 2001; Schmidheiny 2006; Jenning 2014: 22). There, as much as at Arbon-Bleiche 2 and Bodman-Schachen 1, inhabitants experimented slow abandonment processes. In these sites, directly affected by increasing water levels, inhabitants had enough time to plan the exodus, as demonstrated by the artefact distribution as well as the conditions of the found houses. Although the word “abandonment” may cover a message of sudden catastrophic events, the Middle Bronze Age exodus from lakes in the northern part of the Alps was a considerably long process which lasted more than half a century. Lake waters were rising steadily but people had enough time to plan the abandonment and look for new land to settle again. A paramount aspect that former lake-dwellers had to take into consideration was the safety of the new environment, which had to be located far enough from the lakeshores so that is would not have been influenced by the lake transgressions in the years to come (Gross et al. 1987; Hochuli 1994; Menotti 2001b: 163).

Five distinct phases of settlement and occupation are attested at the site of Zurich-Kleiner Hafner that covers a period from the 4th to 2nd millennium BC (Suter et al. 1987; Jennings 2014: 22). Shorter cycles of abandonment and re-occupation also occurred, such as at Bodman-Schachen 1 (Constance Lake) (Köninger 2006) and at Dispilio (Orestias Lake) (Karkanas et al. 2011). At the lake-settlement of Zug-Sumpf (Switzerland) an abandonment of the site four years later to a flooding event that took place around 944 BC was followed by a further phase of occupation occurred between 880 and 860 BC (Bauer et al. 2004; Jennings 2012).

Few lake-dwellings show only a single short occupation, as Arbon-Bleiche 3 (Jacomet et al. 2004; Leunzinger 2001) and Greifensee-Böschen (Jennings 2014) or sites where the Late Bronze Age abandonment have a permanent nature, as they were never resettled. The decision whether or not to reoccupy former lakeside sites can be related to specific causes and involve, as well as trigger, specific explanations. The visual presence of former dwellings on the lake-scape (Robinson 2013; Jennings 2014: 34) plays a significant role: the material evidence of pile-dwelling structures (timber, piles, palisade) must have been visible in the period following the abandonment. These remains and even the social memory of successfully inhabiting that area (Kohl 1981: 112; Arnoldussen 2013) could push communities to return after a gap, as at some Late Bronze Age sites (Ürschhausen-Horn, at Nussbaum Lake, Switzerland, Wasserburg-Buchau, at Feder Lake, Germany, Hauterive-Champréveyres, at Neuchâtel Lake, Switzerland, Zurich-Alpenquai, at Zurich Lake, Switzerland, and Zug Sumpf, at Zug Lake, Switzerland)[7]. There, although it is unknown whether same communities were returning to their previous sites, the material culture from the region indicates local development rather than incoming populations to the area (Jennings 2012: 13). Nevertheless, some factors could act to prevent the re-occupation of a lake-dwelling. Negative properties, values and associations of places (Chapman 1998: 112; Jennings 2014: 36) can go in this direction, together with the indirect memories, that can be related to similar places and times (Bender 2002: 107; Jennings 2014: 36).

The Middle Bronze Age lake-dwelling hiatus may be interpreted in this perspective: when more favourable climatic conditions and more stable lake levels returned, social memories of settlements and the visual recognition of former pile-dwelling structures (Menotti 2001a-b) allowed communities to come back to the lakeshore. The decision whether to resettle a site has been linked also to the will of reproducing or on the contrary changing cultural values and meaning, through the use of historical, traditional and ancestral places (Chapman 1998: 110). According to this perspective, the continued use and re-occupation of lake-dwellings may have been an attempt to maintain the social *status quo*; this condition may enable to retain links to ancestral practices, beliefs and values, creating and continuing a sense of community identity (Jennings 2014: 36).

The cyclic abandonment and re-occupation of lake-dwellings suggests that they were constructed with temporal considerations in mind (Gerritsen 2008: 151); they were built with an intended life-span or temporal duration that may have been dictated by the durability of construction materials used, by agricultural concerns or related to the life cycle of the community, before they were abandoned. The occurrence of “old” objects may be interpreted according to a perspective of continuity. For instance, Early Bronze Age needles in Late Bronze Age contexts in wetland assemblages also raise the possibility that items were curated over extended periods as cultural heirlooms (Fischer 2011: 1301-02). However, such items could be encountered also during Late Bronze Age activities - as agricultural processes - and then retained as curiosities (Hingley 2009). In any case, if they were retained as heirlooms, such objects may have been used as indicators of legitimacy to reside in certain locations. Instead, if they were encountered in the local environment they may have provided indications to settle specific sites. As highlighted by Jennings (Jennings 2014: 118) further interpretation can be garnered from the condition in which objects were deposited. The single objects as well as material evidence of previous occupation may be reused: if they were still visible part of old houses, the may have been dismantled and the wood reused to build new dwellings situated near the abandoned site (Menotti 2001a: 146). The use of halved or quartered timber for piles and the utilisation of recycled timber is attested at few Late Bronze Age settlements, as Hauterive-Champréveyres (Neuchâtel Lake, Switzerland) (Pillonel 2007), Conjux Le Port 3 (Bourget Lake, France) (Billaud 2008) and in oak piles at Zug-Sumpf (Seifert 1996: 64-73) (Jennings 2012: 12); the piles were removed at the sites of ZH-Mozartstrasse, Arbon-Bleiche 2 and Bodman-Schachen 1, except those driven in the ground (Menotti 2001b: 146).

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[7] They are analysed as sample groups by Jennings (2012).

When remains of previous settlements are still available but the distance from the new site is quite substantial, it is not worth it to shift the construction material for long distances; then, settlements are destroyed by setting them on fire (Menotti 2001b: 146). This practice seems to be quite widespread, although, in the majority of cases, the data do not enable to recognise their deliberate or unplanned nature, as in some Italian pile-dwellings and lakeside settlements (such as Fiavé, Ledro, Lavagnone, Lagazzi, Canar, Feniletto, Isolino di Varese and Ciseno). Since in some circumstances single structures appear to have been destroyed by fire at different times, it is possible that they were not accidental conflagrations but the deliberate and selective destruction of individual buildings. Instead of buildings simply being left to decay rapidly after the abandonment (Schöbel 2011), micromorphological analysis have proved that burning events may have been the last action. At Ürschhausen-Horn, individual buildings were destroyed without fire spreading to adjacent, despite the close proximity to structures. This deliberate destruction of dwellings and households (Bönisch 2005) as opposed to accidents or "catastrophes" afflicting the village (Leuzinger 2000: 165) may have marked the end of a life or household stage. Otherwise, it could simply provide an easy method to clear a site in advance of fresh construction, or to ensure that incoming groups could not utilise previous household structures (Jennings 2014: 17). In the archaeological contexts that showed clearly signs of deliberate destruction by fire, a planned abandonment of temporary or indefinite nature can be imagined as the most likely scenario. Further evidences provided for Ürschhausen-Horn can confirm this reconstruction. The typology, dating spread and quantity of artefacts recovered from specific areas have been used as an argument against the sudden abandonment of lake-settlement (Müller 1993: 86). For instance, at Ürschhausen-Horn exceptionally little and few pieces of metalwork were found at the site, suggesting that some of the building were cleared before their deliberate abandonment (Nagy 1999); this process finds support in ethnographic survey (e.g. Deal 1985; Jennings 2014: 118).

Furthermore, the distribution of pottery at the settlement indicates that ceramics were placed along the outside of the buildings and fragments of individual vessels were dispersed amongst several structures (Gollnisch-Moos 1999; Nagy 1999). Even in this case ethnographic studies (e.g. Hayden & Cannon 1983; Deal 1985) have demonstrated that ceramics may be temporarily stored along the outside of buildings, following breakage and during the abandonment such vessels are left in situ, as de facto/abandonment refuse, while intact and usable vessels are removed. All these data may suggest planned abandonment and destruction of buildings rather than accidental fire or hurried evacuation (Jennings 2014: 118). An inverse circumstance seems to characterise the abandonment of the Viverone pile-dwelling (VI1-Emissario). In this Middle-Late Bronze Age site apparently associated metalwork consisting of an entire female "parure" and weapons were found; scholars consequently suggested an hypothetical sudden abandonment of the site or an impossibility to recollect these objects (Menotti et al. 2012: 197). At Castellaro Lagusello (Piccoli 1982: 448) the occurrence of some prestigious elements (such as amber and bronze artefacts) as much as some antler and lithic artefacts have suggested an hypothetical sudden abandonment. Nevertheless, in interpreting our archaeological record, a potential further use of water, highlighted by Menotti (Menotti 2001b: 146) have to take into account. Water courses and water basins, if not used as sources of drinkable water, have always been used as natural dumps. Therefore, also the lake-dwellers discarded large quantities of pottery fragments, animal bones and other objects in the nearby lake, which in some cases was part of the settlement. As a result, the distribution of those objects can be misleading during archaeological analyses.

3.4.2 The causes of abandonment in the lakeside settlements context

Among the many combined factors that influence past social dynamics, climatic change directly or indirectly played a role in the abandonment of lake-dwellings (Magny 1992b, 1993, 1995, 2004a, 2004b; Menotti 2001a-b, 2003, 2004; Magny et al. 2009; Menotti 2009; Menotti & O'Sullivan 2012; Jennings 2014) (Figure 65). For instance, the direct effect of climatic deterioration led to the increase of lake water level and consequently the inundation of the surrounding wetland settlements.

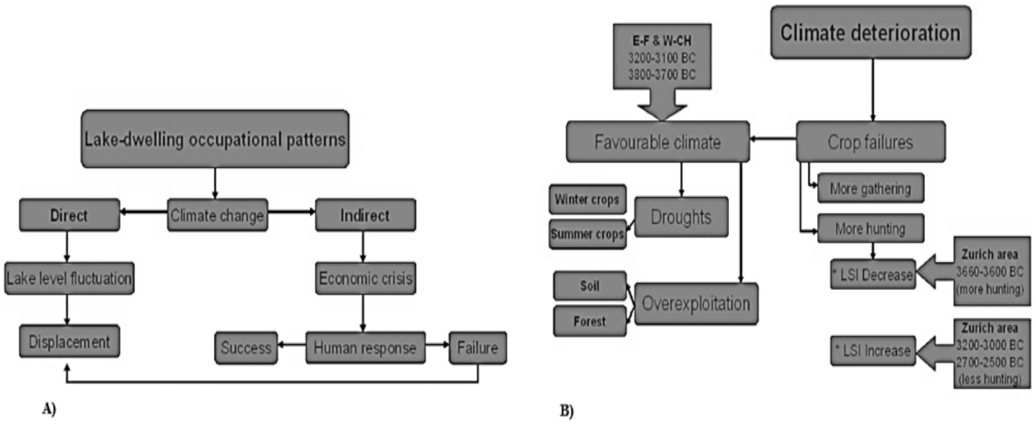
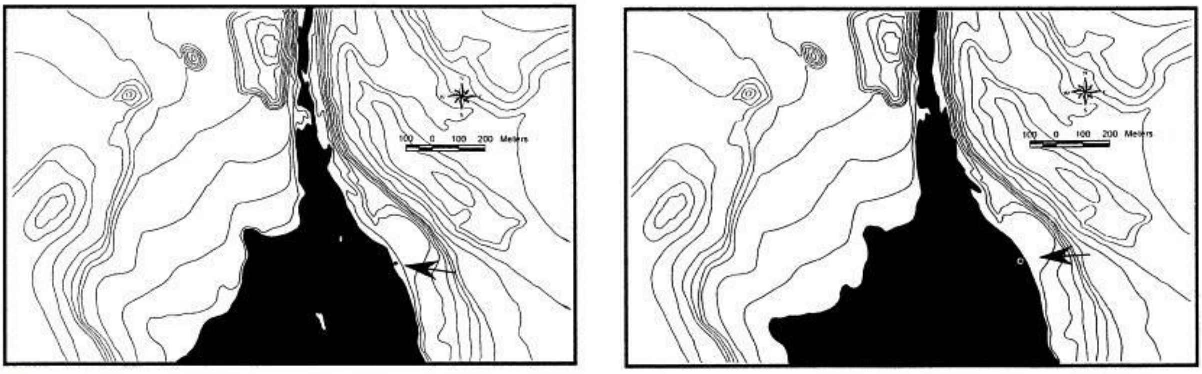


Figure 65 A) direct and indirect influence of climate change on lake-dwelling occupational patterns (from Menotti 2009: 63, figure 2); B) Negative effects of both favourable and unfavourable climatic conditions on crop cultivation in the northern Circum-Alpine region lake-dwelling tradition (from Menotti 2009: 64, figure 3).

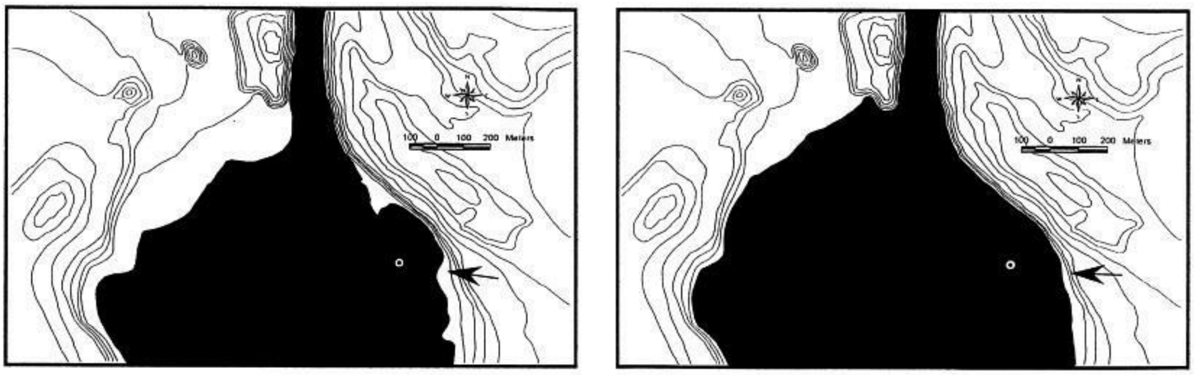
Because of the flat land morphology, flooding reached also the lake hinterland, as it has clearly been shown by GIS computer simulations of lake transgressions in the Zurich bay, Arbon bay and Bodman bay at the end of the Early Bronze Age (sites of ZH-Mozartstrasse, Arbon Bleiche 2 and Bodman-Schachen 1; Menotti 1999; Menotti 2001b) (Figure 66 shows the example of Zurich Lake). Despite this alterations of lakes, hydrological balance used to occur regularly in seasonal term with controlled consequences. When it assumed more drastic long-term character, a forced alternative strategy was required. Since tillable lands in site's surroundings were almost entirely used for agriculture and animal husbandry, their flooding forced lake-dwellers not only to shift their habitations but also to face with economic crises related to food production and subsistence (Schibler & Studer 1998; Menotti 2001a; Menotti 2003; Menotti 2009; Menotti 2012; Jennings 2012, 2014). Furthermore, cooler/wetter conditions meant that sufficient crops could not be produced for the comparatively large and high population density settlements when contemporary inland sites are considered (Arbogast et al. 2006). Then, a loss of economic sustainability can be included into the indirect influences of climatic changes (Jennings 2014: 20): the solution was mainly based on mobility and diversification practices.

Nevertheless, these combined direct and indirect effects may not have been significant enough to cause the abandonment of the lake-dwelling tradition across the entire Circum-Alpine region, particularly given the varying sensitivity of lake level changes across the region (cf. Bleicher 2013). Some cultural influences featured in the widespread phenomenon of lakeside settlements' abandonment: according to the scenario proposed by Menotti for the Middle Bronze Age hiatus (Menotti 2001a), this was not simply a "settlement reaction" to altered conditions, but a cognitive response to changed circumstances. An initial environmentally triggered crisis became a larger-scale cultural phenomenon, through local and interregional exchange networks (Jennings 2014:20), as it came to include sites which would not have been directly affected by rising lake levels (Menotti 2001a: 141).



GIS computer generated simulation of the Lake Zurich level as it might have been in the Early Bronze Age (18th–16th century BC): 403 metres a.s.l. (the black dot pointed out by the arrow locates the Early Bronze Age lacustrine settlement of ZH-Mozartstrasse).

GIS computer generated simulation of the Lake Zurich level as it might have been in the Middle Bronze Age (15th–13th century BC): 404 metres a.s.l. (the white dot pointed out by the arrow locates the Early Bronze Age lacustrine settlement of ZH-Mozartstrasse).



GIS computer generated simulation of the Lake Zurich level as it might have been in the Middle Bronze Age (15th–13th century BC): 406 metres a.s.l. (the white dot pointed out by the arrow locates the Early Bronze Age lacustrine settlement of ZH-Mozartstrasse).

GIS computer generated simulation of the Lake Zurich level as it might have been in the Middle Bronze Age (15th–13th century BC): 407 metres a.s.l. (the white dot pointed out by the arrow locates the Early Bronze Age lacustrine settlement of ZH-Mozartstrasse).

Figure 66 GIS computer generated simulation of the Zurich lake level as it might have been in the Early and Middle Bronze Age (from Menotti 1999: 149-152, figures 3-6).

As within the lacustrine communities of the northern Alpine region towards the Early Bronze Age (16th century BC), effects of the economic crisis experienced by an influential cultural group within a regional context are bound to be transmitted on to other communities through commercial activities which link more groups together (Menotti 2001b: 145-146). The decision to desert lakeshores, which had initially been triggered by environmental factors, became cultural and the influence on lacustrine occupational patterns began to cover much larger areas, transforming the exodus into a global regional phenomenon. The majority of the Early Bronze Age lacustrine sites in the northern Alpine region were abandoned within the 16th century BC and in particular towards the end of it. As highlighted by Jennings (2014: 20), the influence of "negative" attitudes and perceptions of an area due to climatic and environmental change have recently been illustrated by Leary (2009) linked to the early 20th century abandonment of Holland Island (Chesapeake Bay, Maryland, USA): the sea level rise created negative attitudes towards the future of the island, despite the fact that it remained habitable for a significantly longer time span (Arenstam Gibbons & Nicholls 2006). Furthermore, lakeshore abandonment might have been also caused by demographic expansion linked to migrations and environment overexploitation. A good example is the Neolithic lake-dwellings at Chalain (France); possibly due to the influx of external cultural groups (the Eastern-Swiss Horgen groups, South-west Ferrieres groups and northwestern groups from the Saone Plain), a demographic increment between 3200 and 3000 BC was experienced (Arbogast et al. 1995; Pétrequin et al. 2005). A series of effects, such as an increase in hunting activity (due to a higher demand for meat), overexploitation of cultivable land and the felling of primary forest trees for building houses were triggered. A combination of all these factors was probably what forced lake-dwellers to move to other areas, as the region of Clairvaux Lake, in search for more abundant natural resources (Arbogast et al. 2006).

The history of prehistoric settlements in wet areas as those recognised at north of the Alps strongly contrasts with that reconstructed south of the Alpine Mountains. In northern Italy, archaeologists observed that a relative continuity of lake-dwellings was maintained all through the Bronze Age; furthermore, the Middle Bronze Age seemed to mark a maximal development of lake-shore and wetland pile-dwelling villages (Perini 1994; Guidi & Bellintani 1996; Martinelli 2005; Magny & Peyron 2008; Magny et al. 2009: 576) (Figure 67).

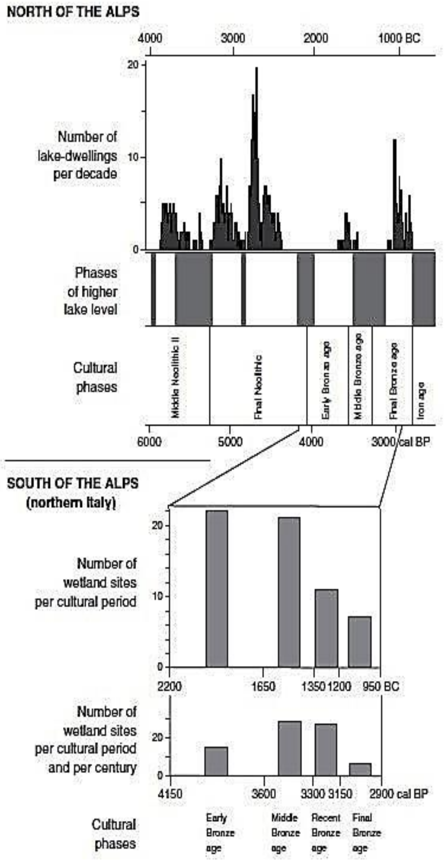


Figure 67 Frequency of lake-dwelling per cultural phases north and south of the Alps. Upper panel: Neolithic and Bronze Age lake-dwellings in eastern France and on the Swiss Plateau. Lower panel: frequency of Bronze Age lake-dwellings in northern Italy as estimated from archaeological remains found in wetland areas (from Magny 2013: 593, figure 34.4, after Magny et al. 2009: 586, figure 9).

The regional peculiarity of northern Italy is still confirmed by Terramare which developed in humid areas of Po plain during the Middle and Recent Bronze Age (Cremaschi et al. 2006). Unfortunately, paleohydrological records established from high-resolution studies of lacustrine sediment sequences and based on robust chronological data are still rare in northern Italy, to test whether differences observed between the history of Bronze age lake-dwellings north and south of the Alps were linked to different regional paleohydrological patterns or to a different socio-economic organisation of societies. Nevertheless, through the pile-dwellings' available dataset, such as those of Ledro (Magny et al. 2009), for the Northern Italy, and some from Central Italy, such as, among others, Mezzano Lake (Giraudi 2004; Sadori et al. 2004), Fucino Lake (Giraudi 1998) and Accesa Lake (Magny et al 2007), scholars were able to draw some preliminary conclusions. According to Magny (Magny et al. 2009: 585-6; Magny 2012: 585-98), despite a climate characterised by increasing moisture between 1500 and 1200 BC, Bronze Age settlements south of the Alps remained in humid areas of lakeshores and in the Po plain. On the contrary, the following drier climatic conditions appeared to be synchronous with a general crisis of lake and wetland villages and also coincided with an abrupt end of Terramare. As a working hypothesis, scholars suggested a peculiar socio-economic organisation of Bronze Age societies in northern Italy (Magny et al. 2009; Magny 2012: 594) (Figure 37). For instance, the end of Terramara culture appeared to be quite sudden everywhere in the Po plain[8]; climatic changes cannot be regarded as the only force that determined their sudden decline (Cremaschi 1997; Bernabò Brea et al. 1997; Cardarelli 2010). The relative degree of human influence and climatic factors largely differs on a regional scale, but on the Po Plain both Holocene climatic changes and anthropogenic activities produced distinctive geomorphological effects. Here much of the land was deprived of its original vegetation by fluvial modifications such as flooding and through human activities as forest clearance and ploughing, this producing intense aerial erosion (Marchetti 2002). Probably a coincidence of many factors (Bernabò Brea et al. 1997) with the synchronous occurrence of climate deterioration and overexploitation, as suggested by the archaeobotanical record of Montale, took place in the area. In fact, in this site signs of crisis have appeared archaeologically around 1300 BC when even the number of settlements in the area diminished, while remaining sites did not enlarge their boundaries (Cardarelli 1997). These data was compliant with the pollen diagram that, for this time-span, detected the fall in forest, less pastures and an increase in open areas with a more stable record of weeds (e.g. *Centaurea nigra type, Cirsium, Polygonum aviculare type*, *Platago lanceolata* type), probably occupying abandoned fields. Such a crisis was possibly due to overexploitation of woods and soils (Mercuri 2006: 57). The environment was less suitable for cultivation than before and the wood was not able to recover quickly. Nevertheless, in marine and lake cores signs of deforestation continued and led to maxima at around 1100 BC (Mercuri et al. 2002; Oldfield et al. 2003). In agreement, archaeological data show that the Terramara di Montale was abandoned at ca. 1200 BC, when this culture ceased quite suddenly everywhere in the Po plain. This climatic event causing dry conditions may also have contributed to the final abandonment of the Poviglio Santa Rosa Terramara (Reggio Emilia-Italy); the clear drop in the water levels during the late Recent Bronze age, corresponding to the final phase of the site occupation, involved the collapse of the hydraulic system discovered, in general, in Terramare culture and in particular at Santa Rosa. The moats surrounding most of sites were probably conceived to concentrate water and redistribute it to the surrounding country through a network of irrigation ditches (Cremaschi et al. 2006: 95). At Santa Rosa a system based on large water wells and interconnecting ditches was found; scholars stated that in this recorded hydrological crisis, the aridity was a limiting factor affecting land use at the final stage of the settlement (Mercuri et al. 2014: 2), as it was the local expression of a regional dry event. The further pollen data from Terramara of Baggiovara (Cardarelli 2009; Mercuri et al. 2014) suggested that the site was always less forested and therefore less suitable for wood exploitation. The greater space for houses is confirmed by archaeological data on demography which states that such pressure was higher in this area than elsewhere. However, this is possibly among the causes of short existence of Baggiovara.

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[8] This point of view will be clarified in the next pages

Cardarelli (2009: 48) concluded that the Terramara di Baggiovara and Tabina di Magreta, among others, were abandoned when a major re-organisation of the territory occurred in the Middle Bronze Age. The land transformation occurred at that time became a cause of crisis for Baggiovara. There, a limiting factor seems to have been the wood loss rather the a water shortage, that took place in later phases (Mercuri et al. 2014: 16). Also in the Emilia region, in the Terramara of Gaggio di Castelfranco Emilia (Modena) the phase of site abandonment is marked by the agricultural exploitation of the intra-site space, between the end of the Middle Bronze Age and the beginning of the Late Bronze Age (Balista et al. 2008; Nicosia et al. 2011: 290).

Although is confirmed the role played by climatic component in the disappearance of Terramare, a multi-causal explanation is required, as suggested by scholars, that considered the end of the Terramare culture as a consequence of a societal collapse (De Marinis 1975; Barfield 1994; Balista & De Guio 1997; Bernabò Brea & Cardarelli 1997; Bernabò Brea et al. 1997; Cardarelli 1997; Pearce 1998; Cremaschi 2006; Cardarelli 2010; Cremaschi 2010; Frontini 2011). This cannot be interpreted as the result of a simple relationship between demography, climatic crisis and environmental decline; then, justifying the radical change that took place in the Po Plain during the first half of the XII century BC, social and political explanations are required. This need did not hinder an environmental factor but may well have been triggered or enhanced by it (Bernabò Brea et al. 1997; Cremaschi 2010). In a social and political system which took place within a tribal order[9], the demographic growth as well as the diminution in land yield and increasing drought did not allowed Terramare to withstand, being impotent to change their economic and social model, as well as their system of production. In this condition it was probably necessary to put an end to the harmonious social development that had been a feature of Terramare for centuries. It is legitimate to suppose that in some areas of territory occupied by Terramare the transition away from the ancient tribal order may have been set in motion (Cupitò & Leonardi 2005; Leonardi 2010; Cardarelli 2006) but it appears generally evident that Terramare remained on the whole a society characterised by a strong sense of tribe and community. Social impracticability of a transition to a new system of production and a new political order seems to have been the principal reason for Terramare's inability to respond to the crisis and hence also the cause of their definitive collapse (Cardarelli 2010: 484). Nevertheless, the end of this culture did not seem to have left widespread signs of violent destruction, neither are there accumulated traces of natural events, as happens when flooding leaves deposits. Archaeologists are not able to establish whether the abandonment was simultaneous across the entire territory or it was a result of several years or decades of crisis. However, this last hypothesis seems more likely, as archaeological evidence shows that various Terramare completed their life cycle before the end of the Recent Bronze Age (RB2) (Cardarelli 2009; Cardarelli 2010: 485). The *diaspora* of Terramare's inhabitants would be the result of a gradual abandonment of villagers divided in limited groups, over decades, following a known process of penetration/colonisation (Yasur-Landau 2007). As suggested by Bietti Sestieri (Bietti Sestieri 2005) and supported by Cardarelli (2010: 486) the depopulation of the Terramare could have occurred with the relocation of small groups, ascribing to this dynamic the transfer to neighbouring regions of techniques and know-hows pertaining to Terramare area.

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[9] For the use of word tribal see Cardarelli 1997; Cardarelli et al 2006; Cardarelli 2009. In the broader sense, the meaning of tribal is substantially equivalent to that of a community with a territorial base or functional and territorial as proposed in Peroni 1996a; 1999; 2004 (Cardarelli 2010: 471).

As in the case of Terramare, the Middle Bronze Age lakeside settlement hiatus was characterised by considerable social changes related to economic crisis those communities were experiencing. Three main Early Bronze Age lacustrine sites (ZH-Mozartstrasse, Arbon-Bleiche 2 and Bodman-Schachen 1) probably played a central role even influencing other lacustrine communities. Due to economic instability, these dwellers decided that lakeshores were no longer safe enough to settle: since they were not committed to vast agricultural production, trade networks and intra-village complex social structures, although they were not threatened by flooding waters, they left lakeshores even earlier than the three main sites mentioned above. The abandonment of the northern Alpine foreland lakeshores (the so-called Middle Bronze Age lake-dwellers' exodus) coincided with the expansion of the Tumulus culture, towards the northern Alpine region fringes. This culture covered a fairly vast territory namely Bavaria, northwestern Austria, the Baden-Württemberg region between the Rhine and the Danube and a few sporadic areas around Constance Lake and Zurich Lake (Menotti 2001a: 146-7). An interesting aspect of the Tumulus culture is that it has never been found on lakeshores. Two plausible hypotheses regarding this culture are formalised: since the time of its expansion was the same as when lakes started to be deserted, probably the hostile flooded lakeshores did not attract those groups; on the other hand, the Tumulus culture in the Alpine foreland could have developed from a process of acculturation between the Early Bronze Age lake-dwellers and the Early Bronze Age terrestrial groups. Indeed, while the former were abandoning their lacustrine settlements, the latter were absorbing them (Köninger 1996; Menotti 2001a:147). However, it is sure that the abandonment of the northern Alpine lakeshores towards the end of the Early Bronze Age and the beginning of the Middle Bronze Age generated an increment of cultural mobility throughout the entire Alpine region.

The climatic interpretation has been favoured even exploring the cause of Middle Bronze Age hiatus settlements (Magny 1995; Menotti 2001a; Van Geel & Magny 2002; Magny et al. 2009). The final abandonment of the lake-dwellings, occurred in 800-600 BC ca. in the northern Circum-Alpine region and in 1200 BC ca. in northern Italy (De Marinis 2009) has instead been interpreted as strongly driven by cultural factors (Jennings 2014: 23). Although the beginning of the Iron Age was marked by a slight climatic deterioration, several phases of favourable lake water levels have followed (e.g. Härke 1979: 32, 65; Pétrequin & Bailly 2004: 40-44). Furthermore, although the time interval when lake-dwellings were being abandoned across the northern Alpine region appears to correspond to a prolonged period of higher lake levels, the gradual decline in the occupation of such sites began during the period of lower levels up until 800 BC (Bleicher 2013). The transition from the Bronze Age to Iron Age in Europe is a complex time period which can in many respects be seen as the expansion of cultural systems and processes that existed during the Late Bronze Age (Thurston 2009: 351). During this chronological phase cultures of the Circum-Alpine region started to gradually reject a tradition of lake-dwelling occupation in favour of open and upland settlements, fortified hilltop sites (Härke 1979, 1989; Benkert et al. 1998; Jennings 2014: 23). The last lake-dwelling in the Alpine region to be abandoned was Ürschhausen-Horn, during the 630 BC (Billamboz & Gollnisch 1998; Gollnisch-Moos 1999). Unlike the Middle Bronze Age hiatus, the Late Bronze Age - Early Iron Age abandonment process occurred over an extended period of time, with lake-dwelling gradually being abandoned and not reoccupied. In the northern Circum-Alpine region this phase has begun immediately following the Middle Bronze Age hiatus, since many lake-dwelling sites were never re-occupied and the number of lake-dwellings known within the Circum-Alpine region is significantly reduced after this hiatus (Magny 2004b; Magny & Peyron 2008) (Figure 33).

Furthermore, several Late Bronze Age settlements show no indication of previous site occupation, such as Greifensee-Böschen and Konstanz-Raue, while few others, such as Steckborn and Kreuzlingen on the Constance and Mörigen Lakes, showed re-occupation from the Neolithic and Early Bronze Age (Jennings 2014: 23). Although the lake-level transgression did not appear as unique cause of the lakeside settlement abandonment, the climate component may have played an important role, as at the Zurich-Alpenquai site. The partial absence of the crucial last occupational layer, associated with a reliable dendrochronological date from a house component (844 BC), led scholars to wonder as to whether there is more to it than met their eyes. However, the current state of the art does not enable to explain why the settlement was left for good (Wiemann et al. 2012: 82).

The inland movement from lakes was, as already mentioned, not limited to the northern Alpine region: although it happened about a century later, also in the southern parts of the Alps the quest for drier land to settle occurred and the cognitive response to adaptive processes was quite similar to that of the northern lacustrine communities. For instance, at the site of Fiavé in the pre-Alpine region of north-eastern Italy, the houses of the last horizon, namely Fiavé 7, assumed particular Late Middle Bronze Age- Late Bronze Age characteristics of construction which resembled those of land settlements. All dwellings belonging to Fiavé 7 were built on the dry ground of both the island of zone 1 and on the hilly area of "Dos Giustinaci", situated 200 metres south of zone 1 and 2. All houses of Fiavé 7 have large planimetry and stone floors are made of gravel and pebbles, very similar to the typical Middle Bronze Age land settlements; dwellers of Fiavè 7 chose to construct their houses according to this model, ignoring examples constructed by their ancestors in front of their eyes (Menotti 2001b: 148). As the foundation of a "new" settlement, may modification of construction models have symbolised the succession of elites before the intention to relocate was marked? Alternatively, the timing of settlement abandonment and relocation or renovation may have been influenced by the age of inhabitants, agricultural productivity, community beliefs, unusual events or the structural condition of buildings (Ebersbach 2010: 152).

Furthermore, asynchronous abandonment of dwellings within an individual settlement and the suggestion of immediate reconstruction after abandonment/destruction are indications that a climatically centred model for the abandonment of lake-settlements does not elucidate the full situation. In some cases, although superficially the example would appear to corroborate the climatically driven abandonment hypothesis, a deeper analysis proves this assumption as simplistic. For instance, at the lake-settlement Zug-Sumpf a flooding event had occurred around 944 BC but the abandonment of the settlement was delayed by four years, with a temporary character, since a further phase of occupation occurred on the site between 880 and 860 BC (Bauer et al. 2004). A further example of continued occupation , despite an increasingly humid or inundated environment, can be seen in the LBA settlement of Ürschhausen-Horn (Switzerland). At this settlement, occupied between 870 and 800 BC, building techniques have changed over time in order to compensate for increasing ground humidity (Gollnisch-Moos 1999; Nagy 1999). These two examples provide clear indications that Late Bronze Age lake-settlements were not always abandoned due to the threat of rising lake-water and the inhabitants of some settlements took measures to counteract increasing humidity and continued occupation despite inundation.

However, the flooded area could have influenced the economy of the community, which in turn may have led to settlement displacement (Menotti 2003). Despite the preservation of structural elements and the potential for highly accurate dating of those elements, other than establishing settlement occupation phases and construction sequences, relatively little theorisation of lake-dwelling biography or development has occurred (Jennings 2014: 5).

3.5. Post-depositional processes in the lakeside settlements context

The significant difference between wetland and dryland contexts in preserving organic material is pointed out in almost every wetland archaeological publication; the particular advantage of the pile-dwelling or lakeside- lakeshore settlements is the preservation of finds to a degree that is rarely found elsewhere. However, it is clearly understood that the level of preservation varies considerably from place to place even within waterlogged conditions; different wetland ecosystems have different preservation properties, which go beyond sheer water-saturation. Soil chemical composition, pH, and redox potential play a crucial role in the survival of artefacts after deposition (Menotti 2012: 226). Furthermore, a myriad of tightly interwoven cultural and environmental factors can alter this “equilibrium” (Menotti 2012: 203; Menotti & O’Sullivan 2013: 417). In most lakeside sites it is not easy to determine the extent of distortion provoked by natural processes in the anthropogenic signal. In such settlements, pile-dwellings are often constructed on raised platforms and the underlying deposits are therefore not directly related to the actual anthropogenic activities. Cultural materials falling in the water are moved, sorted and graded by wave action and redistributed by erosion during lowering of the lake level and bioturbation in the littoral zone (Karkanas et al. 2011: 84). Human activities, as the modern exploitation of lakes and their surroundings, can also alter our archaeological record. After the settlement abandonment, however, natural environment that preceded may sometimes be restored, granting a good preservation of the archaeological record. For instance, at Stagno, the restoration of lagoonal environment is testified by the nature of sediments which sealed the archaeological deposit. This condition ensured the conservation of wooden structures, found in the grey organic clay banks at about 3.5 m below the soil level, whose spread reached an extension of about 4500 m^2 (Giachi et al. 2010: 1260-1, 1267). Furthermore, the absence of strong post-depositional deformations can avoid the re-arrangement of objects that remain in their original place in the strict sense of the term: examples of this phenomenon are the hearths in the Neolithic sites of Ehrenstein (Zürn 1965) and Taubried (Strobel 2000) or the wooden installations of Seekirch-Stockwiesen (Schlichtherle 2004) and Greifensee-Böschen (Eberschweiler et al. 2007), as suggested by Bleicher (Bleicher 2013a: 52). At Arbon-Bleiche 3, the fact that the site was occupied only once, sealed by lake marl deposits soon after its abandonment and even not disturbed by human or natural influences until it was excavated in 1993, enabled the accurate reconstruction of some steps of its formation, revealed by a detailed micromorphological analysis. It was also possible to determine that the thin stratum above the lake marl, accumulated straight after the village was abandoned, was not a subsequent occupation but a layer of reworked debris from the same village, deposited by wave action much later (Ismail-Meyer & Rentzel 2004; Ismail-Meyer 2010; Menotti 2012: 272). Therefore, a full understanding of stratigraphic deposits from a geoarchaeological perspective is crucial in order to reconstruct why our archaeological record is as it is now. This goal will be reached through the analysis of each stage of the deposit deformation.

3.5.1 Natural post-depositional processes

After the deposition stage, a variety of changes can occur within an archaeological sediment. They can affect artefacts on a micro scale, the settlement in a semi micro scale and, finally, the regional perspective in a macro scale. Natural phenomena such as lake level transgressions and flooding, regardless of reasons that provoked them, perturb in different ways the archaeological record. The unstable nature of such changes can involve consequent lake level drops which favour erosion and the compression of archaeological layers. Furthermore, these transgressions involve wave action and water currents that can rearrange the artefacts' spatial distribution. Conversely, if the flooding becomes more stable, it can partially favour the preservation of the archaeological record. In a micro scale, wetland environments (e.g. peat, fen, mire etc.) can facilitate some post-depositional processes as trampling and decaying processes, which affect in particular the micro and semi-micro scale of analysis.

3.5.1.1 Natural post-depositional processes on an artefact scale

Trampling assumes a central role among the most invasive process that can affect the artefact, particularly within the cultural horizons; its effects may appear from the first moment of the site's occupation. When human activities started on platforms, trampling led to a slight compaction of the surface. Wood chips from wood working, loam aggregates for floor and wall structures were accumulated (Pétrequin 1997; Leuzinger 2007); instead, remains of food preparation were trodden into the ground surface (Ismail-Meyer & Rentzel 2004; Ismail-Meyer et al. 2013: 325-326), trampled by cattle and finally scavenged by dogs in rubbish heaps for bones (Bleicher 2013a: 52). Since these are processes that reflect living conditions in the settlement, Bleicher proposed to consider them as an integral part of the archaeological record, rather than as a bias (Bleicher 2013a: 52). Trampling is usually limited to minerogeneous sediments that retain better the change of microstructure (Courty et al. 1994; Matthews 1995; Rentzel & Narten 2000; Ismail-Mayer et al. 2013: 333). Within shore platform sediments, as quoted by Wallace (1999), archaeological traces of trampling in lakeside settlements are limited to installation horizons, loam layers (including clay), sandy in-wash layers and only slightly organic cultural layers, such as at Arbon-Bleiche 3, Lobsigensee and Cham-Eslen (Huber & Ismail-Meyer 2012; Ismail-Meyer et al. 2013: 327; 333) (Figures 68 and 69). Traces of trampling in covered areas are not only characterised by horizontally skimmed clay floors; they also occur within finely stratified cultural layers from covered areas.

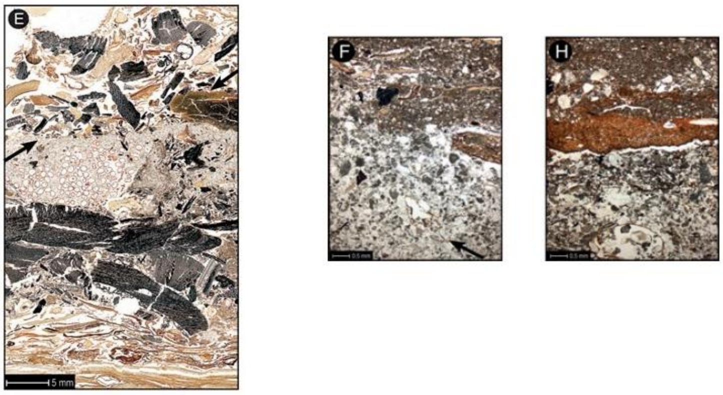


Figure 68 E) an organic occupation deposit at the bottom is covered by a charcoal-rich burning layer and an accumulation of inwashed sand from the hinterland, mixed with lots of poppy seeds. The top of the sandy layer is trampled (left arrow) and covered by charcoal, organic matter and a burnt loam aggregate (right arrow); F)Sandy

beach deposit with caddis fly larvae (arrow) and rounded aggregates of lake marl, overlain by the dark gray, trampled installation horizon; H)Compacted sandy beach deposit, overlain by bark fragments (brown, center) and dark gray trampled peds of carbonate, corresponding to the installation horizon, Arbon-Bleiche 3 (from Ismail-Meyer et al. 2013:330, figures 7E, F, H).

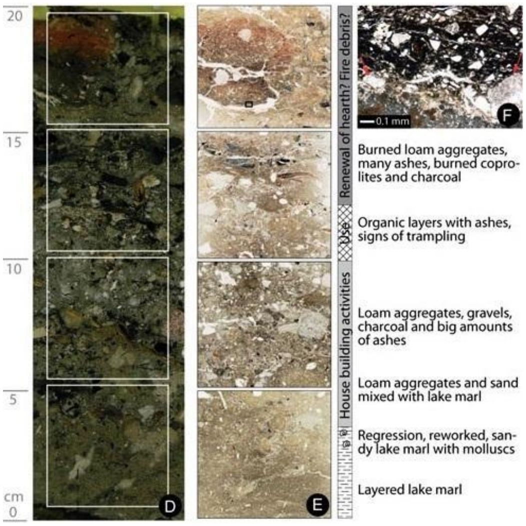


Figure 69 D)Polished section with the position of the thin sections marked in white; E)Scanned thin sections and description of the micromorphological phases and their possible reconstruction; F)Detail of burned clay aggregate with melted quartz grains (arrows) and gray ashes at the bottom, Cham-Eslen (from Ismail-Meyer et al. 2013: figures 3D-E).

Despite positive results mentioned above, scholars pointed out also issues related to the micromorphological evidence of trampling in ductile waterlogged organic sediments. The high moisture content that characterises the deposit causes the sediment to swell quickly again after being walked on, with few irreversible signs of trampling being preserved (Ismail-Meyer & Rentzel 2004). Furthermore, recently grown roots of reeds and rushes can penetrate from the shore into cultural layers, mixing them and changing the arrangement of remains, even if those are covered by 1-2 meters of lake marl (Haas & Magny 2004; Ismail-Meyer et al. 2013: 334). Post-depositional processes caused by reed growth can be seen, for instance, at the sites of Arbon-Bleiche 3 and at Cham-Eslen (Ismail-Meyer et al. 2013: 334). Changes in the spatial distribution of artefacts may be caused even by flooding processes and wave actions (more details in next paragraph). Finally, degradation and taphonomic processes can undermine the preservation of artefacts and ecofacts. The former are mostly subdued to surface's damages (polishing, bioturbation) and loss of material consistency, while organic materials are subjected to more invasive processes. In this context, the balance between pH and redox potentials plays a crucial role: the pH provides the degree of acidity or alkalinity in a given substance, whereas the redox potential gives the level of oxidation or reduction in the soil. In the event of temporary dewatering of a waterlogged area, soluble minerals are oxidized and organic materials are more prone to degradation. Furthermore, certain organic materials showed level of preservation that varies according to different environmental conditions. For instance, bones are better preserved in both well-drained and waterlogged neutral to calcareous environments, but not in periodically wet ones. Conversely, parasite eggs thrive in these latter conditions and not in either well-drained or waterlogged ones (Menotti 2012: 228) (Figure 40).

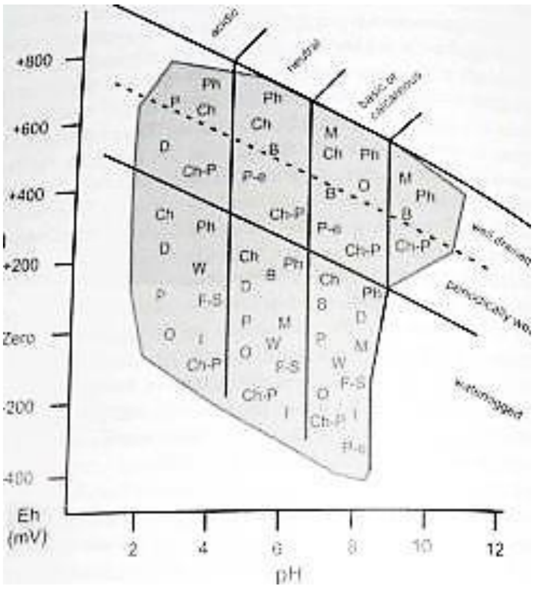


Figure 70 Joint effects of redox potential (Eh) and pH on the preservation of archaeological organic materials (from Menotti 2012: 228, figure 5.17; after Retallack 1984).

Another important factor in the preservation of organic material in wetlands is the presence of bacteria: they are crucial for a large number of chemical processes especially in waterlogged soils. Two kinds of bacteria are attested: the aerobic, requiring oxygen for their metabolism while the anaerobic that do not need oxygen. The latter are divided into two further categories: 1) facultative anaerobes which grow with or without oxygen and 2) obligate anaerobes that grow only without it. Facultative anaerobes deplete the wetland oxygen, reducing the redox potential and creating anaerobic conditions, ideal for the preservation of organic material. However, they also contribute to the deterioration of some organic material, such as wood (Sikora & Keeney 1983; Freeman et al 2004; Menotti 2012: 228).

3.5.1.2 Natural post-depositional processes in a semi micro scale: the lakeside settlements perspective

Flooding processes may strongly affect the site dimension: although the double nature of this phenomenon (human action as natural factors), the analysis is there focused on the second scenario. These processes may have a seasonal or temporal character, producing lake-level transgressions, or a stable nature that involve the overflow of lakeside settlements/pile-dwellings. Climatic oscillations during the Holocene seem to have been the cause of important lake level changes; hydrological sensitivity of lakes themselves can also be involved in these fluctuations (Magny 1992a: 328). A lowering of the lake level, during longer phases of dry and warm climate, exposed platforms of lake marl or the previously deposited sediments (Schurrenberger et al. 2003); the latter may subsequently be re-covered by alluvium deposits or even eroded. Traces of water level changes are preserved into the archaeological record as layers of sand deposition, alternated with *couche de craie* (chalk’s layers) as at Concise (Winiger 2008: 67).

Runoff and high lake levels are caused by heavy rainfall and rapid snow melting, especially in temperate zones and mountainous areas. Major effects of flooding are erosion/outwash and redistribution of accumulations, as well as depositions of brought-in sediments from the lake itself or the hinterland (Turnbaugh 1978). When runoffs reach peatlands, unsaturated parts are quickly filled up but the catotelm is not influenced by this processes (Holden & Burt 2003; Baker et al. 2009). Runoff leads also to sediment transfer by surface flow from the hinterland and this sediment inflow from the catchment area occurs mainly during water discharge in spring (Mitsch & Gosselink 2007). High lake water tables may also lead to peat flooding and they too can be exposed to wave action; the consequence is erosion and removal of fine particles, leaving an aligned and well-sorted coarser substrate, such as sands and gravels (Keddy 2010). Flooding of lakeside settlements due to surface flow from the hinterland causes erosional processes within anthropogenic accumulations (Jacomet et al. 2004). In most cases the uppermost parts of organic cultural layers were affected by flooding: this fact probably is explained by the acrotelm-catotelm model. Whereas the acrotelm of organic accumulations was faster eroded, the dense waterlogged catotelm was not affected by the flooding and remained in situ. Lake flooding led to erosion and even to the removal of fine particles (Brochier 1983; Magny 2004b; Digerfeldt et al. 2007; Macphail et al. 2010); as pinpointed by scholars, in some cases lake flooding is combined with the deposition of micrite (Ismail-Meyer et al. 2013: 334). This presence may confirm that the sediment was probably transported to an area that underwent a further reworking due to a lake transgression; generally, lakeward parts of sites were more affected by lake flooding, while runoffs influenced more landward part of settlement (Jacomet 1985; Jacomet et al. 2004). These components, as micrite, big amounts of well-sorted fine sands, possibly mixed up with organic detritus and micro-charcoal, composed reworked layers. Conversely, deposits that do not contain any freshwater indicators (as mollusc shells, oogonia, trichoptera larvae) can be considered as in situ if they contain fragile components, such as wood ashes or well-preserved coprolites (Huber & Ismail-Meyer 2012; Ismail-Meyer et al. 2013: 334). At Arbon-Bleiche 3 and at Stansstad-Kehrsiten all areas showed flooding markers and also parts that have not been reworked by flooding water (Figure 71).

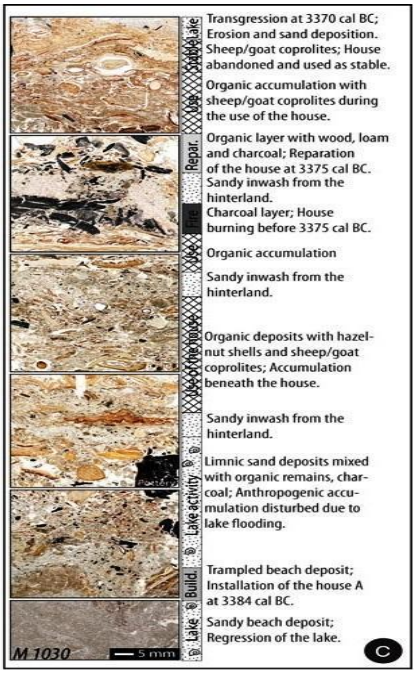


Figure 71 C)The Arbon-Bleiche 3 thin sections of the column M 1030 with the micromorphologically recognised phases of installation, organic accumulations beneath the house floor and inwash of sand from the hinterland (from Ismail-Meyer et al 2013:320, figure 2C).

Sediments with a strong limnic influence are quite common in Cham-Eslen: lake flooding led to erosion and reworking of anthropogenic sediments, but in the central part of the building, archaeological sediments could be considered as in situ (Huber 2009; Huber & Ismail-Meyer 2012) (Figure 72). All investigated sites are covered by limnic sediments indicating a final flooding event during, or shortly after, the abandonment (Jacomet 2004). This condition may avoid the quite destructive effect of a slow water rise that involves erosion caused by wave action (Goldberg & Macphail 2006: 114). This phenomenon, as well as currents in the littoral zone of lakeside settlements could cause reworking, reprocessing and sorting of lake marl. Original laminations are destroyed, terrigeneous detrital sand accumulates, mollusc shells are fragmented and algal filaments disconnected (Brochier 1983; Pétrequin & Magny 1986; Ostendorp 1990a; Ismail-Meyer & Rentzel 2004; Digerfeldt et al. 2007; Ismail-Meyer et al. 2013: 324). After the removal of finer particles, sand became enriched and a lag deposit was formed in the instance of a lake regression.

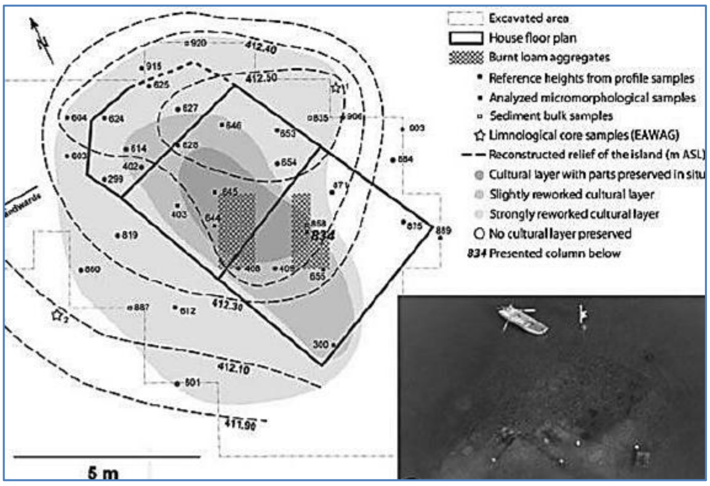


Figure 72 Cham-Eslen: Overview of the site with the floor plan of the single house and the reconstruction of the small island. The house was constructed in the highest part of the island, but flooding led to reworking of parts of the cultural layer (from Ismail-Meyer et al. 2013: 322, figure 3A).

The wave action may affect the occupational layer of archaeological contexts that are not interested by dramatic fluctuation in lake level, as the open lakes. For instance, at Dispilo lakeside settlements, into the microfacies A, a mixing of materials from different occupational periods was attested as result of wave action (Karkanas et al. 2011: 109) (Figure 73).

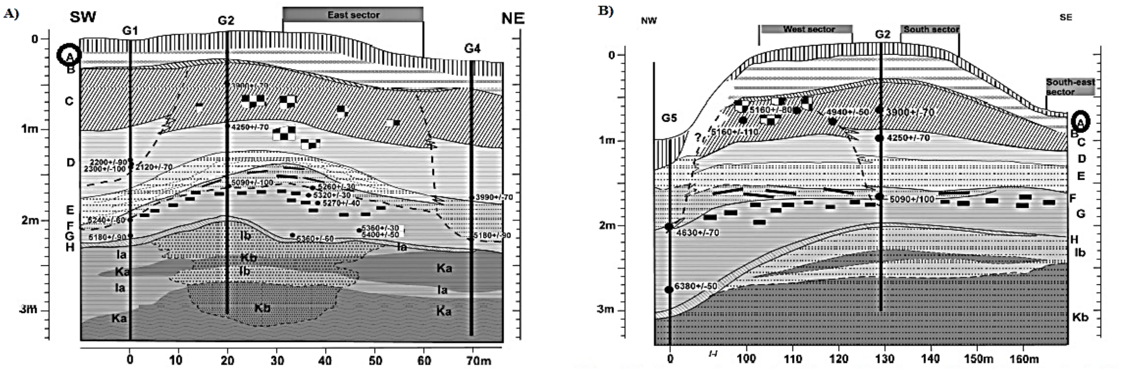


Figure 73 A)Northeast-southwest section of the mound through cores DSG1, DSG2 and DSG4. B)Northwest-southeast section of the mound through cores DSG4 and DSG5. The different microfacies and ^{14}C ages are shown. It is highlighted the microfacies under analysis, the A (from Karkanas et al. 2011: 92-93, figures 5 and 6).

Some archaeological contexts from Constance Lake (Arbon-Bleiche 3, Hornastaad and Allensbach) showed a leaching of the fine matrix that took place during the Neolithic period and consequently sand beach deposits were formed (Ismail & Rentzel 2004; Ismail-Meyer et al. 2013: 323). At Mozartstrasse a leaching of organic materials is attested in the layer 1-c7 (Schmidheiny 2011: 37). Wave erosion may even prevent a further accumulation in the littoral zone: the progression of the shoreline and the formation of a flat surface can expand toward the centre of the lake with time (Magny 1978; Pétrequin & Magny 1986; Platt & Wright 1991; Magny 1992a; 1992b). Sandy layers produced by sediment input into it from the surrounding landscape, through increased erosion of dryland sediments and soils, are attested in some archaeological contexts; for instance, at Fondo Paviani, in the Profil 2, within the Unit 2, a pale brown alluvium, mostly clay-textured but grading laterally to silts and sandy silts is recovered (Nicosia et al. 2011: 284-5) (Figure 74).

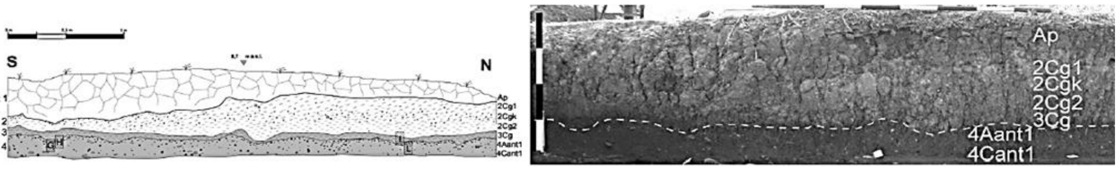


Figure 74 Profiles 2 with main litho-stratigraphic units (left) and pedogenic horizons (right). (From Nicosia et al 2011: 284, Figures 6 and 7).

This alluvial episode took place after the early Iron Age local archaeological phase (post 9th century BC) on the basis of stratigraphic correlations with the site of Perteghelle (Balista et al. 2006 Fig. 2). The extensive alluvial cover is linked to the reactivation of spring-fed streams in the local paleo-river valleys during this time-span, determined most likely by climatic conditions. It is also accompanied by a phase of widespread soil erosion (Nicosia 2006). This sand alluvial accumulations characterised even the upper stratigraphic sequence of several lakeside settlements: for instance, at Cisano (Salzani 1990; Balista & Leonardi 1996: 218), a low energy lacustrine deposit is attested, produced by sand movements from the surrounding landscape. Finally, the surface was made more compact by a strong erosion. This uppermost part of the archaeological record may also be partially modified by the action of recently grown roots of reeds (floralturbation); for instance, at Cortaillod-Les Esserts, roots occupied the north-western portion of the site already in 1927 (Arnold 1990: 95).

3.5.1.3 Pedoturbation processes in a regional analysis scale

In wetland settlements quite all natural depositional and post-depositional processes affecting the site scale, influence somehow also the regional perspective. The lake-level fluctuations as well as the consequent erosion or the colluvial/alluvial accumulations that altered the archaeological record of each site, provoked a macro scale effect as showed by the case study of Fondo Paviani with regards to the Valli Veronesi, or by Neuchâtel Lake, Chalain and many more sites described in next pages. As cultural post-depositional processes also acted with similar effects, this perspective is highlighted at the end of the chapter, in order to show a complete overview.

3.5.2 Cultural post-depositional processes

The archaeological record can be altered as a result of cultural disturbance: major post-depositional effects on wetlands and lakeside settlements are due to human activities, such as agriculture, forestry, artificial lowering of lake levels, drainage systems, stream canalization, dam and dike constructions, mining, water pollution and groundwater extraction (Mitsch & Gosselink 2007; Ismail-Meyer et al. 2013: 334). They may influence the artefact scale, in terms of spatial distribution as well as material preservation, settlement dimension - referring to the material consequence of the modern drainage - and also consolidation, compression, oxidation and pedogenesis, which eventually destroys the wetland (French 2003; Lindsay 2010; Gastaldo & Demko 2011).

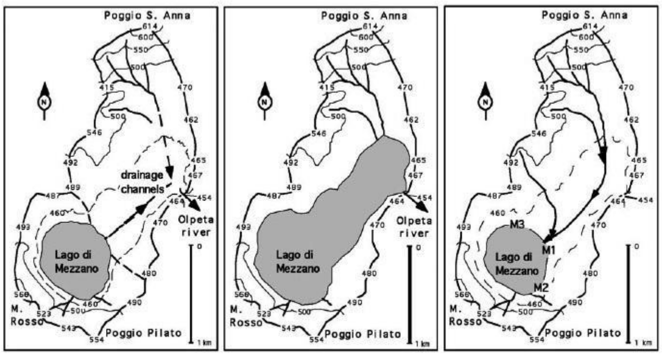
3.5.2.1 Cultural post-depositional processes: reclamation and scavenging in the lakeside settlements context

Across the northern Circum-Alpine region, indications of settlement development are collected through dendrochronological dating. Since an asynchronous model of structures' construction and abandonment is attested (Jennings 2012, 2014), the presence of some archaeological objects as well as structures can be analysed according to a reclamation perspective. For instance, the reutilisation of recycled entire or quartered timber could have occurred between different settlements located in the neighbourhood, mostly in the case of planned abandonment. Indeed, if a catastrophic site's abandonment took place, it is not likely an intentional use of something that probably could be destroyed or left behind due to danger. The same perspective can be applied to old objects found within the Late Bronze Age settlements.

However, although this scenario is theoretically explainable, it cannot be confirmed archaeologically. Nevertheless, this is an interesting perspective that could be useful within the archaeological record of a single settlement. Furthermore, the possible other side of the coin has to take into account: the scavenging. During a post-abandonment phase, entire or fragmented objects left behind could be useful, if not as raw materials (for activities as well as building materials), as toys for kids, as highlighted in some ethnographical and archaeological analyses (Hayden & Cannon 1983; Deal 1985; Schiffer 1985: 987; LaMotta & Schiffer 1999; Cameron 2006).

3.5.2.2 Cultural post-depositional processes in lakeside settlements: the disturbance

Modern drainage may be listed among the most invasive disturbance processes in case studies under analysis. Channels are often built in order to improve agricultural production or to control the water lake level. Drainage was carried out during the XV-XVII centuries at Mezzano Lake (Sadori et al. 2004: 8) (Figure 75), while at Ljubljansko barje (Turk & Velušček 2013: 183) draining operations were undertaken in the second half of the 18th century. The water-table has been artificially regulated for hydroelectricity production also at the Ledro Lake (Magny et al. 2009: 576), whereas at the Lucone Lake, that is currently a marshy area, a drainage work was realised in AD. 1459, in order to increase the cultivation area (Stegagno 1907; Valsecchi et al. 2006: 100). Fenland (England) represents one of the best examples of negative effects has on wetland environments, as Menotti suggested (Menotti 2012: 230). The intense drainage in the second half of the 19th century involved a shrank of peat surface of more than 3 metres in less than 50 years, as is shown by the famous Holme Fen posts (Menotti 2012: 230, Figure 5.18, after Coles 1984: 28).



20th century

XVI - XVIII th century

Bronze Age (M1 - M2 - M3 = archaeological settlements)

Figure 75 The extension of Mezzano Lake size during three characteristic periods: present time, 16-17th centuries and Bronze Age. The 20th century extent of the lake was the result of reclamation works (from Sadori et al. 2004: 6, Figure 2).

Correction of the Swiss Jura's waters can be considered as one possible disturbance activity. This phenomenon consisted of a wide series of hydrological undertaking carried out in Switzerland in the region of three lakes: Morat Lake connected to Neuchâtel Lake by the Broye Canal, the latter connected to Bienne Lake by the Thielle Canal. These projects included operations of cleaning, restoration and diversion of rivers; the main works took place in three distinct phases during the 19th and 20th centuries. The correction has helped to regulate the hydrology, avoiding flooding and adding vast areas of valuable agricultural land. From an archaeological perspective, all these phenomena provoke a well-known dangerous process: the erosion. The strongest effects are attested in some lakeside settlements across the Neuchâtel Lake, at the Concise and at Cortalloid, although this phenomenon is quite widespread (for instance at Bourget Lake, Chalain Lake and Clairvaux, Paladru Lake (Isére) and Chens-sur-Léman (Haute-Savoie) (Pétrequin & Pétrequin 1988). The higher rate of erosion is pinpointed at Cortaillod-Les Esserts, where up to 1,8 m of archaeological deposit has been washed away (Arnold 1990: 95) (Figure 76). At Concise, the construction of a railway in the 19th century made erosion effects on the deposit even stronger.

Figure 76 High rate of erosion attested at Cortaillod-Les Esserts (from Arnold 1990: 97, Figure 79).

At Chalain Lake, water lake level has artificially dropped 12 meters due the employment of hydroelectricity. This sudden drop caused the instability of the banks: 10 hectares or more fell into the lake, causing the loss of nearly half of the lakeside settlements. The seasonal imbalance, artificially maintained, provoked a strong soil erosion, with the deposit being further deteriorated by the subsequent wild tourism. Bathers trampled archaeological deposits and exposed layers in shallow waters (Pétrequin & Pétrequin 1988: 188) (Figure 77). In such a strongly affected area strategies were adopted to prevent the total loss of data; however, the analysis of such procedures is beyond the aims of this chapter.

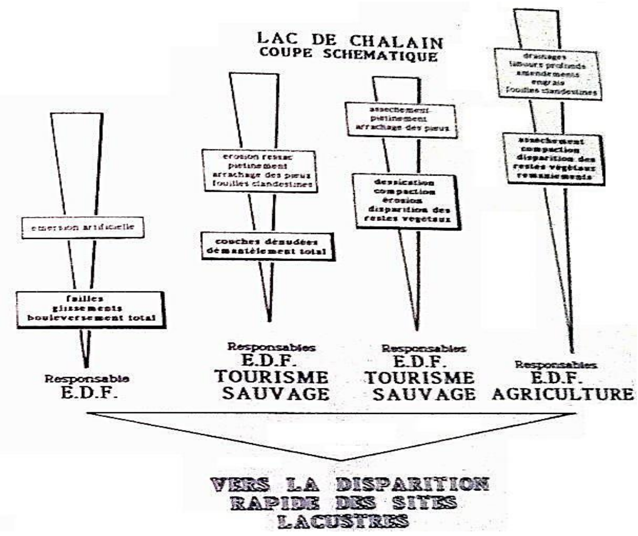


Figure 77 The Neolithic site of Chalain and the mechanisms that provoke its total disappearance (from Pétrequin & Pétrequin 1988: 188).

Modern cultivation practices are further factor of influence in the preservation degree of the archaeological record, in particular respect to the upper layers. A first arable level 50-cm deep was found in the LAV1 core (from Lavagnone) (De Marinis et al. 2005: 228), while at Lucone, two cores (Luc-1 and Luc-2) showed traces of ploughing disturbance in the first 90 cm of deposit (Valsecchi et al. 2006: 101). Partial destroyed surfaces characterised some Terramare, as Montale (Mercuri et al. 2006: 44, 46) and Gaggio di Castelfranco (Balista et al. 2008). Indeed, their dark-coloured archaeological deposits were intensively quarried beginning in the late 18th century to be used as soil fertilizer on fields, particularly those devoted to the production of fodder for bovines (Conversi & Mutti 2009; Bernabò Brea & Mutti 1994; Nicosia et al. 2011: 280). Such deposits were erroneously thought to improve the chemical fertility of local soils due to their high content of organic carbon, nitrogen and phosphorous deriving from human activities. The land deprived of its original vegetation through ploughing and forest clearance for cultivation practices produced intense aerial erosion, as attested in some archaeological contexts from the Po Plain (Marchetti 2002 (cf. Bernabò Brea et al. 1997) and Grandi Valli Veronesi area (among others Fondo Paviani (Balista et al. 2006; Nicosia et al. 2011) and Fabbrica dei Soci (Balista 1990-1991) (Nicosia et al. 2011: 290).

The process of forest clearing and agriculture strengthened the outwash of sands and silts, that provoked a transport of detached sediments downslope and their deposition in the bottomlands (Turnbaugh 1978; French 2003; Zolitschka et al. 2003). This in-wash process certainly occurred also within lakeside settlements. In Arbon-Bleiche 3, older beach deposits in the hinterland were eroded in this way and this process of colluviation (triggered by heavy rainfall) was even noticed during the excavation of the archaeological site (Leuzinger, personal communication, 2003 quoted by Ismail-Meyer et al. 2013:325). Modification of shores are attested at the Banyoles Lake (La Draga) and at Zurich Lake (Mozartstrasse): in the first case earthworks carried out in preparing the lake as a host venue for the 1992 Olympic Games have impacted the site. The level 0 consisted of a deposition of rubble, while the levels I to III are constituted of a set of dark clays in which surface disturbance and intrusions of modern materials have been detected, as a consequence of agricultural works developed in the area until 1989 (Palomo et al.

2014: 61). At Zurich Lake the bay shores were modified in order to gain building land and its immediate vicinity is today rather different from how it looked during prehistoric times (Jackli 1990). The Early Bronze Age settlement of ZH-Mozartstrasse was situated on the little peninsula which, because of in-filling processes, has completely disappeared. The site today is underneath the Bernhard Theatre in the north-western part of Zurich bay and its surviving Early Bronze Age anthropogenic stratum lies at about 60-70 metres from the present shoreline at an altitude between 403 and 404 metres a.s.l. (Menotti 1999: 147).

3.5.3 Natural and cultural post-depositional processes: "diversity in unity"

This short overview of the most widespread post-depositional processes that may alter the lakeside settlements contexts suggested what archaeologists had already hypothesised from the early 1980: these deformation processes are mainly due to erosion. The cause of the increase in erosion is twofold: a marked change in climatic conditions (natural reasons) as well as an increase in human activity around lakes. Together these causes have created an exaggerated effect of erosion that has been destroying natural and cultural heritage in and around lacustrine areas. Particularly affected by this phenomenon is, as mentioned, the Circum-Alpine region and its surroundings, where a large number of lake-shore archaeological sites have already been lost due to erosion over past thirty years. On Geneva Lake for instance, a survey carried out between 1981 and 1985 showed that only a dozen settlements (out of over sixty) still retained anthropogenic layers in place (Ramseyer & Rouliére-Lambert 1996, 2006; Menotti 2012: 232). In order to reconstruct deformation processes that produced our archaeological record, a strategy based on "diversity in unity" is proposed as the most useful approach: combined analysis of cultural and natural post-depositional processes could constitute an interpretative response to the changing material evidence of our archaeological context. Despite this imbalance can be triggered by natural phenomena, anthropogenic factors are mostly to be blamed; short-term reductions may be allowed, providing that the soil has sufficient water-retentive characteristics, but long-term may cause serious problems (Menotti 2012: 226).

3.6. The identification and analysis of formation and deformation processes

This overview of prominent formation and deformation processes producing the lakeside settlements archaeological record suggested that, despite the possibility of a high preservation rate, the recovered material evidence is very biased. Although a partial reproduction of what originally existed is found, a deep analysis of all tiles composing our archaeological "puzzle" enables archaeologists to interpret most exhaustively our evidence, as material consequences of actions carried out during the past. Cultural and natural particles that compose our "sedimentological" deposit have to be taken into account to achieve this goal, since they serve as evidence for past reconstruction. The remarkable quantity of well-preserved organic material, as the diversity of artefacts found in wetland contexts, has required and facilitated the development of a multidisciplinary approach. The synergetic collaboration between the various disciplines allowed to clarify some cultural and socio-economic aspects of such prehistoric wetland communities.

3.6.1 How to codify formation and deformation archaeological processes: geoarchaeology and palaeoecology

The analysis of deposit in geoarchaeological terms has the enormous information potential for deciphering past landscape histories of lakeside settlements: in reaching this goal the use of soil micromorphology, physical and chemical analyses have been introduced, revealing a great deal of usefulness. The creation of thin-sections from sediment profiles permits a microscopic examination of features relevant to the formation of soil deposits in archaeological contexts. As above mentioned, these features provide direct indications for both natural and anthropogenic site formation processes, helping in reconstruct, in a micro and semi-micro scale, each stage of the settlement biography. Of primary importance for the development of lake-dwelling biographies are also well researched dendrochronological records for individual sites. These enable an understanding of development sequences, duration of settlement, expansion and indications of decline (Ismail-Meyer & Rentzel 2004; Jennings 2012: 4). Furthermore, one of the most recognisable features in micromorphological samples from lake-settlements is lake marl, indicating the covering water with higher or lower levels of energy (Schurrenberger et al. 2003; Jennings & Wiemann 2013: 63). The fluctuations of water lake level have recently assumed a central role in the study of lacustrine sediments, analysing its possible influence in the choice of settlement's location (Krier 1997; Hoelzmann et al. 2001; Magny 2004b; Magny et al. 2006). There is a large literature devoted to lake level changes and related paleoenvironmental and climatic reconstructions (Mees et al. 1991; Harrison & Digerfeldt 1993; Magny et al. 1995; van der Meer & Warren 1997; Ringberg & Elström 1999; Magny et al. 2003; Digerfeldt et al. 2007; Holmes et al. 2007). Reconstructing paleonvironments and understanding climate change in the past has become a germane part of wetland archaeological projects, as already highlighted (Zolitischa et al. 2003; Karkanas et al. 2011; French 2013: 555-568; Magny 2013: 585-632). Their joined efforts produced outstanding results in identifying various causes of past climate variations. Nevertheless, as proved by some examples analysed in this chapter, a climatic deterministic perspective did not always work well. For instance, the general abandonment of lakeside settlements in the Circum-Alpine region during the Middle Bronze Age could not be interpreted as an exclusive response to climate deterioration, given its asynchronous and inhomogeneous occurrence in a temporal and spatial scale. A multicausal explanation (based also on social, political and economic factors) seems to be the most likely reconstruction, although probably the climate is the easiest phenomenon to show. Furthermore, the abandonment of lake-dwellings during this time-span does not signify the complete disappearance of populations, that probably have moved to the dryland sites.

These examples pinpoint that, in addition to the collection of paleoclimatic data, the establishment of extensive bases of archaeological and geoarchaeological data, from wetlands and dryland sites, should be a prerequisite before offering conclusions on the role of climate in the past. Furthermore, the material evidence, as ecofacts and artefacts, have to take into consideration in attempt to interpret correctly the archaeological record and reach the most likely scenario of the past. The high fragmentation rate of finds and issues of preservation required a taphonomic approach that enabled archaeologists to overcome these limitations and suggest the best manner of to analyse them.

3.6.2 How to codify formation and deformation archaeological processes: taphonomic approach

Taphonomic-deformation factors influence the site formation and preservation processes, as highlighted before. High quantities of ecofacts retained in waterlogged sites could be misleading if the site's taphonomy is not properly understood and the material evidence not properly sampled. Europe's prehistoric settlements remains in the Circum Alpine lakes and bogs represent an exceptional class of archaeological sites, in combination with the crannogs in Scotland and Ireland (Dickson & Dickson 2000): they permit such detailed insights into daily lives of prehistoric communities. Waterlogged occupation layer provided exceptional conditions for the preservation of material remains through the millennia. In addition to the standard investigation of ceramics, artefacts made of stone, bone and antler, there were also in-depth analyses of organic remains, as timber, plant food, manufacturing waste, human and animal faeces and textiles. In spite of the excellent overall preservation of these organic remains, the effect of taphonomic processes has to be taken into account and miscellaneous small-scale influences must also be observed to correctly interpret finds. Taphonomic effects observed in archaeological lakeside settlements point out the necessity of thoroughly considering all such processes, c-transformation and n-transformation, separately for each category of finds. These issues do not relate only to object sedimentation and displacement but rather concern neglected considerations of the differential preservation and stability of material remains. Although it has been assumed commonly that taphonomy acts upon archaeobotanical and archaeozoological remains in the same way, it is inaccurate (Röder et al. 2013: 36). For instance, further bias is introduced by botanical sample preparation procedures (Hosch & Zibulski 2003; Jacomet 2013: 497-514; Antolin 2013, 2015; Röder et al. 2013).

In interpreting archaeological ecofacts we have to consider both archaeological and biological "facts" (Jacomet 2013: 497). The first perspective is related to the routes of findings entry into archaeological deposits (in general terms see Jacomet & Kreuz 1999:76-9, while for the plant macro-remains Van der Veen 2007; Jacomet 2013: 497-514). Plant remains, animal bones, as well as animal dung and droppings are regularly incorporated into refuse (as primary or secondary refuse) created by human occupants; the same is true for fodder and begging material. From many studies it is clear that seeds, grains and chaff fragments but also macro-remains (such as pollen and spores or parasite eggs) survive the digestive tract of animals (Charles 1998; Hall & Kenward 1998). Another important source of plant materials and seeds entry is human faecal material. Reconstructing processes that involve the entry of ecofacts and artefacts into the archaeological record, even the biography of layer formation have to be taken into consideration. This may be important because horizontal differences in lakeshore settlement layers can be due to human activities, but also to lake level fluctuations or consequences of post-depositional processes (as erosion). They may influence the spatial distribution of finds and also their "biological" features. As highlighted earlier, the state of preservation showed by retrieved finds depends on several natural factors that can vary even within a limited spatial context with similar climatic conditions; as a result, some sites can be extremely well preserved and others can only retain few recognisable observables. The various wetland environments as well as the different categories of finds have controlled the degree of preservation in seemingly infinite variety: for instance, wood may be well preserved in one matrix, but have rotted in another. At the same time, bones may be entirely disintegrated in some acid peats but intact in muds or organic sediments. For all these reasons a taphonomic approach that takes into account the “diversity in unity” of the numerous and differentiated material remains has been required, avoiding inaccurate and biased interpretations of data.

3.6.3 How to codify formation and deformation archaeological processes: ethnography and experimentalism

Despite the large amount of available information from waterlogged sites, archaeologists are often tackling with seemingly unanswerable questions. Providing some hypothetical solutions, experimental archaeology has always played an important role (Menotti 2012: 281). Nevertheless, it is not only about reproducing artefacts, but also understanding the process of making them with correct tools and material, applying the suitable technology contemporaneous to the original objects (Kelterborn 1990; Mathieu 2002; Shimada 2005). Only through this knowledge, light will be shed on more complex issues concerning the socio-economic organisation of the society, group or community.

A field of social sciences that is particularly close to experimental archaeology research is ethnography. A synergetic collaboration between archaeologists and local ethnic groups has become germane for a better and more holistic understanding of ancient material culture. Furthermore, the experimental reproduction of some anthropogenic deposition processes may represent a contemporaneous answer to numerous depositional aspects that are not fully understood. Thanks to the high amount of preserved remains of wooden house in waterlogged sites, even also the smallest architectural detail, the full-scale reconstruction of houses has been possible, combined with ethnographic data (Pétrequin & Pétrequin 1984), such as those from Benin. Although some of these reconstructions are attested in various parts of Europe, from Denmark (in particular at Allerslev where between 1956 and 1958 Hansen (1961, 1962) reconstructed a third millennium cal BC house based on the excavation at Troldebjerg) to Germany, Poland, Italy and United Kingdom (Coles & Coles 1989; Piotrowski 1998; Reynolds 1976, 1979, 1999; Schöbel 2002, 2003), they did not improve our knowledge about the archaeological issue. Conversely, along with other examples, such as houses of Lejre Centre in Denmark, the reproduction of the Hornstaad-Hörnle and Arbon-Bleiche 3 Neolithic houses (Pfahlbaumuseum in Germany) (Menotti 2012: 298) (Figure 78), meticulous experiments are carried out through the reconstruction of two Neolithic pile-dwelling at Chalain, France (Menotti 2012: 293) (Figure 79).

Figure 78

Figure 79

Figure 78 Reproduction of the Arbon-Bleiche 3 Neolithic house (Pfahlbaumuseum in Germany) (from Menotti 2012: 298, figure 7.11). Figure 79 Reconstruction of two Neolithic pile-dwelling at Chalain, France (from Menotti 2012: 293, figure 7.8).

They have reconstructed according to combined archaeological evidence and ethnographic studies (Pétrequin & Pétrequin 1984, 1988; Pétrequin 1997), while the technology employed had to be strictly linked to the Neolithic period. Experiments shed light on some aspects, from the construction techniques (Menotti 2012: 294-296), to the living conditions inside and outside houses (everyday lives activities) (case studies of Chalain Lake as well as the Hornstaad-Hörnle house of Unteruhldingen). They had to withstand natural calamities such as torrential rain, snow, high lake water levels and stormy winds and, apart from a few necessary repairs, passed all the test brilliantly. They continued their experimental tasks for many more years until they collapsed (one in 2002, and the other in 2009) (Figure 80). Material remains of houses have been left in place and will be studied in the future to shed light on the various aspects of site formation processes. Formation processes and the consequent taphonomic issues acquired some more new awareness through the good eye of experimental approaches. The improvement and repetitions of these tests may prove once again the usefulness of these approach in bridging the gap between the archaeological record as it was during its formation and its current deformed appearance and features.

Figure 80 One of the experimental pile-dwellings of Chalain in a tilted position before collapsing in 2009 (from Menotti 2012: 297, figure 7.10).

3.7. Discussion

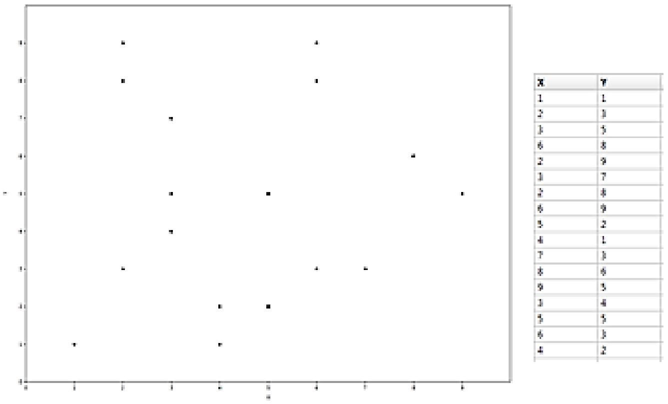
Using a biographical approach to describe lakeside settlements, every stage of formation and deformation processes that produced and altered our archaeological record has been retraced. A deep analysis of geomorphological processes that compose and characterise the natural environment selected to be settled enables us to highlight it strengths and the distinctive modalities of human occupation. Through an hypothetical reconstruction of combined, both cultural and natural, reasons that may involve the choice of settle, these areas are introduced and a reconstruction of the settlement's evolution is suggested. From the techniques used in built houses across the European prehistoric lakeside settlements context, along a quite large time-span that hold especially over the Neolithic Age to the Late Bronze Age, an overview of the best represented models of houses' building is provided. Furthermore, issues related to high quantities of required timber (reuse or conflagration of ancient buildings) and their differential exploitation in light of their functional features are taken into account. Due to the excellent preservation of organic materials into waterlogged contexts, everyday practices carried out inside and outside houses can be reconstructed through the material evidence left behind, i.e. the waste. This refuse, found in primary deposition or rearranged in some ways, constitute residual traces of living houses' life cycle, from the occupation period (which includes all repairs, expansions and/or internal modifications) to the final abandonment. They inform about the cultural background of different life stages of various domestic elements that make up the entire house and the household, including inhabitants (Kopytoff 1986). Moreover, this approach facilitates the possibility of obtaining explanations to the development of houses and, in a semi-macro scale, even of the entire settlement: although micromorphological analyses as well as paleoclimatological and palinological researches may provide solid bases to clarify our archaeological questions, a simplistic answer cannot always explain the complexity of archaeological case studies. A multifactorial causal mechanisms should be preferred in order to correctly interpret our material evidence, as, for instance, in the case of temporal and asynchronous abandonment of lakeside settlements during the Middle Bronze Age in the Circum Alpine region. Material consequences of the definitive abandonment found in archaeological record have to be analysed in light of a required reconstruction of their trigger causes, that are suggested by the nature and spatial distribution of the evidence left behind. In reassembling the biographical puzzle of lakeside settlements post-depositional processes have to be taken into consideration, analysing them in an artefact scale as well as in a more general intra-site and regional dimension. When all the tiles of the archaeological record are clarified, inferences about past societies can be drawn, thanks to a multidisciplinary approach, essential in such conceptually unitary yet practically diverse context, that is wetland environment.

4 ANALYZING INTRA-SITE SPATIAL DISTRIBUTIONS. THE MATHEMATICS OF ARCHAEOLOGICAL DISTRIBUTIONS

4.1. Towards a formal model of accumulation at the intra-site scale

Field archaeologists know from experience that material items in the archaeological space are distributed neither uniformly nor at random (Bevan & Connolly 2009); the same applies to the physical variables that we use to describe environments (Legendre 1993). Consequently, archaeologists should look at the intra-site archaeological space as primarily structured by large-scale social behaviour and geomorphologic processes on ground surface; through energy inputs they cause, on the one hand, the appearance of gradients and, on the other, the occurrence of patchy structures separated by discontinuities (interfaces). Since spatial heterogeneity is thus not the result of some random, noise-generating process, becomes important to study if for its own sake, as it is functional in archaeological space.

The repeated process of discard something at the same place involves a spatial pattern, usually associated with accumulative behaviour: material traces of different but functionally related activities frequently cluster together in what can be called "activity areas". We assume that most of these materials should have been generated by the same individuals at roughly the same time interval and the same location. Consequently, archaeological observables are expected to be denser near the place where discard was supposedly performed and less dense or even disperse far from the central place. Ethnographic data on artefact deposition within activity areas suggest that artifact deposition is expected to be denser in the center of activity areas than at their edges (Kent 1984; Binford 1978). Common sense predicts that the probability of finding a particular frequency value at a particular location will decrease as long as we go far from the place the action originally took place (Barceló & Maximiano 2007, 2012. See also: Ullah et al. 2015). In an attempt to study explore accumulation in space, we need to know the individual location of each accumulated item within the area (Figure 81).



X	Y
1	1
2	3
3	5
6	8
2	9
3	7
2	8
6	9
5	2
4	1
7	3
8	6
9	5
3	4
5	5
6	3
4	2

Figure 81 Example of *xy* plot within a studied area related to specific *xy* coordinate where archaeological observables have been recovered.

With these data at hand, accumulations in space can be properly visualized using Bivariate Kernel Density Estimation graphs. The idea is to convert the pattern of micro distance between each *xy* pair into a measure of spatial frequency at a particular spatial interval; this method can be viewed as a generalisation of histogram density estimation with improved statistical properties. Let $\mathbf{x}_1$, $\mathbf{x}_2$, be a sample of spatial coordinates drawn from a common distribution described by the density function f. The Bivariate Kernel Density Estimate is defined to be

$$\widehat{f_{H(X)}} = \frac{1}{n}\sum_{i=1}^{n} K_h\ (x - x_i)$$

where

- $\mathbf{x} = (x_1, x_2, \ldots, x_d)^T$, $\mathbf{x}_i = (x_{i1}, x_{i2}, \ldots, x_{id})^T$, $i = 1$ and 2 are $2d$-vectors;
- $\mathbf{H}$ is the bandwidth (or smoothing) $d \times d$ matrix which is symmetric and positive definite;
- K is the kernel function which is a symmetric multivariate density;
- $K_{\mathbf{H}}(\mathbf{x}) = |\mathbf{H}|^{-1/2} K(\mathbf{H}^{-1/2}\mathbf{x})$.

The choice of the Kernel Function K is not crucial to the accuracy of Kernel Density Estimators. On the other hand, the choice of the bandwidth matrix $\mathbf{H}$ is the single most important factor affecting its accuracy, since it controls the amount and orientation of induced smoothing. The basic difference between Bivariate and Multivariate Kernel Density Estimation from its univariate analogue is that the bandwidth matrix also induces an orientation, while this latter is not defined for 1D Kernels. This leads to the choice of the parametrisation of this bandwidth matrix (Silverman 1986; Duong 2007). Although there is not "optimal" bandwith, also known as *radius*, this value can be set by depending on the scale of interest (Figure 82). For instance 1)the mean center of the input points can be calculated. If a population field other than None was selected, this and all the following calculations, will be weighted by the values in that field, 2)the distance from the (weighted) mean center for all points can be calculated, 3)the (weighted) median of these distances, D_m, can be calculated, 4)the (weighted) Standard Distance, SD, can be calculated, 5)the following formula to calculate the bandwidth could be applied:

SearchRadius= 0.9 * min (SD, $\left(\sqrt{\frac{1}{\ln(2)}} * D_m\right)$*$n^{-0.2}$

where:

- SD is the standard distance
- D_m is the median distance
- n is the number of points if no population field is used, or if a population field is supplied, n is the sum of the population field values

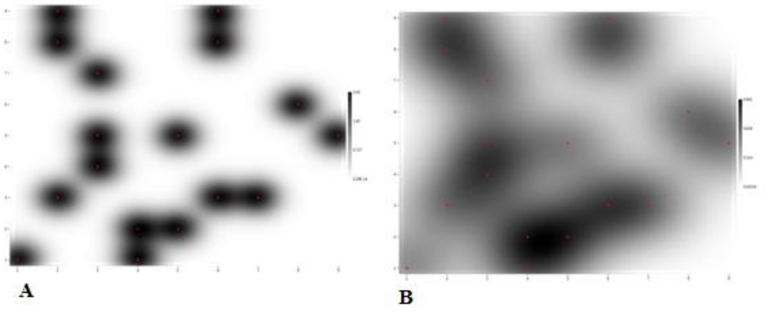


Figure 82 Two examples of Kernel Density Estimation: A)KDE (with Gaussian Function) and 0.04 radius, B)KDE. (with Gaussian Function) and 0.9 radius (Past).

The Kernel Density Estimates method can be used to convert spatially distributed single observations (counts) into spatial frequencies by estimating the amplitude of spatial intervals or cells. The result can be visualized in 3D (Figure 83).

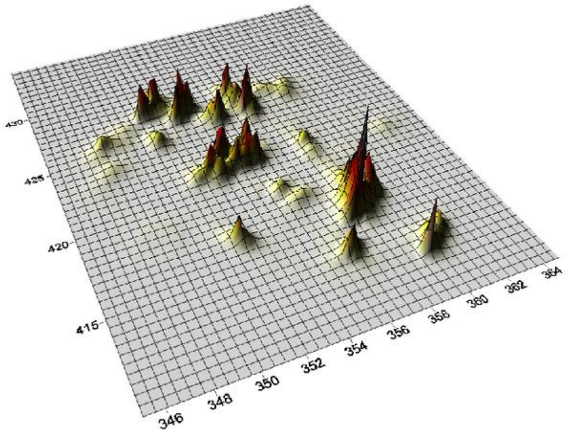


Figure 83 Example of 3D Kernel Density Estimates.

In those visualizations, *z* is an estimate of the local *intensity* of the spatial process in terms of the greater or lower density of locations (Ahsanullah 1985; Kotz et al. 2000). However, such visualization is not enough. The spatial pattern of accumulated archaeological observations at a particular place and it immediate area can be descrived using a variation of standard statistical parameters, like mean, mode and standard devation. In this case, the mean center of a symmetrical spatial distribution can be calculated by separately averaging the *x* and *y* coordinates, as follows

$$\bar{x} = \sum_{i=1}^{N} \frac{X_i}{N} \qquad \bar{y} = \sum_{i=1}^{N} \frac{X_i}{N}$$

We can generate a Weighted Mean Center by weighting each *x* and *y* coordinate by the observed count at each location (w_i):

$$\overline{X} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i} \qquad \overline{Y} = \frac{\sum_{i=1}^{n} w_i y_i}{\sum_{i=1}^{n} w_i}$$

The mean center provides a single point summary measure for the location of a set of points; it may be considered as the center of gravity of a point pattern or spatial distribution, as it minimizes. Nevertheless, it can be more practical to determine the central location that minimizes the sum of unsquared, rather than squared, distances. This location, which minimizes the sum of Euclidean distances from all other points in a spatial distribution to that central location, is called the Euclidean median or median center. Mathematically, this location minimizes the sum:

$$\sum \sqrt{(X_i - X_e)^2 + (Y_i - Y_e)^2}$$

In any case, determining coordinates of the Euclidean median is a methodologically complex task. A weighted Euclidean median is a logical extension of the simple (unweighted)

Euclidean median. The coordinates of the weighted Euclidean median will minimize the expression

$$\sum f_i \sqrt{(X_i - X_{we})^2 + \left(Y_{ij} - Y_{we}\right)^2}$$

As the mean center serves as a locational analogue to the mean, standard distance is the spatial equivalent of standard deviation. Standard distance measures the amount of absolute dispersion in a point pattern. After the locational coordinates of the mean center have been determined, the standard distance statistic incorporates the straight-line or Euclidean distance of each point from the mean center. Standard distance is written as follows:

$$\sqrt{\frac{\sum_{i=1}^{n}(X_i - X_c)^2 + \sum_{i=1}^{n}(Y_i - Y_c)^2}{N}}$$

Or with weights:

$$\sqrt{\frac{\sum_{i=1}^{n} w_i(X_i - X_c)^2 + \sum_{i=1}^{n} w_i(Y_i - Y_c)^2}{\sum_{i=1}^{n} w_i}}$$

which by Pythagoras Theorem reduces to:

$$\sqrt{\frac{\sum_{i=1}^{n} d_{iC}{}^2}{N}}$$

Like standard deviation, standard distance is strongly influenced by the placement of some items at extreme or peripheral locations, well far from the center of the distribution. Because distances about the mean center are squared, “uncentered” or atypical points have a dominating impact on the magnitude of the standard distance.

The standard distance deviation is a good single measure of the points dispersion around the mean center, but it does not capture any directional bias nor the shape of the distribution. The *standard deviation ellipse* gives dispersion in two dimensions: the *major axis* defines the direction of maximum spread of the distribution, while the *minor axis* is perpendicular to it and defines the minimum spread. It is then defined by 3 parameters: 1)Angle of rotation, 2)Dispersion (spread) along major axis, 3)Dispersion (spread) along minor axis.

Calculating the skewness and kurtosis of a spatial distribution will generate useful statistics to describe the general shape of such distribution; in addition, uniformity, irregularity or concentrated patterns of the spatial distribution can be tested for each category of archaeological observation (Mardia 1985; Kankainnen et al. 2004; Barceló & Maximiano 2012). The higher the spatial variability, the more parameters we need to describe the spatial distribution (Kulldorff 1999).

At sufficiently large scale and when archaeological observations are concentrated as a consequence of a single accumulation process, spatial frequencies can be described as an abundance surface, with an approximately Gaussian-bell curve shape (Whittaker 1967; Brown et al. 1995). A bivariate normal distribution illustrates this theoretical probabilistic model (Figure 84).

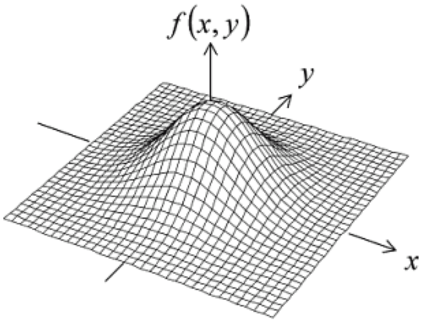


Figure 84 Example of Bivariate Normal Distribution (from Maximiano 2007).

It is a generalization of the one-dimensional (univariate) normal distribution to higher dimensions. One possible definition is that a random vector is said to be *bi*-variate normally distributed if every linear combination of its *x* and *y* dimensions has a univariate normal distribution. The function

$$f(x,y) = \frac{1}{2\pi\sigma_x\sigma_y\sqrt{1-\rho^2}} \exp\left(-\frac{1}{2}Q(x,y)\right)$$

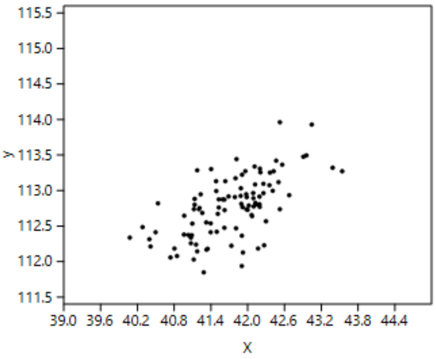
and its quadratic form

$$Q(x,y) = \frac{1}{1-\rho^2}\left[\left(\frac{x-\mu_x}{\sigma_x}\right)^2 + \left(\frac{y-\mu_y}{\sigma_y}\right)^2 - 2\rho\frac{(x-\mu_x)(y-\mu_y)}{\sigma_x\sigma_y}\right]$$

gives the joint density function of a bivariate normal distribution. The bivariate standard normal distribution has a maximum value at the origin. The extra parameter in the bivariate standard normal distribution is the correlation ρ between *x* and *y*. If *x* and *y* are independent ($\rho = 0$), then the surfaces of constant *f (x, y)* are concentric circles around the origin. As ρ increases, the distribution is stretched diagonally, forming elliptical isopleths with positive sloped major axes. For negative ρ, the major axes have a negative slope (for more details see Mardia 1970; Azzalini & Della Valle 1996; Kotz et al. 2000; Rose & Smith 2002; Barceló & Maximiano 2007). This model fits well with what we would expect from Tobler's law at the intra-site scale: discarded artefacts tend to be more densely distributed at the area where the action was performed, and more dispersed far away from that focus. In other words, the distribution is clearly not random, but intentional: locations seem to be clustered in the central zone and overdispersed far away from that center, what implies the lack of spatial *independence* since adjacent locations seem to have something in common.

4.2. An alternative model based on count data and spatial frequencies

In some cases, the location of each single archaeological observations (e.g. lithic tools of a determined functional type, animal bones of a particular taxon) is known, providing all the required information related to this unique event. In such condition, it is better to utilize that information together with the spatial coordinates of that item. However, sometimes it is not possible to analyze archaeological data at the individual level and archaeologists are forced to aggregate such data points into regular spatial areas (sampling units). In this way, single abundance counts are transformed into spatial frequencies *per* sampling unit that can be compared in terms of spatial intensities (see discussion in Chapter 1). The individual data points are allocated to regular cells in a grid, spatially assigning individual observations to the cell in which they all and then frequency is measured counting the number of observations within each cell. Thus, cell becomes the unit of analysis, instead of the individual data point. All the count data are assigned to a single geographical coordinate, the *centroid* of the cell, and the number of archaeological observations of the same type in the cell (e.g. number of sheep bones per sampling unit as well as number of unremontable potshreds per sampling unit) becomes an *attribute* of the coordinate that best represents that particular sampling unit (its centroid).



1	0	1	0	0	0	0	0
2	0	2	1	0	0	0	0
3	0	3	2	1	0	0	0
6	10	54	10	5	2	0	0
0	23	18	9	3	1	0	0
2	0	0	0	1	0	0	0
0	1	1	0	0	0	0	0

Figure 85 Example of Frequency table and associated x,y,z graphic plot (Past).

It should be obvious that when archaeological data at individual level are assigned to a regular cells in a grid, some information is lost. Instead of capturing the unique locations of the objects or fragments, all items that occur within a cell are assigned a single location. Thus, the distance between cells is a singular value for all the points in those zones whereas there is much greater variability with the distances between individual events. Further, cells have attributes, which are properties of the zone, not of the individual events. The attribute can be a *count* or a continuous variable for a distributional property of the cell (e.g., soil ph; height above sea level). Analysis then proceeds based on the cell information. The results will be different than the individual event information, since the spatial characteristics are measured by single points for each cell (e.g., the centroid) and the attribute information is measured by a property of the cell, not the individual events (e.g., the count of events in the cell; a characteristic of the zone such as ground surface). In other words, archaeologists must realize that an analysis of grid data is quite different from an analysis of georeferenced individual observations and that the conclusions might be different. Aggregating data to cells creates properties that may be different from those of individual events and that the relationships between variables at the cell level might be different from at the individual level**.** However, this methodological application shows its effectiveness and strength when single point data are not available. According to this perspective, a 3D histogram allows the visualization of spatial pattern of frequency data, sampled at different locations. As with the bandwith selection in the case of Kernel Density Estimates, an appropriate interval extension should be selected. In some cases, 3D histogram intervals can coincide with the extension of cells in the grid, or cells can be aggregated within intervals. For instance, if a grid based on cells of 50 squared centimeters was used, 4 cells can be integrated into a single interval, representing all observations over 1 square meter. In figure 86 are represented two histogram corresponding to an accumulated pattern of spatial frequencies (A), compared to a random pattern (B).

Figure 86 A)Accumulated pattern of spatial frequencies B)random pattern of spatial frequencies.

In the first case (Figure 86A), an extremely asymmetrical frequency distribution is assumed, in that the initial (or final) frequency group contains the highest frequency, with succeeding frequencies becoming smaller (or larger) elsewhere. Taking into account the frequency values (*z* variable), the shape of the curve roughly approximates an inverted letter "*J*" (as observed in Figure 87); this implies that a majority of observations are supposed to be found in a minority of sampling units, while a majority of sampling units are expected to be empty or with very low frequencies.

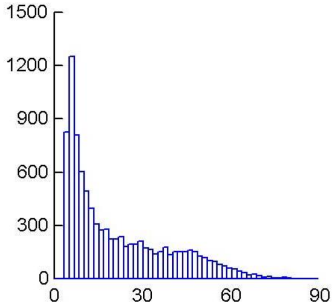


Figure 87 Example of J-shaped curve of frequency values (Systat).

This can be analyzed as a special case of a Negative Geometric Distribution; it is a discrete probability distributions of the number X of observations (Bernoulli trials) needed to report one presence of the discarded material, supported on the set { 1, 2, 3, ...}. Often, the name *shifted* geometric distribution is adopted for the distribution of the number x. If the probability of reporting the presence of the studied archaeological feature on each sampling unit is p, then the probability that the kth sampling unit (out of k sampling units) is the first presence is

$$\Pr(X = k) = (1 - p)^{k-1}\, p$$

for k = 1, 2, 3, ... The sequence of probabilities is a geometric sequence.

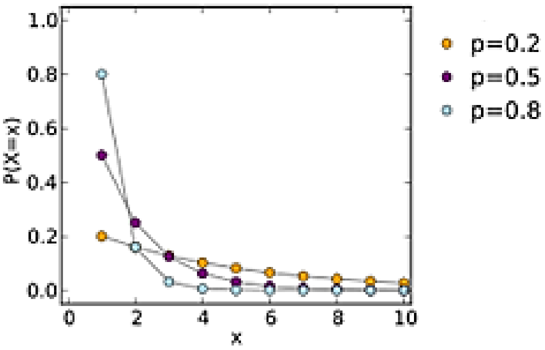


Figure 88 Example of Negative Geometric Distributions with different *p* values.

The mean or expected value of an geometrically distributed discrete variable *x* with probability *p* is given by:

$$\frac{1-p}{p}$$

Other important parameters are: the median $\left[\frac{-1}{\log_2(1-p)}\right]$

The variance: $\frac{1-p}{p^2}$

Skewness: $\frac{2-p}{\sqrt{1-p}}$

And the excess of kurtosis: $6+\frac{p^2}{1-p}$

Consider a spatial area divided in equally sized sampling units, where each cell has only two possible outcomes (some material remains were discarded there –presence- or no remains were discarded at that place –absence-).

1	0	1	0	0	0	0	0
1	0	1	1	0	0	0	0
1	0	1	1	1	0	0	0
1	1	1	1	1	1	0	0
0	1	1	1	1	1	0	0
1	0	0	0	1	0	0	0
0	1	1	0	0	0	0	0

Figure 89 Example of contingency table of a presence/absence data-set.

In this case, the Geometric Distribution is useful to model the number of sampling units with one, two, three… "presences". The distribution gives the probability that 1) observations were not discarded all around the area (zero squares with 1 presence), 2) all materials appear at a single sampling unit, 3) all materials appear distributed among two, three, four….squared sampling units. If the number of archaeological evidence discarded at each sampling unit was considered, it would be convenient to approximate the Negative Geometric Distribution with a Negative Exponential one. The general formula for its Probability Density Function is:

$$f(x;\lambda) = \begin{cases} \lambda e^{-\lambda x} & x \geq 0 \\ 0 & x < 0 \end{cases}$$

With such corresponding plot (Figure 90)

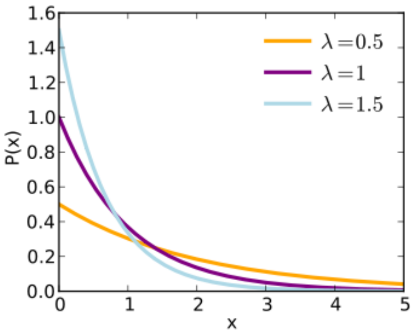


Figure 90 Plot of the exponential probability density function.

The mean or expected value of a geometrically distributed discrete variable *x* with probability *p* is given by: λ^{-1}; the median is $\lambda^{-1}\ln(2)$ and the variance λ^{-2}.

When the dispersal of archaeological observations is not the result of repetitive intentional refuse at the same place, observed dispersion is more homogeneous, spatially random and characterized by spatial independence. That is what would be expected in case of spatial distribution of fragments after accidental breakage: a more or less random distribution of potsherds, that is that all sampling units have approximately the same count of fragments, does not allow us to predict the place where pottery has been broken. What does it mean “random” here? The spatial location of each potsherd within the equally sized sampling units is the result of: 1)infinite number of physical factors, 2)individually, each factor has a very small influence in the final location of sherdpot, 3)all factors are independent among them. When assuming randomness, it is assumed that the same number of artefacts is spaced evenly across the site and, consequently, each location has an equal probability of having an artefact (Kintigh 1988). A random pattern implies the absence of interactions between all observed counts of data and between the location, since all zones offer the same conditions for deposition and preservation (which does not mean than these conditions are (or were) favourable). In addition, the presence of an observation should not affect in anyway the presence of another, i.e. the probability that some archaeological items are attested in particular place do not depend on the number of observations made at neighbouring spatial locations.

If observations are few but the number of sampling units is very high, a Poisson Distribution is useful to estimate the probability of finding a specific number of fragments at some particular location (sampling unit):

$$P_l(\{k\}) := \frac{e^{-1}\lambda^k}{k!} \qquad k = 0,1\ldots.$$

With λ = *np*. If λ appears to be constant, then the underlying spatial phenomeneon is called a homogeneous or stationary point process. The parameter, called *rate* or *intensity*, is related to the expected (or average) number of Poisson points existing in some bounded region. In fact, the parameter λ can be interpreted as the average number of points per some unit of extent such as length, area, volume, or time, depending on the underlying mathematical space, hence it is sometimes called the *mean density*.

In an attempt to distinguish spatially intentional or non-intentional behaviour, a random spatial model would be fitted to our observed data. In the case of an accumulation resulting from the repeated performance of an action at the same place, archaeological observations accumulate at the same place and as a result it is observed the inverted J shape, that is a Geometric (Exponential) model. However, if pottery has been broken by accident, potsherds are distributed randomly because of the force of gravity and the physics of the breakage event. For instance, consider that some artifact broke into 192 potsherds, and they are distributed over an area of 100 square meters. Assuming we have divided the observation area into 100 equally sized sampling units, it would be expected to find 192/100 = 1.92, in case the distribution was totally random (there was no difference in the quantity of sherds per sampling unit).

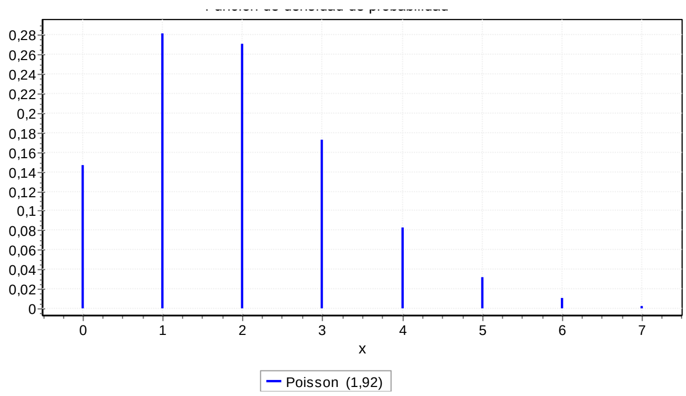


Figure 91 Function of probability density, according to a Poisson distribution, of potsherds frequencies (192) within an area of 100 equally sized sampling units with a λ=1.92.

Because of random variation, it is expected a minority of both empty sampling units and cells high counts of potsherds. In a majority of cases, 1 or two potsherds will be counted. If the same action is repeated, that is, the breakage of some potteries of exactly the same shape, size and materiality, more vessels are broke, more potsherds will be dispersed over the observed spatial area. If each repetition is performed at different randomly selected places, within the studied area, and assuming that each repetition was independent, the different potsherds will be dispersed at random too, over the same space where potsherds, previously breaken, have been accumulated. The result is twice a Poisson distribution.

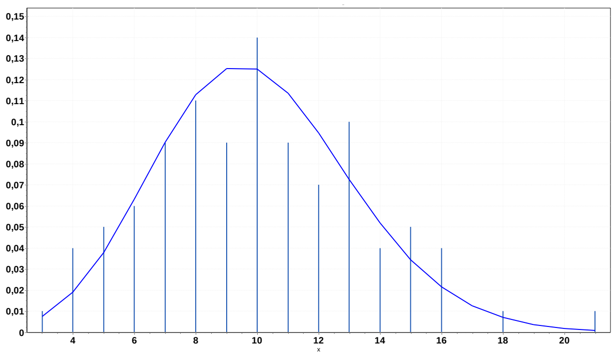


Figure 92 Function of probability density, according to a Poisson distribution, adding six repetitions of six simulated independent breakage events.

In contrast, what happens if repetitions were not independent? What happens if the breakage has been repeated always at the same place? In such a case, events would not be independent – the location of previous event determined the location of the posterior one- and consequences of the action (potsherds) would accumulate always at the same places (Figure 93).

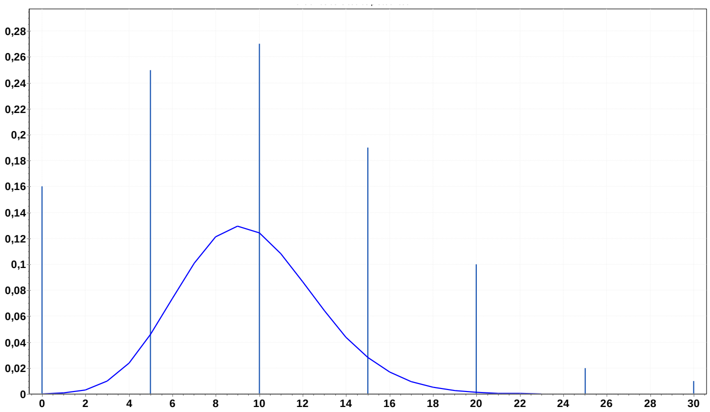


Figure 93 Function of probability density, according to a Poisson distribution, adding one hundred simulated breakage events that accumulated potsherds in the same way at the same place.

It is easy to see that variability increases, but there is still a general regularity: a minority of sampling units are empty or have very low counts of potsherds, as well as a minority of sampling units have high counts, while the majority of sampling units show intermediate counts of potsherds. However, the number of sampling units with higher counts than the mean has increased enormously. To sum up, spatial frequencies generated at the intra-site scale are differently distributed in case the original dispersal was intentional discard at a single place, or accidental breakage. Intentionality or randomness can be distinguished, fitting alternative probabilistic models.

There are two ways to infer whether the observed archaeological sample follows a Poisson distribution. The first implies the comparison of variance v and the mean of archaeological observations counts per sampling unit. Since one assumption of this distribution can be that the occurrence of an event is randomly distributed, every observation has an equal chance and the variance and the mean of distribution are equal. Thus, the variance-mean ratio test is useful to check this assumption. Since Pielou (1977) provides a clear statement on its use, this test is frequently used in geography and statistical ecology. If a distribution has a random pattern, the expected value of the ratio v/m is $1\text{-}n^{-1}$, which for n not small may be treated as unity. If v/m is close to 1, this is evidence that the distribution has a random pattern. Furthermore, under the hypothesis that a distribution has a random pattern, then the ratio *nv/m* for *n* quadrats is a statistic and is distributed as the chi-squared distribution, χ^2_{n-1}, with *n-1* degrees of freedom. Consequently, to test whether the observed value is significatively different from 1, or the observed values come from a random population, we can use a standard chi square test. In this sense, a spatial coefficient of dispersion (Scd) can be defined as the ratio of the variance to the mean of points distributed over a sampling grid (Sokal & Rohlf 1969: 88). A value of SCD much greater than 1 indicates a clumped sample, while a value much less than 1 denotes repulsion between elements.

Alternatively, a standard hypothesis testing approach can be used, with the classical Kolmogorov-Smirnov procedure (Lilliefors 1967, Pettitt and Stephens 1977, Campbell and Oprian 1979; Gürtler and Henze 2000). The test statistic is

$$D_{ks} = \sup_{x} \left| \hat{F}(x) - F_0(x) \right|$$

An approximate Kolmogorov–Smirnov goodness of-fit test for the Poisson distribution with unknown mean was developed by Campbell and Oprian (1979). Their procedure for testing H_0 : *F is Poisson* against H_1: *F is not Poisson* consists of estimating □□, using

$$\hat{\lambda} = \bar{X}$$

and computing

$$D_{CO} = \sup_{x} \left| \hat{F}(x) - P(x;\, \hat{\lambda}) \right|$$

Where

$$P(x;\, \hat{\lambda})$$

is the CDF for the Poisson (λ) distribution, and then rejecting H_0 if D_{c0} exceeds the critical value (Hazra 2013). A similar approach can be used to test the goodness-of-fit of an exponential distribution (Lilliefors 1969). Kolmogorov-Smirnov test for this is also available in a majority of statistical packages, which offer also the possibilitiy of estimating from sample.

Alternatively, Gail and Gastwirth (1978) have suggested using Gini statistic and Lorenz curves.

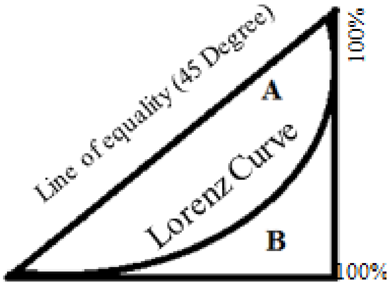


Figure 94 Example of a typical Lorenz Curve.

The curve is a graph showing the proportion of overall number of identified objects found by the *x*% of the sampling units; it is then the cumulative proportion of spatial frequencies plotted, against the cumulative proportion of objects. The *x* value of the curve corresponds to a percentile of the population ordered according to the characteristic in question. The *y* value of the curve represents that portion of the total value of the analysed characteristic held by sampling units, where we have not been able to find more than the *x*-valued percentile of the population. Thus, the value (0.7, 0.3) means that in 70% of the sampling units archaeologists have found 30% of the objects in question. The difference between the straight line and the curved line is the amount of difference, a figure described by the Gini coefficient.The higher the normalized value, the higher the observed distribution departs from the random assumption of equiprobability. The Lorenz asymmetry coefficient (LAC) characterizes an important aspect of the shape of a Lorenz curve. It tells which category of abundance contribute most to the population's total irregularity, as measured by the Gini coefficient. If the LAC is less than 1, the irregularity is primarily due to the relatively many sampling units that are empty or with very low frequencies. If the LAC is greater than 1, the irregularity is primarily due to the few sampling units concentrating the majority of archaeological obserrvations.

4.3 When the model does not fit. Introductory remarks

In most real cases, the spatial distribution of archaeological observables do not fit a standard Poisson model. Since human action is quite never uniform on the ground surface, and consequently it is hardly probable that material consequences of human behaviour be distributed randomnly and independently everywhere, this is what is expected. According to Bevan and Connolly (2009) the processes that produce surface artefacts are themselves often non-random. For instance, people manufacture large quantities of pottery in certain locales (e.g., kiln sites), use sets of pottery in particular places (e.g., in houses), and often discard broken vessels together in dumps. This leads to high clustering of potsherds and when we observe them in several archaeological sampling units, the resulting fragment counts exhibit what is known as "spatial dependence" (broadly referring to situations where measured phenomena that are closer together in space tend to be more related than those further apart). Spatially dependent patterns can have complex causes: some reflect the influence of exogenous factors, such as, for pottery, the correlation between high counts of them and land suitable for farming and settlement (itself a patchy, spatially-structured resource). In other cases, the cause may be attributed to endogenous factors, such as the propensity for pottery to be discarded in groups, and thereafter to break down from larger to smaller pieces.

What does it mean that archaeological data do not fulfill the assumption of spatial randomness? Since social actions that happened in the past are in some cases not homogeneous processes, their material consequences too will probably be no homogeneous (and thus no-random). The probability that a particular archaeological category is observed at a particular place is dependent on the probability that the same archaeological category is attested at neighbouring places. Therefore, the average frequency of event occurrence is not constant, regardless of events occurrence up to the time of observation.

On the contrary, in aggregated – contagious (Dale 1999: 20) - patterns, or accumulations, members of population show a tendency to occur in clumps. In this case, the presence of one point increases the probability of finding another in its vicinity (Dale 1999: 20-21). However, in regular populations, individuals are more evenly spaced than they would be where they distributed according to chance (Pielou 1960: 575); in such cases, points are overdispersed, in such a way that the presence of a point there reduces the probability of finding another nearby.

Two hypothetical scenario can be hypothesized: unintentional accumulation process may be the result of accidental actions carried out in the past, without any intentionality. On the other hand, archaeological category defined analytically would be not a meaningful for past individuals, and hence its spatial distribution does not express the spatial distribution of any social human behaviour.

Although intrinsically non-random, it is also very frequent that the spatial distribution of archaeological observables do not fit the geometric or exponential model too. In theory, the more intentionally performed the activity, the more similar will be a spatial distribution of points to a regular bivariate normal pattern or to a *J*-shaped distribution of spatial frequencies. However, in many real cases, the 3D histogram of spatial frequencies may seem concentrated, but fitting a theoretical geometric or exponential distribution to frequencies per sampling unit, with parameters estimated using the empirical mean and variance gives poor values of goodness-of-fit test. Furthermore, some degree of unexplained stochastic variation around the model expectation should have taken into account (Linden & Mäntyniemi 2011). In a majority of cases, the distribution may be so skewed and irregular that sometimes it would be difficult to recover intentionality beyond apparent randomness. Moreover, there is the probability that the spatial pattern that we can observe and measure in the intra-site dispersion of archaeological observations be not only the result of discard activity. Material consequences of deliberate human decisions about artefact placement suffer the effects of various kinds of post-depositional and taphonomic processes involved in the formation of archaeological record, which may have disordered artefact patterning in the archaeological record and increased entropy. As already discussed (see Chapters 2 and 3), most post-depositional processes make the spatial pattern of discarded artefacts more amorphous, lower in elements density, more homogeneous in their internal density, less distinct in their boundaries, and more similar (or at least skewed) in composition.

As a consequence of post-depositional alteration, an observed accumulation of archaeological material may appear: 1)overdispersed, 2)altered by the presence of outliers and multimodality, 3)predominantly characterised by skewness and anisotropy.

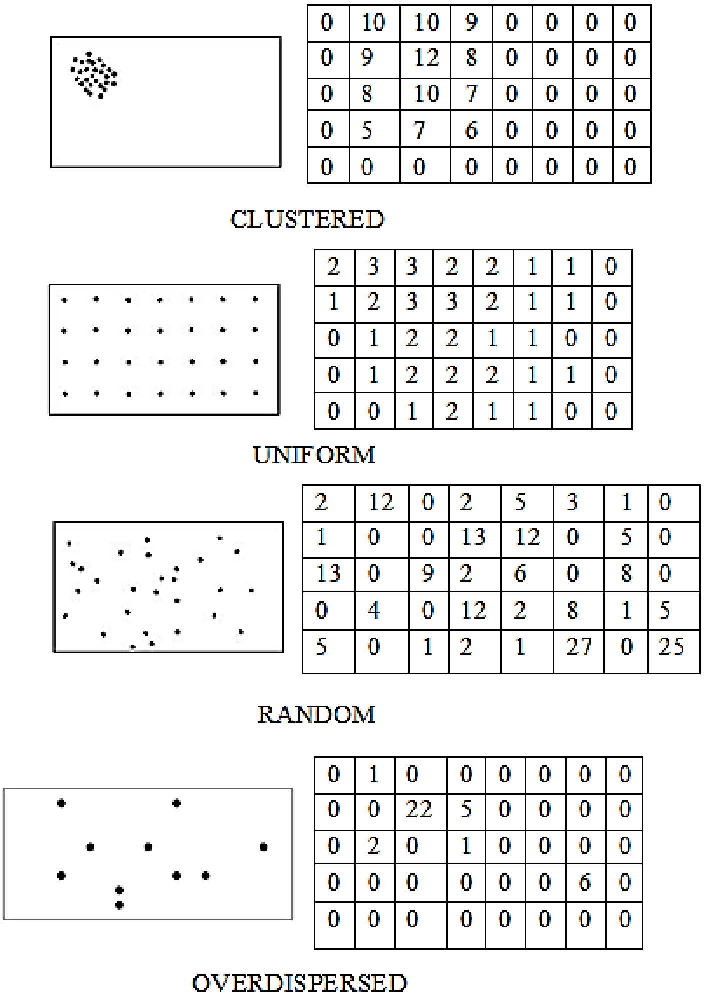
- overdispersed
- altered by the presence of outliers and multimodality
- skewness and anisotropy

Both patterns should be investigated and described properly to study the probability that post-depositional processes may have altered a previously intentionally organized pattern. This investigation will take into account both area-wide ‘trends’ (first-order variation) and correlation structures (second-order variation), or a mixture of both. In the first order case, frequencies of archaeological features can vary from location to location due to changes in the underlying properties of the local environment. For example, frequencies of accumulated refuse material may be influenced by variations in terrain. In the second order case, frequencies of archaeological data vary from location to location due to local interaction effects between observations.

4.3.1 When the model does not fit. Overdispersion

As mentioned in Chapter 1, a common feature of archaeological spatial data-sets is their tendency to contain many zero values, more than expected in a purely random distribution. This is usually referred as *overdispersion*, that is the presence of greater variability (statistical dispersion) in a data-set than would be expected based on a given statistical model. As suggested, overdispersion can be a consequence of post-depositional activity, altering what originally was an accumulated and concentrated spatial pattern.

The spatial distribution of archaeological observables may vary from aggregated (clustered) through a random pattern to the regular (uniform) case. Artefacts and other material of archaeological relevance are randomly positioned if the location of one individual is independent of the positions of all others. Aggregation occurs when items of the same category tend to be close together, resulting in a high variance of density estimates across space (over-dispersion). On the other hand, regularity occurs when the discard of an element at some location tends to avoid the discard of other elements in the neighborhood so that density estimates are less variable (under-dispersion). This is graphically summarized in Figure 95.



0	10	10	9	0	0	0	0
0	9	12	8	0	0	0	0
0	8	10	7	0	0	0	0
0	5	7	6	0	0	0	0
0	0	0	0	0	0	0	0

CLUSTERED

2	3	3	2	2	1	1	0
1	2	3	3	2	1	1	0
0	1	2	2	1	1	0	0
0	1	2	2	2	1	1	0
0	0	1	2	1	1	0	0

UNIFORM

2	12	0	2	5	3	1	0
1	0	0	13	12	0	5	0
13	0	9	2	6	0	8	0
0	4	0	12	2	8	1	5
5	0	1	2	1	27	0	25

RANDOM

0	1	0	0	0	0	0	0
0	0	22	5	0	0	0	0
0	2	0	1	0	0	0	0
0	0	0	0	0	0	6	0
0	0	0	0	0	0	0	0

OVERDISPERSED

Figure 95 Graphic results of four main types of spatial organization (cluster, uniform, random and overdispersion) and corresponding examples of contingency table.

"Overdispersion" is then an excess of empty cells in a regular grid (zero inflation); such zero frequency may have occurred simply by chance, because the action that happened in the past did not saturate with its material consequences the entire suitable area (e.g. because the small probability of having archaeological evidence or its bad preservation), or it is a consequence of the lack of exhaustive surveying[10]. The presence of zero inflation as a result of a big number of unsampled cells in the grid[11] will lead to uncertainty regarding parameter estimates. Hence, it would be no longer possible to determine whether a difference in the number of individuals surveyed over time and space is caused by a change in the population size, or due to a change in the detection probability. Statistical inference based on such data are likely to be inefficient or wrong, unless careful thought is given to how these zeros arose and how best to model them (Martin et al. 2005). Observed overdispersion is then difficult to understand in the archaeological case, because it can be the consequence of too many different unrelated mechanisms.

However, a great number of empty cells (or cells with very low abundance counts) can be expected even in the case of single concentrated accumulations: as above mentioned, far away from the place where the action took place, the probability of finding material consequences of that action is very low. When the center of the distribution – the area with more material observations - is not very large, then the entire spatial distribution may appear as overdispersed with an exceptional outlier in the center.

More rewarding that considering overdispersion, in an attempt to understand why a theoretical model does not fit, would be to consider how the other models of spatial organization (clustered, random, uniform) are related to the theoretical model of accumulation, at a single concentrated area. A measure of *spatial dependency* is usually considered, distinguishing from those kinds of spatial arrangement. Spatial dependency is the co-variation of frequencies within space: neighbour sampling units may be positively or negatively correlated, in terms of frequency of specific observations, or they can appear uncorrelated. If the differences among neighbours are smaller than the overall variation, then a high degree of spatial dependency is indicated. If cells have a similar frequency of specific archaeological observation (the same category of archaeological observables), or if neighbours variation is larger than the overall variation, then the assumption that "close things are more similar" fails.

For artefact distributions, regularity can be generated by various kinds of post-depositional and taphonomic sorting, or due to very deliberate human decisions about artefact placement (in the discussion will be provided more details about such last scenario). Clustered patterns, in contrast, are often the result of 'attraction' processes. We might think of the prefered discard of some material at explicitly made dumping pits, because of various advantages such aggregated locations might offer. This behaviour may have an 'inhibitory' consequence, decreasing the probability of discarding some other evidence at a neighbour place (Ludwig & Reynolds 1988). For archaeological accumulations, the discard of particular category of evidence at some place might inhibit the discard of other kind of items immediately next to the first, for instance in an attempt to preserve a healthy and comfortable environment.

Spatial autocorrelation may be loosely defined as the property of random variables taking values, at pairs of cells a certain distance apart, that are more similar (positive autocorrelation)

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[10] However, in this research unsurveyed areas are not considered as "empty" areas

[11] This is not the case of such research

or less similar (negative autocorrelation) than expected for randomly associated pairs of observations (Legendre 1993). The absence of autocorrelation implies data are independent. An area over which archaeological artefacts and observations are overdispersed has also *negative* spatial autocorrelation. Spurious autocorrelation is an artifact of experimental design that often occurs when samples have not been randomly chosen, but can occur as a result of some other aspect of the experimental design. Gradients or clusters are examples of spatial structures that are positively correlated, whereas negative correlation may be exhibited in a checkerboard pattern, where subjects appear to repulse each other. In any case, if the gradient is very high, then a negative autocorrelation value will show that data changes more rapidly in space than in cases where autocorrelation is positive (Cressie 1993; Legendre 1993; Bailey & Gattrell 1995; Fotheringham et al. 2000; Houding 2000; Diggle et al. 2003; Hanning 2003; Lloyd & Atkinson 2004). In an attempt to quantify the spatial autocorrelation between frequencies of archaeological observables at known locations, Moran's I correlation statistic is used. The description of the procedure is based on Levine (2013).

It is defined as

$$I = \frac{N}{\sum_i \sum_j w_{ij}} \frac{\sum_i \sum_j w_{ij} (x_i - \bar{x}) (x_j - \bar{x})}{\sum_i (x_i - \bar{x})^2}$$

Where *N* is the number of spatial units indexed by *I* and *j*; *X* is the variable of interest; $\bar{X}$is the mean of *X*; and w_{ij} is an element of a matrix of distance-based weight which is the inverse distance between locations *i* and *j* $(1/d_{ij})$. A weighted Moran's *I* is similar to a correlation coefficient, in that it compares the sum of the cross-products of values at different locations, two at a time, weighted by the inverse of the distance between the locations and with the variance of the variable. Like a correlation coefficient, it typically varies between -1.0 and + 1.0. When nearby points have similar values, their cross-product is high. Conversely, when nearby points have dissimilar values, their cross-product is low. Consequently, an *I* value that is high indicates more spatial autocorrelation than an *I* that is low. However, unlike a correlation coefficient, the theoretical value of the index does not equal 0 for lack of spatial dependence, but instead is negative but very close to 0. The expected value of Moran's *I* under the null hypothesis of no spatial autocorrelation is

$$E(I) = \frac{-1}{N-1}$$

Values of *I* above the theoretical mean, *E(I)*, indicate positive spatial autocorrelation (clustering), while values of *I* below the theoretical mean indicate negative spatial autocorrelation (overdispersion). We expect positive spatial autocorrelation in the center of the distribution and negative spatial autocorrelation far away from such center.

Geary's *C* statistic is similar to Moran's I (Geary 1954). The *Geary Index* looks at the differences in the values between each sample point and its closest neighbor. If the differences in neighboring values tend to be less than the differences among all values in the data set, then spatial autocorrelation exists. In this case, however, the interaction is not the cross-product of the deviations from the mean, but the deviation in intensities of each observation's location with one another. It is defined as:

$$C = \frac{(N-1)\ \sum_i W_{ij}\ \left(x_i - x_j\right)^2}{2\left(\sum_i \sum_j W_{ij}\right) \sum_i (x_i - \bar{x})^2}$$

The values of *C* typically vary between 0 and 2, although 2 is not a strict upper limit (Griffith 1987). The theoretical value of *C* is 1; that is, if values of any one zone are spatially unrelated to any other zone, then the expected value of "C" would be 1. Values less than 1 (i.e., between 0 and 1) typically indicate positive spatial autocorrelation while values greater than 1 indicate negative spatial autocorrelation. Thus, this index is inversely related to Moran's *I*. It will not provide identical inference because it emphasizes the differences in values between pairs of observations comparisons rather than the co- variation between the pairs (i.e., product of the deviations from the mean). The Moran coefficient gives a more global indicator whereas the Geary coefficient is more sensitive to differences in small neighborhoods.

The Getis-Ord *G* statistic is also an index of global spatial autocorrelation but for values that fall within a specified distance of each other (Getis & Ord 1992; Ord & Getis 1995; Getis & Ord 1996; Khan, Qin and Noyce 2006). Unlike the other two measures, it *only* identifies *positive* spatial autocorrelation, that is, where zones have similar values to their neighbors. It cannot detect negative spatial autocorrelation where zones have different values to their neighbors. But, unlike the other two global measures, it can distinguish between positive spatial autocorrelation where zones with high values are near to other zones with high values (*high positive spatial autocorrelation*) from positive spatial autocorrelation which where zones with low values are near to other zones also with low values (*low positive spatial autocorrelation*). Further, the *G* value is calculated with respect to a specified search distance (defined by the user) rather than to an inverse distance, as with the Moran's *I* or Geary's *C*. It is defined as:

$$G(d) = \frac{\sum_i \sum_j W_j\,(d) x_i x_j}{\sum_i \sum_j x_i x_j}$$

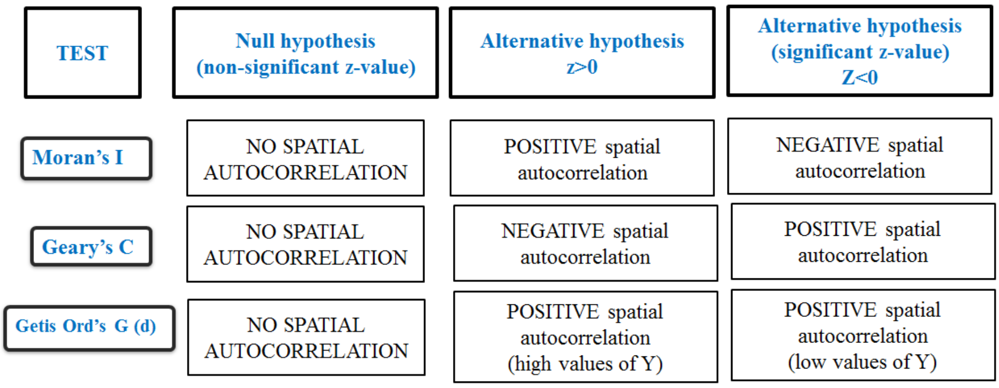
for a variable, *X*. This formula (Lee & Wong 2005) indicates that the cross-product of the value of *X* at location *I* and at another zone *j* is weighted by a distance weight, $w_j(d)$ which is defined by either a 1 if the two zones are equal to or closer than a threshold distance, *d*, or 0 otherwise. The crossproduct is summed for all other zones, *j*, over all zones, *i*. Thus, the numerator is a sub-set of the denominator and can vary between 0 and 1. If the distance selected is too small so that no other zones are closer than this distance, then the weight will be 0 for all cross-products of variable *X*. Hence, the value of *G(d)* will be 0. Similarly, if the distance selected is too large so that all other zones are closer than this distance, then the weight will be 1 for all cross-products of variable X. Hence, the value of *G(d)* will be 1.

By itself, the *G* statistic is not very meaningful. Since it can vary between 0 and 1, as the threshold distance increases, the statistic will always approach 1.0. Consequently, *G* is compared to an expected value of "G" under no significant spatial association. The expected *G* for a threshold distance, *d*, is defined as:

$$E[G(d)] = \frac{W}{N\,(N-1)}$$

where W is the sum of weights for all pairs and N is the number of cases. Relative to the expected value of G, a positive Z-value indicates spatial clustering of high values (high positive spatial autocorrelation or concentration areas) while a negative Z-value indicates spatial clustering of low values (low positive spatial autocorrelation or empty places. A G value around 0 typically indicates either no positive spatial autocorrelation, negative spatial autocorrelation (which the Getis-Ord cannot detect), or that the number of concentration areas more or less balances the number of empty ones.

To sum up, spatial autocorrelation that is more positive than expected from random indicate the clustering of similar values across geographic space, while significant negative spatial autocorrelation indicates that neighboring values are more dissimilar than expected by chance, suggesting a spatial pattern similar to a chess board (Figure 96).



TEST	**Null hypothesis (non-significant z-value)**	**Alternative hypothesis z>0**	**Alternative hypothesis (significant z-value) Z<0**
Moran's I	NO SPATIAL AUTOCORRELATION	POSITIVE spatial autocorrelation	NEGATIVE spatial autocorrelation
Geary's C	NO SPATIAL AUTOCORRELATION	NEGATIVE spatial autocorrelation	POSITIVE spatial autocorrelation
Getis Ord's G (d)	NO SPATIAL AUTOCORRELATION	POSITIVE spatial autocorrelation (high values of Y)	POSITIVE spatial autocorrelation (low values of Y)

Figure 96 Interpretation of standardized values of global spatial autocorrelation.

Following Tobler's principle (1970), if everything is related to everything else but near things are more related than distant things', then spatial autocorrelation values should decrease as the separation distance between cells increases. In most situations, the autocorrelation will stop decreasing at a given distance, which can be interpreted as the distance of dependence or the zone of influence of the attribute; this occurs because sample locations, separated by distance closer than the range, are spatially autocorrelated, whereas locations farther apart than the range are not autocorrelated. Therefore, in a spatially accumulated pattern, some degree of positive autocorrelation should be detected in the center of the accumulation, and negative autocorrelation far away.

However, this pattern cannot be detected using above measures of "global" correlation. An archaeological dispersion area is, by definition, heterogenous, and therefore a single measure of spatial autocorrelation gives not a proper account of the complex pattern of variance differences: not any two adjacent locations are expected to have the same frequency. The most probable condition is that all locations in the periphery of the accumulation are more similar between them, independently of distance between them, than adjacent locations in the gradient of the accumulation, where frequencies decrease quickly. In the bivariate normal model the relationship between frequency and distance is non-linear, although there is still some relationship: the probability of finding some item at (x_i, y_i) increases the probability of finding similar items at the same place (Dale 1999: 20-21). In other words, the place where discard originally occurred seems to "attract" material observables related, in some way, to the occurrence of such action.

To solve this problem, the spatial dependency between spatial frequencies sampled at different cells can be quantified and partitioned it, along the various distance classes. The most commonly used structure functions are correlograms, graphs with autocorrelation values plotted on the ordinate, against distance classes among sampling stations (localities) on the abscissa. The shape of the correlogram indicates the type of spatial structure. A test of significance can be calculated for each individual autocorrelation coefficient plotted in the correlogram. Following Legendre (1993), such test requires that the condition of second-order [or weak] stationarity be satisfied. That condition says that the expected value [mean] and variance of the variable, over the study area, must have constant and finite values, and the autocorrelation function must depend only on the length and orientation of the vector between any two points, not on their position in the study area.

The *Moran* Correlogram calculates the *I* value by different distance intervals (or bins). When graphed, the plot indicates how concentrated or distributed is the spatial autocorrelation (Cliff & Haggett 1988; Bailey & Gatrell 1995). Essentially, a series of concentric circles is overlaid on the points and the Moran's *I* statistic is calculated for only those points falling within each circle. The radius of the circle changes from a small to a very large circle; as this last increases, *I* value approaches the global value. An iterative algorithm takes the maximum distance between points and divides it into the number of specified distance intervals, and then calculates the *I* for those points falling within that radius. Small distances can be adjusted so that the maximum weighting is 1. This ensures that *I* values for individual distances will not become excessively large or excessively small for points that are close together.
The opposite of a correlogram is a variogram, which represents the semivariance of differences among pairs of locations (Oliver & Webster 2014). Consider the vector

$$\begin{pmatrix} x_1 \\ x_2 \end{pmatrix}$$

representing the coordinates of a point in 2D. Let h be the vector separating two points. Sample values z at a pair of points are compared with:

$$\frac{(z\,(x+h)-(x))^2}{2}$$

For all pairs of points in the spatial distribution, we can plot differences against distances. A variogram, as defined originally by (Matheron 1963), is half the average squared difference between points separated by a distance *h*. Hence:

$$\gamma(h)=\frac{1}{2|N\,(h)|}\sum\nolimits_{N\,(h)}(z_i-z_j)^2$$

where *N(h)* is the set of all pairwise Euclidean distances *i-j = h*. |*N(h)*| is the number of distintct pairs in *N(h)*, and z_i and z_j are data values at spatial locations *i* and *j*, respectively. In a variogram, semivariances are plotted against distances.

A variogram value at a given *h* is the average squared difference between the values of the paired locations. If two locations, *u* and *u* + *h*, are close to each other in terms of the distance measurement, two values are similar, so the difference in their values, $Z(u) - Z(u + h)$, will be small. As u and $u + h$ get farther apart, they become less similar, so the difference in their values, $Z(u) - Z(u + h)$, will become larger. As the variance of the difference increases with distance, so the variogram can be thought of as a dissimilarity function.

At a distance $h = 0$ there are no differences between points that are compared to themselves. However, as points are compared to increasingly distant points, differences are expected to increase. This is a consequence of the Tobler's principle: sample locations separated by distance closer than the range are spatially autocorrelated, whereas locations farther apart than the range are not autocorrelated. At some distance, the difference in z between two points will become approximately equal to the global variance of the population itself. This is the greatest distance over which the value at a location on the spatial distribution is related to the value at another point. It is important to take into account that in a Moran Correlogram correlation decreases with increasing separation distance, whereas here *semivariance* increases. As shown in a variogram, spatial dependence may be linear when the variance in the frequency among cells increases proportionally with lag distance, or asymptotic when the variance levels off after a certain lag distance and becomes constant. Asymptotic spatial dependence is the most commonly observed phenomenon, because it suggests that data points are spatially correlated up to a certain distance and then become uncorrelated.

The variogram (Figures 97 and 98) is a measure of variability; it increases as samples become more dissimilar. It decreases if samples become more similar are greater distances than at close neighborhood. The value that the variogram model attains at the range (the value on the y-axis) is called the *sill*. The sill characterizes the maximum variance possible, i.e. global heterogeneity of the lot disregarding autocorrelation and covering the whole range of the variographic experiment, i.e. half the length scale of the profile. At these large values of the lag there is no spatial dependence between the data points.

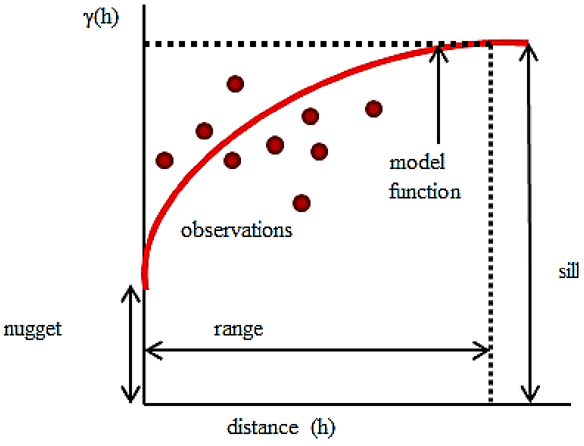


Figure 97 A generic variogram showing the sill, and range parameters along with a nugget effect.

The distance at which the semi-variogram values approach the sill is the *range*. The range is the important part of the variogram because it describes how inter-site differences are spatially dependent. A long range indicates high correlation, a small range indicates low correlation. The higher the range, the higher variance at higher the distances. Therefore, sample locations separated by distances closer than the range are spatially autocorrelated, whereas locations farther apart than the range are not. Often the semi-variogram values do not approach zero at the origin; semi-variogram values may seem to intersect the positive y-axis. This can be seen as the residual, spatially uncorrelated noise, which is also knows as the *nugget*. When there is no correlation the variable is a purely random variable and the variogram will be flat with a nugget effect, representing the measurement error or some variation at small scale, microscale variation at spatial scales.

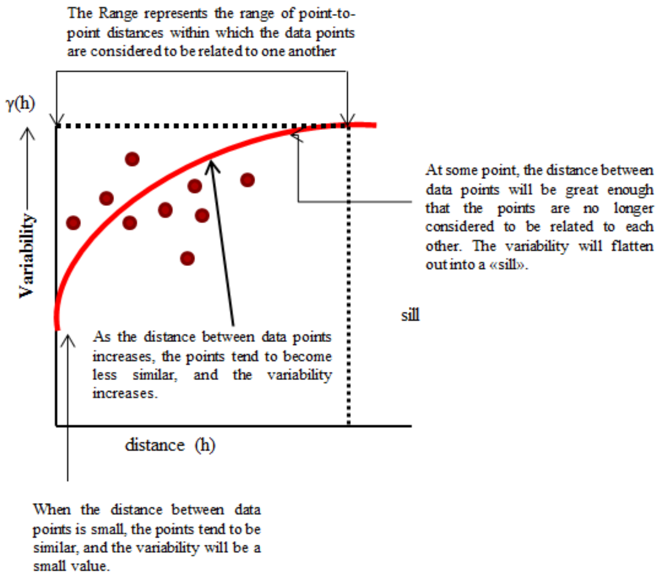


Figure 98 Explanation of main features of a variogram.

The shape of the variogram provides a wealth of information on the causes of the observed spatial variation.

It could be observed that along this orientation, closely-spaced data points show a low degree of variability while distant points show higher values. At some distance, in this case 72 metres, the differences between points will become fairly constant and the variogram will flatten out into a "sill". From 0 to 72 metres of distance, the data points can be considered "related," and this expanse is called the "range." In practice, often one of four primary types of variograms are expected: 1)increasing variogram, 2)flat variogram, 3)cyclic variogram, 4)decreasing variogram. The four basic types of variograms are outlined in the Figure 99, but deviations from, or combinations between these forms, are often observed in practice.

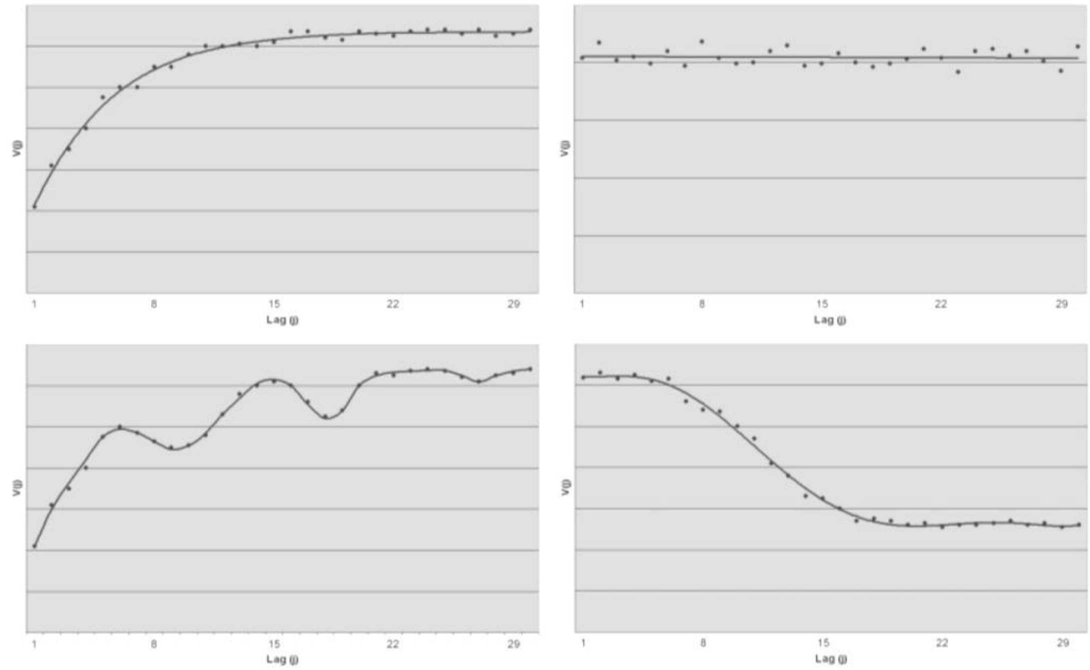


Figure 99 The four basic shapes of the variogram. Top-left: the increasing variogram. Top-righ: the flat variogram. Bottom-left: the cyclic variogram and bottom-right:a decreasing variogram (from Julius & Esbensen 2005).

The increasing variogram is a reflection of units which are autocorrelated when the inter-sample distance(s) is within a specific range, meaning that variance becomes larger as the lag distance *h* increases, until beyond a certain distance (the ‘range’) where the differences level out. This is what we should expect in a concentrated accumulation: at the center of the accumulation, most adjacent cells have similar frequencies of a particular kind of archaeological material (high positive correlation), and when the gradient begins, autocorrelation values decrease until they fit the uniformity condition, at the end of the accumulation, where cells are empty.

The flat variogram is observed when no autocorrelation exists between the units even at the lowest *h*’s. We expect this pattern to appear when there is no accumulation, but a random or uniform distribution. In many cases, overdispersion can be also a cause of this pattern. Adjacent sampling units may have any spatial frequency, signaling the lack of spatial dependency and the independence of all sampling units. Consequently, the curve fit is a straight line denoted “pure nugget variogram”.

A drecreasing variogram is extremely rare, because it is associated to a pattern of decreasing variation with increasing distance.

The cyclic variogram shows autocorrelation values above and below the sill, in such a way that autocorrelation is high at some distances and low at other. This typically appears when there is negative spatial autocorrelation in the data. It can appear when when the variability of the process is influenced by a factor causing a cyclic behavior. This could be an erroneously selected database in which counts of functionally different types of artifacts have been mistakenly confounded. A cyclic variogram may appear when different concentrations mix at a given area.

4.3.2 When the model does not fit. Outliers and multimodality

Outliers can cause many serious distortions in geostatistics. They are not simply extremes or near extremes in a frequency distribution but are unexpectedly large or small values, occurring at some impredictible cells in the regular grid (Barnett & Lewis 1994). Because, by definition, they are exceptional, and, in a sense, unique, they can be particular results of the spatial process in question, or the consequence of an error in the archaeological surveying or recording. Like data in long tails of a distribution, they inflate variograms.

Beyond the presence of outliers, the spatial distribution can present different groups of non-neighbour cells in the grid, with similar frequency values of an archaeological category, as evidence of spatial multimodality, that is spatially differentiated groups of equally abundant cells (not a single overabundant cell). Multimodality in such case can be explained in terms of different simultaneous *loci* of the same activity, or in terms of problems in the categorisation of archaeological objects (Buonaccorsi et al. 2001). In the first case, detailed chronological information should be provided, in order to avoid synchronisms. Obviously, the first rule in spatial analysis is that a spatial pattern has only sense if we have rightly controlled the effect of time. It is not a continuous spatio-temporal distribution what we should describe, but the spatial pattern associated with each differentiated temporal period, within which the probability of change is assumed to be below the indeterminacy level.

A histogram-cum-box plot should help us to identify outliers beyond the limits of the main distribution. Having identified an outlier, what to do with it should be decided; if it seems a mistake related to the process of survey (or excavation), it should be removed from data or replaced with a correct value. If it seems genuine but seems to belong to some population different than the one which is investigating, again it will be removed. There are situations, however, in which it is difficult to decide whether what seems to be outlier belong to a different process, or where the locations of areas with very large values of some archaeological functional category need to be known. In many real situations, what is expected is precisely that a minority of cells (20%) concentrate a majority (80%) of archaeological observations. This is the classical single concentrated accumulation pattern.

A simple way for detecting the presence of outliers or multimodal distributions is by using a 3D visual model. Because variance implies here differences in frequency, we cannot use kernel density estimations, but 3D histograms.

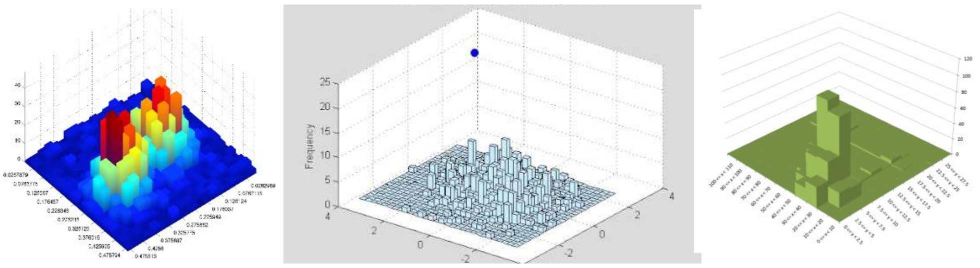


Figure 100 3D histograms generated with different programs (for instance, Systat 13).

In a more formal way, multimodality and the presence of outlier would be investigated by interpolating a surface to the *x*,*y*,*z* data and then considering the *tops* and *valleys* of such a surface as a model of its irregularity: the spatial dependence between the highest top and its surrounding area could be then visualized and interpreted (Mitas & Mitasova 1999). Given a set of samples to which a variable *z* is attached, *spatial interpolation* is the procedure used to estimate the value of the variable at an unsampled location *x*. To achieve that, we should create a function *f*, called the interpolant, trying to fit the samples as well as possible, based on some criteria. Bevan and Conolly (2009) report that technique can also be applied to model a continuous distribution of cultural data, such as artifact densities or event horizons.

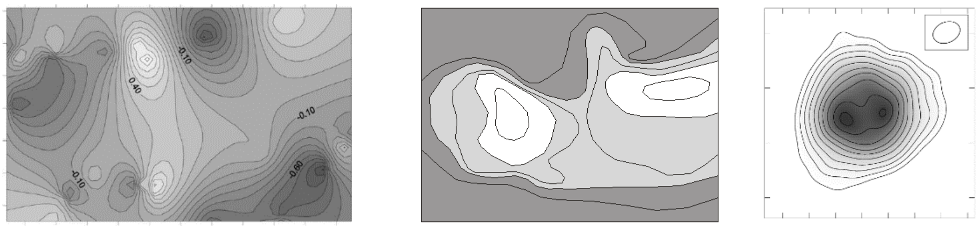


Figure 101 Examples of graphic results obtained interpolating x,y,z datasets.

An interpolated scalar field should not be considered as a “visualization” of spatial data, but as a predictive model of the most probable place where data of a particular category were deposited (discarded) in preference. Consequently, interpolated values should be normalized to the scale 0-1 to be interpreted as a probability. The gradient in this map should then be understood as the amount of change in the probability of the observed archaeological category in some direction, usually the direction for which the amount of change is greatest, i.e. the steepest path up or down the surface. In practice we can specify some distance over which the slope is calculated, such as the amount of rise or drop over a 10 meter distance *in the plane*. This ratio is actually the tangent function: $S=\tan(S_t)$ where S_t is the terrain slope in radians (de Smith et al. 2015). The gradient represents the slope of the tangent of the graph of the function. More precisely, the gradient points in the direction of the greatest rate of increase of the function, and its magnitude is the slope of the graph in that direction. The components of the gradient in coordinates are the coefficients of the variables in the equation of the tangent space to the graph. This characterizing property of the gradient allows it to be defined independently of a choice of coordinate system, as a vector field whose components in a coordinate system will transform when going from one coordinate system to another.

There are many different algorithms to interpolate such a gradient representation from *x, y, z* data. Here we review just two of them: *kriging* and *inverse-distance weighting* (IDW) (Oliver 1990; Royle et al. 1981).

The inverse distance weighted (IDW) interpolation algorithm is a deterministic interpolation method directly based on the surrounding measured values, or on specified mathematical formulas that determine the smoothness of the resulting surface; the closer a point is to the center of the cell being estimated, the more influence, or weight, it has in the averaging process. Kriging or Gaussian process regression is a method of interpolation for which the interpolated values are modeled by a Gaussian process governed by prior covariances, as opposed to a piecewise-polynomial spline chosen to optimize smoothness of the fitted values (Isaaks & Srivastava 1989).

Kriging is similar to inverse distance weighted (IDW) in that it weights the spatial frequencies at surrounding cells to derive a prediction for an unmeasured cell. The general formula for both interpolators is formed as a weighted sum of the data:

$$\hat{Z}\,(s_0) = \sum_{i=1}^{N} \lambda_i \, Z(s_i)$$

- where:

  $Z(s_i)$ = the measured value at the *i*th location

  λ_i = an unknown weight for the measured value at the *i*th location

  s_0 = the prediction location

  N = the number of measured values

In IDW, the weight, λ_i, depends solely on the distance to the cell whose frequency should be predicted. However, with the kriging method, the weights are based not only on the distance between the measured centroids of the respective cells and the prediction location, but also on the overall spatial arrangement of the observed frequencies. To use the spatial arrangement in the weights, the spatial autocorrelation must be quantified. Thus, in ordinary kriging, the weight, λ_i, depends on a fitted model to the measured cells, the distance to the prediction location, and the spatial relationships among the measured values around the prediction location.

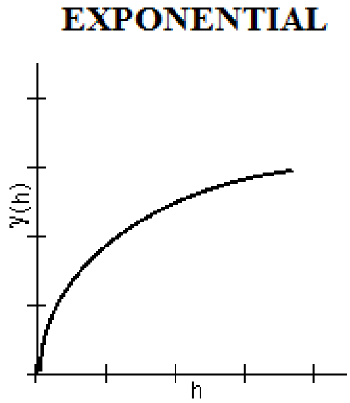
To create a gradient visual representation with the kriging interpolation method, we should discover beforehand the spatial dependency structure. This can be done, as suggested in a previous section by creating the variograms and covariance functions to estimate the spatial autocorrelation as a measure of spatial dependency between adjacent cells. We begin with a graph of the empirical semivariogram, computed with the following equation for all pairs of locations separated by distance *h*:

Semivariogram (distance$_h$) = 0.5 * average((value$_i$ – value$_j$)2)

The next step is to fit a model to the points forming the empirical semivariogram. As we have already discussed, the empirical semivariogram provides information on the spatial autocorrelation of datasets. However, it does not provide information for all possible directions and distances. For this reason, and to ensure that kriging predictions have positive kriging variances, it is necessary to fit a model—that is, a continuous function or curve—to the empirical semivariogram. It is similar to regression analysis, in which a continuous line or curve is fitted to the data points.

The fitted model influences the prediction of the unknown values, particularly when the shape of the curve near the origin differs significantly. The steeper the curve near the origin, the more influence the closest neighbours will have on the prediction. As a result, the output surface will be less smooth. In the next chapters we have fitted an exponential model, given that we are assuming spatial autocorrelation decreases exponentially with increasing distance (the inverse *J*-

distribution of spatial frequencies in the theoretical model of single accumulations). Here, the autocorrelation disappears completely only at an infinite distance.



$$\gamma(h) = C_0 + c\left(\left(1 - exp\left(\frac{-h}{r}\right)\right)\right) \qquad h > 0$$

$$\gamma(0) = 0$$

Figure 102 Exponential model with related formulas.

An exponential fit reaches the sill asymptotically, with the practical range defined as that distance at which the variogram value is 95% of the sill. Like the spherical model, the exponential model is linear at small distances near the origin, yet rises more steeply and flattens out more gradually. Erratic data sets can sometimes be fit better with exponential models.

Kriging is based on the following assumptions:

- The value for an unknown point can be estimated from neighboring points, but that the unknown point is not necessarily *completely* dependent upon the values of the known points.
- Variability in the z-values of a dataset is a function of two factors: *distance* and *direction*. In general, points close together tend to show less variability than points far apart, and in many cases, points along certain bearings will show less variability than equidistant points, along a different bearing.

Compared to alternative methods of surface interpolation, the strength of kriging is in identifying patterns across the data, including directional trends. It helps to compensate for the effects of data clustering, assigning individual points within a cluster less weight than isolated data points (or, treating clusters more like single points). When estimates with their errors are required, kriging is the method of choice instead of another interpolation technique, because it evaluates estimation error (kriging variance), along with estimate of the variable *Z* itself.

It should be taken into account that if the surveyed non-empty cells are dense and uniformly distributed throughout the study area, we will get good estimates regardless of interpolation algorithm, and a proper visualization of the spatial irregularity can be obtained. In the case of the presence of significant outliers, almost all interpolation algorithms will underestimate the highs and overestimate the lows; this is inherent to averaging. Therefore, kriging and related methods are best for deleting the presence of outliers and multimodality, rather than a method to detect those extreme patterns. The situation is even worst in the presence of multimodality.
When the spatial frequencies tend to cluster in separated aggregations with large gaps between them, we will get unreliable estimates regardless of interpolation algorithm. In those

circumstances, IDW may offer a better fit, because this method often does not reproduce the local shape implied by data and produces local extrema at the data points.

Fortunately, this can be detected by cross-validating the fitting function and testing whether the model (in our case an exponential model) fits well the empirical variogram. In this case we can distinguish what the theoretical model predicts from the prediction errors (residuals).

This cross-validation approach can be enhanced using ***local*** spatial autocorrelation statistics to identify local regions of strong autocorrelation, that is concentrations in a particular zone of the global space, such as particular high/low values of a variable, more than the expected mean value. In the same way as an interpolated surface tends to average highs and downs, global estimators of spatial autocorrelation tend to average local variations in the strength of spatial autocorrelation, hiding the presence of outliers and multimodality. *Local indices of spatial association* allow examining the local level of spatial autocorrelation, in order to identify areas where values of the variable are both extreme and spatially homogeneous. This leads to identification of so-called *hot spots –areas*, where the considered phenomenon is extremely pronounced across localities - as well of spatial outliers.

The index, fast becoming the standard tool to examine local autocorrelation, is Luc Anselin’s LISA (local indicator of spatial association)(Anselin 1995). The procedure applies Moran’s *I* statistic to individual zones, allowing them to be identified as similar or different to their nearby pattern. We use here the description by Levine (2013, chapter 9). The definition of “Ii” is from Getis and Ord (1996):

$$I_{i=}\frac{(z_i-\bar{z})}{s_z^2}\sum_{j=1}^{N-1}[W_{ij}\,(z_j-\bar{z})]$$

where Z_i is the intensity of observation *i*, $\bar{z}$ is the mean intensity over all observations, *Zj* is intensity for all other observations, *j*, s_z^2 is the variance over all observations, and W_{ij} is a distance weight for the interaction between observations *i* and *j*. The first term in equation refers only to observation *I* while the second term is the sum of the weighted values for all other observations (but not including *i* itself).

The expected “I_i” is defined as:

$$E\,(I_i)=\frac{\sum_{i=1}^{N}W_{ij}}{N-1}$$

where W_{ij} is the distance weight for the interaction between observations *i* and *j* .

Since the global Moran’s *I* statistic measures similarity in observations over a study area, the local Moran “Ii” also indicates the similarity of a zone relative to its neighbours. Thus, in neighbourhoods where both the zone and its neighbours have high attribute values, the Local Moran will be positive indicating that the particular zone is similar. Similarly, in neighborhoods where both the zone and its neighbours have lower attribute values, the Local Moran also will be positive indicating that the zone is similar to its neighbours. When the Local Moran statistic is positive, this is an indicator of *similarity*, not absolute value of the intensity variable.

Conversely, if a zone has a high value of the intensity variable, while its neighbours have low values or, alternatively, it has a low value, while the neighbours have high values, then the Local Moran statistic will be negative. *Dissimilarity* is an indicator of either a *hot spot* or a *cold spot*, that is zones that are different from their neighborhood. Hot spots would be seen if the number of items in a zone is much higher than in the nearby zones. Cold spots would be seen if the number of observations in a cell is much lower than in the nearby cells.

In other words, the Local Moran statistic indicates whether the cell is similar or dissimilar to its neighbours.

After detecting such “outliers” or hot-spot cells in the grid, an appropriate strategy will be restrict the analysis to those cells with the highest frequencies. This can be a sound procedure, when we consider the probability of an altered spatial pattern given to post-depositional movement of fragments within the sedimentary matrix. In those circumstaces, the more probable scenario would be a post-depositional alteration towards a more uniform pattern, smoothing the difference between cells, rather than a completely random pattern, where the observed frequency at each cell be independent to frequencies observed in the neighborhood.

Let us consider the following example. We have some abundance data from a data set organized into equally sized cells (0.25 squared metres).

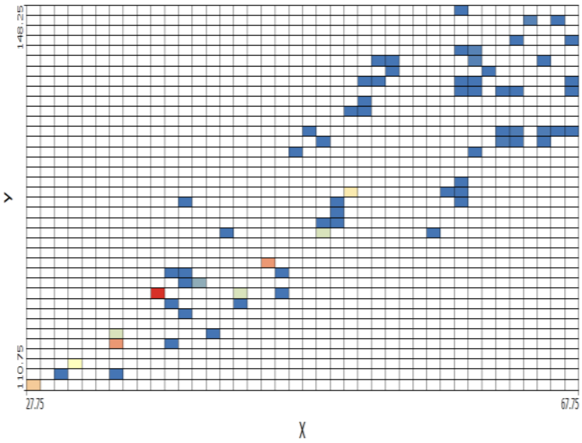


Figure 103 dataset organized into equally sized cells (different frequencies of item in each cell are highlighted with different colours).

In order to increase understendability, we have aggregated contiguous sampling units into 4 square meters areas.

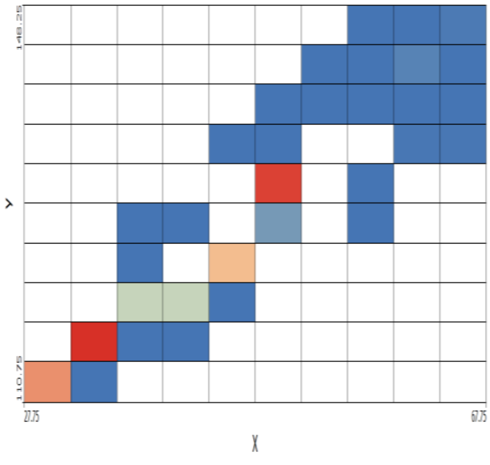


Figure 104 results of aggregation with contiguous sampling units, into 4 square meters areas.

There is no doubt that this re-sampling has altered the original spatial distribution. Let us see how a krigged interpolated scalar field looks in this case.

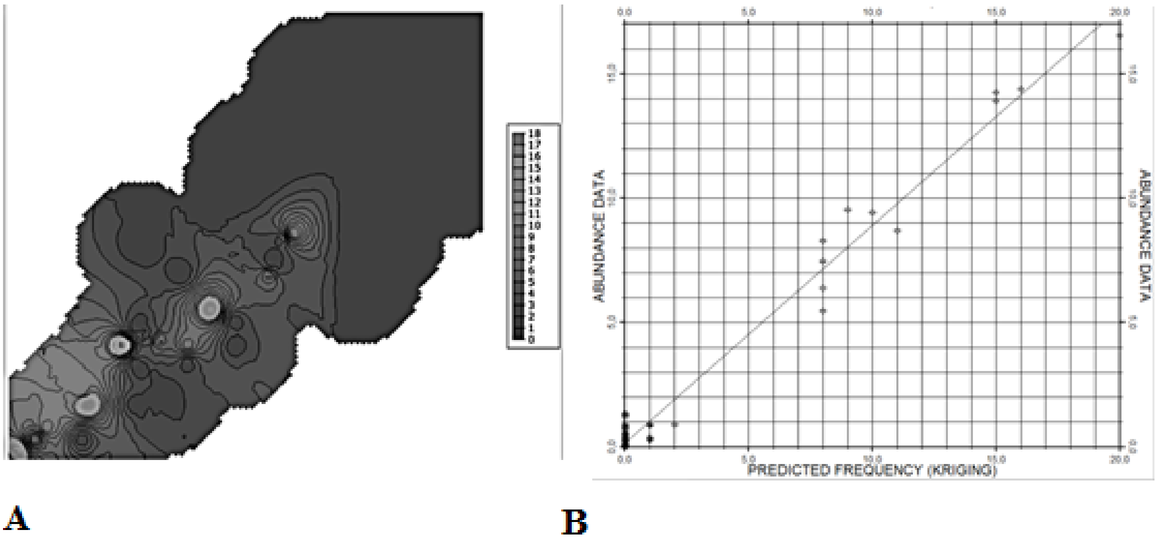


Figure 104 A)Graphic result of krigged interpolated scalar field of the previous dataset. B)Related graph indicating the relationship between abundance data and predicted frequency by kriging.

It fits better to the original distribution, without the compression offered by the second 2D histogram. Although original abundance data are not exactly like predicted values through kriging, there is a very strong linear relationship between original data and predictions (Figure 102 and 104).

We can now normalize predicted data, and use such normalizations as a measure of the probability for the preferred location of this archaeological category. Because this is just a normalization, the map is exactly like the previous one, but it has been rescaled to the 0-1 interval. We have plotted the original abundance data, to understand the way spatial probabilities have been estimated in terms of the frequency per sampling unit: where the archaeological categories are more frequent (per sampling unit), the higher the probability is.

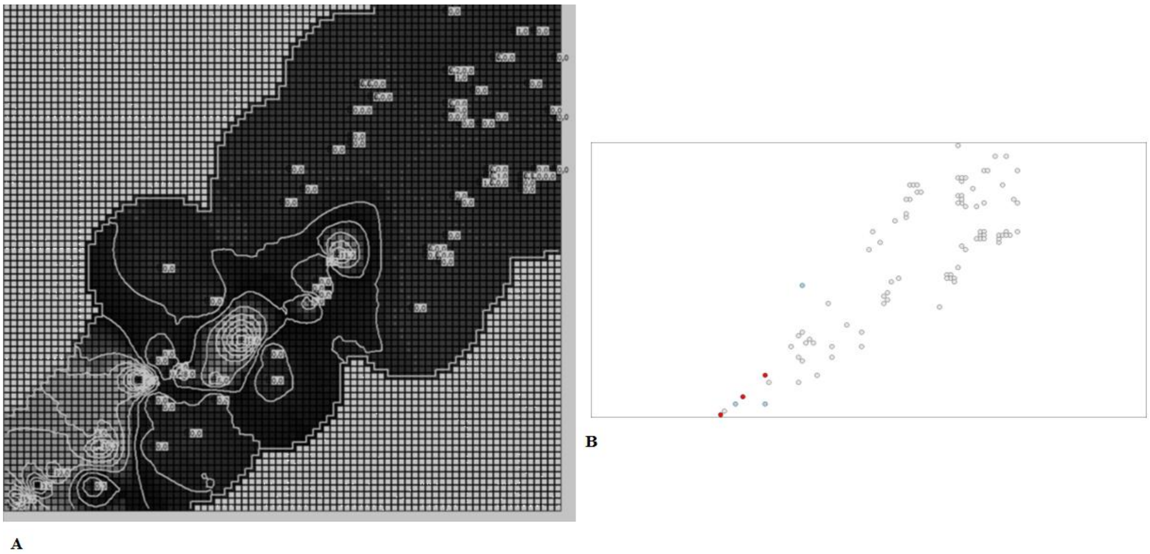


Figure 105 Result of normalization, rescaling to 0-1 intervals and corresponding local indicator of spatial association map.

A local indicator of spatial association map, based on local measures of Moran's *I*, gives higher reliability to the predictive model. It is important to realize how the bottom left concentration in the interpolated surface coincides with cells with higher frequency and with higher positive autocorrelation. However, the central area with higher frequency is not an area with positive autocorrelation, because it is just a single point of higher occurrence, an outlier. The number of contour lines suggest the high gradient (slope), and hence higher anisotropy and less spatial continuity, although it is still a point of higher abundance. On the other hand, in this case, the extense area in the top-right part of the graphs, characterized by low frequency values, does not configure a positive autocorrelation area: there is no continuity in the absence of data.

Once we arrive at this point, it can be of interest to restrict the analysis to those cells whose frequencies exceeds the interquartile range; hence, it can give more details regarding the kind of accumulation, eliminating the misleading effects of false zeros. Nevertheless, when considering only the cells with the highest frequencies, the difference in abundance can be less rewarding than the inter-distance pattern between over-abundant sampling units. This is a classical *point-process* analysis, in which what is examined is the higher, or lower, density of points, or its randomness. The null hypothesis is a random Poisson process, giving a modified exponential nearest neighbour distribution with mean

$$\mu = \frac{\sqrt{\frac{A}{n}}}{2}$$

where *A* is the area and *n* the number of points. The area can be estimated either by the smallest enclosing rectangle or using the convex hull, which is the smallest convex polygon enclosing the points.

The probability that the distribution is Poisson is presented, together with the *R* value:

$$R = \frac{\bar{d}}{\mu} = \frac{2\bar{d}}{\sqrt{\frac{A}{n}}}$$

Where $\bar{d}$ is the observed mean distance between nearest neighbours. Clustered distributions give $R<1$, random patterns give $R\sim1$, while overdispersed points give $R>1$. The expected (theoretical) distribution under the null hypothesis can be calculated as a continuous curve together with the histogram of observed distances. The expected probability density function as a function of distance r is

$$g(r) = 2\,p\pi r \exp\left(-p\pi r^2\right)$$

where $\rho = n/A$ is the point density (Clark & Evans 1954, Ripley 1979, Davis 1986, Hammer et al. 2001).

Ripley's K *is* the average point density as a function of distance from every point (Ripley 1979, Negre 2015). It is useful when point pattern characteristics change with scale, e.g. overdispersion over small distances but clustering over large distances. We follow here the computer implementation by Hammer et al. (2001).

$\lambda = n/A$

represents the estimated intensity of the point pattern, with n points in an area A, as the distance between points i and j is d_{ij} . The estimate of Ripley's K, as a function of distance, is then computed as

$$K\,(d) = \frac{1}{\lambda n}\sum_{i-1}^{n}\sum\nolimits_{j+i} I\,(d_{ij} \le d)$$

where the indicator function I is one if the argument is true, zero otherwise. The normalization of K is such that for complete spatial randomness, $K(d)$ is expected to increase as the area of circles, i.e. $Kd = \pi d^2$. The $L(d)$ function is a corresponding transformation of $K(d)$:

$$L(d) = \sqrt{\frac{K(d)}{\pi}}$$

For complete spatial randomness, $L(d)=d$, and $L(d)-d=0$. A 95% confidence interval for complete spatial randomness can be estimated using 1000 Monte Carlo simulations, within the bounding rectangle.

For the correct calculation of Ripley's K, the area must be known. In the first run, the area is computed using the smallest bounding rectangle, but this can both over- and under-estimate the real area. The area can therefore be adjusted by the user. An overestimated area will typically show up as a strong overall linear trend with positive slope for $L(d)-d$.

Appropriate references for all those statistical measures can be found in Davis 1973, Clark 1979, Odland 1988, Isaaks & Srivastava 1989 and Berry 1999.

4.3.3 When the model does not fit. Skewness and anisotropy

A perfect bivariate normality model fitted to archaeological accumulated data is very unusual in practical circumstances. Middens are always skew, so that kurtosis is far more relevant to detect the presence of accumulation than symmetry, around the central mean (or center of minimum distances). A perfect geometric or exponential distribution of spatial frequencies is only expected when the dispersion is perfectly circular around its centroid.

In case of perfect simmetry, we can refer to *isotropy*. An archaeological accumulation of items, restricted in functional category, time and space, is defined isotropic if observed spatial frequencies per sampling unit are identical in all directions, observations appear to be invariant in relation to a particular direction, and therefore none of its properties is directionally dependent. Conversely, if one of these categories is directional, the spatial pattern is not isotropic, but anisotropic. Anisotropy is an important factor to understand the spatial dimension of an archaeological accumulation: it is in fact an apparent "deformation" of the original shape, in the sense that the variable of interest can change more rapidly in one direction than in another. We can distinguish then between the direction of maximum spatial continuity and the direction of minimum spatial continuity. For instance, in an arid climate the prevalence of certain species of plants changes more rapidly as one moves in a direction perpendicular to a river (direction of minimum spatial continuity), than it does as one moves along the river (direction of maximum spatial continuity). As such, anisotropy analysis is the best way to approach the probabilities of post-depositional alteration: the frequency of artifacts may decrease evenly in one direction, but more chaotically in another (Bevan and Connolly 2009). For instance, the slope of the ground surface can have affected the spatial dispersion of potsherds and bone fragments, than have rolled downhill after deposition, and are finally located far from they were originally deposited. In this situation, the spatial pattern is dependent to the direction of the slope, and anisotropy is present.

In theory, we would expect that anisotropy be more improbable at small distances than at greater distances. Bevan and Connolly (2009) have argued that patterns of spatial autocorrelation are otherwise fairly isotropic over the first 100-150 m, but becomes far more anisotropic at larger distances. This is a consequence of preferential choice of the least-cost path for movement. The higher the distance, the more influence has this choice, whereas at small distances, all directions may have the same cost of movement. This observation also explains the influence of archaeological survey on observed anisotropy of the resulting spatial distribution of findings. Markofsky and Bevan (2012) suggest that directional influences may factor heavily in the distribution of surface material, reflecting not only trajectories of artefact deposition from settlement, but also recovery biases (different behaviours in different directions), that may influence the interpretation of the surface distribution. If an area has been surveyed in transects of rectangular shape (far longer than wider), then the distribution of observations can changes more rapidly in a direction of the longer axis than perpendicular to it, where the number of observations is always lower.

The vast majority of statistical analyses in spatial point processes assume isotropy without checking/testing for it (Guan et al. 2006), because when computing and modelling variograms, we generally look for the direction of maximum continuity. When there is no anisotropy, semi-variogram values will gradually increase from the origin into all directions. However, in most practical cases, more than one principal direction of continuity may exist. The underlying social activity may exhibit dominant structures with different anisotropy. It is obvious that we need to test the degree to which artifact counts exhibit continuity in some directions, more than others (i.e. are anisotropic in nature) (Nicolis et al. 2010). We can measure the degree of anisotropy in a spatial dataset using a variogram. In such cases, the chosen variogram model must reflect the multiple anisotropy of the studied property. This can be achieved by considering multiple variogram structures, each with a different direction of maximum continuity. In any case, it should be taken into account that, checking for the direction of maximum range, will only tell us that anisotropy exists in the spatial dispersion of the variable under study, which is insufficient. To measure the degree of anisotropy, we can use an anisotropy ratio, defined from the different ranges of distinct semi-variogram models at different directions: it is the largest semi-variogram range divided by the shortest range. This reports the directionality of the data. The closer to 1, the less directional (or anisotropic) the data.

A semivariogram is anisotropic if it changes in some way with respect to direction. If the value of semivariance depends only on the length of vector h, then we have an isotropic semivariogram. If the value of semivariance depends not only on length of vector h, but depends also on direction of vector, then we have anisotropic semivariogram (Budrikaite & Ducinskas 2005). Geometric anisotropy occurs when the range, but not the sill of the semivariogram, changes in different directions; zonal anisotropy exists when the sill of the semivariogram changes with direction. It is important to signal that the lower the quantity of obervations, the higher the effects of anisotropy, because distances between non-empty cells are higher.

An anisotropic Semivariance Surface or Variogram Map provides a visual picture of semivariance in every compass direction. This allows the more easily calculation of the appropriate principal axis for defining the anisotropic variogram model. A transect in any single direction is equivalent to the variogram in that direction: the surface (z-axis) is semivariance; the x and y axes are separation distances in E-W and N-S directions, respectively. The center of the map corresponds to the origin of the variogram $\gamma(h) = 0$ for every direction (for more details see Isaaks & Srivastava 1989: 150; Goovaerts 1997: 98).

4.4 *From Spatial Dependence to Spatial Concordance.*
An introduction to Multivariate Analysis of spatial variables.

The presence and abundance of individual species vary through space in a non-random way, displaying spatial structures. Hence, the composition of each particular archaeological area is usually not random, in such a way that potential variations, in assemblage composition, display spatial patterns that should be investigated.

Beyond the relationships between "close" spatial units (spatial autocorrelation), we have already explored, in previous sections, the case of archaeological variables that are spatially *correlated* because they have the same (or similar) value at the same locations, independently of the distance between them. Consequently, spatial correlation is just the co-occurrence of equivalent frequencies at different locations.With respect to this, Hubert and colleagues (Hubert et al. 1985) make a distinction between “point-to-point association” (the relationship within a pair at each location) and “spatial association” (the relationship between distinct pairs across locations). We can also refer to “spatial concordance” or congruence (Gioria et al. 2011; Rey 2014).

We have already presented in Chapter 1 the need of comparing the values of different dependent spatial variables at the same location, as the frequency of faunal remains per sampling unit (z_1) and the frequency of lithic tools per sampling unit (z_2), through a fixed disposition of two independent variables, *x* and *y*, which are the spatial coordinates of sampling units based on their centroid. As an example, consider a hypothetical relationship between two phenomena, *a* and *b*. A simple plot of one set of counts against the other might suggest a "congruent" relationship, where high quantities of *a* coincides with high quantities of *b* (positive relationship), or with low values of *b* (negative relationship).

Inferring processes, underlying differently structured spatial areas at the intra-site scale, depends heavily on our capacity to detect patterns in the spatial distribution of particular functional categories, given that manipulative (field and laboratory) experiments cannot, in most instances, be extensive enough to detect the effects of mechanisms that influence assemblages at large spatial scales. However, ''*because changes in process intensity can create different patterns, and because several different processes can generate the same pattern signature*'' (Fortin & Dale 2005:3), archaeologists face the challenge to draw clear links between patterns and processes.

Whallon (1984: 266) affirmed: "*The aim (...) is generally to define 'tool kits', or clusters of artefacts and other items which occur together on occupation floors as a consequence of having been used together in certain activities*". He considered the analysis proceeding in three steps: (i) "*determine whether the distribution of artefacts or items of each class . . . is essentially random or shows a significant tendency towards spatial aggregation or concentration* . . .", (ii) "*take those classes which do show significant trends towards concentration and to reorganise the original data so that similarities or correlations which are based on . . . these concentrations can be calculated among the classes*", (iii) "*calculate and display these similarities or correlations*".

Standard measures of the association between two ordinal-level variables, particularly Spearman's *rho* and Kendall's *tau*, have been used extensively by geographers (Glick 1982; Haining 1991 for a critical overview). Typically, the measure is between pairs of values, each member of the pair being at the same location. Cross-correlation measures can also be obtained by correlating pairs of values that are separated by fixed lags or distances. This would seem particularly useful in studies involving small areas, and where effects (such as post-depositional factors) can spill over between areas.

Classical correlation coefficients used for spatial concordance or congruence analysis raise important interpretation problems: the sensitivity of findings to different areal aggregations (particularly at equivalent scales of aggregation); the relationship between findings identified at one scale of sampling to the underlying continuous fields (arising in geostatistical applications, for example). Each variable may have a distinctive pattern of spatial variation that contaminates the measure of bivariate correlation. This problem may further undermine comparative studies where different areas display distinct patterns of spatial variation.

The most important drawback of linear correlation coefficients (parametric or not) with spatial data lies in the fact that the relationship between two or more variables, across space, may itself vary, which is termed spatial non-stationarity (Bevan & Connolly 2009). The problem is that, not only the measured strength and statistical significance of this relationship might vary spatially, but more dramatically, it might even be entirely different (e.g. negatively rather than positively correlated) in one part of the study area than in another. To illustrate this point, consider a situation in which the observation points are cells in a regular grid and the data refer to the frequency of remains of hunted animal bones and the frequency of arrow points used to kill those animals. A statistically significant test of association does not necessarily indicate a causal link between the weapon and the prey; in the case of spatial data, however, there is an additional problem in interpreting an apparently significant measure of association between two data sets. Values for either the abundance of animal bones or arrow points, or both, may be drawn from *n* pairs of random variables with means that vary across the map. Also, the random variables may be spatially correlated and hence not independent. In the first case, data values may show evidence of trend; in the second, similar-sized values may cluster together on the map (Haining 1991). What is constructed as a test for the presence of second order covariation between *animal bones* and arrow points, at the intra-site scale, is contaminated by larger-scale patterns in the data. Further, if the areas differ in size and so involve different amounts of aggregation, the variances may not be the same for all areas.

The pattern can be worst if dependent variables are measures of frequency for the same category at two time intervals, expressed in terms of two consecutive stratigraphic layers. If the frequency of materials related with hunting activities was diffusing spatially, standard indicators of rank correlation are not sensitive to the relationship between the two stratigraphic layers –the time periods. Indeed, these measures examine the rank of a sampling unit at time period *t* and the rank of the cell at time *t +1*, using either a cross-products or deviation approach. If the abundance of bones rankings for time *t* are not strongly clustered, standard measures of rank correlation will fail to detect significant association between the two datasets. In fact, the finding of association by these methods would be an artifact of spatial autocorrelation in the time *t* pattern (Glick 1982).

It is clear, then, that we need an alternative approach for spatial congruence. There are graphical ways of overlying scalar fields to calculate what they have in common and where it is spatially located (see chapter 1); it is however important to take into account that a detailed spatial concordance analysis needs many dependent variables and only two –or three in the 3D case- independent ones (the spatial coordinates *x, y*). Then, instead of bivariate spatial congruence (Lee 2001), we should look for a form of multivariate spatial dependence, which is intended to capture spatial congruence or concordance among observations, in terms of their point-to-point relationships, across multiple spatial variables. In short, a multivariate spatial association measure needs to capture the spatial co-patterning, by calibrating both numerical co-varying point-to-point association and spatial clustering.

Spatial congruence and concordance can be visualized using assemblage tables, adopting the form and structure of a contingency table, in which the rows list the different values that, within the same spatial unit (or finding spot), the different variables (columns) showed. The first two (or three in 3D analysis) columns represent spatial coordinates (the independent variables), and any subsequent column, the variables whose value at each area has been measured. Because this is an aggregated presentation, variables refer to equally sized areas around a centroid.

x	y	fauna	saddle querns	wooden fragments	vertical posts	concotto remains	horizontal posts	pottery
38,25	115,25	0	1	0	2	0	0	12
38,75	118,25	0	0	0	3	0	0	0
40,75	116,25	0	1	0	3	0	0	0
42,75	118,75	0	0	10	0	0	1	0
42,75	120,25	8	0	0	0	0	0	3
46,75	120,25	0	12	0	1	0	0	0
38,25	118,75	0	11	0	0	0	0	6
39,25	120,75	0	5	0	1	0	0	13
39,75	121,25	0	3	0	3	0	0	6
37,25	120,25	20	0	0	1	0	0	1
33,75	116,25	8	0	0	0	0	0	2
34,25	115,25	15	0	0	0	0	0	2
30,75	113,25	10	0	0	0	0	0	10
29,75	112,25	0	0	0	0	0	0	20
28,25	111,25	16	0	0	0	0	0	2
27,75	110,75	9	0	0	0	0	0	0
33,75	112,25	0	0	0	0	0	0	11
42,25	126,25	0	0	0	2	0	0	19
47,75	133,75	0	0	0	0	0	0	15
44,75	123,25	15	0	0	0	0	0	0

Let us forget for the moment the independent spatial variables, and we will take into account the dependent ones, that is the archaeological categories. This is still a spatially organized table, although not explicit spatial data are considered: each row is a separate spatial unit, and the frequency of archaeological observations are always referred to the same cells. In those conditions, is it possible to say, with reasonable certainty, that the distribution of different archaeological categories differs significantly from spatial unit, to spatial unit (i.e., from row to row in the cross tab)? The usual means of answering such questions is Pearson's χ^2 test for independence; it tests whether a cross tab deviates significantly from one in which rows and columns are independent. In our case, independence would imply that the archaeological observations occur with the same frequency in all of the spatial units (cells in a regular grid). Unfortunately, the χ^2 test by itself does not provide a solution to the problem of distinguishing the activities that originally happened at each spatial unit or homogenous set of neighbour spatial units. Though it establishes that the distribution of archaeological material differs significantly from one cell to another, it does not tell us whether the cells where some category appear differ from others far away more than they differ from the nearest ones, nor does it allow us to characterize the spatial units in terms of the frequency of archaeological observations.

Answers to these questions are provided by correspondence analysis (Benzecri 1992; Bendixen 1995; Beh 2004; Greenacre 2007 for general details of this technique: in archaeology, Bølviken et al. 1982; Ringrose 1992; Baxter 1994; Groenen and Poblome 2003, among many others). Roughly, 'correspondence' is a measure of how strongly the frequencies across rows and columns of the data table deviate from a null model of "no association" . Using as input a "spatial units x archaeological categories" table, CA would attempt to find a reduced-space answer to questions such as "Where a particular kind of archaeological material was discarded preferently? or "Which locations to my categories *correspond* to?" This is accomplished by performing eigenanalysis on a transformation of the original data table such that each value represents a contribution to the Pearson's χ^2 (chi-squared) statistic computed for the data. When calculating the χ^2 coefficient, "double zeros" are excluded. In this way, this technique allows a simultaneous ordination of the variables in the columns and rows (archaeological categories and spatial units or finding spots), based on the inherent structure of the data, due to their redundancy, i.e. the co-occurrence of groups of archaeological material within the spatial units, and multiple plots showing the same sets of categories.

This technique belonging to multivariate analysis is intended to display the main trends of variation of a multidimensional dataset in a reduced space of a few, linearly independent dimensions or “factors”. Factor extraction refers to the process of concentrating several variables into a set of factors with lower cardinality. It denotes a dimension reduction technique, as well as a vehicle to disclose latent factors. It is in fact based on a transformation of the data, in which the orthogonal coordinates are rotated, in order to load as much variance as possible on the first components, and less variance on subsequent components. Consequently, the first components, formed by a linear combination of the original variables, represent an essential information content of the data and might be understood as factors. Conversely, the final components, presenting little residual variance, might be ignored in the analysis and allow thus for dimension reduction. Following Greenacre (2007: 28, 61), the square root of the total inertia can be considered a measure of the strength of association between rows and columns.

Correspondence analysis can been used visualize spatial congruence using this kind of spatial frequency data (Borcard et al. 1992, ter Braak and Schaffers 2004, Gioria et al. 2011, Dray and Jombart 2011, Dray et al. 2012; in archaeology, we can mention Djindjian 1984, , Smith and Neiman 2007, Peeples and Schachner 2012, Alberti 2013 for spatial analysis applications). If we arrange a set of categories and spatial units according to their first axis CA order, they will look similar to a sorted assemblage table, with dominant categories –more frequent- in the middle, and rare ones on the ends.

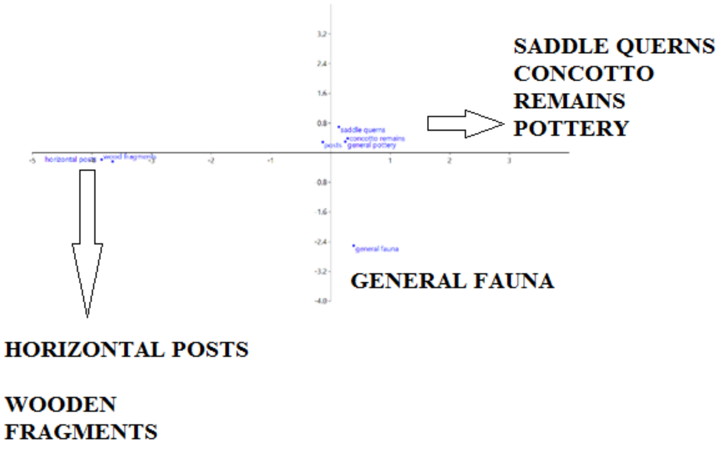


Figure 106 Graphic result of Correspondence Analysis (Past).

In the example (Figure 106), we can interpret Axis 1 as being highly negatively related to the abundance of horizontal posts remains and wooden fragments, and with almost no correlation to the abundance of all other categories. A second axis is necessary because there are spatial units that lie close together in the first axis, but which also have a great deal of differences in composition of archaeological categories. In this example, Axis 2 is negatively related to the abundance of faunal remains, with almost no correlation to the abundance of all other categories. So the "gradient" reflected by Axis 2 is something which prevents the deposition or differential preservation of animal bone remains. The explanation of those “gradients” is easier than expected: as usual in Correspondence Analysis, the first axis distinguishes between spatial units with high frequencies of any category and units with low frequencies. In this case, the cells with horizontal posts and/or wood remains have low frequencies in the most abundant categories (fauna, pottery) (left figure). This particular spatial “uncongruence” explains 27% of the total variance, as explained by the proportion of total inertia.

The simplest approach for integrating multivariate and spatial information is a two-step procedure where the data (without the spatial coordinates) are first summarized with multivariate analysis, such as Correspondence Analysis. In a second step, mapping techniques can be applied to CA scores using the spatial coordinates, that is the independent variables in our assemblage table. Thus, we can plot the row scores of the first and second axis on the *x,y* coordinates. This is exactly an interpolation of the axis scores on the *x,y* plane. We can use the same methods already introduced and suggested: kriging or inverse distance weighting. This “spatial” reading of the CA shows where are located those particular cells with statistically significant discriminat values. In our case, high frequency of horizontal posts/wood fragments and low frequencies of any other category are observed at the center of the spatial gradient and at the extreme corner of the archaeologically surveyed area. The other variables appear in relatively equal values in most spatial units.

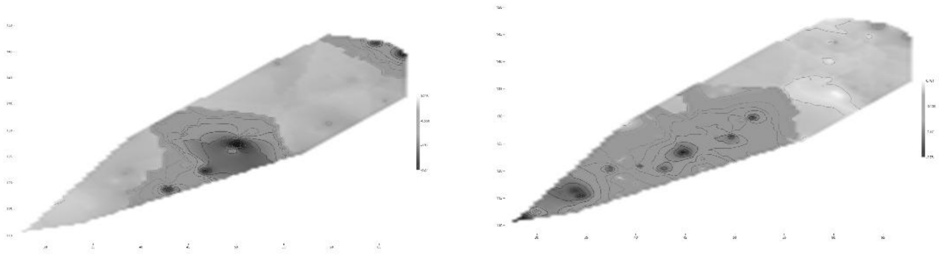


Figure 107 Spatial xy interpolation of Correspondence Analysis Axis 1 and Axis 2, showing spatial congruence between horizontal posts and wood fragments (right figure), and the spatial units were the abundance of faunal remains is statistically significant (left figure). Interpolation algorithm: Inverse Distance Weighting (Past).

There is a potential problem, however. Correspondence Analysis may suffer from two major problems: the *arch effect* and the compression of the ends of the main factors. The first issue is a distortion in an ordination diagram, in which the second axis is an arched function of the first axis; in other words, CA creates a second-order variation where there is none. Wartenberg and colleagues (1987) state that this distortion occurs because spatial units are considered similar due to the corresponding lack of items belonging to most archaeological categories, rather than according to the presence of items ascribable to the same categories. This “artificial similarity” leads to the closeness of dissimilar extremes of an axis gradient (Jackson & Somers 1991).

The second issue that may affect the spatial reading of the axis gradients, is based on the fact that scores are typically compressed near the ends along axis 1 relative to their original spacing. Because of this potential trouble, the spacing of rows (spatial units) and columns (archaeological categories) along the first axis is not necessarily related to the amount of change (or beta diversity) along the primary gradient. Also called “differentiation diversity”, *beta diversity* is a measure of how different spatial units are from each other, and/or how far apart they are on gradients of archaeological composition. Alternatively, it is a measure of the "length" of an ordination axis, in terms of archaeological composition. Total beta diversity can be compared among gradients, but not per unit (e.g. one cannot compare whether the rate of change is higher along a faunal abundance gradient than along a pottery one, but the total change along the gradients can be assessed). An axis or gradient with high beta diversity will have completely different archaeological compositions (i.e. share no archaeological type) at opposite ends (indeed, the ends might be completely different from the middle). An axis or gradient with low beta diversity will be similar in archaeological composition at both ends.

In addition to these distortions, correspondence analysis has an underlying chi-square distance measure that can overemphasize the importance of rare taxa. In extense spatial units that contain multiple rare taxa, perhaps solely because of the large size of the sample, the chi-square distance can exaggerate how distinctive the sample is. It is then important to take into account that variables on the edge of a diagram are often rare categories discarded at very particular places, or that appear randomly in some cells of the spatial grid due to their rarity.

To solve this problem, a “Detrended” Correspondence Analysis technique (DCA) has been invoked (Hill & Gauch 1980). DCA is an iterative algorithm that starts by running a standard Correspondence Analysis on the data to produce the initial arch effect in which the 1st ordination axis distorts into the 2nd axis. It then divides the first axis into segments (default = 26), and re-scales each segment to have mean value of zero on the 2nd axis - this effectively squashes the curve flat. It also re-scales the axis so that the ends are no longer compressed relative to the middle; thus, 1 DCA unit approximates to the same rate of turnover all the way through the data.

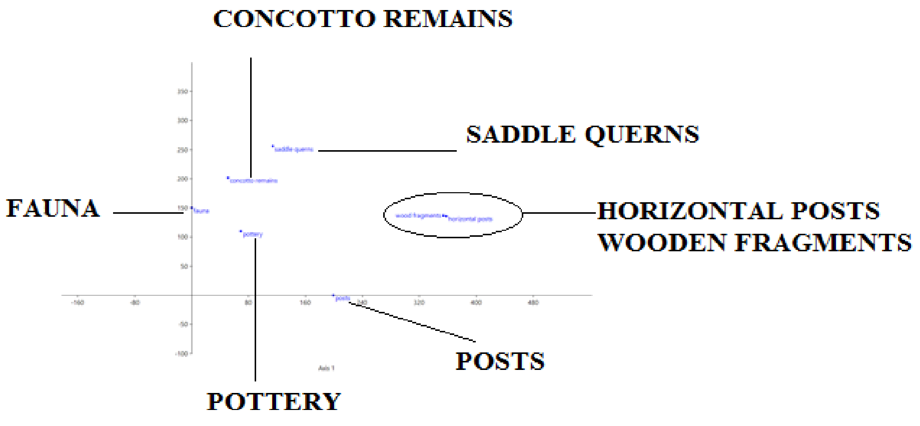


Figure 108 Result of Detrended Correspondence Analysis of the dataset in Figure 106.

We have “detrended” the correspondence analysis shown at Figure 106. Again, the presence of wooden fragments and horizontal posts shows high spatial congruence, given that they appear at spatial units where most other categories have low frequencies. Fauna is not the most spatially uncongruent category with these two, because it is the dominant –more frequent elsewhere-category. We can spatially interpolate Axis 1 and Axis 2.

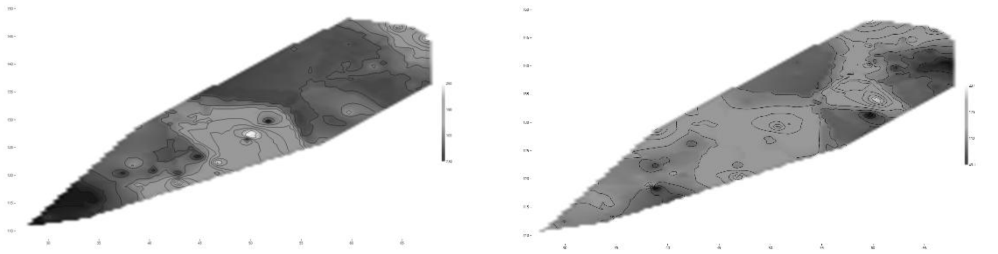


Figure 109 Spatial xy interpolation of Detrended Correspondence Analysis Axis 1 and Axis 2, showing spatial congruence between horizontal posts and wood fragments (right figure), and the spatial units were the abundance of faunal remains is statistically significant (left figure). Interpolation algorithm: Inverse Distance Weighting (Past).

Results are not very different from Standard Correspondence Analysis in the case of Axis 1, but totally differen t in the case of Axis 2. In the first case, we see how the same two areas (in the centre and at the right extreme) that differentiated in the first analysis, are also differentiated in the second case. In any case, the detrended solution gives more information because it differentiates the presence and abundance of fauna, which concentrates at the extreme left edge. Axis 2 is more difficult to explain in the detrended case, because it distinguishes places were vertical posts are concentrated (at the extreme left) and those overdispersed locations where saddle querns have been identified. The lack of an aggregated spatial pattern in the case of saddle querns imposes spatial heterogeneity in the interpolated model of second axis. In any case, the relevance of fauna has been detected by Axis 2 in the preliminar single Correspondence Analysis, that has been integrated into the first Axis. For this reason, Axis 1of the detrended solution contributes much more (51%) to the global spatial variation, than the mere 27% of the single correspondence analysis.

“Detrending” a correspondence analysis solution does not alter significatively the spatial ordination (congruence), although the visualization may be different. It just rearrange the particular correlation between the first and second axis and thus provides a more compact solution.

5 THE SITE OF VILLAGGIO DELLE MACINE: FORMATION AND DEFORMATION PROCESSES

5.1 Introduction

The pile dwelling of Villaggio delle Macine, as already mentioned (Chapter 1), is located in central Italy, near Rome, across the northern shore of the volcanic Albano Lake. It is dated between the 19th and 16th centuries BC (Chiarucci 1985, 1986-88, 1995-6; Angle et al. 2002; Zarattini 2003; Angle 2007; Angle et al. 2014). A more specific chronology is provided by recent radiocarbon dating as 2140-1490 BC cal. 2σ, derived from 7 pile samples, CEDAD, University of Salento (Angle et al. 2014). Although such lakeside settlements are quite widespread during this time-span in Northern Italy and, less extensively, in the Lazio region (at Lake Mezzano, for instance, as discussed in Sadori et al. 2004), the Villaggio delle Macine stands out in Tyrrhenian Italy for its width (between one to two hectares) (Angle et al. 2014: 315-6) as well as for the richness and variety of its archaeological remains, both ecofacts and artefacts. The ecofacts include unworked bones, seeds, fruits and ashes. In the artefact category fall *Grotta Nuova* facies ceramics, bronze artefacts (axes and daggers), a lithic industry (lithic cores, flakes and debitage), a bone industry (deer bones worked into axe handles and awls), piles, drying kilns, ambers, glassy faïence, clay fishing weights and a large number of millstones and grindstones (from which the site's toponym derives).

The settlement was discovered in 1984, just below the surface water of the Albano crater Lake and was initially excavated as an underwater site. From 2001, a drastic contraction of the lake due to climatic factors and uncontrolled water taking led to the partial emersion of the site. Consequently, surveys and excavation campaigns on certain key areas were carried out in 2001, 2003, 2009 and 2012 (Figure 110). As stated in Chapter 1, the material evidence retrieved during these surveys, and attributed to the last phase of site's life and abandonment, is the cornerstone of this research. The spatial distribution of such observables, as well as the differences in frequency in more or less neighbouring locations, enable us to underline different concentrations (accumulations) of artefacts and ecofacts. They may be linked to specialised activities performed during the past in some functional areas of the site.

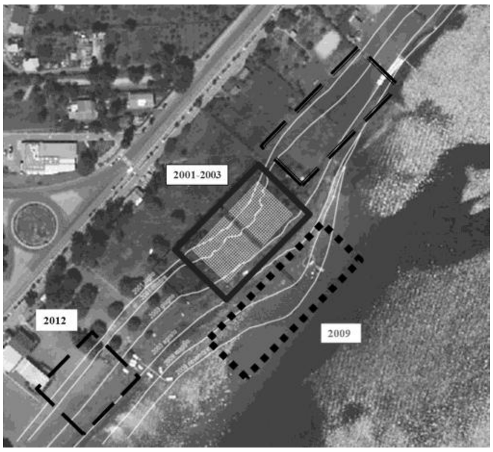


Figure 110 Spatial distribution of the surface surveys carried out during 2001, 2003, 2009 and 2012 at the Villaggio delle Macine.

However, to support this assumption and thus correctly interpret the evidence, depositional and disturbance processes that actively contribute to the formation of the archaeological record have to be taken into consideration (the importance of these processes is fully explained in Chapters 2 and 3). Indeed "understanding the condition under which the material record is created helps us to develop methods for capturing important patterning in the archaeological record and interpret it in a meaningful terms" (Schmader & Graham 2015: 25). In short, this research aims to explore and clarify the role assumed by post-depositional processes in the spatial rearrangement of the material evidence. The reconstruction of such processes has to be preceded by a required overview of the depositional formation stages since, only if combined together, can these two aspects provide a much-needed increase of our knowledge and an improved understanding of the site.

Working towards this goal we faced some issues linked both to the nature of the settlement itself (pile-dwellings involve a preservation "challenge") and to the limited funding resources. For this reason, the site was only partially excavated and even surveys that were carried out on a wide scale have not covered the entirety of the settlement because of several natural obstacles (such as the lake itself and the presence of natural vegetation). Furthermore, the progressive site emersion involved a drastic loss of humidity that led to the decomposition of organic materials and the compression of stratigraphy, mostly near the lakeshore. There, the compacting of the archaeological record in one surface layer forced the undertaking of horizontal sampling. Moreover, micromorphological analysis on the archaeological deposit has not yet been completed.

In spite of these limitations, a multidisciplinary approach integrating archaeological with palaeobotanical, archaeozoological and geological studies was achieved. Although these preliminary results are not exhaustive *per se*, together they provided a useful framework to identify as well as reconstruct possible formation and deformation processes acting on our archaeological context. Firstly, this chapter provides a general overview of these processes by showing the available data. Secondly, the current state of research on the microscale (site) as well as on the macroscale dimensions (outline of the peopling in Lazio region during the Middle Bronze Age) will be pinpointed. Furthermore, we briefly explore the methodological background related to the archaeological strategy adopted in this research, i.e. surface sampling, proving the validity of the method in the light of the aforementioned issues specific to the case study.

5.2 The pre-depositional or zero status of our wetland lacustrine archaeological context: the formation of Lake Albano

The challenging task of past reconstruction starts from the analysis of the environmental setting which hosts the archaeological remains, the Lake Albano. It is located in the volcanic complex of the Alban Hills, South-East of Rome (Lazio, central Italy) (Figure 111), resulting from a polygenetic maar that took place during the Final Hydromagmatic phase produced this basin around 30-40 kyr BP (Fornaseri 1985; Andretta & Voltaggio 1988; De Rita et al. 1988; Fornaseri & Cortesi 1989; Chondrogianni et al. 1996: 17; Giaccio et al. 2007; Bozzano et al. 2009: 1472). The activity of the Albano maar produced a series of eruptive units separated by paleosols.

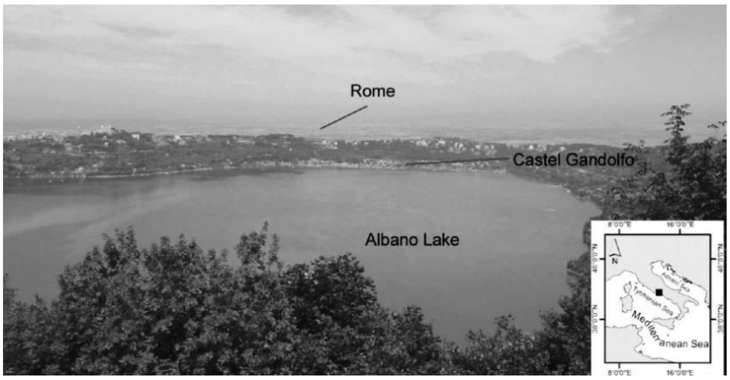


Figure 111 Geographic location of the study area in the framework of Alban Hills (and in a more general scale, in Italy) (from Bozzano et al. 2009: 1470, figure 1).

Albano hydromagmatic deposits are characterised by two typical lithofacies (Giordano et al. 2002). The first one, representing the majority of Albano maar deposits, is in a plane parallel to low angle cross-stratified alternation of scoria lapilli beds and ash-rich layers generally cemented (by zeolitization). The second lithofacies is represented by massive, ash-matrix supporting deposits up to 30 cm thick that contain block-sized xenoliths (again by zeolitization). The subaerial geological frame is completed by recent talus slope and shore deposits that cover the lowest parts of the subaerial inner slopes. Lacustrine sediments cover the lake bottom (Bozzano et al. 2009: 1472).

The first bathymetric surveys of Lake Albano, realised in 1917 and 1986 (Caputo et al. 1986) did not allow for a detailed morphologic survey of submerged slopes, but rather only for the recognition of main large-sized landforms (Figure 112). In contrast, the multibeam swath bathymetric survey of Lake Albano realised in 2005 (Anzidei et al. 2007) provided contour maps and shaded relief that show the roughness and complexity of the crater (Figure 113).

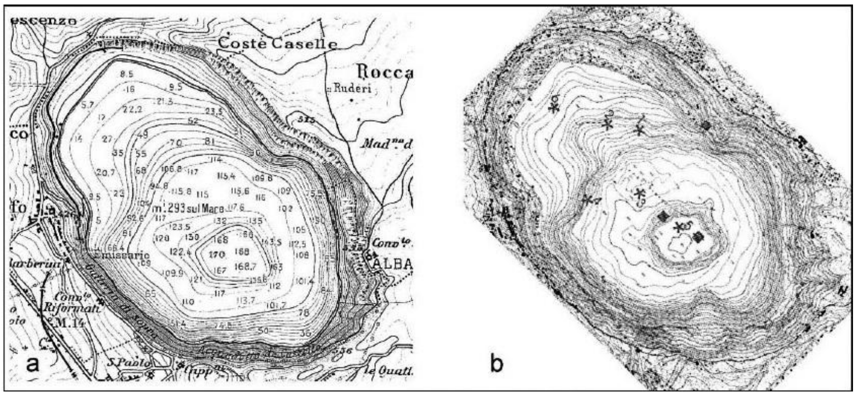


Figure 112 Bathymetric maps of Lake Albano : a)from Agostini (1917); b) from Caputo et al. (1986) (from Bozzano et al. 2009: 1471, figure 3).

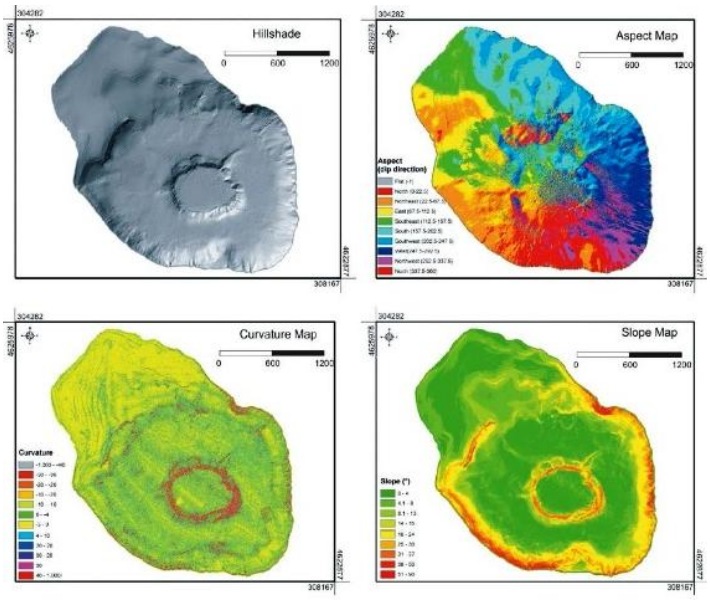
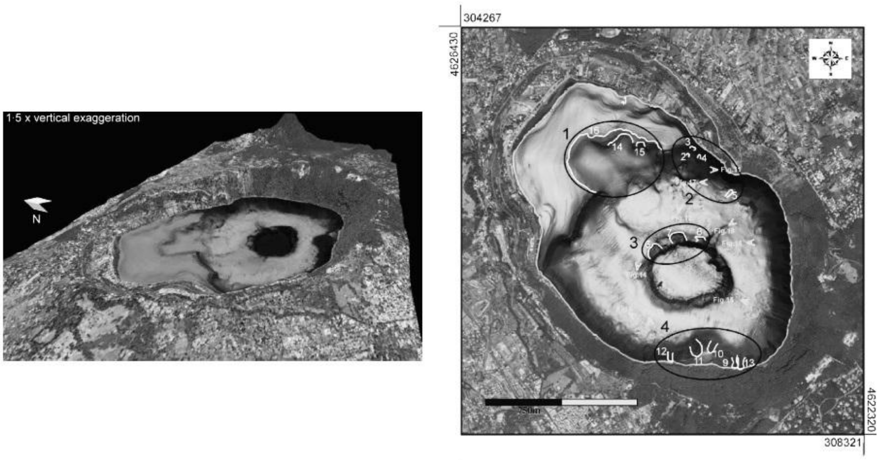


Figure 113 Hillshade and morphometric maps derived from high-resolution bathymetry (Bozzano et al. 2009: 1476, figure 8).

The lake's surface area lies at an altitude of 293 m a.s.l.; the crater rim rises generally to ca. 130 m above the lake in the west and reaches a maximum height of ca. 260 m in the south-east (Chondrogianni et al. 1996: 19). It is a hydrologically closed basin receiving water mainly from atmospheric precipitation and underwater springs. The combination of subaerial and submerged morphology permits a complete view of the Albano polygenetic maar (Figures 114A and B), whose shape is the result of the coalescence of different craters. The overall morphology is characterised by a low aspect ratio edifice distinguished by gently dipping outer slopes and steep inner slopes that correspond to the crater walls (Bozzano et al. 2009: 1473).



A)

B)

Figure 114 A) Three-dimensional perspective view of the volcanic depression partially filled by Lake Albano (from Bozzano et al. 2009, p. 1470, figure 2). B)Main subaqueous landslide scars (white outlines). The white numbers refer to the landslide ID of Table II; the black circles include the four areas described in the text. The viewpoints of the 3D perspective figures of the lake floor are indicated (from Bozzano et al. 2009: 1477, figure 9).

The European funded Palaeoenvironmental Analysis of Italian Crater Lake and Adriatic Sediments (PALICLAS) Project aimed at the reconstruction of the environmental evolution of central Italy within the last climatic cycle (i.e. the last 30,000 years). It consisted of physical, geochemical and biological studies of sediments from crater lakes and from the adjoining Adriatic Sea. Several piston cores were collected from the Albano Lake as part of this (PALB 94/1E, PALB 94/1C, PALB 94/3A, PALB 94/3B PALB 94/6A, PALB 94/6B) (Figures 115A and B). These samplings were collected at different water depths, in particular spatial locations and differ in length:

Core PALB 94/1C- PALB 94/1E (~1400 cm long, taken at a depth of 70 m)

Core PALB 94/6A- PALB 94/6B (~ 840 cm long, taken at 30 m depth)

Core PALB 94/3A- PALB 94/3B (~ 1100 cm collected at 120 m depth)

Cores in position 3 provide the widest chronological sequence, while those from 6 contain only late Pleistocene sediments. Finally, cores PALB 94/1C-1E cover both Holocene and Late Pleistocene lacustrine sediments (Chondrogianni et al. 1996a: 24).

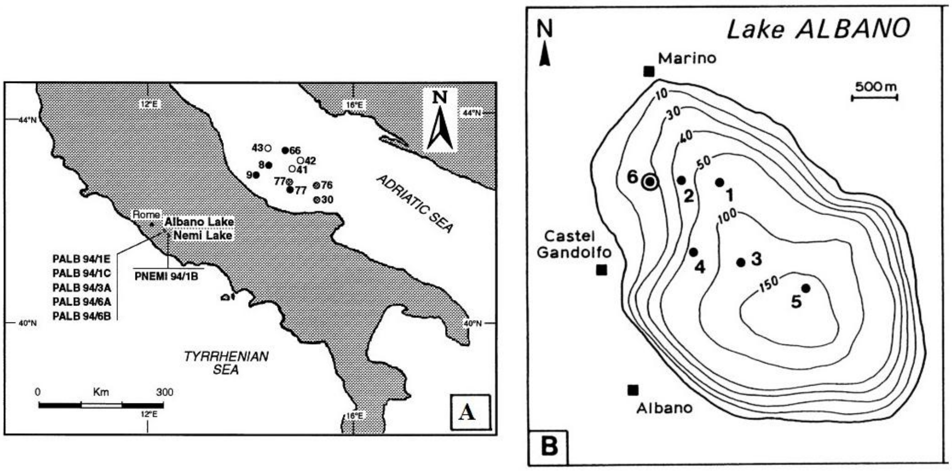


Figure 115 A) locations of the analysed cores from Albano and Nemi lakes and from central Adriatic Sea (from Calanchi et al. 1996: 249, figure 1). B)Study area with the location of PALICLAS cores (dots) (from Alvisi & Vigliotti 1996: 286, figure 1).

In particular, cores 1C and 1E showed alternation of silt layers, rich in organic matter (I) with a 2 cm thick grey tephra layer (t1) and in calcite (V-VI) with muds level (II-III-IV), interposed by a diatom layer (II). Unsorted sands and fine gravel with a coarse gravel base complete the stratigraphy (Chondrogianni et al. 1996a: 25-26) (Figure 116). The bottom of the core is composed of coarse volcanic fragments, related to a phase of Alban Hills volcanism, with fine-grained volcanic material derived from the weathering of catchment rocks occurring throughout the core (Chalanchi et al. 1996: 249-50).

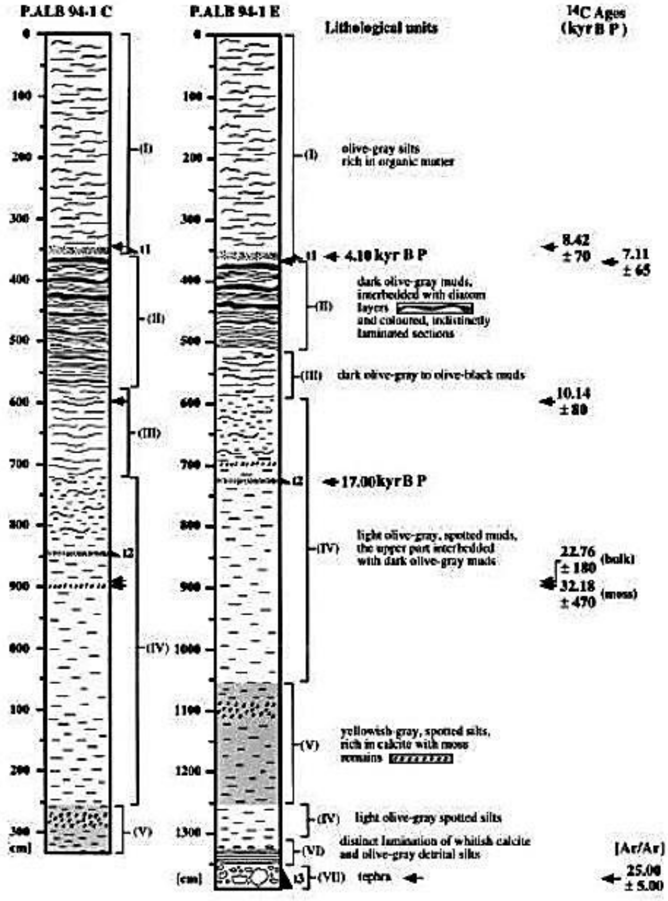


Figure 116 Lithological description of the cores P.ALB 94-1C and -1E from Lake Albano, including tephra chronology (t1, t2: calibrated ages; t3: (Ar/Ar) and radiocarbon dating (uncalibrated ages) (from Chondrogianni et al. 1996a: 25, figure 3).

In cores 3A and 3B, predominant mud layers are intercalated with diatom levels (IV), laminated intervals (V) and both of these (II, III). They end with a silt basal layer (Chondrogianni et al. 1996a: 26-29) (Figure 117). Below the lag deposit that represents the Holocene-Pleistocene boundary, the final cores (6A and 6B) showed layers predominantly composed of silt (I, II, III) intercalated with laminated muds (II), carbonates (III) and calcareous sands (IV). A detrital sand layer with a fine to medium gravel base completes the stratigraphy (a tephra layer) (Chondrogianni et al. 1996a: 30-31) (Figure 118).

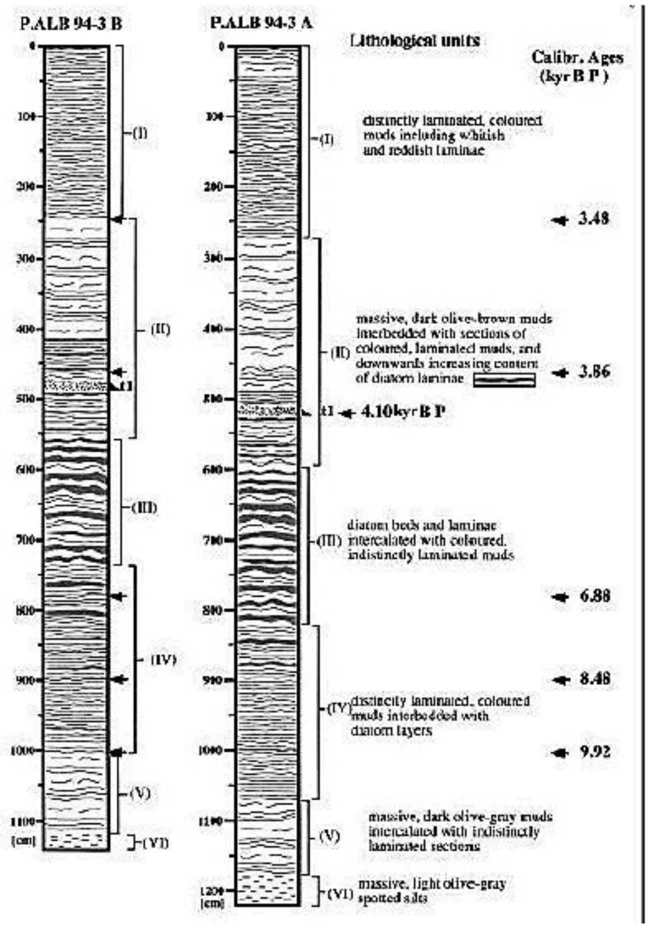


Figure 117 Lithological description of the cores P.ALB 94-3A and -3B from Lake Albano, including tephra chronology (t1) and radiocarbon dating (calibrated ages) (from Chondrogianni et al. 1996a: 28, figure 5).

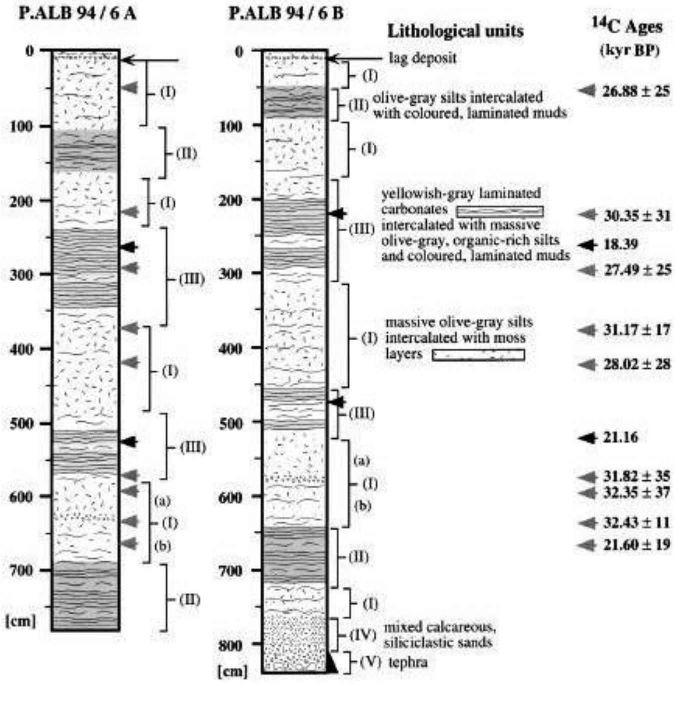


Figure 118 Lithological description of the cores P.ALB 94-6A and -6B from Lake Albano with associated ^{14}C chronology (black arrows: calibrated ages on pollen grains; gray arrows; uncalibrated ages on moss remains) (from Chondrogianni et al. 1996a: 31, figure 7).

Integrated information derived from the examined records enables us to draw a preliminary palaeoenvironmental reconstruction based on the master core PALB 94-1E, with reference both to cores PALB 94-6B and the Holocene core PALB 94-3A (Guilizzoni et al. 1996a; Ryves et al. 1996: 139-41) (Figure 119). Above the basal tephra layer (in the core PALB 94-1E, in particular between 1349-1322 cm), the lake is in its incipient stage, with biota colonising the new environment mainly using the aquatic vegetation as a substrate. Climate changes could have influenced the fluctuation of water levels, displaying lake productivity oscillations (1322-995 cm in core 1E). The section 995-717 cm of core 1E covers almost the entire accumulation at site 6: all proxy records reflect the more littoral and shallow location. The geochemical data and pigment suggest that during this period the lake experienced several large, rapid fluctuations in environmental conditions (Chondrogianni et al. 1996b). Between 717-507 cm of core 1E, assigned to the transition from late Glacial to Holocene, the productivity starts to increase probably coinciding with the onset of stable meromictic conditions.

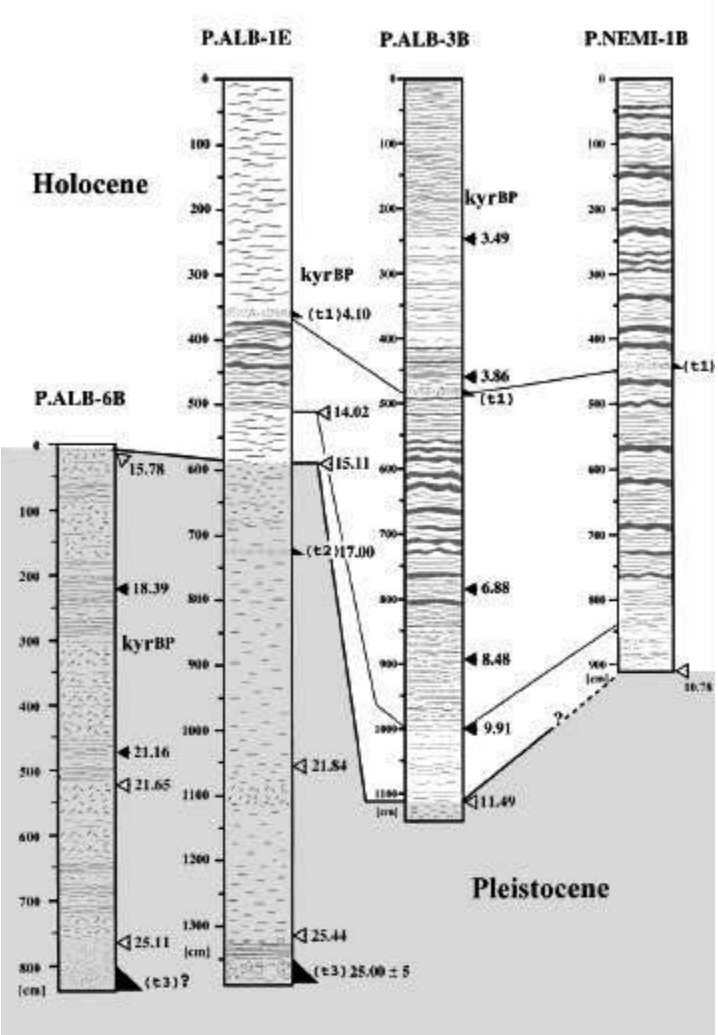


Figure 119 Correlation between the different sediment cores from Lake Albano and Lake Nemi including calibrated ages (solid arrowa: measured ages; open arrows: calculated ages). (from Chodrogianni et al. 1996a: 33, figure 9).

The core 3A covers the entire Holocene. The deeper water layer (between 507-377 cm) from the first portion of this core (from 507-350 cm) is of interest due to fluctuating maximum aquatic productivity which fluctuates and the maximum reducing condition in the deeper water layer (between 507-377 cm). Then an abrupt change is registered between 377-350 cm that covers a period of hiatus in sedimentation and must include a mixture of material of indeterminate age from this period. Four levels of recognised Albano palaeo-shorelines at -20, -34, -37 and -41 m (Figure 120) fall within this sedimentary hiatus that dates to 7.1 ka to 4.5 ka (4100 yr BP to ca 7500 yr BP) (Chondrogianni et al. 1996; Chalanchi et al. 1996: 260). Consequently, this should be the time interval when the lake surface was at those heights (Anzidei & Esposito 2009: 8). The portion of the core from 350-147 cm displays continuous sediment accumulation that suddenly begins during the early Bronze Age. A sharp decline in productivity, a sudden increase in erosion and the end of reductive diagenesis take place. These changes have been interpreted as associated with deforestation and other human-induced disturbance of the environment (Birks 1986; Roberts 1989; Ariztegui et al. 1996). During this stage the Villaggio delle Macine started to be settled and the lake level must have been slightly lower than present (Anzidei & Esposito 2009: 8).

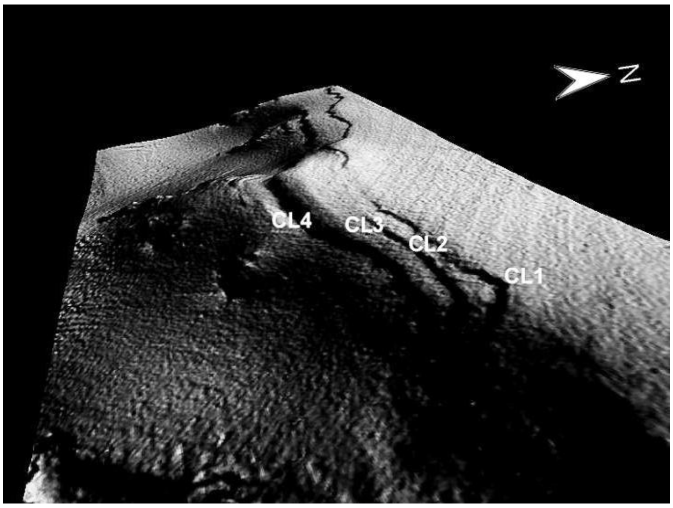


Figure 120 Multibeam images of the four past submerged coastlines (CL1 to CL4), inferred from notches located between -20 and -41 m below the present lake surface. They mark the lake level standings at lower elevations between 7.1 and 4.5 ka B.P., in agreement with independent observations described in Villa *et al.* (1999). Past coastlines are particularly evident along the northern side of the crater, which is covered by soft sediments which preserved their morphology (from Anzidei & Esposito 2009: 20, figure 3B).

These results supplemented the stratigraphic data provided by geoarchaeological analyses[12] carried out during 2001 in the area occupied by settlement's remains. These were performed in order to verify the site's horizontal spatial width and the vertical depth of the archaeological record. In particular, six mechanical continuous coring drills were carried out: they reached lengths ranging between 1.55 to 4.00 metres and were placed along two perpendicular transects. While the first is perpendicular to the lakeshore with a SE-NW orientation, the second ran parallel to the shore in a Nort-East-South-West orientation (Figure 121). A sandy deposit constituted the basis of the cores (SN and SGV). This 2.5 metre deep layer, rich in femic minerals originated from the erosion of pyroclastic lacustrine rocks, refers to a lower level period of the lake, or at least similar to the actual, prior to the first occupation of the site (Figure

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[12] These results partially joined the information provided by geoarchaeological analyses because they were collected at different sediment depths

122A). Silt layers rich in shell from dulcicolous molluscs (gastropods) covered this deposit (LG), which are probably attributable to a submerged lake bottom with a water level that exceeded one metre depth. Since the sandy deposit was recovered even in core S3 located on the inner part of the coastline, it is likely to evidence a phase of lake water decrease (several metres) due to climatic reasons (Figure 122B). The subsequent peat (TB, TBP) and clayish silts (LAS) are associated with the formation of marsh zones near the shore[13] (Figure 122C). During this phase the first occupation of the site took place.

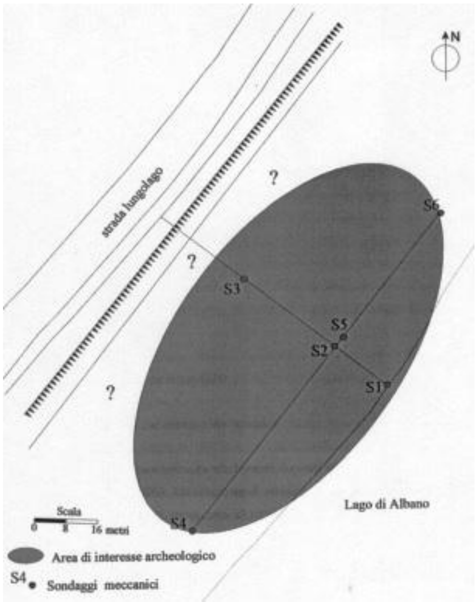

Figure 121 Spatial location of mechanical continuous coring drills: the first is perpendicular to the lakeshore, with a South-East-North-West orientation while the second moved toward a North-East-South-West, parallel to the shore (from the report of the "Lerici prospezioni archeologiche" society which carried out such work, figure 2, p. 4).

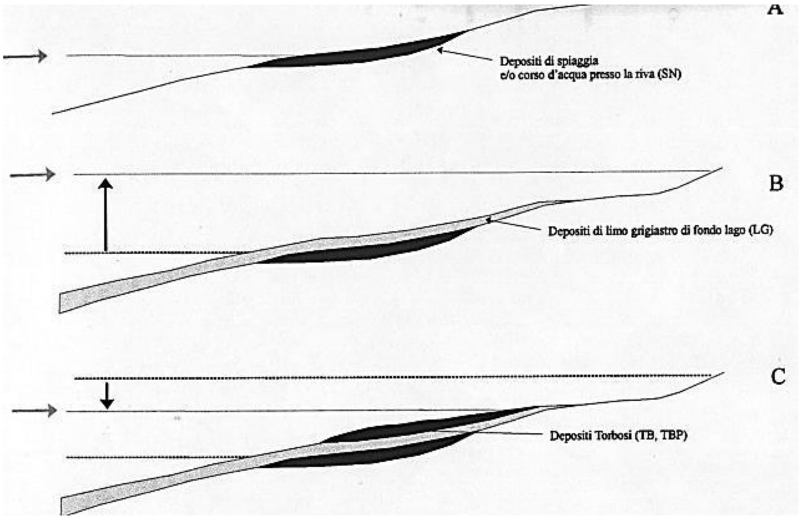

Figure 122 Different layers overlapping recovered during the mechanical continuous coring drills; A) beach or river deposits at the shore (SN); B) grey silt bottom lake deposits (LG); C)Peat deposits (from the report of the "Lerici prospezioni archeologiche" society which carried out such work, figures 5A-B-C, p. 5).

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[13] This last silt sediment was defined, during the excavation, as Stratigraphic Unit 50 (Angle et al. 2002; Angle et al. 2007).

5.3 The first anthropogenic intra-depositional phase: the biography of houses in the wetland context

The Villaggio delle Macine is located on one of three large platforms identified in the Albano volcanic depression. It is specifically placed on the north westernmost one which is characterised by a horseshoe shaped, flat-topped surface, dipping gently (< 5 m) southwards (Anzidei & Esposito 2009: 6; Bozzano et al. 2009: 1476). The crater morphology provides a natural richness of resources with the water, a sheltered microclimate, as well as the nature of the soils which are mainly composed of organic rich silts originating from the weathering of the outcropping volcanic sediments, thus offering favourable conditions for the settlement (Angle et al. 2011: 231-2).

Palaeobotanical and ethnobotanical analyses (Carra et al. 2007) clarify some aspects of the natural setting that surrounded the settlement. The volcanic slopes were covered by widespread broadleaf woodland (71%), predominantly oak, suitable to drained subsoils and a temperate climate (Angle 2008: 399). The brushwood vegetation is less attested and suggested that wet brush was rare. Neighbouring dry grasslands and the lacustrine environment - with a similar percentage of presence, ranging between 13-16% - complete the natural reconstruction.

Taking into consideration such an environmental context, it is not surprising that a massive reduction of forest coverage, most likely caused by humans, was identified in correspondence with the earliest occupation phases of the settlement. As highlighted in Chapter 3 (3.1) this phenomenon is commonly attested in lakeside settlements. At Lake Albano, the occurrence of this phenomenon is suggested by negative oscillations suffered by organic factors embedded in the sediment, which highlighted an oxidising environment with low aquatic productivity. Furthermore, an increase and predominance in non-tree pollen revealed the beginning of cultivation of edible fruit plants (Lowe et al. 1996; Rolph et al. 1996), as those attested at the site (*Rubus Fruticosus*, *Sambucus Ebulus*, *Nigra* and *Prunus Spinosa* (Carra et al. 2007). The increasing rate of sedimentation and the subsequent slope erosion testify to this deforestation event, supported further by a shift from a *Daphnia*-dominated to a *Bosmina*-dominated community among the Cladocerans (*Arthropoda*) (Guilizzoni et al. 1996: 63; Lowe et al. 1996: 64; Ryves et al. 1996: 140; Guilizzoni et al. 2002) (Figure 123).

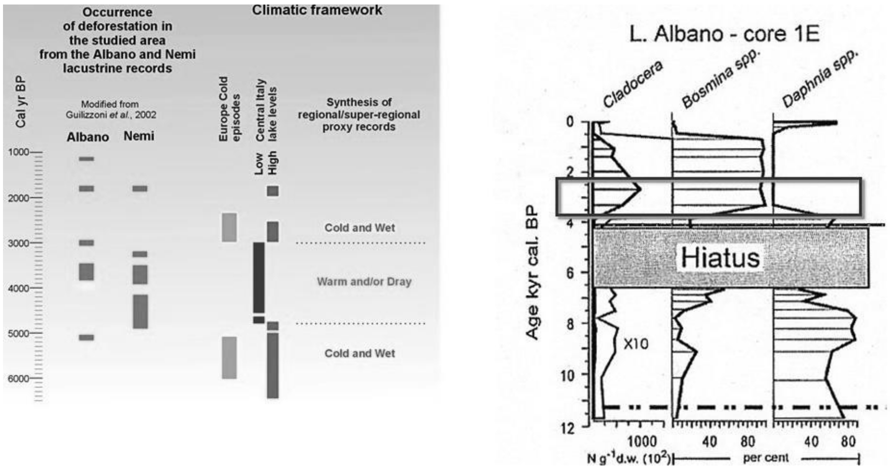

Figure 123 Graphics showed the occurrence of deforestation in the studied area from the Albano and Nemi lacustrine records; this deforestation even is proved even by the shift from a *Daphnia*-dominated to a *Bosmina*-dominated community among the *Cladocerans* (*Arthropoda*) (after Guilizzoni et al. 2002; from Angle et al. 2011, figures 9 and 10).

This resource-rich environment probably persuaded inhabitants to settle the site, thanks to the presence of the large fertile land surface and relatively huge forested area which was progressively overexploited. Traces of defensive structures are currently absent and the emergence of settlement due predominantly to the exploitation of lakeshore resources (for daily subsistence activities) does not seems believable, since fishing was only a limited and secondary activity. Regardless of the reasons that led inhabitants to occupy the site, it is important to focus on the process of house building involved in this choice.

Houses were constructed using piles driven into the lacustrine sediments, as confirmed by the geoarchaeological analysis that highlighted their occurrence in the underlying deposit. More specifically, piles were anchored in the basal sandy layer which provided the adequate supporting capacity (SN layer). During excavations carried out in the later years (2001 and 2003), sub-horizontally-oriented wooden structures of these houses were recovered along with the *in situ* piles[14] (Figure 124). These beams and boards were mostly disposed in two predominant almost orthogonal orientations, i.e. South-East/North-West and North/South (Figure 125). Furthermore, some boards were pierced, displaying sub-rectangular top slots. These probably had a supporting structural function and were required in some house construction techniques (for further details see Chapter 3). Elements considered to be house floors, walls and roofs are currently absent; however, they could be taken away, dumped or replaced by inhabitants. Furthermore, the decomposed vegetation richly preserved in sub-superficial layers might even be part of the structural elements nowadays unrecognisable. Once the surrounding natural setting was occupied and adapted to their own needs, the inhabitants arranged their houses in order to settle the site, taking full advantage of the available botanical and archaeozoological resources, as discussed in the next paragraph.

Figure 124 A portion of the excavation (square A22, Su 11) showing some of the piles still in the original position (from Angle et al. 2011: 232, figure 2).

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[14] These wooden structures are mostly attributable to the median and top layers whereas the deeper layers could be related to a less massive site's occupation since these sub-horizontal oriented structures are actually absent.

Figure 125 Example of beams and boards disposed according to the predominant orthogonal orientations, i.e. South-East/North West and North/South (courtesy of Micaela Angle, Soprintendenza per il Lazio e l'Etruria Meridionale).

5.3.1 The living floors of the site

The choice of where to locate a settlement is certainly influenced by specific features of landscape; in this case study, dwellers seem to have followed the lake water drop in order to exploit the available agriculturally productive land, extend the width of their settlement and increase its stability. The deepest layers, attributable to the site's earliest occupation, did not show evidence of wooden structural elements. These, conversely, characterised upper layers, as mentioned in the previous paragraph, and preserved the material evidence of both daily subsistence as well as specialised activities.

In the first category, i.e. domestic practices, fall general archaeozoological and botanical remains in the form of daily waste, probably discarded in the area of their processing and potential consumption. Sub-quadrangular or sub-circular *concotto* (baked clay) slabs, recovered during all the later excavations (a large one was even retrieved during the last excavation campaign of 2012 in the southern sector, cf. Angle et al. 2014) (Figure 126), in some cases placed on wooden or vegetal elements and densely surrounded by fragmentary faunal remains and seeds, seems to confirm this assumption. The cleaning of these cooking areas following their use involved the formation of a charcoal- and ash-rich layer in surrounding squares. These cooking features showed different internal composition and shape: the sub-quadrangular one was predominantly composed of concotto and clay, while the sub-circular ones consisted of two compacted mud slabs surrounded by stones. This variability might mirror different cooking practices, following some ethnographic examples. Furthermore, combustion areas consisting of sub-circular hardened/compacted mud plates, sub-horizontally oriented, with a clayey-sandy composition, and rich in charcoal inclusions were also identified. During the 2009 surveys, a concotto slab with the imprinted negative of a spike was recovered (Figure 127). This discovery would confirm that corn roasting was carried out in these combustion areas (as proposed in Angle 2007: 403). These probably interrelated cooking-burning areas seem to be spatially overlapping in different layers (as A11 and 18 respectively in Stratigraphic Units 6 and 11), suggesting a potential continuity of use for the same purposes throughout the site's occupation (Tagliacozzo et al. 2012: 146).

Figure 126 Examples of sub-quadrangular or sub-circular *concotto* slabs (courtesy of Micaela Angle, Soprintendenza per il Lazio e l'Etruria Meridionale).

Figure 127 A concotto slab with the imprinted negative of a spike and seeds recovered during surveys of 2009.

It is also interesting to note that on the margin of this structure, medium and large storage and cooking pots were recovered, some of the latter bearing traces of fire exposure (Angle 2008: 403). The same storage purpose could be supported by a set of three *dolia* oriented according to the piles' North-South and West-East orientation and located in the northern sector of the area excavated during the last campaign (2012). In addition, the remarkable presence of fruits, beans and cereals seemingly confirms this storage role of the area (Angle et al. 2014). The presence of a large number of millstones and grindstones suggested the occurrence of crop milling practices and probably even their use in leather and fibre processing activities. Furthermore, a small number of vegetal fiber processing tools were recovered, such as a sub-circular drying kiln.

Material evidence of several other subsistence activities performed during intra-depositional phases were also recovered in the archaeological record.

The preservation allowed by the silty deposits enables us to build a realistic reconstruction of plant growing, harvesting and gathering. A potential strategy of diversification, based on varieties characterised by dissimilar productivity (*Triticum spelta, T. dicoccum, T. monococcum, T. aestivum/durum, Panicum miliaceum, Setaria italica*) and probably cultivated together with other types of corn that require more moisture (e.g. *Hordeum vulgare*) denoted crop growing. This joint approach could limit the risk of losing the whole harvest (Carra et al. 2007; Angle 2008: 401; Angle et al. 2011: 233). The horticulture practice is suggested by plants with spring and summer harvesting periods (*Vicia faba, Linum usitatissimum, Papaver somniferum*). Furthermore, the occurrence of annual infesting plants may indicate cultivation methods with weeding repeated throughout the season. This scenario is completed by the gathering of wild (*Cornus, Corilus, Rubus, Quercus*) and semi-domestic (*Ficus, Malus, Vitis*) fruits. The site's inhabitants displayed a widespread knowledge of all available fruits and their continuous exploitation for immediate use as well as for processing and storing (Angle et al. 2011: 233).

Archaeozoological analysis (Angelini et al. 2006; Angle et al. 2011; Tagliacozzo et al. 2012[15]) revealed the presence of several species, both wild and bred. These activities have probably been favoured by the presence of large fertile land surfaces and the relatively wide deforested available area. The variety and the number of recognised non-domestic species highlighted the importance of hunting to this community (*Cervus elaphus, Capreolus capreolus, Sus scrofa, Vulpes vulpes, Meles meles, Lepus europaeus, Felis silvestris*). The deer are absolutely dominant and their hunting is the most widespread: subadult individuals are prevalent (64,5% age younger than 3 years)[16] and were most likely hunted between the end of the summer and the beginning of the autumn. Boar and roe deer remains of young and young-adult individuals (boar: 1 young individual and 2 young-adult individuals; roe deer: 5 individuals of 7-8 months, 1 individual of 14-15 months) and adults (boar: 3 adults; roe deer: 3 adults) suggest hunting practices based on systematic capture, in contrast with a more occasional approach for carnivores (except foxes). The rare presence of *Emys orbicularis* does not allow to assume a regular collection for this prey.

Among the domestic animals, ovicaprines and swine are the most widespread. Their kill patterns seem to suggest their use for meat production: in ovicaprines, 42% of individuals pertain to subadults (3 individuals have less than 6 months); in swine: 62.5% of individuals have less than 4 years. Even the less frequent cow remains featuring 3 young adults (1 was less than 2 years old, 1 between 18-36 months and 1 adult of undetermined age) were probably used for the same purpose, in addition to their exploitation for working power. Finally, an important presence of dogs (4 individuals) is also attested.

Butchery traces were clearly visible on the trunk, ribs, leg, and skull bones of several mammals. Vertebrae and breastbones were split lengthwise and some transverse/diagonal streaks were attested on epiphyses. In summary, the representation of skeletal elements, kill-off patterns, and butchery traces would suggest specialised activities devoted to carcass processing and support the hypothesis that entire prey carcasses were brought into the settlement (Figure 128).

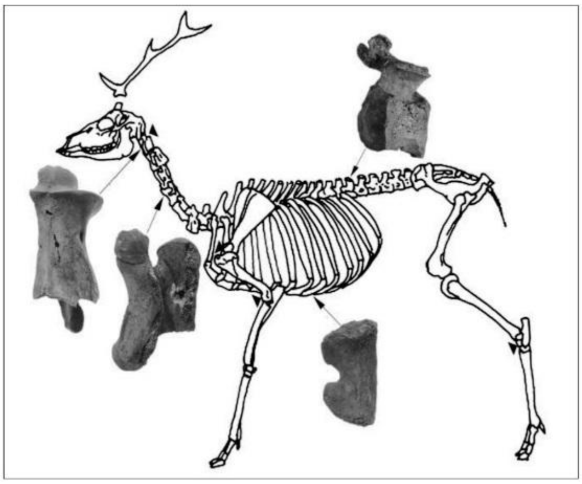

Figure 128 Distribution of the butchering marks on the deer's bones from the site (from Tagliacozzo et al. 2002: 150, figure 4).

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[15] These analyses were carried out by Antonio Tagliacozzo and Beatrix Pino Uría, Soprintendenza al Museo Nazionale Preistorico Etnografico "L. Pigorini", Roma, Sezione di Paleontologia del Quaternario e Archeozoologia.

[16] These data are derived from a study carried out by Tagliacozzo and Pino Uría on a sample of 761 remains recollected in the SsUu 6, 9 and 2; Tagliacozzo et al. 2012; quoted also in Angle et al. 2011.

The almost total absence of antlers may be ascribed to preferential choices in the hunting strategy, based on the predominant capture of young and adult female individuals that compose the unisexual herds among deer. Antlers of the captured deer may also have been removed directly at the hunting site with exchange purposes or introduced only in specialised site areas where this raw material would be worked (Tagliacozzo et al. 2012). However, these areas are currently not identified. Bone and antler manufacturing activities are inferable by some finds, e.g. an arrow-head with a squared cross section manufactured from the apex of a deer antler that shows similarities with some tools recovered from the Terramare of the Emilia and Veneto regions (Provenzano 1997; Zuolo & Hohenstein 2010; Angle et al. 2011; Tagliacozzo et al. 2012).

The working of a lithic industry can be also listed among the specialised activities performed at the site, suggested by findings ascribable to all stages of the lithic *chaîne opératoire* (lithic cores, flakes and debitage). It is to be mentioned that the majority of such evidence has been recovered in the 2009 and 2012 survey. Several metal tools, such as Middle Bronze Age 1-2 daggers and axes, were also abundantly retrieved during both surveys and excavations. Because of the meaningful similarities showed by shapes of objects and an apparent ability to control the composition of the alloy, a certain degree of specialised production of metal is hypothesised (Angle & Guidi 2007; Angle et al. 2011: 231).

These functional/productive activities and daily sustenance practices left behind material evidence in the archaeological record, where they are entered throughout discard processes. These accumulated observables enable us to reconstruct the more likely scenario of the past at the site. In addition to the aforementioned practices, attributed to inhabitants themselves choosing to enact them, some renovations or reconstructions of building structures were also required because of environmental as well as cultural processes, for example due to fire events.

5.3.2 Fire events and lake-level fluctuations as intra-depositional episodes

During site occupation, conflagration events may take place and evidence of these can emerge in the archaeological record. In this case study, for instance, two layers (10 and 11) displayed traces of such events characterized by few burnt, sub-horizontally-oriented wooden structures. Their orientation (relative to the previously defined main axis) and spatial location seem to suggest that they were parts of houses. In layer10, such structures are associated with both objects of daily practice as well as valuables such as an amber bead, a dagger and an obsidian flake**.** Traces of combustion, such as charcoals and concotto, were widespread in the layer and marked even the layer's matrix itself. Layer 11 consisted of a wide burnt area with concotto, small holes, a few areas rich in seeds and a dagger. The available data did not enable reconstructing the cause of the fires, either as the result of anthropogenic activity or natural process, nor their potential spread in spatial terms. Supplementary micromorphological studies could provide essential information to correctly interpret such events.

Among intra-depositional natural events, water-level variations should also be listed. Evidence of these episodes were attested and documented through a multidisciplinary approach. Both geoarchaeological analyses and the stratigraphic sequence displayed these fluctuations, further highlighted by the presence of peat deposits. Notably, this decrease of water-level during the intra-depositional phase favoured the choice of expanding the settlement.

It has been suggested that these fluctuations are associated with the phenomenon of “limnic eruption”, linked to the emission of CO_2 from the lake bottom (Funiciello et al. 2002). In this instance, after reaching a critical limit, there may be a sudden degassing with a simultaneous expansion of the lake water’s volume which would potentially increase height by several metres and flood the surrounding areas. The presence of a wide lahar layer (in this case consisting of redeposited alluvial loams) which expanded the plain toward the actual area of Rome would evidence this event. However, other scholars have excluded the possibility of such a sudden event during the Holocene, since Argon-Argon dating attributed these deposits to a considerably older time span around 36,000 years ago (Giaccio et al. 2009). The most recent layers could be the result of the continuing process of erosion which affects the northern slopes (Angle 2008: 397-8; Giaccio et al. 2009; Anzidei & Esposito 2009; Bozzano et al. 2009).

5.4. The last phase of site occupation and its abandonment: introduction

The inland sectors of the site (near the current road) were investigated during 2001 and 2003. Overall good preservation of the stratigraphy enabled identification of traces of the last stage of the site’s life and its abandonment. This last phase was covered by layers 2 and 1, along with layer 0, which included stones identified on the surface (Angle et al. 2002, 2011; Tagliacozzo et al. 2012: 146). These stones were initially functionally interpreted as an attempt at stabilisation of the unsound soil, in order to prolong site occupation. As such, the high occurrence of stones on the surface could be associated with the site’s last occupation and abandonment. However, these assumptions cannot be confirmed due to the current lack of test pits and micromorphological analyses. The two former layers seem to have been frequented when the sediment was not completely underwater but, rather, only under semi-wet conditions. The suspected associated decreased lake level was evidenced by the presence of silty-peat deposits. Hence, traces of erosive episodes and silty deposits are absent between layer 0 and the higher layers (layers 1 and 2)[17]. Focusing on the site abandonment, the analysis of material evidence retrieved on the site’s surface and left behind by inhabitants during this process could still suggest the most likely reasons and modalities of the abandonment.

5.4.1 The mode and cause of abandonment: some hypothetical reconstructions

As described more extensively in Chapter 2, scholars have suggested that when many portable, valuable or usable objects and a great number of elements in manufacture, use and maintenance processes are left behind at a site, a rapid and unplanned abandonment may be inferred. In contrast, the assemblage highly depleted by curation behaviour and the presence of mostly large and broken objects is ascribed to a slow and planned abandonment.

In this case study, the assemblage consisted of two predominant categories of artefacts and ecofacts: heavy, difficult to transport objects and garbage. Among the former category falls “functionally useless” stones, millstones and, especially, grindstones. This might be due to the bigger dimension of millstones and the ease of supplying the raw material of stone, available at the site and in its surroundings (Chiarucci 1985, 1986-88, 1995-6). In the category of garbage

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[17] These archaeological data were gathered during the first excavation campaign (2001) and were only partially confirmed by the second (2003) due to the compression of stratigraphy.

falls accumulated refuse discarded during the abandonment process. This covers refuse generated by daily-life activities and specialised practices performed during the last site occupation.

The evidenced specialised practices include, for instance, all stages of lithic *chaîne opératoire* (lithic cores, flakes and debitage), mainly retrieved in sectors surveyed during 2009 and 2012. The lithics are predominantly ascribed to the category of debitage, followed by flakes. Some clay net weights, recovered in areas surveyed in 2001, 2003 and 2009, refer to fishing. Furthermore, the retrieval of some examples of spindle whorls confirmed the occurrence of productive activities such as weaving. Daily-life activities are testified by the occurrence of fragmented refuse related to food treatment, cooking and consumption (for instance, bone fragments, some with traces of butchery, and negatives of seeds and spikes on concotto), and of tools involved in these activities (such as concotto slabs). Perishable vegetal materials are mostly damaged: an extraordinary exception is represented by a wooden dry kiln structure.

Precious objects are mostly absent, although some stone axes and a few metallic items were recovered in surface layers during excavations carried out in 2001 and 2003. Pile heads are preserved in place probably due to the difficulty of transporting them. The combination of these archaeological data seems to suggest a planned and slow abandonment of the site: inhabitants probably decided to take usable objects, required supplies and portable items with them. In the upper layers[18], wooden structures related to houses are quite rare in both surveyed and excavated sectors. Additionally, little evidence attesting structures with other purposes was found. Therefore, it is also possible that inhabitants of the settlement brought portions of their houses elsewhere for successive uses.

5.5. Post-depositional processes in the lakeside settlement of the Villaggio delle Macine

After the abandonment, the site appears to have been sporadically occupied, as suggested by some Roman building materials retrieved among the surface. Their spatial distribution does not seem to fit a particular pattern, since they are quite homogeneously distributed.

Although causes and modalities of abandonment can only remain hypothetical assumptions, post-depositional processes which modified the archaeological record retrieved at the site are clearer. In addition to the lake water level variation that enabled the site's extension during its occupation in prehistoric times, inferred through geological studies, Classical written sources mention later fluctuations of Lake Albano. Despite the occurrence of such lake-level changes during the past, it is possible that the site remained in an almost completely subaquatic condition from at least the Roman period until its discovery in recent times[19]. This circumstance favoured the preservation of perishable material evidence, in particular in inner layers.

Nonetheless, when the conditions started to change due to climatic factors and uncontrolled water-takings causing the site’s emersion, strong erosive processes took place. Only few wooden structural elements and vegetal findings were consequently retrieved from the surface during surveys and the stratigraphic sequence of the deposit showed traces of compression.

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[18] Mostly in SsUu 0 and 1 because few wooden structures were retrieved in SU 2 during 2001

[19] Recently the lake level is increasing due to the end of uncontrolled water-takings

Finally, in a few sectors, human activities have influenced the preservation of the archaeological record with modern exploitation of available areas. For instance, the creation of small tourist beaches in the surrounding area or the use of land to build restaurants facing the street.

5.5.1 Natural post-depositional processes

Among natural post-depositional processes, the lake level fluctuations may have been the strongest ones in play and may have perturbed the archaeological record in different ways. On the site scale, the resulting erosive processes and the compression of the archaeological layers are the factors that most affected the surface of the Villaggio delle Macine. Furthermore, the transgression involved wave action and water currents that might have even rearranged the artefacts' spatial distribution. The site's emersion enabled the formation of fertile layers where the growth of natural vegetation was favoured; their roots and the presence of reeds disturbed the original archaeological record from a site-wide perspective (internal features of the archaeological deposit and its spatial dislocation) as well as on the artefact scale (rearrangement of evidence and compositional modifications).

5.5.1.1 Natural post-depositional processes: the artefact scale

The material evidence presenting on the surface of the archaeological deposit had suffered the combined effects of multiple natural disturbance processes. Finds are predominantly of short dimension and show a high fragmentation status: this condition might depend on their original nature since they consist mostly of the discarded material results of productive activities and daily practices carried out during the site's last occupation and abandonment, i.e. garbage. In particular, organic materials (such as wooden structures, beams and vegetal elements including tools as well as seeds) suffered from direct and continued contact with water and even more their further passage to a dry status which caused this strong fragmentation. On the surface, these observables are almost totally absent since they are more subject to invasive processes and degradation.

Furthermore, marks of this passage from an aquatic environment to an aereal one are displayed on most of the archaeological evidence, showing the material effects of chemical and physical degrading processes such as the drop of their internal volume and loss of material consistency, with subsequent deformation. These taphonomic processes even undermined and damaged observables' surfaces. Pottery is affected by polishing, for instance, which removed the most superficial layers, with natural inclusions (e.g. mica) becoming visible on the surface of finds. Both this damage and their high fragmentation prevented attributing most fragments to their original vessel form. Lithic remains are predominantly characterised by cryoturbation and bioturbation, and showed surface patinas probably caused by water submersion conditions. Bones displayed different stages of fissures and exfoliations on external surfaces, up to their complete fragmentation (Cerilli et al. 2000). These alterations have probably compromised, at least partially, the identifiability of other anthropogenic (e.g. butchery striae and marks) and natural modifications (e.g. gnawing or chemical erosions) (Tagliacozzo et al. 2012: 146).

The flooding process that took place at the site and subsequent wave actions may have also caused a re-arrangement of the material evidence: if it was distributed according to a homogeneous-uniform spatial model, disturbance processes have probably produced this after the site's abandonment.

5.5.1.2 Natural post-depositional processes on a semi-micro scale

As previously mentioned (see Chapter 1), flooding processes took place at the site. We cannot know when exactly nor are we able to understand if the process was slow or sudden. Some Classical written sources (Dionysius of Halicarnassus (I, 71, 3), Titus Livius (V, 13,15,16), Valerius Maximus (I, 6,3) and Cicero (*De divinitate* 44, 100)) reported that an odd rise of the water level occurred in 398 BC. Although their unreliable reconstruction explained this water level change as the product of *prodigia,* Valerius Maximus provided important information about the substantial stability of water levels (through the words "*solitum stagni modum"*). Moreover, during this time span (398-400 BC), the construction of an artificial outlet is thought to have been carried out (D'Ambrosio et al. 2009: 128). This structure is located around 290-300 metres above sea level: comparable levels are reached by the remains of a Roman harbour made of tuff blocks in the northern side of the lake (Figure 129). The presence of this outflowing stream structure would have ensured the stability of water levels up to the recent lake water drop. The drop probably occurred over recent years due to uncontrolled water-takings as private and industrial wells (Capelli & Mazza 2005).

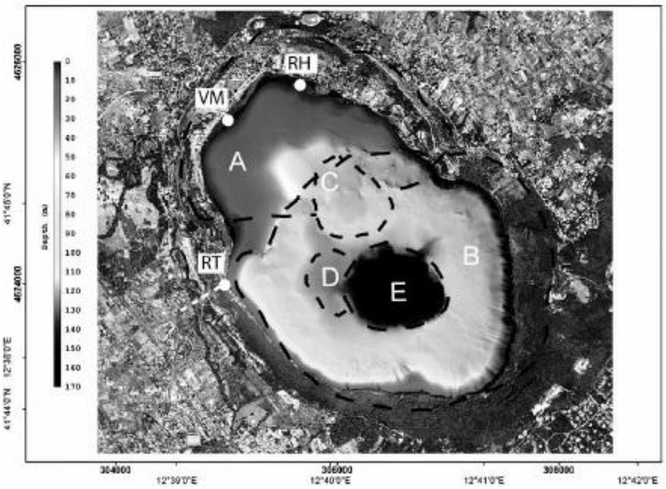

Figure 129 Bathymetric map from multibeam data merged with topographic data of the aerial Lidar survey (Baiocchi *et al.* 2006; Baiocchi *et al.* 2007). A,B,C,D,E are the position of the main craters inferred from sub aerial and submerged surface morphology (sub aerial topography from aerial photo). RT=Roman Tunnel drain; RH=Roman Harbour; VM=Villaggio delle Macine of the Bronze Age (from Anzidei & Esposito 2009: 19, figure 2B).

However, other causes can be also hypothesised such as shallow seismicity (Bianchi et al. 2008; Chiarabba et al. 2010) or ground uplift (Amato & Chiarabba 1995; Riguzzi et al. 2009). Recent seismicity and seismic swarms aligned along a NW-SE striking structure that crosses the centre of Lake Albano and the other craters of the Colli Albano volcano occurred during 1987-1990 (Amato et al. 1994; Bianchi et al. 2008). This was followed by significant lake drawdown in 1990. It was suggested that an increased permeability of the lake basin was produced by these endogenous processes and led to the increasing emersion of the site.

While the lake level was relatively stable during the period between 1940 and 1960, measurements indicate that there has been a continuous lowering of the lake level since 1970, also shown by observational data (Figure 130), with a progressive acceleration during the last 15 years (Capelli et al. 2000; Capelli & Mazza 2005; Mazza & Capelli 2010; Riguzzi et al. 2008). Hence, between 1960 and 2005, a lake level drawdown occurred at a mean annual rate of 8.8 cm and particularly between 1990-1997 at 20 cm per year (Anzidei & Esposito 2009: 9)

(Figure 131). This lake level drop caused the increasing emersion of the site: in 2001, the portion of the site adjacent to the modern road emerged, followed by the progressive emersion of the area up to the present lakeshore.

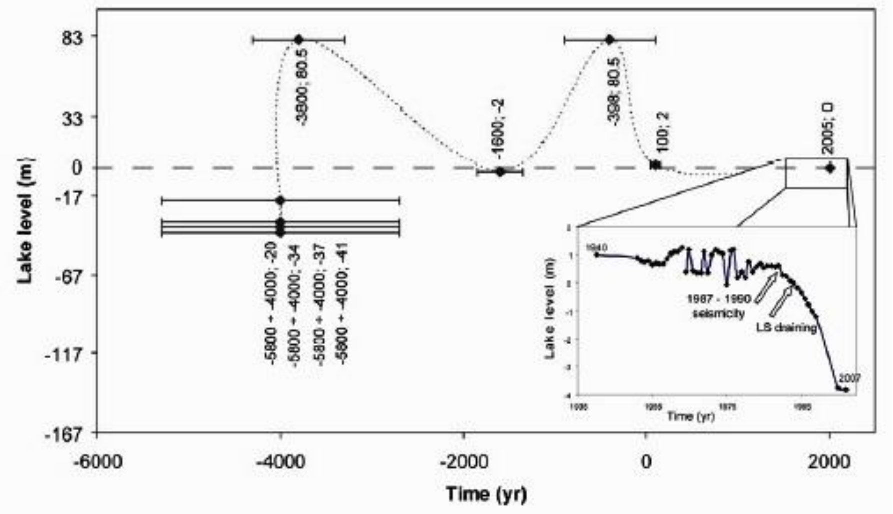

Figure 130 Lake level changes curve based on geological, historical and instrumental data (Capelli & Mazza 2005). Lake level data are collected since 1940 by the limnographic station (LS) located at the entrance of the Roman tunnel drain (RT in Figure 21). The LS dried at the end of 1990 due to the rapid decreasing of the lake level, after a period (1987-1990) of increasing seismicity. The maximum estimated amplitude of the lake level changes is more than 100 m, since historical times. The horizontal dotted line at zero elevation, is the reference lake level at 2005 (MB survey) (from Anzidei & Esposito 2009: 23, figure 6).

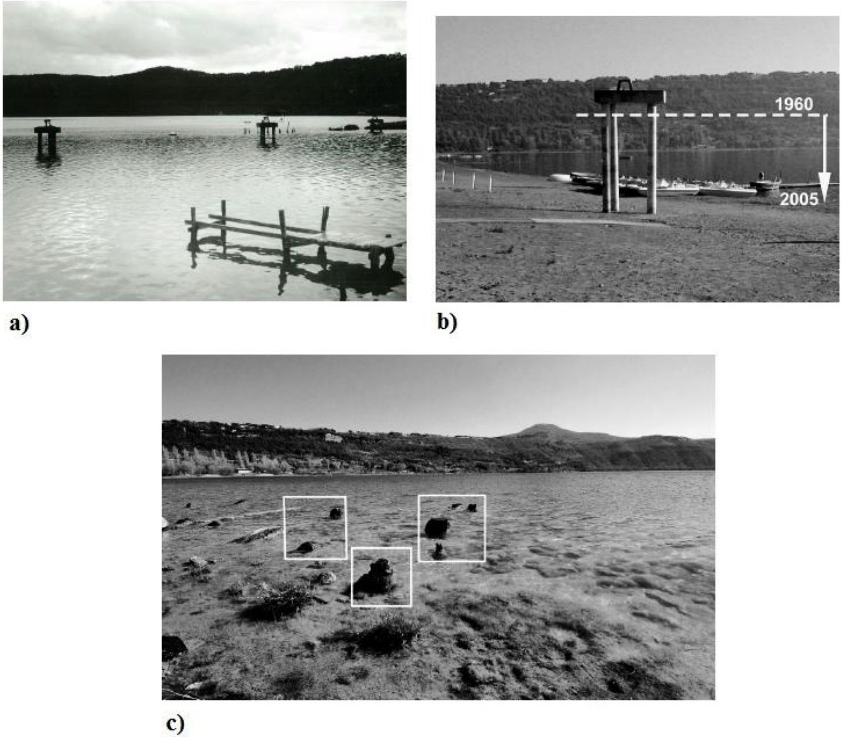

Figure 131 Evidences of the lake level changes a) The concrete tripod installations built in the water for the rowing competitions during the Rome 1960 Olympic Games (photo courtesy of Enrico Tonali); b) the same structures are nowadays completely dried and show about 3.60m lake level decrease and about 60-80 m of shore retreat; c) the remnants of the pile-dwellings (evidenced by white rectangles) of the Bronze Age Villaggio delle Macine (from Anzidei & Esposito 2009, p. 23-24, figures 7).

In 2001, the exposed surface had consisted of a succession of wet layers each several centimetres deep[20]. The deepest layer, layer 2, was 20-25 cm deep, rich in remains of decomposed algae, lacustrine flora, leaves and roots, and contained a few wooden elements preserved in the surface. The high humidity enabled the preservation of these perishable findings. However, the loss of water derived from the emersion caused layer dehydration that in 2003 led to completely dried contexts. From this point, the archaeological deposit appears to be characterised by an internal inhomogeneity, rich in fractures.

The sectors near the lakeshore surveyed in 2009 were predominantly occupied by low, spontaneous vegetation and a few bushes mainly concentrated in direct contact with the lake. In contrast, coverage such as that made by reeds was widespread in the areas surveyed in 2012. The presence of fertile lacustrine silts enabled their growth and therefore the presence of roots and plants disturbed the original deposit and altered the original stratigraphic composition of layers, producing fractures and voids. For instance, a sample of wet lauer 2 dried out in situ was mainly composed of a concentration of long, strong roots that had invaded the entire area despite the presence of stones on the top layer (floralturbation).

The mechanism of the layers' dehydration that first took place in 2001 activated the onset of erosive phenomena. During 2003, their strength caused a significant loss of 20-25 centimetres of thickness, attested in the stratigraphy of the surface layers and a consequent compression of the sediment. Indeed, the clear difference between the early SsUu 1 and 2 in 2001, appeared attenuated in 2003. Finally, during the last campaigns of 2009 and 2012 the archaeological context, near the lakeshore, was characterised by a unitary, compressed, few-centimetre-deep layer.

Consequently, the material evidence ascribable to the latest site occupation are superimposed and definitively joint with the traces of abandonment processes. This “short” vertical comingling of material evidence could also have occurred during the abandonment itself: trampling processes provided by animals and livestock as well as by inhabitants that were leaving the site could have taken place. The same phenomenon could have partially occurred in the early stages of the site’s discovery.

5.6 Cultural post-depositional processes: artefact and site scale

Among the most common cultural post-depositional processes of wetlands and lakeside settlements, can be listed land reclamation. This process is triggered by the presence of exploitable empty, fertile land emerging with the drop of the lake water level, as in this case study. The need for new land to build on, or for agricultural purposes as well as industrial aims drive this reclamation. The geoarchaeological analysis showed that in the innermost portion of the deposit (towards the road, sector S3), surface material evidence had been recently removed after the refurbishment of the area. The same phenomenon took place progressively with the lake water drop in the most peripheral sectors of the lake where some beach properties had been built during the past and are currently partially unused.

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[20] In this paragraph, only the surficial layers (from 0 to 2) are considered, while for a detailed stratigraphic sequence refer to the previous paragraphs.

Further cultural post-depositional processes would have been performed at the site, for example, reclamation. Since wooden structural elements, such as beams, are predominantly absent on the surface, it is possible to hypothesise that being made of rather common material (Chapter 3), these useful remains could be left behind by inhabitants during the site abandonment or very quickly afterwards.

5.7 Discussion

An approach based on the “unity in diversity” between natural and cultural processes, considered as the most useful for lakeside settlements (Chapter 3), is applied in this case study. Hence, in reconstructing formation and deformation processes that produced this archaeological record, a multidisciplinary perspective enables obtaining the results mentioned throughout this chapter. This overview of the site’s biography has to be concluded by also taking into account a regional perspective in order to better contextualise the settlement and its complexity, in the framework of its spatial and temporal location.

5.8 Space and time at the site

The pile-dwelling of the Villaggio delle Macine is set in a wide chronological time span, which embraced three centuries (XIX-XVI BC) and is located in the complex of the Alban Hills, near Rome, in Central Italy. Such a long-term continuity of occupation during this time span in this area is quite uncommon, which highlights one of peculiarities of the settlement. The remarkable availability of different resources probably enabled this unusual longevity: the considerable extent of arable land exposed by the lake water reduction, original woodland resources and the richness of flora and fauna acted as strong attractive factors especially relevant for dietary and energetic purposes. An articulated subsistence economy, based on summer-winter agricultural practices (cereals and leguminous plants), harvest activities (semi-domestic and wild fruits), hunting, breeding and fishing[21] favoured the stabilisation of the settlement (Angle 2008: 408). Common horticulture and woodland farming (for wine and chestnuts) are still common in the area (Angle & Guidi 2007: 155).

Besides the aforementioned predominance of deer hunting, domestic goats and pig farming is also attested mainly for meat consumption, as confirmed by the kill-off pattern. However, the presence of older individuals suggests alternative uses for cattle (e.g. for the production of secondary products and as labour force in agricultural activities). Pig breeding seems to have been emphasised during the early phases of occupation, whereas the cattle and ovicaprids increased in more recent stages. This condition probably mirrored changes in environmental setting from a predominantly wet and damp habitat preferred by pigs, to a drier and open environment more suitable to ovicaprids, as confirmed by environmental reconstructions (Lami et al. 1996; Angle & Guidi 2007: 161). The fishing activities, although less relevant, are attested in two modalities, confirmed by the occurrence of different weights and small lithic points interpretable as harpoons (Angelini et al. 2006).

Among the specialised practices, which testify to the peculiarity of the site, metallurgy can be listed and some authors (Palmieri, personal communication before his premature death, and Bietti Sestieri, pers. comm., about some axes retrieved at Lake Nemi) tend to consider this as an *in loco* production activity. A significant difference in components is attested in relation to production documented in Central and Northern Italy: at the Villaggio delle Macine, tin

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[21] These activities are listed according to their relevance in the site.

components are poor and the lead is absent, similar to the Nemi axes. These recurring features could mark local production of artefacts. Finally, the minor element content, characteristic of different typologies, possibly indicates either a different origin of the metal used or the production in a single workshop yet with non-standardised fusion techniques, specialized according to different functions. Although the lack of homogeneity is high, comparisons were carried out with some sets of artefacts found at Terramare and at Mezzano (Garagnani et al. 1997). These metallic artefacts showed differences in components compared to those from the Villaggio delle Macine, for instance, a higher occurrence of lead is attested in objects from Mezzano (Angle & Guidi 2007: 161).

The list of unusual observables retrieved from the site ends with amber and faience. The peculiarity in the first case lies in the scanty distribution of amber along the Italian territory during the first phases of the Middle Bronze Age. According to literature, this type of amber, part of the succinite group, has been attested in only 3 coeval archaeological sites (i.e. Olmo di Nogara, Fiavè and Grotta Manaccora) (Angelini et al. 2006; Angle et al. in press). In the case of faience objects, attested across the entire Italian peninsula during this period, some conical buttons and beads found during the excavation campaigns at the site are comparable to finds from the Mercurago site (Bellintani et al. 2001; Bellintani et al. 2005; Bellintani et al. 2005a; Bellintani et al. 2006; Angle et al. in press).

This set of archaeological data and observables confirmed a notable circulation of goods, resources and models from regions on the north of Alps and northern Italy. This direct or indirect relationship, operating from the Early Bronze Age, is highlighted by the presence of objects with a clear foreign origin (such as succinite beads of Baltic origin) or based on models circulated from abroad (as with the axes of Avigliana type from northern Italy and the Alps) (Carancini & Peroni 1999; Angle & Guidi 2007: 168). Furthermore, contacts with southern Italy are suggested by the occurrence of a few glass pearls also attested in the Aegean area, the succinite amber retrieved from Grotta Manaccora, and Protoapennic ceramic productions strictly related to southern Italy (Angle & Guidi 2007; Angle & Mancini 2007). The variety and variability of productive activities performed in combination at the settlement and the wide access to economic resources provides evidence of the achieved level of social complexity and internal articulation.

The data collected enables us to reconstruct a hidden landscape where small populations permanently settled along a lakeshore during the Bronze Age for several hundreds of years. Such permanence was favoured by the location in a fertile landscape (with an extent of nearly 100 ha) and the closeness to many other resources. According to studies carried out by Ampolo (1980) regarding material conditions of production during Latial protohistory, on the basis of assumed land fertility and also taking into consideration the need of the land to recover between crops for cereal growing and horticulture, such a large area could have supported a group of 150 inhabitants. These calculations are considered indicative by Ampolo and it has to be considered that in addition to the land set aside for growing and left fallow; further areas would have been needed for grazing and for woodlands, essential to needs of the community. Similar conclusions are obtained using the method of land potential evaluation (FAO 1976) suggested by Cremaschi (1990) to estimate the soil productivity. However, in this case, the evaluation is related to the production of cereals, while in this context important food intakes are also obtained from animal breeding, hunting, fruit gathering, and fishing. The results utilising the ratio between the area occupied by wooden structures of the settlement (more than 1 ha), cultivated lands (nearly 100 ha), and the probable woodland area on the flanks of the *caldera* (nearly 100 ha) suggest such areas could well have sustained the community of around 150 people calculated above (Angle 2008; Angle et al. 2011: 235).

The variety and variability of daily and specialised activities, the size of the site and its longevity seem to suggest a central role for this settlement. The absence of relevant and clear archaeological evidence ascribable to settlements in the immediate surroundings for this time span probably favoured its development as a place of social and cultural integration that would also have a redistributive function in an economic perspective. The size and longevity of this site could be also explained by looking at it as a seasonal place of encounter for multiple communities, distributed in surroundings during other periods of the year (Angle & Guidi 2007). From a more general and regional perspective, is this case study an exception or is it typical in this chronological framework?

5.9 Space and time in a regional perspective

In building up a meaningful background, a precise definition of the words “space” and “time” in the analytical context is needed. The spatial limits taken into consideration in this overview include the Central-South Lazio region. The time span ranges from the final stages of the Early Bronze Age to the first stages of the Middle Bronze Age, when the Villaggio delle Macine was inhabited according to the currently available data.

During the final stages of the Early Bronze Age in this region, settlements were predominantly located in open positions, located in valleys and plains. Most sites occupied the eastern part of the Agro Romano, in the territory of Rome. Most of these settlements were located on the slopes of the Alban Hills and in the vicinity of the *Tuscolana-Anagnina* roads, e.g. Fosso di Torre Spaccata, Casale di Torre Spaccata (Guidi & Pascucci 1996), Fosso di Gregna, Ponte Linari and Lucrezia Romana (Guidi & Pascucci 1996; Iaia et al. 2005; Angle & Guidi 2007; Alessandri 2013). A comparable spatial distribution of sites seems to have characterised the Val Comino (Carancini et al. 2003; Angle & Guidi 2007) and the settlements of Colle Prote and Monte S. Giovanni in the province of Frosinone (Guidi & Pascucci 1996). In last stages of the final Early Bronze Age, a few hilltop sites were attested in the Agro Romano, such as Colle Palumba (Bietti-Sestieri et al. 1991-92; Angle & Guidi 2007) and Colle Tasso (Guidi & Pascucci 1996).

During this phase, the coastal area and the Pontine Plain appear less occupied. The scarcity of settlements in this region is likely to mirror an effective absence of presence, considering both the abundance of recent fieldwork activities (mainly by Groningen University, cf. Holstrom et al. 2004; Attema et al. 2007; Alessandri 2013) and the outstanding archaeological evidence of later phases in the same area. An exceptional case in this region is represented by the multiphase settlement of Tratturo Caniò, located on the shore of a wetland area (Anastasia 2007; Feiken et al. 2011, 2012; Sevink et al. 2013). This picture is completed by the presence of a few lakeside settlements such as Villaggio delle Macine and Carnello (Sora, Frosinone) (Guidi & Pascucci 1996; Angle & Guidi 2007) that endured during the early stages of the Middle Bronze Age[22].

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[22] Angle & Guidi reference also the site of Isoletta, an unpublished site, identified by A. Treglia and described as a lakeside settlement; Angle & Guidi 2007: site n. 33: 152.

According to Alessandri (2013: 535), the widespread presence of settlements in the eastern part of the Agro Romano would be partially explained with the fertility of this territory: fluctuations of the inner groundwater level involved a remarkable lake contraction (Magri & Follieri 1992) that exposed wider portions of dry land and fertile valleys where settlements were installed. The precious presence of forestry coverage proved by pollen analyses at Castiglione and Lake Albano (Alessio et al. 1986; Lami et al. 1996; Carra et al. 2007) could have represented a strong attraction because of the available fauna and flora. Agriculture alone would not be the most suitable subsistence strategy due to soil features.

A combined subsistence economy characterised communities of the final stages of the Early Bronze Age and first phases of the Middle Bronze Age, as confirmed by multidisciplinary archaeological data from the Villaggio delle Macine. In contrast, during this time span in southern Etruria, north of the Tiber, settlement strategies appear completely different. In the province of Viterbo (Tuscia), the Early Bronze Age is characterised, according to Di Gennaro (2000: 99; Pacciarelli 2001) by settlement groups being located around hilltops, i.e. naturally defendable sites. Furthermore, continuity of settlement occupation in southern Etruria between the Early and Middle Bronze Age is common (Cocchi Genick 1998: 356; Alessandri 2013: 540), whereas in central-southern Lazio this model recurred only for few lakeside settlements.

The passage into the early stages of the Middle Bronze Age still showed a predominance of open settlements: 72% of them were built in flat regions, with the remaining 8% in easily-defensible positions on plateaux (Alessandri 2013: 543). The spatial distribution of settlements in this phase is quite dense. Multiple settlements are attested in the Alban Hills, such as Colle Mattia, Colonna, Campo Sportivo, Lariano, Colle S. Lorenzo, Lanuvio, and Villaggio delle Macine (Angle & Guidi 2007; Alessandri 2013). The Pianura Pontina and coastal areas are also densely occupied, e.g. Tratturo Caniò, S. Giacomo, Nettuno, Fosso di Rio-Petroso, and Tenuta di Valleranello. In the Sacco-Liri Valley, settlements were grouped on fluvial terraces or on hilltops dominating lands suitable for agriculture as in the settlements near the Canterno Lake and Monte Castellone (Pascucci & Mancini 2004-2005; Angle & Guidi 2007). In contrast, the Lepini and Aurunci Mountains seem to be settled only sporadically, as attested by the site of Vado La Mola (Sermoneta) (Angle & Guidi 2007) and the previously widely occupied eastern sector of the Agro Romano now appears almost entirely depopulated, although archaeological evidence was recovered at Campidoglio according to Alessandri (2013).

Lagoon or lakeside sites seem to be well-represented in this phase: they probably provided a necessary alternative to agricultural subsistence through a wider range of available resources, which enabled the practice of gathering, hunting and fishing, as at the Villaggio delle Macine. This wide set of alternative resources would provide evidence of considerable mobility in settlements; however, the scarcity of extensively excavated sites prevents outlining a conclusive picture of the social organization and complexity of central-southern Lazio in this period. According to Alessandri (2013: 546), current data does not allow, in most cases, reconstruction of the width of settlements and their social complexity. This is both due to the strength of post-depositional processes, which may have partially or totally obliterated the archaeological evidence (he quoted the case of Caterattino, where findings were retrieved 5,5 meters below the actual level during reclamation activities) and to the existence of unpublished case studies. Thus, the most important traces of human communities in this period and area are provided by the Villaggio delle Macine and its comparison with other central Italian coeval sites.

Among economic subsistence practices, hunting is predominant at the site and it is also attested in coeval central Italian settlements (De Grossi Mazzorin 2001; Wilkens 1989, 1993; Tagliacozzo et al. 2012) such as Narce (Barker 1976), Luni sul Mignone (Gjevall 1967), Castiglione (Minniti 2012) and Mulino Rossi (De Grossi Mazzorin 1985). However, in these settlements the predominant animal taxa are domestic: the only case of a strong percentage of deer (34% of the sample) is attested at Mulino Rossi, Pitigliano, where, however, cattle is the most represented species (De Grossi Mazzorin 1985). In a general more consolidated breeding practice, the specialisation in hunting documented at the Villaggio delle Macine seems to suggest that the site could have been part of a wider economic system which included other settlements predominantly devoted to a more farming/pastoral oriented nature (Tagliacozzo et al. 2009: 151). The variety of features utilised in the region by coastal, lagoon, mountainous or lakeside settlements would mirror their different uses as seasonal sites where particular activities were carried out, based on the corresponding environment.

In an attempt to hypothesise the model of social and political organization which identified these communities, assumptions took into account the tribal model (Peroni 1996: 124) of society based on the cohesion of family groups in the local community (Angle & Guidi 2007: 171).