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Archaeology, New Approaches in Theory and Techniques

Edited by Imma Ollich-Castanyer

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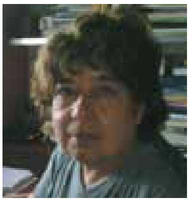
Meet the editor



Dr Imma Ollich-Castanyer (b. 1951) is Archaeologist and Titular Professor at the University of Barcelona (Catalonia, Spain), where she teaches Mediaeval History and Archaeology. Her research has been always developped around mediaeval archaeology, specially on Catalan deserted villages. Author of some books on this matter, she directs since 1991 a research project on Experimental Archaeology near the site of l'Esquerda, where new geophysical tecniques are tested by a pluridisciplinary team.

Contents

Preface

Archaeology has always been a team's work. The best pieces of research are usually made by a great deal of people working together. The archaeologist needs the help of specialists since the first thought of designing a project based upon an archaeological site (geologists, architects, documentary sources), to survey the land (all new geophysical techniques), to dig up the soil (data registration, new computer systems applied), to know and interpret all registered data (historical hypothesis, compared ethnoarchaeology, experimental archaeology), and to spread out the new knowledge and heritage (publishing, making diffusion, museums) to the general public.

So, what is archaeology? The answer seems to be easy, but it is not. From a popular point of view, archaeology is synonymous of adventure, a romantic way to discover our past, especially treasures. Since the first 19th century explorers, the shadow of Indiana Jones is growing here, fed up by movies. But, the romantic hero who is looking for adventures and treasures is always walking alone around the world. Instead, from the point of view of real archaeology there is always a team working together, and they need a lot of techniques to excavate the soil and to classify found artifacts, to study and understand the site. This allows us to know better what kind of culture we are studying, how did it work and to answer a lot of questions about people that lived centuries or millenniums ago, or even millions of years far away in the past. Their technology, their relationship with nature and landscape, their way of living to obtain food and to build a place to rest and to feel safe, their beliefs, are in most of the cases forgotten and covered by layers and layers of soil.

Here we present some papers about the same matter, archaeology, each one speaking of new theories, methodology and applied techniques, and all of them focused on different subjects: geology, astronomy, physics, metallurgy, palaeontology, archaeozoology, museography, chemistry… And so we can see in this book that each chapter is always the result of a team's work, generally done during years, in different parts of the world, and about different periods of human history.

The contents of this book show the implementation of new methodologies applied to archaeological sites. Chapters have been grouped in four sections: *New approaches about archaeological theory and methodology; The use of Geophysics on archaeological fieldwork; New applied techniques: improving material culture and experimentation;* and *Sharing knowledge: some proposals concerning heritage and education.*

In the first one, *New Approaches About Archaeological Theory and Methodology,* Dr. Bryan Hockett exposes a recent standpoint on Scientific Reductionism and its implication on the primitive man's economy in *Optimizing Energy: The Epistemology of Primitive Economic Man.* The chapter by Dr. Alfred Mauri working together with Esther Travé and Pablo del Fresno: *An integrated implementation of written and material sources: conceptual challenge and technological resources,* presents some new approaches to methodological research using both documentary and archaeological sources.

The following four chapters are to show different study-cases in the section about *The Use of Geophysics on Archaeological Fieldwork.* Prof. Jiri Chlachula in: *Geoarchaeology of Palaeo-American Sites in Pleistocene Glacigenic Deposits* gathers some new researches done in prehistoric times in America; Drs. J. Mejuto, J. Gómez Castaño and Gracia Rodriguez-Caderot have written on the possibilities of the astronomy applied to archaeological studies in *GIS Techniques in Archaeology: An Archaeoastronomical approach.* We find several more examples and methodological approaches in *Archaeological geophysics from basics to new perspectives,* written by Roger Sala, Ekhine Garcia and Robert Tamba.

Next section concerns *New Applied Techniques - Improving Material Culture and Experimentation.* Here is the chapter by Drs. Dana Ashkenazi, E. Mentovich, D. Cvikel, O. Barkai, A. Aronson and Y. Kahanov on *Archaeometallurgical Investigation of Iron Artifacts from Shipwrecks: A Review,* focusing on archaeometallurgical studies on iron pieces found under the sea; Drs. Hasibe Cingilli Vural, Ahmet Adil Tirpan, Evrim Tekeli, Seda Akarsu and Babur Akarsu expose their research on gender and species determination through DNA analysis of ancient population in *Molecular Diagnosis through Genetic Typing of Skeletal Remains in Historical Populations of Situated Turkey;* recent studies on experimental archaeology in Middle Ages are discussed in Dr. Imma Ollich-Castanyer, Montserrat de Rocafiguera, Maria Ocaña, Carme Cubero and Oriol Amblàs: *Experimental Archaeology at l'Esquerda: crops, storage, metalcraft and earthworks in ancient and mediaeval times;* and the use of technology and experimental archaeology in work traces in: *The Study of Shell Object Manufacturing Techniques from the Perspective of Experimental Archaeology and Work Traces* by Dr. Adrián Velázquez-Castro.

The fourth and last section is named *Sharing Knowledge - Some Proposals Concerning Heritage and Education,* where problems on heritage and its protection are shown in *Heritage protection in Pécs/Sopianae***,** by Dr. Tamás Molnár. Finally, a chapter focused on diffusion of heritage through museums is written by Dr. Kristian Overskaug: *Homage to Marcel Proust: aspects of dissemination in a museum and a science centre - science communication visions for the third generation museums.*

Many different research projects, many different scientists and authors from different countries, many different historical times and periods, but only one objective: working together to increase our knowledge of ancient populations through archaeological work.

The purpose of this book: to spread out new methods and techniques developed by scientists to be used in archaeological works. This is the reason why we have thought that a publication on line is the best way of using new technology for sharing knowledge everywhere. So I am grateful to Ms. Vana Persen (InTech - open access publisher) to have given me the opportunity to coordinate this book, and for her patience to my constant doubts and requests. Also I would like to thank my colleagues Montserrat de Rocafiguera (Fundació Privada l'Esquerda) and Esther Travé (Universitat de Barcelona) for their comments and discussions about some aspects of this book.

Discovering, sharing knowledge, asking questions about our remote past and origins, all of them are in the basis of humanity, and they are also in the basis of archaeology as a science.

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Section 1

New Approaches About Archaeological Theory and Methodology

1

Optimizing Energy – The Epistemology of Primitive Economic Man

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1. Introduction

> *We are certainly not to relinquish the evidence of experiments for the sake of dreams and vain fictions of our own devising…*
>
> Isaac Newton (1687)

My goal in writing this essay is to provide a broad history of ideas related to human nutritional ecology. The central concept of nutritional ecology is that proper human fetal development, as well as maternal body maintenance before, during, and following pregnancy require a diverse suite of both energy-providing macronutrients (carbohydrates, fats, and proteins) and non-caloric micronutrients (vitamins, minerals, and water) (Hockett and Haws 2003, 2005). As a result, past human foragers who consistently consumed a relatively diverse diet should have set the nutritional framework that may have sparked increases in their population size and density. In contrast, restricted diets are unlikely to be associated with demographic pulses in ancient foraging societies.

By definition macronutrients (energy-producing carbohydrates, fats, and proteins) must be consumed in relatively large quantities compared to micronutrients (non-caloric vitamins and minerals), but this does not mean that the energy producing nutrients are more important to human health than the non-caloric nutrients, including water. A lack of vitamin-A in a human diet would leave a person as dead as one who starved to death through chronic energy deficiency. Importantly, there is not a single food group that provides all of the essential macro- and micronutrients necessary for proper fetal development, maternal health during and following pregnancy, and later growth and development of the individual (Ashworth and Antipatis, 2001; Fall et al., 2003; Ramakrishnan 1999). Humans can survive on restricted diets but these typically cause the over-consumption of certain critical nutrients and the under-consumption of others, which in turn has been shown to negatively impact mortality rates. They also create a host of potential body and mind health problems, particularly if protein is the major energy source consumed rather than carbohydrates (see also Hockett 2011). These facts, however, do not necessarily mean that ancient human foragers were engaged in the active pursuit of a balanced diet (maximizing essential nutrient diversity). Selection, however, may have exerted a greater role upon human societies at particular moments in space and time because of differences in dietary intake.

The basis for a broad theoretical framework of human nutritional ecology may be presented as a series of questions: (1) what are the nutritional requirements for proper human fetal growth and development?; (2) what are the nutritional requirements for pregnant females before, during, and following pregnancy in order to ensure long-term maternal health?; (3) how can these nutritional requirements be obtained in the foods available to various human societies in space and time?; (4) what are the demographic consequences of under-consuming specific nutrients and over-consuming others?; and (5) could differences in the consumption of the variety of macro- and micronutrients have lead to, or at least contributed to, population expansions, declines, and replacements in the past?

Nutritional influences on human evolution must focus on both macronutrients and micronutrients to be meaningful, and nutritional ecology as a broad theoretical model should be developed with this holistic interpretive framework in mind (Hockett and Haws 2005:25, Table 1; Figure 1). Models that focus only on macronutrients, or that give paramount importance to energy as an explanatory framework (e.g., Broughton et al., 2011) reduce data to the point that meaningful interpretations of the past are an unlikely outcome.

The nutrition facts as we know them today, namely that diverse essential nutrient intake lowers infant and maternal mortality rates, are no revelation to anthropology and archaeology. There is a relatively large, anthropologically-oriented literature that has been published on human nutrition over the past 75 years (e.g., Arnott, 1976; Eaton et al., 1988; Harding and Teleki, 1981; Harris and Ross, 1987; Jenike, 2001; Kehoe and Giletti, 1981; Newman, 1962; Quin, 1959; Richards, 1932; Schwarcz and Shoeninger, 1991; Stini, 1971; Underwood, 1975; Vayda, 1970; Wing and Brown, 1979). In addition, the American Anthropological Association incorporated a human nutrition interest group in 1974 called the Council on Nutritional Anthropology, and since 2004 is known as the Society for the Anthropology of Food and Nutrition (American Anthropological Association, 2006). Historically, reductionism as an interpretive framework was discussed by David Hume (1748/1955) in the mid-18th century, concretely formulated in economics in the early-to-middle 19th century by John Stuart Mill (Persky, 1995), formed the core of Max Weber's methodology in sociology in the mid-20th century (Zouboulakis, 2001), and it has become synonymous with *Homo economicus*, or Primitive Economic Man, in microeconomics ever since (e.g., Pearson, 2000).

A reductionistic framework in anthropology and archaeology that hypothesized that the capture of energy was the key to understanding human development may have been first formulated in a comprehensive way by Leslie White in the early 20th century (Adams, 1978). Beginning in the late 1930s, White began to outline his ideas regarding the relationships between cultural systems and technology in reference to the efficiency of energy capture – ideas that he borrowed extensively from researchers such as Hermann Helmholz, Wilhelm Ostwald, and Alfred Lotka. As Binford (1972) reiterated, White's central theses were twofold: (1) that energy flow in nonliving systems fundamentally differed from that seen in the living world; in the case of the former, the second Law of Thermodynamics held that matter and energy flowed from a state of greater organization to less organized states; in the case of the latter, matter and energy flowed in the opposite direction from states of less to greater organization; and (2) as a result, those organisms that could capture and utilize free energy more efficiently than others must necessarily hold a selective advantage over others.

The development of technology in cultural systems was all about the efficient capture of free energy:

> The struggle for existence and survival has two aspects: (1) the adjustment of the organism to its habitat in terms of temperature, humidity, radiation, subsistence, etc.; and (2) the struggle with other living beings for subsistence and favorable habitats. In this struggle, in both its aspects, "the advantage must go to those organisms whose energy-capturing devices are most efficient." Any gains won are kept. The tendency of the life process is always to achieve a maximum of matter-and-energy transformation. This is true regardless of whether the energy is expended quantitatively in mere reproduction of numbers of organisms or in the development of higher forms of living systems (White, 1959:37-38).

In the passage above, White was quoting Alfred Lotka (1945), who was in fact paraphrasing his own words written 24 years prior:

> Furthermore, in the competition which takes place among organisms, the advantage must go to those whose energy-capturing devices are most effective in directing available energy into such channels as are favorable to the preservation of the species (Lotka, 1921:195).

Are these reductionistic conclusions that hypothesize that energy optimization is the key to understanding the evolutionary trajectories of living organisms accurate? Is it the case, then, that human foragers would choose which foods to eat and which to ignore based on caloric return rates available to them in space and time because this subsistence strategy always offers reproductive advantages under any social and environmental circumstances? Has selection been so pervasive in molding human behavior that all economic activities can be reduced to the role they play in energy capture and reproductive fitness? Can archaeologists ignore micronutrients, or non-energy producing substances because they are meaningless to understanding human evolution? Between 1960 and the end of the 20th century, many biologists were arguing that nonhuman animals were energy maximizers as well, (e.g., Kamil et al., 1987; Keene, 1983), so there seemed to be an emerging recognition of a foraging pattern that cross-cut the entire Animal Kingdom, explaining the foraging habits of animals as diverse as locusts, goldfish, flying squirrels, and humans (Foley, 1985).

Does empirical research confirm the validity of this all-encompassing foraging framework? A review of the biological and anthropological literature suggests that it does not (Campbell, 1987; Emlen and Emlen, 1975; Gray, 1987; Heider, 1976; Ingold, 2000; Keene, 1983; Pierce and Ollason, 1987; Schluter, 1981; Weiss, 2000). Yet the 21st century began where the 20th century left off, with anthropologists and archaeologists continuing to argue that human behaviors are best explained through reductionistic models of efficiency of energy capture (e.g., Broughton et al., 2011; Winterhalder and Smith, 2000). Further, human behaviors that were shown to exist outside of an energy optimization model were argued to represent 'ancillary variables' to understanding why, for example, humans forage for food in specific ways (Winterhalder and Smith, 2000). It is more than coincidental that rather than using the phrase 'ancillary variables', John Stuart Mill (1836) called human behaviors that did not lead to an optimization of economic wealth in Capitalistic societies 'disturbing causes' 170 years ago.

To the contrary, it has been well established that humans choose which foods to eat and which to ignore based on a multitude of factors, each of which may have dramatic effects upon mortality and fertility rates. These factors include, but are not limited to, the physiological necessity of consuming macro- and micronutrients to sustain life, taste preferences, availability of specific foods due to factors such as climate, ecological conditions in space/time and competition with other groups, social and cognitive events/festivals/feasts, food taboos related to religious beliefs, established trade networks, and technological innovations (e.g., Counihan, 1999; Harris and Ross, 1987; Thrupp, 1867). None of these variables are necessarily ancillary to explaining human behaviors; to argue that they must be because they do not lead to energy maximization reduces scientific methodology to a tautological argument.

2. The development of nutritional ecology in anthropology

Thirty years ago anthropology and archaeology were poised to develop a theoretical framework of human nutritional ecology. A wealth of nutritional studies in human foraging societies had already accumulated throughout the 20th century; by the mid-1970s general anthropology texts concerning human nutritional ecology began to appear (e.g., Little and Morren, 1976). Nutritional anthropologists were noting aspects of unique human cognition and subsequent dietary choices that dramatically effected mortality trends.

> The difficulties of identifying causative factors and the complex interactions of influential variables underlying even severe forms of neurological pathology may be illustrated in a review of the epidemiology of kuru, a degenerative disorder of the central nervous system found only among the Fore people of New Guinea and their immediate neighbors. The clinical features of this disease, which killed over 2,000 people between 1957 and 1973, have been fully described … Death usually occurs within six to twelve months after the initial appearance of recognizable symptoms of the disease. Until quite recently, the disease principally affected adult females, but children of both sexes seemed equally susceptible. A genetic model was proposed which suggested that kuru was expressed in the phenotype of homozygous or heterozygous children of both sexes and in the homozygous or heterozygous adult female, but occurred only rarely in the heterozygous adult male. Within the last decade, however, the incidence of kuru has declined drastically among the Fore, more noticeably among women and children than adults. The implications of these changes led to more intensive investigations which eventually resulted in the identification of a slow-acting virus as the causative agent of the disease and the detection of ritual cannibalism as the means of natural transmission of the virus. Since women and children are the most active participants in such feasts, the gradual disappearance of ritual cannibalism among the Fore since 1957 has reduced their exposure to contamination from the highly infectious brain tissue of deceased kuru victims and altered the patterns of incidence of the disease (Underwood, 1975:28-29).

Here was an empirical link between the complex relationships amongst diet, human cognitive choice about what to eat and who within a given society is expected to eat it, and mortality trends. Despite studies such as these, holistically-based nutritional ecology studies were never embraced by archaeologists. Instead, archaeologists turned to biological studies of nonhuman animal behavior (e,g, Emlen, 1966; McArthur and Pianka, 1966; Schoener,

1987) for models to interpret ancient human foraging decisions within an exclusively Darwinian framework. These models consisted of variations on reductionistic, energy optimization models (e.g., prey choice and patch choice models) – which I will refer throughout the remainder of this essay as the development of a Primitive Economic Man framework, or simply PEM.

PEM is a deductively-based interpretive framework that creates a narrow vision of human action centered around the maximization of a 'currency'. The currency tracked through time ranges from capital wealth to calories to babies. In archaeology, one or more currencies are often linked, such that, for example, a maximization of caloric intake relative to work effort serves to foster the successful procreation of more babies in those individuals who act accordingly.

PEM has much in common with the *Homo economicus* character much written about in economics for more than a century. Doucouliagos (1994:877) summarized *Homo economicus* thusly: 'The neoclassical economists' *Homo Economicus* has several characteristics, the most important of which are (1) maximizing (optimizing) behavior; (2) the cognitive ability to exercise rational choice; and (3) individualistic behavior and independent tastes and preferences.'

Some of PEM's characteristics, such as individual self-interest, can be traced back to Antiquity, while others have much in common with John Stuart Mill's (1836) theoretical construct of the model Capitalist. 'Economic man', later referred to as *Homo oeconomicus*, was a term applied to Mill's method of economic analysis, but his Linnaean classification was originally created in a context that was not intended as a compliment (Persky, 1995:222). According to Persky (1995), John Kells Ingram's *A History of Political Economy* (1888) may have been the first to use the term 'economic man' in reference to Mill's work. Persky (1995) also argues that Mill's 'economic man' was inherently Lamarkian in character, namely that one generation of rational decision-makers would pass this behavioral tendency on to the next generation, who would then embrace the Capitalistic principles taught to them, and then pass these on to the next generation, and so on. Max Weber (1915/1946) later referred to Mill's 'economic man' as *Homo oeconomicus*, and the term has been commonly used throughout the 20th and 21st centuries in economics.

Archaeology's reliance on PEM as a model to interpret ancient human foraging strategies is most paradoxical when one considers that the nutrition sciences, which is the discipline that has pursued links between dietary intake and maternal and infant mortality rates, has not seriously applied a similar model in their discipline since the 1920s. The nutrition sciences first began breaking away from PEM in the 19th century (Carpenter, 2003a; Carpenter et al., 1997). Carpenter et al. (1997:1018S) note that the discovery that organic and inorganic micronutrients were as essential to human development, growth, and maintenance as were the energy providing macronutrients finally broke the dogmatic thinking that protein, in particular, was of paramount importance to human health, and that reductionistic models that focused only on macronutrients could serve as a primary explanatory framework in the nutrition sciences.

While researching the historical context of ideas related to human nutritional ecology, I discovered that the early history of nutrition and the early history of PEM mirrored one another. Both stem from a number of hypothetical and philosophical beliefs about the universe in general, and more specifically about the place of humankind and human societies within that universe – as well as the factors that cause human societies to change, grow, and die. Many of these beliefs date back to the early 18th century, and some of them date back to the European Middle Ages and, earlier still, to ancient Greece and Rome. And some of these lingering beliefs are still maintained within modern models of PEM (Stoczkowski, 2002). Importantly, however, other disciplines such as nutrition science that once promoted ideas commensurate with PEM have abandoned these beliefs because of intensive empirical research that falsified them. The time has come for more researchers in archaeology to challenge reductionistic energy imperative frameworks, and pay more attention to the nutrition sciences by incorporating the implications of nutrition-based studies into model-building. An historical development of the ideas that led to the creation of both PEM and human nutritional ecology is a necessary step in that process.

3. A brief historical narrative of nutritional ecology and Primitive Economic Man

The following narrative tracks the development of ideas that characterize human nutritional ecology and the PEM frameworks, and the philosophers and scientists who played critical roles in their respective developments. For those already familiar to some degree with the literature, it will be understood that a detailed account that focused only on the philosophical belief that human nature is rooted in self-interested behaviors could fill a small library. This brief summary cannot account for all researchers who contributed in one way or another to the development of PEM and nutritional ecology. I have attempted, therefore, to choose specific authors and their works as representative of broad time periods of human thought as they relate to the development of PEM and nutritional ecology. Consider this as a place to begin an epistemological journey.

3.1 Antiquity: The early beginnings of ideal types, optimal states of nature, self-interest, and cultural ecology

Lovejoy and Boas (1935) and Boas (1948) summarized many of the ideas related to "primitivism" in Antiquity. Important philosophers of this early period included **Lucretius** (*99-55 BC*). A Roman poet and author, Lucretius wrote of individualism and the fact that earlier humans must have lived principally with their own welfare in mind. Self-interest was a consequence of primitive peoples living alone, each fending for his or her own needs and safety (Lovejoy and Boas, 1935:227-228). **Origen** (*AD 185 – 254*) linked rationalism with 'primitive' peoples by way of necessity. Humans are rational because God endowed us to invent better ways of behaving, which we are always striving to do, including better ways to procure food (Boas, 1948:194). On the diet of earlier peoples, the Roman priest **Novatian** (*AD 200 – 258*) noted a common conception of the time: the superiority of meat-eating (Boas, 1948:26); in contrast, **Saint Basil** (*AD 329 – 379*) noted that a vegetarian fare may suffice (Boas, 1948:114). And **Saint Jerome** (*ca. AD 331 – 420*) offered an early glimpse of cultural ecology when he wrote: "But who does not know that each people is accustomed to eat, not according to a universal law of nature, but according to what things are found abundantly in their habitat" (quoted in Boas, 1948:130-131).

Two of the most significant ideas that developed out of Antiquity included the notions of an optimal state of nature and ideal types. **Saint Augustine** (*AD 354 – 430*), like so many writers before and after him, described the first ideal-type, or optimal state of nature: Paradise, or the Garden of Eden:

> Man lived in Paradise as he wished, so long as he wished what God had commanded. He lived in the enjoyment of God, from Whose goodness he was good. He lived in need of nothing, having it in his power always so to live. He had food lest he be hungry, drink lest he be thirsty, the tree of life lest old age wear him away. No corruption was in his body nor did he feel arising from his body any threats to the acuity of any of his senses. No inner disease was to be feared, no blow from without. The soundest health was in his flesh, in his spirit complete tranquility (quoted in Boas, 1948:48-49).

The Garden of Eden represented an ideal, perfect state of nature that supplied maximum subsistence and mental efficiency. After the Fall, it was each individual's choice to try and reach this optimal state as best he or she could. In this framework, rationality was defined by an optimization of behaviors (lack of greed and lust, etc.) that would then be rewarded with eternal life. The general structure of optimization amongst both the story of the Garden of Eden and the Fall of Man, on the one hand, and the natural philosophy of PEM, on the other, is remarkably similar. As unpleasant as many scientists might find this comparison, the similarities amongst the overall structure of the respective models are too complimentary to ignore.

In any case, speculations about early human behavior, as well as the creation of optimal states of nature and ideal types by philosophers of the Antiquity period hinted at the PEM framework that was to formally develop in the 18th and 19th centuries.

3.2 Seventeenth and eighteenth centuries: The beast-machine, least action, the conservation of energy, and hints of a modern nutrition science

The story of PEM changes little through the Middle Ages. The great philosophers and mathematicians of the 17th and early 18th centuries, however, would set the stage for different and often conflicting conceptions of PEM.

PEM models through the 17th and 18th centuries often interpreted human behavior as analogous to energy-maximizing machines. This mechanistic vision of the living universe formed an important part of the philosophy of **Renee Decartes** (*1596 - 1650*) (Brown, 1936), although the idea of pondering the question 'are animals soul-bearing beings or simply machines?' did not originate with him, and can be traced to Antiquity (Cohen, 1936:56). During the first one-half of the 17th century, however, Decartes offered a rather comprehensive vision on the nature of nonhuman animal behavior and motion by contrasting it with the human condition. This vision, referred to as animal automatism, argued that animals did not have souls or think, and therefore their behaviors could be reduced to analogies with the movements of machines – the so-called 'beast-machine' (e.g., Cohen, 1936).

Thomas Hobbes (*1588 – 1679*) offered two important suggestions about early human behavior in the middle of the 17th century: (1) humans were inherently self-serving beings, and (2) this self-interested nepotism naturally lead to a state of competition amongst individuals. These concepts would later become important centerpieces of Darwinian selection, as well as the nature of PEM. Hobbes called this perpetual competition amongst individuals a 'state of war'. Hobbes' (1651:84) famous essay leads directly to one of the most often quoted passages about early humans, which comes at the end of the following paragraph:

> Whatsoever therefore is consequent to a time of war, where every man is enemy to every man; the same is consequent to the time, wherein men live without other security, than what their own strength, and their own invention shall furnish them withal… and which is worst of all, continual fear, and danger of violent death; and the life of man, solitary, poor, nasty, brutish, and short.

Hobbes established this state of early humanity to advocate a centralized authority to govern society, because it is only through the rule of law as established by governments or ruling classes that this perpetual 'state of war' could be avoided, which would then lead to greater advancements in the arts and sciences.

An important 17th century figure for the later development of the principles of least action, as well as those related to maxima and minima in nature that would develop in the 18th century was **Pierre de Fermat** (*1601 – 1665*). In the mid-1600s, de Fermat studied the paths of light rays. In 1657, he published what he proposed as the Principle of Least Time to describe the pathways of light, and defined the principle as 'Nature always acts by the shortest course' (Jourdain, 1913:48).

Isaac Newton (*1642 - 1727*) later published his *Principia*, or *The Mathematical Principles of Natural Philosophy* in 1687. In the latter 17th century, as well as the 18th and 19th centuries, Newtonian physics would be used by others to argue that the living universe could be explained via analogy to the mechanical properties of the nonliving universe. As Carpenter (1994:5) noted, some prominent medical researchers of the latter 17th century began their textbooks with overviews of Newton's *Principia* as a guide to understanding the human body. These analogies, including de Fermat's principle of the conservation of time in the movement of light through space, would form integral components to PEM frameworks into the early 20th century.

There also were late 17th century experiments related to optimal states and ideal types. For example, Sloane (1699) discusses experiments designed to perfect plants through selective breeding. He relates these studies to the fact that the Creator made living things changeable in order for humanity, through selective breeding, to create ideal or perfect types for our benefit. And early in the 18th century, discussions that harkened to the times of Antiquity once again ensued regarding whether humans were or were not, by nature, flesh-eaters. For example, Wallis (1701:775) wrote that it was Man's natural state to be carnivorous.

David Hume (*1711 – 1776*) argued that there are uniformities of human nature, and one component of scientific and philosophical inquiries is to isolate them. Hume suggested reducing actions to smaller, more manageable components or 'regularities'. Hume also asked that even if there are regularities in human nature – which may turn out to be a principle cause of human action - does that mean that we can, by inference, predict the effect, or the outcome of those actions? Perhaps we can in mathematics, but in moral philosophy Hume answers in the negative, although this does not in and of itself render the elucidation of regularities of human behavior insignificant (Hume, 1748:95). Hume's idea that diversity of human action may be reduced to a smaller number of 'regularities' would be brought forward into Adam Smith's analysis of Capitalist markets, the latter published in the same year of Hume's death. It would also form the core of John Stuart Mill's 'economic man' concept in the early 19th century.

In the 18th century the Hobbesian ideals of self-interested behaviors once again took center stage as one of the principal regularities guiding human nature through the philosophical writings of **Jean-Jacques Rousseau** (*1712 – 1778*). As noted by Ogden (1940), **John Locke's** (*1632 - 1704*) *Two Treatises of Government*, published in 1690, argued that men have the right to do whatever they wished as long as their behaviors did not impede others from doing the same. While Locke argued that this was part of 'human nature', he did not advance the idea that such behaviors would only be represented in so-called primitive groups – it was part of all human nature. Rousseau (1755), on the other hand, argued in his *Second Discourse* that humans were not only self-interested beings, but that this behavior was representative of an earlier, primitive state of human nature (Ogden, 1940). Rousseau (1762:50) argued in his *Social Contract* seven years later, however, that self-interested preservation extended from this earlier condition into civilized society as well. Rousseau's argument was soundly attacked in England, ironically by those advocating an optimal state framework (Ogden, 1940). For his detractors, humankind's primary state of being was intellectual; what separated the civilized from the primitive was a continuous desire to reach an optimal state of perfection of being, which would lead to the greatest happiness.

Of greater significance, however, for the creation of a more modern PEM interpretive framework was the discovery of the Principle of Least Action in physics, generally attributed to **Pierre-Louis Moreau de Maupertuis** (*1698 – 1759*), and related ideas regarding the conservation of energy. The Principle of Least Action in the nonliving would later be transformed into a Principle of Least Effort in the living, with the latter serving as the living equivalent to the conservation of energy in the nonliving world. For his part, Maupertuis saw the Principle of Least Action as part of the Intelligent Design of the Divine Universe. Others, of course, interpreted the conservation of the life force differently. Maupertuis figured prominently in the debate between materialist and divine causation in the mid-1700s. And although Maupertuis chose divine causation, he would provide to the materialists of the 20th century a non-divine final cause of the universe – the Principle of Least Action.

Following Maupertuis' writings on Least Action was **Leonhard Euler** (*1707 -1783*). In 1753 Euler deduced a mathematical principle of *least effort* based on a body that begins at rest and moves to a fixed point, the sum of all the efforts operating equal to a maximum and a minimum (Jourdain, 1913:29). Others also advanced mathematical formulae for describing the principle of maxima and minima in nature during the latter one-half of the 18th century. Included among them was **Joseph Lagrange** (*1736 – 1813*), who, in 1759, stated that it was 'his intention of deriving the whole of mechanics, by means of the principle of the least quantity of action, from a method he had of investigating the maxima and minima of indefinite integral formulae' (Jourdain, 1913:51). These principles related to least-action, least-effort, and maxima and minima in nature were later combined with hypotheses about ideal types and optimal states in nature to form the core of PEM interpretive frameworks. For example, the original principle developed in physics of maxima (PEM = greatest energetic efficiency and/or reproductive success) and that of minima (PEM = with the least expenditure of energy or effort) form critical components to models derived from optimization interpretive frameworks of the 20th and 21st centuries.

Early 18th century physics also helped set the stage for what was to develop in economics in the second one-half of that century. Within the throes of the development and controversy surrounding the Principle of Least Action and the conservation of the active force (energy) came the economist **Adam Smith** (*1723 – 1790*). His best-known work, *Wealth of Nations*, published in 1776, was one of only two major works he published in his lifetime (Nieli, 1986). *Wealth of Nations* became, and continues to serve as a sounding board for Capitalist principles. Within this work is also found many of the salient features of the modern PEM interpretive framework. These features include: (1) the belief that humans are, by nature, self-serving beings; (2) those that act only in their own self-interest will have a competitive advantage over those who help others; and (3) self-serving individuals naturally attempt to optimize, or to accumulate material wealth in the most efficient manner possible. These actions define rational behavior. For Smith, those who are the most efficient at the accumulation of wealth will have a competitive advantage. Importantly, if all self-serving individuals attempted to optimize their accumulation of wealth, a net benefit would be realized amongst both the individual and the society:

> Every individual is continually exerting himself to find out the most advantageous employment for whatever capital he can command. It is his own advantage, indeed, and not that of the society, which he has in view. But the study of his own advantage naturally, or rather necessarily leads him to prefer that employment which is most advantageous to the society (Smith, 1776:333).

This would lead to Smith's famous line concerning the unwitting natural state of affairs that lead humans to be judged by an 'invisible hand', a process that leads to greater efficiency for both the individual and society (Smith, 1776:335):

> He generally, indeed, neither intends to promote the public interest, nor knows how much he is promoting it. By preferring the support of domestic to that of foreign industry, he intends only his own security; and by directing that industry in such a manner as its produce may be of the greatest value, he intends only his own gain, and he is in this, as in many other cases, led by an invisible hand to promote an end which was no part of his intention. Nor is it always the worse for the society that was no part of it. By pursuing his own interest he frequently promotes that of the society more effectually than when he really intends to promote it. I have never known much good done by those who affected to trade for the public good.

Smith essentially defined the salient features of *Homo economicus*, who would be further refined into a reductionistic method of economic study 60 years later through the writings of John Stuart Mill and others. There has been much recent revisionist literature in economics concerning the role of empathy and individualism in Smith's writings (e.g., Alvey, 2004; Hill, 2004; Lamb, 1974; Nieli, 1986; Peart and Levy, 2004; Prieto, 2004; Waterman, 2002), none of which negates the central role that individualism was perceived to play in his vision of the ideal Capitalistic market operating within an optimally functioning society.

Even before Maupertuis and Adam Smith, chemistry was slowly molding itself into a respectable discipline during the 18th century. Researchers such as **Robert Boyle** (*1627 - 1691*) and **Peter Shaw** (*~1693 - 1763*) were quietly setting the framework for the Chemical Revolution that would occur late in the century, which itself marks the beginning of a scientific study of human nutrition (Carpenter, 2003a). For example, in 1723 Shaw was 'maintaining that no disease should be regarded as incurable and that there was room for the application of the Newtonian method in medicine, as well as in those sciences based on mathematics' (Gibbs, 1951:213). In 1725, Shaw also published an abridged version of Boyle's works, including footnotes that updated Boyle's original conclusions with current information, and this book was widely used between 1725 and 1817 (Gibbs, 1951). The latter part of the 18th century then witnessed the maturity of chemistry and nutrition. One of the principle players in these studies in France was **Antoine Lavoisier** (*1743 – 1794*) (Carpenter et al., 1997). But a scientific study of human nutrition was also to incur major setbacks in the very place in which it was maturing (Carpenter, 2003a:638). As Carpenter (2003a) details, the Chemical Revolution in France at the end of the 18th century witnessed the identification of the major elements of the universe, which encouraged the development of new methods in chemistry and nutrition. Being at the forefront of these studies and associating himself with the 'wrong' crowd during the Reign of Terror, however, Lavoisier was guillotined in 1794 (Grey, 1982; Hartog, 1941).

3.3 Nineteenth century: Reductionism and an energy imperative paradigm sweep the natural sciences

Chemistry and related nutrition studies both matured rapidly during the 19th century. In the early part of the century, **François Magendie** (*1783 – 1855*) reported on several important studies involving the nutritional requirements of mammals. Carpenter (2003a:639) recently recounted Magendie's experiment in which he fed a dog a purified diet of sugar. The animal appeared to do well for about two weeks, but one month after the experiment began the dog died. Magendie concluded that 'diversity and multiplicity of aliments is an important rule of hygiene; which is, moreover, indicated to us by our instincts' (quoted in Carpenter, 2003a:639).

Definitions of the term 'nutrition' in the early 19th century were general in nature, such as that offered by the Boston physician George Hayward in 1834: 'The process by which the body increases in size, and the waste of its organs is repaired, is called nutrition' (quoted in *The North American Review*, 1834:404). Nevertheless, the first one-half of the 19th century was dominated by thoughts of energy, and in particular protein, rather than nutrient diversity per se. And for these researchers, it was clear that the processes of body growth and organ repair could be explained by a balanced intake of protein. **Justus Von Liebig** (*1803 - 1873*) published his influential *Animal Chemistry or Organic Chemistry in its Application to Physiology and Pathology* in Germany in 1842. Liebig's argument was that muscle contractions were caused by the explosive breakdown of protein molecules, and hence protein was the only true nutrient humans required for fuel and maintenance of healthy bodies (Carpenter, 2003a:641). As Carpenter (2003a:641) noted, some of the preeminent European professors of medicine were concluding that outbreaks of ailments such as scurvy must have been caused by inadequate intakes of protein, despite overwhelming evidence that unknown nutrients found in fruits and some animal organs were known cures for these conditions. The energy imperative paradigm of the time led many researchers to ignore evidence that did not conform to the protein model – including Liebig himself.

Liebig (1842:75) clearly had an energy-imperative paradigm and the principle of maxima and minima in mind when formulating his nutrition model, which included thoughts of the efficient use of energy in all walks of life, including early human behavior:

> Cultivation is the economy of force. Science teaches us the simplest means of obtaining the greatest effect with the smallest expenditure of power, and with given means to produce a maximum force. The unprofitable exertion of power, the waste of force in agriculture, in other branches of industry, in science, or in social economy, is characteristic of the savage state, or the want of cultivation.

This energy-imperative model of human nutrition dominated the thoughts and teachings of many prominent researchers and medical professionals throughout the19th century. In this model, health and disease patterns were caused by inadequate energy intake or imbalance. As Carpenter (1994) notes, Liebig's monumental study deeply affected nutritional studies on both sides of the Atlantic until the end of the 19th century.

Not all, however, embraced Liebig's research. In fact, *The North American Review* for October, 1842, soundly and sarcastically attacked Liebig's conclusions.

> The previous reputation of the author, as a zealous and able analytical chemist, appears to have excited very high expectations of the value of the work that he was to produce, and to have prepared the way for the enthusiastic reception it met with. Professor Gregory declared, in the British Association , as we are informed in the Preface to the American Edition, "that the Association had just reason to be proud of such a work, as originating in their recommendation;" and Professors Lindley, Daubeny, and others, concur in regarding the date of its publication "as the commencement of a new era in the art of agriculture." One of the Copely medals, of the Royal Society of London, was presented to the author the same year. The President, the Marquis of Northampton, in presenting the medal to Professor Liebig's representative on the occasion, said, "My principle difficulty, in the present exercise of this the most agreeable part of my official duty, is to know, whether to consider M. Liebig's inquiries as most important in a chemical or a physiological light." If his Lordship will honor our Review with a careful perusal, we think he may be relieved of a part of his difficulty.
>
> This second Report is announced with the same flourish of trumpets. The American editor declares the author to be, without question, the first living authority in Organic Chemistry; and the translator, Dr. Gregory, has "experienced the highest admiration of the profound sagacity, which enabled the author to erect so beautiful a structure on the foundation of facts, which others had allowed to remain for so long a time utterly useless", and regards its appearance as "the commencement of a new era in physiology." We have thus, already, two new eras, a new era in agriculture, and a new era in physiology; and some two years hence, when the third Report shall be forthcoming, we shall doubtless have a new era in the art of dieting and cookery.
>
> Professor Liebig himself participates in the complacency with which his works are regarded by his admirers. His opinions are often given with a confidence which savours, not a little, of dogmatism; and he is not, always careful to mention the attainments and labors of others with all the respect, that may reasonably be demanded from a candid searcher after true knowledge. For example, he repeatedly speaks of "pretended experiments" and "experiments that teach nothing", for no other reason, that is exhibited, than that they were not favorable to his conclusions; and this, too, while his own observations are referred to only by their results, without

> any details to enable the reader to judge of their accuracy or sufficiency. He demands a confidence from his readers, which he is not willing to render to others. He enters, apparently for the first time, into the field of physiology, with a feeling nearly allied to contempt for the attainments of all its previous cultivators (*The North American Review* 1842:464-466).

Another important nutritional line of work which would be brought forward from the 1600s into the 19th century involved studies of the human body as analogous to an engine, with an interest in calculating the efficiency of that human engine. In 1861, for example, **Hermann Helmholz** (*1821 – 1894*) "estimated that the human 'engine functioned with about 25% efficiency'" (quoted in Carpenter, 2003a:642). In another related experiment, a Swiss scientist compared the amount of protein that a human body could break down with the amount of energy expended by a pair of mountain climbers, and concluded that the fuel utilized by the human body must come primarily from fats and carbohydrates, not from the breakdown of protein (Carpenter, 2003a:642), an interpretation upheld by later studies.

The latter part of the 19th century, however, saw a continued focus on protein and energy as the primary sources of nutrition leading to healthy humans. Wolf and Carpenter (1997:1255) noted that, between about 1860 - 1910, Germany attracted many American and European postgraduate students who desired to learn from the most influential nutritional minds of the day. Two important figures that would carry the energy cause late into the century were **Carl Voit** (*1831 - 1908*) in Germany and **Wilbur Atwater** (*1844 - 1907*) in the United States. Nevertheless, according to Atwater (1888:257-258), although the energy producing nutrients were most important, a variety of foods were required to consume the necessary diversity of energy types needed to efficiently run the human mental and physical machine.

An important economic researcher of the 19th century who advocated an ideal-type analytical framework was **John Stuart Mill** (*1806 – 1873*). Mill, and later Max Weber in sociology, both utilized a deductively-based scientific method of investigation that relied on reductionistic frameworks of ideal types. Zouboulakis (2001) recently analyzed both Mill's and Weber's views on individualism, ideal-types (optimization), methodological reductionism, and the Capitalistic tendencies of human nature. Zouboulakis (2001:32) noted that Mill's method of economic analysis (dubbed the study of 'economic man' by later writers) was an attempt to isolate behaviors within Capitalistic markets that specifically addressed an actor's 'desire for wealth'. Mill (1836) recognized that motives other than the desire for wealth were also in operation in Capitalistic markets, and these behaviors he called 'disturbing causes'. Furthermore, these disturbing causes eventually must be taken into consideration in explaining the full suite of human motives. Nevertheless, Mill believed that a focus on the desire for wealth would explain much of the essential actions driving behaviors in Capitalist markets (Zouboulakis 2001).

The latter-half of the 19th century also saw the maturation of the discipline of anthropology. **Edward Burnett Tylor** (*1832 – 1917*), considered by some the 'father' of modern anthropology (e.g., Radin 1970) published his classic work *Primitive Culture* in 1871. Tylor grappled with the notion that the laws of the inorganic world, as well as those formulated in the study of nonhuman plants and animals, could be equally applied to human behavior. Thus, Tylor (1871:2) questioned the validity of studying human action as just another example of nature's overarching laws:

> Our modern investigators in the sciences of inorganic nature are foremost to recognize, both within and without their special fields of work, the unity of nature, the fixity of its laws, the definite sequence of cause and effect through which every fact depends on what has gone before it, and acts upon what is to come after it… But when we come to talk of the higher processes of human feeling and action, of thought and language, knowledge and art, a change appears in the prevalent tone of opinion. The world at large is scarcely prepared to accept the general study of human life as a branch of natural science, and to carry out, in a large sense, the poet's injunction to 'Account for moral as for natural things.' To many educated minds there seems something presumptuous and repulsive in the view that the history of mankind is part and parcel of the history of nature, that our thoughts, wills, and actions accord with laws as definite as those which govern the motion of waves, the combination of acids and bases, and the growth of plants and animals.

But Tylor (1871:3) sees justification in this very assumption, and thus anthropology is born with the goals of establishing laws of human action that accord with those of the inorganic and nonhuman worlds:

> We may hasten to escape from the regions of transcendental philosophy and theology, to start on a more hopeful journey over more practicable ground. None will deny that, as each man knows by the evidence of his own consciousness, definite and natural cause does, to a great extent, determine human action. Then, keeping aside from considerations of extra-natural interference and causeless spontaneity, let us take this admitted existence of natural cause and effect as our standing-ground, and travel on it so far as it will bear us. It is on this same basis that physical science pursues, with ever-increasing success, its quest of laws of nature.

Tylor therefore advocates the same deductive approach as that discussed by Mill. What, then, should constitute the reductionistic hypothesis through which human action, past and present, can be interpreted? Tylor (1871:6) responds that it is the self-evident truth that all of humankind can be classified as savage, barbaric, or civilized. Further, these self-evident truths are to be considered universal and timeless, applicable to all peoples, in all times, at all places.

Mid-to-late 19th century racism disguised as sound science relied on the same general principles of ideal-types, optimal states, and reductionism to create visions of superior and inferior human races. The ideal race was set in parts of Europe, and its salient features were identified, often by measurements of the mouth region and the skull cap. The general methodology was similar to the creation of the perfect 'economic man' operating within Capitalist markets – only here the issue was the perfection of the physiological, mental, and social characteristics amongst humans. Thus, with ideal type/optimal state methodology in hand, these authors set about a scientific treatise on the idealness of human races by defining their salient features and then judging them against a conjectural optimal state that humanity could strive to become. In this context, race was the currency to track historically, while human perfection served as the optimal state. Policy adoption by governments served as the goal of 'social selection' to reach the optimal state of humanity.

Some of the earliest studies of cranial measurements were completed entirely for medical purposes, and had no racial undertones (e.g., Friend, 1699). Interestingly, one of the earliest works with racial implications focused not on measurements of the brain case, but on measurements of the mouth. **Alexander Nasmyth** (*1758-1840*) argued that the lack of tools, lack of cooking meats, and the prolonged suckling of infants in primitive races caused them to become more prognathic in the mouth than the civilized races, who used tools more often than the mouth in processing foods. The measurement of the mouth was a direct reflection of the degree to which a society was living in an optimal state of humanity – with upright jaw structure representing the ideal type of mouth. It was out of this perfect mouth type that prognathism developed in the degenerate savages who migrated from north to south long ago (Nasmyth, 1848:193-194).

Late in the 19th century, the principles of ideal racial types and an optimal state of humanity based on racial purity took a cruel turn for the worst (e.g., Gould, 1981). In the United States, **Carlos Closson** was one of its leading proponents. Closson attributed the rise of the 'great' civilizations to the ambition of the pure races; their decline was instigated by cross-breeding with the irrational races, including the Fall of the Roman Empire (Closson, 1896:460-461). Closson pondered what to do about all of this racial mixing (irrational behavior) that has been occurring for so long, driving down the ideal-type of race and the optimal state of humanity. He decides there are six fixes for this problem, categorized thusly: 'military, political, religious, moral, legal and economic' (Closson, 1896:462). 'Military selection' is always an option to get rid of an inferior race, but the costs in superior men of the better races through warfare is considered too high. Besides, there are better ways to get rid of people, to mention nothing of the fact that inferior breeds may be useful to serve the elite race and to complete lowly tasks that their superiors may not wish to engage in themselves. So Closson (1896:465) offered six suggestions of how to assist 'social selection' to operate in order to "constitute a natural aristocracy among a given people". Closson (1896) attributed much of his data to the writings of **Georges Vacher De Lapouge** (*1854 – 1936*). De Lapouge, in turn, attributes the originality of the idea of a scientific study of superior and inferior races to the Count de Gobineau between 1853-1855 (De Lapouge and Closson, 1897). De Gobineau is described as a 'genius' by De Lapouge and Closson (1897:56-57).

PEM frameworks of the late 19th century continued the Hobbesian idea that foragers were continually facing famine and a caloric-depleted death. **Garrick Mallery** (*1831 -1894*) noted that "Brutes feed. The best barbarian only eats. Only the cultured man can dine. Savages eat when they can get food and continue to eat so long as the food lasts" (Mallery, 1888:195). **John Wesley Powell** (*1834 – 1902*) provided a vision of naked Darwinian selection: "Competition among plants and animals is fierce, merciless, and deadly; out of competition fear and pain are born; out of competition come anger, and hatred, and ferocity" (Powell, 1888:301). Baker (1890:299) combined Mallery's and Powell's vision into one succinct concept: "The human body abounds in testimony of this sort – indications of the pathway by which humanity has climbed from darkness to light, from bestiality to civilization – relics of countless ages of struggle, often fierce, bloody, and pitiless". Burnett (1892:249) concurred:

> It is no part of Nature's plan to be merciful; the fundamental law of all her actions is inexorableness. Pitliless and stern, with a deaf ear turned to all appeals for consideration or extenuation, she lays the icy fingers of her immutability upon the victim and exacts payment of the penalty in full.

But late 19th century anthropology was not the only discipline guilty of such visions – some economists continued its visions of PEM, too. **E. L. Godkin** (*1831 – 1902*), for example, wrote that:

> It is no less true that political economy, no matter how defined, cannot be taught without assuming the existence of an Economic Man who desires above all things, and without reference to ethical considerations, to get as much of the world's goods as he can with the least possible expenditure of effort or energy on his own part… Ethics and religion in so far as it furnishes a sanction for ethics, exist for the purpose of deflecting him from his normal course (Godkin 1891:491-492).

The same deductively-based, reductionistic methodology also led to some 'higher-order' explanations in the 19th century that, in hindsight, entered the realm of ridiculous. For example, **Louis Robinson** (1894) ironically began his deductively-based conclusions about past foraging behavior by arguing that they could only have been brought about by previous inductively-driven research. The inductively-generated model that Robinson gives credit is Darwin's theory of evolution:

> Although the Darwinian doctrine of human descent has now been accepted for the best part of a generation, we have as yet done little in applying it in interpreting the many records of the past which are found in our bodies. The logical tactics necessarily adopted by the pioneers of the movement are to some extent accountable for subsequent slow progress. While the main question was in dispute all advocates of the evolution theory were striving to establish the principle. In doing this it was obviously necessary to use the inductive method (Robinson, 1894:467).

But now that the general principle of evolution, developed through inductively-based scholarship, has been accepted by all serious and knowledgeable scientists, it is time to jettison the inductive approach to understanding the past through this methodology – for deeper levels of understanding, we are told, we must instead turn to deduction:

> But it is evident that the methods resorted to for purposes of conquest are by no means those which render a new territory of permanent value to the captors. When the fight is over and the victory won, progress is not aided by mangling the carcass slain, or by marking time on the field of battle. Now that the principles of evolution have taken their place forever among the axioms of science, we must resort to deductive tactics if we hope to enjoy the fruits of victory.
>
> It is wonderful, when this is done, how many of the most dull and trivial facts of every-day experience become alive with interest. The new philosophy is found to possess a transmuting power which changes the very dust of the earth into golden grains of knowledge (Robinson, 1894:467).

Robinson argues that many of the common behaviors seen in human civilized babies can be traced directly back to our 'pithecoid arboreal ancestor' – these fruits become sweeter when we take the self-evident truths that our ancestors lived a nasty, brutish life, one in which foragers were ever-staring caloric-depleted death in the face – and place these truths within deductive models based on the general Darwinian evolutionary framework. The eight innate behaviors of human infants that Robinson chooses to deductively explain through the Darwinian framework are: 1) why human infants are fat; 2) why human infants enjoy placing objects in their mouths; 3) why human infants are cute; 4) why human infants cry loudly; 5) why human infants fear strangers; 6) why babies are afraid of the dark; 7) why human infants are terrified of ferocious beasts; and 8) why human infants are jealous. For example, the deductively-based explanation of why babies are afraid of the dark was described thusly:

> A fear of being left alone in the dark is almost universal among little children, and yet, in ninety- nine cases out of a hundred it is purely instinctive and is not founded on personal experience…As I have remarked before, nature develops no new organ or quality except to meet a vital want, and has a way of adapting means to ends which does not allow of the least surplus. An organism is as exactly adjusted to its environment as a casting in metal or plaster to the mould which gave it shape.
>
> The unreasoning night-fears of infancy may therefore be read as a record of past circumstances which at one time rendered them necessary in preserving life. When the cave bear and that grisly nondescript the saber-toothed tiger (*machairodus latidens*) were contemporary with the English troglodyte, and when hyenas which could crunch up the shin bone of an ox like a stick of macaroni were his next-door neighbors, it was obviously indiscreet for a defenceless human being to wander abroad after nightfall (Robinson, 1894:475-476).

More than a century after these deductively-based interpretations of the human infant in foraging societies were proposed, the dangers inherent in extreme reductionism that relies on Darwinian principles as a panacea to explain past human behavior are easily illuminated. Most of the salient characteristics of the PEM framework are embedded in Robinson's writings, including Darwinian selectionist principles as the sole interpretive framework for the explanation of human action that matters in a developmental sequence, as well as self-interested preservation.

However, not all of the deductively-driven models of the late 19th century were similar to Robinson's. In fact, perhaps the earliest modern-looking optimal foraging model can be found not in the biological literature of the 1960s, but in late 19th century anthropology. Perhaps the earliest formal optimal foraging model in anthropology was proposed by **Otis Tufton Mason** (*1838 – 1908*) in 1894, anticipating those proposed in biology by 70 years. Mason (1894:275) begins by stating a common perception of both human nature and the life of savages as filled with hardships: "The chief contest for the inner man has been to appease the insatiable cravings of *hunger* and *thirst*". These inner and outer hardships created a tendency for humanity to stay stationary in order to procure the material items necessary to overcome them, but also an urge to migrate – to move to greener pastures in order to find comfort. According to Mason, in both of these pursuits, humans naturally chose paths of least resistance based on the principles of maxima and minima because the day-to-day struggle for life was so harsh. And here, Mason (1894:276) has also anticipated the studies of least effort in experimental psychology by at least 30 years:

> The law of the circle of employments and of permanent migration may be called *the maxima* and minima of effort – that is, men have always bestirred themselves the year round and moved about the world on lines and to places where there seemed to be promise of the greatest bodily comfort and security for the least effort.

> In this paper especial attention will be paid to this maxima and minima in relation to the food quest, though it will be seen that following this line conducts also to the best results in the other activities mentioned.

Mason then proposes his optimal foraging model to explain the peopling of the Americas. Anticipating modern prey choice models by more than 80 years, Mason (1894:278) argues that the most attractive game within inner terrestrial-based environments is large herbivores, but where available, marine environments offer the greatest subsistence rewards for the least amount of effort: "The greatest natural food supply for the least effort, with few exceptions, was in the water". Mason proposed that humans choose which foods to eat and which to ignore based primarily on net gross food return rates, considering the abundance and variety of foods in relation to their availability on a seasonal basis, capture costs, and preparation costs. Given these principles, Mason (1894:279) proposes a deductively-based model of the probable migration route of the earliest inhabitants of North America – one that likely began in the Indo-Malaysia region of Asia, reached the Pacific coast of North America, and eventually ending in South America.

The theoretical development of PEM was essentially complete by the end of the 19th century. Therefore, there would be only minor developments in optimization models throughout the 20th century. From this point forward to the present day, optimization models have simply been applied to different data sets, often under the disguise of different names to make them appear new or unique.

3.4 Early 20th century: Primitive Economic Man runs his course in nutrition, becomes despised in anthropology, but lands feet-first in experimental psychology

Max Weber (*1864 - 1920*) took the research methodology that focused on ideal-types and conjectural optimal states of behavior to define rationality into 20th century sociology (Zouboulakis, 2001:30). In Weber's 1915 essay concerning Indian religion, for example, he gives an account of the ideal-type method of analysis, noting that the rational behavior generated from it does not necessarily exist in reality, rather it serves as a point of reference to judge how closely actual behaviors reach the conjectural optimal state (Weber, 1915, translated in Gerth and Mills, 1946:323-324):

> The constructed scheme, of course, only serves the purpose of offering an ideal typical means of orientation. It does not teach a philosophy of its own… As will readily be seen, the individual spheres of value are prepared with a rational consistency which is rarely found in reality. But they *can* appear thus in reality and in historically important ways, and they have… They enable us to see if, in particular traits or in their total character, the phenomena approximate one of our constructions: to determine the degree of approximation of the historical phenomenon to the theoretically constructed type.

Here, then, are all the elements of the deductive method of defining rationality in the analysis of social phenomena. Weber was one of the early users of the term '*Homo oeconomicus*' to refer to Mill's model Capitalist. But "Weber … rejected income-maximizing *homo economicus* and sought to replace him with the status-maximizing *homo politicus*, at least within the bounds of pre-modern Europe" (Christesen, 2003:31-32). Modern archaeological models have combined Weber's *Homo politicus* with PEM's Darwinian framework to form models under various names, including "costly-signaling theory", "prestige hunting", and "showing off" (e.g., Broughton and Bayham, 2002).

3.4.1 Ideal cases and reductionism continued: The optimization prophecy of Wilhelm Ostwald

Early 20th century textbooks on theoretical mechanics and natural philosophy continued the dialogue on the principle of maxima and minima in nature and the conservation of energy. An early 20th century textbook on theoretical mechanics by **James Hopwood Jeans** (*1877 – 1946*) was later cited by George Zipf as one of his inspirations for developing the Principle of Least Effort in psychology (see below). The goal of several influential natural philosophy texts remained unchanged from earlier times: unite the actions of the living and nonliving under a single principle: the efficient utilization of energy. One of these general texts was published in 1910 by **Wilhelm Ostwald** (*1853 - 1932*). As in Mill's economics and Weber's sociology, Ostwald argues for a focus on ideal-types, or optimal states, and reductionism as the best method for investigating natural philosophy and science. But Ostwald (1910:45) specifically argued that Mill's disturbing causes are irrelevant when he wrote that "…we repeatedly so find or can form our experiences that certain natural relations *preponderatingly* determine the experience, while the other parts that remain undetermined fall into the background. *The prophecy will cover so considerable a part of the experience that we can forego previous knowledge of the rest*". Ostwald (1910:46-47) then outlined what can be considered the current working deductive model used in North American archaeology today:

> A case in which none of the extraneous elements of experience operate is called an *ideal case*, and the inference from a series of values leading to the limit-value is an *extrapolation. Such extrapolations to the ideal case* are a quite natural procedure in science, and a very large part of natural laws, especially, all quantitative laws, that is, such as express a relation between measurable values, have precise validity only in ideal cases.

Ostwald argues that natural philosophy should decide which finite causes are likely to be the most instrumental in guiding behaviors in the living universe. Sound science makes these reductionistic determinations, and then seeks out those actions or behaviors that appear to confirm the law. Scientists can make observations, interpret them according to the law, and this makes the living world knowable and useful. So what should the final cause of living action be?

> Since our opinion as to what constitutes a higher and lower organism is doubtless arbitrary, let us ask whether it is not possible to find an *objective* standard by which to measure the relative perfection of the different organisms. The question must be answered in the affirmative when we take into consideration the following. Since the quantity of available free energy upon the earth is limited, the organism which transforms the energy at its disposal more completely and with the least loss into the forms of energy necessary for the function of life, must be regarded as the more perfect organism (Ostwald 1910:176).

If we substitute the concept of 'fitness' for the word 'perfect' in the passage above, we would have the essential argument of modern optimization models and current constructs of PEM under the umbrella of "evolutionary ecology". Here is Ostwald's passage again with the substitution of two words:

> Since our opinion as to what constitutes a higher and lower organism is doubtless arbitrary, let us ask whether it is not possible to find an *objective* standard by which to measure the relative [fitness] of the different organisms. The question must be answered in the affirmative when we take into consideration the following. Since the quantity of available free energy upon the earth is limited, the organism which transforms the energy at its disposal more completely and with the least loss into the forms of energy necessary for the function of life, must be regarded as the more [fit] organism.

Ostwald's prophecy was about to become law, despite the best efforts of nutrition science, which was about to bury PEM, and anthropology, which learned to despise him in the early 20th century.

3.4.2 Nutrition science begins to build Primitive Economic Man's coffin

At the time of Ostwald's writings, a major breakthrough in the understanding of nutritional requirements of human health was occurring. In 1911, E. B. Hart of the University of Wisconsin and colleagues embarked on a program to test some of Liebig's protein/energy imperative conclusions (Harper, 1997:1027S-1028S). In what became known as the 'Wisconsin single grain experiment', Hart and colleagues definitively showed that healthy diets required more nutrients than simply protein and a few minerals (Harper, 1997:1027S-1028S).

It was also becoming widely known that mice fed purified diets consisting solely of energy sources died rather quickly, but when milk was added to these diets the animals flourished. The implication of these studies was that there existed a type of nutrient, or a number of nutrients, other than proteins, carbohydrates, and fats, that were present in milk that made the difference between life and death in the living universe. One of the implications was that the living world was more than machines of energy moving through space. That analogy was untenable.

One of these important papers appeared in 1915, and was entitled *The Nature of the Dietary Deficiencies of Rice* (McCollum and Davis, 1915). In this paper we get a first-hand account of researchers who knew the energy-imperative paradigm to be wrong, and knew also that other, undefined organic-based nutrients had as much impact on mammalian growth and development as proteins, carbohydrates, and fats. McCollum and Davis (1915:183-184) called these undefined nutrients 'accessory substances'. The fat-soluble accessory substance that McCollum and Davis knew to be vital to mammalian growth and development would later be known as vitamin-A. The water-soluble accessory substance(s), for which McCollum and Davis were unsure of the number, could have included folate, riboflavin, and/or thiamin, all critical to human growth and body maintenance.

Thus, McCollum and Davis (1915:185) dismantled the notion that, in the living world, energy alone could promote growth when they wrote that: "…all of which make it evident that *purified proteins, fats having the growth-promoting property, and salt mixtures of appropriate composition, cannot adequately supplement polished rice so as to produce a diet which will support growth*". In a case of bitter irony, then, McCollum and Davis (1915:192) argued that increasing attention to the non-energy producing accessory substances would lead to significant economic benefits through better health and nutrition.

The second decade of the 20th century finally witnessed the naming of these accessory substances – 'vitamines' (Frank and Dubin, 1920; Funk, 1925, 1926; Myers and Voegtlin, 1920). By 1918, some nutritionists were actively promoting the essentiality of these nutrients to healthy diets, and recognizing that diversity of diet was necessary to consume adequate quantities of these essential nutrients:

> Vitamines as a class are now acceptably divided into a fat soluble and a water soluble type. Both are absolutely essential in a complete diet and both vary considerably in their occurrence. Individually many foods are deficient in one or both of them, but safety has undoubtedly been assured to the consumer by his desire for variety (Steenbock, 1918:119).

And by the end of the decade, three 'vitamines' were being named by letter (e.g., Dutcher et al., 1919:184). Shortly thereafter, nutritionists were on the trail of other non-caloric nutrients that were critical to the survival of animals. While not yet chemically isolated, they were learning that some foods such as green leafy vegetables were so rich in these nutrients that they could make the difference between life and death. Consider these passages from Evans and Bishop (1922:650-651), who were hot on the trail of 'substance X', later called vitamin E:

> Natural foodstuffs contain a substance, X, which prevents such a sterility or which cures the disorder occasioned by the purified dietary regime. We have thus been able to witness a comparatively sudden restoration of fertility to animals of proven sterility, and whose controls continued sterile, by the administration of fresh green leaves of lettuce.

These studies demonstrated, once and for all, that energy sources could not be considered by themselves a key currency to tracking animal health patterns. From this point (roughly 1920) forward to the present day, advocates of PEM models would ignore these essential facts – but in the earliest stages of the 20th century, PEM ideals were still in good company to all but a few heretics who were quietly building PEM's coffin in the nutrition sciences.

3.4.3 Alfred Kroeber's superorganic challenge to Ostwaldian prophecy

In an important early 20th century anthropology paper, **Alfred Kroeber** (*1876 – 1960*) challenged the ideas that Darwinian selection could explain all human behaviors of any consequence to science, as well as the notion that human action could be understood through mechanistic principles based on reductionistic ideals (Kroeber, 1917). Kroeber's prophecy, however, was that the study of human behavior would be overtaken, so to speak, by the forces of organic evolution, while the true study of the meaning of human action – the social – would be swept aside in the reductionism inherent in zealous claims that the principles of Darwinian selection could explain the essence of human thought and action. Considering the tenacity of the PEM framework, Kroeber can be regarded as a seer in this regard. Kroeber's analysis, indeed criticism, of interpreting human action under the same theoretical principles as organic evolution anticipated some of the objections to optimization approaches developed much later in the century.

Kroeber (1917:208, 212) argued for holistic views of human action, and warned against scientific reductionism:

> Science will attack historical material – social material – by converting it into organic terms - whether psychical or physical does not matter, so long as the ever present individual physiological aspect or basis of the social phenomena is dealt with. These organic results will then be ready for interpretation by the methods of physics and chemistry. Thus the material will be made part of that great unit, the system that justifies and elevates science to its high plane – the system that is pervaded by the principle of mechanical causality as its essence.
>
> The forces and principles of mechanistic science can indeed analyze our civilization; but in so doing they destroy its essence, and leave us without understanding of the very thing which we seek.

3.4.4 Bronislaw Malinowski heads to the Trobriand Islands and fails to discover Primitive Economic Man

In the 1920's, PEM was so pervasive in the thoughts of economists and others that **Bronislaw Malinowski** (*1884 – 1942*) devoted some time to dismembering him in his classic *Argonauts of the Western Pacific*, first published in 1922:

> Another notion which must be exploded, once and for ever, is that of the Primitive Economic Man of some current economic text books. This fanciful, dummy creature, who has been very tenacious of existence in popular and semi-popular economic literature, and whose shadow haunts even the minds of competent anthropologists, blighting their outlook with a pre-conceived idea, is an imaginary, primitive man, or savage, prompted in all his actions by a rationalistic conception of self-interest, and achieving his aims directly and with the minimum of effort. Even *one* well established instance should show how preposterous is this assumption that man, and especially man on a low level of culture, should be actuated by pure economic motives of enlightened self-interest. The primitive Trobriander furnishes us with just such an instance, contradicting this fallacious theory. He works prompted by motives of a highly complex, social and traditional nature, and towards aims which are certainly not directed towards the satisfaction of present wants, or to the direct achievement of utilitarian purposes. Thus, in the first place, as we have seen, work is not carried out on the principle of the least effort. On the contrary, much time and energy is spent on wholly unnecessary effort, that is, from a utilitarian point of view (Malinowski 1922:60).

Despite ethnographies such as Malinowski's *Argonauts*, essays by Kroeber, and research on vitamins in nutrition, these studies did nothing to slow the progression of PEM in natural philosophical texts. If anything, the PEM framework became even more trustworthy for its proponents than ever before. And nobody exemplified this fact any better during the third decade of the 20th century than Alfred Lotka.

3.4.5 The extended hand of Wilhelm Ostwald: Alfred Lotka's energetics and human nature

In precisely the same year that Malinowski published his *Argonauts*, **Alfred Lotka** (*1880 - 1949*) was publishing a series of articles in the *Proceedings of the National Academy of Sciences* advocating a mechanistic view of human evolution based on energetics. Lotka (1922:147) wrote that:

> It has been pointed out by Boltzmann that the fundamental object of contention in the life struggle, in the evolution of the organic world, is available energy. In accord with this observation is the principle that, in the struggle for existence, the advantage must go to those organisms whose energy-capturing devices are most efficient in directing available energy into channels favorable to the preservation of the species.
>
> The first effect of natural selection thus operating upon competing species will be to give relative preponderance (in number or mass) to those most efficient in guiding available energy in the manner indicated.

Three years after these writings, Lotka (1925) published his *Elements of Physical Biology*. Here, Lotka detailed his ideas concerning both the mechanical side of human behavior and the other behaviors guided more by cognitive choice. Lotka (1925) called the mechanistic side of human action 'rigid behavior', or, more famously, the 'automaton type'; the more symbolic aspects of human action he called the 'elastic type'. Elastic behaviors, of course, are nothing more than Mill's (1836) 'disturbing causes' and Weber's *Homo politicus*.

Lotka (1925:350) then states that 'lower' organisms such as plants live on an "*automaton type* of behavior schedule"; "But in the higher animals, and most particularly man, we have an elastic behavior-schedule….". Ironically, Lotka (1925) then argues that elastic behaviors are superior to automaton types. Any changes, or adjustments, in the operation of free choice would naturally tend toward those behaviors favorable to the individuals of the species, and thus they would tend toward a maximum. In this case, the maximum or currency to track is energetic efficiency. But then Lotka (1925:352) considers all of these deductions within a framework of ideal types and optimal states, and in the process reduces them further to the rigid types of human action, turning his model of the ideal type of human being into an automaton, representing classic PEM modeling:

> **Relation between Ideal and Actual Organism**. We have thus far considered an ideal type of organism of the free choice type of behavior schedule, constructed on the principle that the λ's shall be so chosen as to make the proportional rate of increase *r* a maximum.
>
> It remains to consider the relation between this ideal type of organism and the actual organism. The actual organism is not consciously guided by any consideration of the effect of his actions upon the rate of increase of his species… What guides a human being, for example, in the selection of his activities, are his tastes, his desires, his pleasures and pains, actual or prospective. This is true, at least, of some of his actions, those which are embraced in his free-choice type of behavior schedule. That the human behavior schedule also contains an element of the non-elastic (automaton) type may be admitted in deference to those who have leveled their destructive criticism at the hedonistic account of human behavior. We may, however, restrict our discussion here to that portion or phase of conduct which is determined by hedonistic influences.

So what portions of the human condition naturally lend themselves to hedonistically-generated models of automaton action? It's foraging for food, because the health and welfare of plants and animals are primarily determined by the efficient capture of free energy:

> The behavior schedule has been quantitatively defined in terms of energy. This if not the only possible definition, is at any rate a convenient one, and has also the advantage of emphasizing the important relation of the organism to the energy sources of his environment. His correlating apparatus is primarily an energy capturing device – its other functions are undoubtedly secondary. The life contest, then is primarily a competition for available energy, as has been pointed out by Boltzmann. Energy in this sense and for this reason *has* value for the organism – which is a very different thing from saying (as some have said or implied) that economic value *is* a form of energy (Lotka 1925:354-355).

Lotka (1925:356-357) places the self-interested energy-maximizers into the classic Darwinian framework of the struggle for survival, thereby completing the optimality-based PEM framework:

> Our reflections so far have been directed to the selfish efforts of each organism and species to divert to itself as much as possible of the stream of available energy.
>
> This at least seems probable, that so long as there is an abundant surplus of available energy running "to waste" over the sides of the mill wheel, so to speak, so long will a marked advantage be gained by any species that may develop talents to utilize this "lost portion of the stream." Such a species will therefore, other things being equal, tend to grow in extent (numbers) and this growth will further increase the flux of energy through the system. It is to be observed that in this argument the principle of the survival of the fittest yields us information beyond that attainable by the reasoning of thermodynamics.

Lotka (1925:430-431) ends with a metaphysical idealism, with one more deductive state of optimality to propose – man's unity with Nature.

> The fact seems to be that the operation of a fundamental purpose or design in Nature is one of those things that can neither be proved nor disproved. We are, therefore, at liberty, if we so choose to, believe in such a purpose. This is an occasion for the legitimate exercise of faith.
>
> We may, if we *will*, embrace this purpose for our own. Such *will* spells ultimate survival. No better guarantee for the welfare of the race could be furnished, than its essential harmony with Nature. Selection, then, would seem to point the way toward a will in conformity with that general principle which, for want of a better term, we may describe as the Supreme Purpose of the Universe.

3.4.6 The non-caloric organic nutrients change the face of nutrition and disease: The vitamin revolution buries Primitive Economic Man in the nutrition sciences

Research into the 'vitamines', especially vitamins A, B, C, and E accelerated during the early 1920s (e.g., Bishop, 1922; Evans and Leersum, 1929; Funk and Dubin, 1920; Funk, 1925, 1926; Myers and Voegtlin, 1920). With increasing discussion of the value of incorporating these nutrients into diets, some were advocating caution in the creation of dietary guidelines for the intake of the non-caloric nutrients because vitamin research was being performed almost exclusively on nonhuman animals (Mitchell, 1922). For example, by 1925 vitamin E deficiency had been advanced as one of the factors that had a primary influence on sterility in mice (Evans and Burr, 1925).

Then, between 1926-1939, in 13 short years, 12 essential vitamins had been isolated chemically, including thiamin, niacin, folate, riboflavin, and vitamins B_6, C, A, D, E, and K (Carpenter, 2003c:3028, Table 2). As noted above, between about 1900 – 1920, a fundamental shift in thinking within nutrition science took place. Within these two decades, it became apparent that many diseases and malformations, including scurvy, rickets, beriberi, night blindness, and pellagra could be prevented or treated by adding specific food items that contained nutrients other than carbohydrates, fats, and proteins to the human diet (e.g., Elvehjem, 1949). These afflictions, which greatly influenced human demographic patterns in some regions, were not caused by viruses nor by insufficient intake of energy or minerals. Rather, they were caused by deficiencies in unknown organic-based nutrients – and the search was on to define and isolate them (Carpenter, 2003c; Carpenter et al., 1997). This brought about the revolution of understanding of essential nutrient diversity and human health and development in nutrition science between 1910 -1940. And this spelled the death of PEM modeling in that discipline.

For instance, it was discovered that 'Factor A' (later called vitamin A) was crucial to understanding growth and development in mice, as well as treating and preventing night blindness – although this vitamin was not isolated chemically until 1939 (Carpenter, 2003c). Growth and the 'antiberiberi factor' were related to 'vitamin B' (with B_1 isolated in 1926); rickets was tied to a factor we now call vitamin D, and isolated in 1931, and so forth (Carpenter, 2003c). As the vitamins began to fall to science, so to speak, the essential minerals began to receive increasing attention in the 1920s and 1930s as well. As an example, copper was isolated as a factor in the health of cattle in 1931 (Carpenter, 2003c).

One final piece of nutrition research that falls between the two decades 1920-1940 involved the relationship between energy consumption and life span. As Carpenter (2003c) notes, as early as 1917 researchers had discovered a link between early calorie restriction and increased life span in mice. In 1927, **Clive McCay** (*1920 – 1967*) confirmed this finding, concluding that the life span of rats could be greatly enhanced by restricting their consumption of calories (energy) early in life.

Between 1920 – 1940, then, the nutrition sciences firmly established the link between dietary diversity and human health patterns, including the significant roles played by non-caloric nutrients. This general principle has been confirmed by thousands of empirical research projects conducted over the past 65 years – and forms the central concept of nutritional ecology.

3.4.7 Primitive Economic Man moves into experimental psychology

Beginning in the 1930s, experimental psychologists decided to apply PEM modeling in their research. One of the more important articles linking animal behavior with the principle of least effort was published by **Joseph Gengerelli** (*1905 – 2000*) in 1930. Gengerelli studied the behavior of rats moving through a maze to obtain food at the end of the line. Current PEM frameworks are similar to the research Gengerelli carried out on rats in the 1930s. Substitute 'ecological habitat' for the maze and 'human foragers' for rats, and one essentially sees the basics of modern PEM modeling. Gengerelli's early research also continued the tradition of framing itself within the parameters of reductionism, ideal-types or optimal states, least effort or action, maxima and minima, and deductive reasoning.

> In the press and strife of actual research…the problem is to determine which one of the "blunt facts" we shall choose as the corner stone of our explanation. Obviously we must choose those which are capable of embracing all of the varied phenomena with which we have to deal. Also those facts which are "self- evident"; which do not themselves stand in need of explanation.
>
> This is the crux of our problem. In psychology, at least, there is no unanimous agreement as to what the fact or facts are which do not stand in need of explanation… In general, modern psychologists have been too ambitious. They have been drawn with an inevitable fatality to the "self-evident" facts and laws of mechanics (Gengerelli 1930:194-195).

Gengerelli attempts to establish a 'law' of least action, but he notes that the law applies only to specific circumstances; namely specific external and internal conditions arising from need (1930:228-229):

> In view of the fact that our ordinary tools of frequency, recency, redintegration, etc., fail to resolve the phenomenon to a simpler, more fundamental, level, there is only one thing left to do: - state the facts and their conditions as simply and as abstractly as possible. We are therefore forced to state in a somewhat axiomatic form that it is a fundamental law of behavior *that the organism, under the stress of a need, tends in consequence of repetition, to relieve that need by the process of least effort.*
>
> In other words, the capacity of the various stimuli in the external situation to elicit responses from the animal becomes *changed and organized in a fashion prescribed by a definite law*. The law, namely, that the behavior of the animal, in relieving its need, shall become the *minimum possible*.

In 1937, **R. H. Waters** repeated Gengerelli's maze experiments utilizing both rats and human subjects. His goal was to test three related but somewhat different hypotheses, or 'Laws of the Principle of Least Effort' that had been recently proposed in experimental psychology: (1) R. H. Wheeler's (1929) Law of Least Action; (2) J. A. Gengerelli's (1930) Principle of Maxima and Minima (described above), and (3) L. S. Tsai's (1932) Law of Minimum Effort. Waters finds some positive aspects to both Gengerelli's and Tsai's formulations, but because he recognizes that behavioral variability will be contingent upon physiological and cognitive differences between organisms, external constraints, and the like, he prefers Tsai's *Law of Minimum Effort*. Interestingly, **George Zipf** (*1902 - 1950*) would later take 'Principle' from Gengerelli's formulation, 'Least' from Wheeler's formulation, and 'Effort' from Tsai's formulation to concoct the 'Principle of Least Effort' in 1949, apparently unaware that Malinowski had used the term to refer to PEM 27 years earlier.

Nevertheless, while recognizing some positive aspects to Tsai's *Law of Minimum Effort*, Waters also recognized some limitations in that formulation. One of these is the dimension of pain. Specifically, even rats may not choose a path of least resistance or greatest energetic efficiency if that path causes pain. In contrast, non-living phenomenon such as water flowing down a mountain may follow a path of least resistance, but in doing so feels no pain on its journey downward. The water has no other incentive or built-in behavioral capabilities to choose its path down the mountain. Waters has therefore challenged the notion that the living and nonliving are equivalent dimensions that can be explained by a single, overarching 'law'. But the energy maximizing hypothesis is too strong, so Waters

(1937:16-17) suggests simply incorporating the pain dimension into the minimum effort equation:

> Gengerelli points out that by taking the wall these animals avoided the pain consequent upon bumping into these obstacles. This is clearly an instance showing that, if the pathway of minimum effort involves painful stimulation to the animal, then that pathway will be avoided. It might be suggested, however, that the *Law of Minimum Effort* be so interpreted as to include the pain dimension, that is, that that pathway involving least painful stimulation will be taken. If this were done, then we would be able to say that the *Law of Minimum Effort*, with the limitations already mentioned, holds for the following dimensions: distance, time, effort, and pain.

We can sense in this passage an attempt to salvage a doomed scientific postulate. Waters previously noted that dimensions such as pain were unquantifiable, and even if it could be quantified, it would be so variable amongst individuals that the dimension would remain largely unknowable. And yet Waters insisted on making living dimensions such as pain part of what he would call a Law of Minimum Effort. Waters writings also beg the questions: If pain influences a rat's decision regarding whether or not to choose a path of least resistance or least expenditure of energy, what about other dimensions that must be taken into account to understand human behavior such as love, desire, hate, jealousy, sympathy, apathy and the like? Can we quantify all of those dimensions? How, then, would this Law be applied to human behavior? Ironically, Waters all but answered these questions – namely that the *Law of Minimum Effort* does not apply to human behavior.

> In the case of the human subjects no single explanation seems possible, due to the reasons they gave for taking the several paths. If they did manifest a preference, regardless of the number of turns required by it, they usually claimed that it seemed shorter or easier. However, many subjects were activated by other motives, such as the desire to go as many different ways as possible, the thought that the aim of the test was to see how many ways they could find, the fear that they would lose their way if they tried another, and so on… With such maze structure and with such a welter of motives, each individual case becomes a law unto itself and thus prohibits, in our situations at least, the formulation of any single explanatory principle (Waters 1937:17-18).

Waters then notes that not only does his research indicate that the Law of Minimum Effort does not apply to human behavior, but others had already noted as such:

> Tolman …points out that, if there is some physiological principle, some principle of least effort, at the basis of behavior, a knowledge of this fact is relatively barren. "For, given the present parlous state of our physiological knowledge, it appears that the mere fact of such a principle allows us to predict nothing beforehand and prior to concrete behavior experiments". Now, in the first place, he is not in reality telling us to "go to" with our attempts at demonstrating this principle… (Waters, 1937:18).

Despite evidence that the PEM framework was untenable as an explanation of human action, the model became the ultimate panacea of explanation in the universe with the writings of George Zipf in the 1940s. For Zipf, everything in the universe boiled down to the tri-fold phenomena of any real consequence: matter (or energy or action), time, and space (including distance). These interact to create the one true law that unites the entire spectrum of the universe, the living and the nonliving.

In 1942, Zipf was unconcerned about the exact title of his unifying principle. For him, least action, minimum effort and energetic efficiency were essentially synonymous terms.

> As to the verbal pitfall, we must remember that the minimum of least-action can be described equally well by using other words….Yet a different verbal label will not necessarily entail the presence of a different minimum.
>
> There are further variants of least-action, such as **least-work, least-labor**, or, in more disguised form, the economical use of energy… Nevertheless fundamental drives remain fundamental drives, regardless of verbal dressing (Zipf 1942:50-51).

The most fundamental feature of the universe for Zipf is the fact that as time passes, matter moves through space. Once this fundamental fact is realized, then all phenomena can be explained with reference to it. We must further realize that of the tripartite phenomena, matter (or action) (or energy) is the most important. Once these salient features of the universe are realized, the only thing remaining is to have faith that these principles guide every action in the universe, the living as well as the nonliving. But for Zipf, it was not faith to believe in these principles – it was simply a rational, self-evident conclusion to any right-thinking person.

> It is commonly assumed by natural scientists that there is a "unity of nature" in the sense of a "continuity of natural law." In other words, it is assumed that all of nature (i.e., "the entire universe") is organized as a single great unit according to a single body of law which operates at all times and at all places throughout the entire universe. According to this assumption, the same general natural law that governs the structure and behavior of astronomical bodies governs also the structure and behavior of our planet, of life on our planet, and, indeed, of even the smallest minutiae of living activity including the most subtle emotional and intellectual elaborations of human mind (Zipf, 1942:48).

Zipf contrasts this right-way of thinking with those who believe that variability in behavior does not necessarily reflect a deep-rooted, fundamental law of nature. To Zipf, it is the ignorant who think that nature can organize the living in myriad of ways that show fits of randomness.

> In this argument about the existence of social laws, we notice that those who assume the unity of nature, or the continuity of natural law, conclude that there are social laws (and hereinafter we shall call them the **natural social scientists**). By the same token, those who believe that there are no such things as social laws, automatically (though perhaps tacitly and unwittingly) conclude that there is no such thing as a unity of nature. These opponents of natural law in the social field are often referred to as "political theologians" and "economic romanticists", quite analogous to the quacks in medical science…. They might be God who, by definition, decides what the natural codes are to be (Zipf, 1942:52).

But unlike the "quacks" in the medical profession, Zipf understands that his assumption must be borne out with empirical research. Thus, he confidently boasts:

> The unity of nature, the continuity of natural law, the universal principle of least- action can be established only by rigorous empiric research before whose decision all minds must bow(Zipf, 1942:52-53).

Zipf appeals to the Capitalist economic writings concerning labor relations for support, and in the process, sets the stage for what would become known as materialist models in archaeology and patch choice models within an optimal foraging framework in biology and archaeology – namely that people must organize themselves on the landscape with an eye toward least-effort or least-action.

> If we assume in the company of economists that man tries to save labor (i.e., is motivated by the consideration of least-action) in all his activities, we must conclude that he will automatically try to save labor in his exploitation of the raw materials of nature, not only in the procuring and manufacture of raw materials into finished goods, but also in his distribution and consumption of the same (Zipf 1942:53-54).

But Zipf doesn't stop there. Like Alfred Lotka before him, Zipf enters into the metaphysical. Perhaps, he notes, we will one day determine that the human soul, if it exists, operates under the Principle of Least Effort as well. And if that is the case, then Zipf has explained the human soul mathematically, and in the process, perhaps, found God.

> Thus, for example, if man has an immortal soul, as many believe, then, according to our argument, that immortal soul will exist in obedience to the principle of least-action. And whether or not man has such a soul may very well be decided one way or another by scientific inquiry, perhaps even sooner than we think (Zipf 1942:62).

4. Concluding remarks: The future of Primitive Economic Man and nutritional ecology

> *Hallowed with age, having been found helpful in one or many fields of inquiry, it has been the lot of every good idea to be borrowed and reborrowed time and time again, always retaining the essence of its old identity, but adding new shades of meaning or losing old ones with every borrowing* (Hodgen, 1964).

Many of the central ideas embedded in optimization frameworks were first developed in Antiquity two millennia ago. These include individual self-interest, ideal types, optimal states, and least effort. The mathematical representations of principles related to maxima and minima, least-action, and conservation of the active force or energy, developed primarily in the 17th and 18th centuries to describe the movements and interactions of matter in the nonliving world, deeply influenced deductively-based ideas about human nature and human health patterns in the 19th and 20th centuries. Many of these latter ideas have remained intact in the PEM or optimization frameworks in 21st century archaeology (e.g., Broughton et al., 2011). PEM was buried in the nutrition sciences 80 years ago, yet schemes involving protein pills and bad carbohydrates continue to capture the imagination into the 21st century (e.g., see Carpenter, 1994 for protein supremacy arguments reminiscent of Liebig's methods from the middle 1800s).

Why do PEM models continue to be so attractive to many researchers, even after it has been shown that they produce marginal results in discipline after discipline? There could be several reasons for PEM's survival in archaeology. First, there is a certain ring of truth about least effort behaviors. For examples, foragers walking across the landscape undoubtedly at times (but not always) chose a path of least resistance; and specific technological developments undoubtedly became fixed in human societies because they offered greater efficiency in procuring and/or processing foods. Another attractive component to PEM is that the models derived from its principles often develop into mathematical formulations that are tested with statistics. This gives an aura of "hard science" to these models; in short, it looks like good science. Lastly, these models are well suited for the deductive nature of the scientific study of archaeology that students are told in graduate school they must conform with in order to do 'good science' and be 'good scientists'.

Although humans occasionally make choices based on energetic efficiency, it has never been shown that (a) energetic efficiency is of primary concern to human decision-making; and (b) decisions repeatedly based on energetic efficiency would result in greater selective fitness over time. In contrast, it has been repeatedly shown that humans make decisions about what to eat and what not to eat based on a multitude of reasons (such as taste preferences, taboos and the like) that have nothing to do with energetic efficiency in either the procurement or consumption of those foods. Ethnographic research on a multitude of foraging societies across the globe do not suggest that hunter-gatherers were in a perpetual state of famine or chronic energy deficiency (e.g., Lee and Daly, 2006b; Lee and Devore, 1968); nor were their actions overly concerned with seeking more efficient or most efficient methods to capture and consume calories. Past societies, like those documented ethnographically, likely had a multitude of choices – about what to eat and when and where to eat it. And in many environments, both past and present, there were likely a multitude of ways to procure the nutrients to sustain the next generation, none of which necessitated 'optimal' behaviors in terms of either macronutrient or micronutrient intake. And when it comes to selective fitness, those human foragers who were only concerned about procuring calories with the least effort would likely find themselves outcompeted and soon extinct by others who chose (probably unwittingly) a diet that resulted in the consistent consumption of a wide diversity of all the essential nutrients necessary to sustain mother and child.

One of the most ironic factors about PEM modeling in archaeology and its reliance on the deductive method is that the concept of Darwinian selective fitness developed primarily through inductive rather than deductive research. It is difficult to see how deductively based research can be considered 'superior' to inductively based research, or, worse yet, how deductively based research can be considered 'more scientific' in the sense that all research should be conducted under the umbrella of a deductive model. I think that most of archaeology's fact-building and learning continues to occur through the "Well I'll be damned" factor. Inductively based archaeological research, whether through new excavations, experimental archaeology, the development of new technologies applied to old data, and the interpretations resulting from this research often result in new discoveries that teach us more about the who, what, where, when, and why of past societies than deductive approaches. PEM modeling is a good example. It has been used and abused in multiple disciplines for centuries, and in those disciplines concerned with explaining human behavior (economics, psychology, sociology, and anthropology) it has proven to provide marginal results at best. Deductively based approaches have certainly spurred new methods and new ways of looking at data, but the vilification of inductive research in some archaeology circles is unjustified. It is rather astonishing just how much we have actually learned about past societies through strict inductive research.

Nutritional ecology is primarily a tool to conduct inductive research and to generate inductively-based interpretations and explanations of the past, but it does have its predictive capacities as well. It is a model designed to interpret correlations between demographic trends and dietary intake. For example, nutritional ecology has been used in the study of Neanderthal extinction in order to model and interpret whether dietary differences between modern human and Neanderthal populations could have led to differences in the survival rates of women and children in these two populations (Hockett and Haws, 2003, 2005). Nutritional ecology essentially asks: did modern humans have a selective advantage over Neanderthals due to greater consistency in essential nutrient intake in the modern human populations? The framework may have relevance for understanding these specific correlations at both the micro-and macro-scales of analysis, although no assumption is made that macro-scale patterns are mere reflections of micro-scale actions. Quantum physics, or the theory of the very small, may hold lessons in the danger of linking micro-scale actions to macro-scale patterns. Nutritional ecology, however, can also inform on what is possible in human dietary choice (e.g., Hockett, 2011).

In certain cases, differences in energy consumption (or chronic energy deficiency) may help to understand demographic shifts in the archaeological record, but the nutritional ecology framework addresses macronutrient and micronutrient deficiencies or over-consumption equally well, so it is a more 'covering' paradigm than the PEM framework. For those who choose to focus on inductive research and incorporate current knowledge about the effects of essential nutrients on mortality and fertility trends, nutritional ecology offers an alternative to PEM in archaeological theory building.

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2

An Integrated Implementation of Written and Material Sources – Conceptual Challenge and Technological Resources

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1. Introduction

The potential of new technologies in informatics and communication opens great and unrevealed chances in the procedures for developing historical research. This challenge is as much concerned to the instrumental aspects of research as to the opportunity of carrying out multidisciplinary and teamwork researches within a completely new framework for the implementation of information.

When trying to benefit from these chances in technology, researchers are expected to make some changes in research that actually overcome the mere use of technological media. In fact, the matter to discuss is not the creation of new tools, but an innovative conceptualization of historical research overwhelming the discursive fragmentation coming from the different sources in use depending on their archaeological or documental nature. Unfortunately, the confusion between *speciality* and *discipline* still imbues a considerable part of historical works.

On the other hand, dealing with the incorporation of the great potential of the new technologies to the historical research without overcoming this fragmentation we are speaking of would lead us into a simple technological fascination, and would add a new element of disorder: the confusion between the *tool* and the *goal*, which would not help to improve the research quality and efficiency at all.

Consequently, the standpoint that we will articulate our thought from leads us before anything else to the identification of the "raw material" for the historical research. In our theorization this raw material is just the information, whatever is the source that provides it. It means that the dichotomy between archaeology and written sources disappears because both of them are sources for us to obtain historical information. But, what are we speaking about when mentioning the terms *historical information*? To answer this question we need to talk about two key concepts: *time* and *change*.

Perhaps the concept of time has not deserved among scholars the required attention, maybe because of the confusion between time and chronology or maybe because of the consideration of time as an absolute independent magnitude that acts as container of phenomena. This understanding has revealed itself as an insufficient and useless concept.

What we are looking for through the historical research is the identification and characterization of a sum of factors such as environmental, ecological, economic, social, cultural, political, etc., that are conditioning human life within a particular period of time. By means of this characterization of factors we aim to define and set up a model to detect and measure the permanence in front of the change. This rhythm or cadence between what happens before and what comes later is what can be understood as historical time[1].

As mentioned before, the conceptual confusion between speciality and discipline has been quite an unsolvable barrier when trying to define work methodologies in order to make the processes of recuperation, register and exploitation of information work as integrated elements, leaving aside the nature of the sources whether they are archaeological or documental evidences. Consequently, one of the main objectives of this proposal is to design an integrated system for the implementation of information that enables to consolidate a real network of scholars working in a multidisciplinary way.

Accordingly, we aim to present the conceptual and methodological concept to make this possible followed by an exemplification of its development in a second step: the study of landscape and its evolution, archaeological register, documental data exploitation, study of archaeological materials, etc. This process is needed to be strongly linked with the possibilities of new technologies and that is why we present as well some concrete experiences for each application.

Furthermore, this exemplification pays special attention to some pieces of information that sometimes have been considered to be worthless or insignificant from an historical or archaeological standpoint in order to show some satisfactory results obtained from the application of the proposed methodology and tools. We also will discuss about the optimization of the research works by incorporating new technologies.

2. The conceptual and methodological framework

2.1 The theoretical context of archaeology

The work of Edward C. Harris *The stratigraphic sequence: a question of time* (Harris, 1975), which was soon enlarged with the publication of *Principles of archaeological stratigraphy* (Harris, 1979), marked a turn point in the movement of methodological change in archaeology by resetting the main objective of the archaeologist's work. The title of his first abovementioned article, although it was a brief work, clearly focuses the attention in the keyword of his thought: the importance of time as central element in the archaeological study. Particularly, Harris sets up the identification, register and analyses by means of temporal relation diagrams (matrix) of what he calls Stratigraphic Units as the axe of the archaeologist's activity. We can concisely define Stratigraphic Unit as the evidences or remains of actions succeeded in time, whatever they are stratigraphic layers, erosive processes or destruction remains. Again we are speaking of permanence and change.

Within this insight, Harris not only offers a major contribution to the definition of register systems in archaeology but he rearranges the position of archaeological studies in the context of historical research. Strata, structures, objects, etc., gain significance as they contain

[1] To deep inside this matter of historical time, see Aróstegui: 1995.

by themselves evidences of actions that took place in a concrete time. From this standpoint, the work of archaeologists and the register systems become more objectives and give an answer to the main exigency of science in general: the possibility for other scholars to read again and reinterpret the data, if needed. Consequently, we take into account that Harris does not focus in chronological aspects when speaking about time, which has been always one of the interests of archaeology from many years before, but in the temporal information provided by the relation between different Stratigraphic Units, represented into a matrix.

> *"As it is concerned with people and artifacts from pas societies, archaeology is a four-dimensional discipline dealing with observation of physical (three-dimensional) remains throuh time" (Harris, 1992:100). "The goal of archaeology... is to produce historical knowledge; it does mean, to produce properly contrasted information about the structure, the running and the changes of human societies. Consequently, this objective is just the same that those of scholars that carry out their research uniquely by means of written sources. Archaeology produces knowledge from the archaeological register and prospection without leaving aside written sources, which are seriously limited. The archaeological register as well is limited."* (Barceló, 1988:11; translation by E.Travé).

These considerations have a direct consequence: the fact that the study of objects and architectural structures must not be dissociated from or prevailed above the information around them in the research process. Furthermore, the value of a stratigraphic unit must neither be prevailed above another one. In a similar way, the settlement cannot be considered as closed entirety, but it must be treated as a single sample to represent a whole that we only know partially and we always will; to some extent because of what we have convened to call settlement.

The study of the objects, building techniques, and architectural features, etc., is necessary and compulsory but has to be integrated within the knowledge of Stratigraphic Units and its historical significance. When considering these thoughts, we notice that historical research has turn out to be a four-dimensioned matter, instead or three-dimensioned one. As a result, the wrong assimilation between archaeology and excavation is broken and this new conception opens a new way to prospection or landscape studies and –what is more– the avoiding of random location and excavation of sites. Therefore research will overcome its false division depending on the specificity of the information source used.

2.2 The sources for historical research and its treatment

Unfortunately, historical studies built upon written sources have not get through a similar transformation as the one we have described for the field of archaeology. The neglect of information coming from archaeological sources is still too frequent in historical studies, especially when written sources are rich. It also must be taken into account this deficit related to archaeological research in periods with documentary evidence.

The improvement of words and expressions like information and communication technologies, P2P, Internet, network, implementation… and a long etcetera, could sometimes result overwhelming. In fact, we still wish for the renewal of language and working procedures according to the possibilities that these technologies really offer, coming through the simple turn of ancient ways of working into a new performance or the occasional use of informatics.

Certainly, the potential of these new resources and the high speed of their evolution might be shocking, but focusing on the problems we aim to solve instead of getting obsessed on these new tools by themselves is crucial to avoid this shock. As it has been said in the introduction, the main question to clarify is the articulation of an implementation system for processing information that makes possible simultaneously the enlargement of efficiency and cooperation and promotes scientific transparency.

According to these objectives, we are able to define the compulsory requirements for the perfect running of this implementation system:

- It has to allow an integrated management of the information whatever be the origin of the source.
- Historical sources must be able to be exploited at different levels and depths, without an enforced scale.
- There has to be the chance of registering spatial references.
- Spatial associations among different sources must also be taken into account.
- It has to gather chronological references.
- It has also to allow the description of successions, series or sequences.
- Contextualization metadata and the proper assessment of information must be able to be registered.
- The restitution of the original structure of the source must be allowed.
- Researchers must be allowed to share their work or to set up teamwork.
- The data independence must be assured respect of the computing platforms.

2.3 Some concepts for an integrated exploitation of information

Several paragraphs before, we spoke of the concept of information as the "raw material" for the historical research. We evidenced as well the range of sources to gather information from. In order to achieve the goal of an integrated implementation, we should describe a theoretical and instrumental framework that gives as some tools to process information. Let us outline in this subheading the theoretical body. We will use three key concepts that must be accurately defined:

- Topographic Units (TU)
- Actors (AC)
- Stratigraphic Units (SU)

In addition, we have to ensure the ability of registering and making use of the relationship that is likely to be between them.

Topographic Unit (TU):

The information gathered from historical sources is referred to the TU in the sense that every single fact has its place within a spatial and temporal framework, so as to be represented in space and time. All the variables composing a system and the oscillation of their values some time long will be considered as TU; and also the assemblage of Stratigraphic Units (SU) defining a whole phase of a settlement. Actually, the goal is not to register physical evidences only but facts placed in space and time. As a result, their identification with material evidences is not compulsory at all.

A TU has to be understood as the evidence of an action or situation that can be located in space and time, whatever is the specificity of the information source and its biotic, non biotic or anthropic origin.

Examples:

The existence of a vegetal specimen in a determined area; the documentary evidence of the consecration of a church; the documentary evidence of the transaction of a property; the archaeological evidence of a necropolis; the remains of a pathway…

Actors (AC)

TU and SU are the result of biotic, abiotic or anthropic activities. When these units are the result of anthropic activities, we have to identify the individual or corporative agents of these actions.

An Actor has to be understood as the individual or corporative protagonist of an action that has been identified by means of a TU or a SU.

Examples:

Ènyec Bonfill; the monastery of Sant Cugat del Vallès; etc.

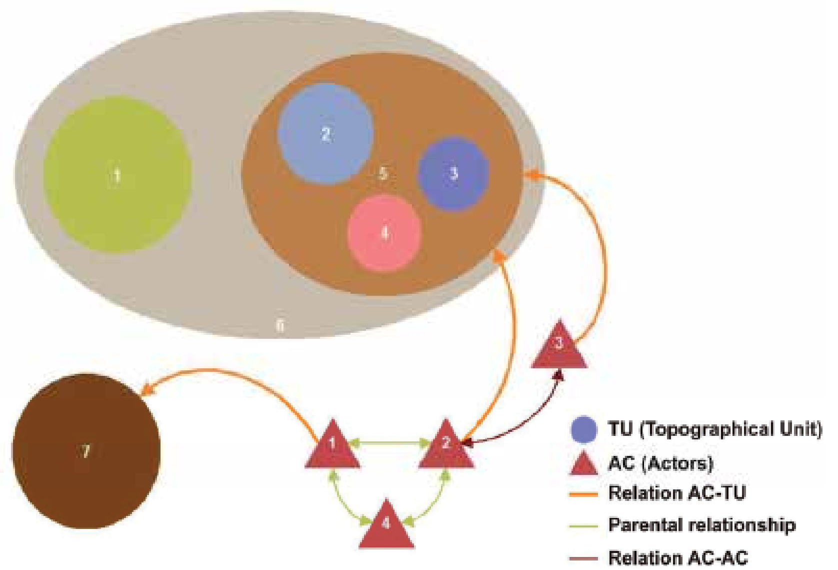

Fig. 1. This graphic shows a scheme exemplifying the relation between TU, TU and AC, and between AC. TU 6 includes 1 and 5, that contains at the same time 2, 3 and 4. None of them keeps any relation with 7. In the case of actors, 1, 2 and 4 are relatives whereas between 2 and 3 there is a transactional (buyer – seller) relation concerning the TU 5. Each identification number is unique for each TU and each AC.

Stratigraphic Units (SU):

SU are, as well as TU, the results of biotic or anthropic activities but they are always identified as a result of material evidence in an archaeological context.

A SU has to be understood as the material evidence of an action that can be located in space and time.

Examples:

The digging of a hollow for a burial, the building of a wall, the spoliation of constructive elements…

In each context, several relations are possible to be made: between different TU, between TU and SU, between both of them and AC and between different AC *(fig. 1)*.

3. The system of register and data assemblages

While the main objective is the integration of the information, it is true that the specificity of each source requires different procedures for the data identification. Therefore, written sources exploitation, archaeological prospection, studies of structures and buildings or archaeological excavation will require different methods.

In the following subheadings we show some examples in order to facilitate the comprehension of practical arrangements of what has been previously exposed: first concerning written sources and second with reference to archaeological sources. In this case, we will focus on the study of ceramic materials and its methodology. The register of spatially located TU and SU will be exemplified in subheading 3.3 by means of showing the database system and spatial registering.

It should be noticed, before deepening into the concrete examples, that those working cases proposed are part of a development still in process. Consequently, they not always show the integration degree exposed in the previous methodological discurse. Despite of this, the examples proposed are quite valid and claim to be a serious standpoint to to the data registering and exploitation.

3.1 The treatment of textual sources

Let us take as an example the document related to a sold (Puig: 1991. document 170). See on the transcription below the identification of different pieces of information and its classification depending on their correspondence with TU (numbered and remarked in purple) or AC (numbered ad remarked in green) as needed. We also highlight in yellow, the relations between them:

In nomine Domini. Ego Semplizia(1) et sorori mea nomine Cixolo(2), nos simul in unum uinditores sumus tibi Guilara(3) presbiter emptor. Per hanc scriptura uindicionis nostre uindimus(1) tibi terra(2) et uinea(3) et arboribus(4) et oliuaria(5), hec omnia francum nostrum (pro)prium qui nobis aduenit, ad me Semplizia per ienitores meos et per compara et ad me Cixolo per ienitores meos et per ullasque uoces. Et est hec omnia in comitatum Barquinona(6) infra termine de Terracia(7) in locum uocitatum Monte Agudo(8). Afrontad ipsa terra et uinea cum ipsos arboribus qui ibi sunt fundatos de oriente in aragallo(9) et in terra(10) de Godmar(4) et suos eredes, de meridie in terra(11) de Ego(5) femina, mulier de Eruiio(6) et de Guisado(7), de occiduo in uia(12) et in terra(13) de te emptor, de circi in terra(14) de Guisad(8). Quantum istas afrontaciones includunt, sic uindimus tibi ipsa terra el uinea et arboribus, in ipso aragallo ficulnea(15) I cum pruneras(16) et uides(17), in alios locos prunera(18) I et ficulneas(19) II et nogaria(20) et pecera(21) et glandifero(22) I et oliuera(23) I ab integre cum exios et regresios earum ad tuum proprium propter precium solidos VI et denarios IIII ex moneda grossa, quod manibus nostris

accepimus et est manifestum, et de nostro iuro in tuo tradimus dominio et potestatem ad faciendum quod uolueris. Quod si nos uinditrices aut ullusque homo qui contra hanc ista carta uindicione uenerit pro inrumpendum aut nos uenerimus, non hoc ualead uindicare, set conponad aut conponamus tibi oc quod supra insertum est in duplo cum omnes illorum inmelioraciones, et in antea ista carta uindicione firma permanead omnique tempore.
Facta carta uindicione VI kalendas februarii anno XXII regnante Rodberto rege.
Sig+num Semplizia. Sig+num Cixolo. Nos, qui hoc fecimus et firmare rogauimus. Sig+num Godmar. Sig+num Mir. Sig+num Issarno
SS. Ansemundo presbiter scripsit cum literas superpositas in uerso V die et anno quod supra.

The contents remarked on the transcription identify a sum of eight actors [AC], twenty-three Topographic Units [TU] and some complementary data such as the price, parental relations between some AC and the date. We have not registered three actors that appear at the bottom sign of the document, one of them being the scribe. It does not mean that these have to be omitted; we just exemplify the possibility of a partial register of the content, but always recording clearly what has been registered and what has not, and which labels have been adjudicated to each piece of information. Hence we make transparent the work onto the source, which allows coming back to the source later ourselves or any other scholar in order to enlarge what needed and extract data in a structured way in order to smooth the progress of exploitation.

TU and AC must be sequentially numbered. Therefore, TU are numbered in the example provided from 1 to 23 and AC from 1 to 8. When studying a new document, new TU and AC will take the following numbers, 24 for TU and 9 for AC, so as each element has a unique identification. The digital registration of this process is made by means of a database as the one shown in *fig. 2*. There we will see the unique identification of TU, its spatial

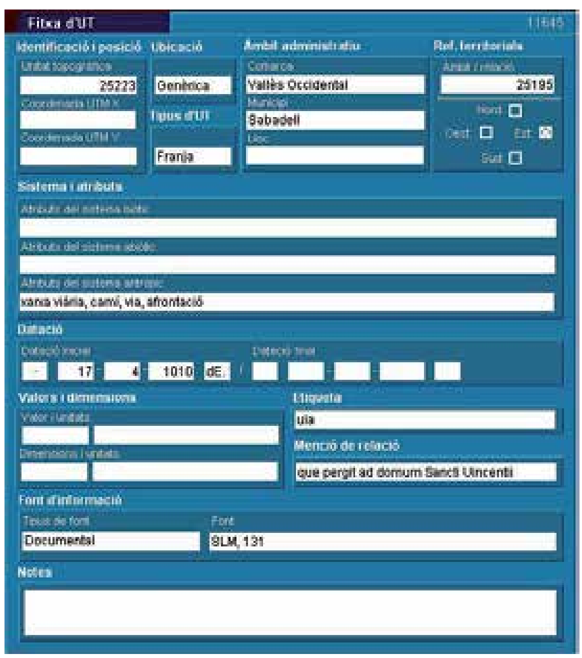

Fig. 2. TU register example.

location when possible, the territorial and administrative limits which it is included in, the relation with other TU, the attribute system, the date, etc. and the precedence of the source.

The link between a TU or AC register and a Geographical Information System (GIS) allows obtaining spatial illustrations *(fig. 3)*, crossing data between different sources concerning the same event or action and making spatial analyses. When speaking of integration and crossed data, we not only refer to the TU identified from written sources, but any kind of evidence. For instance, the existence of a church can be identified by the documentary evidences but also by the existence of the building. It actually means that the building is susceptible to provide a great assemblage of complementary data, recorded as TU and SU, by means of an archaeological and architectural approach.

AC register is made as well in a data base and the relations identified as a result of the information gathered from AC and TU are also registered in the same way.

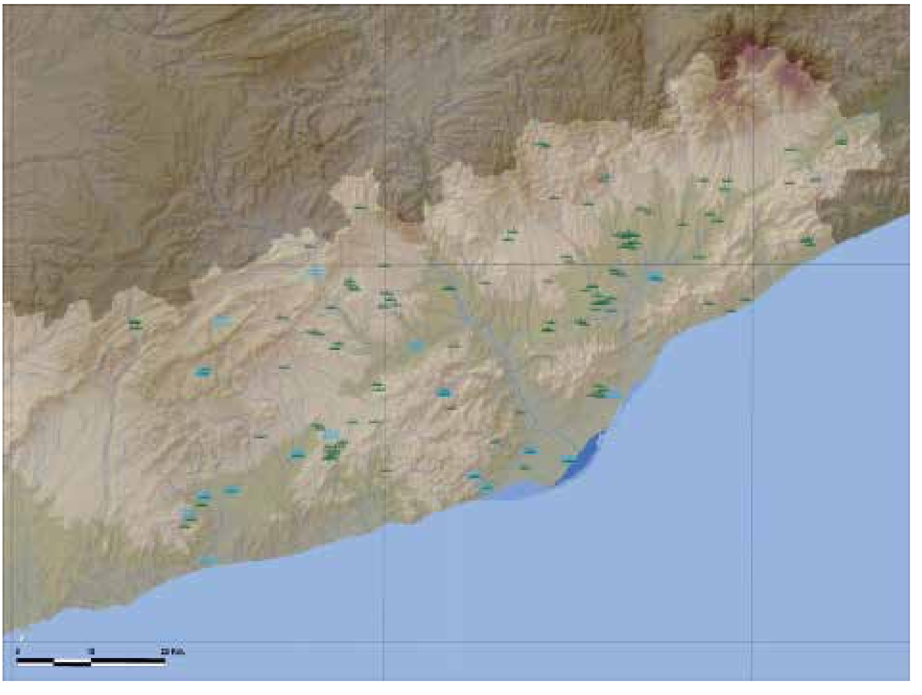

Fig. 3. View of the spatial distribution of written references to meadows and lakes in the County of Barcelona at the end of 11th Century, obtained from the TU register. This distribution could be analized individually or crossed with other TU identified from documentary/archaeological sources, depending on the research interests.

3.2 The treatment of archaeological sources

The requirements of data integration to the perfect running of the implementation of the information system must be solved by designing and developing scientific tools which, as mentioned before, are still in developing process in order to be integrated in a whole system. So, let us now focus on the treatment of archaeological materials and we will keep the SU register for the discussion in subheading 3.3.

In our theoretical design, the detailed analysis of archaeological materials is also considered as a key element. Building our analyses upon a complete database, registering as many variables as possible from the element studied enables us to develop a real interpretative corpus of a settlement, frequently related to an insight of landscape studies. Therefore, we present and propose as an example a procedure for registering archaeological materials focusing on analyses and study of ceramic material.

3.2.1 Techniques for gathering information

The general classification of archaeological materials groups the whole collection in four general assemblages:

1. Specific ceramic materials,
2. Nonspecific ceramic materials,
3. Specific non ceramic materials and
4. Nonspecific non ceramic materials.

Each one of these assemblages is considered in a slightly different way depending on the potential of data exploitation that each sort of material is able to offer. In this sense, each one of the fur assemblages has a particular register *(fig. 4)*. Registering models for specific materials, whatever if they are ceramic or non ceramic, imply the need of linking one or several illustrations and photographs.

Fig. 4. Specific ceramic materials register example.

While the register of non ceramic materials follows a plain procedure, the study of ceramic materials requires the major effort because the grade of detail when analysing pastes. The main goal of this detailed register is to facilitate the research in a later phase: actually, when scheduling an analytical approach by means of Ceramic Petrography, X-Ray Fluorescence, X-Ray Diffraction, Scanning Electron Microscopy, etc., the sampling process is really trouble-free if we can search into a detailed database. Within a tight budget, promising results will be obtained and further analyses will rarely be needed if there has been a correct sampling before. For these reasons, we must distinguish between formal description of ceramics and paste analysis. On one hand, formal description includes the typological and morphometric study of specific ceramic materials and, on the other hand, paste's analysis is made with petrographic criteria both of specific and nonspecific ceramic materials.

We should bear in mind that, if it is actually true that paste analyses must be made both for specific and nonspecific ceramic materials, the procedure for each sort of ceramic is slightly different: In the case of specific ceramic material, each pottery sherd has an individualized register, whereas nonspecific ceramics are grouped in paste groups from the macroscopic observation, in our case with the help of a geologist 20x magnifying glass and a binocular.

Although nonspecific ceramic's paste description follows the same criteria than specific, nonspecific descriptions are usually made for more than one individual. That is why we choose a generic description focusing on the similarities and those features more representatives of the assemblage. These descriptions are generally included in the observations gap.

3.2.2 A registering procedure for specific ceramic materials

Once the general classification of materials has been done and nonspecific and non ceramic materials have been inventoried, it is time to proceed with the specific ceramic materials catalogue. A correlative inventory number must be given to each sherd after the SU number and a new record opened whose gaps must be filled in three different moments depending on the three phases of study described below. This proceeding considers as well the graphic documentation of the sherd obtained from photographs and archaeological illustration.

The steps we propose could be ordered as follows:

a. Sherd's identification and location: As it has been noticed before, each individualized sherd receives an inventory number formed by the settlement capitals followed by a dot and the SU number and followed by a dash and the correlative three-digit-form inventory number (Example: *SME.22-005*).
b. Sherd's description: This phase comprises the first approach to the material study properly speaking. The fields proposed in the database (material, category, type, preserved fragments, number or quantity, paste featuring, paste components, firing type, type of finishing, decoration, etc.) are related to the first insight of the sherds observed at naked eye, following traditional archaeological criteria.
c. Macroscopic analysis of the paste: In this phase, we ought to carry out quite a deeper approach to the ceramic paste with petrographic criteria, sometimes with the aid of a magnifying glass. The main goal of this phase –also called technical analysis[2]– is to characterize the materials in detail in order to facilitate a sample selection if required for further archaeometric approaches. In that sense, the main variables to be analyzed are in pottery pastes are (1) colour, (2) inclusions, (3) porosity, (4) clay matrix and (5) fracture.

[2] "The term of *technical analysis* describes the study of main elements of a ceramic paste allowing us to interpret the evidences of the sherd's productive process, opposed to formal and functional criteria, which pay attention to the result of the process, or what is the same, the pot itself. The technical analysis also looks for the provenance of pottery or the raw material sources. We consider as elements of the technical analysis those referring to the paste, the surface treatment, the sort of fracture and firing and the possible evidences of use." (Travé, 2009: 258).

Consequently, during the description and classification of pastes, we make an individual approach to the three key elements of pottery: inclusions, clay matrix and porosity, observed in hand-sample. Descriptions must summarize briefly the colour of the paste that allows us to determine the firing atmosphere; the nature of inclusions – type, abundance and sorting–, the features of porosity and the surface treatments, by using the terminology taken from mineralogy, petrology and soil micromorphology. As an example, to determine the sorting of inclusions we usually use the tables proposed by Compton (1962) and to determine the features of porosity we follow the guidelines proposed by Whitbread (1995).

d. Sherd photography: We usually take one or more pictures of each ceramic sherd. It must be taken into account that these pictures are not only a traditional element for obtaining data, but also a main tool for the archaeological draw because the final illustrations of ceramics frequently show pictures as a support to describe graphically the texture of the sherd paste.

e. Archaeological design: The technical drawing of the sherd at a real scale sets up the basis for the morphometrical study developed in the next phase. When speaking of archaeological draw, we can consider both the traditional hand-made design and maybe more sophisticated proposals. We will notice below the employment of a 3D digitizer for drawing ceramics, according to the use of digital and technological resources.

f. Size calculation and *vectorization* of archaeological designs:
   - Calculation of top, bottom, minimum and maximum diameter of the vessel.
   - Calculation of the minimum, medium and maximum thickness.
   - Calculation of the height (total, preserved or recreated).
   - Profile *vectorization*: The register file we showed before includes some gapes for data obtained from the generatrix line *vectorization*.

   We understand as *vectorization*, the method consisting on defining the generatrix of a vessel in function of a three-digit combination indicating the type of line that will be vectorized, followed by a five-digit number that will allow us to place on a plan the ends of the line and one or two turning points of this line, depending on the case. The five-digit number obtained allows us to get a quick picture of the line form in our brain and, consequently, a rough idea of the sherd's size and the information that can be gathered from it (Travé 2009: 219). This process is made by using a pattern as the one in *fig. 5*. We will not get into details about the measurement process in this chapter as the reader will be able to deep into it by reading the abovementioned publication (Travé 2009: 219 – 224). Anyway, we must point out that the obtained result is a digit combination that follows the scheme BCYXD, where B, C and D correspond to the definition of vectors outlined by the pattern and YX relate to a Cartesian coordinate (x, y) marking a turn point within the line.

g. Data arrangement: This seventh phase implies, to some extent, a previous and immediate stage to data analyses. This data arrangement, that will facilitate the results attainment in a typological view, starts from two sorts of arrangements that have to do one with another: morphometric tables and typology lamina.
   - Elaboration of morphometric tables: This type of tables can be considered as nothing else but a search in the database for all the ceramic material overlooking the references to pastes. As a result, what appear in these tables are the measures,

the vectorization results and optionally the chronology of materials. Morphometric tables are a useful tool to order data for further analyses.

- Preparation of typology lamina: Morphometric tables set up the basis for vessels ordination. They allow glimpsing the main groups of forms in order to show them joined in the same illustration. Each lamina must show a coherent group of materials generally at a 1:2 or 1:3 scales. They are the last step in the data publication and the most eloquent way to explain the materials analyzed.

3.2.3 Data analyses

The study of data obtained both from size measurements and vectorization procedure allows us to better order the materials in a more precise way and to make an approach to their fragmentation degree. Concerning typologies, the vectorization data arrangement in function of BCYXD combinations allows as grouping the materials in different clusters usually symbolized in roman numbers. This cluster analysis is an abstraction exercise in order to interpret correctly the results so that each cluster has particular features that make it unique, unitary, relatively homogeneous and clearly distinguishable from the others.

On the other hand, the detailed register of paste petrographic description and the grouping procedure imply a first approach to technical analyses that can be enhanced with further archaeometric analyses to go deeper into the materials. In that case, we should only search in the data base for the determined groups and select a proportional number of samples from each assemblage.

3.3 The databases and spatial information register

We have made reference from the beginning to a four-dimensioned archaeological research where the fourth dimension is time. This archaeological stand point is not different to the one for the entire historical research. Consequently, the integration tools to gather information have to offer a particular insight to the spatial significance of data assemblages. We believe that incorporating Geographical Information Systems (GIS) to the implementation system is the most suitable way to face the need of offering an integrated approach. We show below what is referred to this running, centred by the moment in the archaeological view, but with a coherent insight with the treatment of data obtained from other sources.

A GIS can be defined as an assemblage formed by the hardware, the software and the georeferred alphanumeric data. They are designed to gather, store, actualize, operate, analyze and reproduce these georeferred data overwhelming the concept of map understood as a graphic. Within a GIS, what we call map is a representation and analysis of information also from its significance and its spatial and temporal relations.

As a result, a GIS includes, on one hand, the facilities and functions of a relational database and, on the other hand, the particular facilities of assisted cartography and, to some extent, of spatial analyses.

Basically, a GIS can offer:

- Functions for the uploading of graphical, textual or numerical information.
- Functions for the graphic and cartographic representation of information.

- Functions of information management and running.
- Analytical functions.

Again, we need to remind the reader about the requisite of not fail to differentiate the tool and the goal, falling into the technological fascination. We never have to lose the perspective that what we have in front is nothing but a tool. A GIS gives a clear answer to a previously defined question that would be extremely difficult to reach without this tool, but the preceding interrogation must never be avoided.

Sometimes, some efforts to implement the use of GIS applications fail because of the profile overlooking of the users expected to execute this software. The high level of GIS complexity, the high learning difficulties and the great period of time between the data recording and the obtaining of first results sometimes are the main reason for researchers' abandonment. To avoid these errors, is fundamental to dedicate almost a 5 – 10% of the total cost of a project to the analysis, evaluation and planning.

Specifically, the risk factors in the development of a GIS implementation project are:

- Wrong definition of the system because of weak or poorly defined hypotheses.
- Difficulties on forwarding the changing needs of the GIS management.
- Unrealistic analysis of costs and benefits.
- Interest conflicts between different participants of the project.
- Incapacity to obtain the support of implied institutions.
- Wasted previous experiences.
- Difficulties in the continuous funding for long-term projects.
- Insufficient comprehension of the hardness and technical complexity of the project.
- Frustrated expectative on the selected system.
- Aiming unrealistic goals that do not take into account the material and human resources of the work-team.
- Overlooking from the beginning further enlarging of the GIS, which originates the creation of closed structures, hardly ever enlargeable.

3.3.1 GIS and archaeology

During latest years, GIS have been increasingly used in a considerable amount of both scientific and management disciplines. Archaeology has summed to this improvement and there are several pieces of research, proceedings of scientific meetings, workshops and publications that refer to the use of GIS in our discipline. Our objective is not to expose a detailed state of the art concerning this area as the reader could easily find some papers summarizing these efforts and pondering the experiences carried out during these latest years (Bermúdez, 2000 & Baena, 2003) for a deeper insight. Nevertheless, within the application of GIS to the historical studies, we are able to distinguish between two great approaches to GIS depending on the subject matter.

Spatial studies (Sáenz, 2000 & Palet, 1994) relating original patrimonial data with the landscape starting from a territorial data structure, usually from the physic environment. As a result, two different levels of data exploitation are linked: on one hand, the landscape and its variables and, on the other hand, the physical manifestations of the anthropic system. Usually, the technological resources used in this kind of research is limited to a GIS as a product, it does mean, commercial GIS software[3] where only the functions required for these approaches are used *(fig. 5)*.

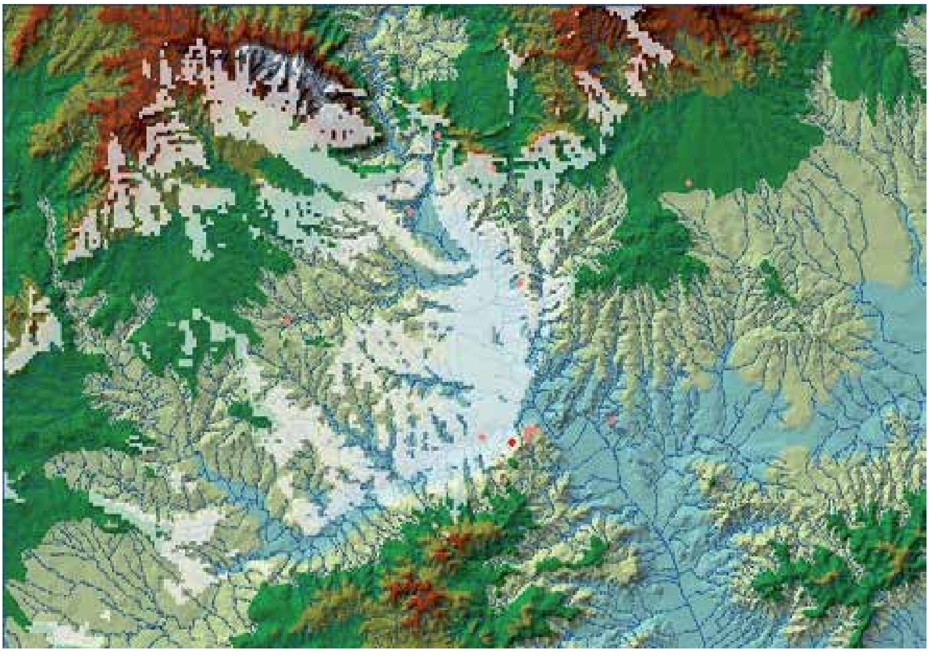

Fig. 5. Interpretation map showing a spatial study of the visual basin from the monastery of Sant Genís de Rocafort (Catalonia), made with a common commercial GIS.

Stratigraphic studies or management. In this case, GIS allow running the information produced in an archaeological fieldwork. In some cases, the common use of a GIS as a product is clearly overcome and specific applications[4] are developed in order to get a better data management or a better showing of results *(fig. 6)*. In that case is really interesting to bear in mind the open discussion (Duque, 2000 & Stallman, 2004) about the use of free software and open code[5].

We must bear in mind that our research is always based upon the information partially known about a preexisting reality. Consequently, the main goal of researcher is to shape the subjective reality they perceive when acting with an information source whatever its origin: the excavation of an archaeological site, the prospection in a determined area, the constructive sequence of a building, the evolution and transformation of a landscape…

Archaeological practices have traditionally focused on the settlement and its excavation. This framework has been progressively overcome by means of the application of non-

[3] Some commercial programmes are: ArcGIS (ArcView, ArcInfo), Mapinfo, Maptitude, Geomedia, Geoconcept, GenaMap, Autodesk Map, MicroStation Geographics, GeoWeb Publisher, SmallWorld, Manifold, Idrisi, MapPoint, TatukGIS, TNT mips, or MiraMon.

[4] Projecte Life Tiermes. http://mapas.topografia.upm.es/tiermes/arqueologia/; *SIA*+, GONZÁLEZ PÉREZ, 1997.

[5] Tax-free software: GRASS GIS, JUMP, MapServer, Quantum GIS, gvSIG, SAGA GIS, MapWindow GIS, Kosmo.

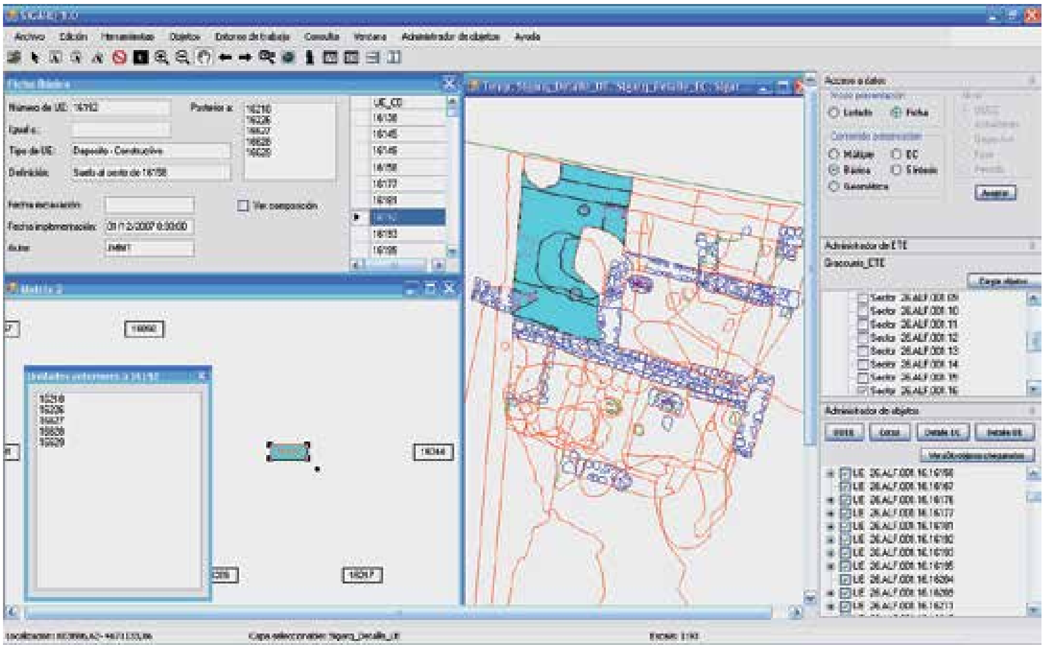

Fig. 6. Screen view of SigArq project showing the main issues in stratigraphic management. In this case, SigArq s.1.0., which will be explained in detail before, is a GIS specifically created to give a solution to the archaeological fieldwork running.

intrusive prospection techniques not only in a settlement area but also in extended regions, so as to generate a new sort of archaeological information that suits properly the concepts of TU and SU exposed above. The wideness of these works and the increasing number of excavated sites strongly require the implementation of new formulas allowing task sharing to the uploading, management and access to the information for a better scientific development of research and for a more efficient administrative running of heritage to its whole extent.

The project SigArq[6] (Archaeological Geospatial Information System) was born to offer an answer to these challenges. It aims to put forward a tool for the management generated in archaeological fieldworks, without regarding the nature of the heritage element to study, the scientific technique used –but also related to the concept of SU (Harris, 1979 & Carandini, 1997)–, the size or the chronology of the site. Furthermore it points toward the interrelation of archaeological sites between them and with the landscape within an extended period of time. Therefore, SigArq allows the management of information coming from archaeological fieldwork as well as prospection, territorial studies or landscape archaeology.

The goal is not only to facilitate the data collecting during the fieldwork but also guarantee their reliability and to give them uniform criteria allowing comparisons between data

[6] The project **SigArq** takes its name from the Spanish form "Sistema de Información Geoespacial ARQueológica"and it has been developed by two archaeological companies *Sistemes de Gestió de Patrimoni (SGP)* and *QarK (Arqueología i Gestión del Patrimonio Construido)* in association with the *Laboratori d'Informació Geogràfica i de Teledetecció (LIGIT)* from UAB and with the support of *Diputación Foral de Álava*, the *Gobierno de la Rioja* and the Town Council of Alfaro. For more information, visit the website www.sigarq.com.

obtained in different fieldworks. In other words, it looks for a group of recording standards, indispensable for the proper running of any work discipline aiming to be scientific (Carandini, 1997:3) and it does it by using common criteria, procedures and tools that allow an agile, easy, and trouble-free register.

The subjacent idea is that the archaeological site by itself is not the highest unit of register, so the boundaries of a settlement are not a barrier for historical research. Hence the integrated data management from many different settlements and fieldworks of quite a wide variety joint to the landscape will allow the transformation of mere data in historical knowledge. This knowledge is expected to be a new resource which could be exploited by public administrations in the framework of heritage management, research communities whose goals are historical and archaeological research and private companies needing a detailed awareness of the environment in order to design projects that might affect heritage elements.

Actually, the design of a tool for heritage management does not seem a new challenge as so many efforts have been done in this sense and some of them have really improved in the management of patrimonial data in a homogeneous way. Within this framework, which ones would be the innovations of **SigArq**? In our opinion, this project shows some incomes that would make it different from other attempts:

- According to the philosophy of its development and its authors, the distribution of this software will be tax-free.
- This project might be used by research groups and scholars with a tight budget that can find in this application a chance for synergy and collaborative tasks. Their experience and particular needs will enhance the possibilities of enlarging the project by including new functions.
- The uncomplicated software will allow GIS-non-specialized users to run an application designed by historians and archaeologists to satisfy their needs.
- This is also a tool for the administrative management of heritage, designed from an archaeological standpoint but taking into account the requirements from the administration in charge.
- Register systems have been standardized from a four-dimensioned perspective enlarged to the territorial components.
- An integral and integrated treatment both of the territorial and stratigraphic information enables the data exploitation related to all historical sources: archaeological register and documentary evidences.
- This application is structured into modules so as to develop this modular distribution in order to incorporate new modules if needed. For example, modules designed for the spreading of knowledge to a non-specific public could be incorporated.

From the beginning, this software has been designed for a two-dimensioned treatment of cartographic information. Our perception is that the vast majority of research projects will see fulfilled their purposes of management and spatial representation at this level. Despite of this, the project could incorporate 3D data exploitation as the main interpretation model proposed will not be questioned.

3.3.2 Database structure

We will not make a detailed explanation about the structure of the SigArq database, which would overcome the objectives of this chapter. Nonetheless, let us point out the main development lines, where the concept of TU discussed before structures and makes coherent the application design.

SigArq shows a series of information domains according to the language used by different user profiles and to their particular needs. The key elements always are TU or SU but specifically structured in order to solve different problems. The main information domains incorporated by this system are:

- Data related to people and institutions
- Territorial administrative data
- Fieldwork formalities and official procedures
- Territorial archaeological data
- TU register and management
- SU register and management
- Burial anthropological data
- Archaeological material data
- Analytical sampling data
- Stratigraphic synthesis data
- Stratigraphic sequence data
- Heritage documentary data

The idea organizing the entire arrangement is the archeological fieldwork understood as a systematization element, in other words, the application is not related to any particular object from the archaeological register but to a work process temporary limited (a process that has a beginning and has an end) and developed on a key element of the archaeological register (Parcero Oubiña, 1999:8). As a result, we bump into a TU contemporary to the research process that joins the entire data assemblage, structures it and ensures the wholeness of the information. Furthermore, the archeological register taken into account depends on the different sorts of fieldwork and all of them are considered:

- Territorial Fieldwork: It has to do with inventory, control and research processes without affecting the subsoil. This fieldwork is not constrained by the limits of a settlement and it is defined as a determined Study Area (SA).
- Preventive Fieldwork: It consists on control and evaluation approaches to areas that will be affected by performances non related to archeology. Their implementation may or may not affect the subsoil and its extension is not limited by the boundaries of a settlement. In these cases, we speak of an Affection Area (AA) whose limits are determined by the abovementioned non archaeological performances.
- Stratigraphic fieldwork: It is a research work in a determined archaeological settlement (SET). It can affect totally or partially the site and may or may not affect the subsoil. In any case it is always developed by using the archaeological stratigraphy to set up the basis for registering the fieldwork.

3.3.3 The protocol for stratigraphic register

The structure of the system proposed implied a review of the registering process from the beginning of the fieldwork. Consequently, the archaeological concepts and methodology used has been re-examined in order to get a better suitability to the information system. As a result, a new protocol for stratigraphic register has been created.

This protocol aims to regulate the process of gathering information from the beginning, by opening a new SU register until the integration of this register to the stratigraphic scheme. The main goal is to guide the user through this process by offering a batch of procedures that will gradually allow them to complete the registration task. In order to assure the concordance of data with the structure of the system and the particular requirements of the archaeological method, the user will find when needed some restrictions, obligations and register possibilities previously delimited. The objective is to reduce as much as possible the risk of introducing wrong or incoherent data.

3.3.4 The application's network

The particularities of the archeological discipline, in other words, the great amount of information obtained from fieldworks, their chronological extent and the wide range of people in charge of this data exploitation, make relevant the advantages of working into a corporative system. Developing all tasks in a shared framework enlarges extensively the meaning and significance of the information shared and contrasted by all system users.

To fulfill the main goals of this project a whole corporative network is set up to a net server that lodges the data from several research projects. This net server is managed by a principal system administrator, allowing the joint work of users geographically dispersed and offering the chance of working off-line. In this scenario we are able to define different kind of users with specific functions depending on their status within the general organizational structure. Broadly speaking we will distinguish between:

- Group users: These are the final users of the system. They are expected to develop all edition, analysis, search and publication tasks related to their own archaeological data when working off-line and they can obtain and process the data from their group when working on-line and once the group administrator has validated them.
- Group administrators: Each network has a person in charge expected to control the different versions of a work, to contrast the information and validate it before uploading it to the main net server and to make it available for all group users.
- Central administrator: They would carry out the administration tasks but at a final level that controls the entire network.

4. Digital and technological resources

4.1 Their use for keeping a record of stratigraphic units

The incorporation of digital technology to the topographic and photographic tools has opened a new range of possibilities in the procedures of archaeological register and data exploitation. The improvements experienced both in the phase of scientific approach and the spread of knowledge have raised levels never imagined before. Here we will briefly consider the application to fieldwork of topography and earth photogrammetry.

The availability of total stations able to read without prism by means of laser technology enlarges precision and reduces considerably the time spent during the fieldwork. We will not deep into its running, which may be well-known or easily found in specific texts. What we are interested in is the chances topography and earth photogrammetry and particularly, those resulting from the combination of both procedures.

Measurement by means of using a total station offers a data compilation easily exploitable with adequate software. In addition to the traditional plans of an archaeological site, this measurement allows obtaining digital models of the landscape suitable to feature a wide area and also to define the detailed SU register. As a result, new forthcoming approaches to three-dimensional graphics *(fig. 7)* could be explored in order to get a better representation of archaeological evidences.

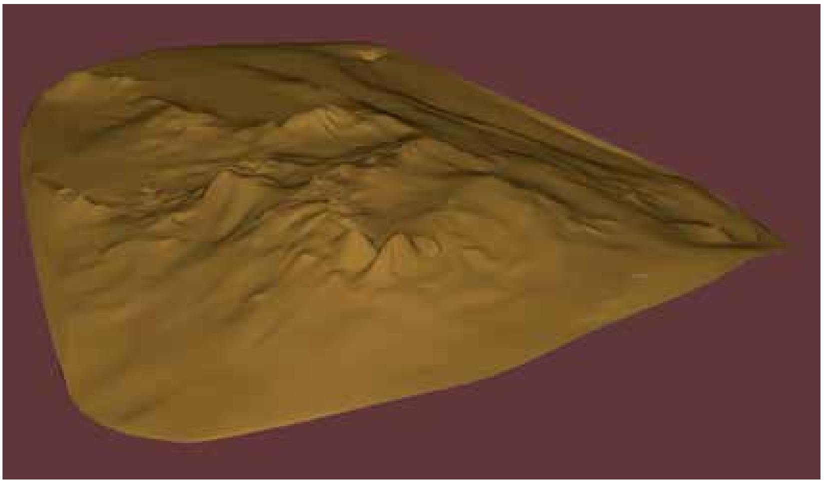

Fig. 7. Three-dimensional view of the archaeological site of Sant Llorenç de la Sanabra (Catalonia) obtained from the topographic measurement and registering of the area.

The development of new techniques related to digital photography allows obtaining orthoimages from traditional photographic equipment. This procedure consists on correcting (or "orthorectifing") digital images by using specific software such that the scale is uniform and the resulting orthophoto has the same lack of distortion as a map or an elevation draw. This method is applicable to the SU documentation within the archaeological excavation and also to the study and SU register when studying buildings *(fig. 8)*.

4.2 Their use for the study of ceramic materials

Finally, we would like to show another way to benefit from the use of technology applied to the study of archaeological materials as a tool to gather as much information as possible from pottery vessels. Designing ceramics through 3D Scanning and photography has been a turning point in morphological analyses of ceramic materials. This new way of drawing implies a considerable lessening for measuring and drawing tasks as well as data introduction in databases.

Our proposal suggests leaving aside hand-made draws and drafts and incorporating the use of a 3D digitizer to the daily designing methodology. In our case, we regularly use a 3D designing hardware *MicroScribe Digitizer* run by a 3D-image processing software *Rhinoceros 4.0. (fig. 9)*. Using this kind of software we are able to record with high reliability the vessels size and especially their diameters and proportions. Draws are generally made in two different moments clearly defined: (1) Profile digitalization and (2) vessel's image edition:

Fig. 8. Orthoimage of the main façade from the Castle of Penyafort (Catalonia) with the SU registers representation.

Fig. 9. Picture of a 3D *Microscribe Digitizer* (left) and view example or its employment (right).

- Profile digitalization: It is the key element for the vessel's digitalization. It is a measurement process by means of 3D digitizer in order to obtain the generatrix line of the vessel and their top, bottom and maximum diameters *(fig. 10)*. Obtained results are the basis for abovementioned profile *vectorization*. We strongly recommend saving these pictures in a double format: in 3DM format, used by *Rhinoceros* software, and in WMF format. This second one is easy to import from most of image processing software and will always be on hand as a common record for computers where Rhinoceros is not available.
- Vessel's image edition: From the generatrix line obtained and calculated diameters, we are able to obtain the archaeological depiction of a pottery vessel with the vast majority of image processing software[7] just following the traditional standards. Bear in mind that these illustrations must be exported to TIFF or JPG format for their incorporation to the database. It should also be taken into account that these pictures will be viewed from the database, therefore they have to include a scale bar and their identification number.

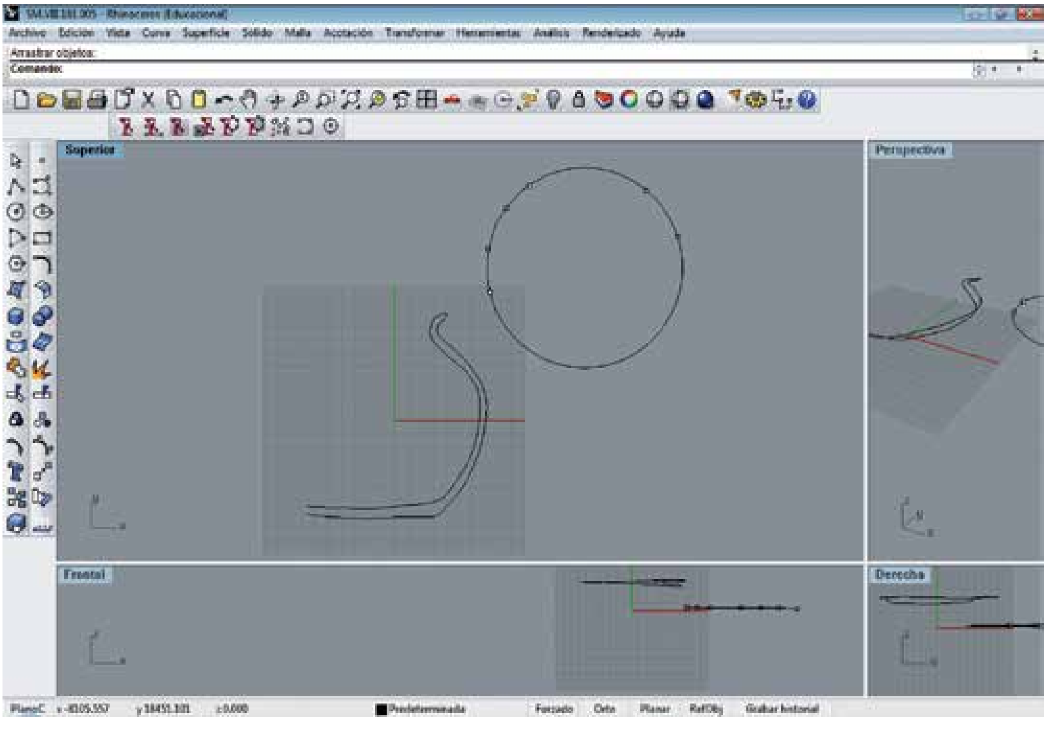

Fig. 10. Screen view of the result obtained from the digitalization of a pottery vessel's generatrix line and its diameter.

When possible, it is really interesting to enrich these depictions with the photography. We cannot forget that photographs are the best way to solve a minor lack of 3D digitalization, which is the ornamentation. To make possible the incorporation of a photograph to an archaeological vessel depiction, there are some practices to keep in mind during the photography session:

[7] E.g. Adobe Illustrator, CORELDraw, AutoCAD, FreeHand, etc.

- Two types of photographs are needed: what could be named *traditional pictures* and what we call *front view*. The first one is a photograph that will not be modified or used for anything but the real view of the pottery sherd (or any other archaeological material). The second one is a photograph that will be incorporated to the archaeological depiction by cutting off the vessel profile and removing the background *(fig. 11)*.
- To take traditional pictures, we always have to include in the scene a scale bar and a label with the sherd's identification number. The background must be clear and as much uniform as possible, trying to place a back color clearly distinguishable from the sherd.

The *front view* is the picture that will be incorporated to the archeological depiction, so the only rule to consider is that the sherd must be correctly placed in order to take a picture from the frontage. Remember that the background will be removed, so do not hesitate to use any support as clay, for instance, to secure and fix the sherd.

Fig. 11. 3D-Digitizer-made archaeological depiction of a ceramic vessel with and without front view.

5. Conclusions

We strongly believe that the outlining of a methodology that allowed incorporating territorial and written evidences from an archaeological standpoint was a much-needed effort. To sum up, we searched for an integrated management of historical sources broadening the mere settlement or monument interpretation and looking for a further use of cartographic tools.

The difficulties to obtain and interpret archaeological information and the dissemination of written sources and published studies imply a great inefficiency of research processes. That is why we are forced to look for solutions and take advantage of new communication and information technologies. Once we have planned a regulated and integrated register, researchers are able to set up new team work formulas where each scholar contributes to the system enlargement instead of working by oneself; and this is the only way to transform juxtaposed information into an integrated resource to increase research efficiency.

What could have been a high-priced proposal some years ago now is an available organization model by using daily technological facilities. Information management processes, database running, GIS and network information spreading are easily shared by the Internet and common software. Technological development gives an incomparable chance to optimize time and to work faster and more precisely.

This process is what we have tried to exemplify. We actually are not able to present a completely developed schedule, but a conceptualization in process where the precise definition of concepts allows developing a new methodology and the employment of new tools enlarges efficiency and efficacy without leaving aside research objectives. As a result, we aim to consolidate archaeology as a scientific discipline in order to reduce conflicts when intervening in urban environments and to potentiate divulgation, which will significantly contribute to a better understanding and social concern about heritage.

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Section 2

The Use of Geophysics on Archaeological Fieldwork

3

Geoarchaeology of Palaeo-American Sites in Pleistocene Glacigenic Deposits

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1. Introduction

Initial prehistoric peopling of the Americas is one of most discussed archaeological themes. The Pleistocene human occupation of the continent predating the well-known Palaeoindian cultures that suddenly emerged after 13,000-12,000 years ago is still a rather problematic if not controversial for many American archaeologists. The traditional model envisages a one-wave migration of modern people from northeast Asia across the exposed Bering Land-Bridge and represented by big-game hunters equipped by sophisticated fluted bifacial stone projectile points that decimated in few centuries the Final Pleistocene megafauna. Their expansion onto the Western Interior Plains south of the continental ice-sheet is perceived as linked with re-opening of the „ice-free corridor" - an unglaciated land in the upland prairie along the eastern flanks of the Canadian Rocky Mountains. Its existence has been viewed as a major precondition for the southern movement of the Palaeoindian groups from Eastern Beringia, i.e. the ice-free Alaska and the western Yukon Territory (Fagan, 1987). This term was introduced to explain the sudden appearance of the archaeologically distinct Clovis bifacial projectile point tradition at the very end of the Pleistocene (Haynes, 1980; 2002).

The emerging scenario arguing for a "pre-Clovis," or a pre-13 000 year-old Palaeo-American occupation, implies an earlier date of the initial entry to the New World during some of the climatically moderate Pleistocene stages with the sea-shelf palaeo-geography of low-water levels connecting the Chukotka and the Alaska Peninsulas. Just because of the exceptional nature and unusual geological contexts, that may imply a high age of potential early cultural sites, some reservations and reluctance to accept evidence that does not fit the long-established culture-historical paradigm may still persist. There is a general tendency to question, often by using very simplistic arguments, the potentially early cultural records represented by rudimentarily flaked tools from controlled stratified positions, just because they may differ from the well-known cultural manifestations such as fluted projectile points.

The views on the earliest North American prehistory may be partly challenged in the light of some recent discoveries (Waters et al., 2011), but this seems to be a slow process before the once-trendy "Clovis-first model" is fully dropped. There is no reason to discard earlier cultural evidence that complies with all the standard archaeological, contextual and dating criteria routinely applied at the Palaeolithic sites in Europe, Africa or Asia. In fact, there may be no problem with the archaeological authenticity of some of the potential "pre-Clovis" American sites, but at the first instance, with a limited experience and training of the opponents lacking the requisite background in the Palaeolithic studies and the stone-flaking techniques. The absence of rigorous scientific and data-supported arguments addressing the well-reported Pleistocene cultural records represents a certain form of the North American culture-anthropological folklore (e.g., Driver, 2001). Contrary to the European schools where the Pleistocene studies are in-framed in the multi-disciplinary Quaternary investigations, the North American archaeology is traditionally a part of cultural anthropology with very weak if any ties to Quaternary geology. This fact may result in incapability to locate and evaluate objectively the potential Pleistocene cultural evidence, particularly if manifested by simply worked lithic implements in unusual and/or deeply buried old geological contexts. A survey for the Palaeo-American sites in the Pleistocene geo-settings, radically different from the presently studied, may thus still be problematic for some archaeologists because of the long-lasting traditional models and perceptions on the initial peopling of the continent.

The northern part of North America was repeatedly glaciated with ice covering the areas of plausible (or sometime the only possible and passable) spatial movement such as the NW coast of British Columbia and the western Alberta prairies (Fig. 1). Despite a certain progress in the earliest American studies indicating human presence in distant regions on the Great American Plains between 15 300-13 000 yr BP, i.e., prior to the Clovis complex (McAvoy & McAvoy, 1997; Adovasio et al., 1990, 1998; Webb, 2005; Holen, 2006; Joyce 2006; Collins & Bradley, 2008; Gilbert et al., 2008; Lowery et al., 2010), no consensus has been reached about the timing of the initial human migrations entering the Americas, the level of technology and the associated typological variety of stone tools the early inhabitants of the new continent brought with them. The North American archaeologists still tend to look for assemblages with bifacial or micro-blade flaking patterns in geologically recent deposits, assuming a possible continuity with the Siberian Upper Palaeolithic projectile point and palaeo-Arctic technologies, respectively, or follow possible evolutionary links with the Clovis complex in immediately timely preceding archaeological inventories (Waters et al., 2011). On the other hand, there is still a persisting and unfounded resistance to the notion that there could be anything earlier on the Upper – Middle Palaeolithic technological stage.

This reluctance to accept cultural evidence consisting solely of crudely flaked tools, which are radically different from the easily diagnostic stone projectile points such as Clovis and the associated lithic complexes, is one of the main reasons for the debate. The situation is more complex, since in eastern Beringia (Alaska and Yukon), where the oldest cultural evidence would be anticipated, the earliest archaeological manifestations recorded so far relate to the Palaeo-Arctic Tradition with micro-blade stone industries linked to the east Siberian Dyuktai Culture. The earliest local stone projectile points date to about 11 700 yr BP (Hoffecker et al., 1994, Kunz & Rainier, 1994). This fact largely reflects the research focus on shallow, near-surface final Pleistocene / early Holocene geoarchaeological contexts, but not on earlier deposits, and illustrates difficulty to recognize cultural records with more simple stone-flaking technologies (Dixon, 2001). These rudimentary modified lithics, however, would normally be accepted as humanly made if found in a contextual setting on or close to the present surface chronologically post-dating 12 000 years as it is the case with most "postglacial" prehistoric sites in North America (Chlachula & LeBlanc, 1996). A refusal of a Pleistocene-age cultural evidence on these grounds is therefore fully unsubstantiated.

In fact, simply flaked core and flake stone artifacts represent the most abundant form of archaeological remains in the Canadian Interior Plains and possibly other areas as well, because of their time-cultural technological indifference and a high preservation potential. In the study area of western Alberta, similarly as in North Siberia, pebble tool assemblages are chronologically distributed in varying proportions to other types of cultural material in all archaeological cultures throughout prehistory and persist until the historical times (the 18th and 19th Century). The broad geographical and chronological distribution of these (occupation or workshop) sites with such implements is accentuated and typified by exploitation of widely available raw materials, mostly of quartztose rocks, derived by fluvial and glacial processes from the Rocky Mountains. Yet, probably because of the high frequency of occurrence and association with the more eloquent archaeological inventories (such as elaborate stone tools made on exotic raw materials, ceramics or metal objects), there has been much less attention paid to these marginal cultural lithic assemblages and for most archaeologists less attractive finds. Although time-transgressive in both the mode of production and the resulting forms, the rudimentary flaked core and flake industries, however, encompass more than 99% of human prehistory in both the Old and New World.

In this perspective, particularly the most durable instruments made of stone thus logically provide the key information about all these issues related to the early American adaptation to the new environments. One of the principal problems concerns the recognition of these artifactually flaked lithics and other cultural remains deeply buried under or within glacial and glacigenic (glacial setting-associated) deposits presently extensively distributed as surface-exposed or covered in the formerly glaciated areas of the Pleistocene Beringia. This fact largely reflects the lack of appropriate geoarchaeological investigations focusing on field survey and research of early prehistoric (Palaeolithic) American sites deeply buried under the present surface, as well as on the contextual Quaternary research and the related geomorphological, stratigraphical, sedimentological and rock-mechanical investigations. Introduction of innovative and open-minded geoarchaeological research techniques and strategies incorporating glacial geology and Palaeolithic archaeology, and a more active role of natural sciences (substituting speculative culture-anthropological discussions) may thus significantly contribute to elucidation of the earliest New World prehistory (Bryan, 1986). For *early* sites must be searched in *early* geological formations! This very simple idea, applied routinely in Africa, Europe and Asia (including the gateway to the Americas – Siberia), seems not to be fully compatible with the American archaeological thinking.

The archaeological material recorded *in situ* in the (pre-glacial, i.e. pre-Holocene) geological context in Eurasia and Americas may also deliver a significant source of proxy data on the past climates and climate change in areas of the Northern Hemisphere that experienced the Pleistocene glaciations, in terms of their timing and the geographical extent. Investigations in Alberta, west Canada, at the Palaeolithic sites sealed by thick (10+ m) deposits derived underneath or close to the continental ice-sheet and the Cordilleran valley glaciers during the last glacial stage have provided the first definite evidence on the palaeo-American occupation of the foothills and the adjacent plains east of the Canadian Rocky Mountains as well as the local extent of the ice during the Last Glacial Maximum (ca. 21 000-18 000 yr BP).

Although any potential "pre- glacial" archaeological record pre-dating the Last Glacial internal (24 000-12 000 yr BP) may be taken with some reservation because of the rather unusual geological context producing flaked lithics of a rude unsophisticated cultural oblique (which are normally accepted as humanly made if found in a setting on or close to the present surface, as it is the case with most Holocene prehistoric sites in North America), multidisciplinary contextual studies can confirm not only the cultural character of these findings, but provide a significant palaeogeography and palaeoenvironmental information which cannot be drawn from the geological record alone. Because of the nature of this cultural evidence, the methodological intellectual background for the field investigations should imperatively entail both the Old World-style Palaeolithic archaeology as well as the Quaternary geology. Particular attention should be paid to complex contextual and palaeo-ecological aspects of early site investigations that relate to provenience of raw material used for production of stone tools, the site stratigraphy and chronology, and the Quaternary environments and related past climate change. Pioneering investigations at the pre-glacial Late Pleistocene occupation sites in western Alberta have produced a clear evidence of early human presence of this part of North America long before the appearance of the traditional Palaeoindian cultures on the Great Plains, which may be regarded as one of the earliest manifestations of the prehistoric peopling of the New World (Chlachula 1996a, 1996b, 1997; Chlachula & Leslie, 1998). The multidisciplinary geoarchaeological studies, implementing the "pre-glacial" geoarchaeology concept thus open a fundamentally new and broad niche of geoarchaeological research in completely unexplored geological formations extending over the vast and formerly ice-covered areas of the Northern and Southern Hemisphere. Open mind is equally important as a professional training and introduction of flexible methodological approaches and analytical techniques (Chlachula & LeBlanc, 1998).

This contribution provides some perceptions on the geological contexts, methods and approaches of the geoarchaeological investigations of the Late Pleistocene cultural occurrences associated with deeply buried geological contexts, following the pioneering research of the pre-Last Glacial Palaeolithic occupation sites in Alberta, west Canada (Fig. 1). It also raises some principal issues relating particularly to fieldwork strategies dealing with archaeological evidence embedded by Pleistocene geological processes, more particularly in periglacial or glacial settings. Although these are discussed on the example of the cultural sequences from Canada, the methodological aspects and field reconnaissance implications are valid also for other formerly glaciated regions of northern Eurasia. The chapter brings up and highlights some fundamental questions that are overlooked or ignored by many North American researchers, bearing on identification of the potential artifactual remains in various geological contexts of diverse ages and genesis. In conclusion, it is argued that a high number of Palaeo-American localities can be readily found sealed in deeply stratified formations by using the standard "Old World Palaeolithic" survey techniques, despite the fact that some of these locations were subsequently exposed to major erosional processes and/or redeposition, but still may deliver undisputable traces of actual human presence antecedent of the Clovis horizon and other Final Pleistocene Palaeoindian complexes largely clustering in the south-western portion of the U.S. Most of the photographs from the field research in the principal study area of western Canada carried out in 1990-1998 are here published for the first time in order to demonstrate the authenticity and technological range of the Alberta Upper Palaeolithic Complex. This should give an impetus for new systematic Quaternary geoarchaeology studies aimed at cognition this fascinating prehistoric period.

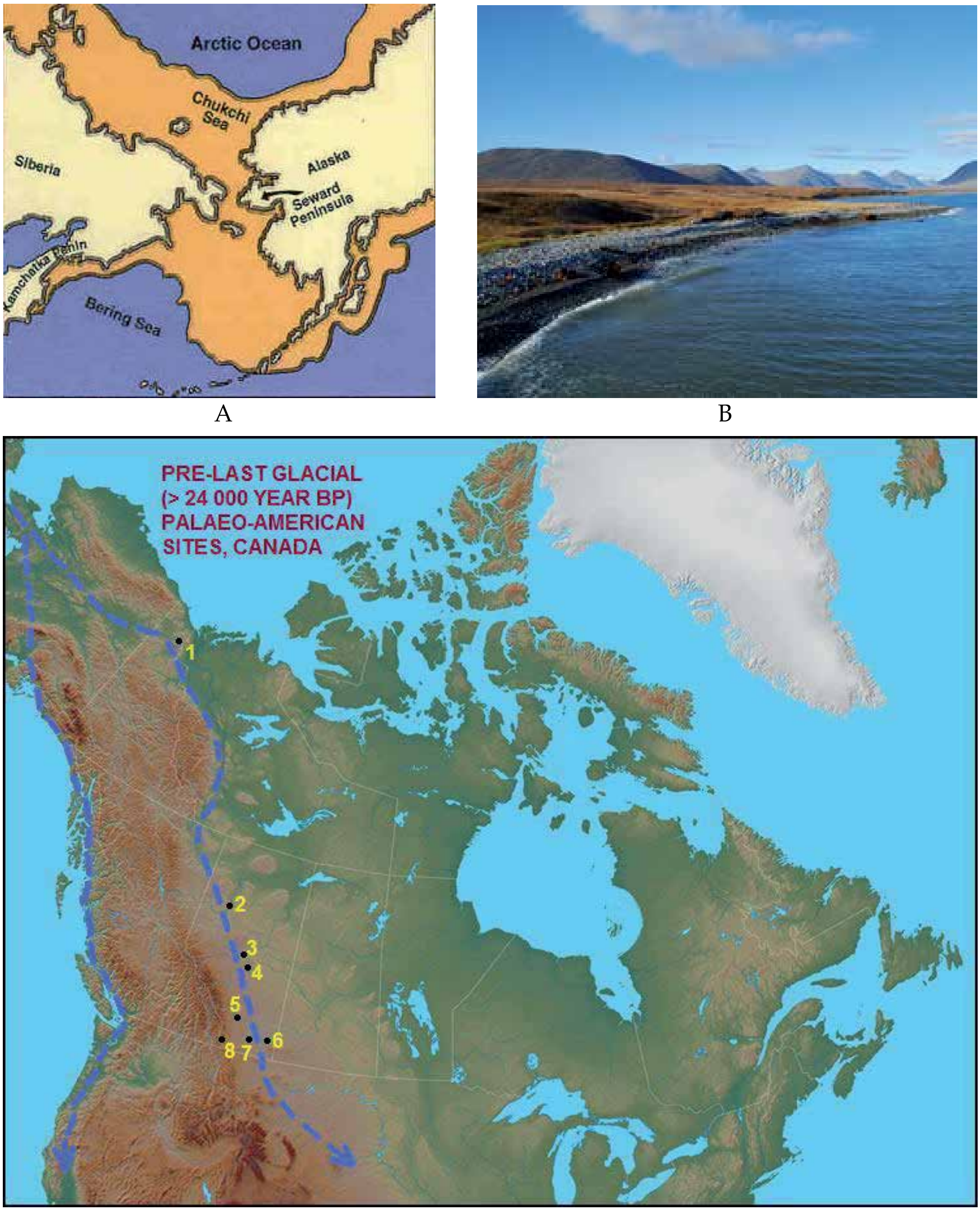


Fig. 1. A. Geographic map of Beringia (the exposed Bering landbridge) during the last glacial; B. present Bering Straight environment (Chukotka); C. Geographic dispersal of people from NE Siberia to North America along the eastern flanks of the Rocky Mountains (the interior route) and the NW coast, with location of the Palaeolithic occupation sites (1. Bluefish Cave, north Yukon; 2. Grimshaw, 3. Villeneuve, 4. Edmonton-Riverside, 5. Calgary - Silver Springs & Varsity Estates, 6. Medicine Hat, 7. Lethbridge, 8. Eagle Cave, Crownest Pass, Alberta).

2. Contextual studies of the Palaeo-American occupation sites

2.1 Methods and approaches

Investigations of deeply-buried archaeological sites in unusual geological contexts, such as glacial and glacigenic settings, pre-requisite adequate knowledge of corresponding research methods ad approaches that may differ to some extent from the standard techniques applied at most American prehistoric localities that have been documented until know. Awareness that a *different* kind of archaeological records in *different* and till now undiscovered and fully unmapped contexts may actually exists is *a priori* a main pre-condition for objective, matter-of-fact perceptions of discoveries that are not in compliance with the established culture-historical paradigm on the initial peopling of the New World. Although the methods and approaches may not be dissimilar to those routinely applied at the Old World Pleistocene archaeological sites (e.g., Chlachula et al, 2003; 2004; 2011), their elaboration and adjustment to particular on-site geological, geographic and environmental conditions may be necessary.

Because of the contextual positions of the potential early cultural Palaeo-American finds that may be buried up to several ten of meters under the present surface (opposite to shallow-sealed sub-surface sites) (Fig. 3), these should be treated and evaluated primarily by geology and stratigraphy standards analogously as "trace fossils" for establishment of their original / secondary contextual positions, age and (post-)depositional and/or taphonomic histories. Quaternary geology studies, knowledge of physical properties of raw materials applied for stone tool production, anthropogenic/natural lithic flaking and use-wear analyses are of utmost importance for demonstrating cultural authenticity of these sites and records (Chlachula, 1994a; Dillehay, 1997). Introduction of well-defined geoarchaeological research strategies incorporating glacial geology and Palaeolithic archaeology, and a more active role of other natural sciences can thus significantly contribute to elucidation of the earliest human prehistory in the formerly glaciated regions of mid- and high latitudes.

In the frame of the initial investigations of the Palaeo-American ("pre-Clovis") sites in western Alberta, Canada, the geoarchaeological research carried out in 1990-1998 focused on establishment of the locality chronostratigraphic framework with 10-25 m buried cultural horizons in terms of sedimentary environments, contextual occurrences of diagnostic lithic industries and chronology of the artifact-bearing deposits (Chlachula, 1994b, 1996a, 1996b). Stratigraphic studies and the local palaeoenvironmental reconstruction at the pre-last glacial (> 20 ka BP) localities from the western interior plains provided fundamental information on the technological characteristics, the geological context, and a relative age of the Palaeolithic stone tool assemblages. For the field documentation of sedimentary geological structures, several criteria were applied to differentiate between deposits of a glacio-fluvial and glacio-lacustrine genesis, specify their sedimentological history and palaeo-current direction, and provide the site stratigraphy control. Particle size analyses of shape, size and the lithological composition of clasts (sandy-gravel deposits) was applied for a lithostratigraphic correlation of deposits and study of the dominant mechanism of sedimentary transport and deposition (Gale & Hoare, 1991). Fabrics (orientation of sedimentary particles), primary / secondary textures of deposits, principal physical characteristics of each sedimentary unit and forms and surface texture of selected rocks in sedimentary units provided together with the directional measurements information on current flow of clast-supported and fine-grained laminated sedimentary structures. Finally, a genetic assessment and stratigraphic correlation together with a contextual interpretation of individual sedimentary facies was performed.

A B C D E F

Fig. 2. Present landscapes & ecosystems of NW North America. A. the North Cordillera range ice-fields (the Kaskawulsh glacier, the NW St. Elias Mountains, Yukon); B. sub-arctic forest-tundra, central Yukon; C. mountain boreal forest (Emerald Lake, the Watson River basin, SW Yukon); D. mountain desert (Carcross Desert, SW Yukon) – sand deposits of the last-glacial Lake Bennett; E. mountain valley (the Bow River valley, southern Canadian Rocky Mountains, west Alberta); F. semi-arid prairie (the Oldman River, southern Alberta).

The palaeogeographical setting at all the sites is reconstructed from the geological record and comparative studies of actualistic sedimentary (fluvial, colluvial and glacial / glacio-fluvial) processes and their facies in various sedimentary environments in Alberta. Genetic analyses of the past sedimentary settings from the study sections constitute a crucial component for determining mechanism of flaking /edge damage of the lithic assemblages. Application of the general concept of sedimentary facies models is thus a prerequisite for the reconstruction of the dynamics and interaction of natural forces acting during deposition of sediments in a particular environment (Fig. 2) and assessment of their kinetic potential for simulating cultural stone flaking patterns. The past depositional geological environments reconstructed through facies models (Harms et al., 1982; Reading, 1989; Walker, 1986) provide key information about the palaeoecology of the study area. Internal textural and structural changes within a particular facies sequence controlled by shifts of the local sedimentary environment are evident in the grain size distribution, thickness of single deposits and variability of mineral composition. These, in turn, are governed by external environmental factors, such as climate change, tectonics, change in vegetation cover, *etc.*, ultimately influencing the rate of input, transport and deposition of sediment (Anderton, 1985; Walker, 1986; Brodzikowski & van Loon, 1991). Accordingly, a facies model must be implemented as a general summary of specific characteristics within a sedimentary environment and the related processes of deposition in any geoarchaeology studies of buried cultural sites.

2.2 Geological contexts

Because of the time focus, geoarchaeological contextual investigations are crucial to demonstrate the chronological and cultural authenticity and integrity of any particular Late Pleistocene archaeological record, especially if this is represented only by rudimentarily flaked cultural lithics. Specific characteristics of local depositional environments, associated with the occurrences of lithic industries, being the most likely archaeological inventories to be anticipated, should be studied for the primary position of cultural evidence, but also of their natural potential for production of possible geofacts that can be mistaken for authentic stone tools. The geographically most distributed geological settings in Western Canada, which is likely to include buried early cultural record (Fig. 3), are the old river systems with subsidiary valley channels and related fluvial deposits; alluvial fan, slopewash and other gravity flow settings; glacial and glacigenic (glacio-fluvial, glacio-colluvial, ice-contact, etc.) depositional environments; lacustrine and glacio-lacustrine settings, sea-shore areas and raised marine beaches (along the Pacific coast), and caves (in the Rocky Mountains).

2.2.1 Fluvial settings

Particularly the fluvial and glacial deposits are the most widely distributed in western Canada (plains and foothills), as well as in other formerly glaciated areas of North America, and provide the major potential for geoarchaeological early site's survey. These, in turn, may have significant implications about the regional as well as territorial climatic change. Recognition of simply flaked stone tools in a riverine (fluvial-channel and river-bank) setting may be rather problematic, particularly if these are found within thick and massive clast-supported sedimentary units composed of heavy-load gravels (e.g., Tricart &Vogt, 1967). On the contrary, flaked artifacts in fine-grained interchannel and overbank deposits should be identifiable without major difficulties even if produced on local raw materials. Periglacial river basins represented the most occupied Pleistocene natural environments.

Fig. 3. Geological contexts of buried Pleistocene archaeological records in Alberta, Canada, associated with the documented Palaeo-American lithic artifact distributions: A. interstadial (Mid-Wisconsinan) gravels (Grimshaw, Peace River); B. a massive alluvium truncated by a glacial diamicton (Medicine Hat, S. Saskatchewan R.); C. the Late Wisconsinan Laurentide clayey till (Edmonton-Riverside, N. Saskatchewan R.); D. interstadial fossiliferous sands (Edmonton-Riverside); E. the Mid-Wisconsinan fluvial deposits ^{14}C-dated by fauna to 40-21 ka BP (Villeneuve); F. an erosional contact of the fluvial and glacial formations (Villeneuve).

Evaluation of authenticity of flaking of an early lithic assemblage should take into consideration the following aspects: determination of sedimentary dynamics, including energy level, periodicity and palaeo-current direction; density of the fluid, and the amount and composition of the saturated matrix; velocity of the current and rate of sedimentation; structural disconformities and depositional irregularities in sedimentary units; secondary post-depositional disturbances; assessment of the mechanical potential of the present high-energy natural factors in the vicinity of a site and the surrounding area to imitate cultural modification patterns on local rocks and clastic minerals, identification of specific natural stone-modification factors in the same geological context, etc. Understanding of the basic principles of fluvial processes is therefore essential for critical assessment of the source and the extent of modification of flaked lithics in a buried geological context, as well as for interpretation of the past palaeoenvironment and its early human inhabitation potential at the moment of the enclosing deposit formation.

A separate contextual study issue is the concentration of archaeological inventories within the sealed deposit. A patterned spatial distribution of the flaked lithics is one of the most important aspects which may support, although not conclusively establish, the cultural nature of flaking of a lithic assemblage enclosed in a geological context. However, a more or less homogeneous dispersal of flaked lithics within a deposit does not *a priori* exclude their artifactual origin. The degree of spatial compactness in particular (glacio-)fluvial settings is governed by several factors, including the distance of re-deposition, dynamics (velocity and density) of the stream, character of the local topographic setting, etc., all of which can significantly contribute to a high mixing of the original cultural assemblage with the derived sediment. At most of the mapped Alberta Palaeolithic locations (Chlachula, 1996a; 1997), a random dispersal of flaked lithics within a deposit was documented in fluvial and glacio-fluvial settings (Calgary 2, Edmonton 1 - Riverside). Under favorable circumstances, the archaeological material may be horizontally spatially dispersed within a small area on top of the originally subaerially exposed layer (e.g., a river bank deposit), and subsequently buried by fine sediments without any major reworking and redeposition. Such occupation surfaces, defined as spatially limited places of association of cultural remains (lithic and other artifacts, patterned cultural material accumulation, etc.) may be expected to occur in low energy fluvial and lacustrine sedimentary settings potentially sealing many early Palaeo-American sites. Distribution of the cultural record at the Bow Valley locality at Calgary confirms the fact that deeply buried artifacts and other cultural remains are likely to be preserved, but are largely dispersed by high energy streams within braided periglacial floodplains. The Calgary Site 1 (the uppermost cultural level on top of the till) is currently the only Palaeolithic site in western Canada with a spatially well-defined occupation area.

2.2.2 Alluvial fan settings

Pleistocene cultural finds are commonly associated with alluvial fans which proved to be a rich source of Early Palaeolithic sites in the Old World (e.g., Isaac 1977; Clark et al., 1984; Bar Yosef, 1988; Chlachula, 1993). Alluvial fans accumulated near mountain fronts and formed by interstratified sands and gravels are likely to incorporate early cultural records within inter-bedded sequences of sandy-gravelly strata. Periodic precipitation variations, climate-related changes in vegetation cover and tectonics are the most important agents affecting the alluvial fan formation, especially if acting concomitantly. Particularly inter-bedded sandy and gravelly strata cyclically accumulated by sheet-flows and perennially active, laterally shifting braided streams in the American mountain fronts should be a subject of a close geoarchaeological field survey. The likely complex geological histories of these geomorphic formations possibly including deposits of various ages may complicate exact chronological assessment of the enclosing cultural records (e.g., Calico Hills Site) (Bischoff et al., 1981).

Periods of intensive debris accumulation usually coincide with accelerated erosion in the source area as a result of disturbance of slope balance due to subsidence and orogenic activity, change in regional precipitation patterns or as a result of a progressing bedrock weathering due to increased insolation and/or frost action. Differences in clast composition and varying amounts of fractured rocks in a vertical profile in the deposit have a direct bearing to the above factors. Debris flow processes are common in the semiarid as well as periglacial zones of North and South America. The specific character and intensity of these phenomena and physical properties of incorporated clastics have a direct bearing on assessment of the potential of an early stone industry distribution in the deposit and degree of its preservation. The resulting alluvial fan facies can be highly variable, depending on the amount of water-saturated / dry debris introduced to the particular locality, their lithology, periodicity of deposition, stability of the local geological bedrock, *etc.* Accordingly, alluvial fan deposits can occur as chaotically supported paraconglomerates formed by mudflow activity, or orthoconglomerates with interbedded and subsequently cemented fine sandy and gravelly strata periodically laid down by sheetflows and perennially active braided streams (Reading, 1989; Nemec & Steel, 1984).

In respect to the wide geographic distribution of alluvial fan formations and their dynamic genesis character susceptible to climate change in the framework of the Pleistocene history, deeply buried early American sites in the formal ice-marginal settings along the Alaska – British Columbia /Alberta Rocky Mountain foothills as well as in the southern extra-glacial regions must be anticipated. These transitional regions between the mountain fronts and the plains provide most potential for location of deeply buried Palaeolithic sites.

2.2.3 Glacial and glacigenic settings

The occurrence of early cultural records in glacial and glacigenic (glacial setting-associated) deposits is not perceivable for most archaeologists. These geological formations have not been researched for early sites till know also in the traditional areas of Palaeolithic research in Europe and Asia, with just a few exceptions (Ashton et al., 1992; Lauhkin, 1990, Pitulko et al., 2004). Yet, the discoveries of a series of pre-Holocene archaeological localities in western Canada in patterned geomorphic settings and geological contexts open a completely new niche of geoarchaeological research that can put the earliest human history of the Americas in a completely new light (Chlachula, 1996a, 19996b, 2003). In view of the emerging evidence, numerous early Palaeo-American Late Pleistocene cultural records, represented principally by diagnostic Palaeolithic artifacts positioned below or partly entrained in glacial deposits throughout the eastern foothills of the Canadian Rocky Mountains is to be expected in view of the Quaternary history and dominant regional geological structure with extensive, deeply buried, yet relatively young, non-glacial mid-last glacial fossiliferous formations covered by the overlying tills laid down by the last glacial mountain and continental ice-advances.

Past ice-marginal and periglacial settings provided rich biotic potential for human occupation – a fact that seem to be neglected by most archaeologists despite the documented archaeological evidence from Siberia (e.g., Pitulko et al. 2004, Chlachula & Serikov 2011) and modern analogues from the northern regions of the American and Eurasian continent.

In respect to the high-energy dynamics of ice-advances over a formerly ice-free landscape, a proper understanding and interpretation of the structural sedimentary facies is essential for the palaeoenvironmental reconstruction and geoarchaeology evaluation of incorporated cultural records. Glacial processes are the most effective high-energy agents in a terrestrial environment responsible for erosion of quantities of surficial materials, their large-scale and long-distance transport, subsequent reworking, and final distribution over large areas. Eroded rock debris of varying form and size are secondarily transported by meltwater or in the form of saturated deposits as gravity (mass-)flows, all significantly contributing to a progressive modification and a marginal edge damage of derived clasts. However, the main source of a variety of fractured clastic materials, particularly close to the mountain areas, is the glacial diamicton (till), being a massive, unstratified, poorly sorted deposit accumulated during an ice advance. Except for simple fracturing, the resulting damage patterns on entrained and transported and differentially abraded rocks carried by a glacier from its source area, or incorporated from former non-glacial deposits into its basal part in form of sub-glacial debris, include polishing, faceting and striating (Hambrey, 1994).

Other processes of mechanical disintegration and mechanical modification of pebble-cobble clasts, especially encountered under periglacial conditions, are related to seasonal temperature fluctuations in permafrost regions, thawing of a buried ice, causing subsequent disturbance of surrounding deposits, frost action and thermal stress, periodic freezing of capillary water in rocks and migration of the fluid in the supporting matrix, movement of unconsolidated surficial materials over partly frozen ground (solifluction), cryostatic pressure (involutions and cryoturbation), glaciofluvial processes of episodic nature active at peaks of thaw seasons, and drastic desiccation of rocks exposed on a barren land by strong periglacial winds during minimal precipitation conditions. Yet, a surficial clast (cobble) modification by all these phenomena can be positively discriminated from the controlled anthropogenic flaking. Stone artifacts, however, may be difficult to detect in a buried context within a glacial deposit, particularly if generally recognizable cultural attributes are lacking. In such cases, comprehensive contextual as well as actualistic studies are useful to carry out, even if the results obtained are not fully conclusive or are limited to an assessment of a degree of probability (Schnurrenberger & Bryan, 1985; Chlachula, 1994a).

Although glacio-fluvial outwash may be considered as a rather unlikely geological depositional environment to incorporate early cultural inventories, even this should not be completely discounted as shows the evidence from the Bow Valley sites at Calgary West (Chlachula, 1996a). Particularly in Alberta, the occurrence of Palaeolithic finds represented by flaked quartzite artifacts at the base of glacigenic deposits or partly entrained within the till body attest to complex archaeological site formation processes. In view of the regional surficial geology characterized by deeply buried Quaternary non-glacial (last interglacial or mid-last glacial) formations covered and partly distorted by the overlying last glacial tills, contextual inclusion of early cultural records in these geological contexts must be logically expected. A regularity pattern of the early prehistoric (pre-Palaeoindian) cultural occurrence distribution across the province under the Cordilleran or Laurentide tills, analogous to the Silver Spring Site (Calgary 2) and the Edmonton-Riverside Site, is well evident. The cultural nature of the recorded lithic specimens from the western Alberta Pleistocene-age glacial and glacigenic sections is inferred on the basis of their *recurrent patterning*. In both the flake- and the cobble-core components of the artifact assemblages, the cultural nature of modification is witnessed by technological stone flaking procedures diagnostic for Palaeolithic cultures.

2.2.4 Lacustrine settings

Lake basins were preferred places for human settlement since the earliest times of human prehistory. Apart of lakes occupying depressions formed by tectonic, volcanic, landslide or other geomorphic processes, which are marginally distributed in western Canada, old glacial and glacio-fluvial lake settings, on the contrary, have a major importance for the Palaeo-American geoarchaeology investigations. Periglacial agents were especially active over the vast areas bordering the major mountain ice-fields and continental ice-masses of the Pleistocene North and South America. Gravity-slope erosion, glacial debris mass-flows or active glaciers dammed parts of river valleys that were transformed into glacial lake basins filled by glacial meltwaters as documented from other mountain regions (Baker et al., 1993; Chlachula, 2010). A varying sedimentation rate in the Pleistocene glacio-lacustrine basins reflects fluctuation of the former lake shoreline and/or the blocking/releasing ice margin, and a relative abundance of river-derived clasts, which can be used as an unlimited source of raw material for stone tool production. Humanly flaked lithics from the early Palaeo-American sites should be readily identified in lacustrine settings as these differ significantly from the enclosing fine-grained matrix in size and composition. Besides this, stone artifacts should be preserved in a relatively fresh condition and a spatial concentration because of low-energy sedimentary environments (i.e., the Late Wisconsinan Calgary Site 1).

Coarser clastic materials as well as lithic artifacts, originally distributed along the lake shore, can be affected to some extent by reworking by wind-generated waves, and, on a larger scale, by landslides or glacial calving. High-energy lake drainage currents may also secondarily modify deposited materials, although only exceptionally in shallow shoreline waters. On the contrary, in lakes with an interior drainage, fluctuation of the lake level may cause much reworking of the sediments in the proximal shoreline zone. However, all these actions are more a source of abrasion and rounding of larger clastic materials than fracturing leading to a geofact production that should be discernable from the authentic stone tools.

2.2.5 Sea-shore settings

The only, though principal area where the Pleistocene-age (>12 000 year-old) American sites associated with glacial and glacigenic deposits can be expected is along the northwest cost of Alaska and British Columbia, which may have repeatedly served during the non-glacial intervals as another passage to early human immigrants to the New World alternative to the intercontinental route along the eastern slopes of the Rocky Mountains. Both tides and waves produce mass drifts of water due to coastal currents that are the principal agents of shoreline sedimentary transport. However, only in exceptional locations are tidal currents capable of eroding coastal rocks (Selby, 1985). As in lacustrine environments, wind-induced surface waves are the main source of kinetic energy, but acting here on a much larger scale. Accordingly, the natural modification of clastic rocks (as well as potential cultural remains) is expected there to be more effective. Coarse pebbly rocks occasionally used for stone tool manufacture until the late historic periods are being re-deposited mainly by on-shore water movement during periods of ocean transgression, or originate from the eroded portions of exposed cliffs. Recognition of artifactual flaking patterns on lithics scattered on raised ancient beaches and terraces, or incorporated in marine glacigenic sediments, therefore, can be extremely complicated by two factors: a high degree of abrasion of a possible culturally-produced implement; and a high probability of pseudo-artifact occurrences, particularly where rocks fall from eroded cliffs, and where frequent and violent storms occur.

Another significant aspect involves the accessibility, visibility and preservation potential of potential early sites located on or near a sea-shore. It is likely that most of these sites, for example on the Northwest Coast (Mandryk et al., 2001) may have been completely scoured off by fjord glaciers during later glacial advances and/or subsequently submerged by a rising sea-level during the Final Pleistocene and Early Holocene. A detailed study of the Pleistocene coarse-grained coastline deposits, subsequently uplifted and exposed above the present sea-level, reconstruction of the past depositional processes, and comparative observations on the frequency of naturally produced fractures in the local area, all these aspects should significantly contribute to understanding of the true nature of modification of a lithic sample whose artifactual character is suspected but not proven.

The Pleistocene costal environments were closely associated with human resource exploitation and repeated migration processes leading to the pre-historic colonization of the regions along the Pacific Rim. In fact, the major geographic passage to the New World was represented by the Bering land-bridge – the periodically exposed sea-shelf connecting the Chukotka and Alaska Peninsulas. Logically, many early Palaeo-American sites are now submerged under sea-water (ca. -70 m) or sealed in deposits of various ages and genesis along the present coastline at the formerly higher topographic elevations (by considering the Bering Sea-level drop by ca. 100 m during the Last Glacial Maximum) (Hopkins, 1973). By implementing a proper geoarchaeological approach in combination with palaeogeographic and palaeoenvironmental spatial and temporal analyses, the latter sites that are currently absent in Alaska (…) should be discovered as their existence is undisputed. Discontinuous early human movements from Asia to America (and *vice-versa*) may have taken place for up to several ten of thousands of years as a part of natural biotic exchanges between the two major continents. The cultural vestiges of these initial passages, however, are still rather sporadic, mainly in respect to the Late Pleistocene Palaeolithic dispersal (e.g,, Pearson, 1999).

2.2.6 Hillslope settings

Preservation and recovery of early prehistoric sites in hill-slope locations is less likely than at other, more stable landscape settings in respect to acting dynamic geomorphic processes. In terms of recognition of rudimentarily flaked artifacts, is must be kept in mind that down-slope movement of coarse unconsolidated sediments can also produce fracturing, marginal flaking and other casual damage on individual clasts. In more cohesive deposits, creep may trigger stresses leading to an increased deformation of rocks, eventually resulting in their structural fragmentation. The same applies for other high-energy gravity-slope phenomena including talus accumulations, rock-falls near steep cliff faces, and slope-wash, all causing breakage of incorporated rock debris to form a variety of geofacts, especially if fine-grained, matrix-supported deposit is absent. The scale of these processes depends on several factors, the most important of which are the relief gradient, presence and type of vegetation, amount and frequency of seasonal rainfall, and tectonic activity. Accordingly, contextual studies clarifying the origin of clastic rock fracturing at the Palaeo-American sites, where a cultural activity is disputed and other compelling evidence is missing, are of the utmost importance.

2.2.7 Cave settings

Caves were a natural habitation place of people since the beginning of humankind. In NW America, in the area of passage into the New World, an early human presence in a cave setting (Bluefish Cave) was documented in the north Yukon Territory (Cinq-Mars, 1990). Because of the geological structure, there are only a few cave sites in the Canadian Rocky Mountains, which may have served as refugia for Palaeolithic people during the Pleistocene Period, such as Eagle Cave, SW Alberta (Chlachula, 1997). In a cave setting in general, the possibility of natural production of lithics that would resemble genuine stone tools is relatively limited. This is because the natural intra-cavernal milieu *a priori* excludes presence of other non-indigenous clastic material, unless these were secondarily derived by gravity slope processes, or external stream and glacial actions. Chert nodules, occasionally occurring in limestone formations, may be an exception. Except for sudden structural underground cavern disturbances resulting in roof falls, and presence of cave streams, there are no other natural forces which could contribute to clast fracturing. Thus, even a very "primitive" lithic industry made on mediocre-quality rocks showing rough "undiagnostic" flaking excavated from undisturbed cave deposits suggests a cultural origin (e.g., Belle Roche site, Belgium; de Lumley,1969). This is particularly true if the raw material does not naturally occur in or near the particular cave. Perfectly spherical siderite concretions, originating from the Cretaceous shales in the Rocky Mountains ca. 90 km distant from Eagle Cave, Crowsnest Pass, SW Alberta, found 50 cm beneath the late Wisconsinan glacial deposit, may be another example.

2.2.8 Sub-aerial sediment settings

Sub-aerial (sand and loess) sediments, constituting a part of the mid- and high-latitude periglacial formations, are traditionally associated with a high number of the Palaeolithic sites particularly in Europe and north-central Asia (Siberia). Primary massive or slightly bedded loess-facies display an average size of single grains 30-50 μm. Recognition of the cultural inventories (bone or stone industries) of any size, form and concentration is thus less problematic since, regardless of the artifactual modifications, these *a priori* represent an allochtonous element (manuport) in undisturbed sedimentary contexts evidently brought by people if seen from the geological (sedimentological) viewpoint. Subsequent colluviation processes mixing surficial materials of various genesis and provenance can contribute to an increased sediment heterogeneity and distortion of the original aeolian matrix with a secondary inclusion of other small-size natural clasts (coarse sands to small gravels). This process specifically applies for fossil soil horizons. Palaeolithic sites sealed in sandy and particularly in loessic formations can be located several ten of meters (Chlachula, 2001b), i.e., in the stratigraphic contexts deeply buried underneath the present surface depending on thickness of the particular stratigraphic units reflecting the overall sedimentary dynamics of the catchment area. By applying this logical and elsewhere widely practiced Quaternary geology approach to the New World archaeology, many areas of the extensive loess deposit distribution, particularly along the Pleistocene continental ice margin south of Canada, provide an unexplored niche potentially enclosing many Pleistocene-age occupation sites.

In sum, a proper understanding of geological contexts of pre-Holocene habitation localities represented solely by rudimentary flaked stone inventories is crucial, particularly where no other evidence exists in support of the cultural character of the particular site. This is especially important since the early sites found in a direct, conformably stratified and undisturbed geological contexts, *in situ (sensu stricto)*, are likely to be discovered very rarely. Interdisciplinary contextual studies of depositional environments thus constitute a crucial part of any geoarchaeological research. Unusual or directly unique geo-contexts delivering potential cultural records should not be *a priori* discounted just because they do not fit into the range of well-documented geo-contexts of (more recent) American archaeological sites.

2.3 Analytical rock-flaking studies

In addition to contextual geological investigations, studies on physical properties of rocks constitute an integral part of Palaeo-American geoarchaeology. A logically-structured analytical methodological framework for a critical assessment of a potential Palaeolithic stone industry should comply with a specific depositional context, particularly if the lithic record represents the only alleged cultural manifestation. An adequate knowledge of physical properties of particular clastic rocks and minerals in their natural depositional environment as a potential source of prehistoric raw material exploitation is one of the primary and key requirements for determining the cultural origin of a lithic assemblage.

2.3.1 Physical properties of raw material

Structural strength of a specific lithic raw material is to be tested in terms of its ability to resist deformation by tensile, shear and compressive stresses. Especially in glacial and mass-wasting sediments, a study of once-active frictional forces at the contact between bedrock (or underlying geological materials) and the transported deposits may provide information about the potential of natural fracturing of individual clasts. Other aspects of the structural analysis relate to the mode and frequency of modification (i.e., breaking, crushing, chipping, cracking, grinding, polishing) identified in a local depositional setting, and the resulting dominant clast surface patterning (fissures, striations, grooves, etc.). The latter study aspects are especially useful by reconstructing the history of the clastic deposits in terms of geology provenance and transport mechanism, and the character of the most recent depositional processes imposed on the rock surface. Similarly, the actual state of weathering, textural homogeneity, and other physical aspects should be included in every comprehensive study. Geological context of a lithic collection becomes important in determining if nature might have had the probable capacity of fracturing the specific lithic sample, especially in a direct percussive manner (Patterson, 1983). This analytical field of study deserves much attention in frame of the earliest New World prehistory linked to the initial peopling of the Americas.

2.3.2 Experimental and functional analysis

Detailed technological analyses and experimental flaking is necessary for an independent critical assessment of a possible cultural origin of rudimentary modified lithics from buried geological contexts. Both analytical aspects imply a testing of the available raw material, including the production of stone tool replicas by using indigenous, deposit-forming rocks, and their comparison with possible artifactual specimens. Experimentation must be carried out on a variety of available raw materials occurring in the local deposits within the entire size range and physical qualities of clasts in order to deduce the cultural technological stone-flaking limits and the degree and modes of potential cultural adaptation in working the particular raw material. Finally, comparative studies on (cobble/pebble-sized) support-reduction flaking, retouching, utilization traces and degree of overall standardization of the resulting sample with applying specific stone-flaking procedures is of principal importance. Experiments in rock fracturing implemented to a variety of clastic raw materials for specific depositional environments, observations on naturally broken clasts of a very ancient (pre-Quaternary) geological provenance and comparative simulations of damage patterns can provide very important analytical proxy data. It is evident that the potential of fluvial and alluvial depositional settings for direct percussion is strongly overestimated without any reasonable grounds (Kuenen, 1956; Schumm & Stevens, 1972). As a matter of fact, the majority of clasts in gravel beds are broken by pressure of overburden without additional marginal artifact-simulated flaking, whereas the principal factor of the syndepositional clast modification is rolling leading to gradual shape reduction of coarse fluvial clastic materials.

Since natural forces act in a random manner, the resulting stone (clast) modification features are arranged in irregular patterns. In demonstrating the artifactuality of a lithic assemblage, it is necessary to document all consistent and progressive modification traits separately for the clastic rock or its fragment, pre-form and the final product (the stone tool). Although many elaborate geofacts may also occur in natural, high-energy settings, they are generally characterized by a rather limited number of casual morphological forms arranged in chaotic and random manner differing from the logically placed and recurrent functional working edges of authentic stone tools. Thus, a frequency of the repeatedly occurring lithic forms with identical flaking patterns is a very important factor to support the cultural origin of the scrutinized sample. Solely technological criteria, as well as the use of individual "diagnostic" attributes are, however, only of limited value. “Objective” statistical evaluations such as by chi-square tests will, because of their nature, discard even perfectly-shaped single stone tools if these do not reach the “quantitatively significant” values (Gillespie et al., 2004).

Finally, use-wear analysis is a very useful technique in assessing the likely function of a particular tool (Beyries, 1988), but also the authenticity itself of a cultural lithic specimen as humanly produced and/or used (e.g., d'Erico 1985; Vaugham, 1985; Grace, 1996)). The application of the use-wear analysis may be considerably limited by the fact that during re-deposition processes of a particular lithic assemblage, microscopic as well as macroscopic utilization traces may be effaced by rolling and abrasion (e.g., Knutson, 1988). Another main controlling factor is the specific physical quality of a raw material. Distinction of patterned, non-accidental micro-flaking from accidental "pseudo-retouch" randomly distributed on morphologically functionless edges should be reliably determined in most cases.

2.3.3 Natural/cultural stone flaking

Criteria specifying "diagnostic" flaking patterns of early prehistoric stone industries, and distinguishing them from naturally induced fractures in a particular geological context, are only exceptionally a part of a description of the alleged culturally modified lithic collections. In both the Old and the New World, only a few attempts were made to address this issue (e.g., Dies, 1981; Patterson, 1983; Schnurrenberger & Bryan, 1985; Peacock, 1991). Most of those, however, concern very fine-grained, high-quality isotropic raw materials, and some of the defined attributes may not be observable on coarse-grained rocks and minerals. It is therefore imperative to derive *a priori* specific stone flaking criteria for the particular lithic assemblages, as any uncritical generalization may be rather misleading and non-objective.

Authenticity of the Late Pleistocene Palaeolithic stone industries (Fig. 5) from the investigated "pre-glacial" Canadian sites is based on a rigorous quantitative and qualitative comparison of the stone tools and artifacts with geofacts (pseudo-artifacts) naturally produced from the present fluvial and glacial environments from the broader study area, the analogous Holocene-age Indian industries from the surface context and the experimental stone tool specimens. The identical raw material in all data sets contributes to the objectivity of the study in terms of a general scheme of the nature and arrangement of flaking patterns, and the specific edge modification (flaking, retouching). Surface texture, i.e., the range of features found on the surface of flaked specimens, is considered to be equally informative.

2.3.4 Artifact-diagnostic stone flaking attributes: General aspects

The Palaeolithic stone tool assemblages from western Alberta are characterized by specific flaking and edge retouching features, which proved to be absent in patterned associations in any of the comparative and naturally-produced clastic rock assemblages (Fig. 4) of identical geological origin and mechanical properties. In respect to their dominant occurrence in the unequivocal stone industries made on quartzite cobbles, these specific formal, textural and edge-modification attributes are considered to be diagnostic for the cultural flaking of the tested lithic assemblages, especially if they occur in identical patterned combinations of the Palaeolithic as well as Holocene Indian sites (Chlachula & LeBlanc, 1996). In both the flake- and the cobble-core – stone industry components, the cultural nature of modification is well-documented if several independent early technological stone flaking procedures are present. However, none of the particular attributes defined as "diagnostic" can be considered as a reliable cultural indicator if found in isolation on flaked lithics. The cultural nature of any recorded and presumably cultural lithic specimens from the Pleistocene-age glacial and glacigenic sections is inferred on the basis of their *recurrent patterning* in the assemblage.

The artifactual nature of the lithic assemblages from the Late Pleistocene sites in Alberta, the Bow Valley sites, is based on the following general criteria (Chlachula, 1994a):

a. regularity and control of flaking (Figs 5A-E, 11A);
b. recurrent and technologically coherent patterns of modification (Fig. 12);
c. standardized size range of the resulting forms;
d. presence of a set of associated flaking attributes diagnostic for the Palaeolithic stone tool production (Fig. 6), which are absent in assemblages of identical lithological compositions from glacial and fluvial settings (Fig. 4), despite the similarity of contextual environments.

The association of the above general criteria on flaked clasts in respect to particular geological contexts excludes any possibility of modification of these lithic assemblages by natural forces acting during the accumulation of fluvial and glacial deposits. In view of the characteristic flaking patterns and surface texture on the Bow Valley site's lithic specimens contextually incorporated on top of fluvial gravels below glacial diamictons, the actual working must have occurred *after* deposition of the gravel beds by braided streams and *before* the subsequent disturbance of the fluvial sedimentary context in the superimposed

Fig. 4. Past and present natural settings subjected to analyses of natural and cultural clast-modification attributes made on identical raw materials as used for stone tool production: A. rock-fall at the Athabasca glacier, Alberta; B. sub-glacial debris at the Athabasca glacier retreating ice-front; C. braided channels of the upper Bow River; D. the Bow valley till, Calgary, Varsity Estates; E. alluvial gravels washed from a base of a glacial diamicton (South Saskatchewan R.); F. Fe-hydroxide-cemented Late Pleistocene gravel beds (S.Saskatchewan). Unambiguous differentiation of the two study groups (geofacts and artifacts) can be made.

Fig. 5. Some characteristic stone flaking attributes of the Palaeo-American stone industries. A. a unifacial flaking with overlapping negative flake scars (a controlled hard percussion); B. a regular alternating bifacial flaking; C. a unifacial distal-edge retouching on a thick flake (a traverse side-scraper); D. a steep edge retouching on primary cortical flake (end-scraper); E. a regular one-direction faceting (a single-platform cobble-core preparation for a flake extraction); F. concentrated indentation marks on a cobble surface (a cobble hammer-stone). A-C: Silver Springs (pre-last glacial alluvial formation), D-F: Varsity Estates (the till surface).

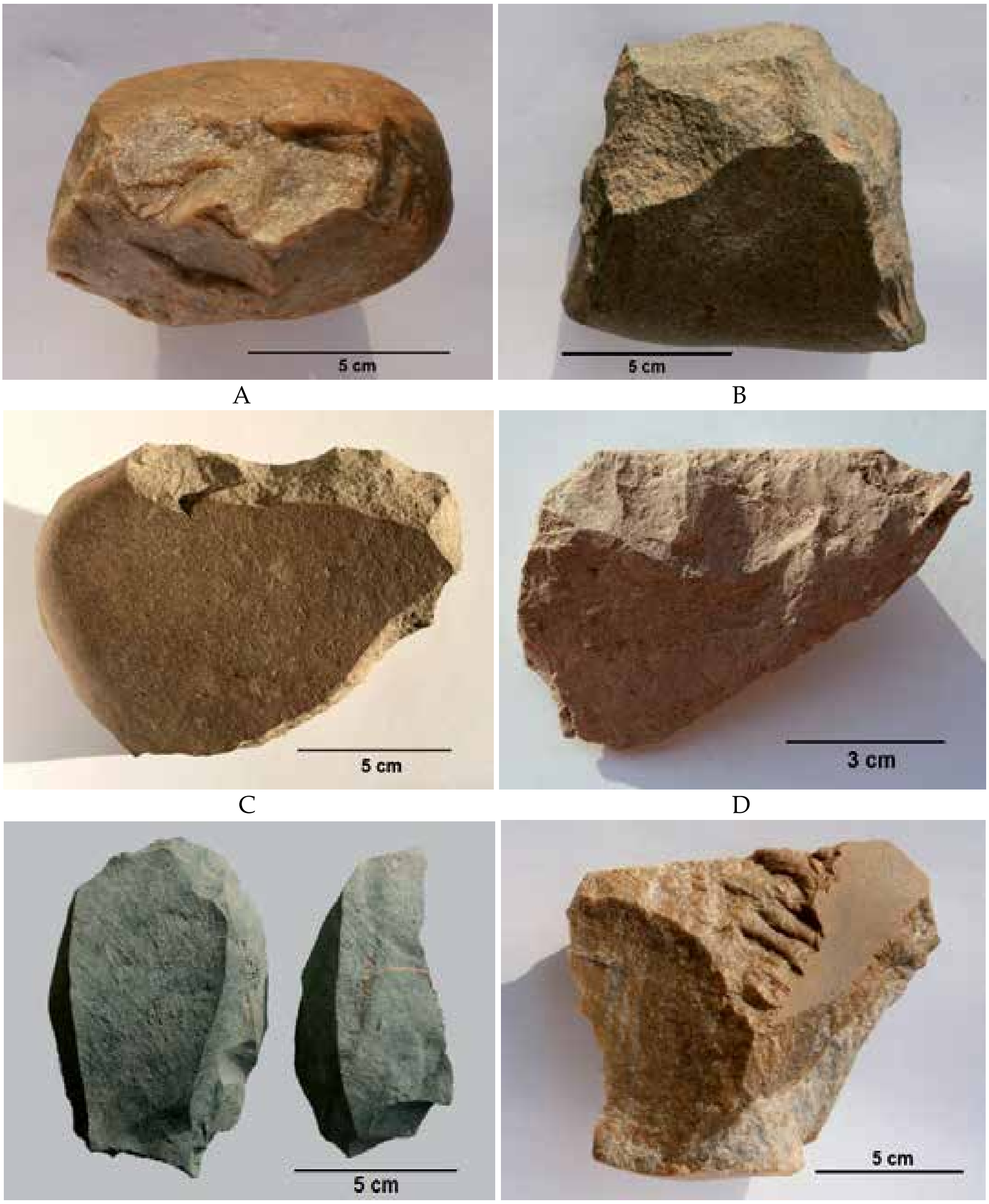


Fig. 6. Examples of the Old World Palaeolithic (A-E) and the prehistoric North American (F) lithic industries made on quartz (A) and quartzite (B-F) with the identical flaking patters as at the Alberta pre-glacial sites: A. a Lower Palaeolithic bifacial tool (the Dyje River basin, southern Moravia, Czech Rep.); B. a Middle Palaeolithic utilized core (the Kama Basin, Fore-Urals, Russia); C. an Upper Palaeolithic cobble scraper & D. a side-scraper (Primorie Region, the Russian Far East); E. retouched /left: burin-scraper/ Upper Palaeolithic flakes (Primorie, the Russian Far East); E. an unmodified flake (the Milk River, southern Alberta, Canada).

glacio-fluvial and glacial environment (Menzies, 2002). Although there are many specimens at the sites which can be easily recognized as tools/artifacts without any formal comparative lithic analysis, the stated criteria address specifically those variably reworked exemplars the cultural authenticity of which could be subject of debate. It is reasonable to argue that their cultural origin might be supported because they are directly associated with an undisputed Palaeolithic industry. In fact, these "less convincing pieces" do not change geoarchaeology implication about the early Palaeo-American settlement of western Canada. The assumption is maintained that if definite stone tools are present, then it is an archaeological site.

In sum, the characteristic artifactual attributes, recurrent technological procedures, patterned typological variability, and a variety of utilization traces clearly document the cultural origin of the pre-last glacial lithic assemblages from the investigated Alberta sites. *The specific mode and intensity of retouching when associated with other diagnostic attributes, and the appearance of distinct tool types produced in patterned technological ways explicitly differentiate the stone industry from naturally fractured clastic materials.* The variety of rock flaking methods on a different technological level and common recurrence of classifiable forms is the most characteristic trait of the authentic stone artifact assemblages (Chlachula & LeBlanc, 1996).

2.3.5 Formal characteristics of the Palaeolithic industries from Alberta

The artifact assemblages from the mapped pre-last glacial sites in Alberta are defined by the most diagnostic technological aspects and corresponding typological forms of stone tool production and lithic inventories that are found in the Eurasian Palaeolithic. Under the term industry is meant a set of lithic instruments chronologically and contextually associated in one technologically and typologically coherent cultural assemblage defined by recurrent tool types produced by a set of specific flaking procedures. The term "Palaeolithic" is used to refer to the particular technological stage as well as the contextually documented Late Pleistocene time interval corresponding to the traditional European and African concept. It must be agreed with the argument that "it is illogical for archaeologists to bar the term Paleolithic from crossing the Bering Strait if the evidence indicates that people bearing simple stone and bone industries of the Old World ancestry entered in Pleistocene times" (Bryan & Gruhn, 1989:83). The term "Palaeolithic" has been avoided in the North American archaeology in order to "preclude any attribution of great antiquity to New World lithic assemblages, as well as any indication of a direct cultural relationship with specific Old World lithic traditions of the Pleistocene" (op. cit.:82).

There is no reason why the lithic industry from the Late Pleistocene sites in Alberta should be formally described and named differently than the analogous lithic assemblages from the Pleistocene contexts in Europe or Siberia, just because they were found in North America (Fig. 6). Since the Late Pleistocene age of the local artifact assemblages is firmly established, this fact entitles to speak about the *Palaeolithic industry* in the traditional culture-historical terms equivalent the Old World concept, where the upper chronological limit is determined by the Pleistocene / Holocene boundary, i.e., 12 000 years ago. From this perspective, the Clovis points are archaeological manifestations of a specific final Pleistocene American Palaeolithic culture as well. The question is not whether or not existence of an American Palaeolithic has been demonstrated, but whether an Old World formal stone tool-classification system can be used in the New World. It is evident that evolutionary pathways were different in the Americas than in the areas of the "classic" Palaeolithic research, but probably not dissimilar from cultural developments in parts of Siberia and Eastern Asia. Accordingly, in compliance with the Old World Palaeolithic concept, the stone industry from the investigated sites in western Canada includes principal technological elements of "pebble-tool" or core and flake industries dominated by the unifacial flaking techniques, a more elaborate bifacial flaking, a variety of flake-based technologies, and an elaborated blade-extraction stone flaking technique. The typological variety within the stone tool assemblages corresponds to the technological level of their production. In this sense, numerous forms can be found which have direct parallels with the Old World Early, Middle as well as Late Palaeolithic stone tool inventories as it is the case at single Siberian localities. These stone tool forms occur together without any particular association with each other, what is the principal characteristic trait of the Pleistocene artifact assemblages from Alberta.

The "Early Palaeolithic" level of technology includes rudimentary unifacial / bifacial flaking in the form of direct percussion (including an anvil percussion flaking and a bipolar flaking). The "Middle Palaeolithic" technological elements are exemplified in a more specialized polyhedral core preparation. In accordance with the overall technological trend, the application of hard-hammer flaking is also indicated by hammer-stone percussion marks (5F), short flake negative scars on cores, the well-developed bulbs, and the thick basal parts of detached and secondarily retouched flakes. The typical "Late Palaeolithic" technological features are less frequently encountered in the lithic industry, but are nonetheless apparent. This particularly concerns the cores with one or two non-cortical flaking platforms with a series of parallel and well-organized negative blade scars after blade removals, as well as small blade fragments and some micro-blades. Numerous *débitage* recorded at the key Bow Valley locality (Calgary 1) demonstrates that stone flaking actions took place at the very site.

At all the sites, only local clastic raw materials transported by fluvial and glacial processes from the Rocky Mountains area and forming the Quaternary glaciofluvial deposits at the site sections were used for stone tool flaking. An exception is a large, white-patinated flake on a fine-grained quartzite originating from the base of the South Saskatchewan River erosion near Medicine Hat (Fig. 7A). The principal stone tool types of the western Alberta Palaeolithic Complex include a patterned series of unifacially and bifacially flaked choppers, bifaces, specific side-scrapers on fractured cobbles and cobble cores. Typologically variable small scrapers, burins and retouched flakes prevail in the small lithic inventories (Figs 5, 11).

The well-defined and diagnostic artifactual attributes, recurrent technological procedures, the patterned typological variability, and the variety of SEM utilization traces clearly document the cultural origin of these unique lithic assemblages sealed in the pre-last glacial geological formations (>20 000 year BP). The specific modes and intensity of edge retouching associated with other diagnostic attributes of stone working and the appearance of distinct tool types produced in patterned technological sequences explicitly differentiate the lithic industry from naturally fractured clastic materials. The variety of the applied rock flaking procedures, the technological modes and a common recurrence of readily classifiable tool forms is the most characteristic trait of the local lithic artifact assemblages referred as to the Alberta Palaeolithic Complex (Chlachula, 1994a). Because of the patterned contextual geological and spatial geomorphic distribution across the province, the stone industries are clearly part of a *Palaeolithic*, pre-Palaeoindian (>13 000 yr BP.) cultural tradition and not an isolated phenomenon. Further research on the lithic artifact / geofact differentiation criteria may significantly contribute not only to resolving questions about the antiquity of human culture in the Americas, but also the early human dispersal in the Old World.

A B

Fig. 7. Anthropogenically worked and utilized edges of quartzite stone tools with cut-marks. A: a flake /utilized core from pre-glacial gravels (the Oldman River Site near Medicine Hat); B: a handaxe from a prehistoric Indian surface site (the Mohave Desert, southern California).

3. Geoarchaeology of the Palaeolithic (pre-glacial) sites of western Canada

The north-west North America, including Alaska and the adjacent west Canadian provinces (the Yukon Territory, British Columbia and Alberta) have a fundamental bearing for elucidating migration processes, adaptation strategies and environmental contexts of the Pleistocene expansion of Palaeolithic people from Siberia, the Far East and the northern Russian Arctic areas into the New World. Interactions of past climate change and a regional relief modeling by cyclic glaciations and related eustatic sea-water fluctuations controlled transformations of the East Beringian Pleistocene ecosystems. Dynamics of the Late Quaternary landscape development and the extent of lands allowing a free passage ultimately governed timing and the spatial distribution of the Palaeo-American occupation in the new territories (Fig. 1).

The contextual geology, palaeoecology and palaeontology records from the investigated pre-glacial archaeological sites and the deeply-stratified geological sections of glacial and non-glacial deposits provide evidence of pronounced (palaeo)environmental and biotic shifts triggered by the global climate evolution and the time-related glacial and interglacial geomorphic processes (Brigham-Grette, 2001). The Quaternary climatic cycles regulated the spatial and temporal movements of prehistoric people migrating from the high latitudes of NE Asia through Chukotka and the Bering Straight / the continental land-bridge. Integrated palaeoecology multi-proxy databases document trajectories of evidently a complex and long occupation history of this extensive, but still a very marginally explored part of the World.

The term "pre-glacial", with a direct chronostratigraphic connotation (Chlachula 1996a,1996b), refers to the human occupation sites positioned stratigraphically under the last glacial deposits and, more specifically, pre-dating the Last Glacial Maximum (21 000 yr BP). Discoveries of these sites in the patterned geological settings provided definite evidence for the Palaeo-American occupation in this part of North America within the postulated "ice-free" corridor area and pre-dating the "Clovis-horizon" (ca. 13 000-12 000 yr BP) associated with the Final Pleistocene cultural development on the Great Interior Plains. The Canadian Palaeolithic sites are sealed by thick (10-50 m) last glacial deposits accumulated under or close to the continental Laurentide ice-sheet or the Cordilleran valley glaciers during the last glacial stage (24 000-12 000 yr BP). These occupation sites are unparallel in the Americas in respect to their rather exceptional geological contexts, *a priori* fixing the Late Pleistocene age. Systematic geoarchaeology investigations delivered evidence of a previously fully unknown American Palaeolithic tradition inhabiting the Pleistocene Western Canadian Plains and the adjacent Rocky Mountain Foothills as manifested by *in-situ* recorded stone tools reminiscent of the NE Asian Middle and Upper Palaeolithic cultures.

At the present time, there are several localities in the western part of the province of Alberta distributed in the river (and former glacial) valleys east of the Rocky Mountains over a broad territory extending ca. 1,500 km from north to south (Fig.1). Geologically, the buried early Palaeo-American occupation sites are characterized by the patterned contextual stratigraphic (and palaeoenvironmental) location with the archaeological finds buried under the last glacial deposits (glacial diamictons and associated proglacial and glacio-lacustrine sediments) related either to the Cordilleran glaciation (Calgary Sites 1-3) or the Laurentide glaciation (Grimshaw, Villeneuve, Edmonton, Medicine Hat, Lethbridge) (Chlachula, 1997; Chlachula & Leslie 1998; Chlachula, unpublished data). The key sites in the Bow Valley (Calgary 1-3) (Chlachula, 1996a) represent the most significant and best-studied Palaeolithic locality in Alberta with fundamental palaeoenvironmental and palaeogeographic contextual implications on the last glacial history of the "ice-free corridor" (Chlachula, 2002, 2003).

3.1 Geography and natural setting of the study area

The south-western margin of the Interior Canadian Plains, being the principal study area, is formed by a gently rolling terrain rising from 900 m asl in the east to 1200 m asl. in the west at the Rocky Mountains front. The open landscape is transected by deeply incised valleys with drainage pattern oriented in the W-E/SW-NE direction following the continental slope (Fig. 10A-B). To the west across the foothills, the Eastern Cordillera Range creates a natural boundary with maximum elevations above 3000 m asl. Most of the surficial geology cover is formed by unconsolidated Late Pleistocene deposits of non-glacial as well as glacial origin (Moran, 1986; Jackson, 1987; Fulton et al., 1986; Fulton, 1986). The earlier Quaternary fluvial sediments are distributed on high plateaus and local uplands, and occasionally fill bottoms of pre-glacial valleys. Most of the area is covered by grasslands with isolated communities of scrub (mainly aspen and willow) in the river valleys. Parklands with spruce and poplar are distributed in the foothills; boreal coniferous forest dominated by pine and spruce in the Rocky Mountains, with alpine meadow vegetation at the higher elevations (Fig. 2E-F).

Quaternary climate fluctuations and geomorphic processes modeled the present topography of relief. Originally broad and shallow river valleys were carved by glaciers and subsequently filled up with glacial, glacio-fluvial and glacio-lacustrine deposits. During the ice-advances as well as ice-retreats, proglacial and periglacial lakes formed in former fluvial basins and local topographic depressions. In the interglacial and interstadial periods, rivers largely re-established their original drainage patterns, or partly shifted their flow into newly excavated valleys scoured by glaciers. The characteristic hummocky terrain, covering a large part of the western prairie, developed during the latest deglaciation. Repeated erosion of the former surficial deposits of various pre-Quaternary ages and genesis as well as large-scale excavations of bedrock formed of unconsolidated shale exposed by glacial-scouring during glacial advances accumulated massive quantities of glacigenic (mostly till and glacial lake) deposits reaching in places up to several tens of meters per a glacial advance (Figs 3C, 4D). These fine matrix (sand, silt and clay)-supported tills either of the Cordilleran or Laurentide origin underlain by non-glacial fluvial or proluvial formations (Fig. 4E) are most prominent for the last glacial stage attaining thickness of 5-50 meters depending of a particular location.

All the mapped Palaeolithic sites are located on the western to SW margin of the Interior Canadian Plains east of the Rocky Mountains within a geographically uniform belt of a rolling prairie and open parkland of an altitude of 600-1100 m asl (Figs 1C, 10A). The sites are situated in eroded river sections, 10-100 m high along the former or still active river channel banks affected by erosion (Figs 3, 8). The principal Bow Valley locality comprises a series of natural exposures along the NW-SE oriented northern side of the Bow River, with surface altitude of 1070-1084 m. Two principal places near Calgary with the actively eroding Late Pleistocene-Holocene sections, referred to as Site 1 (Varsity Estates) and Site 2 (Silver Springs) are located 2.5 km apart (with the latter site being farther upstream) within steep sections along the river valley 35-51 m high. Varieties of glacial (moraine), glacio-lacustrine, glaciofluvial, alluvial and colluvial deposits form the local Quaternary geological formations overlying the Tertiary sandstone over the Cretaceous sedimentary rocks (Fig. 8). Most of the surficial materials distributed on the present surface are geologically young, being largely derived during the last glacial (Late Wisconsinan) mountain and continental ice advances (Moran, 1986). Lithology of the coarse clastic deposits (and lithic tools produced from them) is more or less uniform throughout the broader investigated area, comprising mostly rocks derived by fluvial and glacial processes from the nearby Rocky Mountains (Fig. 4C-D).

3.2 Geological context and stratigraphic position of pre-glacial cultural records

The Palaeolithic industry assemblages in the west Alberta prairies and the adjacent Rocky Mountain foothills are recorded in patterned geological contexts defining the "pre-glacial" localities from eroded natural exposures delivering humanly flaked quartzite and carbonate cobbles and flakes exposed by the Holocene river erosions in the Bow, South and North Saskatchewan, Oldman and Peace River basins (Fig. 3). The stratigraphically documented archaeological material was incorporated in various contexts, including stratified non-glacial Late Pleistocene fluvial deposits (Medicine Hat, Lethbridge and Villeneuve sites), partly entrained into the basal part of the overlying glacial diamictons / till (Edmonton-Riverside, Calgary 2 and the Peace River sites), in the top part of a till at the contact with glacial lake deposits (Calgary 1) and possibly within an interstadial facies in a cave setting (Eagle Cave) (Chlachula, 1997). Depth of burial of the particular cultural horizons, some of them associated with fossil fauna, ranges from about -5 to -50 m below the present surface.

The first and principal Palaeolithic locality was found in 1990 during a field survey in the Bow River valley at the SW margin of the Plains about 100 km east of the Canadian Rocky Mountain Front Range (Fig. 10A-B). Two natural exposures extending for 70-100 m 2.5 km apart referred to as the Calgary Site 1 (Varsity Estates) and Site 2 (Silver Springs) are situated on the north side of the valley at the western periphery of the city, at the altitude of 1070-1085 m asl. During the early postglacial, the valley wall was exposed by erosion of the Bow River cutting through a series of glaciolacustrine, glacial, and pre-glacial deposits to bedrock to form the present 35-50 m high, cliff-forming slopes. The stone industries are associated in a primary context with the Mid-Wisconsinan fluvial sands and gravels, but also secondarily redeposited at base of the overlying Late Pleistocene glacial diamicton (Site 2)

A

B

C

Fig. 8. A. A View of the Silver Springs archaeological site (Calgary Site 2) with the position (xxx) of cultural finds (the section SSW); B. The section stratigraphy and the site excavation with artifacts (ca. 32 ka BP) distributed on top of the mid-last glacial (MIS 3) river gravels and secondarily entrained into the basal part of the overlying till during the Bow Valley ice advance; C. An aerial photograph of the Late Pleistocene sections at the occupation Site 1 (Varsity Estates) exposed above the Bow River valley, Calgary NW, SW Alberta. The flat topography above the slope sections is the bottom of the former Glacial Lake Calgary (dated to ca. 20-13 ka BP) dammed by the Laurentide ice and overlying the Cordilleran Bow Valley till at the Calgary Site 1 (Varsity Estates). More recent (ca. 24-22 ka BP) Palaeolithic artifacts occur at the contact of both geological formation at the depth of -24 m below the top surface.

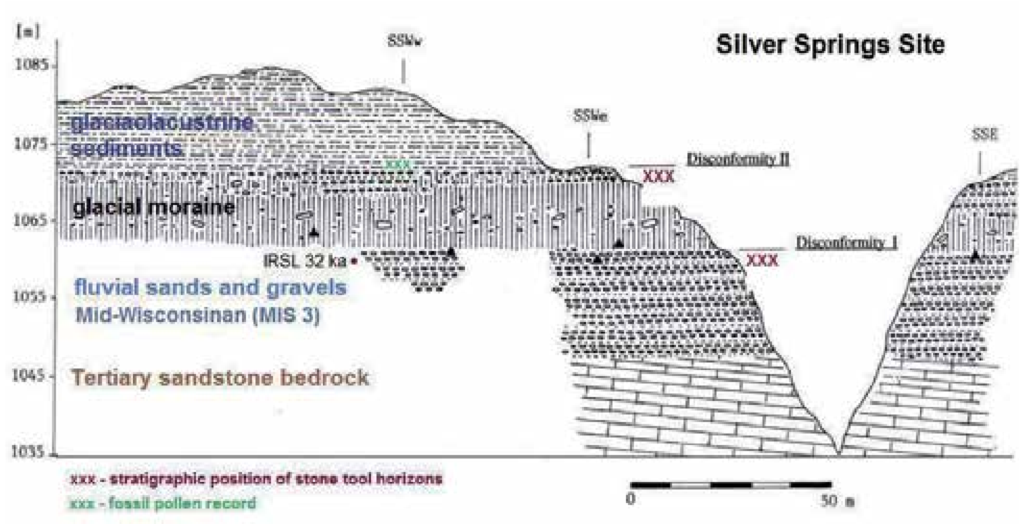
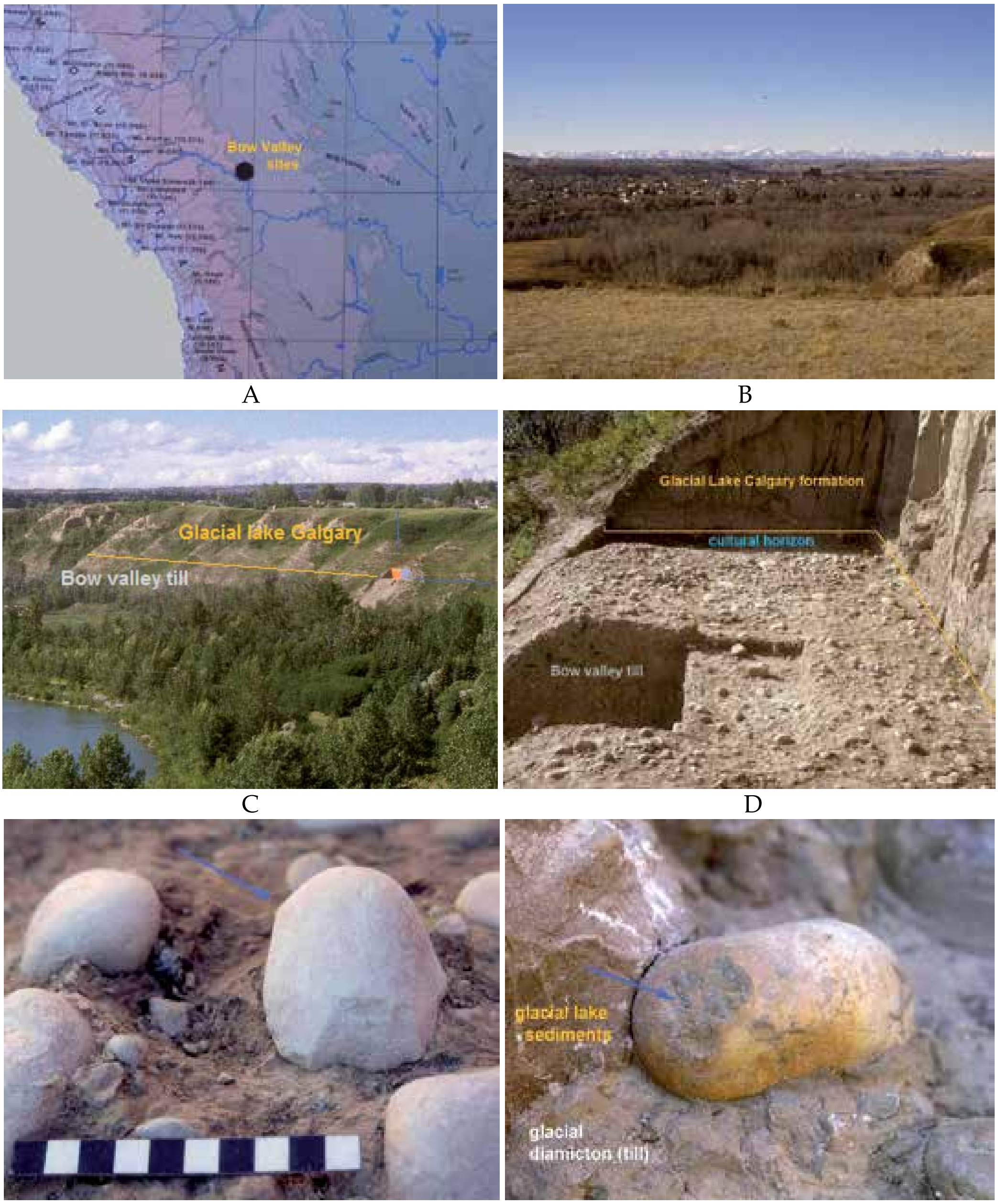


Fig. 9. Stratigraphy of the Late Pleistocene sections at the Silver Springs Site, Calgary NW, with two Palaeolithic occupation horizons – on the top surface of the pre-glacial (MIS 3) gravels and the base of the overlying last glacial Bow valley till (Disconformity I) - *the lower series stone industry*, and on top of the moraine below the Glacial Lake Calgary sediments (Disconformity II) – *the upper series industry*, with fossil pollen of spruce, pine and grasses.

by the Last Glacial / Late Wisconsinan Cordilleran ice advance (23 000 year BP) (Figs 8B, 9). At Site 1, numerous artifacts (100+) with the diagnostic lithic waste resulting from stone-tool manufacturing were found *in situ (sensu stricto)* in the 55 m^2 excavation on the surface of the glacial moraine (till) from an intact and buried context under 24 m of the lacustrine sediments of Glacial Lake Calgary (Figs. 8C, 10C-F)(Chlachula, 1996a, 1996b, 2002, 2003). The best-documented Calgary Site 1, discovered already in 1990, produced the most unique lithic artifacts from an intact place interpreted in view to the lithic assemblage composition as a habitation area – a workshop – delivering stone tools at various stages of their production with the accompanying (micro-) lithic waste /*débitage* retrieved by floating.

In spite of, at the moment of discovery, the very unexpected geological contextual position of undoubted Palaeolithic tools at the top of the Cordilleran Bow Valley till beneath thick glacio-lacustrine sediments of Glacial Lake Calgary (24 m below the present ground and 23 m above the Bow River), this was confirmed by controlled excavations in the places, where the most eloquent find – a bifacial stone tool – reminiscent of typical handaxes, was found (Fig.11A). The original assemblage of 22 artifacts, including 3 finished tools and 2 cores was embedded in the top of the gravely till within a cohesive clayey matrix at the contact with the overlying lake deposits. Most of the lithic assemblage included 17 small flakes, which could have been partly fitted back on to the biface made from a flat quartzite cobble. At the Calgary Site 2, discovered in 1991, similar percussion-flaked artifacts were found in the basal part of the same glacial deposit (Bow Valley till), and in the underlying river gravels. A site-specific geoarchaeology-glacial geology was implemented during the subsequent geoarchaeology investigations in 1993-98 by expanding to final 60 m^2 of the total excavated area at the Calgary Palaeo-American Palaeolithic locality (a final report in preparation).



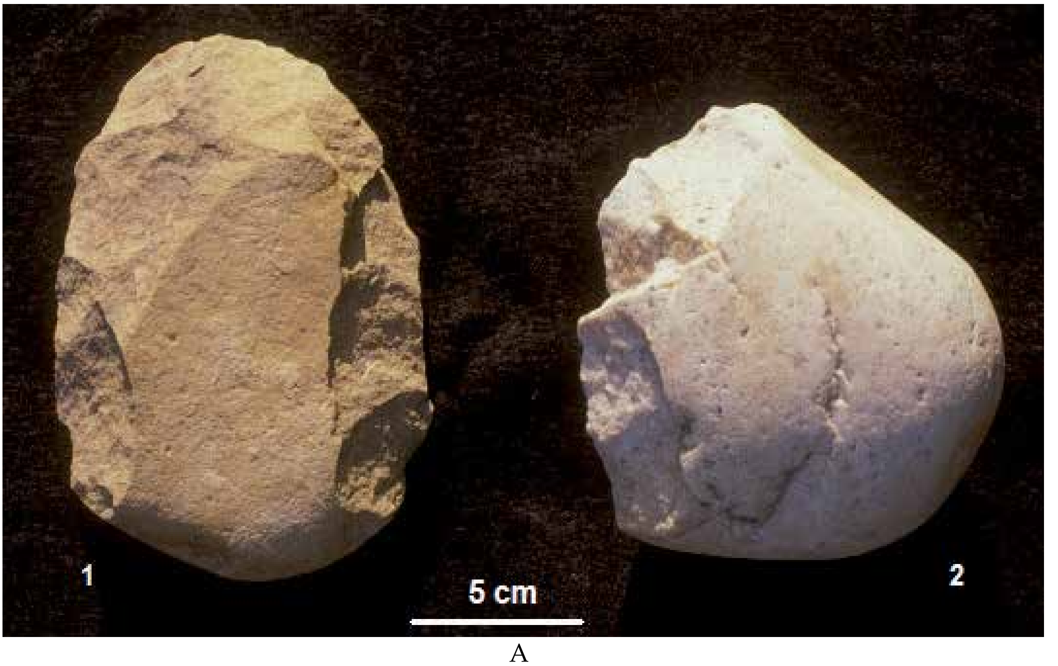
A B C D E F

Fig. 10. Calgary Site 1 (Varsity Estates). A. The site location in the western Alberta foothills; B. The Bow valley view from the site top surface (a former bottom of Glacial Lake Calgary); C. The site view above the Bow River; D. The site excavation with the Palaeo-American occupation horizon (>20 000 yr BP) on top of the Late Wisconsinan Cordilleran Bow Valley till underneath of 24 m of glacial lake deposits; E. End-scraper on a flaked quartzite cobble on top of the glacial diamicton; F. A quartzite hammer-stone with concentrated percussion marks (indicated by arrow) sealed *in situ* at the contact of the till and the glacial lake clays.

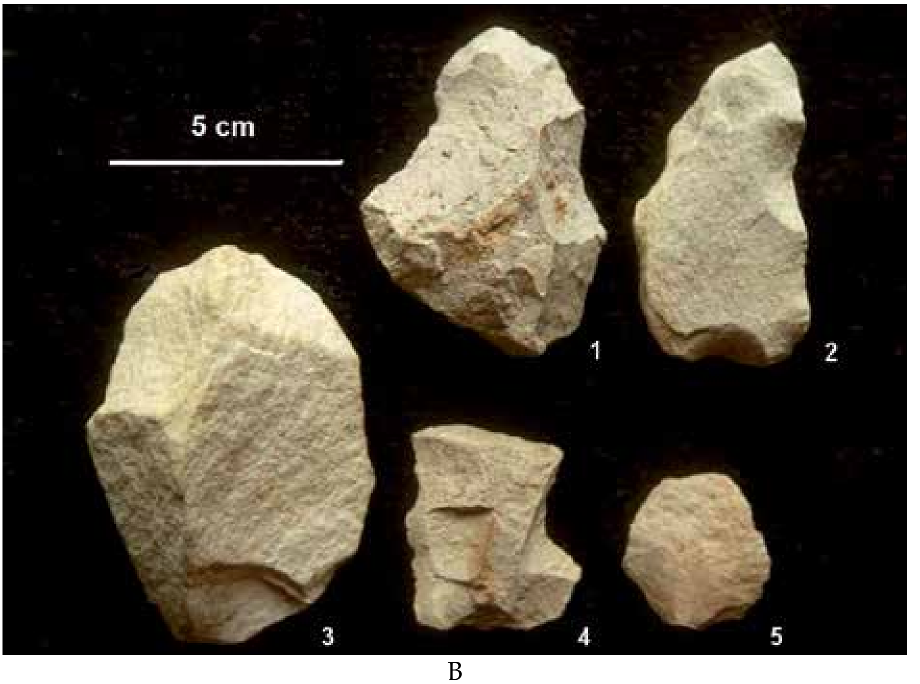
The stratigraphic sequence from the Bow Valley sites, providing a straightforward evidence of the Late Pleistocene peopling of western Canada, documents a model succession of alluvial facies in the lower part of the composite geological site profile into glacial and glaciofluvial facies in the middle sections, as a result of a gradual establishment of full glacial conditions in the former Bow Valley (Fig. 9). The reconstructed general sedimentary facies model illustrates one glacial cycle with an ice advance and retreat. The basal fluvial or proglacial complexes at Site 2 *(Facies Association 1)* were formed during the (Bow valley) ice advance stage; the glacial deposits *(Facies Association 2)* during maximum glaciation, while the overlain proglacial sands and gravels *(Facies Association 3)* document the retreat phase. Two main disconformities, defined as the major chronostragraphic hiatuses of the regional Late Pleistocene glacial history, were identified. *Disconformity I* relates to the time interval elapsed between the accumulation of the uppermost (glacio)fluvial gravels and their burial by the Cordilleran till during the Bow Valley ice advance. Deposition of the glaciolacustrine sediments in the upper part of the study exposures *(Facies Association 4)* at Site 1 is linked with the subsequent Laurentide glaciation reaching down to the present NE Calgary area. *Disconformity II* then relates to the temporal hiatus elapsed between the two (mountain and continental) glacial events. Both disconformities, associated with past open environments, corroborate with the stratigraphic positions of the cultural horizons, implying two episodes of the Palaeo-American occupation of the upper Bow River valley, with the earlier at Site 2 (Silver Springs and Bowmont), and the later at Site 1 (Varsity Estates). Age assessment of the locality is based on the chronostratigraphic correlation of the stone industry-bearing layers with the regional Quaternary geology scheme (Chlachula, 1996a). An IRSL date of 32 ka BP from a fine sand deposit just above the older Palaeolithic industry-bearing horizon at Site 2 indicates the Mid-Wisconsin timing of the original Bow valley occupation (Chlachula, 2002).

3.3 Palaeolithic cultural evidence

The artifacts at the Calgary sites are made from local quartzite and hard siltstone cobbles collected by early people at both locations from the Mid-Wisconsinan river gravels and from the top surface of a gravelly Bow valley moraine after the ice retreat at the Site 1. The stone flaking technology is not uniform, but repeated in the patterned occurrences on specific tool types, produced and used in the same or a very similar functional manner. A simple, direct, hard-percussion flaking, using a cobble hammer-stone, was the dominant technique (Fig. 5). A bipolar (bi-directional) flaking also was frequently applied. A typical soft-hammer stone percussion technology, using bone or wood and characteristic for the Upper Palaeolithic stone flaking, is documented by few cores with a single flaking platform and unidirectional, parallel blade removals. The formal typology of the artifact assemblages consists of a variety of typical "pebble tools," including unifacial and bifacial choppers (Figs 5A, 11A-2, 12C), bifaces (Fig. 11A-1), as well as specific massive scrapers produced on large cobble fragments fractured by an anvil percussion technique and meticulously edge-retouched (Fig. 12B). Flakes were worked into side-scrapers (Figs 5C, 12A) and end-scrapers (including typical carinate forms analogous to those found in the Upper Palaeolithic in Europe or Siberia) (Figs 5D, 11B-3), and simple burins. A particular stone tool type is represented by small (1-5 cm), edge-retouched pointed tools (Fig. 11B-2). Overall, the Palaeo-American collections from the Bow Valley sites display a very close technological level and a typological repertoire typical of the Late Pleistocene industries of north-eastern Eurasia (Chlachula, 1996a, 1996b, 1997). Analogous stone-working techniques are present at the other Late Pleistocene Alberta sites.



A



B

Fig. 11. Varsity Estate Site. A: bifacial tools from the excavation on top of the Bow moraine. B: a comparative quartzite flake artifact assemblage (2-3 Calgary Site 1 – Varsity Estates; 1, 4-5 Ondratice, an early Upper Palaeolithic site in southern Moravia, central Europe /Svoboda 1980/) displaying identical technological patterns of quartzite working.

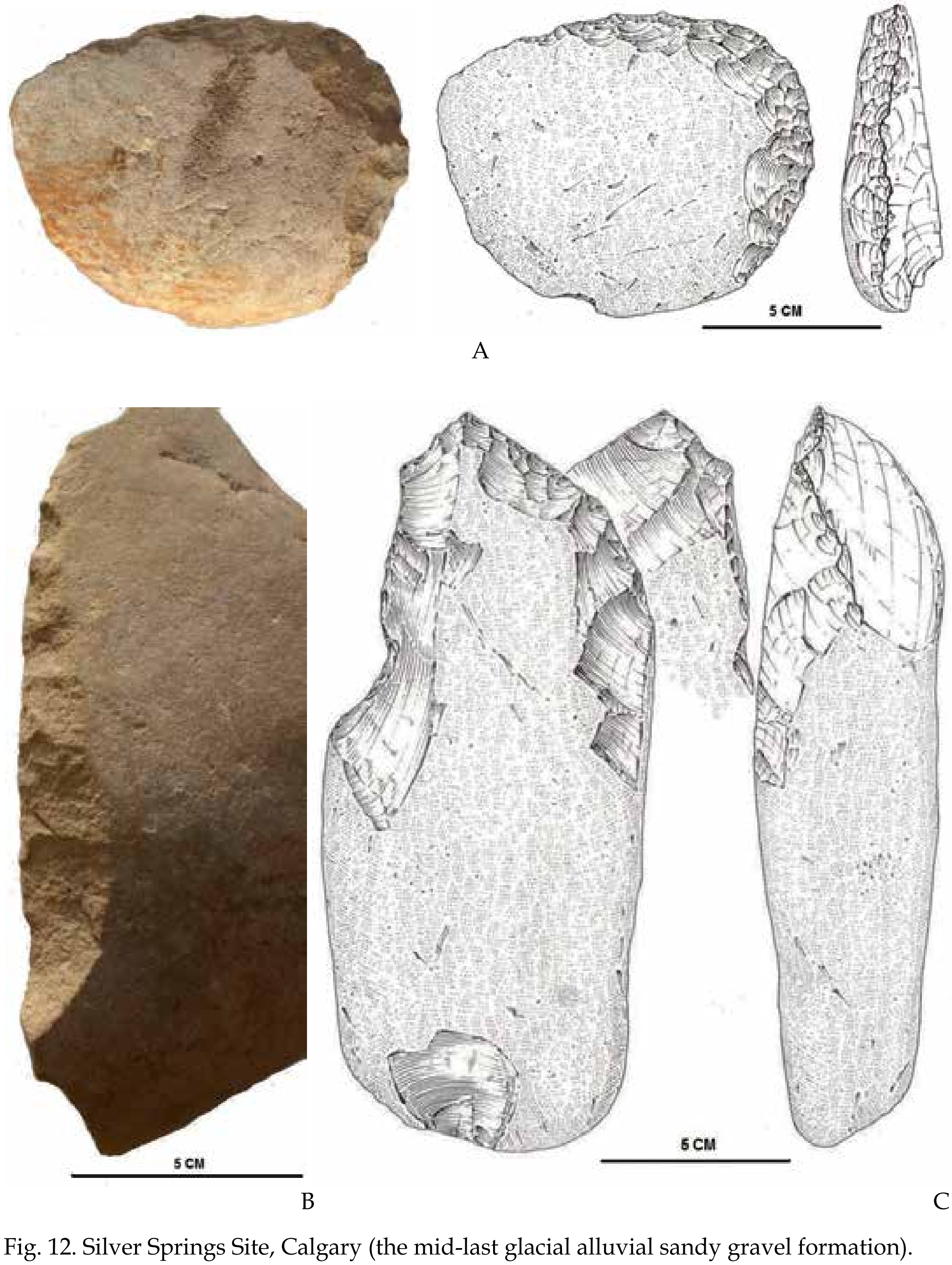


Fig. 12. Silver Springs Site, Calgary (the mid-last glacial alluvial sandy gravel formation). Palaeolithic stone tools made on quartzite flakes (A) and cobbles (B-C). A. a side-scraper on fractured flake; B. a massive unifacially retouched scraper on a cobble fractured by an anvil-percussion technique; C. a pointed bifacially worked tool (all photos & drawings by author).

The unequivocal cultural character of the Alberta Palaeolithic stone industries consists of sets of patterned flaking and edge-retouching attributes, which are characteristic of the Old World Palaeolithic stone industries (Fig. 6), but commonly also found in the local Holocene Indian traditions produced on a similar raw material and persisting throughout the prehistory of the western Canadian prairies (Chlachula, 1994b; Chlachula & Le Blanc, 1996). In a detailed comparative study, it was demonstrated that these culture-diagnostic patterns, however, are virtually absent on the lithologically identical rocks naturally found in the area, which were subjected to high-energy fluvial and glacial transport and that could potentially mimic some artifact-like flaking pattern (Chlachula, 1994a) (Fig. 4). Independent SEM analyses of retouched edges of small utilized flakes and tools displaying use-wear utilization marks indicate use for hide, bone and wood processing (Dept. of Anthropology, University of Alberta; Department of Archaeology, Universidad Autónoma Barcelona).

In summary, the defined diagnostic procedures of anthropogenic stone flaking and retouching in association with the distinct tool types produced in patterned technological ways clearly differentiate the local industries from the naturally fractured clastic materials. The west Canadian pre-glacial stone tool assemblages display a variety of applied controlled rock-flaking techniques on different technological levels and a common recurrence of well-classified tool forms. The most characteristic artifactual attributes, recurrent technological procedures, a patterned typological variability, and a variety of the utilization macro- and microscopic traces confirm beyond any doubts the authenticity of the stone tool industries of the Alberta Palaeolithic Complex as also confirmed by many experts in the early lithic technologies of the Old Word Palaeolithic as well as the North American Palaeo-Indian archaeology. At this moment it is impossible to draw some definite cultural links to a particular cultural area in East Asia / Siberia since the Alberta's lithic components display a wide range of time-transitional and geographically distributed Palaeolithic stone-tool types.

3.4 Chronology and environments of the pre-glacial sites

The Late Pleistocene age of the mapped Palaeolithic sites in western Alberta is conformed by their "pre-glacial" geological context buried under extensive bodies of glacial till and other glacigenic deposits. The stratigraphic position of the Bow Valley sites separated by the Cordilleran till implies clearly two episodes of the Palaeo-American inhabitation in the area. Reconstructed palaeoenvironments at Site 2 (Silver Springs) indicate a braided river setting during the earlier occupation. Discarded artifacts, subsequently sub-glacially entrained into the glacial deposit document distortion of the earlier human occupation surface by a valley ice emerging from the Rocky Mountain ice-lobe. The Bow Valley glacier is likely to have been confined only to the main valley leaving the surrounding foothills unglaciated. Presumably a temporary terminal ice position, followed by a progressive wastage of the glacier is indicated by the accumulated till deposits that are characteristic of a stagnant and disintegrating ice-front. Although no chronometric control exists for this glacial event, it is most likely (early) Late Wisconsinan (Bobrowsky & Rutter, 1992). This implies the Mid-Wisconsinan (mid-Last Glacial / MIS 3) age for the Palaeo-American occupation. This temporal assessment is corroborated by the IRSL date of 32 000 BP (± 10%) on a laminated silty sand unit of the fluvial formation sealing the cultural horizon (Chlachula, 2002).

Following the valley deglaciation caused by climatic warming, people re-occupied the SW Alberta area, presumably after several millennia, as indicated by the analogous stone tools excavated *in situ* on top of the Bow Valley till at Site 1. This more recent (Late Wisconsinan / late Last Glacial / MIS 2) occupation surface was subsequently buried under 24 m of glaciolacustrine sediments after submergence of the river valley by a proglacial lake (Glacial Lake Calgary) dammed by the Lau rentide ice advance from northern Alberta. The chronology of this later (continental) glaciation is extrapolated from the age of fossiliferous fluvial river gravels dated to ca. 40 000-21 000 yr BP in central Alberta near Edmonton ca. 300 km north of Calgary overlain by a till of this continental glaciation (Young et al., 1994). In view to its stratigraphic position beneath the Glacial Lake Calgary sediments, this more recent cultural horizon at Site 1 clearly predates formation of the glacial, ice-marginal basin. Absence of pedogenic weathering of the (till) occupation surface and the fresh appearance of the excavated stone industry suggest that a relatively short time span likely separated the Bow Valley and the later continental glaciation, and that lithic artifacts were discarded not long before the Laurentide ice blocked the Bow River to form the glacial lake. The unique stone tools, recorded in the excavated and spatially limited area with the refitting *débitage* show that the human activity occurred directly at this spot and the archaeological record underwent only minimal disturbances during the site inundation by the glacial lake.

Pollen of sedges (Cyperaceae) and sporadic arboreal taxa (*Pinus* sp. and *Picea* sp.), recorded from the occupation surface at Site 1, indicate a moderately cold, semiarid interstadial climate within a periglacial parkland/steppe tundra setting in a zone of seasonal permafrost. Coniferous forests were distributed throughout Alberta during most of the Mid-Wisconsinan Non-Glacial Interval (65 000-23 000 yr BP). However, pine and spruce were absent in western Alberta during and after the last glacial maximum (Schweger, 1989) and re-colonized the present western Calgary area as late as 10 000 years ago. The temporary Cordilleran glacier advance with the ice front, terminating within the site-location area, seems not to have had a major effect on continuity of the local Palaeolithic inhabitation of the Western Alberta foothills. The glacier evidently disrupted the prehistoric occupation of the valley, but probably did not force people to leave the western Calgary area until the continental ice advance. The two occupation episodes may thus have been separated by only a short time span in a range of several hundred of years or even less.

Despite the absence of fossil remains at the Bow Valley sites, the cultural record shows environmental potential for human colonization of the western Canadian prairies early in the last glacial stage and before that time. The cultural horizon from Site 1 with the palynological evidence does not support the view of an extremely cold, inhospitable glacial environment on the eastern slopes of the Canadian Rocky Mountains throughout the last glacial stage (23 000-12 000 yr BP). Its stratigraphic position also provides an eloquent proof for temporal asynchroneity between the Cordilleran and Laurentide ice during the last glacial maximum in this part of Alberta (Catto & Mandryk, 1990), the area of presumed coalescence of the two ice-masses (Rains et al., 1990). The cultural record from the Calgary sites further suggests that the early prehistoric people were adapted to local periglacial environments. This does not corroborate the idea of an expansive Cordilleran glaciation gradually extending far into the Alberta Foothills and plains or the inability of a Pleistocene American population to survive in an ice-proximal setting. Environmental fluctuations during the early Late Wisconsinan (23 000-21 000 year BP) probably did not affect human occupation in the southern Alberta Foothills until the maximum Laurentide advance over the adjacent southern prairies (ca. 20 000-18 000 year BP). As there are no formal differences between the lithic assemblages from each site, they are considered to represent one early Palaeo-American tradition with clear links to the Middle and Upper Palaeolithic cultures in Siberia and the Far East. The uniformity of the stone tool assemblages further suggests that the Palaeo-American people maintained more or less the same environmental adaptation.

Because of the explicit and environmentally determinant chronostratigraphy, the Palaeo-American archaeological evidence from the Bow Valley has direct implications for elucidation of the last glacial history and reconstruction of the spatial and temporal configuration of the Cordilleran and the Laurentide ice-sheets in SW Alberta – the loci of the postulated "ice-free" corridor during the last Ice Age. The stratigraphic position of the cultural records shows that the Laurentide ice advance from the north along the continental slope margin damming the Bow River took place when the Cordilleran Bow Valley glacier *had already retreated* farther west towards the Rocky Mountains, outside the present Calgary city limits, opposite to the scenario of an extensive ice-coverage and ice-masse coalescence (Osborn et al., 2000). This ice-free time interval is evidenced explicitly by the *upper series* stone industry excavated *in situ* at the Calgary Site 1. The fresh and unrolled artifacts from the top of the Bow till clearly imply re-occupation of the formerly-settled area in the river valley following wastage of the Cordilleran glacier and preceding the formation of the glacial lake. The stratigraphic and contextual geological positions of the cultural record thus clearly exclude a coalescence of the Cordilleran and Laurentide ice at Calgary during the last glacial maximum, ca. 21 000 yr BP (Moran, 1986), and imply a hiatus between the two glacial events (Fig. 13). The undated time span of 21 000 – 17 000 yr BP allowed time for peopling of SW Alberta even is some parts were covered by ice. In terms of regional conditions during the early last glacial stage, the geo-archaeological evidence suggests more localized glacial advances from the Rocky Mountains in the SW part of the province in the form of piedmont ice-tongues of the Cordilleran ice-cap, restricted to the major valleys cutting the eastern foothill slopes, and a more readily responding to the last glacial climates, instead of a single continental ice-mass covering most of western Alberta. Morphological, textural, and fabric properties of the glacial diamicton facies and the associated proglacial deposits in the mapped sections show intensive mass-wasting processes before and after the terminal position of the Bow Valley ice-front within the area of the palaeogeographic position and the stratigraphic contextual setting of the archaeological locality (Chlachula, 1996a).

3.5 Late Pleistocene ecology of western Canada

The present geoarchaeological evidence from mostly deeply buried sites from pre-glacial and glacigenic geologic formations discovered in a pilot field survey across Alberta (Fig. 1) shows the Palaeolithic inhabitation in the western Canadian prairies at various stages during the Late Pleistocene interstadials and the following the early last glacial (Chlachula & Leslie, 1998; Chlachula, 1997). An alternating pattern of a mosaic parkland-boreal forest expansion during warmer climatic intervals followed by establishment of dry steppe-tundra during glacial stages characterizes the regional environments between 130 000 and 12 000 yr BP. After the early last glacial maximum (ca. 70 000 yr BP), glacial activity was significantly reduced during the mid-last glacial stage (65 000-23 000 yr BP), but a dry land continued to connect for millennia the eastern Chukotka and Alaska because of the low-sea level stands (Hopkins, 1967). During most of that time, a boreal forest cover in the foothills passing into open parkland-steppe in the plains became distributed from Alaska across Yukon, north-

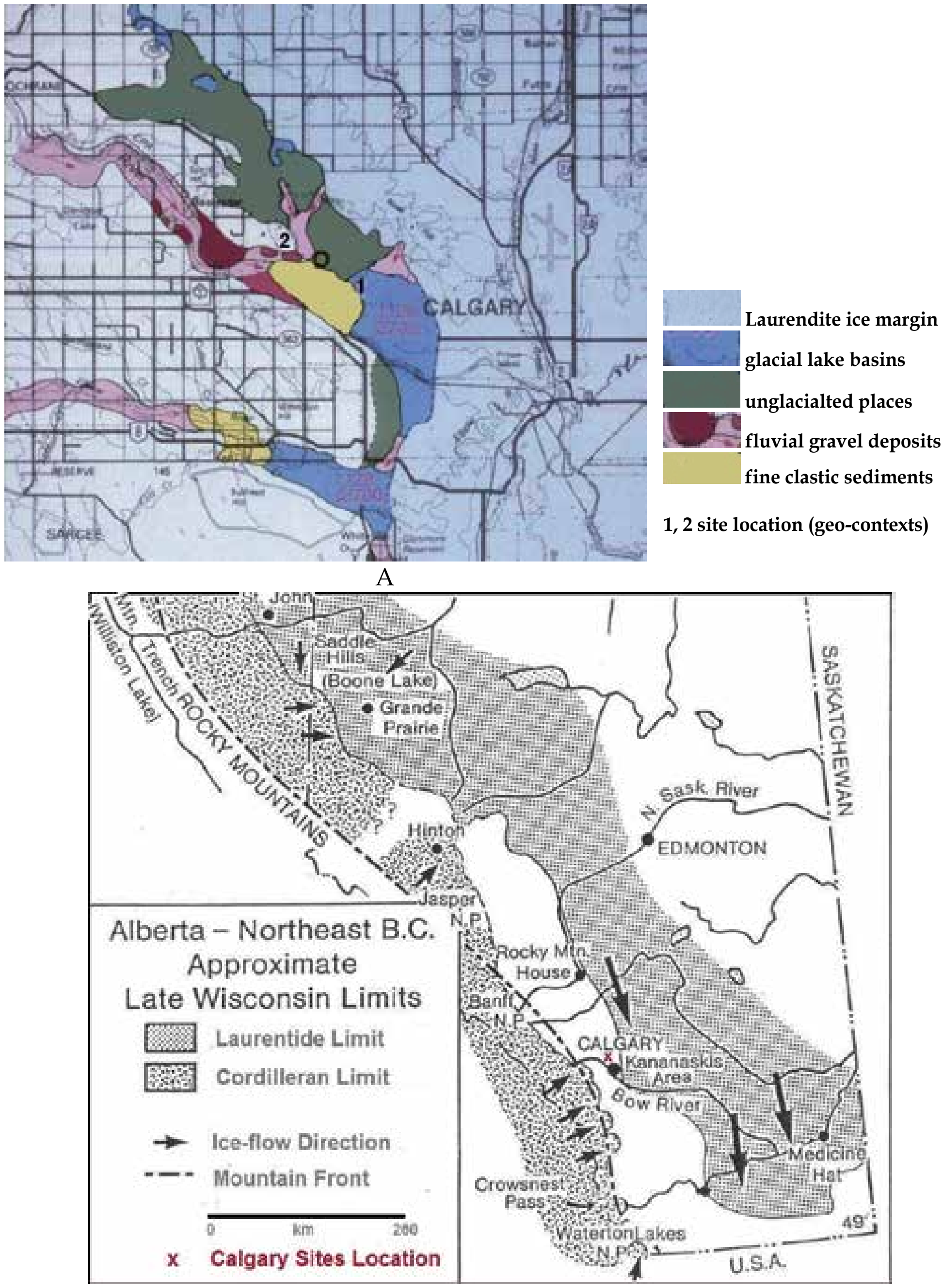


Fig. 13. The last glacial history of the upper Bow River valley. A. Location of the Pleistocene occupation sites at the margin of a glacial lake (Moran, 1986) dammed by the continental ice (ca. 20 000 yr BP) and inundating the former ice-free occupation area; B. The stratigraphic position of the cultural records below the Glacial Lake Calgary beds corroborates the non-coalescence of the Cordilleran and Laurentide ice-masses (cf. Rutter, 1980; Catto et al., 1996).

east British Columbia to western Alberta, providing favorable conditions for movement of Palaeolithic people migrating across the exposed Bering land-bridge and along the eastern side of the Rocky Mountains further south into the interior of North America.

The mid-last glacial (Mid-Wisconsinan) biotic records from the western prairies and the adjoining foothill areas indicate a moderately cool climate with reduced seasonal fluctuations throughout Western Canada. Pollen, fossil plant remains, wood fragments (spruce, pine and birch), molluscs and insect from fossilifeous deposits from the Smoky River ^{14}C-dated to 43 500-27 400 yr BP show an interstadial setting, similar to the present one, with a mixed coniferous-deciduous forest and average July temperature around 18°C (Liverman et al., 1989). It is possible that spruce and pine, indicative of a moderately cold climate and distributed across western Alberta during most of the long interstadial interval, survived in protected southern locations in the foothills for some time into the early Last Glacial /Late Wisconsinan prior to the Laurentide glaciation of the nearby prairies. The absence of pollen zonation from January Cave in the Livingston Valley, 60 km south-west of Calgary, with a low arboreal pollen component (less than 7 %, and dominated by spruce, pine and some alder, birch and willow), representing a habitat of semi-arid parkland-steppe, indicates environmental stability from ca. 33 000 until 23 000 yr BP (Burns,1991), temporarily corresponding to the earlier Palaeo-American occupation in the Bow Valley (Calgary Site 2).

The Western Prairies and the adjacent Rocky Mountains were inhabited by a large Rancholabrean fauna, including mammoth, caribou, bison, horse and camel, distributed as fossils in the Middle and Late Wisconsinan deposits from the north-western Yukon across the Rocky Mountain Interior to south-central British Columbia. Faunal exchanges between the northern and southern prairie areas are evidenced by the similar composition of the Late Pleistocene grassland animals from the most prolific fossiliferous sites at Old Crow flats in northern Yukon Territory and at Medicine Hat in southern Alberta (dated by radiocarbon to 28 600-24 500 yr BP), indicating a relatively mild and dry climate (Schweger, 1989). Some species (such as mammoth, giant bison and the Mexican ass) survived in SW Alberta until the very end of the Pleistocene (13 000-12 000 yr BP).

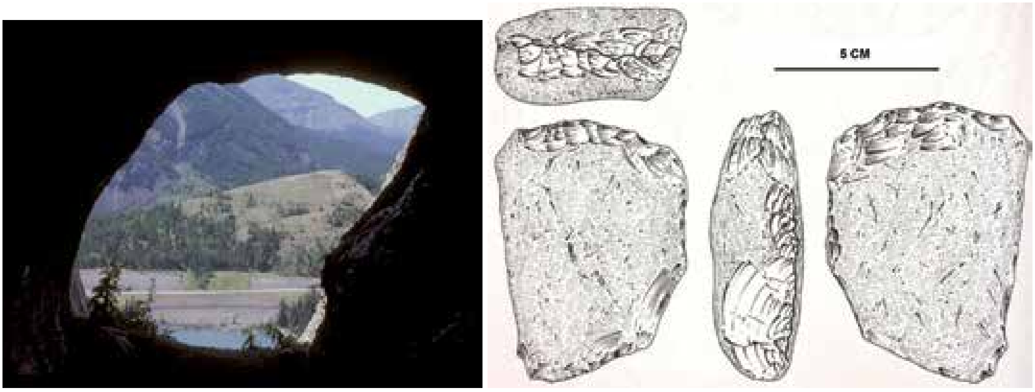
With progressive cooling towards the late Last Glacial stage, mixed boreal forests, discontinuously distributed over the Western Prairies, were replaced by periglacial semiarid herbaceous forest-tundra and steppe-tundra that undoubtedly provided a suitable natural habitat for human occupation, especially in the less densely vegetated mosaic areas and in the river valleys. From Alaska to Alberta, pollen records show sparse tundra vegetation dominated by Cyperaceae, Gramineae and *Artemisia* until about 14 000 yr BP (Clague & MacDonald, 1989; Schweger, 1985). It is evident that the Late Wisconsinan sub-stage cannot be correlated with a single glacial episode, but likely includes several stadial and interstadial intervals witnessed in biotic data. The presence of mammoth and muskox indicates opened parklands over most of western Alberta. Accordingly, the necessary biomass was available at least until about 23 000-21 000 yr BP to sustain the local Palaeolithic groups on the upland prairie east of the Rocky Mountains, especially in more protected settings in the ice-free river valleys in the Foothills. An analogous survival of prehistoric people is assumed in the northern Altay foothills, SW Siberia, because of micro-climate conditions (Chlachula, 2001). The incipient glaciation in SW Alberta, including the Bow Valley, most likely started not earlier as about 21 000 BP, and the extent of the glaciated area was apparently rather limited. Also, is evident that the Late Wisconsinan cannot be correlated with a single glacial episode, but likely includes several very cold as well as moderate climatic intervals. Independently of the biotic evidence, the geoarchaeological record from Calgary suggests a relatively limited environmental impact of the valley ice on the Palaeo-American occupation and ecological viability of the area prior to the Last Glacial Maximum around ca. 20 000 yr BP. The climate and the mean annual temperature were evidently cooler than at present, although the seasonal climatic shifts were less pronounced. Dry atmospheric streams from the Pacific coast leaving most precipitation in the Cordillera Range analogous to present-day Chinook may have caused significant short-term but regular warming during winters. If and for how a long period of time people could have survived in an inhospitable, harsh, ice- marginal environment under full glacial conditions with sparse tundra vegetation dominated by Cyperaceae, Gramineae and *Artemisia*, lasting until about 14 000 yr BP, is unclear. At that time, they are likely to have moved to more southern areas of the North American plains.

Following the pioneering research at the Calgary locality, a systematic survey for other pre-glacial cultural evidence was conducted covering ca. 10 000 km of surveyed area. Active and up to over 100 m high slope erosions in the major river valley flowing W-E across Alberta, and their main tributaries were surveyed to test the hypothesis that other early sites can be recorded in similar pre-glacial contexts (Fig. 4). The field investigations, locating intact Quaternary sections by using maps and air-photographs, focused on the fine alluvial (presumably mid-last glacial or last interglacial) deposits, some also fossiliferous, beneath the last glacial tills in order to secure *a priori* the relative age of the potentially incorporated archaeological finds. These field investigations resulted in discovery of other Palaeo-American sites across the western part of the province - in the middle Peace River area in the north, the North Saskatchewan River valley in central Alberta, as well as the South Saskatchewan River basin in the south, all in the same stratigraphic position beneath the last glacial Laurentide till related to the continental glaciation, and deeply buried (up to 50 m!) below the present surface (Chlachula & Leslie, 1998; Chlachula, 1997). Together with the Bow Valley sites, this patterned occurrence of the early cultural records clearly shows a geographically broader inhabitation of western Canada prior to the Last Glacial.

Except for the protected river valleys with sites established on south-facing slopes, some cave sites in unglaciated valleys close to the Rocky Mountain front were probably also occupied. A small artifact assemblage on hard limestone cobbles, including a massive side scraper on a large cobble fragment identical with the typical Calgary specimens and several utilized flakes, was found in Eagle Cave in Crowsnest Pass, dated by small mammal bones from the cave filling to 22 700 years BP (Kigoshi et al., 1973; excavation A. Bryan) (Fig. 14).

3.6 The Palaeolithic peopling of North America: A pre-glacial perspective

The evidence from western Alberta shows that Palaeo-American people inhabited parts of Western Canada at latest from the second half of the Mid-Wisconsinan (35 000-24 000 yr BP) and were able to cope with the periglacial environments *prior* to the Last Glacial Maximum. However, a possibility of an earlier occupation during ice-free conditions cannot be ruled out. As an alternative to the former "Clovis-first" model, it is assumed that people arrived to North America much earlier, likely within a natural process of faunal exchanges between the Eurasian and American continents. The new species coming from Eastern Asia in the last large wave during the early Late Pleistocene included, among other, deer, wapiti, caribou, Neogene horse, musk-ox, mountain sheep, pronghorn, porcupine, hare and raccoon.



A B

Fig. 14. A. Eagle Cave - an early occupation site the south-west Alberta Rocky Mountains. B. a bifacially-flaked limestone cobble found with fossil fauna beneath the last glacial till.

Nevertheless, it is unlikely that the prehistoric people were exclusively dependent of the large-game (e.g., mammoth, mastodon, bison) hunting, but practiced more general foraging subsistence activities. The “pre-glacial” cultural discoveries in western Canada imply that the 'ice-free' corridor along the eastern Rocky Mountains existed more than once, and, therefore, human and animal migrations, besides non-glacial vegetation cover expansions, happened before the Last Glacial Maximum, and quite conceivably, even earlier than during the Mid-Wisconsinan interstadial interval during the Last Interglacial – sub-stages MIS 5a-d (120 000-74 000 yr BP) not taking into consideration the interglacial climate optimum (MIS 5e; 130 000-120 000 yr BP) with raised sea-water above the present level.

The initial prehistoric colonization of the Americas is seen as a gradual process in the broader ecological context of the Pleistocene Beringia, presumably as an opportunistic infiltration of small hunting and foraging groups from NE Siberia into the new territories. The expanded land bridge, connecting Alaska and Chukotka (Fig. 1A), was available during most of the Late Pleistocene and maintained repeatedly for thousand of years before the Last Glacial Maximum (Frison & Walker, 1988). The presence of Palaeo-American people in the unglaciated area of the Yukon Territory is indicated by flaked lithics and worked bones from Bluefish Caves and possibly by humanly fractured and modified bones from the Old Crow flats (Morlan, 1986; Cinq-Mars, 1990). After entering the New World, physically, it was possible for the Middle-Upper Palaeolithic hunter-gatherers to penetrate further south either along the western coast (Gruhn, 1989) or the eastern flanks of the Rocky Mountains during most of the Middle Wisconsinan interstadial interval (65 000-24 000 yr BP) (Fig. 1C).

Mixed boreal forests, discontinuously distributed over the western prairies during the mid-glacial interstadial interval and herbaceous forest-tundra and steppe-tundra during the early last glacial stage undoubtedly provided a suitable habitat for human occupation, especially in the less densely vegetated mosaic plain settings and in the river valleys. Fossil remains of mammoth and musk-ox point to opened parklands over large parts of western Alberta in corroboration with pollen records until the early Last Glacial. The cultural finds from the Bow Valley themselves precondition inhabitability of the area prior to the LGM with necessary biotic resources. Periglacial steppe was one of most productive Pleistocene biotopes. Naturally protected settings in the ice-free mountain valleys in the foothills would host favorable ecosystems for the Upper Palaeolithic occupation. The climate and the mean annual temperature were evidently cooler than at present, although the seasonal climatic shifts were probably less pronounced. Periglacial adaptations are evidenced by the cultural records from the polar regions of Siberia as far as 70° N during the later part of the mid-last glacial interstadial dated to 28 000 - 26 000 yr BP (Pitulko et al., 2004). If people could have survived in a marginal environment under full glacial conditions is a matter of discussion.

It is illogical and by any reasoning unfounded to assume just a rather late (Final) Pleistocene peopling of the Americas (Lynch, 1990; Hoffecker et al., 1994; Goebel et al., 2008, etc.), when the Early and Middle Palaeolithic people clearly colonized the vast regions of the adjacent Siberia and the Far East along the Pacific rim long before that time. The Palaeolithic oikumene persisted for hundreds of thousand years on the western side of Beringia, dating back to at least the Middle Pleistocene (730 000-130 000 yr BP) and possibly even earlier (e.g., Medvedev et al., 1990; Mochanov, 1992; Derevianko & Shunkov, 2009; Vasilevskiy, 2008), and concomitantly with the periodic exposures of the land-bridge connecting both continents (Hopkins, 1973). The mapped presence of the Middle and the Upper Palaeolithic occupation sites in the polar regions of Eurasia and along the Arctic coast (Pavlov et al., 2004; Pitulko et al., 2004; Vereschagin, 1977; Mochanov & Fedoseeva, 1996), just demonstrates human adaptation to periglacial environments for at least 40 000 years.

The Late Pleistocene glaciations of the northern Cordilleras had very likely only a temporary effect slowing down the human dispersal into the southern latitudes of the continent. The regional geographic configuration of the mapped Cordilleran, Laurentide and montane glaciers indicates the absence of any obstacle in the form of a major ice body (Catto et al., 1996) that would have prevented dispersal of the Palaeolithic people to North America. By coupling the existence of the land-bridge and the penetrability of the western Canadian prairies alongside the Rocky Mountains during the Late Pleistocene, then people could have freely passed from the western side of Beringia into the interior America without major natural constrains at many times and for many millennia during the Late Pleistocene especially during the climatically moderate interstadial intervals (65 000-24 000 yr BP). The only documented coalescence of the Cordilleran glacier and Laurentide ice sheet during the Last Glacial Maximum in the Athabasca Valley, northwestern Alberta (Bobrowsky & Rutter, 1992) must not have had any direct implication for the occupation of the southern portion of the province and constituted only a major temporal barrier for a southern movement of *later* (Palaeoindian) groups. Re-opening of the "ice-free corridor" in west-central Alberta along the eastern slopes of the Canadian Rocky Mountains at the end of the Last Glacial, sometime between 14 000 and 12 000 yr ago (Rutter, 1980; Liverman et al., 1989), thus should not be considered as a major natural precondition for the “initial” peopling of North America south of Beringia. Evidently, people already occupied this vast area well before that time.

4. Discussion

Although the archaeological studies during the last decade disproved the Clovis tradition as the cultural entity associated with the initial peopling of North America, question about chronology of the initial Palaeo-American migration(s) and the level of technology the early Americans brought with them is still from fat to be resolved. The recent discoveries in the SW United States (Waters et al., 2011) have demonstrated that the Clovis Culture (^{14}C-dated to ca. 13 100-12 800 yr BP) is a result of an entirely autochthonous New World culture-historical development analogously as the Dyuktai Culture in the Russian Far East dated to ca. 14 100-13 000 yr BP (Mochanov, 1969). Although the antiquity of presently the earliest in the U.S. - accepted Buttermilk Creek Complex at the Debra site, Texas, has been extended by some two thousand years (to 15 300-13 200 yr BP), the research focus on shallow-subsurface geological contexts of investigations remained (the cultural horizon at the Debra sites lies just at -1 m!). This situation with early sites' visibility in unlikely to change unless adequate geology and geoarchaeology approaches and analytical methods will be implemented in the field survey aimed at the *deeply-buried* Pleistocene occupation sites in the high depositional-rate geographical areas. Also, there is still an unfounded resistance to the notion that there could be anything on the Upper - Middle (or earlier) Palaeolithic technological stage level.

It may be this unwillingness to take seriously into consideration any lithic record from the Pleistocene-age deposits that differs from generally recognized industries, and/or an inadequate professional knowledge and capability to evaluate objectively rudimentarily modified stone artifacts which may altogether be largely responsible for the "controversy" surrounding the earliest American prehistory. This directly reflects the fact that most North American archaeologists lack training in Quaternary geology. What is most important, they do or may not look for the ancient sites in the right, including the deeply-buried Pleistocene geological settings. Not necessarily visibility, but primarily recognition of simply worked lithic records is the main factor which can significantly contribute to new discoveries of very old Palaeo-American sites. Especially the formerly glaciated as well as the extraglacial areas of a high sedimentation input have a major potential and should be systematically surveyed. Recurrent patterns of the "Palaeolithic" stone flaking with knowledge of the diagnostic artifactual attributes and their associations in a particular lithic assemblage is one of the fundamental study criteria, apart of the geological context. On the other hand, the cultural material recorded in its original geological context may provide a significant source of proxy data on the past climates and climate change in some areas of the Northern Hemisphere that experienced the Pleistocene glaciations, in terms of their timing and the geographical extent corresponding to the general concept of paleontological "trace fossils" in historical geology. This approach is routinely practiced in Africa or Eurasia, and search for 10 or 100 m-deep geoarchaeological locations, some of a very high age, may be standard and nothing unusual (e.g. Medvedev et al., 1990; Mochanov, 1992; Chlachula, 2001b). Because of the close ties of archaeology and Quaternary geology, many of the ancient Early or Middle Palaeolithic sites are found during a geological (loess-palaeosol), stratigraphic and/or geophysical mapping.

The dissention about the archaeological expressions and the contextual associations of the Pleistocene New World early prehistoric evidence reflects the absence of an uniform and internationally accepted methodological framework used as a model procedure for evaluating the summary data of the potential pre-Clovis (or "pre-Buttermilk") complexes. This should involve both the field geoarchaeological studies as well as laboratory analyses. Particularly the identification of an early "non-diagnostic" lithic industry in an unusual or unexpected deep stratigraphic geological context may be a complex problem. This, however, cannot be approached only "intellectually," as it has been a common practice, by simply refusing evidence as this does not fit the established historical model or paradigm without providing supporting, own hard data-based scientific arguments. All the more so if the opponent(s) lack the necessary professional background in the lithic and the contextual geology studies.

The cultural nature of rudimentarily modified artifacts can be established by a set of criteria applied in a simple, but logical sequence. This includes discrimination on lithic specimens of unambiguous modification traits which do not occur in analogous deposits at other places with identical raw materials, and which possess clear attributes encountered on definite stone industries easily replicated by experimental flaking. It must be kept in mind that nature can under certain circumstances also produce some recurrent patterning of rock modification, and any simplistic generalization should be avoided. Rock flaking criteria should, therefore, comply exclusively with the local geo-contextual and sedimentary conditions. Accordingly, correct interpretation of the geological context, and a sufficient knowledge of physical properties of raw material and potential sources of natural edge-wear are of utmost significance. An exclusive reliance on formal morphological resemblances with Palaeolithic tool types, or a presumed lithic technology should be avoided. Nevertheless, the diverse Old World Palaeolithic collections can be used only as proxy data. Finally, the overall quality of presentation with clear description and detailed documentation of (archaeological) material, completely assembled contextual data, and their critical evaluation are equally important.

As the fundamental issue in the early American prehistoric geoarchaeology field research concerns the recognition of artifactually flaked lithics in deep geological contexts, implementation of adequate techniques of study is prerequisite. These should not be limited just to (at best statistical) determining the degree of probability of the cultural status of a particular lithic assemblage, but its authenticity should be explicitly qualitatively assessed. Geomorphological, sedimentological, petrographical and rock-mechanical investigations, combining both field observations and analytical laboratory expertise play a crucial role. Dynamics of a depositional environment should be studied in order to determine the actual potential for natural modification of a particular lithic material. Easily accessible deposits with naturally fractured rocks of old geological ages can be used for a control testing. All these and other study aspects are especially vital for the possible Palaeolithic assemblages found without association with any other archaeological record or cultural features. This, however, is not possible without a broad multidisciplinary approach following more than one line of supporting evidence. It is very important to pursue such approach, not only for elucidation of the earliest American (as well as Siberian) prehistory, but also for a further development of field as well as analytical methods, which can also be applied in other parts of the World in similar study contexts and for the same ultimate research goals (Fig. 15).

Although the principal above-discussed „pre-glacial" sites near Calgary are unique among all the early American sites in view of the unusual glacigenic geological contexts, antiquity as well as the archaeological manifestations, there is a striking parallel from western Europe -- the Lower Palaeolithic site at High Lodge, England, with flaked flint artifacts distributed in the Anglian till as a result of glacial transport (Ashton et al., 1992). This Middle Pleistocene occupation locality, stratigraphically estimated to date to ca. 0.5 Ma and formerly established in a riverine setting, was subsequently overridden by the Anglian ice, causing a subglacial entrainment of the flint artifacts secondarily distributed in the till, i.e., experiencing the identical post-depositional geological process as the Bow Valley sites.

A

B

Fig. 15. The Calgary prehistory: A: The Late Pleistocene site (Varsity Estates) with the exposed occupation horizon on top of the Bow Valley till stratigraphically - 24 m below the present top surface (B). B: A Holocene-age Indian site (Calgary Bowmont) with tepee rings and stone tools excavated in shallow (-30 cm) cultural layers on top of the Bow valley cliff. An illustrative example of *different* field investigation approaches in *different* geological and geoarchaeological contexts delivering the chronologically *different* cultural evidence on early inhabitation of a particular study area. For the early sites, it must be searched in the deeply buried geological formations that are extensively distributed across the province of Alberta.

5. Conclusion

Glacial and glacigenic deposits of diverse geological genesis of the Pleistocene glacial stages are extensively distributed over vast areas of the mid- and high latitudes of Eurasia as well as North and South America These deposits and the underlying non-glacial interstadial and interglacial formations have proven to incorporate cultural materials that would normally be unexpected by most archaeologists. Particularly in North America, where archaeology has developed in frame of cultural anthropology based on Indian or other recent aboriginal ethnological studies, the ties to Quaternary geology have been historically rather marginal contrary to the Old World and the Siberian archaeology (Chlachula, 2011). Accordingly, the overwhelming survey approaches and the associated field prospection techniques focus more or less just on the Holocene cultural manifestations visible on the present surface (such as tepee stone rings or scatters of lithics or ceramic fragments) (Fig. 15B), and sealed in the shallow-buried geological contexts. This fact is rather absurd, since very massive and deeply stratified Quaternary formations, the Late Pleistocene in particular where the earliest human traces in North America would be logically most anticipated, are distributed in the very area of the presumed continental passage of prehistoric immigrants on their way from NE Asia.

Until the early 1990's, these Quaternary formations, exposed in many and easily accessible and geologically readable sections, some of them fossiliferous, were totally out of any geoarchaeological survey and research interest until the discovery of the "pre-glacial" cultural horizons at the Calgary / Bow Valley locality. The following pilot geoarchaeological investigations in western Alberta resulted in the locating several other anthropogenic sites in the same geological / palaeoenvironmental settings, thus providing definite, unequivocal evidence of the existence of the Palaeo-American peopling of western interior Canada long before the emergence of the Final Pleistocene (Palaeoindian) cultures. Based on a critical multidisciplinary examination of the archaeological as well as geological data, the Bow Valley with other Alberta localities are contextually the first Pleistocene – Palaeolithic sites in America discovered below glacial deposits, although close parallels come from Europe as well as the North Russian Arctic (Ashton et al., 1992, Laukhin, 1991, Pitulko et al. 2004).

The term "Palaeolithic," applied for the "pre-glacial" stone tool assemblages from western Canada, is used to refer to the particular technological stone flaking stage as well as the time period corresponding to the traditional Old World culture-historical concept. These early cultural records, representing *de facto* "trace fossils", may also significantly contribute as palaeoenvironmental proxy data to mapping of past climatic events and reconstructions of Quaternary environments. Even if obtained from a concise geographic area, but a clear geological context, such early cultural records may have definite local as well as regional implications. Realization that the American *Palaeolithic* sites, potentially of considerable antiquity, can be found in similar (pre-)glacial geological settings and introduction of the adequate geoarchaeological site-survey techniques, have crucial relevance for elucidation of the earliest New World prehistory. Geographically extensive river valley exposures along the eastern slopes of the Canadian Rocky Mountains and the adjacent western plains have an excellent potential for preservation and recovery of such buried early cultural archives.

For *early* sites must be searched in *early* deposits! The pioneering geoarchaeological investigations in Alberta, opening a completely new niche of research in the areas formerly affected by glaciations, show the necessity of implementing the corresponding geological methodological approaches and research techniques into the earliest prehistoric studies in the formerly glaciated parts of the Americas as well as other regions of Pleistocene Beringia.

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4

GIS Techniques in Archaeology: An Archaeoastronomical Approach

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1. Introduction

Geographic Information Systems (GIS) has proven to be a very useful tool when it comes to represent the elements of an archaeological site. Geographers initially used these systems as resource management tools (Burrough & McDonell, 1988). A geographic information system is a special case of information systems where the database consists of observations on spatially distributed features, activities or events, which are definable in space as points, lines, polylines, or areas. These datasets are composed by a collection of geographic coordinates (latitude, longitude and altitude) or on an UTM projection (X,Y,Z), relative to a reference Datum and alphanumeric information.

Traditionally, this information has been stored on spatial databases as PostGIS or Oracle Spatial, and they have been transformed using geoprocess techniques to get valuable derived information as DEM (Digital Elevation Models), thematic maps, and other relationship between the elements and the environment.

Nowadays this point of view of GIS as a cataloge technique has been improved and we go ahead to Spatial Data Infraestructure (SDI) (IGN, 2011).

While GIS is a data-driven, SDI is a service-oriented. In an SDI the data resides outside of our computer, and they are distributed across the network. Each layer of data is maintained by the team responsible for its data. In Archeology, the layer of interest are related to the archaeological site in study.

An SDI is composed by a set of technologies that includes data and geographic attributes, with services that allow the visualization of this mapping and the integration with other systems. The goal of this technology is effective share of geographic information avoiding duplication and ensuring the use of a set of basic geographic data, enabling the integration of these sources, maintained by different agencies.

Therefore, a SDI is more than geographic information (GI) stored in a traditional GIS. The GI can be accessed via Internet and it can be used with other data sources, this is where the potential of this technology.

GIS have some advantages comparing to other technologies, for example, data is collected just once and kept where it can be managed most effectively. It is possible to combine seamless spatial information from different sources across all over the world, sharing it with a huge amount of users and applications. It allows different levels of detail from the same data source; e.g. detailed for regional research or general for strategic purposes.

In European Union, we can find INSPIRE Dierctive which aims to create a european spatial data infrastructure (EU, 2007). This will develop the sharing of spatial information among public sector organizations activating public access to spatial information across Europe. Globalization and Interoperability are the basis of this technology.

1.1 Services offered by an SDI

There are some services that allow mapping visualization and integration with other systems from data and geographic attributes that shapes SDIs. These services are described as standards by the Open Geospatial Consortium (OGC, 2011a). The OGC is an international industry consortium of 438 companies, government agencies and universities participating in a consensus process to develop publicly available interface standards.

These support interoperable solutions, one of the most important objectives of an SDI. Among its objectives are: Facilitate the adoption of open, spatially enabled reference architectures in enterprise environments worldwide. Advance standards in support of the formation of new and innovative markets and applications for geospatial technologies. Accelerate market assimilation of interoperability research through collaborative consortium processes.

Fig. 1. WMS server structure

The standard services provided are WMS, WFS, WCS and CWS. The layers produced by this method represent a big advantage because they can be mixed with other geographic information get from any source. Users just need a thin client to get these services and geographic data remain in the original service provider.

1.1.1 WMS (Web Map Service)

It is the standard for displaying geographic information over the Internet. It provides a picture of the real world for a requested area. The sources may be GIS data files, spatial databases, digital maps, orthophotographies, satellite images and so on.

WMS is organized into one or more layers, which can be displayed or hidden one by one, being able to view information about individual elements of the map. It allows visual overlaying of vector and raster data with different reference systems, coordinates and servers.

Returning, in any case, a raster image in a widely used format, such as PNG, JPG or SVG, to the final user.

WMS specifies three operations (figure 1):

- GetCapabilities: Returns metadata to service level.
- GetMap: Returns a map image when geographical parameters and dimensions have been defined.
- GetFeatureInfo: Returns information with particular features shown on map.

1.1.2 WFS (Web Feature Service)

This is the standard that allows accessing and viewing to all the attributes of a spatial element, called feature, represented in vector mode, which geometry is described by a set of coordinates.

WFS specifies three operations:

- GetCapabilities: Retrieves the formal description or metadata of the service to determine available options.
- GetFeature: Performs the actual query by means of parameters such as bounding box and any other filters. The result is a group of data that contains geometry and asociated alphanumeric data.
- DescribeFeatureType: Retrieves the XML schema to allow the WFS client to parse the resultsets.

The data are provided in GML format (another OGC standard). A WFS allows not only to display the information as permitted by a WMS, but also the free view and download of the complete dataset.

1.1.3 WCS (Web Coverage Service)

Sometimes, geographical information is composed of values or properties describing spatial locations by means of a system of geographic coordinates, this is the so called Coverage. The GI can also contain temporary, regular or irregularly spaced information, as happens representing a Digital Elevation Model (DEM). The OGC defines Web Coverage Service to enable the recovery of geospatial data in the form of digital spatial geographic information coverages that represent phenomena of spatial variation in a representative way or as input data for scientific models.

This service is useful to consult digital elevation models and to calculate horizon lines. Operations defined in a WCS are:

- GetCapabilities: Metadata service and coverages offers.
- DescribeCoverage: Detailed description of hedging.
- GetCoverage: Get cover or part of it.

As mentioned, the DEM is the most important coverage in an archaeological SDI. As sources of MDE the recently released ASTER Global Digital Elevation Map (NASA, 2011) can be cited. It is formatted in 1 x 1 degree tiles as GeoTIFF file, covering the Earth's land surface between 83° N and 83° S latitudes, with an accuracy below 10m.

1.1.4 CWS (Catalogue Web Service)

The Web Catalog Service (CWS) is defined by the Open Geospatial Consortium (OGC) as interfaces to discover and query metadata about data. It enables requests for a diversity of information in terms of source and theme. These services are implemented using catalogue software as Geonetwork. It allows to discover all kind of IDE services as WMS or WFS using metadata from every service, dataset or layer.

Metadata are data about data. It is information and documentation making geographical data identifiable, understandable and sharable by users and other services. Metadata objetives are:

- Search for data sets, what data exits or are available in a certain area, for a given subject on a scale, a general date or specific features. Due to do this metadata stores information about the data set: what is said, why was prepared, when, who produced it and how, and so on.
- Choice between data sets, to compare different ones, so you can select which ones meet user requirements in a better way for the intended purpose.
- The use, describing technical characteristics of data, in order to allow efficient operation. It helps users both maintaining and updating these data.

Metadata must fulfill ISO 19115:2003 which describes the schema required for describing geographic information and services. This defines:

1. Mandatory and conditional metadata sections, metadata entities, and metadata elements.
2. The minimum set of metadata required to serve the full range of metadata applications (data discovery, determining data fitness for use, data access, data transfer, and use of digital data)
3. Optional metadata elements allowing more extensive standard description of geographical data and if required a method for extending metadata to fit specialized needs.

1.2 SDI components

Main SDI components are described in figure 2. These components allow the storage and distribution of geographical information.

- **File datasets**. The most common way to exchange geographical information in archaeology is using files. Sometimes these are open standard but the problem begins when data are stored using a propietary system. To ensure the availability of data between diferent services, software and users, data files must achieve OGC standards.

  DWG or DWF generated by AutoCAD, or Shapefiles, an ESRI widely used format are standards of this type. Sometimes a raster image can be used when it has been georreferenced. So we can use geoTIFF images or JPG and JGW files with information about projection, rotation and scale.
- **Spatial Database**. It stores the spatial elements and their attributes (Features). Some products are widespread as PostgreSQL PostGIS, Oracle Spatial or MySQL. These data are stored in tables using spatial indexes. There is a special language to create tables, select, update and delete records. This is Simple Feature Access for SQL (SFSQL) (OGC, 2011b). This allows to get spatial entities and represent them from an unique repository to any software.

- **Map Servers**. Software that allows publication of the maps and provide WMS and WFS services through Internet. Some examples are GeoServer and MapServer. Spatial datasets can be stored in Shapefiles, spatial databases or even georreferenced raster images. The servers allow additional operations such as layers reproduction, very useful in case of working with different reference systems. The different map servers characteristics are shown in table 1.

Name	Language	WMS	WFS	WCS
Spatial Fusion Server	Java/C++	Yes	Yes	No
ERDAS APOLLO	Java/C++	Yes	Yes	Yes
ArcGIS Server	.NET/Java	Yes	Yes	Yes
MapServer	C	Yes	Yes	Yes
Deegree	Java	Yes	Yes	Yes
GeoServer	Java	Yes	Yes	Yes
Basic-wms2.py	Pythom	Yes	No	No
Manifold System	ASP/C#	Yes	Yes	No
MapLarge API	C#	Yes	Yes	No
SpatialFX	Java	Yes	No	No
Orbit EOS	Java	Yes	No	No

Table 1. Main map servers. Adapted from OSGEO (OSGEO, 2011)

- **Desktops applications**. Traditional desktop applications that allow the processing of geographic data. In Archeology we are used to use Computer Aided Design (CAD) software such as Autocad to produce the traditional layers. But this can not generate standard information. Therefore, it is recommended to use other programs that generate geographic information in these formats. We have examples like gvSIG, UDig, QGIS or ArcGIS Desktop.
- **Thin Clients**. These applications are usually web clients, which allow viewing a small geographical and managing data from another possible data sources. These clients are created with API like Google Maps or OpenLayers. Its main utility is that can be used embedded in other applications and they can integrate information from different map services, both archaeological and other tematics.

All the elements in a SDI are represented only by a few components: Points, Lines, Polylines, Polygons and Raster data.

2. Archaeoastronomy

Since the beginning Archaeoastronomy has been developed by specialists of several and very different disciplines. This, added to the fact that it is a very young scientific branch, has caused a methodological and conceptual disorder. It can be seen, for example, in the variety of Archaeoastronomy definitions: *"Discipline which studies the way that ancient peoples' societies conected with the cosmos, taking into account archaeological, etnogrpahical and historical data"* (Cerdeño et al., 2006), *"Discipline which studies the degree of astronomical knowledges of past societies, connected with their vision of the cosmos"*(Belmonte, 2000) and *"Discipline which studies the development of astronomy of prehistoric societies inside their cultural context"*(Esteban, 2003).

Concerning to these lines, perhaps the best definition would be the science that studies the celestial landscape in the past taking into account any cultural data source such as

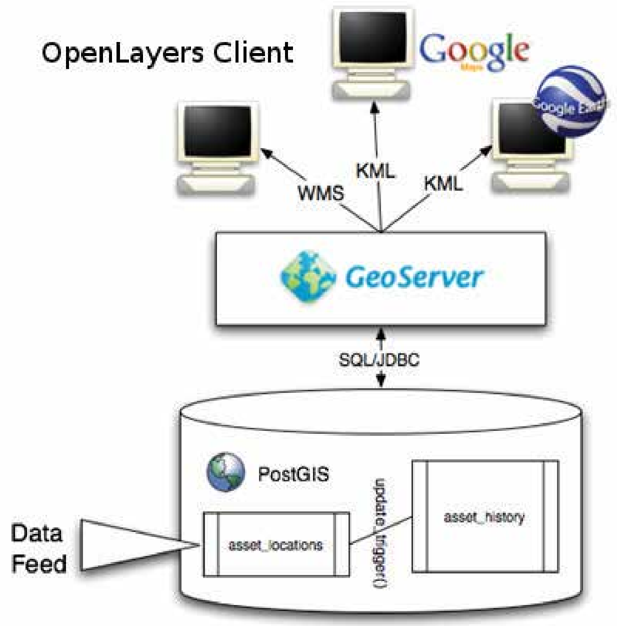

Fig. 2. Main SDI components (GEOSERVER, 2001)

archaeology, antropology, ethnography, historical data and so on. But in order to understand the situation in these days we should take a look of its beginnings.

The very first steps in the discipline were made by the interest of some people about the intentionated orientation of several megalithic monuments. These studies were made in XVIII century by the architect John Wood (Wood, 1747) and the antiquarian William Stukeley (Stukeley, 1740) related to Stonehenge, Callanish, Castle Rigg and Sarsen Circle. With these two first studies begins also two tendencies which remains nowadays. The first one is the predominant importance of megalithic studies in Archaeoastronomy against any other epoch archaeological sites (figure 3). The second tendency is related to the main role that british researchers had in this type of works.

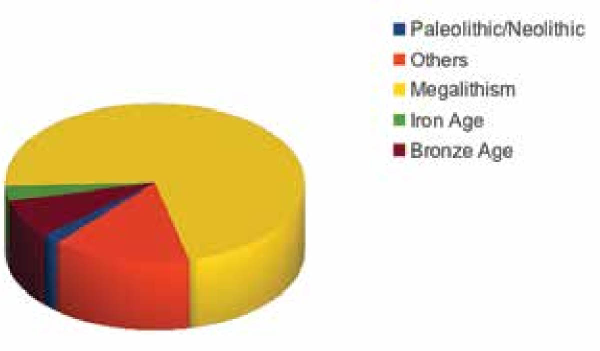

Fig. 3. Archaeoastronomical studies sorted by epoch. Based in (Cerdeño et al., 2006)

After Wood and Stukeley's contributions, the next remarkable work was made after the century change by another antiquarian, A.L. Lewis. It was a recopilation of archaeological sites with probable astronomical signification, which was used and extended by the British Army's Captain H.B. Sommerville and Sir Joseph Norman Lockyer (Lockyer, 1909).

Alexander Thom is considered as the father of the modern Archaeoastronomy. His important publications "The solar observatories of Megalithic Man" (Thom, 1954) and "Megalithic sites in Britain" (Thom, 1967) are essentials in the bibliography. The main contribution of this engineer is applying topographical techniques and mathematical science to the study of different archaeological sites. Thom did not only based his research only in the traditional sites but kept studing only the megalithic ones.

With this new methodological approach the discipline reach to the 80's decade of the XX century. In this period the discipline spread in many european countries in some cases by the hand of researchers as Michael Hoskin and Carlos Jaschek who founded in 1992 the SEAC, (Sociétè Européenne pour l'Astronomie dans la Culture/European Society for Astronomy in Culture) to stimulate innovative concepts and methods that would serve to open up new understandings of the many and deep interactions between astronomy and culture. It was almost the only effort to get interdisciplinary works in Archaeoastronomy against traditional separated from archaeology ones.

2.1 Archaeoastronomy and Archaeology

The huge gap between natural and social sciences was a problem affecting to archaeoastronomical research, often this produced negative reaction between archaeologists in many cases rejecting astronomical conclussions. Afortunately it seems that, in the last few years, is changing with the appearance of some well designed interdisciplinary archaeoastronomical projects.

Archaeoastronomy can be seen as another archaeometry, the application of natural sciences techniques to the analysis of archaeological contexts. In this case, archaeoastronomy can handle inmaterial archaeological record, believes and ritualism interpretations unachievable with another point of view. The archaeologist will need a specialist to interpret astronomically an archaeological record. But, obviously, the cultural interpretations need an archaeologist who will discern between posible only astronomical interpretations.

Fig. 4. WMS client example in Casa Montero archaeological project (Montero, 2003)

So, both sides are needed and essential, in any other case archaeoastronomical interpretations will be inexact or false; measurements without sense or archaeological contexts badly interpreted. Thus, we need interdisciplinary projects and researches feeding back each other to avoid that.

3. Spatial data infrastructure: Role in archaeoastronomical works

In archeology, the data traditionaly is stored in analogical format, only in the last few years archaeological information is appearing in digital format, mainly in DXF and DWG AutoCAD files. Analogical format carries some problems in geographical related projects, specially in Archaeology. The data is not easily shared between persons in different places being each person's work disconnected to the others work. The digital processing is somewhat complicated, having to digitalize each plane, if it is necessary, without the possibility of put the whole information together. In archaeological contexts, where the aim is getting as information as possible about human societies, this is specially important. As happens nowadays, we can not understand a society only with only one layer of information, for example, the religion. Information need to be together taking all human ancient societies aspects into account, including elevation, resources, soil utilization and astronomy (figure 5).

As a solution to this, the SDI is easily applied in archaeological research. Examples of this can be seen in figures 4 and 6. Systematically on each site, takes out a topographical reconstruction work. This involves making an inventory of all items that appear at the site, with the location information. The SDI, allows digital inventory of information, easily publicable in standard formats described above. All SDI are available via Internet, which making accesible information to different working groups in modern information society. Obviously, if necessary, it is possible to grant restricted access to the Cartographic Server based on the user role profile.

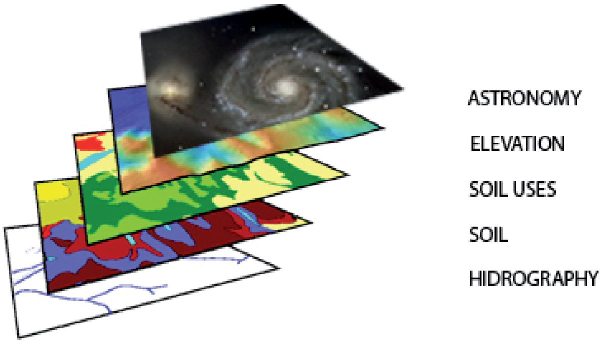

Fig. 5. Archaeoastronomical information as another layer of information in an SDI

To carry out the process of generating a digital inventory and publication in the SDI, some steps have to be perfomed:

- Land Survey. Using GPS, theodolites, technical photography and LIDAR data taken at the site. The GPS allows pinpointing each element in an archaeological site. This way, any building position can be taken, plotted or landscape elements can be mapped. LIDAR techniques has special interest, due to land reconstruction and performing high-precision DEMs. With airborne laser sensor -typically at rate of between 20,000 and 50,000 pulses per second- can reconstruct the whole field in study with centimeter accuracy. LIDAR and GPS gives georreferenced measures, so it is perfectly possible to generate the map. In each point the sensor picks up the echoes of the laser, measuring the height of each element of the terrain. The final result is a 3D model of the entire site.

- Spatial Database. The data collected are georreferenced and stored with its geographical location. Then stored in the database space.
- Geoprocessing. In most cases it is necessary to process this data (raw data). Depending on the work involved will be coordinate system transformation, change between representation styles, data crossing with other databases and SDIs, etc.
- Publication of the features. Finally we proceed to publish the vector data of the database server using the map. On it, as mentioned, images are generated to be used by different applications, showing the characteristic images of flatness and they can access the data of each object georeferenced.

How to use all this together with astronomical data? The solution comes from using data published by the Archaeological SDI through applications clients. The most helpful are the WMS and WFS. We can publish the astronomical data using two ways: Vector or Raster datasets.

The simplest way is to offer the data via GeoRSS GML format. This is a consistent standard in XML in which each element is associated with its geographical position. This option is better when we try to use a thin client, like OpenLayers and Google Maps. It uses a reduced bandwidth and increase time responses. It is very useful to represent separate elements, as the line of heliacal rising of a star or if we combine our archaeological layer with other vector and raster layers from other SDIs, such as geology, elevation model, etc. It is also possible use geoJSON. This is an open format to geoencoding different data structures. It is a more compact than geoRSS.

Fig. 6. SDI in Life Tiermes archaeological
http://www.mat.ucm.es/archaeoastronomy/project (Tiermes, 2007)

Another option is to generate a complete map layer, which could be stored in the database as raster or vector data sets and is published as a layer within the SDI. This solution is valid for representing lines such as northern and southern boundaries of an eclipse of the sun or near a transit visibility.

Using the user interface, the archaeologists can zoom into a selected region. Getting information is reduced to click on a layer element, even create new data or views mixing existing layers. Obviously all interest information can be downloaded to a local repository for later use.

3.1 Representing astronomical data

We have described the SDIs and what kind of information we can get from them, now we will focus on the astronomical data we have available and which are likely to be useful in historical studies. We will discuse:

- Heliacal rising of the bright stars and planets to determine alignments matches present in the mapping.
- Data on local circumstances in eclipses of the sun and moon, for dating historical events.
- Azimuth over the horizon of sunrise, sunset and passed the meridian of the Sun at the Solstices and Equinoxes.

3.1.1 Heliacal risings

In the case of heliacal Ortos, we will take into account the geometry described by Robert Purrington (Purrington, 1988). As a starting point, we need to have some knowledge about the profile that can be observed from a required position. To construct it, we can use a Digital Elevation Model (DEM) as basis. This consists in a file with a digital representation of the terrain's surface. For each X,Y position, an elevation value is given. There are several sources for this information, the most common used are satellite missions as SRTM or GETOPO30 (NASA, 2000). These projects provide free access to elevation models all over the world with different spatial resolutions and scales. From these files and the position of an observer, it is possible to reconstruct the profile of the horizon using any GIS software as gvSIG or QuantumGIS.

Next step is to determine the points of sunrise and sunset. To compute sun's or object position at any time on the horizon, we have to implement the following algorithm to ensure a good accuracy:

1. Apply correction for proper motion of the star.
2. Apply correction for precession.
3. Determine the date of the heliacal rising.
4. Apply refraction correction.
5. Calculate the azimuth of sunrise.

The result can be seen in the chart below, for each period, there is a shift in the position of azimuth on the horizon of this phenomenon, using the geometry of Purrington.

To determine the position of the heliacal point on rising to being able to represent the mapping, a whole set of software libraries can be developed that allow to apply this algorithm to remote dates from 4000 BC. For the calculations of precession we have applied the algorithm

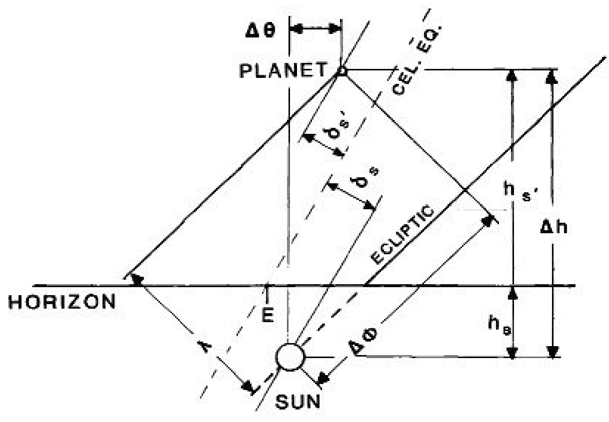

Fig. 7. Azimuth position shift by effect of the refraction. From (Purrington, 1988)

described by Gómez, J. (Gómez Castaño, 2006). And the method described in the latest edition of the Explanatory Supplement (USNO, 1992) for atmospheric refraction correction, see figure 7.

Among the objects observed by different civilizations are the Sun, the planets and some bright stars. In some cultures -e.g. egyptian culture-, the output of some stars, like Sirius, were taken as elements to indicate the beginning of the calendar. As a reference star positions and proper motions, the FK5 catalog (Fricke et al., 1991) can be used and the Bright Star Catalogue (Hoffleit & Warren Jr, 1991) for the positions according to the J2000.0 reference system.

Concerning to the planetary positions in these times, the easiest source is the software using the JPL Horizons (figure 8). This provides for remote time, planetary positions using the JPL DE406 theory. It includes neither nutations nor librations. It is referred to the International Celestial Reference Frame. Time gap goes since JED 0624976.50 (-3001 FEB 04) to 2816912.50 (+3000 MAY 06). In any case we can develop customized applications from the coefficients of the theory. From the positions of the planets, the sun or the stars, the point on the horizon can be determined in which these stars appear or disappear. The azimuth of these points are plotted on a shape file or generates a vector layer which is distributed through SDI.

3.1.2 Alignments

Once those calculations get the ephemeris providing the Azimut of the Orto for every object, they have to be carried out to local times and places of archaeological site of interest. In the site, data are tested to get possible alignments. This can be achieved from a comparison between the astronomical layer containing rising and settings of the objects for a given date and the archaeological layer. Getting these layers into a SDI interface, the lines can aligned with terrestrial and architectonical elements.

3.1.3 Eclipses

On the other hand, for a given location historical events can be dated from the calculation of the local circunstances of an eclipse. This visibility can be calculated from the same besselianos elements of the eclipse. Recently, Fred Spenak has published Five Millennium Catalog of Solar

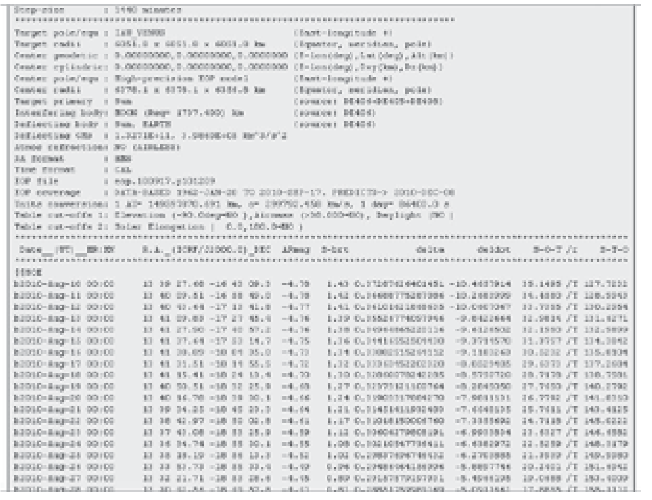

Fig. 8. Ephemeris calculated with JPL's Horizons software

Eclipses -1999 to +3000 (Spenak & Meeus, 2009). These ephemeris are a important help dating historical events.

3.2 Using astronomical data in the archaeological SDI

At this point it is clear that the main advantage of using this tool is to encapsulate the complexity of astronomical calculations, providing only useful information for the archaeologist.

In this type of work it is necessary to take into account the time to which we refer our calculations. The archaeological sites correspond to a date in antiquity, or a period. The Earth is subject to precessional motion so we must take into account when ephemeris are generated (Vondrák et al., 2011). The archaeological community is not used to deal with this type of calculation, but it is possible to encapsulate it within the astronomical SDI and generate, this way, information that is integrated with the other layers. This makes it easy to use for the archaeologist.

To integrate the two types of information is useful to follow the following process:

1. From classical astronomical software commented before, we can calculate object possitions, taking into account the astronomical factors such as precession.
2. Ephemeris generation can be done on demand in real time or by storing ephemeris and serving sets as needed. These ephemeris are independent of the observing site.
3. Then, taking into account the position of the archaeological site corrections are made to include local factors such as atmospheric refraction, and calculating "local circunstances"
4. This ephemeris in vector format, lines, polylines or poligons, can be stored in spatial databases. It is also possible to generate shape files with the outcome of the ephemeris which can be added to the rest of archaeological GIS.
5. From the stored information in the database, a complete layer that is available to users through WMS or WFS can be generated. even downloadable in vector format if desired. It is also possible to publish data via GeoRSS and GML format to represent them in any kind of OpenLayers client or Google Maps.

The most important for the archaeologist is how to access these layers with astronomical information. To do this a client software is only needed to consume the services offered by the astronomical SDI. Any of the programs commonly used in archaeological can do that. It also can be developed customized programs based on thin clients, OpenLayers and the popular Google Maps that allows to user to integrate all kinds of layers and remote services with data stored locally.

Sometimes it can be useful the possibility of doing some geoprocesses with the information. As example, it can be useful the determination of the horizon visible from an archaeological site. Using the intended position of an observer and a DEM, the target profile shapefile is generated. These geoprocessing tools depend on the chosen program. There are very useful extensions like SEXTANTE (Olaya, 2011) or GDAL libraries (GDAL, 2011), open source software for Desktop or ArcGIS.

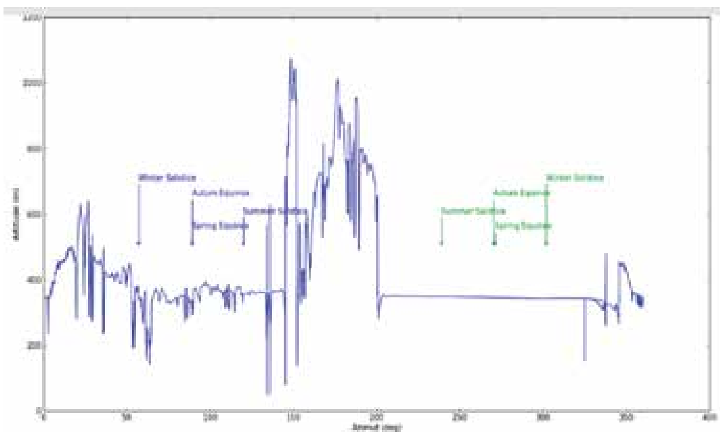

Fig. 9. Example of geoprocess. Horizon profile from Moreiros archaeological site at 4,000 B.C. (Mejuto et al., 2011; Valera & Becker, 2010; 2011)

As a result of applying these new layers to the existing archaeological and astronomical ones, a new tool for the analysis of the findings in archaeological sites appeared, and a line of knowledge about the culture of its inhabitants. The use of SDI allows to integrate these layers from astronomical servers, with the layers of the findings themselves.

4. Case study: Ditched enclosures in Portugal

The data used in this example have been achieved in the context of the project *Ditched Enclosures' plans and Neolithic Cosmologies: A Landscape, Archaeoastronomical and Geophysical Point of View.* This project is funded by Calouste Gulbenkian Foundation and scientifically leaded by the archaeologist Antonio C. Valera from Era Arqueología, the geophysical part was carried out by Helmut Becker from Becker Archaeological Prospections and the archaeoastronomical part was responsability of the authors (Valera & Becker, 2010; 2011).

The work involves Neolithic and Chalcolithic periods which are very interesting from an archaeological and astronomical point of view. Neolithic is a period of changes, very important and strong changes in some cases, as the transition to sedentary populations and the development of agriculture. It was also, an epoch of revolution in technology and minds. The ritualism, symbolism and social complex processes raised strongly.

Ditched enclosures are monuments with a tendency to circularity in shape with several concentric ditches from a few meters up to several hundred meters in diameter. Initial distribution was over a large part of Europe (specially in Germany, Austria, and Southern Britain) but nowadays we have an increasing number of this type of monuments all over Iberian Peninsula generally because of the civil works and a few of research projects.

We will take as example Moreiros site which is located in Arronches, Évora, with several enclosures some of them so called wavy enclosures. Usually the explanations of this type of sites have been referred more to group identity management or symbolic world distribution, putting the stress in the construction process itself as a social stimulator. Others just have seen in these sites a reflection of sedentary groups settlements in which typology talk us about hierarchy in the territory.

Methodology talking the aim is joining traditional GIS techniques with the astronomical ephemeris calculation and its representation over the landscape and terrain. We should stress the peculiarities of this study. The first one is that no one of the sites was never digged and the ditches are no structures that can be oriented. These aspects had to be solved by the work methodology.

On the one hand data gathering has been done on terrain including very precise GPS coordinates of each site. From UTM coordinates, we have made the calculation of the visible horizon from the site. After calculation we get a shape vectorial file that we can use with a Digital Elevation Model and the magnetic data.

The second part of the work is related to astronomical variables. In this example only the solar main positions are implemented. But it is perfectly possible to include some other lunar events, heliacal rises of stars, planetary events, asterism positions and so on. To get this we use a Python programmed code that give us another vectorial shape file as output which we can cross over the Digital Elevation Model again to get the astronomical orientations.

In figure 9 we can see one of the outputs of this software; this is the horizon profile from Moreiros at four thousand before Christ again with the solar main positions on it. In the horizontal axe the azimuth angles are displayed and in the vertical one the height in meters. At left in blue there are the rises and in the right the sets in green. It can be seen that, in this case, there are no topographic markers, astronomically speaking.

One of the other outputs of the software is the calculation of the azimuth angles of solar main positions all over the year. The final result can be seen in figure 10. In this case the sun main directions are shown: the summer solstice, the equinoxes and the winter solstice taking into account the topography. As you can see, the east door of the enclosure is oriented to winter solstice at the rise and the west door is oriented to the same event in the set. The shape of one of the enclosures is also related to the winter solstice as other structures marked with an arrow in the graphic.

This methodology has several interesting points, the technique used can be used in standard OGC services in internet as a way to outreach results of the research. Also gives us the possibility to study a site from different views (topoastronomy, orientation ...), everything with noninvasive techniques, Allowing us, in a simple way, getting geographical information useable in any other GIS tools where the astronomical information is another layer of information which can be served as other data in an archaeological project.

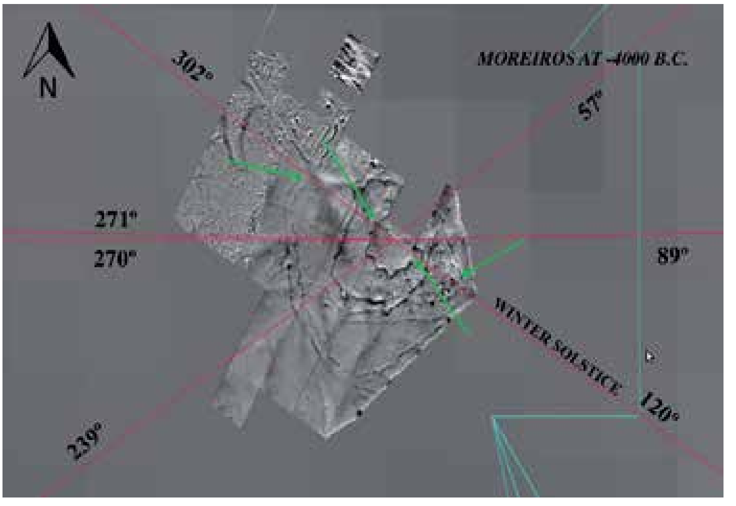

Fig. 10. Solar archaeoastronomical study for Moreiros at 4,000 B.C. As can be seen topography, landscape and geophysical data are considered (Mejuto et al., 2011).

5. Acknowledges

This work has been developed inside **UCM910596 Research Group: "Grupo de estudios ionosféricos y técnicas de posicionamiento global por satélite (GNSS)"** in the framework of the project entitled **Aplicación de la Interferometría Radar Satélite y los Sistemas Globales de Navegación por Satélites en Estudios sobre Control de Deformaciones de la Cordillera Bética (AYA2010-15501 (subprogram ESP))**.

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5

Archaeological Geophysics – From Basics to New Perspectives

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1. Introduction

The chapter aims to show a wide overview of the more used archaeological geophysics techniques and their last improvements and challenges. This will be done through two parts.

The first 5 tittles are dedicated to definitions, technical principles and a brief introduction of how the different geophysical techniques are used to answer archaeological questions.

In this first part we will also treat other methodological questions such as data interpretation or information exchange with archaeological teams, which are critical points to extract the maximum benefit from the results of a survey.

In the second part we will concentrate on the new perspectives offered by the last technological and methodological improvements in Archaeological Geophysics.

Since early 2000 decade, instrumentation manufacturers have enhanced the precision of systems, but what really meant a revolution are the stacks of sensors in GPR, magnetics or resistivity survey systems. This has brought to geophysicists a dramatic improvement in time and resolution of area surveys, in some cases multiplying by 5 or 10 the area explored in a single day, and enhancing spatial resolution of measurements by factors of 5.

Obviously these enhancements have a lot of implications in terms of cost or accuracy, but they have also created new technical problems, such as how to locate accurately the measurements at high speed or how to manage and process large amounts of data in reasonable times.

A last title will be dedicated to expose short examples of geophysical surveys.

These examples correspond to the highlights of the previous tittles, exposing the results and interpretations of seven survey cases.

The case studies shown will illustrate a wide range of sites and casuistic, from basic surveys based in one single technique, multi-system surveys or the new multi-sensor platforms. In addition, some of these cases will include excavation data to explore problems related to interpretation.

2. Basics. Imaging the subsoil with non destructive methods

The geophysical imaging techniques applied to archaeology are acquiring a growing weight in nowadays archaeological projects.

Although aerial imaging was the traditional way to open the focus to explore large areas or landscape evolution, the first generations of geophysical survey instruments in the 1980's, which were thought specifically for archaeological uses, revealed the potential of these techniques.

British, German, French and North-American geophysicists promoted an increasing specialization in survey techniques, data processing and interpretation that resulted in a well defined discipline called Archaeological Geophysics.

But in the last ten years, the capabilities of the sensors used have increased their quality, resolution and speed (and decreased their application cost) in a factor that has placed Archaeological Geophysics as one of the most valuable tools in the hands of Archaeologists.

The use of geophysical surveys to delimitate, describe or image cultural remains at low costs and in a non-destructive way allowed conceiving Archaeological projects in a different way. On the one hand, Archaeological Geophysics had dramatically enhanced the real area covered by a single project, helping archaeologists to explore large areas and to understand the sites in wider points of view, and not only by the material objects or remains. On the other hand, the information obtained in a single survey allows archaeologists to select the location of their excavation with previous information that helps optimizing their resources and increase the effectiveness of excavations.

2.1 Definition

There could be a lot of valid definitions; one of them is that Archaeological Geophysics is the non-invasive description of archaeological objects and facts by measuring the vatiation of their geophysical proprieties in the space, and interpreting them.

Out from this kind of never exact definitions, usually, Archaeological Geophysics are understood as extensive explorations made with instruments that create maps of proprieties of subsoil to obtain information of archaeological remains. But as we will see, the latest applications could go far away from this conception.

2.2 Measures, data formats, 2D/3D

As geophysics are a group of techniques that work in measuring different magnitudes of soil contents, every one of these magnitudes have their specific characteristics and a specific methodology to measure it.

Measures are taken by electronic devices that usually use a spatial reference (X and Y relative positions or geographical absolute coordinates) to record every measurement.

Geophysical techniques are also divided in the kind of spatial information that are being handled. Although magnetism could be measured in 3D, the most common applications use a single level of measurements to create an image or dataset with no direct information on depth. We call this kind of techniques as 2D. That is, single measurements placed in two space coordinates.

2D techniques also include the acquisition of profiles. The result is a vertical section similar to a stratigraphical section displaying the variations of a geophysical property. The graphical expression of this process represents the space in the X axle and the depth or time in the vertical axle. In resistivty acquisitions a profile is called pseudosection, in GPR prospection a profile is named radargram.

3D techniques are those that use multiple measurements in every X and Y points to obtain additional Z axle information. They can be built by the integration of several 2D profiles in a unique 3D block. They are commonly used in resistivity and GPR prospections.

Other techniques, such is 3D tomography use a real 3D technique, placing multiple sensors over a surface and combining them to obtain a real 3D ERT model.

In some techniques as GPR time-slice the 3D dataset is generated from the integration of several 2D datasets (GPR profiles). For example, GPR uses a directional, electromagnetic pulse that is emitted through the soil by the emitter antenna and measures his reflections with the receiver antenna to obtain information from subsoil.

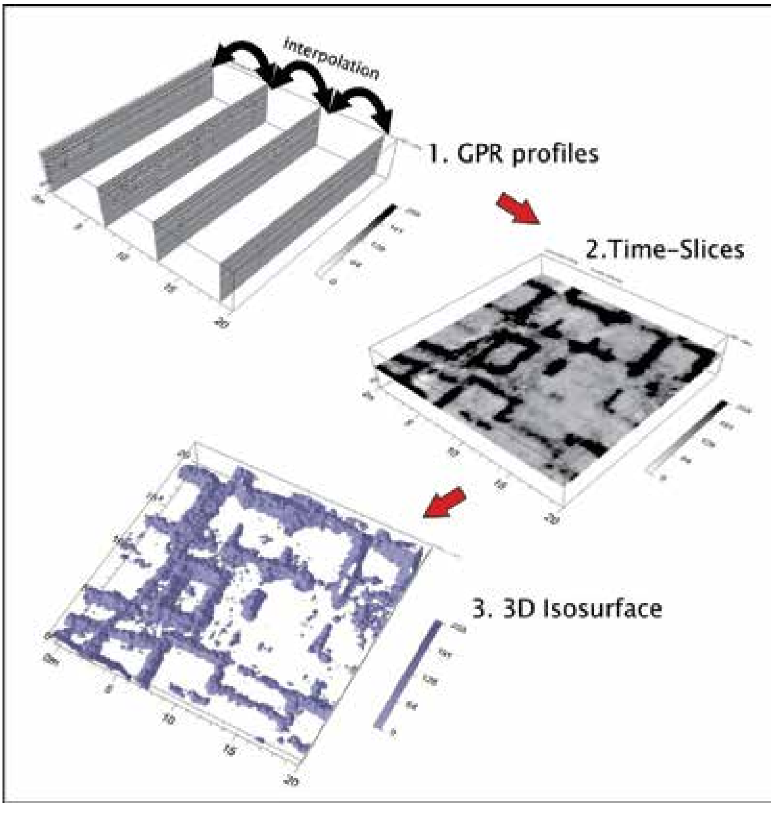

Fig. 1. 2D and 3D data. Example from Empúries Roman city site. A GPR extensive survey as an example of a 3D dataset built from 2D data. 1. Single GPR profiles are combined in order to obtain a 3D block which is represented in Z cuts (2).3. The entire information of the 3D dataset could be represented in an isosurface, establishing an opacity threshold of detected anomalies (in this case 70% of amplitude).

Measuring the amplitude of the reflections we can obtain dielectric proprieties of the soil. Measuring the delay from the emission time and the arrival time of the reflections, and knowing the velocity of propagation of the emitted pulse we locate the depth of the measurement in the depth axis. The graphical expression of this process is the radargram, which represents the space in the X axle and the depth or time in the vertical axle.

Finally, we can generate a 3D data block by integrating several GPR profiles of known position and represent it in the three axles (See Figure 1).

2.3 Typical applications

The geophysics has been applied in a very wide range of archaeological investigations, sometimes in imaginative or unusual ways.

But we can trace the gross lines of a short classification of most common surveys by their objectives.

Landscape archaeology

In combination with aerial and satellite multi spectral imagery, geophysics have been applied to study large areas of land. The speed of application of magnetic survey systems allowed projects that aimed to describe old agricultural divisions, gardens or other landscape features buried by time.[1]

Other techniques such as extensive phosphate measurements or soil or conductivity helped to carry other studies about land uses in the past[2].

Exploration and delimitation of archaeological sites

For the last 15 years it has been common for archaeological research teams involved in long term projects to use geophysics to raise again their investigations. Taking in mind that the complete excavation of some archaeological sites could be a work of decades, the possibility to explore the complete area of the site and have a clear delimitation of remains, is definitely a better way to take decisions about where to dig and why to do it.

Architectural analysis and description of specific archaeological elements

Some geophysical survey techniques, more sensible to the morphology of objects such as GPR or resistivity are used at shorter scales.

Using sensors and methodologies specifically thought for the building and engineering industry, the geophysicists have applied these techniques to solve the problems related to the architecture restoration or to obtain images from specific archaeological objects.

The capabilities of high frequency GPR are commonly used as a diagnostic tool in restoration architecture, since the use of 3D analysis could help to obtain information from hidden or non accessible objects and structures of a heritage building.

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[1] An example of these large-scale surveys is the South-Cadbury Environs Project (UK) that has used geophysics to map extensively the Cadbury Castle area. The main aim of the project is to study the transformations of the landscape and human occupation patterns from the Neolithic to the Late Saxon periods.

[2] Magnitudes as phosphat contents or magnetic susceptibility could be mapped extensively as a complementatry layer to add information to the data obtained with other systems

Using antennas from 600MHz to 2.2GHz, the GPR could be used to image the hidden structure of a building, detect cracks on stone blocks or detect small cavities or voids. Other advanced applications use separated emitters and receivers to obtain higher resolutions.

Applications of high resolution resistivity have been used successfully to detect or delimitate cracks or to test the integrity of building materials, also using small-scale 3D configurations.

2.4 Using geophysics from an archaeological point of view

A single geophysical anomaly in a given space, it's no matter if it's magnetic, electromagnetic or electrical, could have a long list of plausible interpretations. That is because subsoil is a very heterogeneous media and there are a long number of other factors involved in measuring geophysical magnitudes that we use to characterize the contents of the soil.

There's no doubt that archaeological geophysics is a scientific discipline. But it is important to remark that a dataset obtained from a survey needs to be processed and interpreted to have a real use.

As we will see, geophysicists manage objective information (data) and must interpret it to bring relevant archaeological information. Taking in mind that anomalies could have more than one explanation, the interpretations are always uncertain in a variable degree.

But this degree of uncertainty must be pointed from an archaeological view. Thanks to the work of generations of archaeologists we have detailed descriptions of a lot of cultural remains, studies about their characteristics, building materials, and finally a growing bibliography of archaeological geophysics with hundreds of case-studies. Taking into account all this knowledge when we interpret is what makes the difference between geophysics and archaeological geophysics.

3. Overview of common survey techniques applied on archaeology

Under this heading we introduce the more usual survey techniques applied to Archaeology in a synthetic way, avoiding their physical and mathematical basements. The comprehension of these geophysical methods requires a basic knowledge in natural sciences and mathematics but they are not so far from the Archaeology as it could seem at first sight. Demonstrations of this are some good books specifically addressed to archaeologists that introduce these techniques and that will be recommended in each sub-section.

3.1 Magnetometry

The earth has a magnetic field that can be measured from the surface. This technique uses devices that measure extensively the local variations of this earth's magnetic field to describe the subsoil of a given area. The geologic materials contain iron particles in different degrees and with different magnetic behaviours. These iron particles can be magnetized by natural or human processes, creating local magnetic fields that can be measured[3]. The surface layers of earth tend to show higher magnetism than deeper materials due his

[3] A good guide for magnetic methods is *Magnetometry for Archaologists* (Aspinall et alii, 2008)

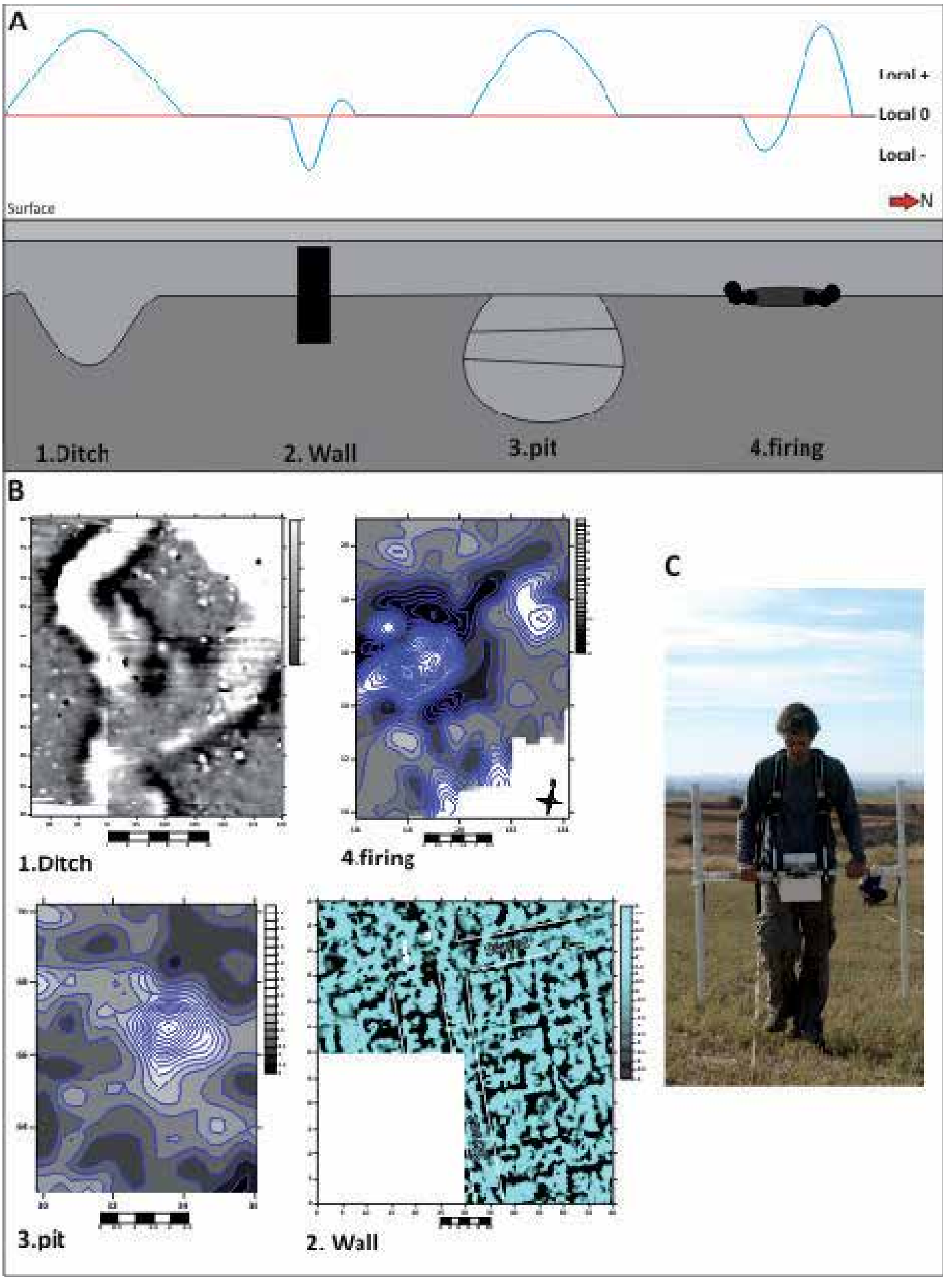

Fig. 2. Magnetism. Magnetic survey devices allow to detect some of the most important archaeological objects. At A there's a diagram showing the usual magnetic traces of tipicall arcaheological objects when using a magnetic gradiometer. B show data from real cases. An Iron Age ditch in Sant Esteve d'En Bas (Girona, Catalonia). A building mapping example from Empúries Roman City (Girona, Catalonia). A pit and a fired house at Puig Ciutat Roman Republican site (Oristà, Catalonia). C Fluxgate gradiometer Bartington G-601-

exposition to the sun, to the atmosphere and to human activity. Rocks could also have very different magnetic proprieties depending on his forming conditions and composition.

Applied to archaeology, this means that we can detect magnetic anomalies produced by the alteration of a sedimentary structure (a ditch excavated in a plain) or the anomaly produced by the rocks used in the building of a buried house. But it will always depend on the contrast between the magnetic proprieties of the archaeological materials and the media where they are laying.

That's why a pottery kiln or a burned house generates high contrast anomalies. The iron particles of the kiln building materials get polarized every time the kiln is fired, since temperatures of near 700ºC are enough to modify the magnetic structure of them. By the same reason, bricks or ceramic materials are also detected as high contrast anomalies, since they have coherent magnetic fields acquired during the firing.

The iron objects generate big anomalies according to his size and weight. This has a consequence that is one of the handicap of magnetic survey techniques. The abundance of iron in the actual urban environments, does not allow the use of magnetic systems, where the anomalies produced by these iron objects could be hundreds or thousands of times bigger than the trace of a buried wall.

The devices used in magnetometry are divided in two families depending on the method that they take measures. The total field magnetometers read the entire value of earth's magnetic field with a single sensor. Since this magnetic field has diurnal variations, geophysicists could use an additional magnetic sensor placed in a reference location to correct the survey data by this diurnal variation.

The gradiometers use at least two opposed magnetic sensors, which are calibrated in a same location. The value of earth's magnetic field in this calibration location will be taken as a conventional 0 value. The two sensors of a gradiometer measure the variations from this reference value, by recording in the memory of the instrument the difference between values measured by the two sensors in each reading point.

The depth of investigation and the resolution of magnetic acquisitions depends the distance between the ground and the sensors and of the distance between the sensors in the case of gradiometers.

These two kinds of magnetometers have a wide range of applications in archaeology, depending on the purposes of the survey. In cases of large area exploration, related with landscape archaeology, total field magnetometers are used to describe the archaeological features in relation with his geological context. When the objective is just to map archaeological remains lying near the surface, gradiometers are more used, since they describe better the local variations produced by near objects.

3.2 Resistivity

The electrical resistivity method consists in the measure of the electrical proprieties of the soil. Injecting a current in to the ground and measuring how this current gets altered we can calculate for every measuring point a value of apparent ground electrical resistivity[4].

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[4] The resistivity techniques are exposed in a clear and simple way in the book *Seeing Beneath The Soil: Prospecting Methods in Archaology* (Clark, A. 1996)

There are multiple ways to inject current and measure the soil resistance depending on which depth or kind of anomalies we want to map. The most used in archaeology mapping is the extensive survey, since the resistivity variations produced by buried archaeology could give precise and geometrically consistent maps of these features. Other common application of resistivity measurements is earth resistivity tomography (ERT), where, the electrodes are disposed in a line to generate a single section of electrical proprieties of the soil. A number of systematically positionned ERT sections could also be combined to generate 3D models of earth resistivity.

The depth of investigation of a resistivity measure is directly conditioned by the relative position of electrodes that inject current and the ones that measure the resulting variations by his pass in the ground. After this, the modern resistivitiy survey systems take multiple measurements in the same location by activating sequentially the measurement of electrodes with different spacing. Thanks to this, we can obtain several maps resulting from every electrode configuration.

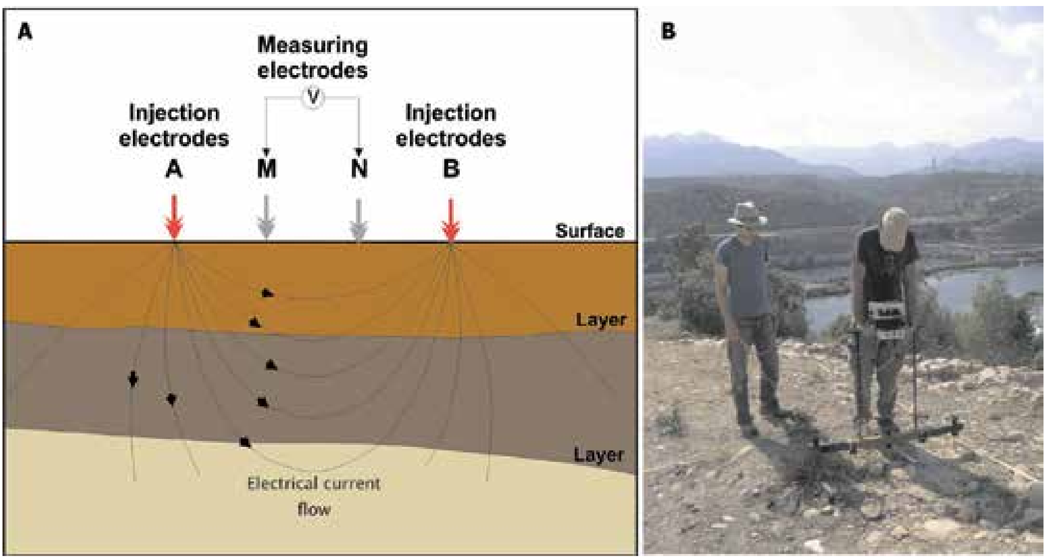

Fig. 3. Resistivity. A. A diagram of an ideal resistance measure (wenner array). B. RM-15 resistivity meter during data acquisition. This popular instrument uses a specific array called “twin” array. This electrode system places a pair of electrodes (A, B) fixed away from the survey area and uses a mobile pair (B,N) to take the resistance readings in every measuring position in the grid.

A significant part of buried human activity remains could be mapped with a resistivity survey. Walls and building materials tend to be more resistive than sedimentary soils as well as cavities, ashes or paved floors. But as other methods, resistivity surveys have his specific handicaps. The humidity and mineral composition of the soils could determine the success of an electrical survey in dry conditions, since the conduction of electricity could get more or less stable depending on these factors. In addition, the quality of the measurements is also influenced by the contact between the electrodes and the ground surface, and by the time spent in take every reading.

Although manufacturers as Geoscan Research have recently put on the market a new wheel electrode system that enhances the speed and resolution of area surveys, one of the traditional problems of resitivity extensive surveys was the time spent in the fieldwork. The operator must introduce the electrodes in the ground at every reading position manually, which can be a slow and hard work for large area surveys.

Other high speed resistivity systems as ARP are actually used in Europe in archaeological mapping of large extensions.

3.3 GPR

The Ground Penetrating Radar (GPR) is a survey method based on the principles of electromagnetism. An electromagnetic, directional pulse of known proprieties is generated by the system and transmitted into the ground by an emitting antenna. The changes in the propagation media of this pulse (the ground) generate reflections that are recorded by the antenna receiver sequentially depending from their arrival time. The memory of the GPR system records a sequence of amplitude values for every reading position in a time lapse. Knowing the velocity of the pulses into the ground we will be able to calculate the depth of the objects that produced the reflections recorded at a given time[5].

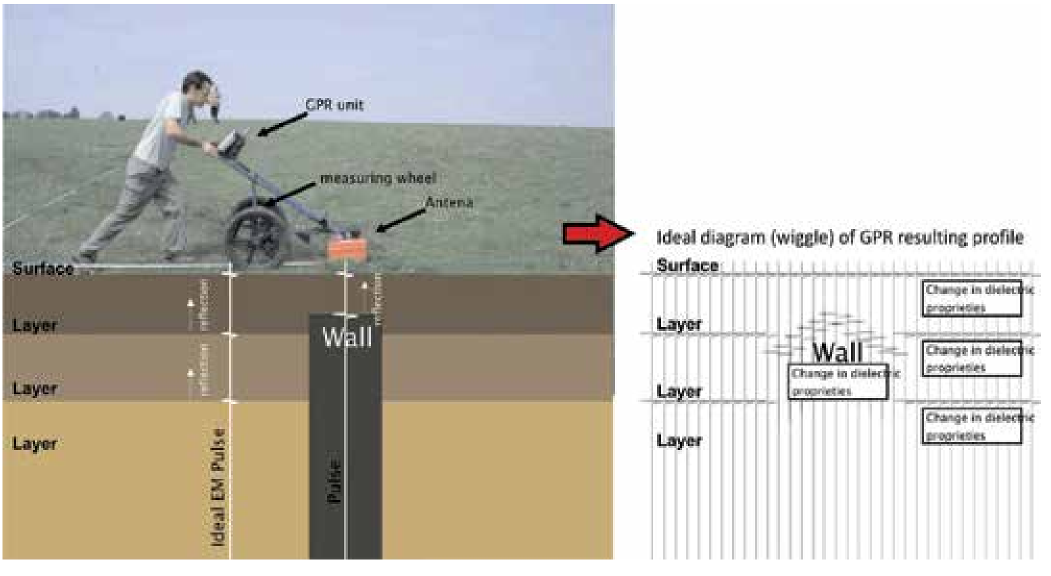

Fig. 4. GPR. A GSSI SIR-3000 GPR system. The system generates electromagnetic pulses that are emitted by the antenna. The pulses reflect a part of their energy with every change in dielectric conditions. These reflections are received by the antenna and saved in the memory of the instrument according to his arrival time and his amplitude. The result of this operation is a GPR profile, where every pulse is represented vertically, and the motion of the system is represented by the horizontal axis.

[5] A good manual of GPR adressed to Archaeology is *Ground Penetrating Radar: An Introduction For Archaologists* (Conyers & Goodman, 1997)

The electromagnetic pulse generated by the GPR system get modified in his travel into the ground attending to the dielectric proprieties (conditioned by proprieties such as conductivity, porosity or humidity) of the media. Every change of these parameters generates a reflection of a part of the pulse energy, and therefore an attenuation of the power of the original pulse that continues his travel on the ground. The depth range is determined by this loss of energy and directionality of reflections, as the returning pulses from the ground can not be discriminated from noise.

Another important factor in the GPR operation is the frequency of the emitted pulses. The usual frequency range of GPR antennae is located between 24MHz and 2.1 GHz (2.100MHz) in most of commercial systems, but the most applied in archaeology varies from 100MHz to 900MHz.

Lower frequency pulses could travel deeper into the ground than higher frequencies. In the other hand higher frequency pulses loss his energy in short depth ranges, but they get modified by smaller objects.

Applied to archaeology, this means that lower frequency antennae allows us to reach greater depths but could not describe small objects. Higher frequency antennae are more efficient in describe shallow and complex objects.

The result of GPR measuring files are usually represented in radargrams. the radargrams are diagrams of reflection strenght where the motion of the antenna is represented in the horizontal axle and the vertical axle represents the increase of time from the pulse emission or calculated depth.

One of the challenges for the use of GPR in archaeology is the complexity of results, since the shape of anomalies described in the radargrams does not correspond necessarily with the real geometry of buried objects. One of the last improvements in the GPR methodology is the *time-slice* technique which has introduced a visualisation method of area surveys that meant a decisive step in the information exchange between geophysicists and archaeologists.

The GPR area surveys consist in the covering of an area with profiles of known position. The time-slice technique uses these profiles integrating them mathematically to obtain a single 3D file that can be examined in the three axes. The use of time-slice cuts (plain views of data at the same time or depth) is a powerful tool to explain the results of a survey, since they represent buried objects in a similar way that archaeologists express their work.

Consequently, the results of a GPR area survey could be expressed in a sequence of time slices at increasing depths. This way, the archaeologists can obtain an overview of the subsoil contents and locate and plan the excavation areas or study the shape of archaeological features according to his depth.

3.4 EMI and other techniques

The geophysics apply a long list of other methods to study the geology which are based in the measure of other magnitudes. These methods are less usual in archaeological works by reasons of scale of measure or by their application methodologies. Techniques as gravimetry, or seismic refraction are methods designed for civil engineering, mining or geology imaging and are used at resolutions that exceed the size of archaeological objects.

Other methods, as thermography or LIDAR can also be applied to solve multiple questions related with geophysics although they come from other scientific and professional fields[6]. The EMI (Electromagnetic Induction methods) are another family of geophysical methods. They have been applied intensively in agriculture and in metal detection. The EMI are survey techniques based in the emission of magnetic fields by a coil of wire (transmitter) and the measuring of the electromagnetic reaction of the ground with another coil of wire (receiver). The system is based in the principle that a time-varying magnetic field could generate a time-varying, induced electrical current and vice versa. The transmitter coils of the instruments generate a time-varying magnetic field of a given frequency, which induces time-varying currents in the ground objects, in more or less intensity depending on his electric proprieties. These induced time-varying currents are measured by the receiver coil by the magnetic field they induce giving a value of the apparent conductivity of the soil. The frequency and phase of these induced currents are also measured to obtain additional data relative to magnetic susceptibility. The distance between the transmitter and the receiver and their orientation define the depth of investigation and the resolution of the measurements. Equipemnts with several receivers allow simultaneous acquisitions of several depth levels.

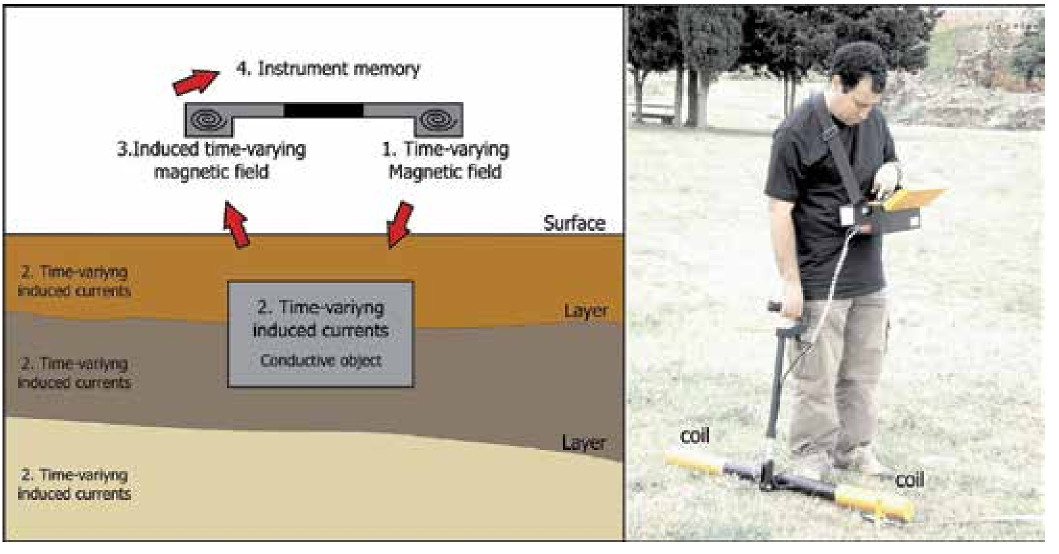

Fig. 5. A EMI instrument function diagram. At right, the geophysicist Mahjoub Himi taking readings with the GISCO CMD conductivity meter in the site of Ciutadella de Roses (Girona, Catalonia)

The archaeological applications of EMI instruments are wide if we think in terms of applicability: it is a fast method wich can be used to survey large areas and in some conditions the conductivity maps could give relevant information about buildings, metals or stratigraphyc alterations. Unfortunately, maybe because of the complexity of data interpretation, maybe because of tradition, systems such as EM-38 or EM-31 are less usual in archaeological works than magnetic or GPR methods.

[6] An exhaustive presentation of the preceeding techniques and gravimmetry, seismics or EMI methods could be found at *Handbook Of Geophysics And Archaology* (Witten, A., 2006)

Other EMI devices are metal detectors. Even if they are maybe the most popular geophysical instrument, their applications to archaeology are restricted to some specific fields. Most of these devices do not allow recording data since they are conceived as a tool to locate objects without spatial references. The Archaeology of Conflict uses metal detectors in combination with GPS to locate and map metal objects related with battles, military camps or other human activities that could leave a dispersion of metal objects in the shallower layers of the soil. The objects obtained and their positions are studied statistically in order to locate and map a conflict area or a battlefield.

Besides this recent applications, the use of metal detectors is well known by archaeologists since it is one of the most destructive tool in hands of "treasure hunters". Illegal excavators use metal detectors to locate valuable objects which they remove from archaeological sites, destructing their archaeological context. A sad reputation for what should be just another tool.

4. The first step. Adapting methodologies to each project and to each site

The investment of a survey comes most of times from an archaeological "problem". An archaeologist could need help from geophysics in the situations where a previous knowledge about buried features could help to take decisions, or to interpret his own work.

4.1 The archaeological questions

In order to reach its objectives, a geophysical survey must be planned from the begining placing the archaeological questions to be solved as the main axis of the work. It is no the same to delimitate a site of 16 hectares (where resolution should not necessarily be high) and to obtain a precise diagram of a specific room in a building to locate a mosaic

In a singular site, let's say a Roman pottery factory, if the main archaeological question is to locate a group of kilns, then a magnetic survey should be applied. But if the aim of the survey the structure of pottery workshops, in that case it would be better to use GPR, Resistivity or EMI.

But what if the Roman Pottery Factory was placed in a Field in the south of England? Or if it was in Sicily? Or buried in a Mediterranean forest in Girona? External conditions influence the viability of archaeological geophysics and sometimes are decisive.

For that reason it is always recommended to obtain the more information as possible about the site characteristics, chronology, geology and environment conditions or accessibility.

Therefore, it's important to adapt the survey strategy to a clear objective, selecting the right system and using it in the right parameters to obtain relevant information.

4.2 A complex media and unknown targets

To understand why archaeological geophysics is sometimes so complex, we can take a look to the media where it takes place.

The soil, and in particular the archaeological soils are a heterogeneous media. The most of archaeological projects where geophysics are used work in a lapse of 3-4m under the surface. This first layer of the geology is variable by definition, since is the part of the soil involved in erosion phenomena and human activity. In consequence, the geophysical methods applied to obtain information of the subsoil can detect a long range of anomalies, sometimes not related with human activity.

A good archaeological definition of the targets and his context will be always helpful to design a good survey strategy and to interpret rightly the obtained data.

4.3 Measuring the right magnitude (if it's possible)

An archaeological object, let's say a burned, medieval house buried under a modern cultivation field, has several measurable physical characteristics. It could have a particular magnetic trace if the fire that destroyed the house has reached high enough temperatures to modify magnetism of building materials and his context. If the basement walls were done in stone, we probably can obtain images of them with area surveys of resistivity or GPR , and even describe the debris areas.

Indeed, we can obtain different views from the same object, measuring different magnitudes with the right sensors at the right resolutions. But, unfortunately, things are not always so simple.

The external conditionings are most of times a decisive factor. The first and most important is local geology. The geological context of a site could determine which method will give us more information or even eliminate some of them. For example, we can't pretend to detect a ditch in a site with magnetics if it's located in the downtown of your city. If we try to obtain a plan diagram of a roman site in a desertic context, it could be easier to do it with GPR or magnetics, since the low humidity of the soils could complicate the use of resistivity.

Another decisive factor is the resources or time we could spend in the survey. This could condition the area that we can explore, the data resolution that we can expect to obtain or the number of different sensors we want to use.

4.4 Resolution

Spatial resolution of the surveys could be a very complex matter, but it's reasonably simple in what is essential. In area surveys we can not expect to image correctly objects smaller than our measure spacing. The data should be collected in a resolution or in lapses smaller than the size of the archaeological object we want to describe.

A building of 40cm thick walls could not be well imaged in a GPR area survey using a space between profiles of 80cm.

Also, there's a structural limit for the resolution in survey systems, over which it has no effect in the sharpness of the images to increase the real data resolution[7].

Some investigators have reached spectacular results increasing the resolution of 3D GPR surveys until few centimetres.

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[7] This is the case of traditional GPR systems, where our spatial resolution depends not only on our reading resolution, but also the frequency of the antenna used.

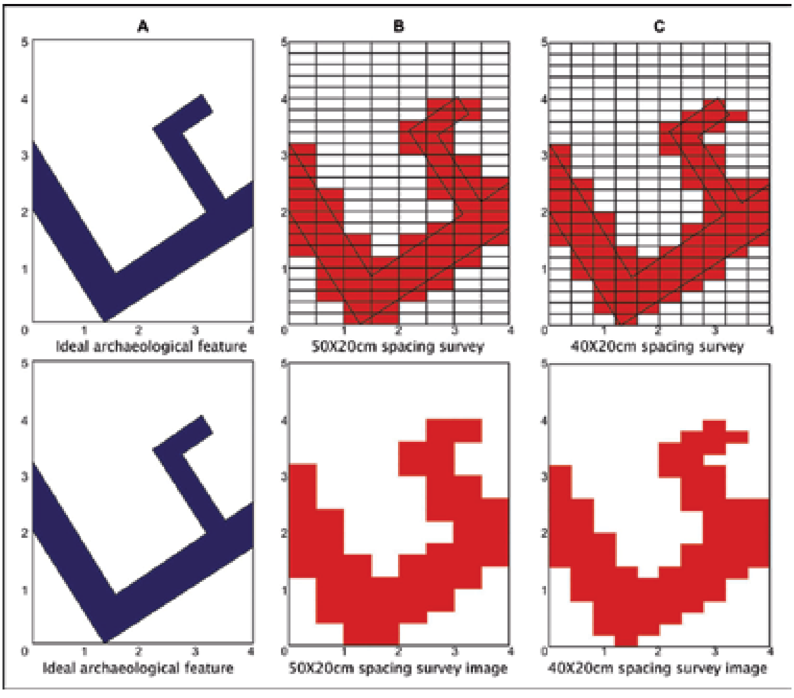

Fig. 6. Survey Resolution. At top-left, an ideal plant of an archaeological feature. The upper right diagrams show grids representing a 50X20cm and 40X20cm data resolution, respectively. Assuming that the feature was detected at every measuring position, the resulting representations are shown in the lower row with the ideal archaeological feature.

The new GPR antenna arrays or the gradiometer stacks that some manufacturers are putting in the market from 2000's, offer the possibility to survey large areas in spacing between profiles of 6 to 12cm, and it seems that this could change the way that geophysics are applied in archaeology.

All this could suggest that more resolution is always better, and possibly it is. But in cases that we just need to locate an object or to delimitate a settlement, resolution is not as important as the accuracy of measurements.

After all, the area covering and the spatial resolution of a survey will be one of the main components of the survey costs for its implications in terms of field work (data collection) and the further data analysis works.

4.5 Multiple factors. A survey plan questionnaire

Once the archaeological questions are exposed, we have seen how multiple aspects influence the methods and instruments that we use and how we use it. All this aspects, from the archaeological targets to the local geology or the external conditionings should be cleared at the start of every project.

In the figure 7, we reproduce a questionnaire created by Ekhine Garcia as a list of basics to create a survey project from zero.

Some of the information collected from the archaeological teams to plan the survey will be also used in the data process and interpretation of the surveys to understand the data. It is also recommended to collect and organize additional documentation. Counting on aerial imagery of the site of different chronologies, stratigraphic sections of previous archaeological works, geological analysis of soils or simply the archaeologists experience in the site's period could make the difference of a successful survey.

1. Previous information availability.
   Excavation reports
   Aerial imaging
   Preliminary delimitation of the site
2. What is the extension subject to exploration?
3. What is the geologic context of the site? (clay, sands, limestones, silt)
4. What kind of archaeological features are expected to locate/map?
5. What building materials are expected?
6. Is it expected to find burning structures (pottery or metal kilns, fired areas)
7. At what approximated depth are the structures expected, what is their expected depth range?
8. Could the site contain overlaying building levels?
9. Which detail level is needed?
10. Is it a dry or humid location? Could it be stationally? Which are the extreme seasons (rain, hot, etc..)
11. Is the site placed in an urban area? Vicinity of airports, electric facilities, communication antennae?
12. Are there metal objects fixed near the survey area (litters, enclosures, informative displays.
13. Is there any building in the survey area?
14. How is the surface covering? Vegetation (how high is it)? Sand? Concrete pavement? Cultivation field?
15. Is it a flat area or are there slopes in the survey area?
16. Are there obstacles in the survey area. Could we have images of the condition of the survey area.
17. Accesibility. Could vehicles arrive to the survey area?
18. Must the survey results be included in a GIS project?

Fig. 7. A simple questionnaire designed by Ekhine Garcia to plan a survey. It resumes in a short document the questions relative to the previous documentation available, the archaeological characteristics of the site, and the ambiental and logistic conditionings to trace a first survey strategy.

5. Data processing and interpretation

After a survey, the data collected are analyzed and processed in order to correct errors or to enhance quality or visualization. The objective of data processing is to extract as much information as possible from the datasets to be used in the further interpretation process.

But the interpretation will not be done just over the geophysical data, since there will be necessary to take in mind the previous archaeological information collected.

5.1 Data processing

Once the data are collected, they should be processed to remove undesired "noises" or positioning errors caused by the systems or field operators. After this the data could be statistically analyzed or enhanced in order to obtain the most information as possible from it.

Usually, the data resulting from a survey consists in a numeric file that contains a magnitude value for each spatial coordinate measured.

A first step in the data processing is to evaluate the quality of the acquired data. The objective of this step is to correct the errors in the position of measurements or to eliminate the wrong readings that could create artefacts if they were taken as real anomalies.

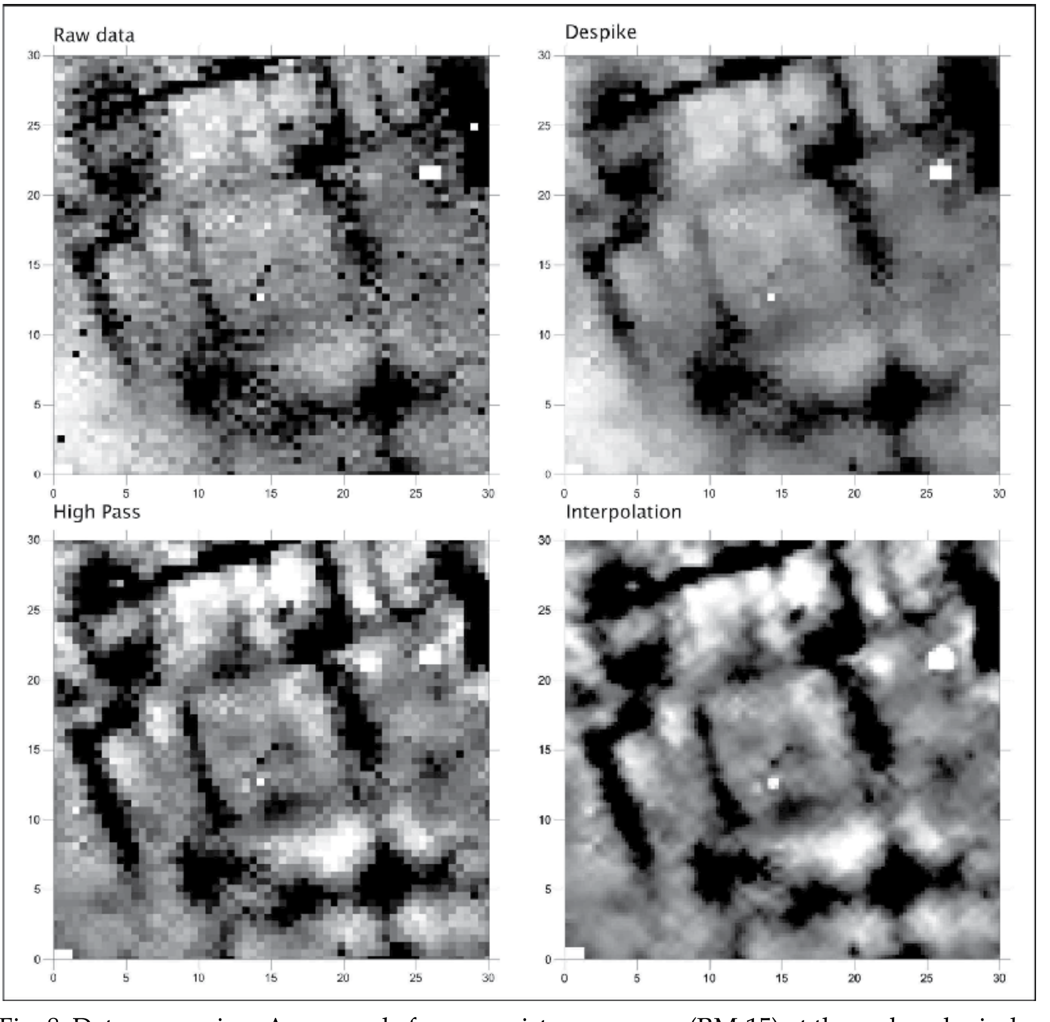

Fig. 8. Data processing. An example from a resistance survey (RM-15) at the archaeological site of Irulegi (Lakidain, Basque Country). The images show the same dataset with different processes applied. The raw data are despiked, in order to eliminate over-range readings. A High-Pass filter enhances the view of local anomalies. The interpolation increases the resolution artificially to achieve a smoother image of anomalies.

Some geophysical survey systems, as magnetics or EMI could need other additional statistical corrections to obtain clearer views of the data or to create a single, consistent dataset.

These data files are treated with statistical/mathematical tools called filters, used to enhance the contrasts of features, smooth the shape of detected anomalies or to study a specific kind of anomalies.

The data files could be also processed to extract other statistical information that could bring qualitative information that is not evident in the original data. In data processing, geophysicists start the data interpretation. A correct use of available information will be helpful to understand how to process data, and also a well processed data could be basic to reach a good interpretation.

5.2 Visualising data

The creation of data representation is a sensible point in the further data interpretation and communication. The 2D methods like magnetometry or extensive resistivity are usually represented as plan, colour or monochrome plots, where every data location is assigned to a single pixel. The colour of this pixel will depend of the measure obtained in its position.

The imaging of GPR data is more complex because of the special characteristics of his data.

A GPR profile could be represented as a single profile or vertical section called radargram. The GPR 3D imaging techniques start with the integration of a group of profiles which are

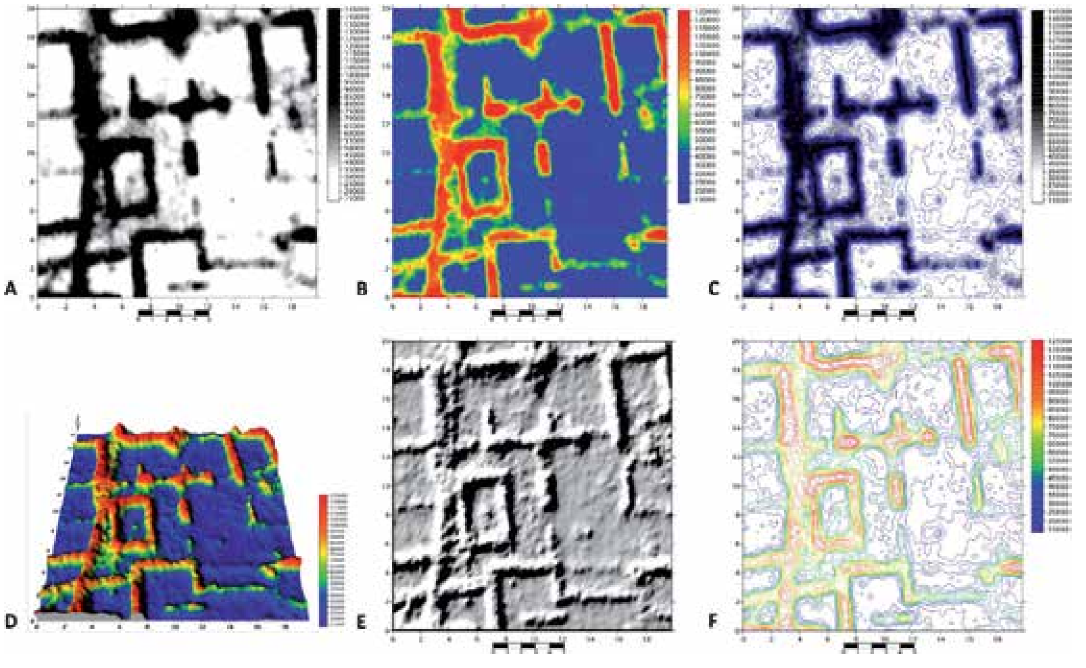

Fig. 9. Data visualization. Some examples of plots of the same time-slice (Empúries Roman City, Girona, Catalonia). A. Greyscale plot, B. Multiple colour plot, C. Greyscale with overprinted contour lines. D. Pseudo-3D relief plot. E. Shaded relief plot. F. Coloured contour lines.

collected under the same spatial references. The data of all this profiles could be resampled in a single 3D data cube to generate views in the three axles, allowing the visualization of the data from different perspectives.

One of the most used view tools in archaeological geophysics GPR is the time-slice technique, which generates sequences of plants representing different depths (or times in the pulse travel into the ground). Although it could be considered as an imaging technique, it requires a specialized processing of data that could generate spectacular images of archaeological features.

The use of 3D visualizations is a help to understand the position of anomalies and to show images of subsoil features to archaeologists in a visual language.

Although there is many ways to plot a dataset, the main objective of this kind of graphics is to communicate, to show which part of the data we are interested in.

5.3 Data interpretation. A team work

Although in some particular cases the interpretation of high-resolution datasets could look like a geometry question, the work of translating archaeological geophysics to archaeological information is not always so easy (see figure 16).

In essence, the interpretation of the data consists in offering plausible explanations for geophysical anomalies. The hypothesis or interpretations should be based on a previous given information and the results of the survey. To systematize this process, the problem is that no one of these two factors is predictable or constant.

There's a long list of factors involved in the final quality of data obtained in a survey. The ones that we can know or control are the particular system used, the local geology and the condition of the surface of the survey area, the field technique applied, the resolution of the acquisition and the ambient or weather conditions.

Another group of factors are the ones that we ignore. They are also determining the data quality in some cases: the conservation degree of the archaeological elements that we are trying to describe, the existence of other more recent features over the ones that we expect to find, the geometry of the features to describe and the materials used to build them.

Once the data have been examined and processed taking into account all these criteria, starts the interpretation itself.

As seen before, the information and experience of archaeologists in their own fields could be crucial in the right planning of geophysical surveys. For the same reasons, in the interpretation process, the geophysicists must hold a dialogue with the archaeologists and take into account the previous information available about the site, and all the factors exposed above.

A good way to start this dialogue is to share preliminary reports with the archaeologists or the research team. This could help to introduce the visual language of geophysical plots, and to obtain first interpretation suggestions. A geophysicist could take the magnetic trace of a buried trench filled of debris materials as a building wall, since they could generate similar images. An archaeologist that is familiar with his own site could discard it as a wall by the orientation or depth of the anomaly that is generating in the data.

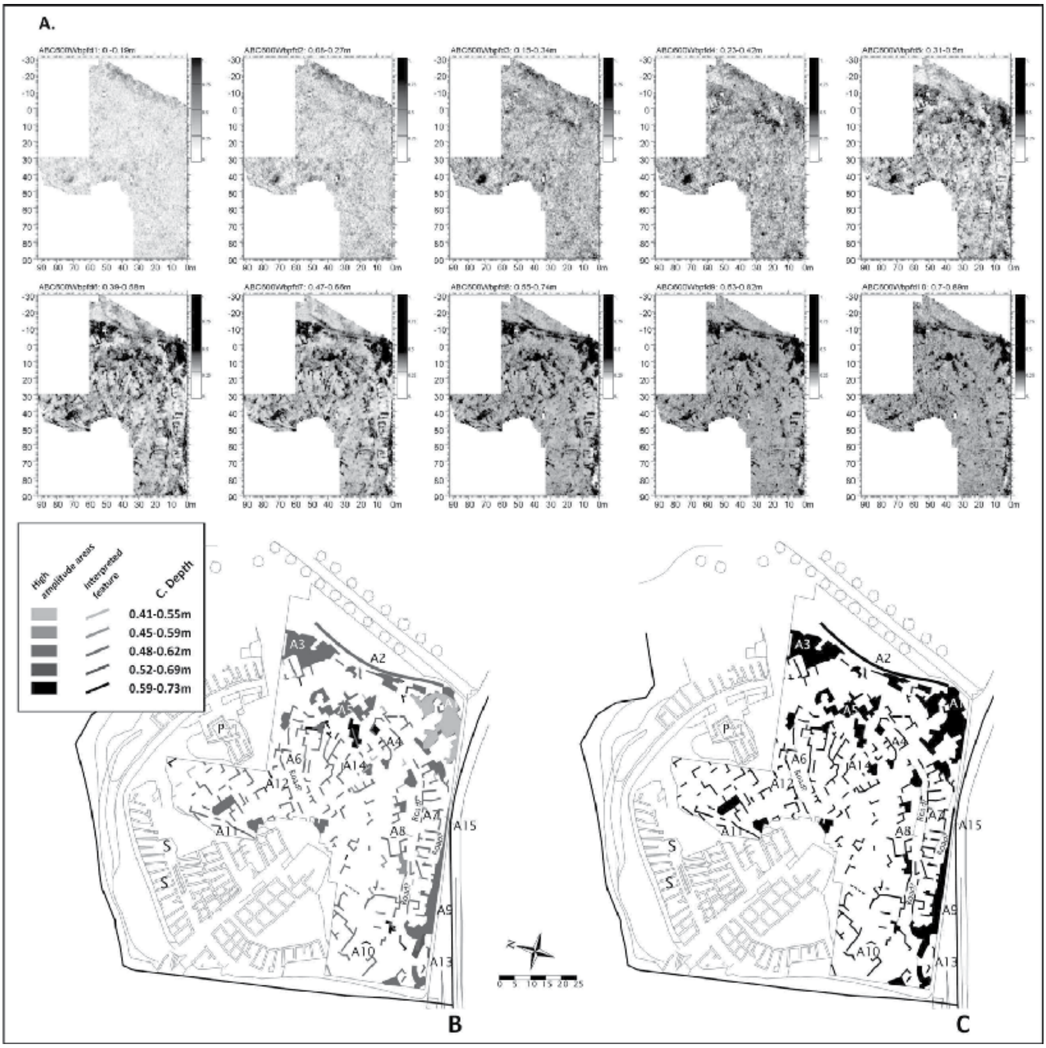

Fig. 10. Interpreting data. GPR survey at Molí d'Espígol Iron Age site, Tornabous (Lleida, Catalonia). A shows a time-slice sequence from 0 to 1m depth. B is a coded diagram with detected features in a scale of greys according to their calculated depth. C Represents all the detected features in black.

Taking the results of this dialogue and the survey results, geophysicists create the survey report, containing the representation of the results and their interpretations. The results could be exposed in different kinds of plots, but the interpretations are usually represented in coded diagrams (Figure 10).

At this point, the question is what should we explain in the interpretation and how should we explain it. If we only describe the shape and position of anomalies, we will get a simplification of the survey results. If we take too much "risks" suggesting detailed geometries for the buried features from ambiguous anomalies, we will generate to much expectative from uncertain informations. In front of this, common sense is the best ally: it's recommended to let clear in the text and graphics of the report which are the most consistent information extracted from the survey and which are just possible or probable explanations.

For the same survey area, all this process could vary depending on the previous information available, the quality of the data and the system used. But in multi system surveys, when we combine and compare more than one magnitude obtained in the same survey area, the interpretation could be more complex.

The aim of this kind of surveys is to obtain two or more datasets from the same area which will give us complementary information about the subsoil contents. The building remains of a roman villa could be described in a GPR or resistivity survey and complemented with a magnetic survey to locate fired areas, high contrast building materials or iron objects in the same context. The result of multi system surveys could bring more information and, this is the main point, more consistent, since it will come from a cross validation of more than one survey technique and the sum of qualitative information extracted from each of those techniques.

6. Multi-system surveys. Solving archaeological questions from multiple points of view

Multi system surveys are used in some cases to describe the same survey area from the different physical points of view. The combination of datasets resulting from several survey magnitudes could bring us different information that could be combined to obtain a sum of subsoil proprieties which is not possible to reach applying just one kind of measures.

There are two main cases where multi-system surveys are usual. In cases where the objective of a survey is to delimitate and describe a site, the delimitation of the archaeological remains could be determined using a fast method as magnetics or EMI. After this first approach, the most interesting areas could be explored with higher resolution or more effective techniques to obtain detailed descriptions of specific features.

The other typical group of cases where multi-system surveys are applied is when a project aims to obtain detailed descriptions of buried remains to locate a specific target or to draw an excavation strategy for the survey area. In these cases, the use of multiple survey techniques are a way to obtain maps of different proprieties brought by each survey.

Combining these maps we can create a single diagram that relates the geometry and position of detected features with other measured proprieties. These final maps bring additional criteria to understand the function or the condition of detected features, and therefore are useful in to focus the attention of further excavations over one or other area of the site.

7. Towards high resolution. Large scale surveys, ultradense surveys

The technological evolution of survey systems in the last ten years has pointed three basic aspects: sensor accuracy, resolution and speed of acquisition. As the technological advance has ran in parallel with the computing and electronics revolution, the capabilities of the survey systems have been enhanced also in terms of size and versatility.

These evolution factors are condensed in the trend to create systems based on arrays of sensors. GPR, magnetics and resistivity have been the fields where the manufacturers and research teams have made the most remarkable advances.

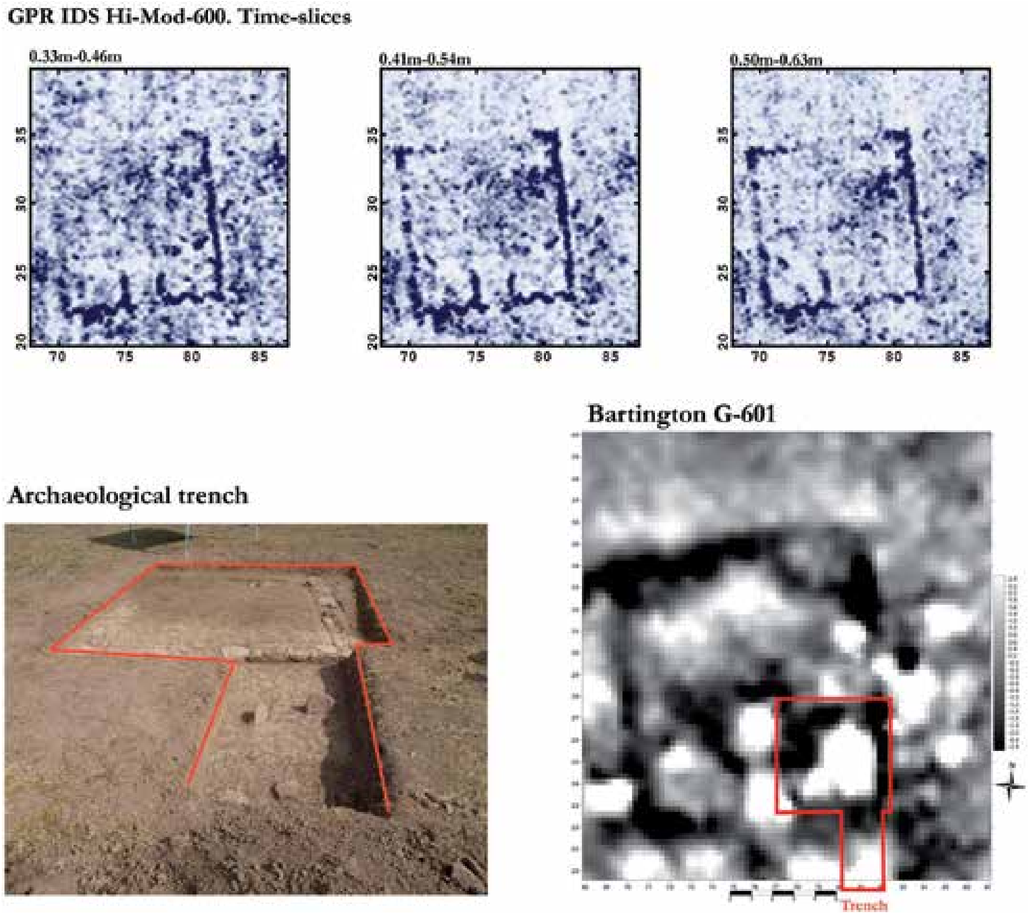

Fig. 11. Multi-system surveys. An example of Puig Ciutat Roman site (La Torre d'Oristà Barcelona). At the top, a sequence of time slices allows to distinguish clearly the building perimeter. The magnetic survey (bottom-right) shows a similar perimeter, but other internal anomalies reveal an increase of contrast in fired areas as the excavated room (bottom-left).

In the case of GPR, the creation of antennae stacks that "read" simultaneously, allow geophysicists to survey large areas at high resolutions at speeds that would be not possible applying the 1980's and 1990's single channel systems. Although this has been a technological challenge -not yet completely solved- the high costs of these systems are restricting his use to large scale projects. In some cases, the spectacular results reached in the surveys, especially in the description of building remains, show such detail that archaeologists start their own interpretations at first sight.

The magnetic surveys have been from the 1980's the fastest way to survey a large area. Even working with a single fluxgate gradiometer system is possible to survey from 7.000m^2 to 1Ha in a working day when the survey area has no obstacles. The last improvements in these systems allowed creating arrays of sensors that could be carried by vehicles, enhancing the survey speed until area coverings of several hectares per day. Once again, these systems are most used in large-scale surveys, to map the subsoil in the placement of

Fig. 12. A stack of magnetic gradiometers built by Eastern Atlas for large area surveys. Image courtesy of Cornelius Meyer.

future civil engineering works (railways, highways, building complexes, etc.) or to study a specific archaeological site in relation with his hinterland (mapping ancient agriculture or old field divisions).

Something similar happens with multiple resistivity systems than can survey large areas with two or more levels of depth. The high speed of measurement and the resolution of these devices could be useful in context with low magnetic contrast or in areas with rugged surfaces that are not the best environment for GPR surveys.

Another interesting trend is the exploration of high resolution limits. The speed and size of modern GPR systems allowed carrying experiments that used centimetric spacing to obtain high density 3D datasets of a survey area. Although there's a theoretical limit for the resolution of every technique, the results of these experiments reached spectacular and sometimes unexpected results.

8. New techniques and new problems. Positioning and data management

All this intensification in terms of data density or survey speed has generated problems that are common for these new systems. Sensors based on electromagnetic phenomena could influence other sensors placed in his vicinity. One of the major problems with this kind of systems is to avoid the influence between sensors placed very closely. This influence has been solved in multiple ways such are triggering the readings in alternative sequences or modifying the architecture and the relative position of the sensors.

One of the important problems that the manufacturers are facing is the accurate positioning of data. Since the multiple sensor systems tend to use high resolutions in wide areas, they need an accurate system to relate every reading with its real position.

The actual satellite positioning systems (GPS) have a military origin in the 1970's. The accuracy level of the GPS ground receivers is not enough accurate to monitor in real time the motion of a survey system. Further evolution of the GPS systems has used other additional ground references or radio positioning to enhance the accuracy and speed of measurements. Even with the most advanced positioning devices the matching between GPS and GPR is not yet completely solved. Nevertheless, in urban survey environments the GPS loses a significant part of his precision. To solve this, manufacturers as IDS are working in the adaptation of optical positioning systems that are not affected by the electromagnetic contamination of modern cities.

The datasets resulting from large scale surveys or ultradense grids are files that can be several hundred Gigabytes or even Terabytes. They are also related with positioning files that should be processed, examined and interpretated. The results of large scale surveys are studied in GIS environments to relate it with other archaeological or geographical information. The management of such volumes of data generate computation problems, since in 3D surveys the processing sequences could result in enormous files, not easy to study in his integrity with a common computer.

9. Data analysis. From high resolution to regional archaeology

GIS environments have become the way to systematize study and analyze information in archaeological projects in a spatial view. The ability to dispose and analyze in one single work environment relevant information from multiple fonts (topographic, geophysical, aerial and multispectral imaging, paleoecologic or historic) is a trend that is changing the way how archaeology integrates and analyzes scientific information. One of these fonts is archaeological geophysics data which acts as one more layer of information in GIS-based projects. In fact, geophysical surveys are used in regional studies as another information layer that could be correlated with the rest of georeferenced data and maybe that is one of the most interesting new vectors of investigation of GIS works. The use of mathematical processes in order to correlate and integrate the different geophysical surveys with each other and with other space-referenced magnitudes also used in archaeology looks like an open field for new investigations.

While computers and software are not yet ready (or just not completely) to assume interpretation roles, the work of geophysics in archaeology is still a kind of artisan's work. Every time that a surveyed area is excavated, geophysicists should be interested in having as much information as possible to understand "what was really down there" and close the circle with their surveys. This drives us to another interesting field of investigation: the systematic comparison between collected data and real objects and the generation of synthetic models of archaeological features to understand why they show this magnetic trace or why they reflect GPR pulses that way. The use of modern computing techniques in these analysis are a promising, since they could help to understand much better the behavior of geophysical sensors in relation with archaeology and to develop new interpretation criteria.

10. Survey examples

This last section contains a group of survey examples that could be illustrative from what's exposed in the chapter.

10.1 Large-scale magnetic prospection with multi-channel gradiometer arrays (Germany)

By Cornelius Meyer and Burkart Ullrich (eastern atlas, Berlin, Germany) info@eastern-atlas.com

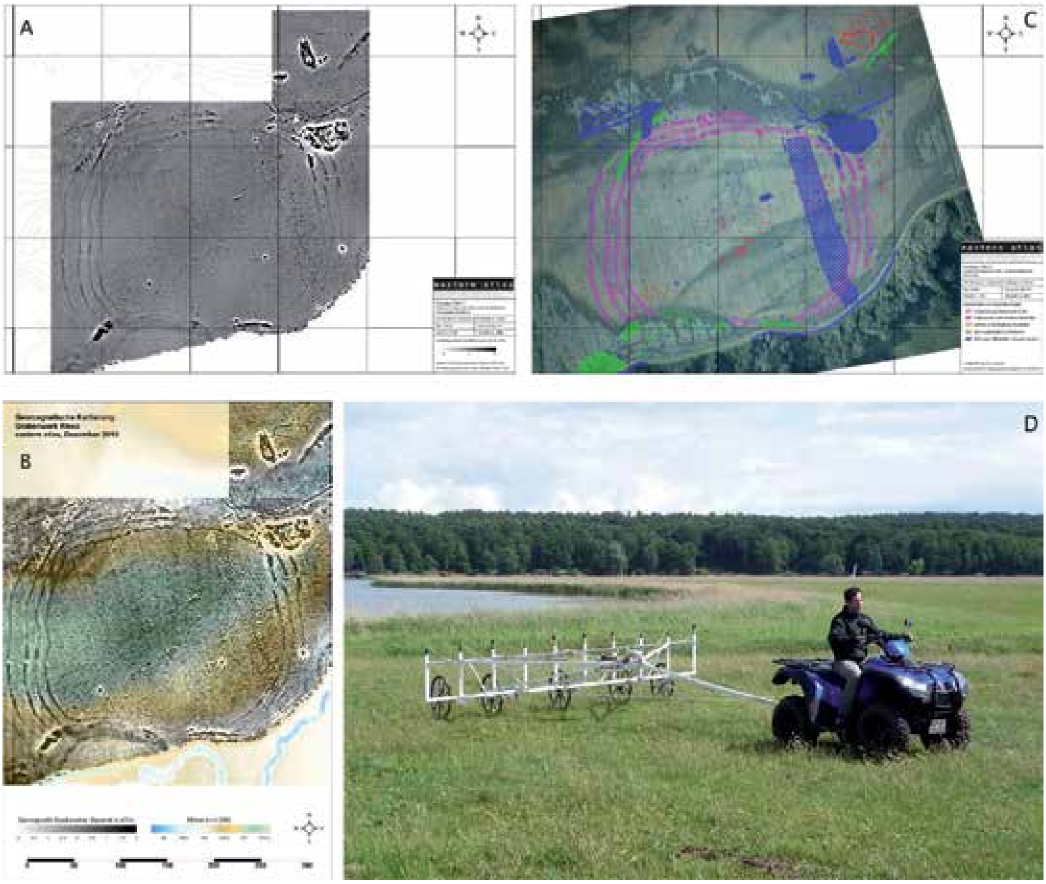

Fig. 13. A. Magnetic Plot. B. Combined Magnetic-altimetric plot. C. Interpretation dyagram overimposed to an aerial view of the site. D. Eastern Atlas, 10 probe fluxgate system.

Magnetic mapping is the most common geophysical method in the investigation of archaeological sites. Magnetic prospection is especially suitable for the prospection of large settlement areas and archaeological landscapes when wheeled arrays of gradiometers are applied. During the last decade the development of these arrays have focused on the application of fluxgate gradiometers. The economic advantages of fluxgate magnetometers is that they can be assembled to large arrays (D) with comparatively low costs in contrast to the costly Caesium (Cs) or SQUID magnetometers. Most important precondition for the successful application of fluxgate arrays in archaeological research is a high-quality data logging exploiting the dynamic range and the maximal resolution of the probes to a maximum extend. Using a high-resolution broadband data logger with high sampling rates (up to 1000 Hz) the measuring accuracy of fluxgate sensors can be fully utilized.

The example shows the magnetic data of an Neolithic circular ditch system near Riesa (Saxony, Germany). The data was registered using a light-weight wheeled fluxgate gradiometer array consisting of 10 individual probes and the newly developed 24-bit digitizer LEA D2. For positioning both a GPS system and a survey wheel (odometer) were used. The total area was 11 hectares, and the time needed for the data collection only one day (in December 2010)

The magnetic data show the course of the four ditches as positive anomalies due to their fillings consisting of material enriched with organic components and hence with higher magnetization. In the northern part some modern perturbances overlay the Neolithic structures, but in the uppermost part of the area another smaller Neolithic ditch structure is visible. In the southern part the ditch system is partly eroded by a meandering stream.

10.2 Silchester Roman town (United Kingdom)

By Neil Linford (English Heritage)

Data for this case study were collected over the abandoned Roman town of Calleva Atrebatum, close to the village of Silchester, Hampshire, UK. An area of over 5ha was covered at a sample density of 0.075m x 0.075m using a 3D-radar GeoScope GPR system, together with a vehicle towed V1821 array antenna. The GeoScope is a stepped-frequency, continuous wave (SFCW) radar system recording the amplitude and phase over a wide bandwidth of user defined frequencies and dwell times for each sample location. Measurements were made over a bandwidth between 50 and 1250MHz in 2MHz steps with a dwell time of 2.5μs at each frequency. Positional control was provided by a real time kinetic differential GPS antenna mounted on the GPR array. The amplitude time slice between 15.6–16.8ns (approximately 0.78–0.84m) shows details of the basilica-forum complex at the heart of the Roman town, surrounded by a grid pattern of internal streets with numerous ancillary building remains. The survey was conducted by the Geophysics Team of English Heritage in collaboration with colleagues from the University of Reading, further details of the survey and subsequent data processing can be found in Linford *et al.* (2010) and Sala and Linford (in press) respectively.

10.3 Puig Ciutat Roman Republican Site (Oristà, Barcelona)

By Sala, Garcia & Tamba

The archaeological site of Puig Ciutat is placed in central Catalonia, in an elevation surrounded by a meander of Gavarresa River. Since his casual discovering in 1982, there only have been carried a survey in 2005 by Roger Sala and Maria Lafuente, covering the Field C1, using a fluxgate magnetic gradiometer (Geoscan Research FM-256) and a 20X20m GPR survey. The results of this first survey revealed an entire occupation of the explored area and evidences of several burned areas, including a singular building placed in the center of the field.

In 2010 the team of SOT Archaeological Prospection and the archaeologists Àngels Pujol and Carles Padrós started the Puig Ciutat Exploration Project, witch aims to establish a first approach to the site and his environs, and at the same time, to explore new work methodologies, combining archaeology and geophysics.

Fig. 14. The 3D radar systema applied to Archaeology in the Silchester Roman Town. Amplitude map of approximately 0.78–0.84m depth, showing the plant of the forum.

The 2010 and 2011 seasons have been divided in geophysical survey campaigns (June 2010, May 2011) and excavation campaigns (July 2010, July 2011) in witch archaeologists have took part of geophysical surveys and geophysicists have took part in the excavations. Although the field works have just started, the preliminary results of first surveys and excavations revealed an interesting archaeological site. The excavation of four specific areas previously explored with magnetometry and GPR showed a roman settlement that suffered a firing destruction. The analysis of excavation works dated preliminarily the destruction between 70 and 30 B.C.

The results of magnetic surveys in the fields C1 and C2 are shown in the figure 15, B. In both cases, delimitated high-contrast areas are detected, witch are interpreted as fired buildings. The GPR surveys carried in the same fields the time slices (figure 15C) reveal a complex building distribution.

Using the interpretation diagrams (figure15D) four excavation trenches have been placed (figure 15E), revealing building areas with evidences of fire destruction, including roman military weaponry and importation italic pottery.

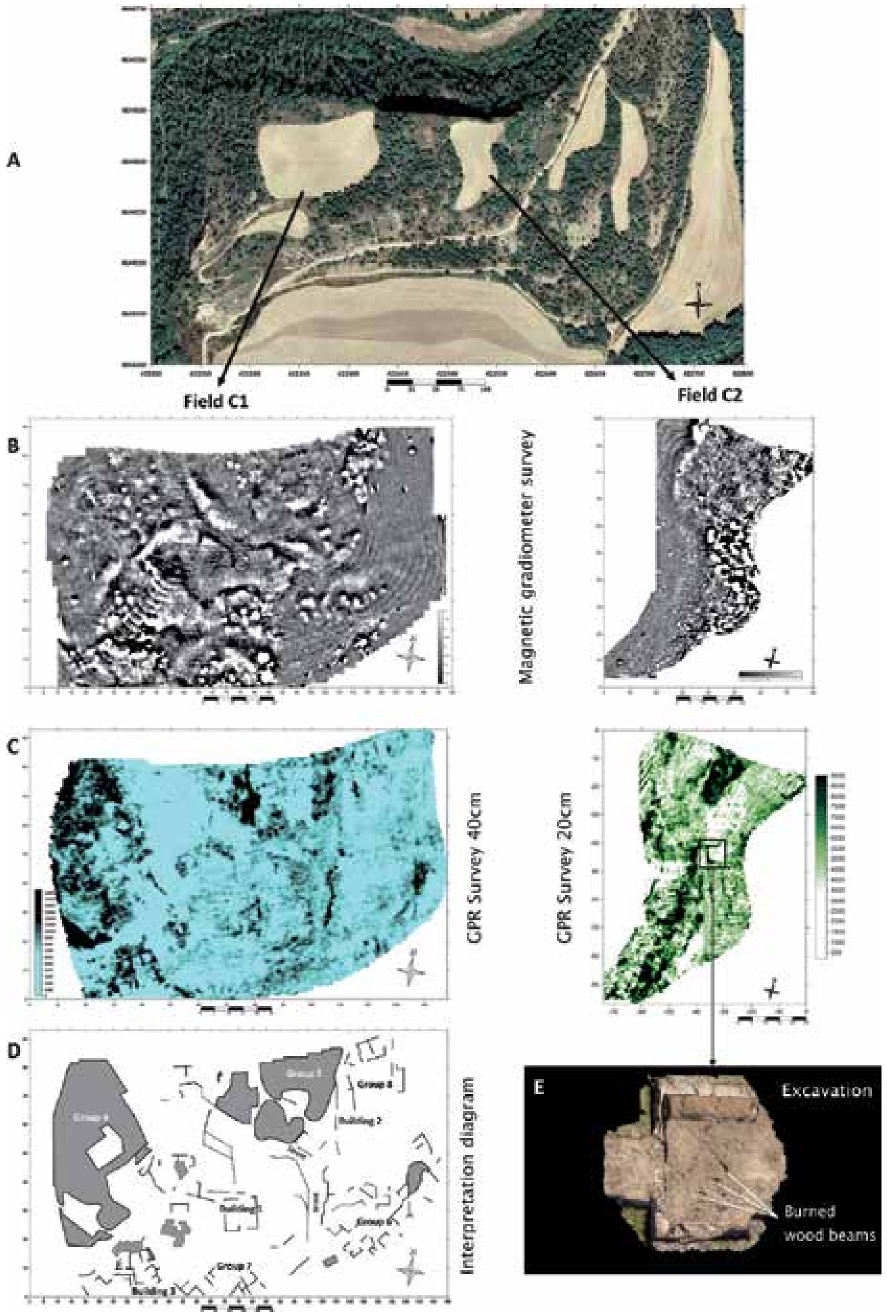

Fig. 15. Puig Ciutat Exploration Project 2010-2011.
A. Aerial view of the site (ca. 5ha). B. Grayscale plots of the magnetic surveys using a Bartingron G-601 Fluxgate gradiometer. C. GPR survey plots of the same fields using a IDS HI-Mod system with dual antennae of 200 and 600MHz. D. Interpretation diagrama of field C1 based in GPR data. E. Photogramteric plant of a building located in the field C2 in the GPR survey during the excavation.

10.4 La Dou Neolithic-Late Bronze Site (La Vall d'en Bas, Girona)

By Sala, Garcia & Tamba

Placed in the south face of Pyrenees, the Garrotxa region consists in a group of valleys and plains around an inactive volcanic area. The investigations carried by Dr. Maria Saña (UAB)

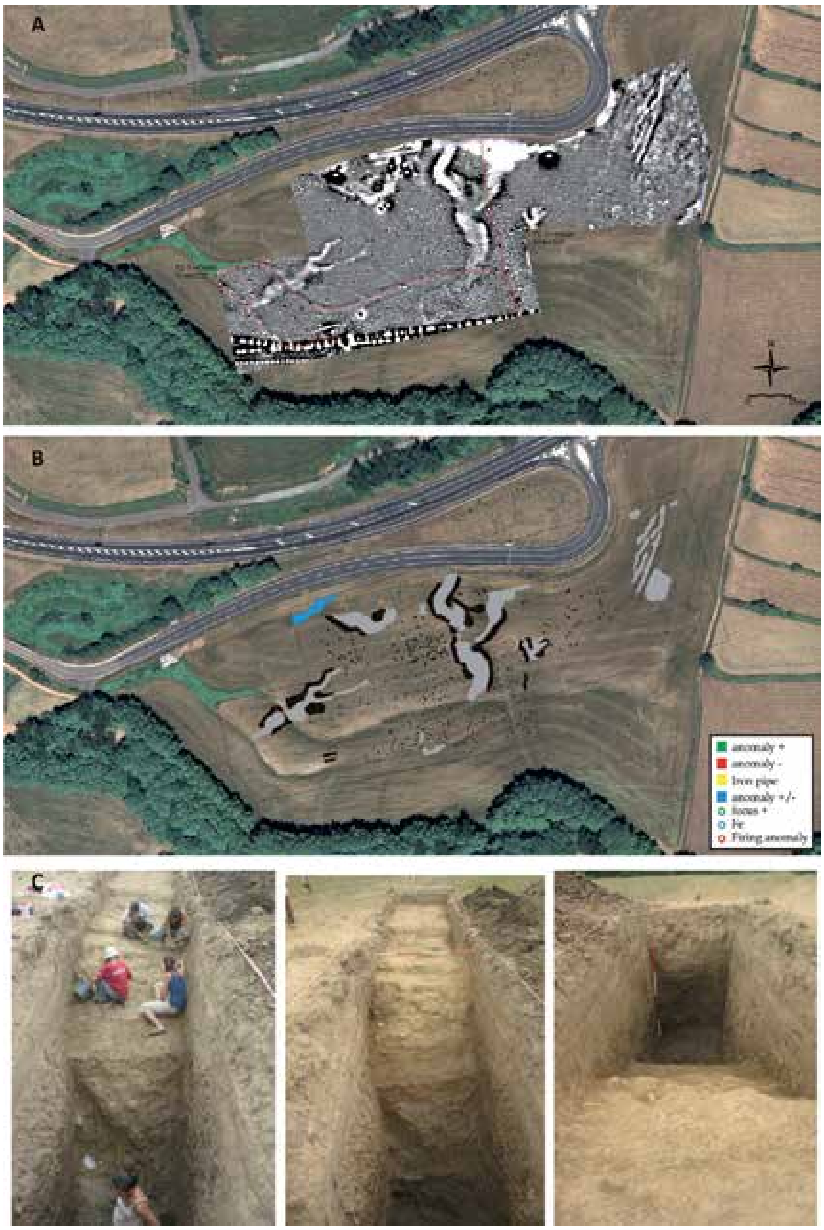

Fig. 16. Archaeological site of La Dou. A. Aerial view of explored area with over imposed magnetogram. Old field divisions are marked in red, thanks to the previous documentation. B. Interpretation diagram. C. Images of the excavation of a trench crossing the ditch.

centered from the Neolithic to the Bronze Age of this region, discovered a group of neolithic firing pits in a rescue excavation in La Dou (St. Esteve d'En Bas).

In 2009 the team of Dr. Maria Saña contacted the SOT team to carry a geophysical survey, witch aims to map a possible settlement related with the known firing pit areas. The survey used a fluxgate magnetic gradiometer (Bartington G-601) to explore a 2,48ha area. The results shown in the figure 16B show multiple groups of magnetic anomalies placed in the access of the valley. The most important group has been interpreted as a possible ditch with a quadrangular geometry. The excavation trenches carried in 2010 by the Dr. Saña team, discovered the remains of a Bronze Age ditch, also locating remains of a fired palisade in the bottom of the excavation (figure 16C).

Other interesting groups of magnetic anomalies are located in the survey, such as a group of focus positive anomalies interpreted as post-hole concentrations or other high-contrast bipolar anomalies interpreted as other firing pits.

10.5 IDS STREAM-X multi antenna GPR system test in Empúries Roman City (L'Escala, Girona)

By Sala, Garcia & Tamba and Alexandre Novo

The archaeological site of Empúries (L'Escala, Girona) is one of the most important sites of Catalonia for the Helenistic and Roman periods. It includes a Greek settlement (palaiapolis) and a Roman city dated from IIth BC to IIth century AC.

In February of 2010, collaboration between SOT Archaeological Prospection and the SOING-GeoAsiter companies allowed to carry a test survey of the IDS STREAM-X, 200MHz GPR multi antenna system in the Roman city area. The local archaeological research team designed a ca. 2Ha survey area in the south west corner of the city perimeter in order to compare the results with the hypothetical insulae divisions extracted from the excavated areas (figure 17A).

The IDS STREAM-X system is one of the most advanced array antennae system based in the Fast-Wave IDS control unit technology. The specific array used in the survey uses a stack of 15 200MHz antennae separated 12.5cm. The entire system was mounted in a frame pulled by a quad, locating readings with a GPS system (17B).

The data obtained were processed in order to obtain plain views of the results using the time-slice technique. The figures 17C and 17D show sequences of time slices of the two explored areas and an interpretation diagram. The time slice plots show how the high data density allows obtaining sharp images of buried buildings and urban divisions. The clearness of the results provide an easy understanding document that archaeologists could use intuitively and to interpret it.

10.6 GPR survey in the basilica of Santa Maria (Castelló d'Empúries, Girona)

By Sala, Garcia & Tamba

The Basilica of Santa Maria d'Empúries is one of the most important monuments of the village. Builded in the XIIIth and XIVth centuries as a witness of the economic and political

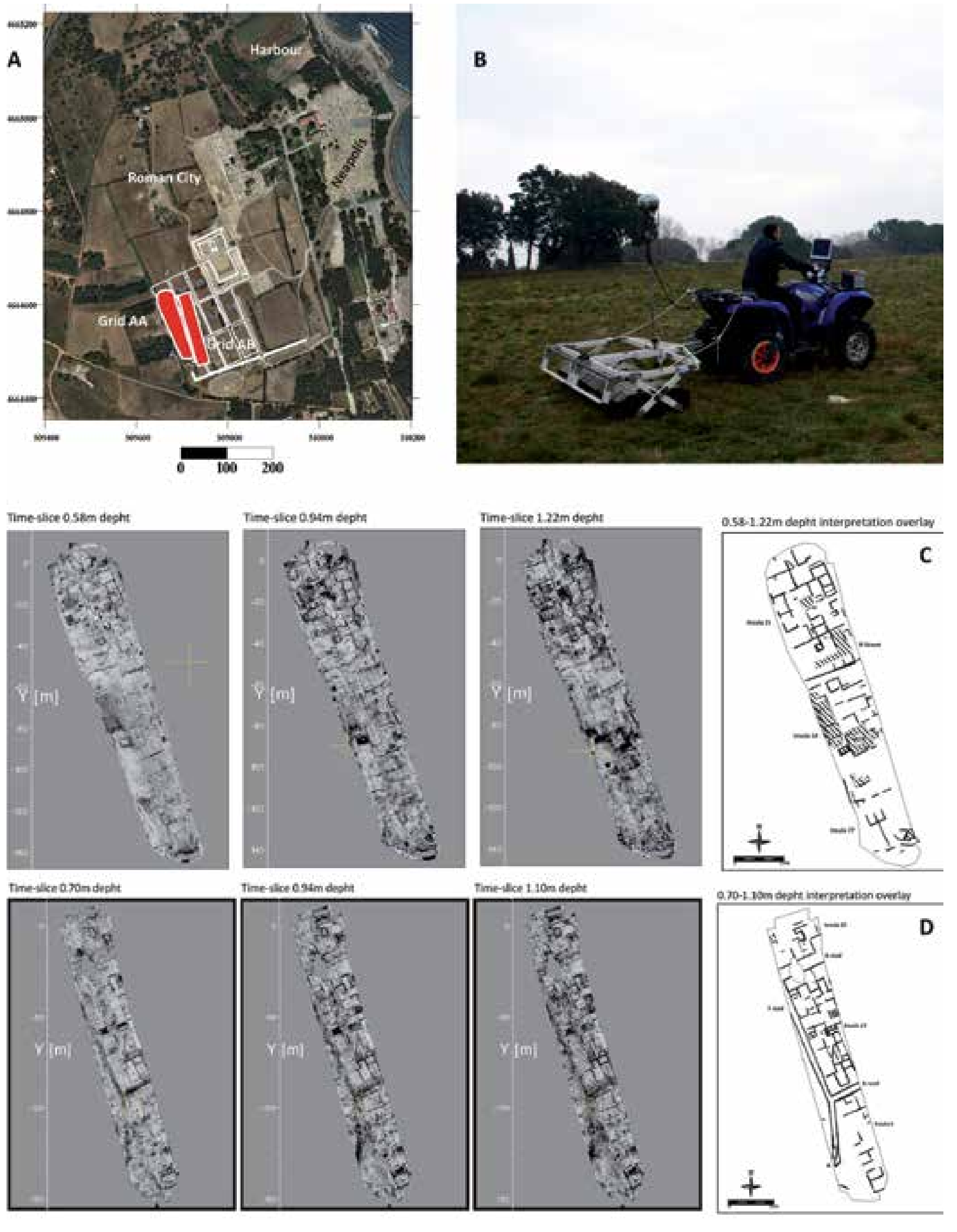

Fig. 17. A. Aerial view of the Empúries archaeological area with the suvey area remarked in red. B Geophysicist Alexandre Novo collecting data with the STREAM X system. C. Grid AA time slices and an interpretation diagram D. Grid AB and an interpretation diagram.

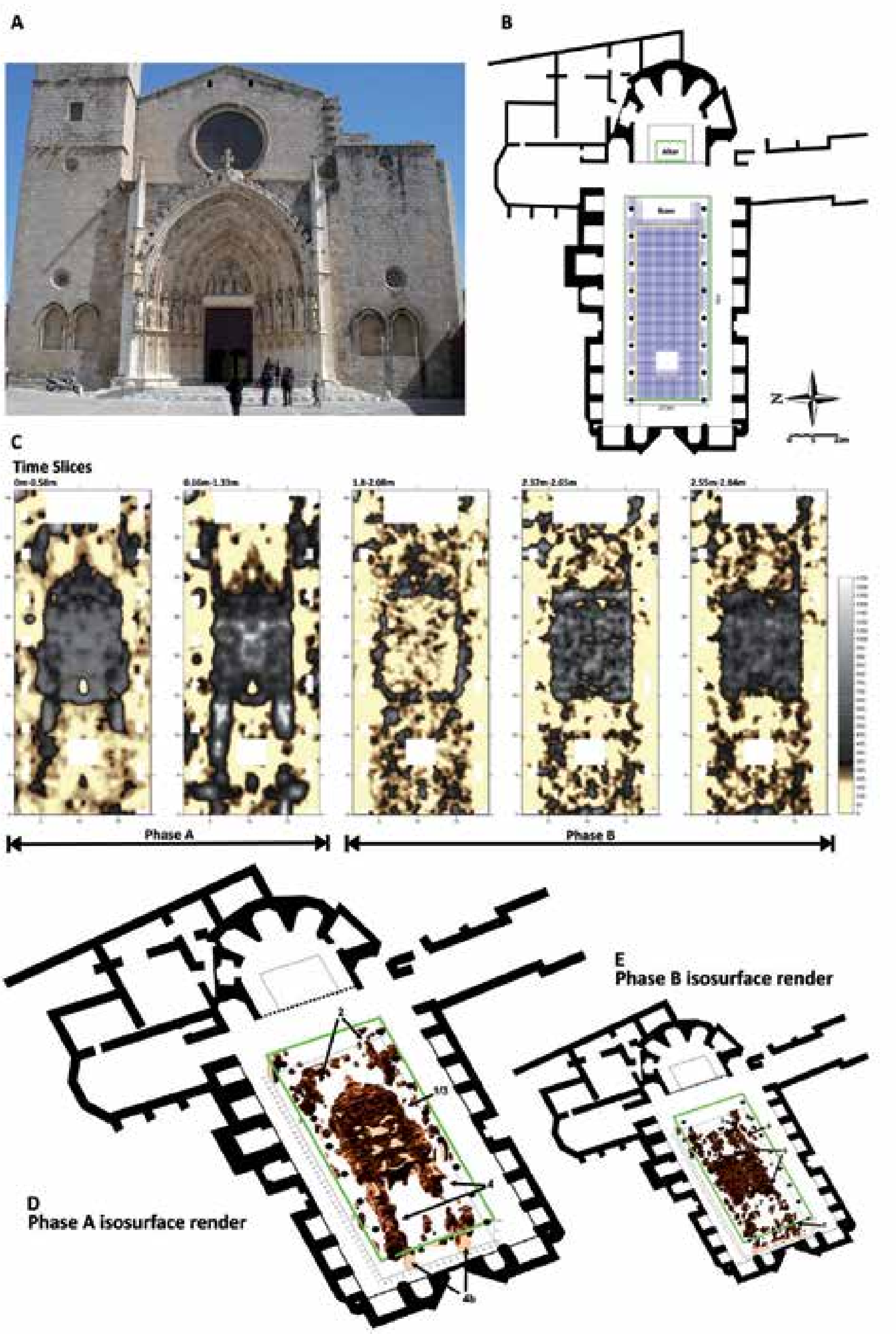

Fig. 18. GPR survey at the Basílica of Santa Maria, Castelló d'Empúries. A. Image of the façade of the Basilica. B. Plant of the building, with a plot of explored area. C. Time-slice sequence indicating the two interpreted phases. D and E. 3D isosurface renders of the two phases in the context of the church's plant.

influence of the Empúries County, it's one of the points of investigation the archaeologist Dra. Anna Maria Puig. After years of investigation, Dra. Puig collected documental and archaeological documentation that explored the evolution of medieval churches of Empúries County from early medieval period (Ss. VIII-XI).

In 2007, with the support of Castelló d'Empúries Town Hall, there was planned a GPR survey to explore evidences of previous buildings buried under the gothic-stile Basilica.

The survey was done applying an area survey in the central nave of the church, using a GSSI SIR-3000 system with a 270MHz antenna. As shown in the figure 18B, the survey strategy consisted in cover the central nave with perpendicular GPR profiles with 40cm spacing, covering an area of 41X17.5m.

The collected data was processed using the time-slice technique, generating horizontal cuts to obtain plain views of detected features. The plots shown in the figure 18C allowed describe two phases under the basilica's pavement. A first layer called Phase A (0.3-1.7m depth), is interpreted as the remains of a previous building of smaller dimensions, but with at least a central nave placed in the same axis of the actual building.

A second layer, or Phase B was defined in deeper time-slices (from 1.7m depth) as an underlying rectangular feature, that could be interpreted as a structural or basement part of Phase A building, or as the remains of a earlier building.

11. Conclusion

This chapter aimed to expose the basic knowledge of archaeological geophysics as a first approach for archeologists. The measured magnitudes used in these techniques and the way to represent them are not away from the daily work of an archaeologist. Indeed, when our eyes allows us to differentiate each strata in an excavation, we are using a kind of geophysical survey, measuring the different reflection of light and mapping it in our mind.

After decades of investigation and application, Archaeological Geophysics are intensively used in both investigation and rescue Archaeology in some European and American countries. But unfortunately, not all archaeologists feel familiar with these methods, since they are not yet in all the archaeological careers as a didactic content. Obviously this should change, because otherwise, future archaeologists could loose the opportunity to use a powerful tool and to optimize his resources.

In the other hand, the evolution of geophysical sensors has enhanced their capabilities in precision, resolution and speed. As seen, the use of GPR antennae arrays or multi sensor systems opens a new perspective for archaeologists, increasing the potential range and resolution of their studies, allowing a much more effective work. But all this technification should not make forget that the objective, after all, is Archaeology.

Indeed, all the techniques and methods exposed have evident applications in archaeological works (exploration, delimitation, detailed description), but there's a new and long way to expand their use in combination with other non-destructive techniques and in the study of the correlation between magnitudes of different existing survey methods.

12. Acknowledgments

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The short cases studies and examples presented are the product of scientific collaborations with archaeologists Dra. Maria Saña (La Dou), Anna Maria Puig (Basílica of Castelló d'Empúries), Jordi Principal (Molí d'Espígol), Joaquim Tremoleda (Empúries) and the archaeological section of Aranzadi Society of Sciences.

Finnally, we want to thank the teaching and advice of Dr. Dean Goodman, Dr. Armin Schmidt and the important task of all members of ISAP society, witch is an example of how a scientific collective could be connected and cooperate as a knowledge web.

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Section 3

New Applied Techniques – Improving Material Culture and Experimentation

6

Archaeometallurgical Investigation of Iron Artifacts from Shipwrecks – A Review

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1. Introduction

This chapter reviews the archaeometallurgical investigations of ancient iron artifacts, which were retrieved from two different shipwrecks. The analysis is based on materials science and archaeological literature, as well as archaeometallurgical observations made by the authors. Various tools were used in the investigation process, such as radiography, optical microscope, SEM with EDS, XRF, OES and microhardness measurements, and the results were compared with archeological-typological analyses within the relevant historical context. The connection between microstructure and mechanical properties enables the materials scientist to surmise the use of processes such as hammering, heating and quenching in ancient times. Such information regarding the iron artifacts may assist the archaeologist in understanding ancient manufacture processes, and what the probable uses of the objects were, as well as dating the objects and finding their ore origin. This information may also assist in the conservation process of these objects.

2. Archaeometallurgical background of ancient iron objects

Studies of ancient metals exist in the literature (e.g., Wadsworth & Lesuer, 2000; Pense et al., 2000; Blyth et al., 2002; Perttula, 2004; Nicodemi et al., 2005; Hošek & Košta, 2006; Mapelli et al., 2007; Barrena et al., 2008; Caporaso et al., 2008). However, it is rare to find a general review which relates to the archaeometallurgical methods and includes an interpretation of the microstructure. It is even more challenging to find a metallurgical review relating to iron objects retrieved from a marine environment. The present paper attempts to fill this gap and provide information regarding the techniques of archaeometallurgy as they are applied to

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archaeological objects made of iron and retrieved from shipwrecks discovered in the Mediterranean Sea.

Information regarding ancient iron objects, including composition, trace elements and microstructure, as well as their manufacturing processes, can provide essential data concerning their date, their probable use, their origin and the technology of the time (e.g., Mentovich et al., 2010; Ashkenazi et al., 2011; Eliyahu et al., 2011). Intercultural interactions such as wars or trade connections can also be examined through this data. This information can also assist in improving the objects' conservation process. From the materials science and engineering point of view, it is interesting to explore the ways in which metals have been employed in the manufacturing process of metallic objects in ancient civilizations. Combining the empirical experiments of materials and the theoretical models allows an appreciation for the effects of structure on the material's properties. The relation between microstructure and mechanical properties enables the manipulation and control of the properties of metals by processes such as casting, cold working, hot working, heating and quenching. These technological aspects are strengthened and become more intriguing after the reaction of the iron with the seabed environment.

2.1 Wrought iron, cast-iron and steel

In the classification of ferrous alloys, pure iron (Fe) is defined as iron containing less than 0.008 by weight (wt%) carbon (C). At room temperature, pure iron is composed of a ferrite phase, which is an α iron body-centered cubic (BCC) unit cell. At higher temperatures (912^{o}C), the ferrite phase transforms into austenite γ iron, with face-centered cubic (FCC) unit cell. For rather pure iron manufacturing, a reduction process should be applied at a temperature of around 1200^{o}C (viscous slag with solid-state phase), turning the iron ore into a spongy matter called bloom (Tylecote, 1962). The bloom contains many inclusions, known as slag. In order to reduce the amount of slag in the metallic iron bulk, the bloom is then hammered. The result is a heterogeneous, ductile, malleable, and easily welded material named 'wrought iron', with an average amount of 0.1 wt% C (Tylecote & Black, 1980). The term 'wrought iron' literally means 'worked iron'. In order to join two pieces of iron together, a forge-welding process is carried out at temperatures below that of melting (1538^{o}C for pure iron) and above half of it, resulting in an austenite ductile phase, which allows for intensive dislocation movement (Murray, 1993; Barrena et al., 2008).

Ferrous alloys such as steel and cast-iron are defined as alloys containing Fe as the prime element and C as the secondary element (Callister, 2000). Iron alloys containing 0.008–2.14 wt% C include a combination of α ferrite and an intermediate compound called cementite (Fe_3C), and are defined as steel. The alternating microstructure between α ferrite and Fe_3C gives the pearlite phase optimized mechanical properties. The massive amount of cementite results in good hardness and abrasion resistance, but also in higher brittleness (Goodway, 1996).

Outstanding crystalline microstructure is formed when steels are cooled from extremely high temperatures at a critical cooling rate. This kind of microstructure, named Widmanstätten (or Thomson structure) was discovered by the geologists A. von Widmanstätten and C. von Schreibers in 1808, after they etched various meteorites, and revealed different morphologies (Vander Voort, 2004). Widmanstätten structure pattern

(Fig. 1) is a very common iron meteoritic structure (Szurgot et al., 2008). Widmanstätten microstructure of proeutectoid ferrite is observed only over a limited range of transformation temperatures and C contents (Vander Voort, 2004). The main factors affecting the formation of Widmanstätten structure in steels are the chemical composition of the steel, the cooling rate and the size of austenite grains (Aliya & Lampman, 2004; Todorov & Khristov, 2004). Low C steels, which contain less than 0.3 wt% C, have a tendency to form a Widmanstätten pattern, when they have a coarse austenitic grain, and have been rapidly cooled from austenitic phase (Todorov & Khristov, 2004).

Archaeological iron can be classified into two different categories: wrought iron and cast-iron. The use of cast-iron as a significant structural material, and its mass production, began in England (at Coalbrookdale) during the eighteenth century, when A. Darby devised a new method of smelting iron with coal (Goodway, 1998). The properties of cast-iron can be controlled by adding various alloying elements to it.

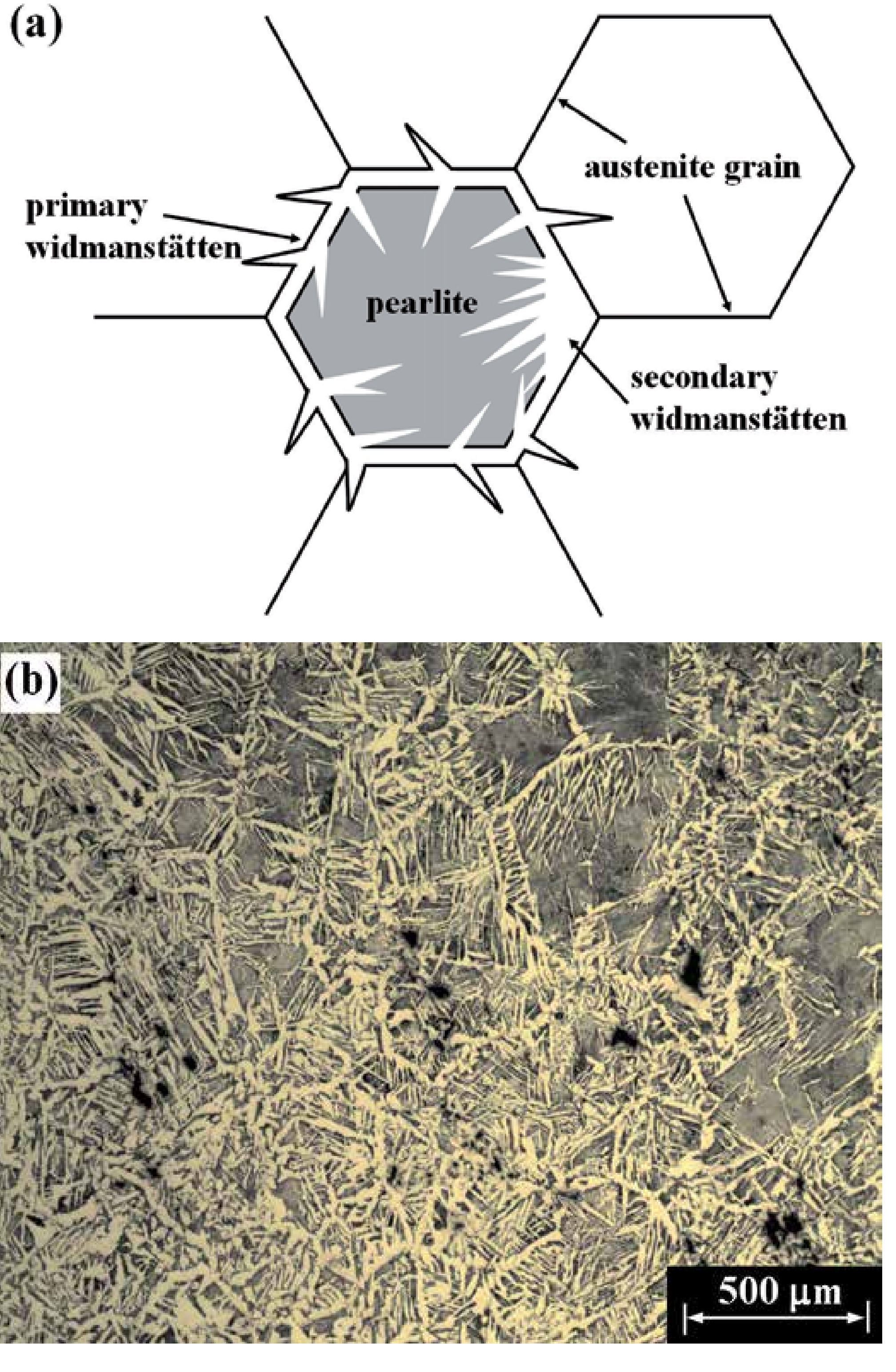
Commercial cast-iron is defined as a ferrous alloy containing between 2.14 and 4.5 wt% C, and it usually contains between 0.5 and 3 wt% silicon (Si) and smaller amounts of other elements as phosphorus (P), sulphur (S) and manganese (Mn) (Stefanescu, 1996a, Mentovich et al., 2010). It has a relatively low melting point, good fluidity, good hardness and good wear resistance, but it tends to be brittle. The main difference between white and gray cast-irons is in the amount of silicon present in the alloy. While white cast-iron contains less than 1 wt% Si, gray cast-iron contains more than 1 wt% Si (Goodway, 1998; Mentovich et al., 2010). White cast-iron is named for its white fractured surface, whereas gray cast-iron is named for its gray fractured surface, which occurs because of the presence of graphitic flakes. Both white and gray cast-iron can be identified by their fractured surface (Callister, 2000).

The slow cooling rate of solidification or the high presence of silicon (which is a graphite stabilizing element) in the cast-iron, causes a graphite formation (Menon & McKay, 1996; Stefanescu, 1996b). Adding more than 1 wt% Si causes the carbon to precipitate as dark graphite flakes surrounded by a matrix of bright pearlite (alternating thin layers of α ferrite and dark cementite) (Callister, 2000).

The structure of steels and cast-irons may oscillate between different microstructures as a result of C amounts, different alloying elements, the temperature of the heat treatment, and the rate of cooling. When steel with a pearlite phase in room temperature is heated to a higher temperature (912^{o}C) and rapidly cooled (quenched) to room temperature, another phase is formed called martensite (metastable state). This has a body-centred tetragonal (BCT) elongated unit cell, which includes C atoms occupied in it. The martensite morphology depends on C content: below 0.6 wt% C content, the structure consists of martensite needles; between 0.6 and 1.0 wt%, the martensite is a mixture of needles lath and plate morphologies; and above 1.0 wt% C, the structure consists of plates with some retained austenite remains between the plates, as well as some martensite needles extending from the plates (Aliya & Lampman, 2004). The martensite phase has high hardness but it is also a very brittle phase (Callister, 2000).

2.2 Underwater corrosion

When iron is exposed to an atmospheric environment it forms different iron-oxides, such as Magnetite (Fe_3O_4), Hematite (α-Fe_2O_3) and Maghemite (γ-Fe_2O_3) (Cornell & Schwertmann,


(a)
austenite grain
primary
widmanstätten
pearlite
secondary
widmanstätten
(b)
500 µm

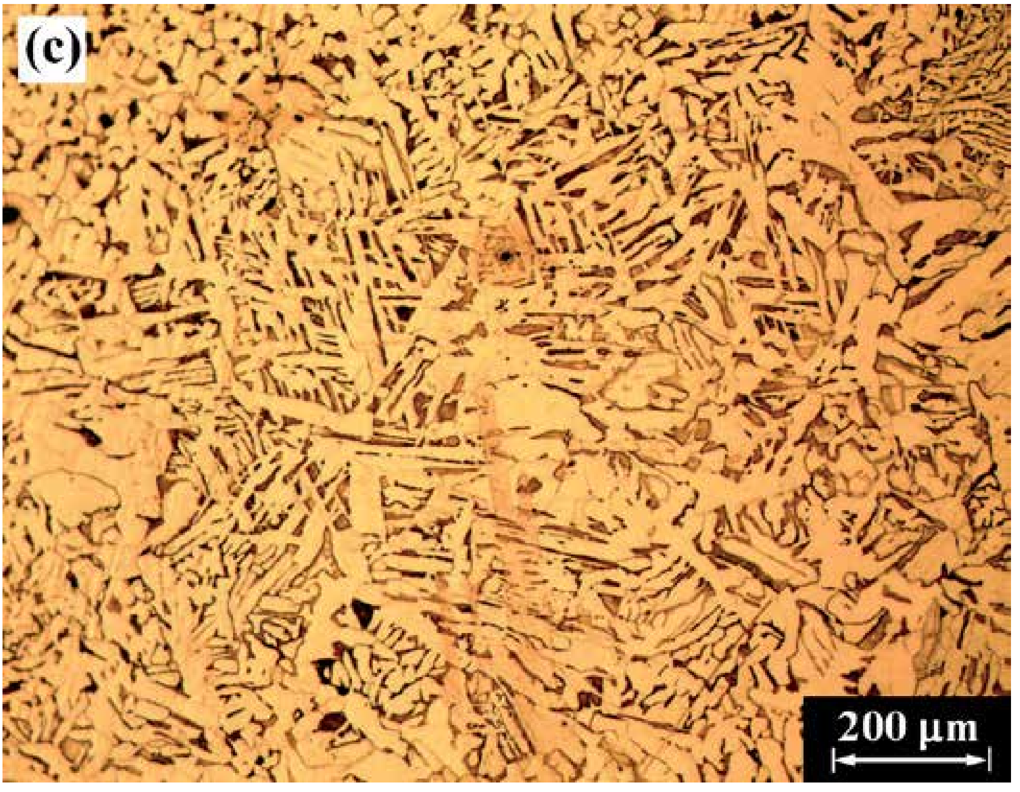


Fig. 1. Widmanstätten microstructure: (a) schematic illustration (Drawing: D. Ashkenazi), (b) OM (ZEISS, AXIO Scope A.1) metallographic image (of a T-shaped anchor) showing Widmanstätten microstructure, and (c) Widmanstätten microstructure in higher magnification OM (Photos: A. Aronson).

2003). At temperatures higher than 560^{o}C, the common order of iron-oxide layers (from the internal to the surface respectively) is Fe/FeO/F_3O_4/F_2O_3/O_2 (Fontana, 1987). Reddish-orange powder rust and the presence of many cracks and cavities on the surface of the objects are indications of an ongoing active corrosion process, causing continuous loss of metal, as well as degradation of mechanical properties (Selwyn, 2004).

Ancient objects made of iron, which were excavated from a marine environment (e.g., shipwrecks) after being buried for centuries under layers of sand of various types and thickness usually suffer from severe corrosion, and are generally covered with a thick encrustation coating and concretion, similar to what happened to the copper nails of the Ma'agan Mikhael shipwreck (Kahanov et al., 1999). The nails excavated from the Ma'agan Mikhael shipwreck had black colored concretions, which were assumed to be iron, but were identified later as unalloyed copper. The concretion was composed of a black-blue mineral called covellite (CuS) matrix. The concretion also included quartz particles (sand), and shell (calcium carbonate) inclusions (Kahanov et al., 1999). Copper in aerobic underwater surroundings tends to oxidize quite rapidly, resulting in a toxic protective layer that protects the copper from sulphides resulting from a reaction with microorganisms. Therefore sulphidization of the copper nails occurred only inside the wood, in a rich bacterial environment which probably accelerated the concrete formation (Kahanov et al., 1997; Kahanov et al., 1999).

Therefore, for successful study and conservation of these items, it is important to understand the corrosion and concretion mechanisms of submerged iron artifacts. Corrosion of archaeological iron artifacts buried under sand in seawater is an electrochemical process, which involves anodic and cathodic reactions in an aqueous electrolytic environment and a biological process as well, involving anaerobic bacteria (North, 1976). When iron is buried in aqueous solution, the oxide layers grow slowly, resulting in oxide compounds such as: Goethite (α-FeOOH), Akaganeite (β-FeOOH), and Lepidocrocite (γ-FeOOH) (Balasubramaniam, 2003; Cornell & Schwertmann, 2003; Neff et al. 2004; Neff et al. 2005; Neff et al. 2006a; Neff et al., 2006b; Balos et al., 2008; Barrena et al., 2008; Park et al., 2010). During the underwater concretion the metallic iron slowly dissolves and then the metallic surface is covered with a ceramic, aggregate coating. This concretion, which covers the iron artifact, forms a protective 'cocoon' in the sea. Concretion formation occurs as a result of interaction between iron and its surrounding environment. In this process, which is one of the most fascinating features of iron corrosion, the metal's surface decreases, whereas the concretion conglomerate increases.

Since iron is a non-toxic metal, it can be colonized in the underwater marine environment, which includes sand, shells particles and marine organisms, and these create a calcium carbonate ($CaCO_3$) shell (North, 1976). Sometimes the catalyst for this process is bacterial organisms, which are present in wooden ships and consume/degrade the cellulose of the waterlogged wood (Kahanov, 1997).

Removal of the concretion layer or cleaning the corrosion is required in order to learn about the artifacts, but this procedure might damage the metal object, if anything remains. In such cases it is recommended to examine the object with a non-destructive method, such as X-ray radiography, before the de-concretion process begins. Sometimes, information about an object can be obtained from the radiography itself (Pulak, 2004).

After retrieving the objects from the sea and beginning the de-concretion/corrosion process, wrought iron and cast-iron tend to corrode in dissimilar ways. Wrought iron corrodes along the slag inclusions, and the presence of chlorides in the alloy accelerates the corrosion rate (Balasubramaniam et al., 2003). Orange-brown drops, known as 'sweating', are formed on the surface of the iron object, indicating the presence of chlorides (Selwyn, 2004). Cast-iron exposed to the atmospheric environment can be corroded by graphitization, with accelerated corrosion on the external surface of the object (which is rich in graphite) and at the boundaries between the graphite and the metal (Najjaran et al., 2006).

3. Studying cases of iron artifacts from shipwrecks for a better understanding of ancient cultures

The present paper describes two case studies related to iron objects recovered during underwater excavations in Israel. The earlier case is the archaeometallurgical study of two iron anchors retrieved from the seventh-eighth century Tantura F shipwreck (Eliyahu et al., 2011), and the second is the archaeometallurgical study of two cast-iron cannonballs retrieved from the nineteenth century Akko 1 shipwreck (Mentovich et al., 2010).

Archaeometallurgy studies were used to provide essential information regarding dating, processing, and manufacturing techniques of the objects. In both cases, the artifacts were found covered with corrosion, encrustation and a concretion layer (Fig. 2 and Fig. 8). The samples were cut, roughly polished, and mounted in Bakelite at 180 psi pressure and a temperature of 180°C. Surface preparation included grinding the samples with silicon carbide papers, grades 240–600 grit, followed by polishing with 5 to 0.05 micron alumina pastes. Finally the samples were polished with 0.05 micron colloidal silica polishing suspension paste, and etched using Nital acid (Mentovich et al., 2010; Eliyahu, et al., 2011).

3.1 Case Study I: T-shaped iron anchors from the Tantura F shipwreck

The Tantura F shipwreck was discovered in Dor lagoon, Israel in 1995. It was excavated during five seasons in 2004–2008. Combining ^{14}C dating with typological study of the pottery, the shipwreck was dated to between the second half of the seventh and the end of the eighth centuries AD (Barkai & Kahanov, 2007; Barkai et al., 2010). Among the finds exposed in the Tantura F shipwreck were two T-shaped type iron anchors: one on the starboard side and the other on the port side, close to the bow (Fig. 2). Both anchors were found broken, with part of the shank and the anchor cable ring missing. Anchor A was found under the wooden hull, touching it (Fig. 2a), while Anchor B was found concreted to the outside of the planking below the hull (Fig. 2b).

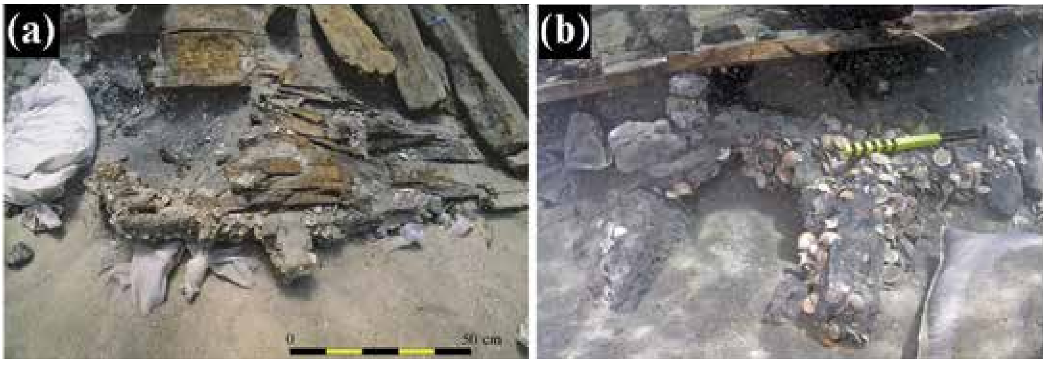


Fig. 2. The Tantura F anchors covered with a thick encrustation coating and concretion: (a) Anchor A and (b) Anchor B attached to the vessel (Photos: I. Grinberg).

Both anchors (Fig. 3) were considered to be found in-situ, thus dating them to the time of the shipwreck. The two anchors were retrieved from the seabed covered by a 4 cm thick gray layer of encrustation coating and concretion composed of sea sand, shells and small stones; however, the core of the iron shank and the arms were of solid, shining and hard iron.

The examination of the T-shaped anchors included radiography, metallographic cross-sections (Fig. 4), Optical Microscope (OM), Vickers microhardness tests, Scanning Electron Microscope (SEM) with energy dispersive spectroscopy (EDS) analysis, and Optical Emission Spectroscopy (OES) analysis (Eliyahu et al., 2011). For the metallographic sampling three cross-sections were cut from two different parts of Anchors A and B for according to ASTM E3-01 standard.

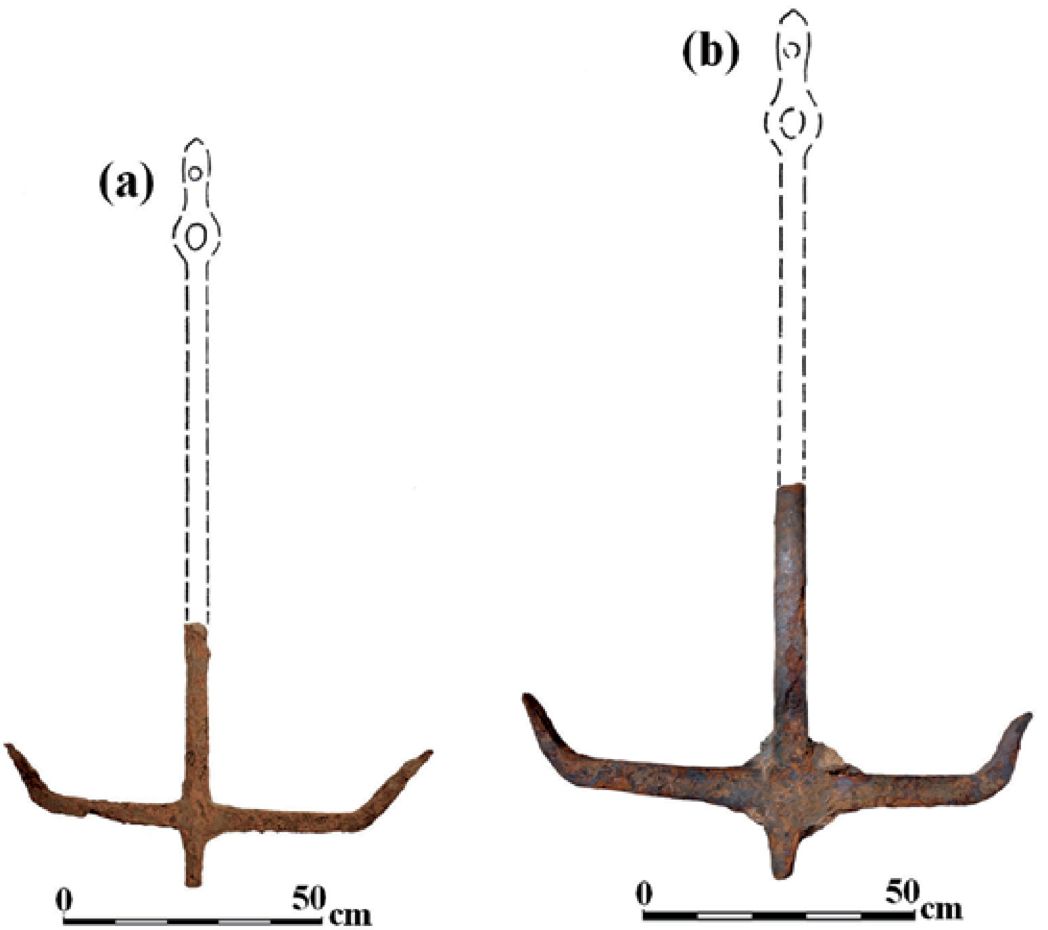


Fig. 3. Images of the Tantura F T-shaped iron anchors: (a) Anchor A and (b) Anchor B (Photo: J.J. Gottlieb, Drawing: O. Barkai).

The study revealed the microstructure and manufacturing process of the two T-shaped iron anchors (Eliyahu et al., 2011). A microscopic image of the concretion coating of Anchors A is shown, revealing the corrosion layer and sand particles (Fig. 5). A heterogeneous microstructure was observed at the core of the iron Anchors, containing ferrite, pearlite and Widmanstätten ferrite-pearlite (Fig. 6). This kind of microstructure is typical of wrought iron which has been made by bloomery. Slag inclusions were observed in both anchors, with a typical morphology of wüstite (FeO) trapped in a glassy matrix. Typical OM image of slag inclusions that were trapped in anchor A are shown in Fig. 7.

Vickers microhardness (Future-Tech Model FM-700e tester) measurements, with a load of 100 g-force, revealed decarburization, probably due to the final hot-working process. A decarburization profile was achieved for both anchors along the diameter of the shanks cross-section (Eliyahu et al., 2011). Chemical etching followed by soda-blast cleaning revealed some forge-welding lines, hinting at the manufacturing process of the two anchors (Eliyahu et al., 2011).

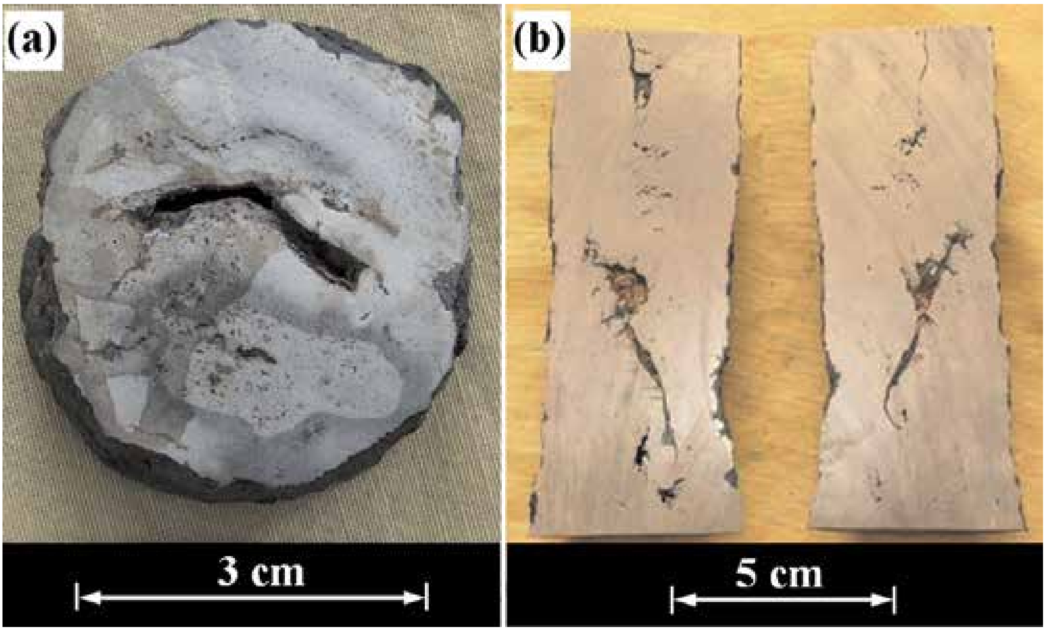


Fig. 4. The metallographic sections of the Tantura F Anchor A at the (a) transverse cross-section after polishing and etching, and (b) longitudinal cross-section before polishing and etching (Photos: A. Aronson).

Fig. 5. Metallographic section of the Tantura F Anchor A corrosion layer (left) and the encrustation coating that includes sand particles (center and right) (Photos: D. Ashkenazi).

3.2 Case Study II: Cast-iron cannonballs from the Akko 1 shipwreck

The Akko 1 shipwreck was a Mediterranean naval auxiliary brig discovered in Akko harbour, and excavated during three seasons between 2006 and 2008. Various artifacts were discovered in the shipwreck, among them small-arms and ammunition, suggesting its involvement in a naval battle (Cvikel & Kahanov, 2009). Three cannonballs, which were identified as 9-,12-, and 24-pdrs, were retrieved from the Akko 1 shipwreck. Theoretically, any of them could have been a shot that hit the ship (Cvikel & Kahanov, 2009: 51; Mentovich et al., 2010). The cannonballs were found covered with a thick layer of encrustation coating (Fig. 8). Two of the cannonballs (Fig. 9), the 9-pdr and the 24-pdr, were studied using archaeometallurgical methods (Mentovich et al., 2010). The

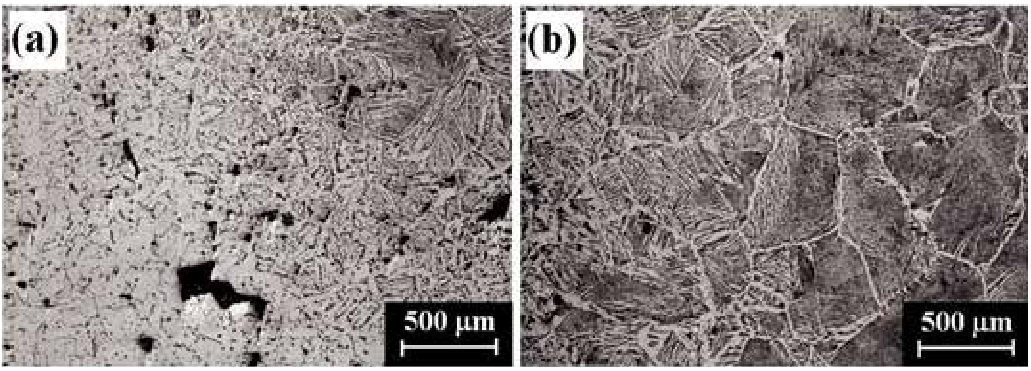


Fig. 6. OM metallographic image of the T-shaped Anchor A showing the heterogeneous structure of a 'wrought iron' (Photos: A. Aronson).

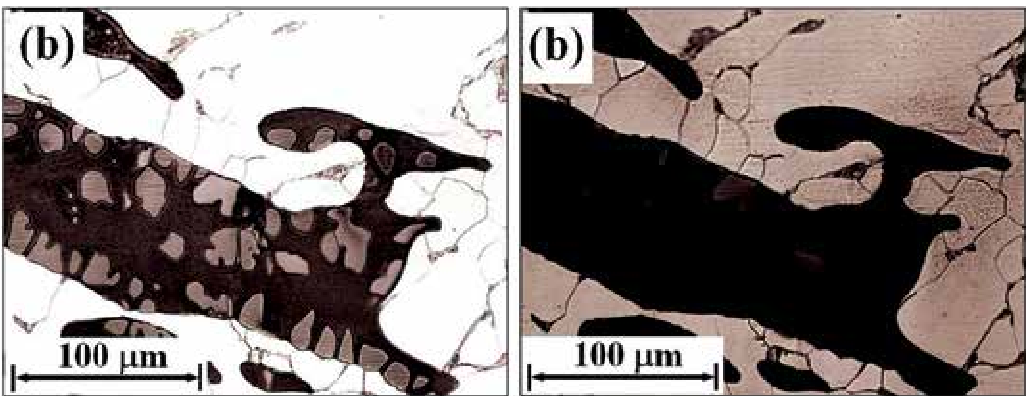


Fig. 7. OM metallographic image of (a) typical slag inclusions that were trapped in anchor A (high intensity of light), (b) α ferrite grains at the area which surrounds the slag inclusions (Photos: A. Aronson).

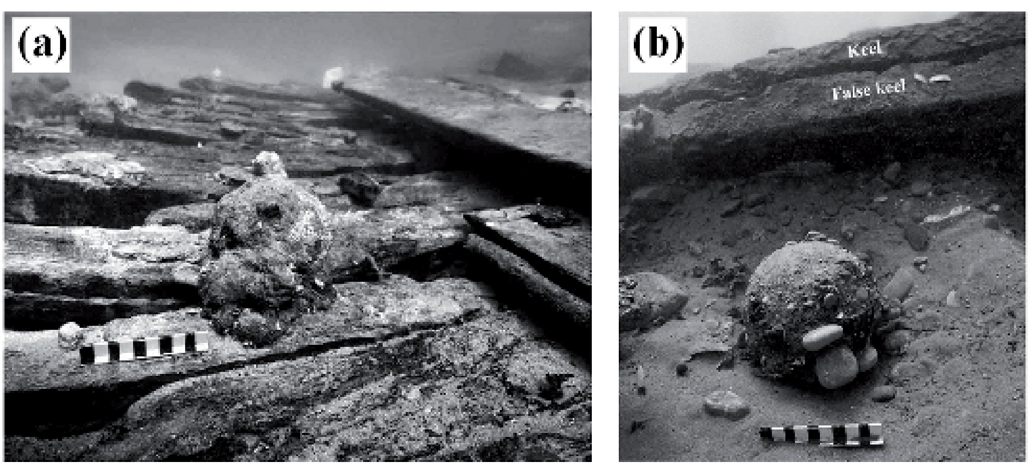


Fig. 8. Images of Akko 1 shipwreck cannonballs covered with a thick layer of encrustation coating: (a) on the framing timbers, and (b) near the false keel (Photos: S. Breitstein).

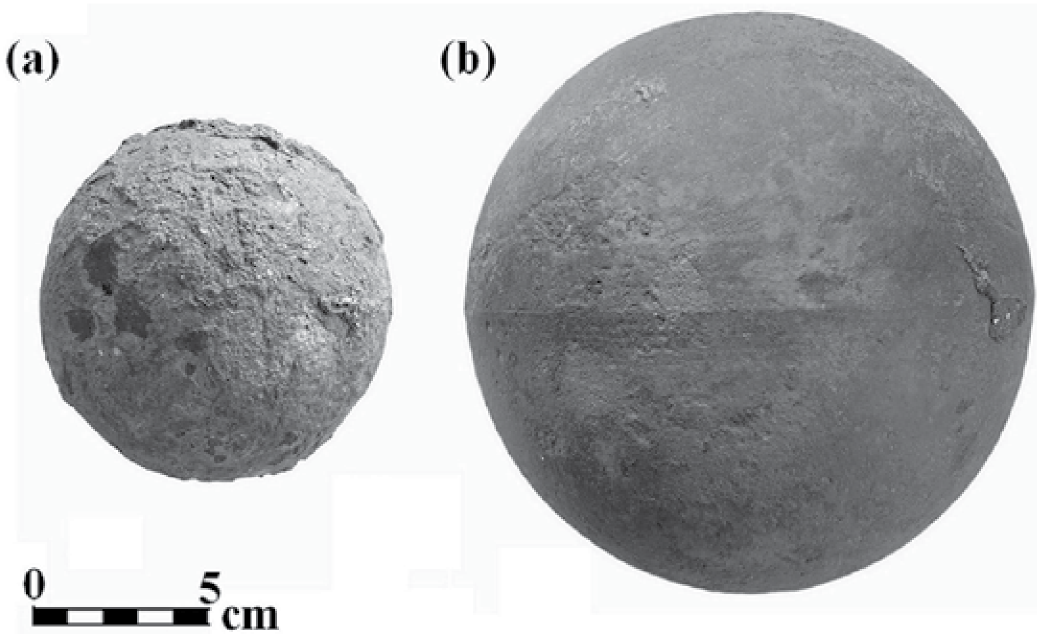


Fig. 9. Images of the Akko 1 shipwreck (a) 9-pdr and (b) 24-pdr cannonball, after removal of the concretion layer (Photo: J. J. Gottlieb).

examination of the cannonballs included OM, SEM-EDS, X-Ray Fluorescence (XRF) and Vickers microhardness tests.

The results showed that the two cannonballs were made of cast-iron and manufactured with sand casting moulds. The sand remains found within voids in both cannonballs were also studied by petrography (Mentovich et al., 2010). The OM examination of the two cannonballs revealed a corrosion layer at the surface of the cannonball, and a dendritic cast-iron microstructure beneath the surface (Fig. 10a and Fig. 11a). The 9-pdr cannonball was uniform and included only white cast-iron (Fig. 10). The cast-iron in the 24-pdr cannonball was non-uniform (Fig. 11) and included white cast-iron in the inner part of the cannonball, whereas the external part of the cannonball was composed of gray cast-iron. The difference between the two cannonballs may suggest the use of different technologies in their manufacturing process (Mentovich et al., 2010).

A chemical analysis of the composition of the cast iron of the cannonballs, revealed more than 0.5 wt% of manganese (Mn) in both cannonballs (Mentovich et al., 2010). In 1839 J. Heath wrote a patent involving the addition of manganese to cast-iron, which resulted in metal free of gas porosity and blow holes (Wiltzen & Wayman, 1999; Wayman, 2000). Thus, it was suggested that the Akko 1 shipwreck cannonballs were manufactured around the 1840s.

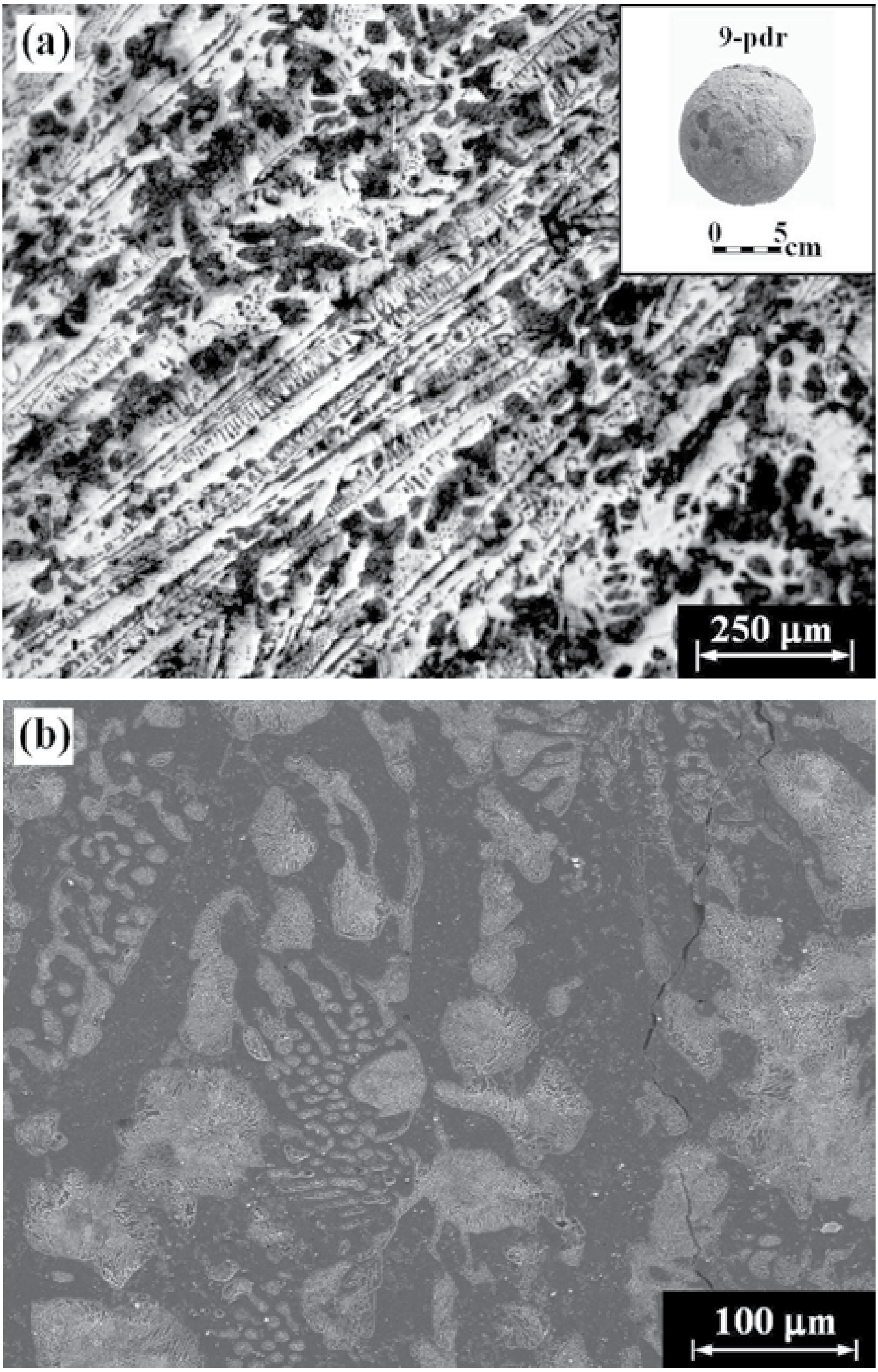
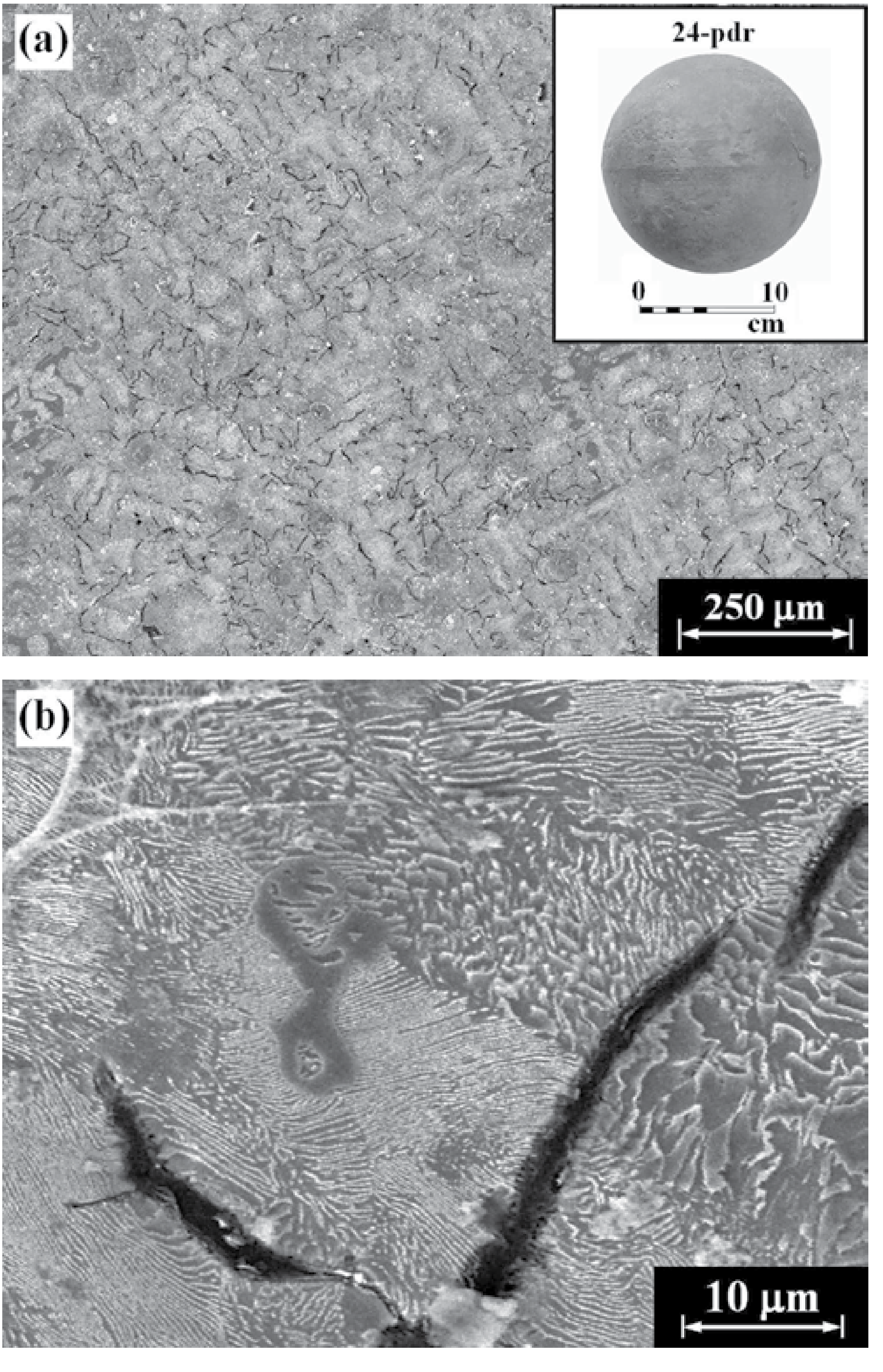


Fig. 10. The 9-pdr cannonball image of a white cast-iron as shown by (a) OM (ZEISS, AXIO Scope A.1) metallographic analysis, and (b) SEM-EDS (FEI Quanta 200FEG ESEM) analysis. (Photo: Z. Barkai / E. Mentovich / D. Schreiber).


(a)
24-pdr
0
10
cm
250 μm
(b)
10 μm

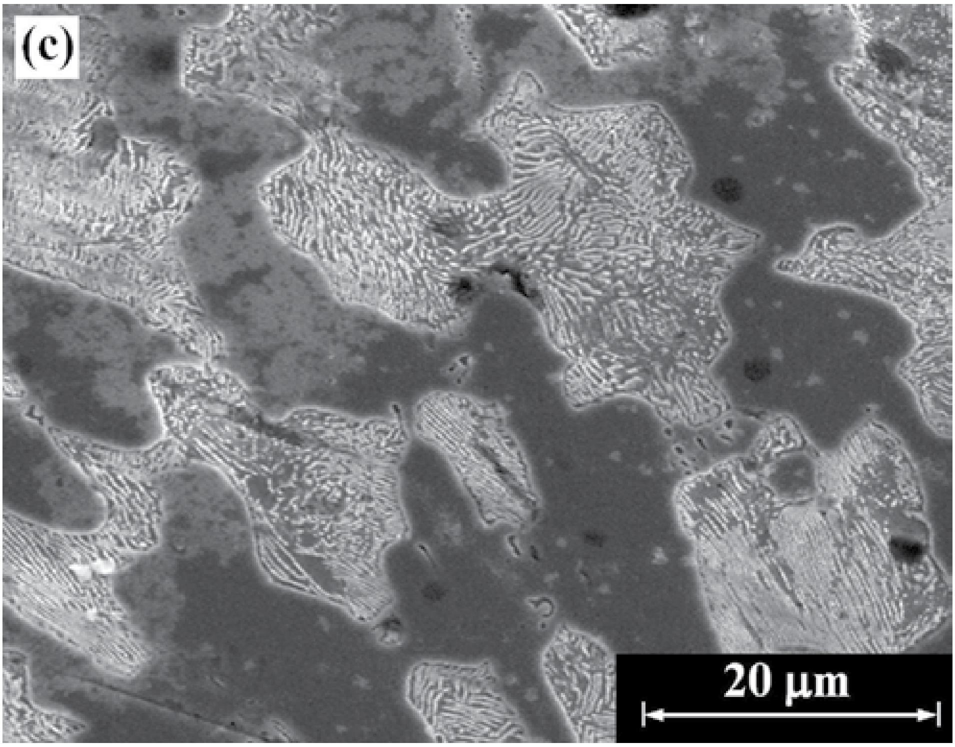


Fig. 11. The 24-pdr cannonball image of (a) a gray cast-iron as shown by an OM at the external part of the cannonball, (b) SEM-EDS analysis showing the gray cast-iron at higher magnification, and (c) a white cast-iron as shown by SEM-EDS analysis at the internal part of the cannonball (Photo: Z. Barkai / E. Mentovich / D. Ashkenazi).

4. Discussion and conclusions

This chapter has demonstrated a multidisciplinary study of archeology and metallurgy. It reviewed archaeometallurgical investigations of ancient iron artifacts retrieved from shipwrecks. The analyses were based on the archaeological-typological study of the finds, materials science, and archaeometallurgical observation.

It has been demonstrated here that using tools like OM, SEM-EDS, XRF and microhardness test may assist archaeologists in revealing more information regarding ancient iron objects retrieved from a marine environment, including their manufacturing process, as well as providing a strong hint for dating the objects, and hence a clue to the wrecking event.

In the study of the T-shaped iron anchors from the Tantura F shipwreck, it was concluded that decarburization had occurred (which is supported by microhardness measurements), probably as a result of the final hot-working process (Eliyahu et al., 2011). The information gathered from the archaeometllurgical investigation of the two T-shaped anchors found in the Tantura F shipwreck has enhanced understanding of metallurgical knowledge in the Eastern Mediterranean in the early Islamic period, and expands the database of anchors of that period. Specifically, this study indicated that the anchors found in the Tantura F shipwreck were of better quality and manufacture in comparison to other studied anchors, such as, for example, the eleventh century Serçe Limanı shipwreck (Stech & Maddin, 2004; Van Doorninck, 2004).

The study of the two cast-iron cannonballs from the Akko 1 shipwreck revealed that the amount of Mn in both hinted that they were manufactured post-1839, and consequently led to relating the shipwreck to the 1840 naval bombardment of Akko (Mentovich et al., 2010). In addition, historical evidence points to the fact that on the eve of this battle, a merchant brig was observed anchoring in the harbour (Codrington, 1880).

To summarize, the metallurgical analysis of the two T-shaped anchors found in the Tantura F shipwreck has contributed significant information relating to their manufacturing process, and the analysis of the chemical composition of the two cannonballs from the Akko 1 shipwreck has provided a strong hint regarding their dating, and hence of the wrecking event. These two case studies present the valuable contribution made by archaeometallurgical investigations for the study of shipwreck and their artifacts.

5. Acknowledgments

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Molecular Diagnosis Through Genetic Typing of Skeletal Remains in Historical Populations of Situated Turkey

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1. Introduction

1.1 History of archeological excavation site

The Börükçü Location and The Lagina Hekate's Temenos are in the Muğla Province's Yatağan Town, in Turkey. In ancient world, The Börükçü Location and The Lagina Hekate's Temenos had been a part of Caria Region. At the ancient times, The Lagina Hekate's Temenos had a 9 km long holy way to the city Stratonicea, which is at the south of it (Akurgal E., 2000). An uninterrupted settlement has been seeing in this district since early bronze age (3000 B.C.) to present day (Güngördü E., 2003). Caria Region (Figure 1a-6b) had been having a mountainous geography and its name has been coming from "Car" people. They had a peculiar language and they were thinking themselves the natives of Anatolia (Güleç E., et.al., 2006). Anatolia has geographical regions because of its natural elements (Güngördü E., 2003). Since ancient period, these geographical regions has been shaping Anatolian people's life styles and connections betweeen each other. In Aegean region which contains Börükçü Location, The Lagina Hekate's Temenos and ancient Caria Region, mountains lines straight to the shore. These chains of mountains lines to Aegean Sea by becoming peninsulas, islands, promontories. Aegean Sea owns many islands and because of this, it's called the sea of islands. Approximately at the fourth geological period in Aegean Region, lands collapsed underwater, so Aegean islands existed (Baykara T., 1988 and Sevin V., 2001). At the same geological period, all Anatolia had the shape of present time and by the effects like; tectonic movements and outer factors, it still continues to change. Aegean shoreline is quite intricate. The Aegean pit plains are between mountain chains that usually progress in the east-west direction. And these pit plains have been progressing towards to sea by accumulation of silt that carried by rivers. So the ancient coastal cities and ports are left inside the land today.

Because of its physical elements, Aegean Region is divided into two parts, named; "Actual Aegea District" and "Inner Western Anatolia District". There's The Inner Western Anatolia

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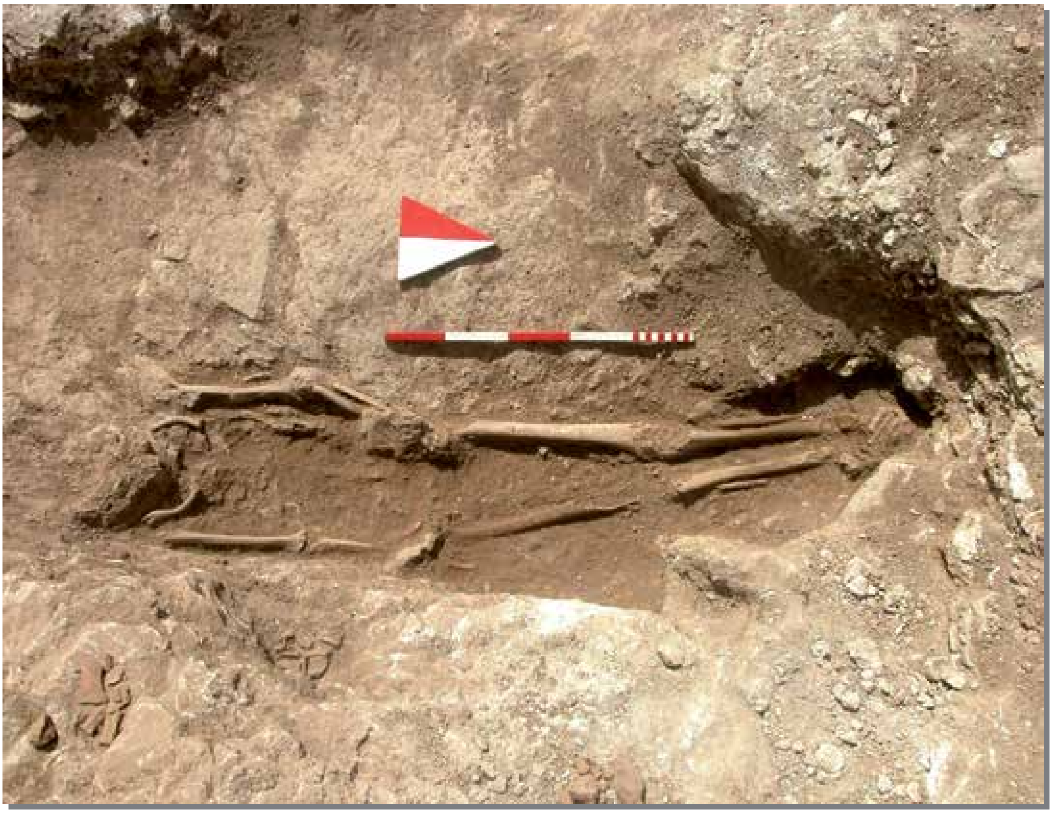

05BM29-S01 05BM29-S01

Fig. 1a-1b. 05BM29 number, were found in tombs dated to the Hellenistic period, length 1.36 m as measured skeletal north-south direction and lies parallel to the floor. Hand side of the skeleton was taken from the hip and right leg below the left foot is on the case thrown. Bone on the spinal cord, a standing bronze coins were found. Dated to the fourth century BC coins on the front of the commander's head in profile Persian, the rear side has a relief of the monument.

District between horst and graben structered Actual Aegea District and The Central Anatolia Region. This district has a high altitude and prevents costal climate entering further inland but doesn't prevent tranportation. Aegean Region is generally under the influence of Mediterranean Climate, i.e. mild, wet winters and hot, dry summers. There are differences in climate between Actual Aegea District and Inner Western Anatolia District. Actual Aegea District is closer to The Mediterranean Climate. On the other hand, Inner Western Anatolia District is colder than Actual Aegea District, because of being far from coasts and its physical elements.

Ancient Caria Region's frontier contains today's Muğla, Aydın provinces' major areas and Denizli province's western end segment. At the ancient period, Caria Region is surrounded by, Ionia and Lydia Regions in the north, Phrygia and Lycia Regions in the east and southeast (Prag J., Neave R., 1999). The west and the south boundary of Caria Region is The Aegean Sea. Carian frontiers are generally known but it's not known exactly or in the course of time, it had undergone many changes like many other ancient regions. Some of the the local kindoms before VII. Century B.C. are known at present, but much earlier period of Ancient Caria Region isn't known much. This region had experienced the control of Lydia state at VII. century B.C. and in the first half of VI. century B.C. After the victory of Ionia cities, The Persians under the command of Harpagos marched to Caria Region and at 545 B.C. Persians took this region under control. Heredot notifies that; except the Pedasians brief resistance, there hadn't been any resistance against Persians in Caria (Mansel A. F., 1988) and (Olmstead A. T., 1960). With this victory, Persian Satrapy period began in Caria and many satraps reigned in this Region. At the begining of V. century B.C., although Persians decisiveness to control the west Anatolia, after some discontentions and movements, a rebellion began in Ionia Region. At the first times, Caria didn't join this rebellion but later Caria joined too. Then rebellion had spread to a large area and continued many years. At 494 B.C. despite some great victories obtained and Ionia cities' heroic battles, rebellion failed.

At 478/477 B.C. Athens established "The Attika-Delos maritime alliance" with the main purpose to fight against Persians. Greek sacred island Delos was the center of this alliance and this alliance had established by taking an oath;"to contineu forever". After a while Caria joined this alliance too but this union couldn't contineu much. Many of Carian and Lycian cities left the alliance and other cities had begun thinking negative abaut this alliance. At the begining of The Peleponnes War, the alliance ended completely (Akurgal E., 2000). At 395 B.C. Caria, itself had turned into a satrapy and its administration had given an indigenous family. After satrap Hecatomnus (395-377 B.C.) Mausolus became the satrap of Caria. He married with his sister Artemisia (Whitley J., 2001). Mausolus expanded the domain of Caria and embraced Hellenic culture. He moved capital from Mylasa to Halicarnassus and expanded the city within Greek style. He brought sculptors and architects to make Hellen culture dominant in the other cities of Caria too. After his death a monumental shrine, called Mausoleum, built by his wife Artemisia. This monumental shrine is known, the seven wonders of the ancient world (Tekin, 2007). In Roman Empire, emperors Augustus's and Hadrianus's monumental shrines were also called Mausoleum so, this shows the influence of Mausoleum of Mausolus in ancient world (Whitley J., 2001). At 353 B.C. Artemisia took over the sovereignty of Caria after the death of her husband Mausolos. After Artemisia, Hidrieos and then Hecatomnos's daughter Ada ruled Caria. Ada overthrown and exiled by Pixodaros, then Pixodaros began to reign Caria. After Pixodaros, Orontobates began to rule Caria. At 334 B.C.

Alexander the Great seized Caria Region and gave the sovereignty to Ada again. The Dominance of Seleucid Empire began in Caria Region after Alexander the Great's death. At 180 B.C. Caria incorporated into the mainland of Pergamon Kingdom. At 133 B.C. this region became a part of the Roman Empire's Asia Province.

In a big probability, in the second half of II. thousand B.C., "Karkiša-Karakiša" in the Hittites' texts and at I. thousand B.C., "Karka" in persians' texts, belons to Carians. Discutions abaut the origin of "Car" people who named "Caria" hasn't ended. They were bleiving that they were the natives of Anatolia and Lydians, Mysians were their relatives (Prag J., Neave R., 1999). Heredotus and some Greek writers had reported that, Carians were Lelegian origined people and they had migrated to west Anatolia from Greek islands. Heredotus had written such: "Carians had come to mainlands from islands. Formerly, they were living in the islands with the origin of Lelegian and their nationality was Minoan. Much later Dorians and Ionians sent out the Carians from islands, thus the Carians went to mainlands. This is what the Gretans tell about Carians, but Carians themselves doesn't accept this, they say that they are the natives of mainland and they have been having the current name ever. They show a very old temple in Mylasa belongs to Zeus Carios that they accept only Mysians and Lydians to this temple because of being brother nations (Whitley J., 2001)

Athenios had written that: "In Philipus of Theangela's book which was about Carians and Lelegs, it was reported that Lelegs were used as slaves by Carians. Geographer Strabon had written the "Car" people as the most former nation of Greece, in Epidaurus, Hermione[1]. Pavsanias, who was a geographer and a traveller, had indicated that one of the Megaran castle's name was "Caria".

Greek had known some nations had lived in Anatolia before them, but they didn't have a clear view on this issue. Today, some academics argue the hypothesis which's main idea is; The "Car" people can be the continuation of Luwians. But the Luwian language which is a member of Indo-European languages family, never match with Carian place names and Carian religion. Carians' consideration about the "double axe" symbol and in the second half of II. thousand B.C. Gretans' usage of this symbol, attracts the attentions on this matching. Carians had a peculiar language and the studies are still going on about the origins of this language. In Ancient Greek epic poet Homer's Lliad, Carians had written thus: People with a coarse language (different from Greek language) . Carian alphabet was similiar to Phoenician alphabet and had between letters 30-37 (Whitley J., 2001).

Carians were qualified as warrior people. They were using crested helmet and carrying handled shield which can be hung on shoulder. They were the first people who were decorating external surfaces of their shields with pictures. And sometimes they were mercenaries in the armies of other states. In his lliad, Homer had written thus: Listen, let me tell you the most accurate, there are the Carians who are close the shore, there are the Paions who have curved springs, and the Lelegians, the Cauconians, divine Pelasgians, Lycians and Mysians are at around Thymbre, Phrygians, there are the Maionians too who fights with horse carts. And Strabon had written about Carians this: "Some authors attracts the attention to Carians' handled shields, shields decorated with symbols and crests which all called Carian, to indicate their enthusiasm for military. İn this topic at least Anacreon says so:"Come, pass your arm into the handle of the shield which is an invention of Carians." And Alcaios writes:"Caria by shaking crests (Güngördü E., 2003). At the ancient period, livestock production was constituting a large portion of the total production in Caria. Cereal was being produced in the valleys and high plateaus. Alabanda District's sulphur was being used during the cereal production for disinfecting.

Olive and fig production was widespread in the region. Olive production produced much in the valley Maindros and its coastal section where the mediterranean climate is seen. At IV. century B.C., the quality of Carian olive oil was being talked even in Athens. Strabon mentioned about Carian Antiocheia's dried figs called "trifoliate". Furthermore, it's known that dried fig was an important export of ancient Caria Region and it was being exported to Egypt and Italy by ships in large quantities. In addition, viticulture and as a result wine and vinegar production, cabbage and herbs production, reed production used in manufacturing pen, various oils production and amphora manufacturing that used for transporting and storing, had been produced in ancient Caria. And also beekeeping, fishing, marble production and maritime trade had an important place in the economy of Caria.

The city of Stratonicea was one of the ancient cities in Caria Region as; Tralleis, Coscinia, Euhippe, Orthosia, Alinda, Alabanda, Antiocheia, Mylasa, Halicarnassus and Caunos. History of Stratonicea city and the sacred places connected to Stratonicea city is quite old. Ancient sources transfers that, at 270 B.C. Stratonicea city was being founded by Seleucid king I. Antiochus in the name of his wife, queen Stratonice. Queen Streatonice was the stepmother of I. Antiochus before he married with her. Strabon had written abaut Stratonicea city thus: Miletus Poseidon is arrived after Iasus. There are three cities in the interior to sign: Mylasa, Stratonicea and Alabanda. The others are depend on these or depend on the other coastal citie (Prag J., Neave R., 1999). Stratonicea City was being founded in an old Carian town called Chrysauris or Idrias or around it. In the early of II. century B.C. Rhodes dominance began in this city but at 167 B.C. it became independent again. Stratonicea City had an automnous and rich position in the Roman Empire era. After this, in the christianity period, Stratonicea City became a bishop center, depending on Aphrodisias Metropolitan. Some important structures of the Stratonicea city were bouleuterion, gymsasion that was being built in the middle of II. century B.C., theatre, the Roman gate which was the beginning of the holy way to Lagina.

1.2 The archaeology of human skeletal remains

After the archaeological works was led by Osman Hamdi at 1891-1892, excavation and restoration works have been continue by an archaeological research team led by Prof. Dr. Ahmet Tırpan since 1993, in The Lagina Hekate's Temenos The propylon is at the southwest corner in The Lagina Hekate's Temenos. The stoa lays along the pribolos, at the northwest of the propylon (Prag J., Neave R., 1999). There's a water reservoir, almost 150 metres away from the southwest of the propylon. İn the Temenos, there's an oval pool which has an approximately 10 metres diameter. Lagina's ancient inscriptions are talking about a sacred pool. In a big probability, revealed out and restored pool must be this sacred pool. The altar, which is in The Lagina Hekate's Temenos is at the south Hekate's temple and also at the east of propylon. The Börükçü Location is at 100 metres east of the holy way which is between Stratonicea and The Lagina Hekate's Temenos Excavations of Börükçü Location are being made by an excavation team led by Prof. Dr. Ahmet Tırpan from Selçuk University, Archaeological Department.

Between 1967-1970, Prof. Dr. Yusuf Boysal found materials that proves an uninterrupted settlement has been seeing in Lagina and araund since early bronze age. Late geometric

Fig. 2. 06BM02 numbered, dated to the Classical period in the grave, above ground level at a depth of 0.75 m is revealed burial inhumation style. Skeleton of the east-west, head north of the way and placed in the style of Hocker was buried were found.

period was saw in Aldağ and Bozukbağ, classical settlement and tombs was found in Emirler. An archaic period settlement was revealed and many terra cotta materials was found in Hacıbayramlar mound. A sacred area that belongs to Apollon and Artemis and tombs used in classical period was revealed by excavations in Koranza. The Börükçü's finds indicates that the Börükçü Location belongs to the same period as the settlements above. It was determined that an intensive habitation existed from VII. century B.C. to II. century B.C.

At the excavations of Börükçü, abundance of weaving workshops and olive oil workshops attracted the attention. Researches' and excavations' results, distance to other places, owned roads, water sources and wells araund, have shown that, Börükçü Location was contemporary with other settlements but different from them (Mansel A. F., 1988).

Remnants of the water structures were found in Börükçü Location. And also reconstructed structures were revealed which were belonged to Ottaman period. archaic period's fountain which is at the roadside of the holy way proves that this way was quite old. A natural inclination was converted to a terrace so this revised field was used to place the buildings in Börükçü. In some of the terraces only graves was found. Ways formed with steps and ramp formed paths revealed in this sloping field. Börükçü Location has an apperance as industrial and manufacturing spaces and cemeteries. Certain professional groups was collected in

Fig. 3. 06BM05 numbered graves, with a north-south direction, lattice-type boats have been built in the inside 1.40 m in length. Hocker style of the skeleton was buried east-west and head north toward where it was deposited were identified. Bone anatomy and morphology after examining the molecular work, dated to the Classical period in the 10-12 age burial belongs to a daughter.

certain areas. Most revealed archeaological finds are olive oil workshops. Also organic, glass, metal finds revealed too (Mansel A. F., 1988). Graves that belongs to interval from geometric period to Roman period were revealed in Börükçü Location. Many of them were from archaic and classical period. Hellenistic and Roman graves were revealed too. Many skeletons were revealed during the excavations of graves (Güleç E. et.al., 2006).

Fig. 4. 06BM09 numbered north-south direction in the grave with oyğu boat, 0.05 m at a depth of skull and skeleton belonging to the same 0:20 m. were uncovered at a depth of body. Skeletal north-south direction have been credited with extending the right arm from the elbow was extended slightly broken. The skull is looking toward the southwest.

2. Genetic analysis of aged skeletal material

2.1 Material and methods

2.1.1 Collection of samples

DNA isolation a subset of 100 bones from the total set obtained from Mugla in Turkey was analyzed in this study. Upon recovery of the skeletal remains, the bones were described in terms of sex, estimated age, and some of the skeletal weathering stages. Existing techniques were refined by targeted primer design focusing on a DNA fragment shorter than 200 bp, an approach allowing us to identify up to all bone samples at the same time. In order to allow

Fig. 5. 06BM13 grave number, type and north-south direction are **oyğu boat**. A part of the east and west walls of the tomb wall **oygu soil,** other aspects are carved into the rock. One regular burial in tombs and 11 skulls were recovered. However, the irregular parts and skeleton skull burial uncovered determination could be made.

ratings on individual bones, a new staging system was developed at Archeometry-Biotechnology Laboratory in Selcuk University, Science Faculty, and assigned as period or era each bone based on visual inspection for the DNA study. The bone samples of more than 100 individuals were chosen to study the genetics of this skeletal population. In addition to numerous human skeletons, the cave contains bones from some autochthonous animal species. All skeletal material was wrapped in aluminum foil, placed in plastic bags, and labeled. Earlier analysis showed that the state of DNA preservation in the bones is excellent, mainly due to the low temperature prevailing in the cave since prehistoric times (Burger et al., 1999). Eleven animal bone samples were chosen for aDNA analysis.

2.1.2 Contamination controls

All DNA extractions and PCR setups were carried out in a dedicated ancient DNA laboratory following the suggested protocols for contamination controls and detections (Herrmann and Hummel 1994). All bone samples and extraction reagents were exposed to UV irradiation. Furthermore, all post-extraction manipulations were conducted by H.C.Vural. Disposable laboratory coats, gloves, fitler tips, dedicated pipets, and disposable laboratory ware were used throughout the analyses. Benches and equipment were

Fig. 6a-6b. Geometric period is dated 06BM18 numbered graves. Type of boat was built in marble tomb. Been left entirely as a rough floor sculpture made of marble in a single block. In the eastern side of the head of the skeleton in the form of slight increase has been given the bag.

frequently treated with a 20% bleach solution. Sterile water was aliquoted and irradiated by placing the tubes directly on a light source of 254 nm for 30 min (Sarkar and Sommer, 1990). Two extractions were prepared for each bone sample by two researchers to test reproducibility and aDNA quality. The amount of contaminant DNA in this study was probably not significant.

2.1.3 Decalsification of bone and genomic DNA extraction

Extraction of DNA was carried out using the laboratory handling and cleaning protocol (Römpler H., et. al., 2006). After cleaning of bone with chromatographic water, small piece of ancient bones were ground to powder with a mixer mill. Aliquots of the powder were subjected to a calsification method. 150 mg of bone powder was extracted with 0.7 ml of 0.5 M EDTA (pH 8.3) for 48 hours at 56 ^{o}C. After addition of 1 U of proteinase K, solution of bone was incubated at 37^{o}C. Genomic DNA from supernatant was extracted automatically by using EZ1 Automatic DNA Isolation System (Qiagen, Germany) with investgator kit (Qiagen, Ilden, Germany) from ancient bones. Amount and purity of extracted DNA from ancient bones were measured by Shimadzu UV 1700 Spectrophotometer. Extracted DNA was then stored at -20 °C until assay for the amelogenin was performed (Figure 7).

2.1.4 Sample preparation and DNA isolation

Approximately 1 cm^3 of bone was cut from the source section using a Dremel MultiPro tool and was collected in a tube. Samples were then immersed in filter-sterilized wash buffer (1% SDS, 25 mM EDTA) and 0.1 mg/ml proteinase K, and incubated for one hour at room temperature. Following the incubation, the wash buffer was poured off and each sample was washed with 1ml of sterile dH_2O six consecutive times. Samples were allowed to air dry. Bone powder from the dried bone samples was collected in one of two ways. Bone was either ground to powder drilled using a the Dremel tool both fitted with 1/16 microfuge tube and weighed. Four hundred microliters of digestion buffer (20 mM Tris, 100 mM EDTA, 0.1% SDS) and 0.4 mg/ml proteinase K was added to each ground bone sample and incubated overnight at 56 ^{o}C. A standard phenol/chloroform organic extraction was

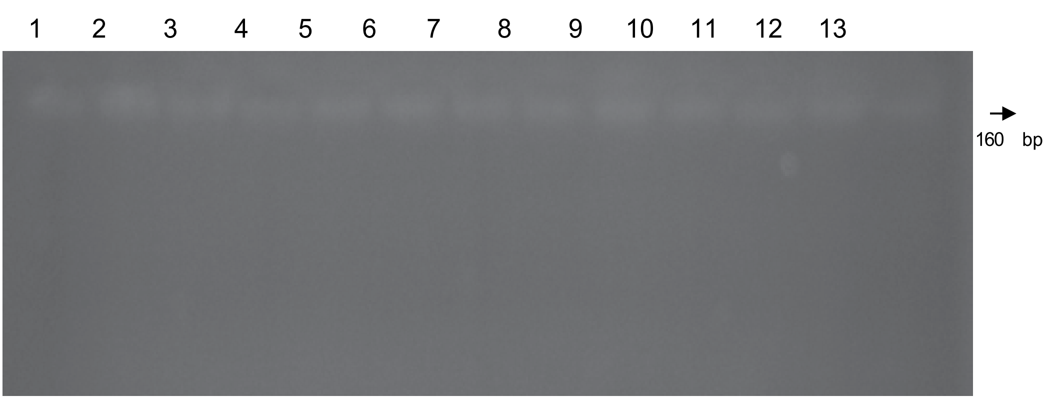

Fig. 7. Genomic DNA was isolaled from fossil bone tissue remains, respectively, Lane 1, 2, 3-13 with Bio Robot EZ1. aDNA samples submitted to electrophoresis in 1% agarose gel. Sample codes, respectively, 05BM13, 05BM22, 06BM09, 05BM29, 06BM40, 05BM21, 07BM05, 05BM23, 06BM39, 07BM13, 05BM64, 05BM30, 05BM106 illustrated in the table 1.

performed on each of the samples. DNAs were precipitated using 3M sodium acetate and 95% ethanol, vacuum dried, and resuspended in TE buffer (10 mM Tris, 1 mM EDTA) based on the original mass of the bone powder. Furthermore, After addition of proteinase K, solution of bone was incubated at 37 °C. Genomic DNA from supernatant was extracted automatically by using EZ1 Automatic Nucleic Acid Isolation System (Qiagen, Germany) with investigator kit (Qiagen, Ilden, Germany) from ancient bones. Amount and purity of extracted DNA from ancient bones were measured by Spectrophotometer. In addition to spectrophotometric measurement, extracted DNA was applied to 1 % agarose gel, stained and imaged under ultraviolet (UV) irradiation. As a result, 50 ng pure DNA was extracted from ancient bones. Several precautions were taken to prevent contamination during the experiments. Grinders and drills used to generate bone powder were washed with 70% EtOH and 10% bleach, and were UV irradiated between each sample prep. Pre-amplification and post-amplification steps were carried out in separate rooms. Finally, negative controls and reagent blanks were included in all experiments.

2.1.5 Ancient DNA Quantity

Genomic DNAs isolated from fossil bone remains were showed by spectrophotometric analysis. DNA quality and concentrations were evaluated nearly 1.8. Genomic DNA from supernatant was extracted automatically by using EZ1 Automatic Nucleic Acid Isolation System (Qiagen, Germany) with investigator kit (Qiagen, Ilden, Germany) from ancient bones. Amount and purity of extracted DNA from ancient bones were measured by Spectrophotometer and then extracted DNA was applied to 1 % agarose gel, stained and imaged under ultraviolet (UV) irradiation. As a result, 50 ng pure DNA was extracted from ancient bones. Several precautions were taken to prevent contamination during the experiments. EZ1 Nucleic acid isolation method; This tehnique is quite useful for high yield and quality of aDNA isolation from human skeletal remains. In this methods, no further purification was needed for molecular analysis.

2.2 PCR amplıfıcatıon

2.2.1 Polymerase chain reaction (PCR) amplification of species determination

Molecular archaeology is an emergent field in archaeology that has been brought about by the advancements of the recognition and understanding of DNA. This new developing branch of archaeology focuses on the acquisition of either DNA or mtDNA (mitochondrial DNA) and being able to determine species of natural archaeological finds as well as determine blood lines and/or sex of animal or human remains. These DNA. As our technology advances as well as our knowledge of the DNA itself our understanding of ancient peoples, plants, and animals, will allow us a biological window into their lives.

A 200 bp segment of the mitochondrial cytochrome b gene was amplified using the primers;

CB7u: 5′- GCGTACGCAATCTTACGATCAA-‘3 and

CB7l: 5′-CTGGCCTCCAATTCATGTGAG-‘3.

The PCRs were carried out in 50 ml of 60 mM KCl; 12 mM TrisHCl; 2.5 mM $MgCl_2$; 150 mM dNTPs; 0.18 mM each primer; and 2U AmpliTaq Gold (Applied Biosystems), and 0.2

microliter BSA. The temperature profile was 95 °C for 4 min, 95 °C for 30 s, 54 °C for 1 min, and 72 °C for 30 s, for 40 cycles and 72 °C 5 min.

2.2.2 Polymerase Chain Reaction (PCR) amplification of sex determination

Ancient DNA (aDNA) sex identification was used to aid in the verification of individual identification through comparisons to historical documentation of burials and small sizes human fossil skeletal bones estimations of sex. The PCR reaction is manipulated through primer design to favour the amplification of the Y fragment over the X fragment thus minimizing the occurrence of 'false female' results for male samples (Faerman M., et.al., 1995). In this study, the primers for PCR amplifications used are as follows:

Sequence Amel-A (5'- CCCTGGGCTCTGTAAAGAATAGTG -3')

Sequence Amel-B (5'- ATCAGAGCTTAAACTGGGAAGCTG -3')

These primers amplify a small region in intron 1 of the amelogenin gene that encompasses a deletion polymorphism giving a product of 106 bp for the X allele and a product of 112 bp for the Y allele, so both products should be present in males, but only one in females. 0,5 mg genomic DNA was amplified in a mixture composed of 5 µL 10XPCR Taq buffer (pH 8.8), 2 mM $MgCl_2$, and 10 mM dNTPs (dGTP, dATP, dTTP, dCTP) at each, 0.5 mM of each primer, and 0.3 U DreamTaq polymerase (Advanced Biotechnologies Ltd., Fermantase Life Science). Amplification was submitted to denaturation at 94 °C for 10 min, 50 amplification cycles with denaturation at 94 °C for 30 s, annealing at 60 °C for 10 min and extension at 72 °C for 1 min in a thermocycler (Biorad, Germany). PCR blank reactions did not show spot contamination during the collection of the data. As as result, sex gender of ancient human bones was determined related with DNA fragments with different length of base pair as male and female. Studies of ancient DNA from museum and fossil samples can provide valuable information toward a better understanding of degraded DNA preserved in postmortem specimens. This information helps to improve molecular techniques designed to recover and analyze old DNA to be used for evolutionary studies and as well as for forensic analysis. Our comparison of commonly used ancient DNA extraction techniques based on glass bead-based methods usually cause noticeable loss of genomic DNA during purification. We also found that the choice of extraction buffer may be critical to the success of recovering endogenous DNA from different types of tissue (for example, soft tissue, and bone material) preserved under different physical and chemical conditions. We have obtained results only either at the lowest or at the highest amounts of aDNA extracts analyzed. Multiple steps were taken during DNA amplification procedures to decrease the effects of PCR inhibitors found in the amplification reaction. For fossil material, PCR mixes were set up in dedicated hood in the ancient DNA laboratory using appropriate contamination control procedures and then brought to the main molecular genetics or archaeometry laboratory for thermocyling. For all ancient and modern reactions, amplification products were not detected in the negative extraction (Figure 8).

2.2.3 Negative control amplification

An increase of PCR cycle may increase the risk of minute amount of modern DNA contamination in the resulting in DNA amplification. In this study, potential modern DNA contamination was assessed based on the possible amplification produced in the negative

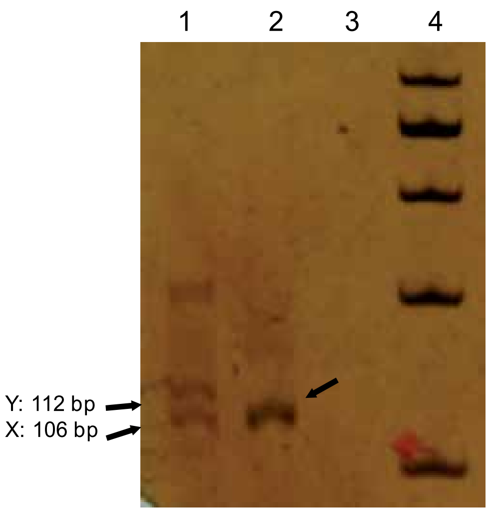

Fig. 8. Polyacrilamide gel electrophoresis of PCR products in male and female fossil DNA templates or 106/112 bp amelogenin gene PCR products. Respectively, Lanes 1-4, Lane 1 : amelogenin male sample 106/112 bp, and lane 2: amelogenin female PCR fossil sample 106 bp, Lane 3 negative control water blank or none DNA, Lane 4, 100 bp ladder size standard marker.

control extraction. The negative control extraction is a sample that contains everything used during DNA extractions procedure followed by PCR amplifications except the powdered ancient bone of the respective sample was substituted with deionized water (Yang et al., 2003; Yang et al., 1998; Pääbo S., 1985; Pääbo S., 1989; Pääbo S., et.al., 2004). An indication that a very low level or non-existence of modern DNA contamination as well as specificity of the primers and sensitivity of PCR amplifications procedures that had been utilized in this study.

2.2.4 Gel electrophoresis of PCR amplicons

PCR product was separated by electrophoresis on 2 % agarose gel in 1XTAE buffer (45 Mm Tris, 1 mM EDTA, pH 8), stained with ethidium bromide. In addition to electrophoresis of agarose gel, PCR products were completely loaded in 1,5 % acrylamide:bisacrylamide gels, stained with $Ag(NO_3)$ and agarose gel systems were visualized under UV, and Poly Acrylamide Gel Electrophoresis systems were illuminated from above using an white fluorescent light source. We isolated the samples from a histological section of the burial place material and repeated the procedure three times. In each of the three repeated approaches, amelogenin could be amplified in all samples showing a successful DNA extraction. Amplification products generally showed weak signals in agarose gel analysis, presumably due to low amount of extracted material. Nevertheless, high-resolution polyacrylamide gel electrophoresis demonstrated that the ancient DNA is derived from a female individual, as in all amelogenin PCR products only the X-Chromosome specific 106 bp fragment was visualized

2.2.5 Determining using RT-QPCR of aDNA quality

2 µl of DNA and 3 µl primer mix was used in a final volume of 20 µl according to the manufacturer's directions. LightCycler amplification and Real-Time QPCR detection with

SYBR Green was done as described by the supplier using the Fast Start DNA Master SYBR Green I (Roche Applied Science) with 8 mM $MgCl_2$ in the reaction mixture. Amplification conditions were 95°C for 10 min and 45 cycles, each cycle at 95 °C for 10 s, 56 °C for 10 s and 72 °C for 20 s. The LightCycler amplification and Real-Time PCR detection with fluorescence labeled hybridisation probes was done following the protocol provided either for the LightCycler. Positive and neagtive controls were included in all reactions (Figure 9).

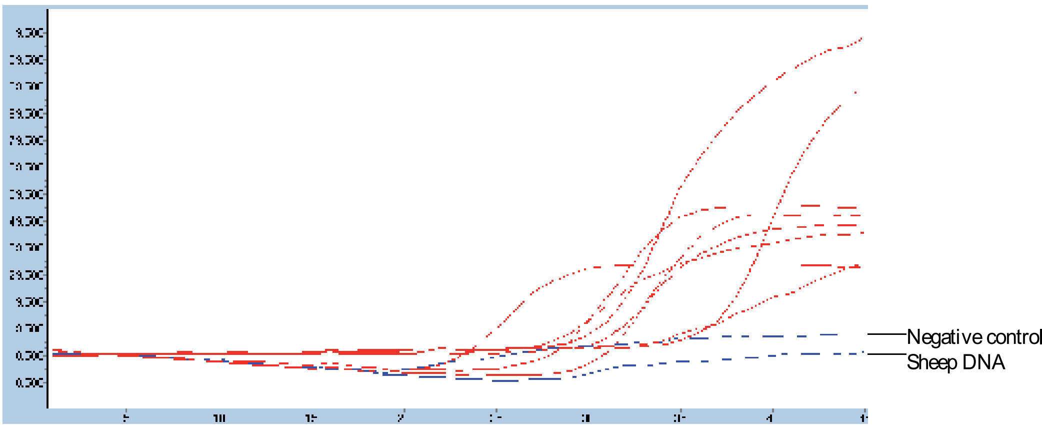

Fig. 9. Determination of species and quantification in ancient DNA isolated from burial remanis using RT-QPCR

2.2.6 Statistical analyses

Statistical analyses were performed in Microsoft Excel. Single factor Analysis of Variance (ANOVA) was used to examine the effect of weathering stage, sex, age, and bone type on the DNA quantity and quality results from the Voegtly bone samples. ANOVA was also used to examine the effect of skeletal weathering on amplification success of multiple bones from a single individual, as well as the effect of skeletal weathering, bone weathering, and bone type on amplicon size. DNA quantities for sex and age statistics were averaged when multiple bones originated from a single individual. Amplification success vs. DNA quantity was examined using a t-test with equal variance assumed. The effect of PCR inhibition during QPCR on spiked samples with and without anti-inhibitory addition (BSA or commercial enhancer) was examined using a two-tailed paired t-test. In all cases results were considered significant at $p<0.05$.

3. Result and discussion

Ancient DNA (aDNA) and proteins provide valuable clues to questions about nutrition, domestication, population genetics, kinship reconstruction and human evolution. By investigating ancient biomolecules with the use of newer molecular biology techniques and robust procedures of inference genetic data from both archaeological remains and living populations, molecular anthropology has begun to draw more informed conclusions about human evolutionary history. Ancient DNA can shed light on the relationships between populations and how they dispersed through the ancient world and validate evolutionary hypotheses inferred from archaeological, linguistic and historical records. Also, aDNA can help solve archaeological puzzles and build up a picture of the demography of past societies by identifying the sex of skeletons that cannot be determined by osteology and to assess the degree of maternal relatedness in multiple burials (Hagelberg et.al., 1989 and Hagelberg et.al., 1991). The remarkable thing about sexual differentiation is its diversity. That males are the heterogametic sex, larger than females, more aggressive than females, and the 'non-default' mode of sexual differentiation are concepts not valid throughout most of the animal kingdom. Sex chromosomes are characteristic only of land animals. In birds, the heterogametic sex is female and the sex chromosomes are not related to those of mammals. External factors such as temperature determine sex in lower vertebrates, and there is no similarity among sex-determining genes of different species (Delgado S. et.al., 2001).

Sex determination using DNA can be valuable for both forensic and archaeological research. Standard osteological methods, however, are less expensive and more rapid when the skeletons of adults are complete and the bones are in good shape. For archaeological research, the use of DNA to determine the sex of juveniles provides an opportunity to extend traditional mortuary analyses through the inclusion of children of known sex (Delgado S., et. al., 2005). Molecular analyses can also address questions regarding the sex of adult skeletons that fall in the overlapping range of male and female morphological variation. By using this method in combination with routine genotyping more information about a material under investigation can be obtained. In addition, the amplification of the AMEL gene can also be used as an internal control. In conclusion our findings show that the PCR assay based on the AMEL gene is reliable for sex identification of fossil bone remains in Koranza and Necropal area are situated in the region of modern city Mugla in Turkey. The advantage of this assay is that neither additional control amplicons with a second locus specific autosomal primer pair nor restriction endonuclease steps are necessary for sex determination and control of the PCR reaction. However, despite these objections and characteristic features of aDNA mentioned above, it can be shown that the molecular approach is the most powerful tool for the identification and reconstruction of kinship of skeletal human remains of archaeological excavations. These validated protocols allow the assignment of unknown men to every major branch of the global human population. Hopefully these protocols will encourage new research groups to implement a broader range of anthropological surveys, archaeological excavations and archaeometry studies etc. Furthermore, there is not the only parameter that determines the overall specificity and sensitivity of the PCR reaction; primer design and optimization of PCR parameters also have a profound effect. Results of our present work demonstrate that the primers utilised in this test (Amel A and Amel B) provide robust and highly efficient amplification. It is envisaged that this test will prove to be an advantageous addition to other methods of forensic DNA analysis.

The size difference between the amplified segments of X and Y copy of AMG was not big enough to be detected clearly on agarose or polyacrylamide gel electrophoresis (PAGE). For that reason, we searched the list of commercial restriction enzymes and find a new enzyme capable of recognizing and cleaving the PCR product for Y copy of AMG, but not the X copy. The molecular determination of gender based on AMG PCR/Restriction enzyme digestion was compared with anthropometric reports. At the beginning stages of the project the molecular sex determination was both different from anthropometric reports and also not reproducible (Mitchell R.J., et.al., 2006). However, after optimizing the procedure and setting guidelines to eliminate the risk of contamination we were able to have reliable and reproducible molecular sex determination.

DNA originating from individuals from major phyla of vertebrates was isolated by the organic method from various specimens. Extracted DNA was subjected to PCR and direct cycle sequencing using a universal pair of primers. In order to evaluate the utility of this gene for discrimination of fosil bone remains as well as for exploring their phylogenetic relationships. These data show that the Cyt b gene is useful for phylogenetic study of fosil bone remains (human or animal materials) (Gill P., et.al., 1994).

Real-time PCR is now a common method for measuring gene expression, it is increasingly important for users to be aware of the numerous choices available in all aspects of this technology. Unlike traditional PCR, there are many complexities with real-time PCR that can affect overall results. However, with a well-designed experiment performed with the proper controls, real-time PCR can be one of the most sensitive, efficient, fast, and reproducible methods of measuring gene expression and DNA quantification. LightCycler Real-Time PCR using SYBR Green for detection was applied to quantify the actual amount of the prepared DNA. For every sample, a primer pair amplifying a single copy region of the genome was designed amelogenin primers. The specificity of the PCR reaction was tested after every run by determining the melting point of the respective product. All reaction products showed single peaks and the product size was verified to be in the expected range by gel electrophoresis.

As our technology advances as well as our knowledge of the DNA itself our understanding of ancient peoples, plants, and animals, will allow us a biological window into their lives. Molecular archaeology can in time, as our knowledge and technology increases, provide us with the ability to learn more about the life of ancient individuals. It can be seen how modern humans may differ from our ancestors or what plants and animals may have existed at the time and been utilized by them, which can be found by exploring what their tools and clothing or other artifacts were constructed out of. Not every area of the world is accessible to this technology due to the variety of climates, but in those areas where suitable DNA samples may be taken a whole new knowledge of the ancient culture under examination may be gained.

4. Acknowledgment

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Experimental Archaeology at L'Esquerda – Crops, Storage, Metalcraft and Earthworks in Mediaeval and Ancient Times

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1. Introduction

The archaeological site of l'Esquerda is placed in the inlands of Catalonia, in the town of Roda de Ter, county of Osona, 70 Km north from Barcelona. The site occupies a big peninsula of 12 ha over the river Ter. It is situated in the intersection between a fertile and plane plateau called Plana de Vic, and some scarped and bushy mountains named "Les Guilleries", crossed by the river Ter on its way to Girona and the coast. The site is only accessible from the north face where the walls were built and its particular placement makes it be an outstanding strategic location in the inlands of Catalonia, with natural protection.

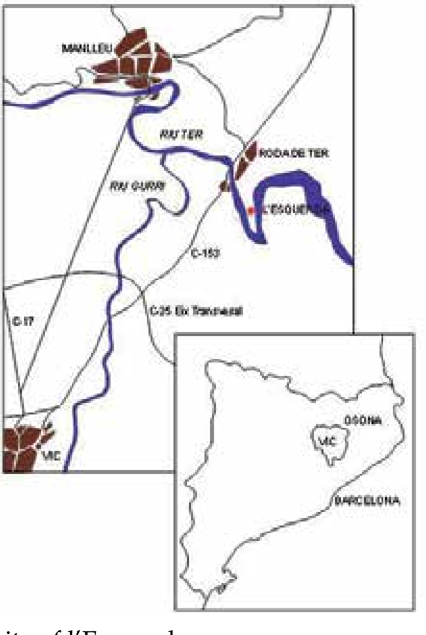

Fig. 1. Location map of the site of l'Esquerda

Fig. 2. Aerial view of the site of l'Esquerda, surrounded by the river Ter

The site was inhabited during a long period. The earliest evidences are dated back to late bronze-age, by some hand-made potteries. The hypothesis of an early Iberian phase has been recently established for the site (Rocafiguera-Ollich-Ocaña, 2011).

Later, in the 5th century BC, a strong *oppidum* was built there. The structure takes profit of the natural geology of the environment and a big wall was built in the northern face. It is a huge barrier-shaped wall, with two massive towers in its front. All the structure is made on coarse rough stones without mortar. From an archaeological insight of the destruction levels, the highest part of the structure is presumed have been built in clay.

The fortification was the main pattern of urbanism in the whole site along the centuries. Between the two entrance towers, there is a NS two-metre-wide street, with different levels of pavements. The street and walls set up a reticular plan that is followed until 13th century AD in the site (Ollich-Rocafiguera, 2002). This Iberian *oppidum* lasted until the end of the 3rd century BC. Some new constructions or architectural changes in the site have been discovered for this time. The main one corresponds to the end of the fortress. In this latest period, all the defences were strengthened: some gates were closed, some *armora* were built and even the street could have been closed by a slope wall in stone (Ollich-Rocafiguera, 2001). All of these changes seem to be due to the general instability of the Iberian Peninsula in late 3rd and early 2nd century BC, caused by Punic wars, the Roman victory and the indigenous revolutions in the earliest roman period, in which *Ausetani* took regularly part.

At the end of this convulse period, in early 2nd century BC, the *oppidum* of l'Esquerda was completely destroyed. Even though there are no evidences of direct fighting, all the walls, towers and other defence structures were totally destroyed and became completely unusable. Afterwards, a little late Iberian town was built over the ruins, taking profit of the same prime materials. This little town with small houses, and a possible new wall weaker than the primitive one, was active during the 2nd and 1st century BC. Little archaeological information has remained from this period because of the modern agrarian fieldworks carried out in the site from 17th century, which have seriously damaged these archaeological levels.

During the Roman period there was not any occupation in the site that might have been in ruins by this time. Meanwhile, a new roman city, *Auso*, was growing 5 km southwest – where now is Vic (the mediaeval *Vicus Ausonensis*), the new capital of the county.

L'Esquerda site was newly occupied during Visigothic times (from 5th to 7th centuries AD). Presumably this new occupation was due to the instability in the area caused by the crisis of Roman Empire. A big silo field, dated by Radiocarbon from those times, has been found in the backside od the old walls. At the present time, 66 silos have been dug, but the silo field seems to be much bigger. The silos were built inside the Iberian levels, and only their bottom part has remained. These pits were used for grain storage, as palaeocarpological analysis reveals. In some of them the covering rounded-shape stone has also been recovered. However, they were used as garbage holes at last, when being out of use for storage. They are all filled with stones, pottery and specially with a lot of fauna bones recently studied (Valenzuela, 2008). This silo field seems to have been in use for a long time, since there are some structures built over some others which were already destroyed, and it seems to correspond with a visigothic settlement, probably the *Rota Civitas* mentioned in written sources (Ollich, 2000)

In late 8th century BC the place of l'Esquerda was occupied by Frank Carolingians in order to establish a frontier in the river Ter against Muslims. They tried to stop them going to northern Europe through Pyrenean mountains. At l'Esquerda, Frank people probably reused the ancient Iberian and Visighotic stone-made fortresses, but they also built some new ones made with wood. The post-holes and spaces carved in the rock seem to correspond to this phase, when some round wooden towers were built to control the river and the land around it. L'Esquerda is really well located, with a complete view from the south to the Pyrenean Mountains and the way to the north. Also, in this point, the river goes to the east, to Girona and the coast. So, for Carolingians was so critical to control this place, to defend Girona (that was given itself to Carolingian Empire of Charles the Great in 785 AD) and to stop the Muslim armies in their way to Narbonne. L'Esquerda was called *Rota civitas*, using the old visigothic name.

All these first Carolingian wooden structures at l'Esquerda were destroyed in 826 AD, during the rebellion of Aissó, a pro-muslim indigenous chief that tried to get out Carolingian, occupied the site and controlled the river until 875 AD. At that moment both the county of Osona and the bishopric of Vic were reorganised. Documentary evidences mention a first church in l'Esquerda in 927 AD, and archaeological works had shown the remains of its *presbiterium* and its stone altar. This high-mediaeval church was surrounded by a necropolis with anthropomorphic graves. Some little stone houses gradually grew around it too (Ollich, 2006).

At some point between 10th and 11th century, l'Esquerda began a complete urban reform and a new church, consecrated around 1040 AD, was built. It followed the new norms of

Romanesque art that bishop Oliba of Vic had introduced in the region. At the same time, some new stone houses were built inside the *sacraria*, a sacred space of 30 meters around the church in order to profit of its protection. They used both stone and clay for walls, with wood timbers and tiles for roofs. Archaeological works show this was a very good period for l'Esquerda: all the town was growing around the church, with a square and a long street with stone buildings in each side, a smithy, a granary, some water tanks and other structures. This low-mediaeval village expanded until last 13th century, when some problems of agricultural production began, and some fights between the feudal lord of Cabrera and the King took place. In 1314, during one of these fights l'Esquerda was absolutely destroyed and its population moved to the new parish near the bridge (Ollich et al., 1995)

2. Principles of experimental archaeology

The discovery of a 13th century granary belonging to the latest period of the mediaeval village of l'Esquerda, and the palaeocarpological data obtained from the sediment found inside opened the chance to research about experimental archaeology. The first step of the project was to get in touch with Dr. Peter J. Reynolds, director of the Butser Ancient Farm (Petersfield, England), a research centre devoted to experimental archaeology. In collaboration with Butser Ancient Farm members, the basis of the project of l'Esquerda were established, together with the theoretical principles that would be followed in the site (Reynolds, 1988, 1996).

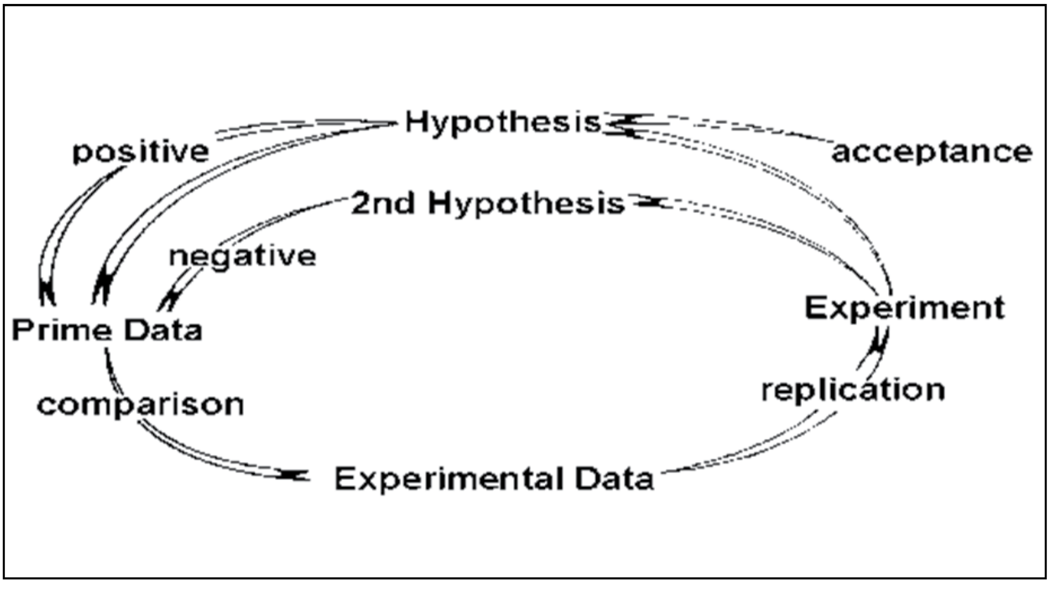

Fig. 3. Principles of Experimental Archaeology, by P.J.Reynolds

Thereby, in the site of l'Esquerda, experimental archaeology was directly learnt from Dr. Peter J. Reynolds who became a member of the research team. Experimental archaeology is a scientific research method to get experimental evidences by experimenting to verify or deny archaeological hypotheses. The methodology is always based in experiment - an organised in a systematic way of proving or disproving a specified hypothesis- that must be previously planned, and capable of replication. Hypotheses from archaeological data must be proved only by empirical data obtained through experimentation. In 1991, a long-term project of experimental archaeology was started in l'Esquerda. We named it LEAF Project. Since then, five three-year research projects have been carried, all of them funded by Spanish *Ministerio de Educación y Cultura (DGICYT Projects)*.

All the research works are carried on in the AREA (Archaeological Research Experimentation Area), a land in front of the site, specially consecrated to experiment in archaeology, that was gently given to us by the Town-Council of Roda de Ter. There is also a laboratory to work in. All together is used as an Open Air Area to research, to learn and to teach about experimental archaeology.

The first project, *Experimental archaeology, application to mediaeval Mediterranean agriculture* (DGICYT, PB90-0430*)*, aimed to establish the basis of a long-term agricultural study. The design of the experiments consisted on four fields where 3 year and 2 year rotation were studied, together with autumn and spring sawn. In the same project a haystack was built, and also two ditch-and-bank structures to study the processes of erosion and sedimentation.

The second project, carried out simultaneously with the agricultural one, was named *Experimental Archaeology. Storage constructions in Middle Ages* (DGICYT, PB94-0842), and had the goal of building an exact real-sized replica of a 13th century granary identified at the site, and some underground silos. The aim was also to solve a lot of questions about mediaeval framework and constructive techniques.

In the third project - *Experimental archaeology: Tools and agricultural techniques in Middle-Ages* (DGICYT, PB98-1241) - the aim was to deep insight all the necessary implements for the agricultural process, from the ploughing to the storage in granary and silos. This third project, together with the discovery of a blacksmith's in the mediaeval site, opened the need to learn more about metal craftwork. This was the most important goal in the fourth project: *Experimental Archaeology: technologies of metallurgical production in mediaeval agriculture* (DGICYT, HUM2004-5280/HIST). In this time an iron furnace was built and experimentally used, and also a bronze smelting kiln was built and tested.

Finally, the fifth project *Experimental Archaeology: ethnoarchaeological application to experimental agricultural processes in Middle Ages* (DGICYT, HAR2008-00871/HIST), wants to close the experimentation about the agricultural cycle and its ethnoarchaeological aspects. So, new experiments have been carried about building and burning haystacks, about evolution and reparation of agricultural structures, like the granary, the silos and the iron smith's, and also to food processing, with experiments of milling, and cooking bread in a hand-made bread oven.

Twenty years of experimental archaeology in l'Esquerda have given a great amount of results, and also some new solutions for the interpretation of archaeological data in the site. So, experimentation has been demonstrated as a very important way to the knowledge of some aspects of the history that otherwise would have been impossible to clarify.

3. The LEAF agricultural project: 20 years of experimental crops

Among all the experiments carried out at l'Esquerda, the growing of ancient species archaeologically registered in the site is the most important one. The origin of this

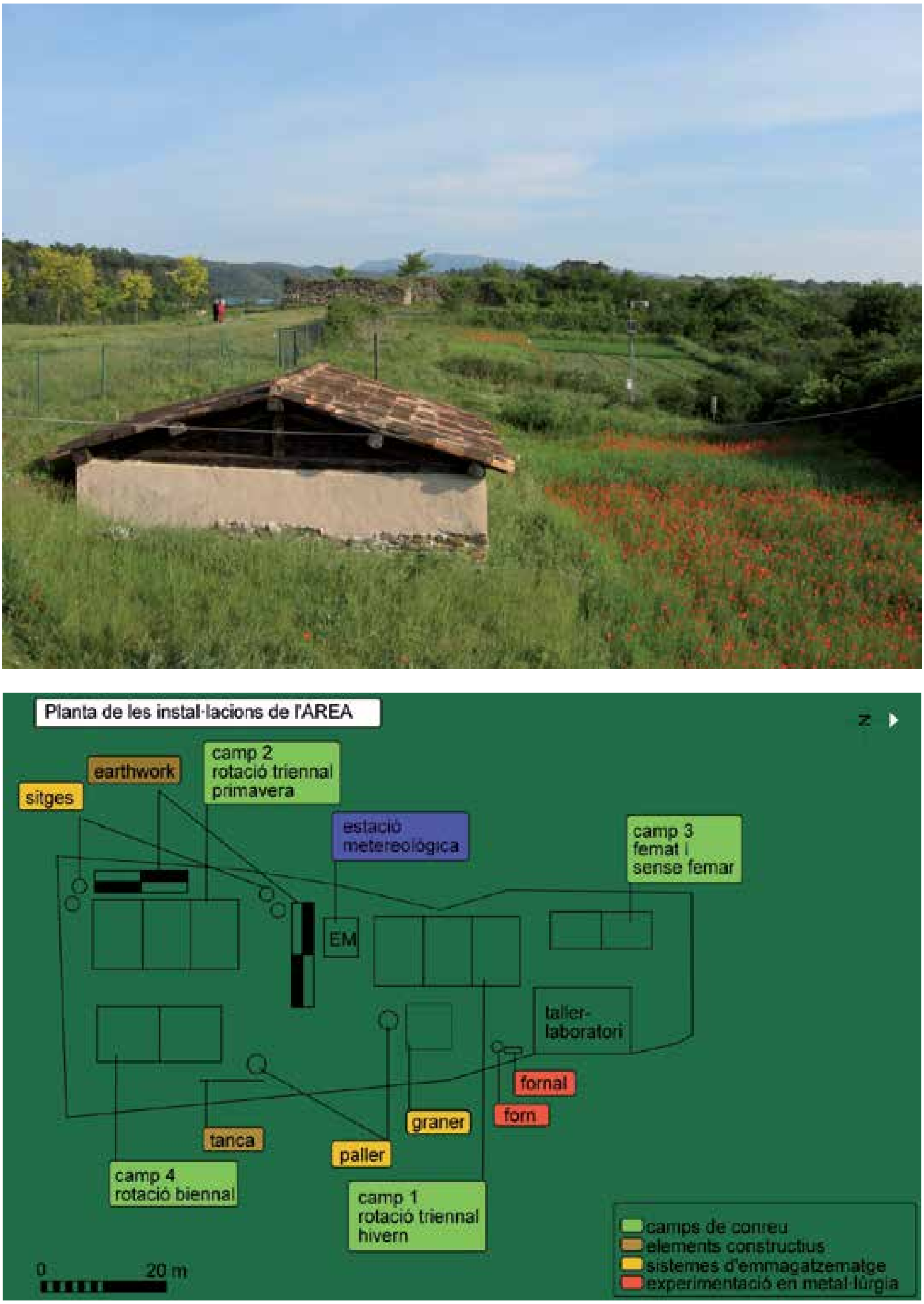

Fig. 4. View and map of the AREA (Archaeological Research Experimental Area) at l'Esquerda

experiment is related to the discovery, in 1986, of a mediaeval granary with a lot of evidences of the kind of seeds that were cultivated in the zone during Middle Ages. The experiment reproduces in the AREA the three-field rotation system (cereals-fallow-beans) in winter (Field 1) and spring sawn (Field 2), the two-field rotation system (cereals-fallow) (Field 4), and crop production in manured-fertilized and non-fertilized soil (field 3 A & B).

All the cereals planted were detected within the palaeocarpological analysis of the granary soil. The main species identified, and consequently plated in the experimental fields, are: emmer wheat (*Triticum dicoccum*), einkorn wheat (*Triticum monococcum*), spelt (*Triticum spelta*), rye (*Secale cereale*) and barley (*Hordeum vulgare*). In the three-field rotation system, emmer wheat, einkorn wheat and barley are combined with beans (*Vicia faba* var. *major*), together with fallow (Cubero et al., 2008; Ollich-Cubero, 1989, 1990).

During the crop's season a set of controls are developed: the ploughing of the soil has eventually made by a traditional plough pulled by a mare. In these cases we studied how the soil was removed and how deep reaches the plough into the soil. Then the same kind of ploughing has been usually reproduced by mechanic means.

There are two ways for planting, both of them registered in ancient agriculture. One is throwing the seed, like is shown, for example, in the Bible (Mt, 13); the other is planting the seeds in 30 cm a part furrows. This last technique is widely registered in medieval times, especially in areas and periods with difficult life conditions. Planting in furrows, even though requires a longer time for planting, requires much less expertise and allows saving a lot of seed. In l'Esquerda planting is made in this second way that allows, in addition, being more precise in the yield analysis (Ollich-Rocafiguera-Reynolds-Ocaña, 1998).

During the growing of the plants, their average measurement and eventual information about insects, weeds and meteorological events are weekly controlled.

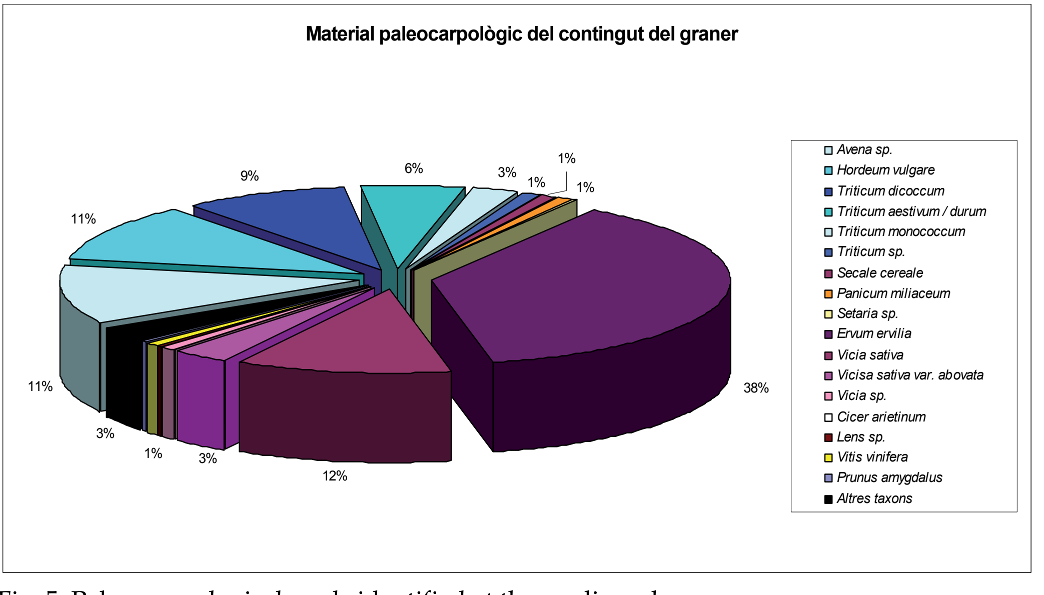

Fig. 5. Palaeocarpological seeds identified at the mediaeval granary

CEREALS	UBIQUITY (N:15)	TOTAL (NR:413)
Avena cf. *sativa*	1	19
Avena sp.	1	4
Hordeum vulgare	3	19
Panicum / Setaria sp.	1	1
Panicum miliaceum	3	5
Setaria sp.	1	1
Triticum aestivum / durum	5	35
Triticum dicoccum	5	14
Triticum sp.	4	7
LEGUMES		
Ervum ervilia	2	5
Lens sp.	2	2
Vicia / Lens sp.	1	1
Vicia / Pisum sp.	1	12
cf. *Pisum sativum*	1	1
Vicia sp.	1	1
FRUITS		
Prunus sp.	1	1
Vitis vinifera	6	84
ADVENTICIOUS		
Agrimonia eupatoria	1	1
Agrostemma githago	1	2
Anthemis cf. *praecox*	1	30
cf. *Aphanes*	1	1
Asperula arvensis	1	2
Bromus cf. *sterilis*	1	2
Caryoplyllaceae	3	3
cf. *Chenopodium*	1	1
Galium aparine	2	2
Gramineae	5	27
Lithospermum arvense	1	2
Lolium sp.	2	74
Nigella sp.	1	1
Plantago lanceolata	2	2
Rubus fruticosus	1	1
Rumex cf. *crispus*	1	3
Urtica dioica	1	2
Veronica hederifolia	1	2
OTHER		
Avena sp. (raquis)	1	3
Gramineae (base espigueta)	1	7
Gramineae (fragment espigueta..)	1	2
Gramineae (pellofes, glumes, canya..)	1	50
Gramineae (raquis)	1	6
Hordeum vulgare (raquis)	1	10
Triticum sp. (base espigueta)	1	5
Triticum sp. (raquis)	1	1
Vitis vinifera (peciol)	2	2

Fig. 6. List of plants at the AREA of l'Esquerda

Fig. 7. Seeding, growing and harvesting process in the fields of l'Esquerda

A further set of measurements is made before the harvest. The most important one is the average stand heights of a statistical part of the plants (500 or 300 per field). These data allow comparing the annual process of growing, and contrasting this process with the meteorological data in order to obtain also information about the process of soil depletion. At the same time a survey of weeds growing into the fields and around is made in order to obtain information about variations in the weather and correlations with some weeds and good harvests or crop failures. An average extension of 5 m² is harvested separately from the rest of the field. For each squared metre of planting, all the ears are cut, counted and weighed. A sample of them will be chosen for a more fine analysis to recover the amount of fruiting heads, and the net weight of the production.

Harvest is made in a traditional way. The ears and the straw are cut together with a sickle. They are put together in sheaves that allow the grain becoming completely dry. Then, at the threshing hall they are threshed with a wooden engine named *batolles* in Catalan –similar to a flail- that permits to put apart the straw from the grain. In l'Esquerda straw has been used for building haystacks and to experiment with them, and the grain is analysed and is used for the next season planting.

Emmer wheat in autumn sawn in a three field system is the most regular species that has a better yield (between 1:9 and 1:18); in contrast, barley in winter sawn has totally disappeared. Spelt and rye used to grow properly when other crops have been fallen, and spring sawn, even though has a minor return, helps to strengthen the annual harvest when winter has been too dry or too cold for the autumn sawn crops.

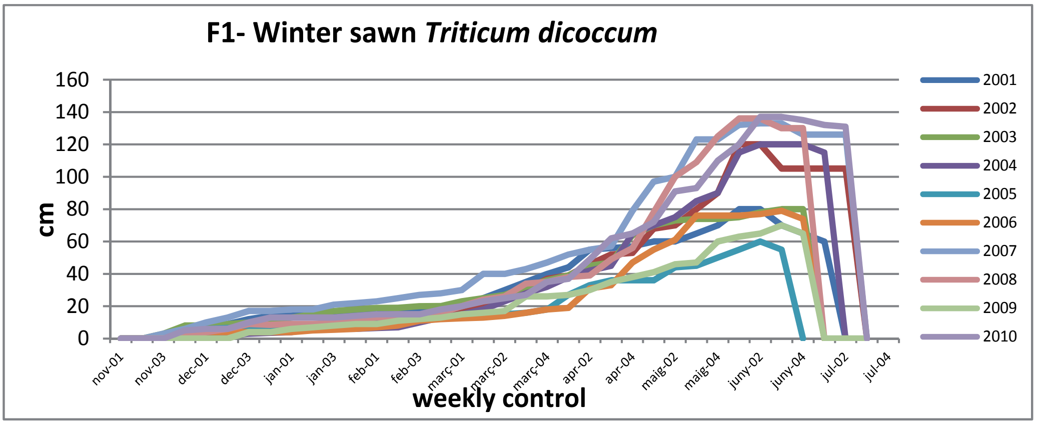

Fig. 8. Growing of *Triticum dicoccum* per months

Nowadays, after 20 years of crops, we have obtaining promising results that supply some lacking information about crop yields, the process of soil depletion, and the total link between agriculture and climatology in ancient times. The most important conclusion is that there is an absolute correlation between meteorological data and production crops, especially with variation in rainfall and temperatures during a 20-years-long period; besides, depletion of the soil is not significant during the same period. The annual yields are very variable and no regular pattern has been observed. There are many crop failures, in different species; that makes totally necessary the polyculture. Some total crop failures have been obtained in 2005 and 2006, not for any particular cataclysm occurred, only due to a bad storm before harvesting.

4. The building and storage experiments in silos and in a granary

In the archaeological site of l'Esquerda two storage systems have been documented: in silos -underground pits- and in a built granary. The granary found in the site dates back to middle ages, in 12th-13th centuries AD, and the silos mostly belong to 6th-7th century AD, in Visigothic times. Some Iberian silos are also found in the far end of the meander.

In order to know better how those grain stores were built, how they were working, and how much efficiently their function was, some replica of them have been made in the Area of Experimental Archaeological Research at l'Esquerda. In 1993 two silos were excavated in the soil and the rock and they were filled with modern barley. These silos have been submitted to different tests: they were filled, emptied, cleaned, burnt, etc. In 1997 the building of a full-scale granary was started, following the hypotheses generated by archaeological data.

4.1 The underground silos

The first storage experiment in the area took place between November 1993 and December 1994. It was a storage experiment with modern barley in two silos excavated in the soil, in order to check the evolution of the grain in a six month period and 12 month period respectively.

Silos were excavated in the soil in a depth of 90 cm and 1 meter until reaching the bed-rock. Two different layers were dig out; the first one was arable soil, and the second one contained a great deal of marl – eroded calcareous rock- fragments. They have a pear-shape, with the shore narrower than the bottom. No kind of plastering has been applied around edges. Both were filled up with grain, covered with a round-shape thin rocky cap, and they were sealed with clay and topped with soil. Some engines to measure the inside temperature were placed there (Reynolds, 1998).

The first silo was filled up with 275 Kg of barley. It was opened in june 1994, after 6 months of storage. The grain was in excellent conditions with a post-germinability of 90% in the central sample of the silo, and of a 87,8% in a side sample, nearer to the edge. The calculated lost index is lower than 4%. The grain is only lost when it is directly in touch with the silo edges, the soil and the cover. There were no evidences of microflora contamination, except for the interficies between the grain and the silo edge; nor were they evidence of rodents or microfauna attacks.

The second silo was filled up with 400 kg of barley and was opened and emptied in December 1994, after 12 months of storage with similar results.

After that, a new experiment was planned, in order to clean the silo of grain remaining in the inside wall after being emptied, and to prepare it for further uses. The aim was to burn it. During that June we were suffering a really hot summer and so was a very dangerous period for firing, so this operation was delayed until September. This experiment was planned because in the surroundings of archaeological excavated silos and inside them, a test of magnetic susceptibility suggested that these structures could have been submitted to high temperatures. Consequently we presumed that silos migt have been burned to be cleaned and reused.

The result of this burning process has been also very interesting to see how fire behaves inside a silo. The fuel was made with little bits of dry grass and small tree branches in the bottom. After some half an hour, the husks of the seeds start to carbonize, and only some quarter of an hour later fire explodes inside the silo, with some meters high blazes.

When fire stopped, all the rests of grains were completely burned, and so did the possible insects and microorganisms. In a few hours the pit could be completely cleaned, giving it a scrape around the entire wall and throwing away the ashes. And then the silo was ready to be used again.

Many other experiments have been carried in the silos after this one. They have been refilled many times, in different durations, different periods and different species. One of the silos was filled up and left *ad infinitum*; another one was emptied after 1 year and a half. This time ashes coming from the burning were put over the barley seeds together with topsoil, in a 5-6 cm layer. They also remain ash evidences in the edge of the silo. This could be the explanation of this kind of remains inside the archaeological silos, which are often interpreted as a preparation of the silo’s walls before a new storing.

After ten years of the abandonment *ad infinitum* of the silo, in June 2004, it accidentally collapsed under a person’s weight. The silo appears totally empty, with very clean edges.

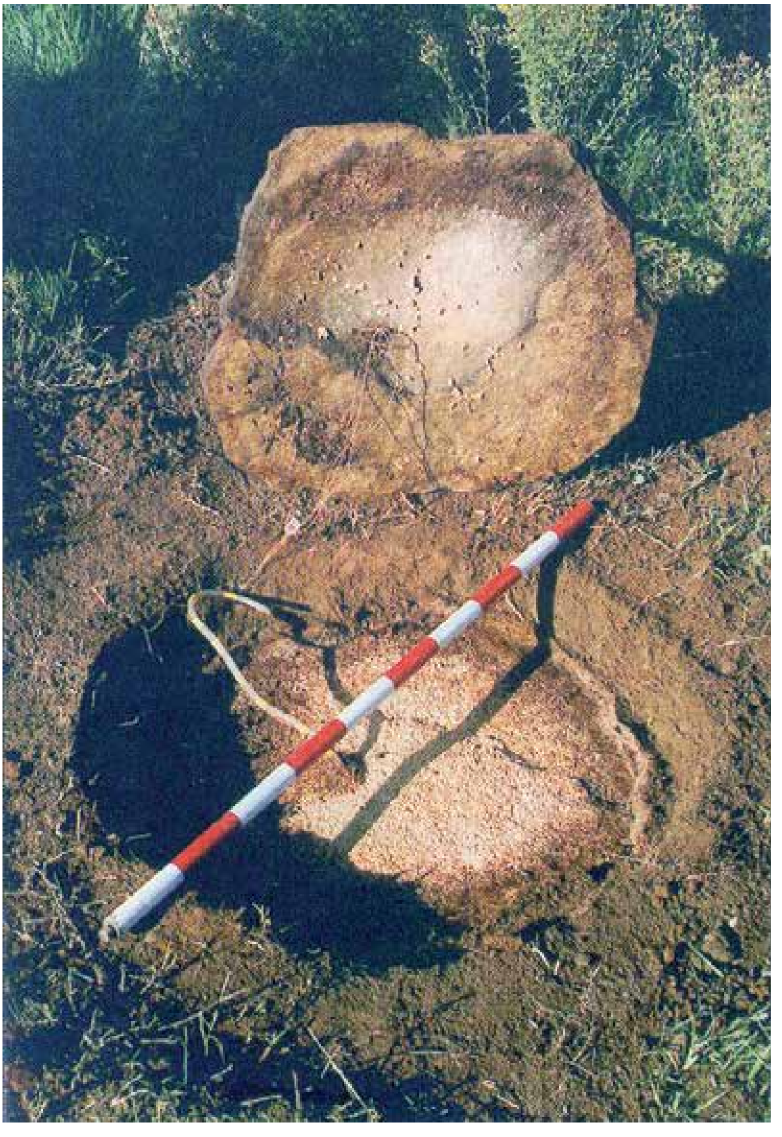

Fig. 9. Silos's opening process after six months of experimental storage

The covering stones and soil had totally disappeared. Some samples of the sediment have been taken, in order to check if there are still remains of seeds. This datum is especially interesting, because Peter J. Reynolds assumes that the life of a silo can be around 10 years. Even though this assessment is not demonstrated, the author uses economical reasons to this statement (Reynolds, 1988: 111). He rather refers the deterioration that silos can experiment after continuous processes of filling and emptying, that has also been demonstrated experimentally. Silo number 2 was filled in 2005 and in 2007 in one-year storage process. Both experiments failed. Probably the silo has ended its life. It is, however, very interesting that a long-term abandoned silo and a continuously used one were lost in the same period of time.

4.2 Building and using the granary

The construction of a full scale replica of the granary is based upon the archaeological excavation, done in 1986, of a building identified as a mediaeval granary. It had an initial rectangular plant that, after a fire, had been transformed into a squared plant. The result was a 5 x 5 m building. The excavation gave light about its function, features and contents, and the stratigraphy was very clear: (1) the upper part showed the arable soil on the top; (2) under the topsoil there was a demolition layer from the walls with freestones and clay, and with remains of burned wooden timbers and tiles from the roof; (3) under this layer, a 5-10 cm thick burnt level was found, situated over the soil rock (4). There was also a very thin layer of plaster over all the inside walls, and a lack of common domestic material, like pottery or animal bones, was observed (Ollich-Cubero, 1990). All the sediment samples were kept separately by sectors to be analised, and up to 32 different plant species have been identified (Ollich-Cubero, 1992).The soil was also protected by plaster and in the doorway there was a clay mortar 5 cm thick layer. In the rock soil there were many little carved holes, put in a strict order which were limiting rectangular spaces (1 x 1,50 m approx.) to divide the room into compartments.

Fig. 10. The granary of 13th century in process of excavation

Concerning the building framework, archaeological remains showed a structure built with stone base walls, measuring about 1 metre high and 70 cm width. As in other medieval structures, the rest of the wall would have been built with adobe wall (Cat. *Tàpia;* Fr. *pisé-de-terre*), and the covering would be made by oak wooden timbers and tiles. Inside, the building presented a plastered soil and stone wall, and a set of compartments or containers separated each other by a vegetal fence sustained by posts and post-holes carved in the rock. These containers were covered with chalk to protect and isolate them. This kind of fence has been deduced from post-holes, little burnt branches, and also from the wooden prints left in the burnt clay, that have been conserved inside the granary. The door opened to the south and it was protected by a clay step of 30 cm width and 5 cm high. This step had 3 little squared holes that seemed to correspond to a closing-system for the door. No wooden remains have been found into them.

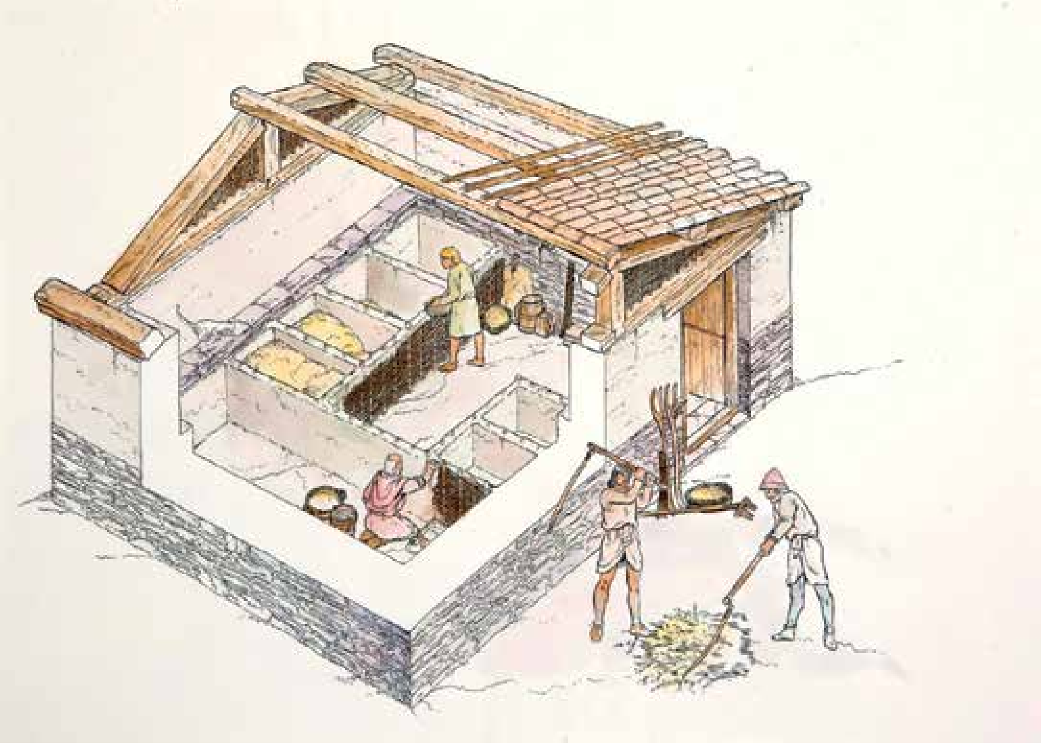

Fig. 11. Hypothetical restitution of the mediaeval granary (drawing: F. Riart)

In 1997 the full-scale replica of the granary was started. The full process ended in 2000. Ten years later, in 2010, different reparations have been needed. During the experiment, the amounts of stone used and the chalk and sand needed for mortar could be evaluated. Wooden formworks, in Catalan called *tapieres*, were made in order to build the *tàpia* or adobe walls, using local clay soil, after a deep research in traditional architecture. The appropriate kind of roof needed also to be discussed, because, apart from materials that appeared in archaeological levels, the final shape of the roof is based in hypotheses.

Once the granary was finished, one of the containers was filled up with modern barley in order to start the experiments of storage in an aerial structure. The first container was emptied in 2003, and the loss and conservation of seed were analysed. The data obtained could be compared with the storage's experiments in underground silos.

Fig. 12. Building the experimental granary at l'Esquerda in 1998, with P.J. Reynolds standing near the adobe wall

Fig. 13. The experimental mediaeval granary and haystack real size at l'Esquerda

5. Metallurgy and production of agricultural tools

In 1996 a mediaeval blacksmith's was discovered in the archaeological site of l'Esquerda, which provided a lot of information about the mediaeval process of metallurgy; in the Iberian part of the site, also a blacksmith's had been found (Ollich-Rocafiguera, 2000). Moreover, the site has provided a great number of iron instruments and artifacts used in the agricultural tasks (sickles, hoes, billhooks, knives) and in agrarian construction (nails, bolts, etc.). All of these findings present a very interesting research line in experimental archaeology in order to know the infrastructure, the workshop, the materials and techniques to made metallic implements.

Archaeometallurgical study of agricultural tools found in the site has allowed knowing the composition or the techniques of working with metals, by means of metallographical analysis. For instance, the metallographical observation of a small sickle found in the blacksmith's confirms that it was in transformation process (Amblàs-Molera-Ollich, 2008).

In the experimental Area of l'Esquerda, the inner structures of the 13th century mediaeval blacksmith's have been reproduced: a smith furnace for forging iron and a bucket furnace for smelting bronze and other metals.

The smith's furnace is very simple: it is made by a small depression surrounded by coarse stones, where charcoal is placed. In one edge there is place for a bellows that will allow reach the right temperature for heating iron to be worked (800-1000ºC). An anvil to hammer the hot iron and a water tank for tempering the iron, are all infrastructure that is needed for making iron tools.

The bucket furnace is made of clay mixed up with grog (Fr. *chamotte)*, in order to reach high temperatures without cracking. It has a tubular shape, with a small entrance on the low front part and a hole in the top for the smoke. Its fuel is also vegetal charcoal. Bronze, copper or lead are shattered in small bits and put in a stone crucible. Furnace reaches the 1000-1100ºC necessary for smelting the metals. The liquid metal is poured into a mold, and polished after cooling.

Fig. 14. Experimental smith's furnace and bucket furnace at l'Esquerda

All these experiments on ancient metallurgy, largely reproduced, have allowed us verifying archaeological hypotheses about production process of metallic instruments, and they have evidenced the little infrastructure that is needed for the forge of agricultural tools and for the production of smelt copper alloy objects. Data supplied from experimental archaeology and archaeometallurgy must be completed with an ethnoarchaeological study, paying special attention in the use of the tools: the moves, the techniques and the work organization. All this information can be compared with archaeological remains.

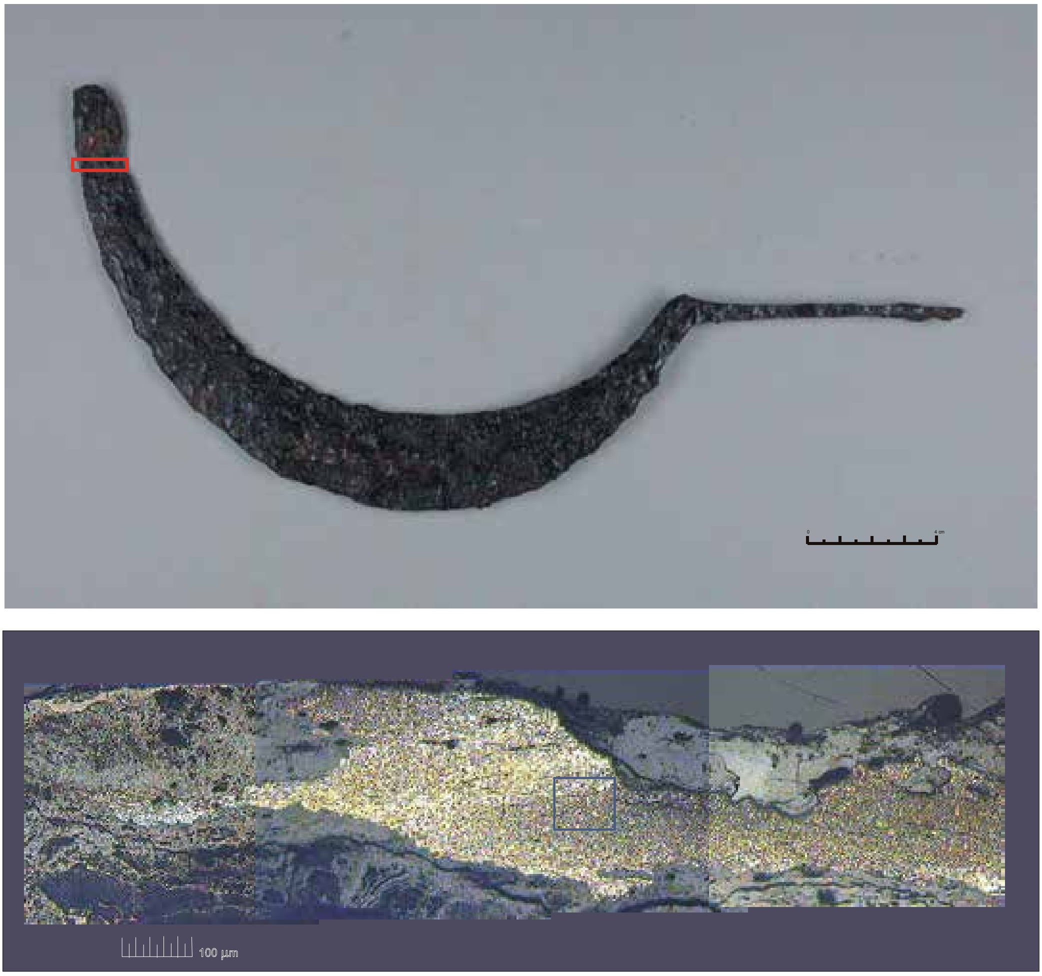

Fig. 15. Iron sickle found at the mediaeval site of l'Esquerda and its metallographic analysis

Fig. 16. Experimental process of an iron sickle forging and production

6. Other experiments about erosion, sedimentation and burning

Many other experiments are carried in the Area of l'Esquerda. Since 1991 a set of experiments about erosion, sedimentation and destruction of structures are in process.

6.1 The earthworks

The earthworks at l'Esquerda are two ditch-and-bank structures built between 1993 and 1994, one in North-South direction and the other one in East-West, that have been built to control their own process of erosion and sedimentation. Both of them are divided in four parts, in order to control the erosion under all conditions. The East-West ditch measures 16 m long per 1,50 m wide per 1,50 m deep (Ollich-Reynolds-Rocafiguera, 1993), and was carved into the rock, so its soil level was the bedrock itself. The eastern part has the bank in the south, made of soil and the broken rocks obtained from the ditch. A half of its part has a berm, and in the other one the bank lies directly in the edge of the ditch. The western part has the bank in the north and it is also divided in two parts, one with a berm and other without it. The North-South ditch was carved into the soil and has the same structure and the same measures of East-West one. The bank in the northern part is in the East and it is also divided in two, and the southern part has the bank in the West.

Fig. 17. Ditch-and-bank East-West

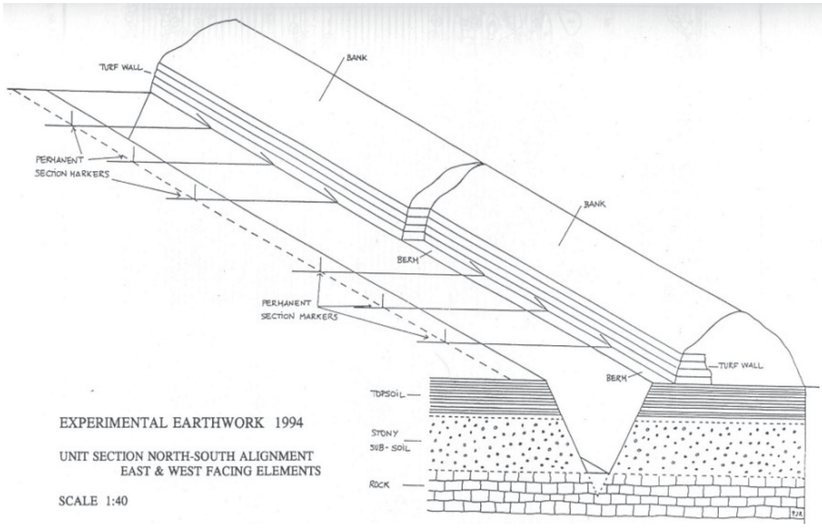

Fig. 18. Experimental earthwork at l'Esquerda, with the ditch-and-bank (Reynolds 1998)

The aim of this experiment is to check if this kind of defensive structures, which are very common in northern Europe, could also work in the Mediterranean areas. The *a priori* thought was that, because of the Mediterranean variable climate and the stronger rainstorms, ditches would be quickly filled up in a little time, so the structure would be unusable. The experiment was designed in order to be compared with the ditch-and-bank structures built by Dr. Reynolds in England: one in the grounds of the National Science Museum Reserve Collection at Wroughton, near Swindon in 1985; a second one in the grounds of Fishbourne Roman Palace, Chichester, Sussex in the same year; and a third one was built at Butser Ancient Farm at Bascomb Down (Charlton, Hampshire) in 1992 (Reynolds, 1998: 154).

Since 1994 a study of plant colonization is carried every year in spring, and a profile of the erosion of the ditch into the bank is outlined. The fact is that even though the weather is less stable in Catalonia than in England, plant colonization is much faster, so plants are ready to contain the soil erosion much earlier. Fourteenth years later earthworks were totally stable and fully colonized by plants. The last part of experiment is still to be done. In the near future, the two ditches will be surveyed and fully excavated in order to recognize how their stratigraphy has been formed.

6.2 The wooden fence

In 1995 a wooden fence of 6,60 m long and 1,20 m high has been built in the experimental area of l'Esquerda, as a long-term experiment. Twelve post-holes of 10 cm depth have been carved in the rock,following a serial of post/holes found near the castle of Savassona, a site near l-Esquerda. New experimental posts were made of oak (*Quercus pubescens)* timber, and the fence with hazelnut (*Corylus avellana)* outbreaks cut in early spring in a place near the site at the river (Reynolds, 1998c).

Since its building, the fence has been under control, in order to study its degradation process. No reparations and no maintaining works have been done. After three years of stability, the degradation process has started by plant colonization, mostly by blackberry plants. Now most of the long hazelnut timbers have disappeared, and also have done some oak posts. In a few years, when the process of destruction will be completed, this area will be surveyed and excavated. All the data obtained will be useful to research perishable structures in archaeological sites.

Fig. 19. The wooden fence at l'Esquerda in process of erosion

6.3 The haystacks

Haystacks are organic and perishable structures which take part of any cereal agrarian landscape, even though mechanization has made them disappear from modern fields. Inside the experimental archaeology project developed in the AREA of l'Esquerda, some of these structures have been built with a double purpose: first, as a necessary part of the agrarian storage project, second, to recognize the evidences of these structures in the archaeological soil.

An experiment about destruction is been carried with haystacks. Two of them have been built in 1992 and 2000, the first one made with hay and the second one with straw. After building, they have been abandoned and the degradation process has been under control (Ollich, 1998). Nowadays, the first one is almost disappeared, due to organic decomposition. The other one is still in putrefaction process.

In July 2010 a third haystack was built with straw. It measured 2,50 m high per 3m diameter, and 600 kg straw was used to build it. Seven months after its building, in February 2011, this haystack was burnt in order to study the complete combustion process and the archaeological evidences remaining in the soil. All of the registers about the process have been taken. In November 2011, burnt soil has been surveyed by geo-radar. Then the half south part of the haystack surface has been excavated. The other half part will be excavated in the future, when it would be more degradated (Ollich/Rocafiguera/Ocana 2011& 2012). The study and comparison of all these data will allow us to recognize some little archaeological burned evidences or some post-holes in relationship with perishable structures like haystacks.

Fig. 20. The haystak n.3 in process of building and burning

7. A perspective of future

The LEAF project about Experimental Archaeology carried out at l'Esquerda since 1991 until nowadays allowed us to obtain a lot of data that can be compared with archaeological remains. So in the next future, we will carry on with new experiments.

The results of the experiments about ancient crops, storage and earthworks are very useful to understand how and what did ancient people for building, planting and storing. After twenty years of experimental research, we know a little bit more about the field production and its relationship with meteorological conditions, the people's diet, their techniques to work wood, stone and metal, and the framework and organisation of their living. It is critical for the research to understand that Experimental Archaeology allows us a good empirical tool to verify archaeological hypothesis and, at last, to understand History better. As Dr. Reynolds wrote some years ago in his book, experimental archaeology is a perspective of future.

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9

The Study of Shell Object Manufacturing Techniques from the Perspective of Experimental Archaeology and Work Traces

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1. Introduction

The techniques employed to manufacture mollusk shell objects in pre-Hispanic Mexico have been little studied to date. This may in part to be attributed to the fact that, as in the case of the majority of precious materials, these pieces are found as already finished pieces in funerary or votive offerings in construction; the discovery of evidence of their production—such as rejected pieces, workshop waste, or discarded tools—is rare; only occasionally is such material found in trash deposits, construction fill, or sometimes where the shell objects were actually produced. Given this general scarcity of information, two research projects devoted to shell object manufacturing techniques have been conducted at the Templo Mayor Museum in Mexico City. To overcome the lack of information stemming from the paucity of direct indicators of production, researchers have turned to experimental archaeology and the characterization and comparison of manufacturing traces. The present article describes the theoretical-methodological foundations of these projects and presents the principal results obtained to date concerning shell pieces found in offerings in the sacred precinct of Tenochtitlan.

2. Background

A review of research on shell object production techniques for societies that did not use metal tools in different parts of the world (Oceania, Asia, Europe, South America, the Caribbean, North America, and more specifically Northern Mexico and Mesoamerica)[1] has made it clear that the identification of instruments utilized in making shell objects has been based on their association with production evidence in the archaeological contexts of the respective discoveries. The result of this method has been the reconstruction of different steps in the production sequence, which are occasionally based on historical or ethnographic information. Rarely is any attempt made to corroborate the inferences arising from contextual relationships, which is a problematical approach because often the deposits where the objects were found were not production zones, but rather trash heaps that might

[1] See Allen et al., 1997; Dacal, 1978; Dales & Kenoyer, 1977; Di Peso, 1974; Fash, 1991; Feinman, 1999; Feinman & Nicholas, 1995; Flannery & Winter, 1976; Gómez, 2000; Hartzell, 1991; Haury, 1976; Hocquenghem & Peña, 1994; Hohmann, 2002; Kenoyer, 1989; Mayer, 1997; Miller, 1996; Suárez, 1977; Turner, 1987; Vargas et al., 1993; Villalpando & Pastrana, 2003; Woodford, 1908; Yerkes, 1983.

contain waste material from many different types of activities. In exceptional cases, experiments have been conducted to test hypotheses concerning production processes, which although they might increase the probability that these were indeed carried out, they in no way conclusively confirm these processes. Seldom are work traces present on the pieces examined, even though they might in fact constitute the best evidence to propose or reject the use of specific manufacturing techniques.

Given these reservations, several general conclusions can be reached concerning the processes and tools reported for working shell in societies based on a lithic technology. In many of the cases reviewed, reference is made to percussion—understood as the action of striking one material with another, generally of greater hardness—as the first step in the manufacturing process, which, according to different authors was carried out with hammers and stone anvils. This same technique was sometimes employed to produce preforms. Different forms of abrasion were then used to shape irregular pieces of shell, to correct irregular edges, to smooth and polish surfaces, to cut, perforate, and even work decorations. The tools used for these purposes were passive surfaces for abrasion (stone slabs, rounded rocks, grinding stones) and active stone instruments; and lithic implements made of flint, obsidian, or slate, such as flakes, blades, knives, and points. Occasionally the use of sand as an abrasive and water is mentioned, together with the above-mentioned utensils, as well as cords for cutting and incising, reed perforators, and cactus spines. Noteworthy is the research conducted at the Inca site of Tumbes, Peru, where evidence suggests that surface abrasion of the valves was the first step in the manufacturing process and apparently no type of percussion was used to produce the objects (Hocquenghem & Peña, 1994). Information on other specific techniques includes heating shells of the *Olivella* genus in Davies, California, a treatment used to turn them uniformly white and to facilitate cutting, abrasion, and perforation in bead production (Hartzell, 1991); and decoration engraved with acid that was practiced in Snake Town, Arizona (Haury, 1976).

3. Experimental archaeology projects

Experimental archaeology, together with ethno-archaeology, form part of so-called middle range theories, which make it possible to infer the social dynamics of the past from archaeological contexts, which are static moments of the present and that have undergone changes resulting from diverse factors, from their formation to the moment of their excavation (Binford, 1977:6; Gándara, 1990:74). Experimental archaeology is based on replicating past events, which can range from producing a tool to the simulation of a way of life, under controlled conditions (Callender, 1976:174). To design experiments, numerous factors should be considered, such as the utilization of the materials and tools characteristic of the society and the historical moment that is being studied. Particular importance should be given to "uniformitarian suppositions", which makes it possible to infer that what is happening in the present was what occurred in the past (Binford, 1991:22).

3.1 The conchological material experimental archaeology project

In 1997 the first experimental archaeology project on shell materials was begun at the Templo Mayor Museum; its principal objective was to augment knowledge of the manufacturing techniques employed in the production of almost 2,300 conchological objects found in the offerings excavated by the Templo Mayor Project in the central religious building in

Tenochtitlan, the capital of the Aztec Empire, and its nearby structures. The basic assumption was that the use of a specific tool, made from the same material as used in ancient times, employed in a specific way should project characteristic and differentiable features (Ascher, 1961). In this way, determining the traces produced by the different techniques and implements tested could be identified in archaeological materials. Therefore, the analysis and comparison of manufacturing traces was defined as the principal uniformitarian criterion.

The materials for experimentation were the same shell species that were used to make the objects from the Aztec offerings. The tools used were those that were typical in the Basin of Mexico at the time of the Mexicas (i.e., Aztecs), based on archaeological finds and information from documentary sources. The entire range of modifications (abrasion, cutting, perforation, incision, and openwork) based on typological analysis and known to have been used to transform the raw material into the objects studied were performed.

The project began with a phase of exploratory experimentation (Gibaja Bao, 1993:12), which permitted determining the diverse factors that had to be systematically taken into account in all of the experiments, which resulted in the creation of a format. It consisted of a progressive number for each experiment, its name, its objective, the materials utilized, their initial and final measurements, the time it took and the processes carried out, in addition to observations. Furthermore, photos were taken of the materials prior to the start of the experiments, the work phase(s), and the final result (figure 1).

Fig. 1. Work process of abrasion of outer and middle layers of *Pinctada mazatlanica*: unmodified material (a), abrasion process (b & c), final result (d). Photos: SOMTPM.

Analysis of manufacturing traces was conducted at both a macroscopic level (the naked eye) as well as with the help of low amplification microscopy; 10x and 20x magnifiers were used, as well as an Olympus stereoscopic microscope, model TLZ S2-STS, yielding photos with a magnification of 10x, 30x, and 63x. The results of this first phase were encouraging. For example, it was possible to determine that for the identification of techniques such as percussion, it was not necessary to employ any sort of magnifying device, because the characteristic irregular edges that it produced were clearly visible to the naked eye (figure 2). It was determined that the use of lithic tools to perform abrasion on surfaces or edges, cuts, perforations, and incisions produced clearly marked scratched patterns that could even be identified without magnification (figure 3); these traces differed considerably from the traces left by the use of abrasives, whose fine lines are imperceptible on a macroscopic level, barely distinguishable at a magnification at 10x or 30x (figure 4). However, it was also evident that with the means of observation employed it was not possible to differentiate between the traces left by similar tools made of different materials. This was the case of obsidian and flint instruments, which indistinctly produced similar patterns of straight, parallel lines on cuts, or else concentric linear patters on perforations (figure 5).

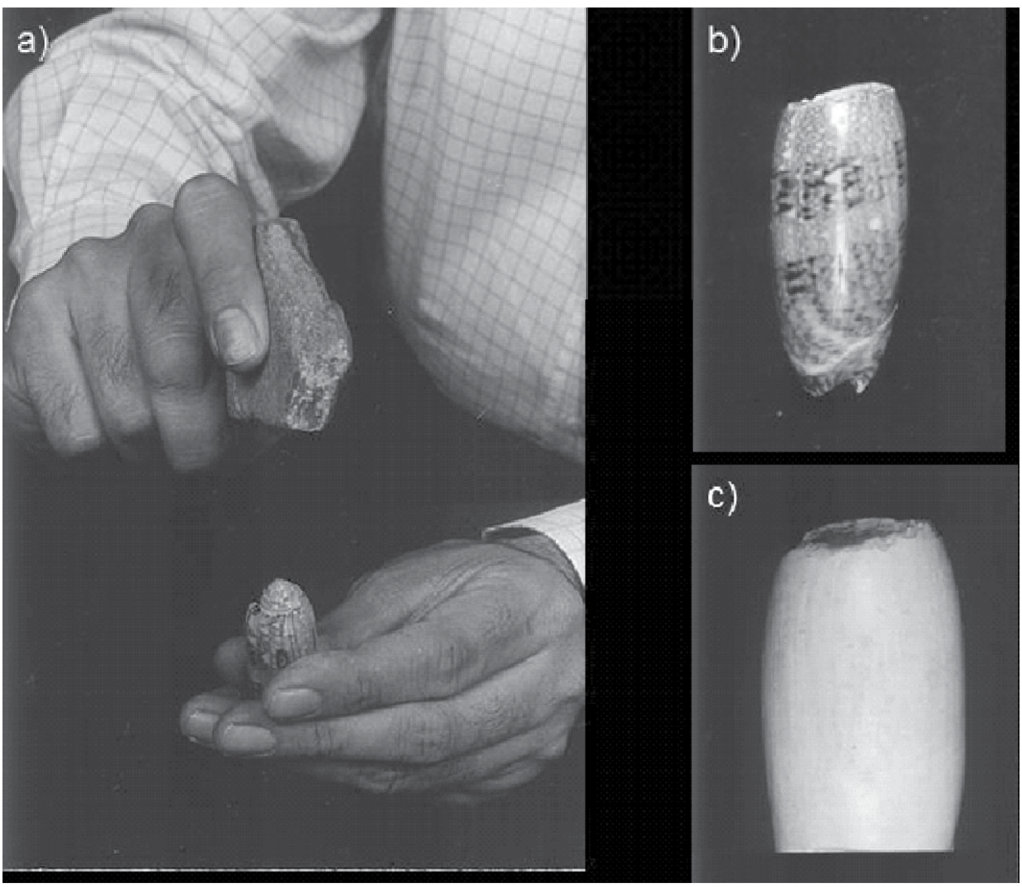

Fig. 2. Process of removing spire from an *Oliva sayana* shell (a), experimental result (b), archaeological piece (c). Photos: G. Zúñiga.

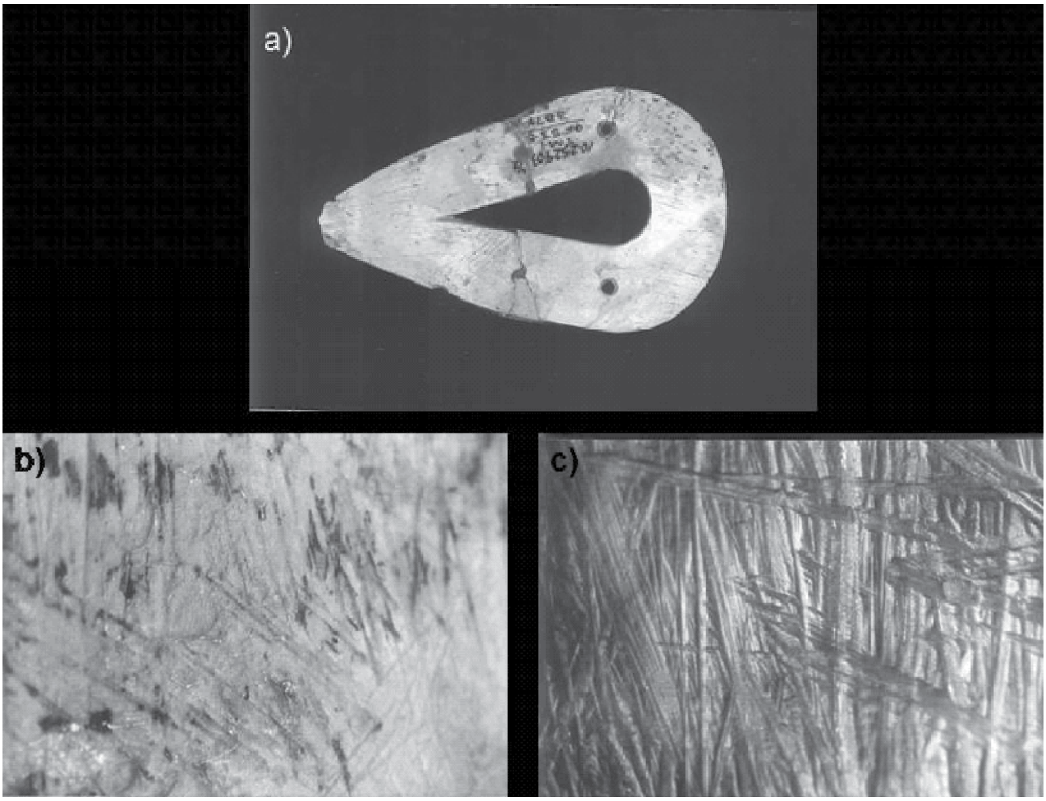

Fig. 3. Archaeological *Pinctada mazatlanica* piece with surface scratches visible to the naked eye (a), magnified 10x (b), experimental scratches produced by abrasion with basalt magnified 10x (c). Photos: G. Zúñiga & J.L. Alvarado

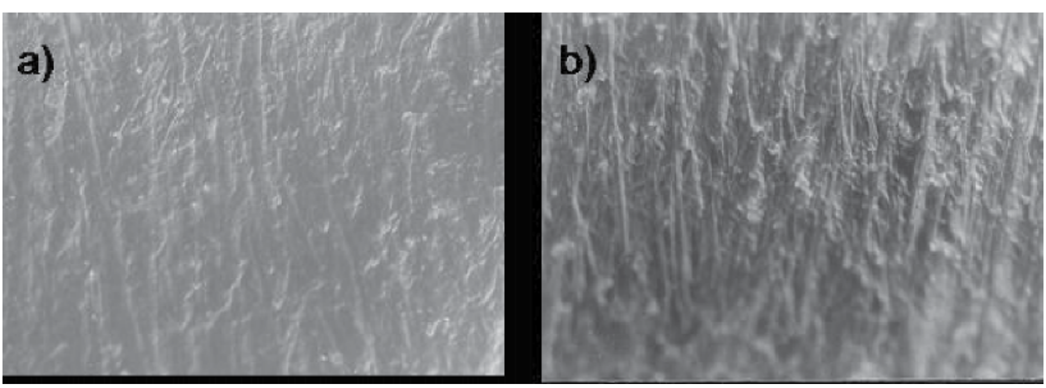

Fig. 4. Traces produced by abrasion with basalt and sand on a *Pinctada mazatlanica* valve magnified 10x (a) magnified 30x (b). Photos: J.L. Alvarado.

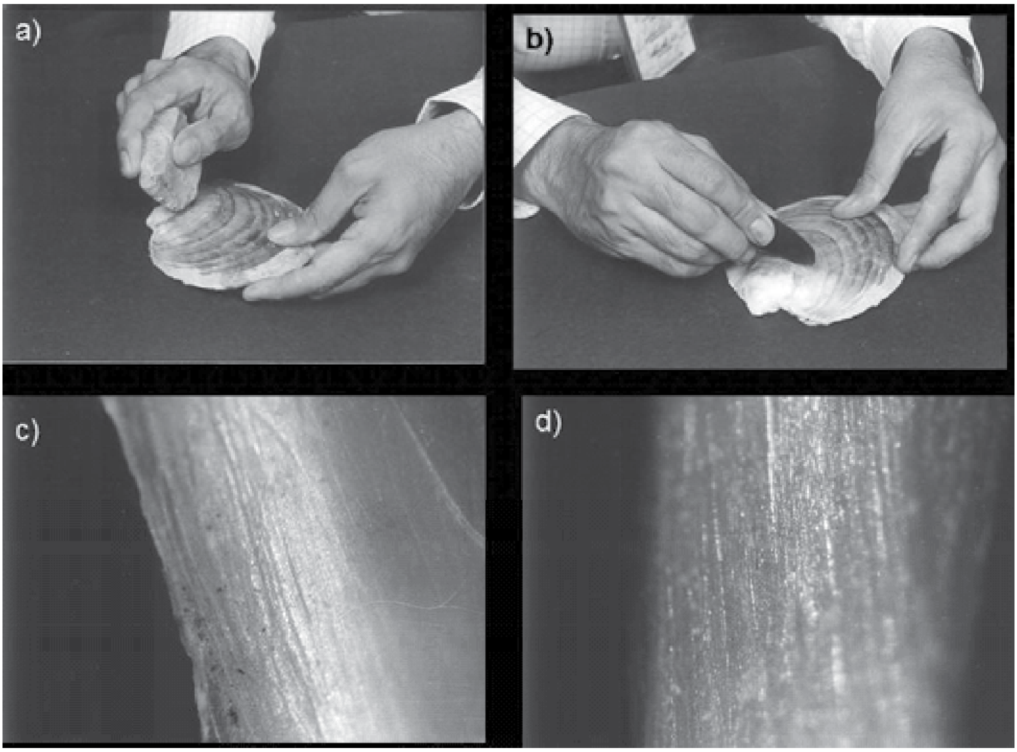

Fig. 5. Process of cutting a *Pinctada mazatlanica* valve with flint tools (a) with obsidian tools (b); traces of the cut magnified 30x worked with flint flake (c) and obsidian flake (d). Photos G. Zúñiga & J.L. Alvarado.

3.2 The Shell Object Manufacturing Techniques in Pre-Hispanic Mexico project (SOMTPMP)

The need for observation techniques that would allow for greater precision in analysis led to establishing contact with the Instituto Nacional de Investigaciones Nucleares (ININ), specifically with Dr. Demetrio Mendoza Anaya, who works with high- and low-vacuum scanning electronic microscopy (SEM). SEM is an ideal technique for the analysis of the surface characteristics of materials. For this technique a high-energy beam is aimed at the sample, which produces electrons and other signals that are captured by special detectors; based on this process it is possible to form a highly detailed digital image of the surface of the material, permitting characterization of its topology, texture, porosity, and other features. In early microscopes it was necessary for the sample chamber to be in a high vacuum, so the samples had to be conductors of electricity; and for those that were not conductors, they had to be coated with a fine layer of metal. However, in recent models it is possible to make observations in a low vacuum and even at environmental pressure, which has made it possible to analyze moist, organic materials without any coating. SEM permits extremely high magnification (theoretically as high as 300,000x), also enabling semi-quantitative analyses of the elemental composition of the samples. Prior to the observation of manufacturing traces, it was necessary to become familiar with the structural characteristics of shells; the surfaces of various modern biological specimens, as well as parts of them that had been previously corroded by immersion in acetic acid were observed for this purpose; this allowed for discovery of the inner layers of the material without having to resort to the intervention of any type of tool.

At the start of the project, a number of archaeological pieces were taken to the SEM lab; this presented certain complications, because to move the material it was necessary to request special permission and the samples had to be escorted by security guards. In addition, the size and shape of some of the pieces hindered their analysis, because the microscope's sample chamber is relatively small (approximately 10 x 10 cm) and it is not possible to produce a clear focus on elements that are not flat (i.e., that are curved or three-dimensional). Therefore, tests were made to produce replicas in polymers softened with acetone, which were pressed onto the zones of the objects to be analyzed (figure 6) and later they were covered with gold ions for their observation in a high vacuum. The replica method, typical of metallography, avoided having to move the archaeological materials, because the polymer samples were produced in the repositories where the original material was kept; it made it possible to examine pieces that would not have fit into the microscope's sample chamber and also to produce high-quality images of modifications that did not conform to a flat plane, such as perforations; finally, it facilitated work sessions in which up to twenty samples could be examined in a two-hour session. Based on the experience of these initial analyses, the decision was made to undertake systematic observations of manufacturing traces at 100x, 300x, 600x, and 1000x, because at higher magnification the crystalline structure of the material dominated the image. For

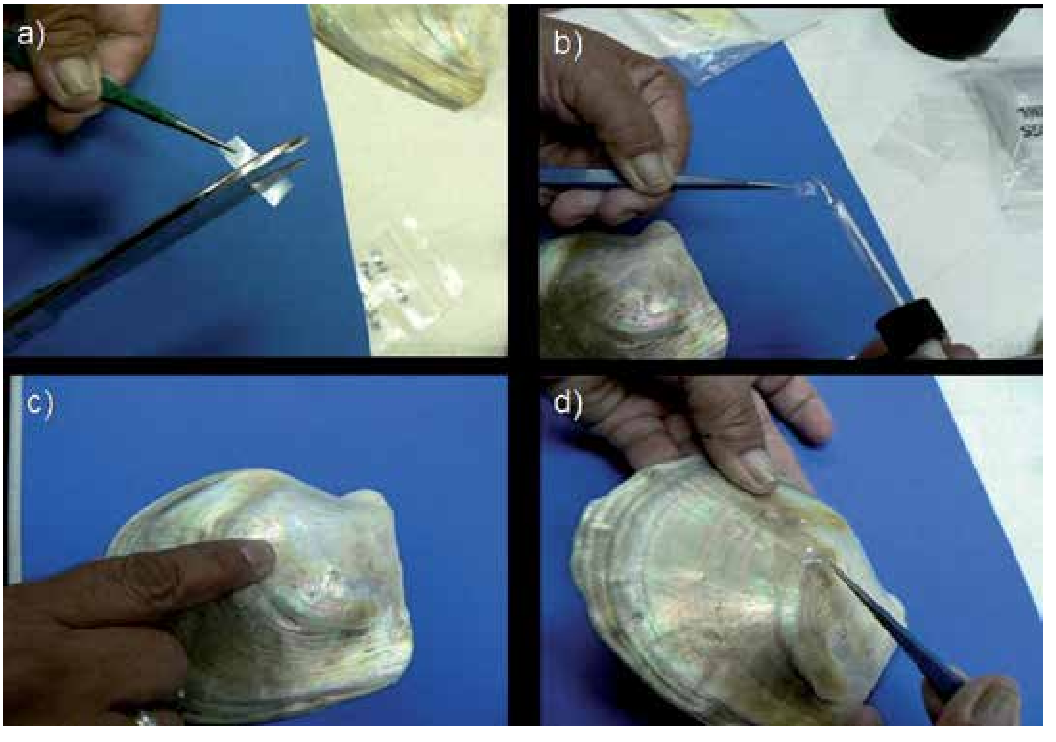

Fig. 6. Obtaining polymer replicas of manufacturing traces: cutting the polymer (a), moistening it with acetone (b), pressing it against the object (c), obtaining the replica (d). Phtos: A. Velázquez.

purposes of characterizing work traces, it was necessary to describe their shape (lines, bands, particles), their thickness, their tendency to form larger elements (agglomerations of lines or bands), the appearance of surfaces (smooth, rough, porous), among other traits. As a result of this technique, it has been possible to find patterns of work traces that permit the establishment of clear distinctions between materials, which permit their identification in archaeological objects (figure 7); now traits that seemed undifferentiated at low magnifications can be distinguished with SEM (figure 8).

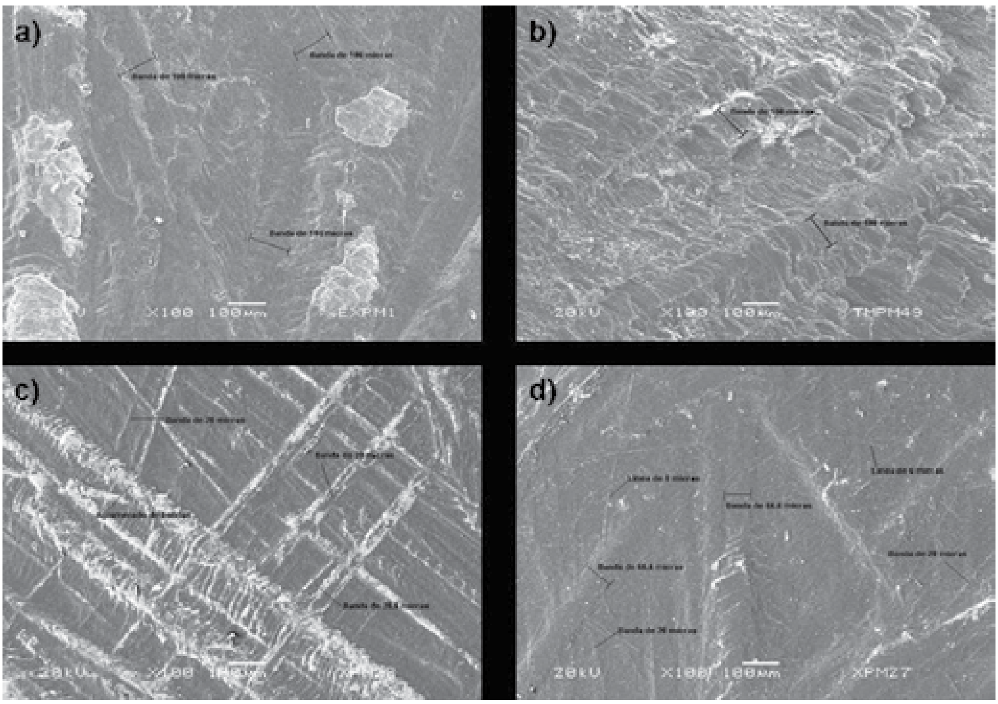

Fig. 7. Abrasion traces on *Pinctada mazatlanica* valves seen with SEM at 100x: basalt (a), archaeological piece from Templo Mayor of Tenochtitlan (b), rhyolite (c), and limestone (d). Photos: SOMTPMP.

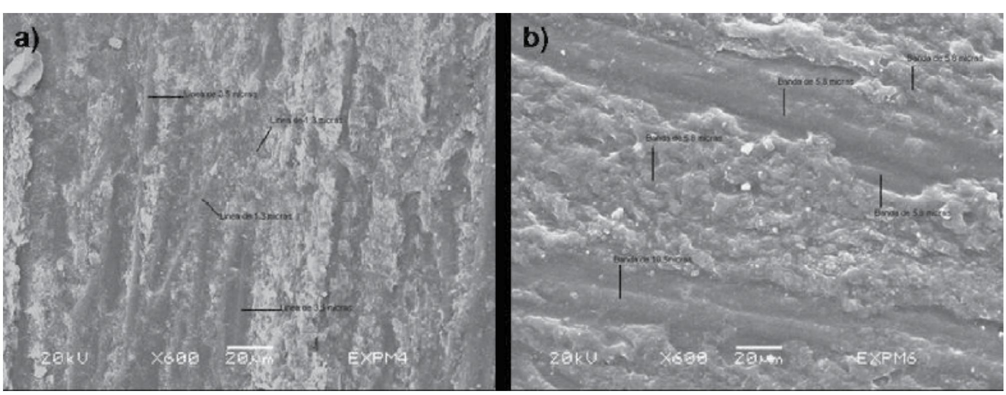

Fig. 8. Traces of cutting on *Pinctada mazatlanica* valves seen with SEM at 600X: obsidian flake (a) and flint flake (b).

As its name indicates, this project—which was formally instituted in 2000, when the specific collaboration agreement between the INAH (Instituto Nacional de Antropología e Historia) and ININ was signed—has studied and continues to research shell materials from different sites and periods of pre-Hispanic Mexico. The researchers have included the present author, as well as undergraduate and graduate students in Archaeology; the project has grown by increasing the materials and tools used in experimentation. Therefore, it has been necessary to establish a methodology that consists of the following steps:

1. Analysis of the material, which consists of the biological identification of the species and the characterization of its morphological and functional typology. During this phase, it is necessary to research the type of materials and tools that appear at the site or in the region of study and it is useful to conduct experiments with materials that have not been studied before.
2. Parallel to this phase, observations are made of the manufacturing traces with the naked eye and with the help of 20x magnification.
3. Selection of a sample to obtain photos at low magnification with a stereoscopic microscope (10x, 30x, and 63x). Specimens should include recurrent traits as well as uncommon features in the archaeological collection.
4. Based on the results of the preceding phase, the selection is made of the sample of objects from which replicas will be made.
5. Observation of the replicas with SEM (100x, 300x, 600x, and 1000x).
6. Analysis of the micrographs and comparison with the project's database of experimental work traces.

To date more than 700 experiments (table 1) have been carried out and archaeological collections spanning roughly 2700 years of the pre-Hispanic history of Mexico (1250 BC to AD 1521) have been studied. The experiments include material from sites in the Maya zone (Moral-Reforma, Tabasco; Calakmul, Campeche; Oxkintok and Xuenkal, Yucatán; CALICA, Oxtankáh, Ichpaatun and Kohunlich, Quintana Roo), from the Central Highlands of Mexico

Modifications	Tools
Abrasion	Basalt, andesite, rhyolite, granite, sandstone and limestone, adding water and occasionally sand
Cuts	Abrasives (sand and powdered obsidian), water and strips of leather; flint and obsidian lithic tools (flakes with sharp edge reworked by pressure and percussion: scrapers, knives, and blades)
Perforations	Abrasives (sand, volcanic ash, and powdered obsidian and flint) used with reed stalks, adding water. Flint and obsidian lithic tools
Openwork	Abrasives (sand, volcanic ash, and powdered flint) used with reed stalks wide in diameter, adding water. Flint and obsidian lithic tools
Incisions	Flint and obsidian lithic tools
Finishes	Polished with abrasives (sand and volcanic ash), water and pieces of leather; polished with flint nodules. Burnished with pieces of dry leather. The use of both finishes

Table 1. Modifications and tools used in the experiments

(Las Bocas and Cantona, Puebla; Teotihuacan and Xaltocan, State of Mexico; Xochicalco, Morelos; Tula and Tizayuca, Hidalgo; and Tenochtitlan, Mexico City), from the state of Guerrero (Teopantecuanitlán, Pezuapan and Malinaltepec), Oaxaca (Monte Albán), the Gulf of Mexico (Tlacojalpan, Veracruz; Tamtoc, San Luis Potosí, and sites in the valleys of the Sierra Gorda in Querétaro); West Mexico (La Presa del Cajón, Nayarit, and sites in the Sayula Basin, Jalisco), Northern Mexico (Chalchihuites, Altavista, Pajones, and Cerro Moctehuma, Zacatecas, and sites in northern Sinaloa and Nuevo León).

4. Results from the study of Aztec shell objects

The Mexicas or Tenochca, as the Aztecs are also known, established the largest empire in Mesoamerica during the Late Postclassic period. According to sources written in Spanish from the time of the conquest, in a lapse of less than two hundred years (1325–1521), they went from being a semi-nomadic group of recent arrivals in the Basin of Mexico to a tributary of the Tepanecs of Azcapotzalco, to ultimately forge a vast empire conquered by force, which extended as far north as the Huastec region, and as far south as Soconusco, encompassing settlements from Atlantic to Pacific coasts of the territory today comprising Mexico. Their capital, Tenochtitlan, located in the heart of modern-day Mexico City, inspired awe among the Spanish conquerors for its magnificence, scale, and order (Díaz, 1986:160 & 173). From 1978 to the present, the Templo Mayor Project has been in charge of the excavation and study of all the archaeological vestiges found in the area occupied by the ceremonial center of the Aztec capital (Matos, 1990:27). Seven construction stages or phases of major architectural expansion have been identified at the Templo Mayor (Great Temple) and in the surrounding ceremonial precinct (Matos, 1988:176), which have served as the basis for a chronology. Based on this sequencing, the first stage corresponds to the foundation of Tenochtitlan, which occurred in 1325; the second, to the first three Mexica rulers (Acamapichtli, Huitzilihuitl, and Chimalpopoca); and the following, to successive kings (*tlatoque,* "great speakers" as the emperors were known [*tlatoani* in singular]) (Itzcoatl, Moctezuma I, Tizoc, Ahuizotl, and Moctezuma II), with the exception of a partial expansion known as stage IVb, which was attributed to Axayacatl (Matos, 1988:64, 70, 73, 74 & 176).

What stand out among the vast quantities of discoveries made by the Templo Mayor Project are the ritual deposits composed of objects, referred to as offerings, which were buried in and around the structure of the Templo Mayor and the buildings in the sacred precinct; they now number almost 200 offerings in total. These deposits display striking variability in terms of their arrangement, the type of receptacle containing them, their composition, and the placement of their diverse contents. The study of forty-eight offerings buried in the Templo Mayor and the nearby structures dealt with a total of 2,245 complete shell pieces and 745 fragments (Velázquez, 1999:117). The materials employed for the production of these elements came from both Atlantic and Pacific coasts of Mexico, and the corpus yielded the identification of three classes (Gastropoda, Bivalvia, and Polyplacophora), 14 families, 16 genera, and 15 species (Velázquez, 1999:116). The collection of shell objects is comprised of ornamental pieces (pendants, pectorals, inlays, beads, earflares, noseplugs, and lipplugs), musical instruments (trumpets), and what seem to be purely votive elements (an anthropomorphic plaque, a disk with an incised spiral, the representation of spearthrowers, slightly flaring rectangular objects, a disk with four perforations, a pigmented gastropod, worked valves, and a section of a columella) (Velázquez, 1999). Although shell objects predating stage IV of the Templo Mayor, which corresponds to the reign of Moctezuma I—a time of the conquest of settlements in the region of the Gulf Coast of Mexico—have not been found to date, there does not seem to be a direct relationship between the presence of this type of materials and Mexica imperial expansion. It should be pointed out in this regard that the large quantity of specimens from the Pacific in the above-mentioned architectural expansion, as well as in stages IVb and V, predate the conquest of settlements on the Pacific coast, which took place during the rule of Ahuizotl, who is linked to stage VI.

As a result of the bellicose nature of Mexica society, one of its principal motivations for its expansionism was the collection of tribute. Little attention has been given to the effects of tribute on Aztec material culture, much of which has traditionally been regarded as foreign in nature (i.e., not produced in the capital). For example, it has been posited that the majority of the manufactured objects from the Templo Mayor offerings were acquired through tribute, trade, gift-giving, or looting (López, 1993:137). Specifically in terms of shell objects, Matos does not regard them as Mexica products (Matos, 1988:92-101) and there is a deeply rooted idea in academic circles that shell objects were produced on the coasts. However, despite the non-local character of the raw materials, what is puzzling is that many of these objects represent iconographic elements characteristic of Nahua deities from Central Mexico. This is the case of the ring-shaped *anahuatl* pectorals, associated with Tezcatlipoca (Smoking Mirror) and bellicose stellar deities; the droplet-shaped *oyohualli* pendants of Tlahuizcalpantecuhtli (Venus as the Morning Star) and divinities of music and dance; the crescent *yacametztlti* noseplug of goddesses of the moon and pulque, to name only a few (Velázquez, 2000) (figure 9). It is important to emphasize that many of these objects are

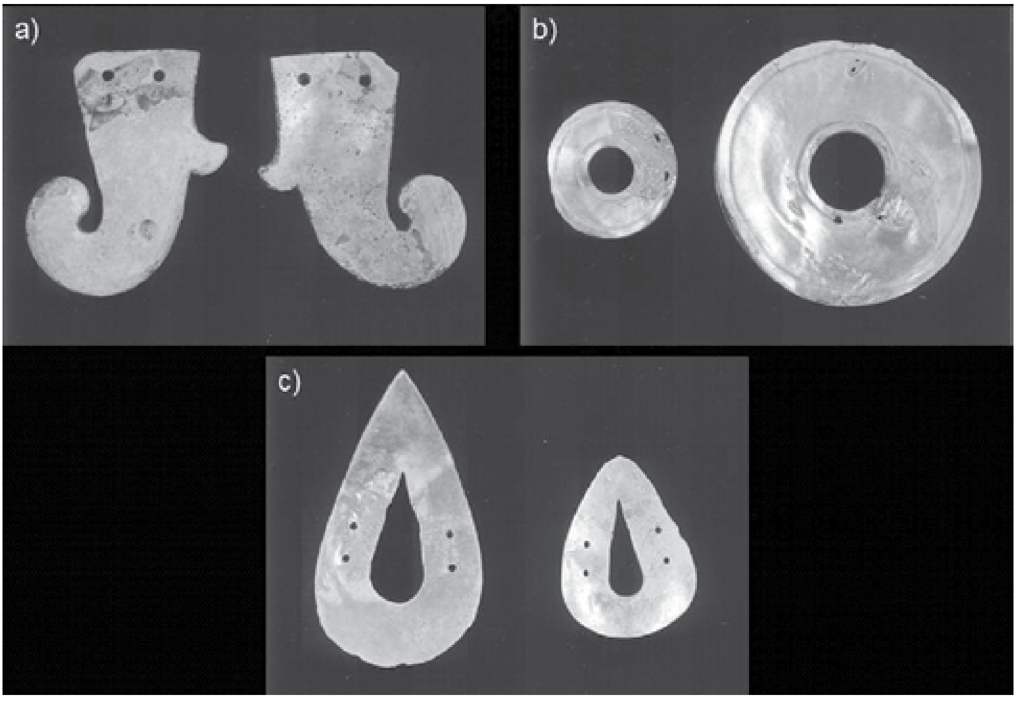

Fig. 9. *Pinctada mazatlanica* objects found in Mexica offerings: *epcololli* ear ornaments (a), *anahuatl* pectorals (b), and *oyohualli* pendants (c). Photos: G. Zúñiga.

found almost exclusively in the offerings found in the Templo Mayor itself and are absent in many of the neighboring buildings; significantly, no specimens identical in shape or raw material have been found at any other site in the Basin of Mexico. An interesting example is the spiral-shaped *ehecacozcatl* (wind jewel) found at Hualquila, Iztapalapa, which differs noticeably from specimens from Tenochtitlan, because the former was made of *Strombus gracilior* and displays perforations for suspension, while the latter are invariably made of *Turbinella angulata* and bears no bored holes (Mancha, 2002:212-215; Velázquez and Melgar, 2006). Therefore, many of the shell pieces appear to be exclusive, not only to Tenochtitlan, but to its most hermetic and elite ritual practice, namely the interment of offerings in the empire's principal temple. This in itself strongly suggests their manufacture must have been local and controlled by the state apparatus.

The study of manufacturing techniques employed in shell objects from Tenochtitlan offerings was carried out initially on a representative sample composed of pieces of the Pacific, *Pinctada mazatlanica* pearly bivalves and shell pendants of the *Oliva* genus, whose different species come from both the Pacific and Atlantic (figure 10). These elements were selected because they were the most numerous in the collection; together they form 61.46% of the complete pieces in the overall research corpus: 595 complete objects and 605 fragments of *Pinctada mazatlanica and* 785 pendants and 106 fragments of *Oliva* shells (1380 complete pieces and 711 fragments in total). They appear in the largest number of offerings

Fig. 10. Shell pendants of the *Oliva* genus from offering in the sacred precinct of Tenochtitlan. Photo: G. Zúñiga

(32 of the former and 35 of the latter), and they are the only shells that were present in all construction stages of the Templo Mayor and the sacred precinct of Tenochtitlan in which shell objects are present (stages IV–VII). Similarly, there is a diversity of forms and modifications of the specimens (Velázquez, 1999:110–117). In addition, it is important to mention that the *Pinctada mazatlanica* objects are exclusive to offerings found at the Templo Mayor, because they are absent in votive deposits from the neighboring structures and from any other location in the Basin of Mexico. Furthermore, shell pendants in general, including those manufactured from specimens of the *Oliva* genus, show a broader distribution, because they are even found in other Late Postclassic period dominions in the Basin of Mexico. This suggests two spheres of circulation for shell objects: one free and the other restricted.

Through the analysis of manufacturing traces, the objects made of *Pinctada mazatlanica* revealed strong standardization of production techniques. In all cases the pieces displayed traces of abrasion with basalt tools on surfaces and edges; the use of obsidian tools for cutting and incised designs, and of flint perforators in round borings. The few elements that show evidence of surface finishes reveal a combination of polishing with a still-unidentified abrasive and of burnishing with a soft material, similar to leather (table 2). In the case of the *Oliva* shell pendants, although it was possible to detect a tendency toward standardization, groups of objects were also found with specific modifications, made with unique procedures and tools. One of the most frequent work processes—the removal of the shell's spire—was evidently done in most cases through abrasion with passive tools made of basalt; in fewer cases was this performed through direct percussion; and in an intermediate number of cases combining both procedures; in only one piece was the use of powdered obsidian detected as an abrasive to cut this part of the shell. The second most important modification numerically was the making of a grooved perforation in the dorsal zone of the shell; in all cases it was done with obsidian tools. In the few examples of conical boring the use of a sand abrasive or flint perforators was detected (table 3).

Modification	Stereoscopic microscopy				Scanning electronic microscopy	
	Present	Not identifiable	Absent	Total	Identified material	Pieces analyzed
Surface abrasion with stone tools	151	54	1	206	Basalt tool	5 (IVb & VI)
Cut with lithic tools	76	36	94	206	Obsidian tool	6 (IVb, VI & VII)
Abrasion of edge with stone tools	157	49		206	Basalt tool	4 (IVb & VI)
Perforation with lithic tools	92	29	85	206	Flint perforator	6 (IVb)
Incision with lithic tools	42	16	148	206	Obsidian tool	5 (IVb, VI & VII)
Openwork with lithic tools	32	34	140	206	Obsidian and basalt tool	6 (IVb & VII)

Table 2. Manufacturing traces identified on *Pinctada mazatlanica* pieces

Modification	Stereoscopic microscopy		Scanning electronic microscopy	
	Technique	No. of pieces	Material	Pieces analyzed
Spire cut	Abrasion with passive tool	339	Basalt	9 (IVa, IVb, VI & VII)
	Percussion	94		
	Abrasion and percussion	188		
	Abrasion with active tool		Powdered obsidian	1 (IVb)
Grooved perforation	Abrasion with lithic tools	430	Obsidian tool	10 (IVb, V, VI & VII)
Conical perforation	Abrasion with abrasives	23	Abrasive sand	1 (IVb)
	Abrasion with lithic perforator		Flint perforator	1 (VII)
Total pieces analyzed: 652				

Table 3. Manufacturing traces identified on *Oliva* genus pieces

After determining the specific procedures and tools used in the manufacture of shell objects, some of the *Pinctada mazatlanica* objects that occurred in standardized forms and that appeared in several offerings and construction stages of the Templo Mayor were experimentally replicated. In addition to the opportunity to focus on particular issues related to the production of certain pieces, this made it possible to calculate, although only hypothetically, a portion of the production time that the workshop(s) must have devoted to preparing for an important ritual event: the inauguration of construction stage IVb, when ten sumptuous offerings, among the richest found to date (López, 1993:237), were interred. In this regard, suffice it to say that among the different types of objects and materials contained in these deposits, 731 pieces of shell were found, including the three types of replicated elements: the droplet-shaped pendant (*oyohualli*), the ear ornament with a volute (*epcololli*), and the round, incised, openwork pectoral (*anahuatl*). The steps to produce these pieces were as follows:

1. Removal of outer and middle layers of the shells through abrasion with a basalt tool.
2. Producing a preform, making straight cuts on the contour of elements with sharp obsidian bladed tools.
3. Correcting the preform, smoothing the edges with basalt tools. In the case of the *epcololli* ear ornament, the preform had to be made thin through friction with the rock to later shape the specific parts of the object, cutting it with obsidian tools.
4. Producing the openwork parts in the middle for the *oyohualli* pendant and the *anahuatl* pendants, cutting with sharp-edged obsidian tools and correcting the edges through abrasion with obsidian implements.
5. Making the biconical perforations, smoothed with sharpened flint tools in the *oyohualli* pendant and the *epcololli* ear ornament.

Producing two concentric incised lines with an obsidian instrument on the *anahuatl* pectoral (figure 11, table 4).

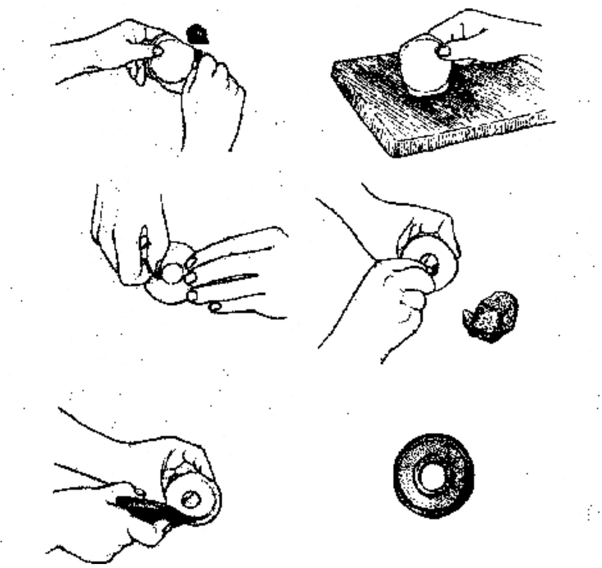

Fig. 11. Process of making an *anahuatl* pectoral. Drawing: J. Romero.

Type of piece	Number of specimens	Production time for each piece	Total time
Epcololli ear ornament	11	91 hours 32 minutes	1006 hours 52 minutes
Anahuatl pectoral	35	39 hours 29 minutes	1381 hours 55 minutes
Droplet-shaped pendant	10	24 hours 59 minutes	249 hours 50 minutes
		TOTAL	2638 hours 37 minutes

Table 4. Production times for *Pinctada mazatlanica* objects from offerings in Templo Mayor construction stage IVb

As for the *Oliva* shells, a similar calculation was made by multiplying the production times obtained in the experiments by the number of archaeological pieces displaying these features. It is worth noting that in the cases in which the deteriorated condition of the objects made it impossible to determine the specific techniques used in their production, they were regarded as the product of the more efficient processes and tools (table 5).

Discerning the processes and tools used to manufacture Mexica shell objects makes it possible to draw inferences regarding specialized production, in which specialization is understood as an institutionalized form of organizing production, in which certain groups are at least partially removed from subsistence activities, by receiving remuneration, in money or in specie, for work or knowledge that is exclusively theirs (Clark & Parry, 1990:297; Costin, 1991:3-4; Evans, 1987: 113; Longacre, 1999:44). The striking homogeneity detected in tools and techniques, in the case of *Pinctada mazatlanica* pieces, makes it possible

Modification	No. of pieces	Individual production time	Total production time
Removal of spire by abrasion using basalt	76	50 minutes	63 hours 20 minutes
Removal of spire by percussion	21	18 minutes	6 hours 18 minutes
Removal of spire by percussion and abrasion	39	35 minutes	22 hours 45 minutes
Removal of spire by unidentified means	50	18 minutes	15 hours
Grooved perforation with obsidian tools	113	41 minutes	77 hours 13 minutes
Grooved perforation with unidentified means	66	41 minutes	45 hours 6 minutes
2DRC perforation with obsidian flakes	3	1 hour 30 minutes	2 hours 30 minutes
Total modifications	368	Total time	234 hours 12 minutes

Table 5. Production times for *Oliva* genus shell pendants from offerings in Templo Mayor construction stage IVb

to infer a concentration of productive activities, because it has been proposed that standardization is indicative of large-scale production in few locations, while variability attests to production in low volumes in multiple independent workshops (Costin, 1991:35-36). This idea, together with the exclusiveness of the objects, not only in the sacred precinct of Tenochtitlan, but also in its supreme religious building, gives rise to the notion that production was local and must have been carried out under the strict supervision of the upper echelons of the priesthood—possibly in a context of dependency or patronage (Costin, 1991:5, 7 & 12)—within workshops located in the very palace of the Mexica ruler. From documentary sources we know these workshops were devoted to producing luxury goods made of feathers, lapidary stone, silver and gold (Sahagún, 1989:521). Based on the reconstruction of the hypothetical time required to make some of the most important pearly shell objects, and multiplying it by the number of elements produced for the consecration of architectural stage IVb, it has been possible to calculate the number of hours employed to produce a small part of the total number of pieces of shell buried on that occasion. Although it was an event of singular importance, for which there must have been an exceptional investment of labor, the above-mentioned calculation gives us an idea of the intensive activity that must have involved workshops producing luxury objects; it should also be recalled their production was not only intended to be buried in offerings for special events, but also for other celebrations scheduled throughout the year, public ritual, as well as elite ostentation and use. Therefore, it seems highly probable that the specialists responsible for producing these pieces worked full-time in this activity.

In contrast to the strong standardization of the *Pinctada mazatlanica* pieces, the shell pendants made from the *Oliva* genus display a generalized tendency to homogeneity in their manufacturing techniques, in which some pieces with particular variants stand out, suggesting a certain dispersion of production groups. Perhaps there were several workshops, each of which could have had its own way of working objects, which would explain their relative diversity. Hypothetically, one might propose that the objects that display the most recurrent techniques (removal of spire by abrasion with a passive basalt tool, percussion, or a combination of both techniques, as well as the production of a grooved perforation with obsidian tools) might be pieces produced in the Basin of Mexico—perhaps even in Tenochtitlan itself—while the less numerous groups of pieces (those that display cutting of the spire through abrasion with active tools and conical perforations) might be non-locally made pieces. Another explanation for this lack of standardization might reside in the wider circulation of these ornaments, with which the Mexican state could have recognized plebeians who excelled in warfare; therefore, they might have been elements of lesser status than the *Pinctada mazatlanica* objects, produced in greater volumes, perhaps sacrificing uniformity and quality of production for the sake of greater technological efficiency. Suffice it to compare the hour and a half of work spent manufacturing an *Oliva* shell pendant, removing its spire through abrasion with a passive basalt tool, and producing a grooved perforation at its base with an obsidian tool, with the twenty-four hours fifty-nine minutes that it took to make an *oyohualli* pendant, which is the least laborious *Pinctada mazatlanica* piece from the technological standpoint. Although information available at this moment is not sufficient to draw conclusions regarding centralization, context, and intensity of *Oliva* genus pendant production, it is difficult to imagine the Mexica state did not have direct control of the manufacture of an important element of social mobility. It is tantalizing to suppose that in the workshops located in the ruler's palace, artists with greater expertise performed the most delicate production processes on the most complex pieces, while apprentices were responsible for carrying out the more monotonous work and the manufacture of simpler objects of lesser value.

As mentioned above, the study of the production technology of shell pieces in Mexica offerings has contributed information for further discussion of the origin of their manufacture. In the case of *Pinctada mazatlanica* objects, the fact they are exclusive to Tenochtitlan and specifically to its most important religious and political building, together with their strong technological standardization have made it possible to posit not only the local character of their production, but even the existence of a technological style characteristic of the Aztec capital (Velázquez, 2007:182-183). The concept of technological style is based on the fact that in the different phases of the technical processes—also known as operational chains (Leroi-Gourhan, 1943, 1945)— producers have to make decisions when faced with a variable array of choices, restricted by environmental, historical, social, and cultural factors (Lemmonier, 1986:153; Schiffer, 1992:51). There are no external limiting factors for a sufficiently powerful human group to be the only causal factors in the entire decision-making process in the operational chains (Pfaffenberger, 1988:241), which according to ethno-archaeological research tend to be systematic and consistent, dictated to a large extent by custom (Sackett, 1990:33), in which technological limits coincide with those of communities. Therefore, the notion of technological style has been proposed as the group of choices a human groups makes, which constitute knowledge of a manufacturing tradition (Stark, 1990:27). When it comes to *Oliva* gastropod pendants, their relative heterogeneity suggests they are the product of different technological traditions, a principal one in which two techniques (abrasion and percussion) are used and the combination of them to remove the shell spires, as well as abrasion with an obsidian tool to produce grooved perforations, which is displayed by the greatest number of pieces and appears from construction stages IV to VII; and others that are represented by few examples and that appear dispersed in different offerings or else concentrated in particular votive deposits. Again, the principal style is tentatively proposed to pertain to Tenochtitlan itself, while the techniques and tools that appear sporadically might be indicative of non-local traditions, whether from the Basin of Mexico, tribute-rendering provinces in the Aztec Empire, or regions beyond their sphere of domination (Velázquez, 2007:183–184).

Recently another group of shell pendants also found in Mexica offerings was studied. These belonged to genera other than *Oliva* (*Nerita*, *Neritina*, *Cassis*, *Polinices*, *Columbella*, *Nitidella*, *Olivella*, *Agaronia*, *Marginella,* and *Conus*). In these cases, the use of sandstone, not found in the Basin of Mexico, was identified as the material used to remove the spire of some examples, abrade the surface of others, and produce irregular perforations. The fact that the majority of the species identified come from the Atlantic littoral makes it highly likely that these objects came from the Gulf Coast, perhaps from the Huasteca region, where there is an abundance of sedimentary rock and which was conquered by the Aztec Empire during the reign of Moctezuma Xocoyotzin (1440–1469), and remained a subject of the empire until the rule of Moctezuma Ilhuicamina (1502–1520) (Velázquez et al., 2010; Velázquez & Zúñiga, 2010). Six *Olivella volutella* pendants found in Burial 1 of Building 1 in Tancama, Querétaro, a Postclassic period site pertaining to the Huastec culture, are relevant to the case in point. These objects are identical to those found in the offerings in the Templo Mayor of Tenochtitlan and the study of their manufacturing traces made it possible to identify sandstone as the material employed to make the irregular perforations by abrasion (Velázquez et al., 2010) (figure 12).

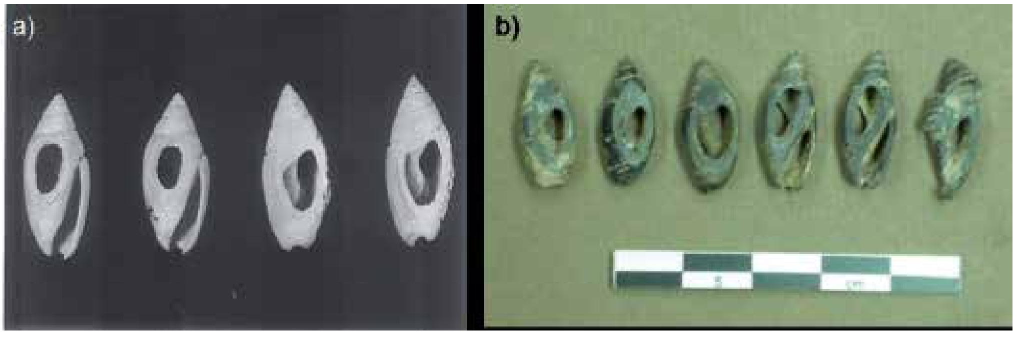

Fig. 12. Shell pendants of the *Olivella* genus from the sacred precinct of Tenochtitlan (a) and from Tancama, Querétaro (b). Photos: G. Zúñiga.

5. Conclusion

The analysis of experimentally replicated manufacturing traces has shown that the different processes and tools produced different features with distinctive characteristics that make it possible to differentiate them and identify them with archaeological materials; this can be conducted on several levels (macroscopic and microscopic), depending on the extent of fineness that one requires. In the specific case of the present research project, it was of vital importance to distinguish between tools and materials with the greatest degree of precision possible, because it provided the key to obtaining important information on technological homogeneity or heterogeneity, the basis for discussion of the origin of shell artifacts and regarding some parameters of specialization; in this work, the use of the scanning electronic microscope (SEM) has been invaluable. Nevertheless, it is important to mention that SEM analysis of manufacturing traces is not an easy, mechanical task, because it is necessary to know the material that is being studied and to be familiar with it, to avoid confusing aspects of its structural characteristics with human modifications or with deterioration processes. For the characterization and identification of work traces, characteristics of relief, texture, bands, lines, and particles visible in micrographs on four magnification settings (100x, 300x, 600x, and 1000x), which seem to be the most adequate for present purposes, are taken into account. One cannot overlook the fact that characterization and identification of the micrographs implies interpretational work in which training and experience play a crucial role; this is an especially delicate matter in the case of archaeological objects, which almost always display some degree of deterioration, even when their condition might appear to be optimum. In this way, although it is possible to define clear parameters to distinguish to a certain degree the different materials and tools, there is always an element of subjectivity in their assessment.

The information obtained from the analysis of work traces on archaeological materials from the sacred precinct of Tenochtitlan has made it possible to discuss aspects such as their origin and specialized production. The discovery of strong formal and technological standardization in *Pinctada mazatlanica* pieces and of a general tendency toward standardization in the case of *Oliva* genus shell pendants have made it possible to propose their production pertains to a style that can be regarded as identified with Tenochtitlan. Other groups of objects that display different forms of production have also been found that seem to represent non-local styles. This is the case of the shell pendants of genera other than *Oliva* that can hypothetically be proposed as pieces of Huastec production. The high degree of technological standardization in the *Pinctada mazatlanica* pieces might suggest a strong concentration of production units, which were possibly in the very palace of the ruler and where the artisans worked and resided, sponsored by the elites. The elitist character of these pieces and their major symbolic and ritual importance support this idea. On the other hand, their lengthy production times, the skill necessary to produce them, and their high demand in Mexica ceremonial life strongly suggest the individuals in charge of their production were full-time artists, expert in the production of divine attributes.

On the other hand, the relative variability of manufacturing features of *Oliva* shells, pertaining to the style posited as Mexica, suggests the dispersion of groups of artisans responsible for their production. The low production time for these elements, compared to *Pinctada mazatlanica* pieces, are congruent with their lesser status, because they were circulated among lower social groups as a means of recognition for services rendered to the state in warfare. Therefore, their production seems to have taken into account technological efficiency for the sake of the high volume of production and in lieu of optimum results. The preceding provides an alternative explanation for the heterogeneity of the pieces, which might have been produced in the same workshops as the pearly objects, but by less experienced artisans or perhaps apprentices.

In closing, the purpose of this text has been to show the potential of the study of manufacturing traces through scanning electronic microscopy in elucidating different aspects of ancient societies.

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Section 4

Sharing Knowledge – Some Proposals Concerning Heritage and Education

10

Heritage Protection in Pécs/Sopianae

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1. Introduction

Pécs is a historic city. A unique symbiosis of four important historical ages, namely the Roman Age, the Middle Ages, Turkish times and the late Baroque Age is present in the city. The topography of Pécs, together with the large green areas in the downtown, forms a special architectural neighbourhood.

The Late Roman, Early Christian cemetery of Pécs had already been discovered by 1780. Since then, preservation and exhibition of the cemetery has been of continuous importance for everybody. As a reflection of several hundred years work on the Early Christian cemetery of Sopianae (Roman name of Pécs), the site was awarded World Heritage status in 2000.

Over the last 40 years, research and planning works of the burial site has been carried out by Prof. Dr. Zoltán Bachman and his colleagues from the University of Pécs, Pollack Mihály Faculty of Engineering and Information Technology. Over this time a university course was established in the field of architecture, and later the Marcel Breuer Doctoral School was founded, where the main research field is heritage protection. With the foundation of the doctoral school, an important research base of heritage protection was established.

Several important projects were carried out over the last few years. The Cathedral Museum was built to provide a place to house the original stonework of the Cathedral, originating from the 12-13th century. The northern and the western walkways along the town walls were constructed as important green areas of the downtown. Preservation of the Early Christian Mausoleum and of the burial sites in Apáca Street, together with the construction of the Cella Septichora Visitors' Centre, represented a great challenge for the architects and engineers. During the archaeological works of the Cella Septichora, the seven burial chambers located around it were also preserved. Nowadays all of these chambers and burial objects can be visited from the visitors' centre.

The City of Pécs has two main squares. The religious main square, in front of the cathedral is connected to the civil main square by a promenade that was reconstructed during the works of the Cella Septichora Visitors' Centre. The moving bell-tower of St. Bartholomew and the building of the Archaeology Museum mark the beginning of the promenade.

2. Methodology

The question was the same at every archaeological site: how to start the works. Foreign projects were studied but did not provide much insight because in Italy the conditions were so favourable that they only had to ask for an admission fee at similar archaeological findings. The Bulgarians replicated the artefacts for the public and the Romanians simply blocked access of the archaeological sites. However, it was a Bulgarian building engineer who helped the team of Prof. Bachman. This expert achieved great results in the field of treating the air. His expertise opened new paths in the approach of the planners.

2.1 Basic questions

Three basic questions needed to be solved to save the archaeological sites in Pécs:

Firstly the painted burial chambers had to be isolated from the earth surrounding them, so they could no longer get contaminated by micro organisms breeding in the moisture which destroy the frescos. The solution was the establishment of a buffer zone, that is, a system of corridors surrounding the archaeological artefacts, the burial chambers. Secondly, constant air quality had to be secured as this is optimal for the frescos. In the special climate the temperature should be 13°C and relative humidity should be 55%. Special glass structures had to be designed to protect the frescos. Thirdly, the question was how to work securely but efficiently underground. The answer was given by miners, by Swabian excavation crews from the Mining Company in Dunaszekcső. They were brave and comfortable in at least four different trades, most of them were real artists of manual labour. They had intelligent hands (Bachman, 1989).

2.2 Problem of understandable presentation

Maybe the hardest question for each project was how to present the protected archaeological site to the visitors in a way that they can also understand what they are seeing. The solutions came through special views, natural light, transparency or clear visibility from different angles for the architects. The most important point at the world heritage site of Pécs was to make it clear for visitors that this cemetery was above the ground in the 4th century AD and this is what differentiates it from any other Early Christian archaeological site of the world.

3. The Cathedral Museum

The Cathedral Museum can be found in front of the vaulted passageway leading towards Pécs' Cathedral. It was sunk into the area of a former moat, between the walls of the bishop's castle and the contrascarpa, which was then filled up, in the Baroque Age. This considerable building was turned into an almost hidden, subterranean anti-building, providing a spacious interior to house the collection of the Cathedral (Bachmann, 2010).

3.1 Stone findings of the cathedral

The Cathedral of Pécs, founded in 1009, preserved outstanding architectural and sculptural elements from the 12th and 13th centuries even on a European scale. In the 19th century it was reconstructed following Purist principles according to the plans of Frigyes Schmidt, a German architect. The original stone sculptures were replaced by new, reconstructed elements (see Fig. 1).

Because of the reinterpretation, frequent reconstruction and completion of the Romanesque and Gothic architectural elements, the original stones were forced to wander for decades,

Fig. 1. The Cathedral and next to it the Cathedral Museum

being taken to various locations several times. A Cathedral Museum was really needed to establish a suitable place to display the original stone sculptures.

In the 1880s a find of stone-sculptures and architectural carvings was made in Pécs, the largest one that had ever come to light in Central Europe. In the course of the reconstruction of the Cathedral more than a thousand stone carvings were uncovered, providing evidence of a stunningly rich church decoration; it was unique in Romanesque Hungary and was rarely matched in the neighbouring countries. The exceptional discovery created a nation-wide sensation at the time and generated an international interest in scholarly circles. These decorations were made in the second half of the 12th century, an exceptionally prolific period of Romanesque sculpture. They embellished the church interior, primarily the central area between sanctuary and nave. It was precisely in this zone that the most outstanding sculptural ensembles were uncovered in the late 19th century. The ruins found at the centre proved to be the remains of a lavishly adorned small edifice, while the stairs descending from the nave to the crypt were framed by unusually high walls with relief decorations.

The Altar of the Holy Cross (see Fig. 2) stood on a separate platform in the very centre of the Romanesque church, a place determined by its liturgical significance. The altar was enclosed in a vaulted structure gorgeously decorated both inside and outside with carved ornamental reliefs, gilding and polychromy; placed in the church's interior, this small building must have looked like a large jewellery box. The masters who accomplished them imported the

Fig. 2. The Altar of the Holy Cross

traditions of Northern Italian ornamental stone carving to Pécs. In the process they created a unique work of art: such a lavishly decorated altar baldachin in the shape of a building is unparalleled in the whole of Europe. As indicated by a further series of carvings, decoration of this kind was not absent in the area around the altar either.

The abundance of ornaments and colours were integrated within the narrative framework of large-scale relief cycles, which covered the walls of the entrances to the crypt. Their images spanned all that medieval man considered to be his past and future: the history of Salvation, from Genesis to the Last Judgement. It was an immense and ambitious programme, paralleled by only a few similar works in contemporary Europe. To carry out the plan, a number of outstanding masters were invited from abroad, which mediated recent trends in sculpture from France and Northern Italy. The walls of the southern entrance to the crypt were decorated with parallel cycles of the life of Christ and that of Samson, a hero in the Old Testament. They rank among the greatest achievements of medieval art in Hungary, while some of their scenes, for example, the Three Magi and the Passion of Jesus or the story of Samson are also regarded as remarkable works of universal Romanesque sculpture. In the presentation of the Creation and Adam and Eve in the northern entrance to the crypt, local craftsmen were also engaged. They were equally responsible for the sculptures of the elders of the Apocalypse and the angels. One of these figures, an exceptionally well preserved and beautiful angel (see Fig. 3), escaped the usual fate that befell most of the stone carvings in Pécs during the Ottoman occupation, since it had been incorporated into the Gothic triumphal arch of the sanctuary.

Fig. 3. The figure of the angel

In the opinion of the 19th century restorers of the Cathedral, the uncovered remains of the once so splendid Romanesque decoration were too fragmented to be incorporated into the new church. The only acceptable solution seemed to be replacing them with copies reflecting the tastes of the time; the entrance to the crypt is now decorated with such copies. Detached from their original contexts, the carvings became pieces in a sculpture collection. During the one hundred-year history of the collection, periods of exhibitions alternated with spells of confinement in storerooms. Owing to the dampness of its walls, the last venue of the stone carvings, the Romanesque Lapidary Museum closed its doors more than twenty years ago. That was the time when the collection’s confinement to storerooms began eventually ending up in a cinema in a village near Pécs, the eighth station in the calvary of the stone carvings. In the meantime a generation grew up for whom these splendid relics of medieval Hungarian art and European culture simply do not exist.

Having been made homeless, the stones of Pécs’ cathedral were almost added to the long list of Hungarian cultural losses. The decisive turn in their fate came as a result of the concerted efforts and financial support of central and local authorities - the Ministry of Culture and Education, the Hungarian Bureau for the Protection of Historical Monuments, the City

Council of Pécs, the County Council of Baranya, and the Janus Pannonius Museum of Pécs - as well as of the Bishopric of Pécs. On their initiative, the Pécs Cathedral Museum Foundation was created in 1990. Its trustees launched a dynamic action for the physical presentation and cultural survival of the collection with two objectives: the conservation of the stone carvings and the construction of a new Cathedral Museum. The conservation was the first comprehensive effort of this kind in the history of the collection. The carvings were cleaned, the condition of the stones was stabilised, and a good part of the strongly faded polychromy, along with important portions of gilding, was successfully recovered. The substantial financial support of two prestigious foundations from the United States (the Grant Program of the J. Paul Getty Trust, Los Angeles, and the World Monuments Fund, New York, administrator of the Samuel H. Kress Foundation's European Preservation Program) played a major role in the conservation, and so did the generous donations by a group of Hungarian-born American citizens.

3.2 Concept and structure of the museum

The two castle walls provided the western and the eastern walls of the museum. The building had to be confined with the help of a buttress from the north, while from the south a glass screen entrance was constructed. Simultaneously, visitors were given the opportunity to walk up on top of the Cathedral Museum to the exhibition, providing a modern, wonderful spectacle of the sanctuary of the Cathedral from an angle never seen before. The architectural heritage of the Middle Ages, the church architecture in this case

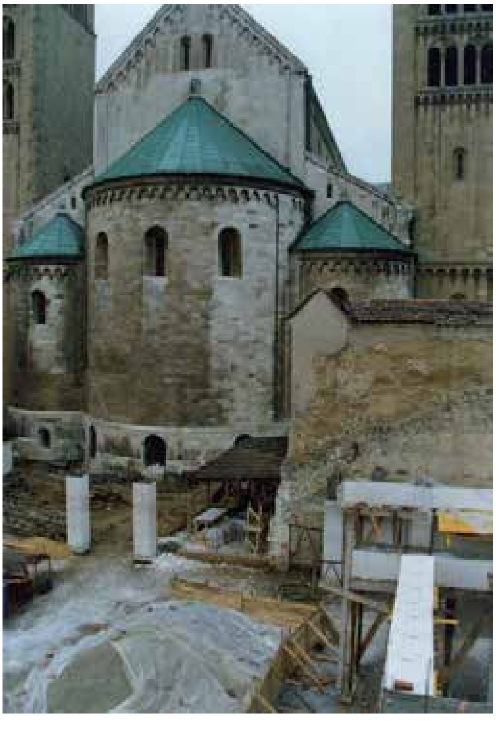

Fig. 4. Construction site of the Cathedral Museum in the former moat

remained quite fragmented because of the storms of history and the reconstructions of different ages. Because of this, the cathedral's collection of stone findings is represented in a way that these priceless treasures can be seen in almost their original setting. (see Fig. 4)

The basis of the architectural concept was to place the western gate, the Altar and the two access ways in the same way as they could be found in the Cathedral. Owing to the incomprehensible and inexplicable resistance of art historians, the architects have not managed to achieve this. It was also an important architectural consideration that regarding its view, the large subterranean museum should somehow be connected to the Cathedral. It has been achieved with the help of a glass wall that was cut into the western wall of the Bishop's Castle. The glass wall continues in the form of a wedge shaped glass ceiling. Thus the view of the Cathedral meets the eyes of the visitors in the museum, helping them to identify the former location of the stone findings; where the gate, the Altar and the entrance to the crypts were located in the original Cathedral. In addition to the regular planning work the architects had to struggle with two other things: to find funding for building the museum ; and as the construction of the museum was extremely slow, the concept had to be created according to the most modern principles.

The concept of the museum building follows the idea of the 'house in the house' composition. Damp-proof insulation of the building guaranteed protection from the moisture of the soil. In the construction at the museum, gypsum-concrete was applied, also known as frosted concrete, the patent of Béla Sámsondi Kis. At that time, the person responsible for the patent, István Szövényi, used to work for the Hungarian Bureau for the Protection of Historical Monuments, therefore the Bureau could also provide financial support to develop a new building under the pretext of technical improvement. The neutral appearance of the structure is perfect for establishing a museum. The structure achieved unparalleled solidity. Three centimetres of special consistency concrete is sandwiched between two 1 cm thick 60x60 cm gypsum panels with steel reinforcing. As the gypsum solidifies it absorbs water from the concrete creating the so-called 'frosted concrete' whose strength is outstanding. The longest span is 12 meters which is loaded in the middle. The presence of gypsum regulates the humidity in a natural way. Hans Hollein had already applied this material in a museum in Mönchengaldbach. The structure had another great advantage: the site was so narrow that it was impossible to use cranes to build the structure. When constructing the building, migrant workers from Romania worked on the project under the leadership of a project supervisor. The potential provided by these traditional tradesmen could be utilized, who even made the tools for the technology themselves. The facades provided great opportunities. The subterranean building emerges with two facades: the western façade whose main constituting element is the wall of the Bishop's Castle. The large glass wall was concealed here, interrupting the castle wall for didactic purposes and also continuing it as this joins the 'new castle wall' that follows the path of the former wall. This new wall is made of sandstone similar to the stone of the Cathedral. An emergency exit, a castle gate has also been built into the wall. The southern façade stimulates viewers with its strong colours. This was a conscious decision, as strong and vivid colours were popular in the Middle Ages. The dead and tired colours of its surrounding allow, what is more, demand the appearance of a bright red facade. (Bachman & Bachmann, 2010)

The interior of the museum has a simple double-deck arrangement. The way the gate, the altar and the passageways leading to the crypt dominated by stonework are displayed, compiled and made understandable, together with the technical details, are absolutely outstanding. Integrating this fragmentary collection of stonework findings has always been a problem. The stone restorer, Vilmos Osgyáni came up with an original idea. He created a steel structure similar to the shelves we can find in the pantry of our grandmother. Stainless steel “shelves" connect the superstructure and the jointing of the stones. Using this solution the stones are stabilized by their own weight. The stones were built together clearly without being damaged in any way. It is perfectly visible that the medieval gate was made of Roman tombstones (Romváry & Szilágyi, 2005).

The collection of the Cathedral Museum, which is an outstanding example of European culture, is now in a safe place. The museum (see Fig. 5) should remain a neutral architectural framework fitting in its environment, and should also be attractive. It should provide, as far as possible, an interactive museum presentation. The main block of the museum was built into the former moat, so it fits into its surroundings, the Cathedral, as a quasi anti-building: in which the brilliant stone sculptures of the medieval Cathedral play the most important role.

Fig. 5. Inside the Cathedral Museum

4. The Early Christian Cemetery

The Early Christian Cemetery Complex of Sopianae was established in the 4th century A.D. The cemetery ruins, which were initially at ground level in the Late Roman Era, now lie underground in the historical city centre, near the Cathedral. Below the surface were several hundred tombs. Of these, a seven-celled tomb (Cella Septichora), and a three-celled pentagon shaped tomb (Cella Trichora) were excavated on two levels. The challenges of preservation were solved by isolating the tomb from the surrounding soil and creating an environment with a constant air condition. When displaying the cemetery the architects tried to retain the experience that would have greeted those first archaeologists who excavated the 1600 year old Christian cemetery.

4.1 Early Christian Mausoleum

The Early Christian Mausoleum was discovered during the reconstruction works of the cascade in front of the Cathedral in Pécs and was opened to the public in 1986. The Early Christian building was reconstructed in 2007 (see Fig. 6).

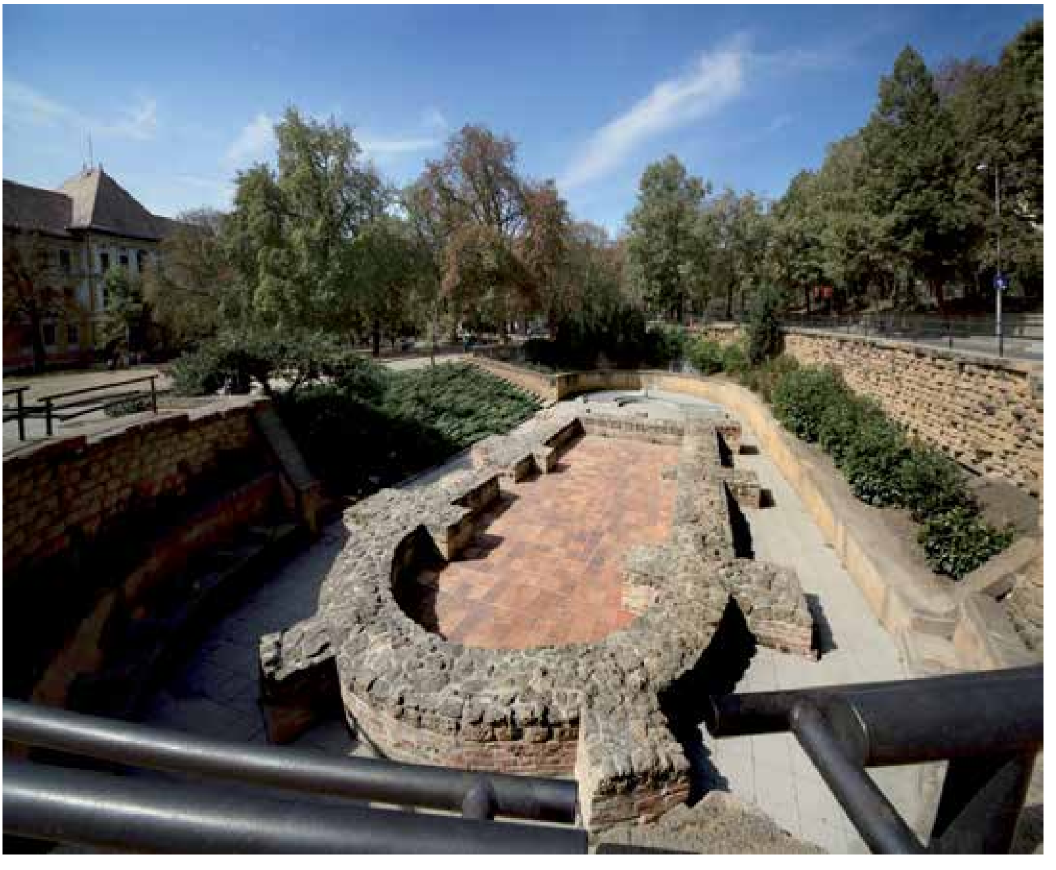

Fig. 6. The ground walls of the Early Christian Mausoleum

Three people positively influenced the planning process of the mausoleum. The first was Ferenc Mendele, who asked Dr. Zoltán Bachman to introduce the Early Christian Mausoleum, discovered when reconstructing the cascade in front of the cathedral (Bachman & Bachmann, 2001). The archaeologist at that time was Ferenc Fülep, who was also the director-general of the National Museum in Budapest at that time. He believed in the concept of the architect. Finally the project was further reinforced by the trust and love of

Archbishop József Cserháti. Unfortunately over the following years, the three who played such an important role at the beginning, passed away. That was the time when a group of students joined Prof. Bachman as creative partners.

The plans were conceived under favourable circumstances: the project won a silver medal at the Architecture Biennale in Sofia, internationally confirming that the concept was right. To make the site readily comprehensible for the general public, the mausoleum, which had been below street level for centuries, had to presented in the following way: the part of the building that was originally under the ground in Roman times should remain under the surface while the part that was above the surface should recall the sunny world of the Mediterranean. Therefore the architects decided to present the remaining meter-high ground walls of the huge, one-nave building of the mausoleum in an amphitheatre-like opening so the visitors could view the site from the present surface.

The underground world of the burial site has been separated from the surrounding soil with a corridor built around the burial chamber, which makes it possible to walk around the chamber and also protects the back wall against the potential danger caused by water entering the site. (see Fig. 7.) The Early Christian Mausoleum was opened to the public in 1986. Since then the condition of the building has decayed. In 2007 the Early Christian Mausoleum was reconstructed with the help of EU funds. (Bachman et al., 1988)

Fig. 7. Frescos and a carved sarcophagus inside the mausoleum

4.2 Wine pitcher burial chamber

The wine pitcher burial chamber received its name from the wine pitcher that was painted on the wall of the chamber. It is also unique that the building can be accessed through the wine cellar of the Baroque parsonage, giving visitors the chance for architectural time travel, experiencing the beautiful Baroque vaulting techniques.

The way the architects presented the Wine Pitcher burial chamber was relatively well paved. The principles of protection were similar to those of the Early Christian Mausoleum. The only difference lay in how the visitors could see the site. While in the case of the Mausoleum the visitors enter a glass box separating them from the regulated air-conditioned space where the frescos were, here, owing to the small size of the chamber it was impossible to achieve this. The frescos of the chamber were saved by the restorer Attila Pintér. The chamber was isolated with the surrounding corridor, which provides a space that levels off the greater air pressure inside the burial chamber and also protects it. However, the visitors, who could only look through a small door, and could not see the frescos. The vaulting of the chamber had collapsed. The architects used this opportunity to put glass vaulting over the chamber (Bachman, 1990). Through the glass structure visitors can see the mystical space of the chamber. To add the experience that the whole building was under the ground a winding staircase was needed leading the visitors from the area in front of the chamber up to the upper level, the reconstructed Roman ground level, where the ruins of the walls of the chamber are preserved in situ (see Fig. 8). Today the chamber is connected to the Cella Septichora Visitors' Centre.

Fig. 8. Wine Pitcher burial chamber under the glass vault

4.3 Peter and Paul burial chamber

The Peter and Paul burial chamber received its name from the portraits of the two apostles that are painted on the vault of the burial chamber. The location is really unique as the burial building can be found immediately in front of the south-eastern tower of the cathedral, nowadays 8-10 meters below the ground. It was discovered in 1780 so it has suffered several intrusions (Bachmann, 2002).

Despite the experience and knowledge gained in the case of the protective buildings of the Early Christian Mausoleum and that of the Wine Pitcher burial chamber, the Peter and Paul chamber posed the most difficult challenge. Its location was already a matter of concern.

The most important exploration from earlier times took place in 1913 using the plans of István Möller (see Fig. 9). He found a brilliant concept that was similar to the idea of Frigyes Schulek who designed a protective chapel resembling the Fishermen’s Bastion in Budapest (see Fig. 10). According to the concept the chamber was separated from its immediate environment, was surrounded with a protective building and the air was ventilated between them using pressure differences.

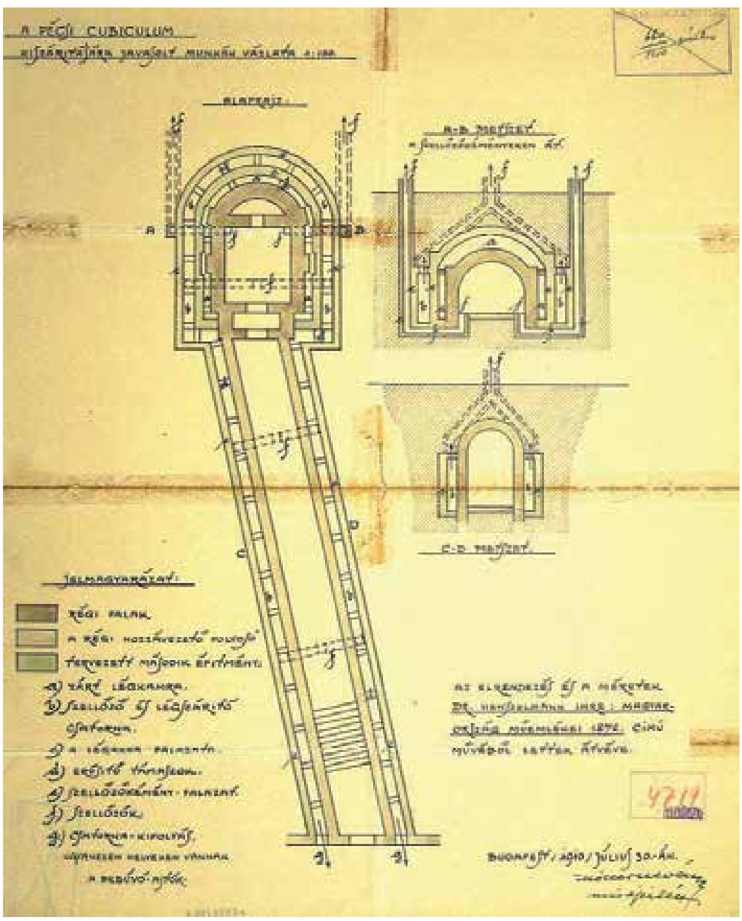

Fig. 9. The plan for the protective building of the burial chamber by Mr. Möller

Unfortunately the dampness of the air created an ideal environment for the growth of microorganisms. A further danger appeared in the form of the visitors who further

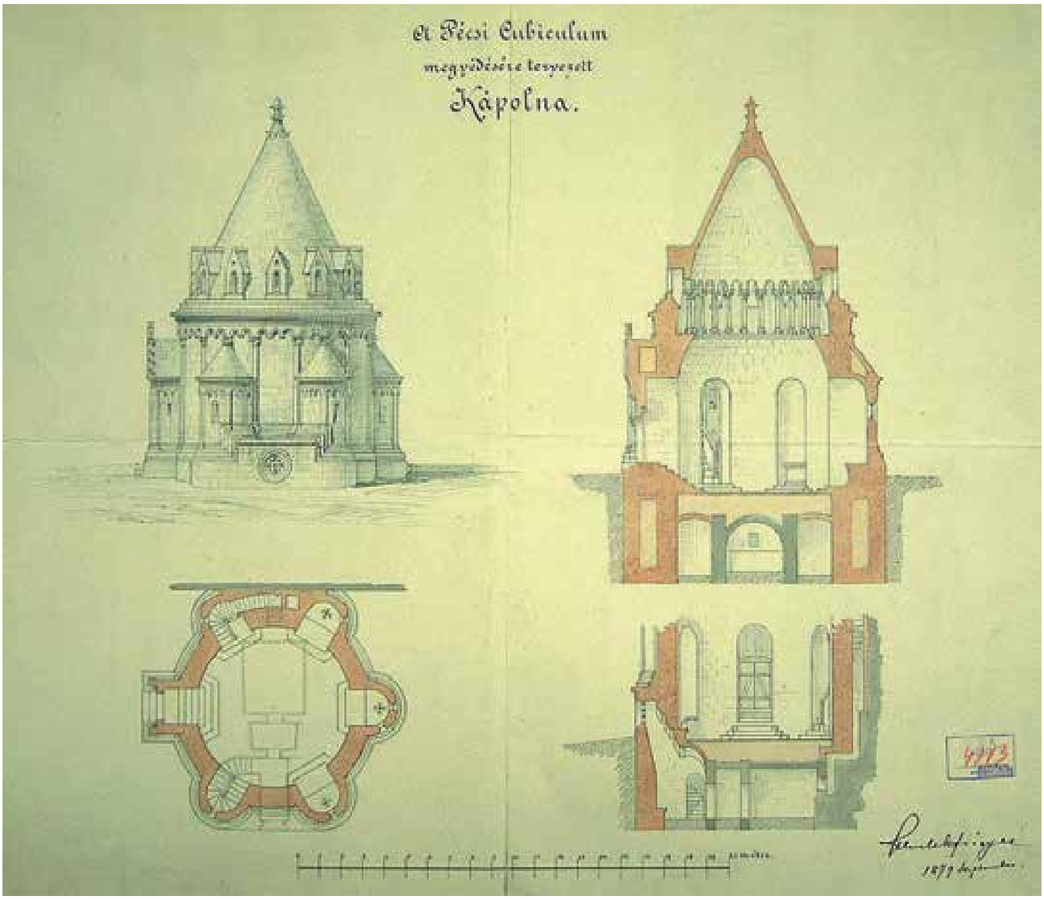

Fig. 10. The protective chapel of Frigyes Schulek

introduced pathogens on their body and breath. Möller's design included a masonry structure for the protective building. In reality however, being an excellent engineer, who was well acquainted with reinforced concrete, he decided to try this method and left the wooden formwork there, which presented another medium for microorganisms. In the end, the protective building of Möller had to be destroyed. It was a superhuman task to demolish the protective building. The more than hundred year-old concrete structures had to be demolished. It was the miners who again rose to the challenge. Using special diamond drills they drilled several holes into the reinforced concrete structure, placed steel cylinders, cut in half into them, and then put the jackhammer into these to destroy the concrete without creating any vibration. The work took half a year. As the chamber lay at the foot of the south-eastern tower of the cathedral, the architects had to unearth the foundations of the tower, too. This was only possible if the workers excavated a horizontal shaft into the unbroken soil below the level of the burial chamber. The big surprise was that the tower had no foundations. Finally soil beneath the tower was reinforced with a jet-grouting method that solved the stabilization of the tower. (Bachman, 2009a).

The concept of protection was the same as in the case of the previous burial chambers: the painted chamber had to be isolated first, then ideal air conditions had to be established, a slight pressure had to be created inside the burial chamber to make the humidity move outwards and not condense on the surface of the frescos and because of the greater pressure a buffer zone had to be built, that is a system of corridors surrounding the chamber. The chamber had been protected this way, but unfortunately the visitors were unable to see the frescos. The architects had to do something for the chamber with the most beautiful frescos. Finally they decided to build another ground floor underneath the floor of the chamber. This was the level the workers had already traversed when the research tunnels were drilled to reveal the foundations of the tower. Walking down a winding staircase and through a corridor, visitors find themselves underneath the floor of the burial chamber that has been replaced with glass (see Fig. 11). Visitors enjoy a wonderful view as a biblical world unfolds in front of their eyes: the allure of Paradise welcomes the visitors on the frescos as the late inhabitants of the burial chamber won the grace to be in Paradise because they suffered martyrdom for their faith. People entering the Peter and Paul burial chamber become silent. Something touches the visitors' heart.

Fig. 11. View of the painted vault in the Peter and Paul burial chamber

The edifice to the east that the architects believed to also be a burial chamber was also enticing, therefore the planners built the eastern wall of the protective building in a way that could be easily demolished and would not prevent future exploration. In connection with the Peter and Paul burial chamber, also burial chamber No. III was placed under protection. This chamber is closely attached to the Peter and Paul burial chamber from the west. A part of the reinforced concrete protective structure of Möller was left here as a memento. The architects did not risk demolishing it because of the danger of damaging burial chamber No. III.

4.4 Baptistery

The early Christian building of the baptistery is also known as Burial Chamber No. V. This building has a single floor, an octagonal shape and an antechamber. The baptistery has the tallest Roman walls that exist in Hungary, further enhancing the importance of the Early Christian burial ground. During the excavation works a stone window was also discovered.

The baptistery is another major burial chamber that is located east of the Peter and Paul chamber. Owing to its location at the bottom of the tower, Möller demolished the north-western part of the octagonal walls so he could underpin the south-eastern tower of the Cathedral with reinforced concrete. Beautiful and mysterious architectural details were revealed that will require the explanation of archaeologists in the future.

Since the edifice is in the immediate vicinity of the Cathedral, it seemed useful to build in a skylight, so a 3mx3m glass slab was built into the surface of the Cathedral Square making it possible to see the tower. This idea also adds to the historical continuity of the site.

Burial chamber No. V. lies completely under the surface of Cathedral Square so the incoming light makes people feel as if they are walking on the ground level of Roman times. The steel grid pavement is an important element because, on the one hand, hanging from the ceiling of the protective building above the floor of the edifice it seems to be floating in the air providing an ideal view for the visitors. In addition, it isolates the people from the ruins and finally, it illustrates the ground level of the former cemetery. In fact, it is the Cella Septichora Visitors' Centre that makes the pavement attached to the slab important as it leads the visitors through the site (see Fig. 12).

Fig. 12. Visitors on the steel grid structure looking up to the tower of the cathedral

4.5 Cella Septichora Visitors' Centre

Cella Septichora is the name of the Early Christian building which has a special elliptic form with seven apses around it (see Fig. 13). The centre provides a single framework for all other Roman and Early Christian wonders. The architects aimed to make the underground cemetery visible in a way that the visitor could get an impression of the cemetery when it was in the sunshine. This task was solved by building a 300 m^2 walkable glass-cover over the burial chambers, which also allows Cella Septichora to be viewed from street level (Bachman, 2009b).

Great poets usually had two topics to write about: death and women. The Early Christian Cemetery – a poem of Győző Csorba, the Kossuth Award-winning poet, led Prof. Bachman to visualize the concept. The poet, who, as a librarian, used to work next to the archaeological sites, watched the excavation works of the Early Christian cemetery from the windows of the library and witnessed archaeologists digging out the skeleton of a woman.

Fig. 13. Inside the Cella Septichora Visitors' Centre

Mr. Csorba described how she was lying there and imagined her coming alive. The poet 'clad' the woman with flesh and blood and muscles and the woman stirred and got up. According to the architectural concept, the world of graves is covered with a glass ceiling where Heaven may be contemplated from underneath: looking from the graves in the hope of resurrection. However, looking down, visitors can see the dark field of graves and between them the frescos of the fall and resurrection explaining the abstract state of the other world.

Funding from the European Union that the architects could apply for in relation to the 'Cella Septichora' provided the financial backing to establish the architecture required by the vision. Because of the funding process, the architects had to produce an authorization plan before the archaeological excavation. This created a bizarre situation where the construction of the protective building took place at the same time as the excavation creating a lot of tension between the archaeologists and the architects.

During the excavation works south of burial chamber No. V, incredible new findings were discovered. Thanks to the excavations of the archaeologists, the planners managed to locate the entrances of the new chambers and clarify the way the corpses had been taken into them. It was absolutely necessary to present the new findings, as it became an indispensable connecting area in the topography of the cemetery. A completely new type of burial building was discovered, which confirmed the reason why the area should become part of a world heritage site. The ground plans of the newly discovered chapels, that are named chapels No. XIX and XX, are semi-circular. These types of chapel had never been previously found. Here in the case of Pécs, this is the only Early Christian cemetery in Europe and possibly in the world, which is above ground. If Prof. Bachman wished to express high thoughts he could say that the Early Christian architecture itself was born here as a result of the Early Christian cemetery, because before that time, when this new faith was still illegal, its believers could only bury their dead in secret and under the ground, for example in the catacombs of Rome, while in Sopianae, believers could build small chapels over the burial chambers.

It was not only the Romans who valued the area of the cemetery, the people living here in the Middle Ages also made it the centre of their bishopric. It was a great responsibility and possibly forbidden to intrude into this fantastic symbiosis of historic monuments. Therefore the architects connected the various sites under the ground with the help of steel grid-structured bridges suspended from the concrete ceiling that is meant to symbolize the original surface level of the Roman cemetery. According to the architectural concept, light is allowed to enter the underground burial sites through a glass slab that is at today's street level to make people understand that they are not walking in catacombs but among chapels that once existed above the ground. This is how the Cella Septichora Visitor Centre was born, whose entrance opens from the promenade in front of the cathedral (Baliga, 2007). The entrance has a symbolic meaning as made from a massive transparent concrete gate with a small stream flowing next to it, which refers to this Early Christian symbol, water. The transparent concrete called LiTraCon is the invention of Áron Losonczy, a Hungarian architect (see Fig. 18). The stream flows over part of the glass slab, giving light to the corridor that leads visitors to the huge hall of the Cella Septichora, the seven-apse burial chapel, which is covered by a 300 m^2 glass ceiling. This is supported by a cross-shaped bridge serving as a representative pavement for the bishop. At night, when it is illuminated, the cross lying on the glass surface further reinforces the Early Christian symbols.

From the entrance hall of the Cella Septichora Visitor Centre, west of the parsonage, a passageway was built with the help of great engineering virtuosity by excavating under the parsonage itself. This corridor leads visitors to the magical space of the Cella Septichora. Returning from underneath the parsonage we can enter the world of the Wine Pitcher burial chamber. Going north, connecting the sites of burial chambers No. XIX, XX, V, III, IV and I and that of the Peter and Paul burial chamber, that had been built earlier, walking east inside the cellar and among the historic stones of the parsonage, the visitors reach a north-south corridor that ends in the courtyard of the Cathedral Museum. North of it people can recall the Middle Ages by opening a sliding roof and entering the museum. Walking to the south we return to the upper level of the Cella Septichora and reach the entrance.

It is interesting to study the reactions of visitors to the site. Especially the common labourers are those who confirm the vision: they are moved by the spaces that had previously been unknown to them and understand the message of this 1600 year old new faith. They are not only interested in the children walking and playing on the glass ceiling, but they are also impressed by the prettier shapes. The well-travelled intellectual (who has never come across this type of site before), appreciate the uniqueness of this new protective building: the symbiosis of the antique culture and the new faith. Most importantly, the citizens of Pécs feel that this space is theirs. The Cella Septichora Visitors' Centre turned into a cultural meeting place. Concerts take place here, art exhibitions are organized, new books are launched, wedding ceremonies are held, etc. So this place is alive, it has become part of the promenade. The people of the 21st century may travel in time through the exhibition of a 20th century artist, under the baroque barrel vault and over the medieval walls into the Cathedral Museum where they can listen to an organ concert and end the journey in the shady park next to the town wall.

Fig. 14. The entrance of the Cella Septichora Visitors' Centre

It was a great step forward on this project that the architects managed to combine several smaller sites, however this is still insufficient. As the Early Christian burial ground, the bishop's palace, the buildings of the Middle Ages, Turkish times and the Baroque, which form quite an eclectic group, are built upon and next to one another, architects had to integrate this colourful and valuable historic mixture. The task was complimented with another task of making a connection between Széchenyi Square, which is the town's main square, and Cathedral Square. The promenade has been reconstructed and walkways were built along the inside of the western and northern town walls. Therefore, in addition to the uniqueness of the various historic periods built upon each other, there is another specialty offered to the citizens of Pécs: a chain of lush, green parks. In 2009, the bishopric of Pécs became 1000 years old. It celebrated this occasion with a great present: the façade of the buildings of the Cathedral Square, the Cathedral, the Bishop's Palace and the parsonage were all renovated. Today's Bishop's Palace, the walkways along the town walls and the world-class Early Christian cemetery all offer great experiences for both locals and international visitors, too. The north-western quarter of the historic town centre has never been so integrated and impressive as today. The establishment of the gardens adjoining the walkways along the northern and western town wall, the reconstruction of the Roman graves in Apáca Street and the renovation of the Civil Community House have all come true as part of this EU programme.

To complete the complex of buildings around the Bishop's Palace in all their splendour, one thing remains to be built. The task of saving the Cella Trichora plays a unique role in the history of Hungarian architecture. It represents the continuity between the Roman times and the Middle Ages because it still functioned as a church in the 11th century.

5. The Archaeology Museum

The concept of the architects was for the reconstruction of the museum, preservation and establishment of connections. The mosque of Ghazi Kasim was built on the site of the former Saint Bartholomew church, whose ruins - according to an archaeological excavation carried out at the beginning of the 20th century - can be found partly under the mosque and partly north of it, in front of the museum. With the reconstruction of a museum these unique artefacts could be presented to visitors.

5.1 History of the museum building

The Janus Pannonius Archaeology Museum is located on the main square of Pécs, at the eastern end of the reconstructed promenade (see Fig. 15). By walking west from the building, pedestrians can approach the buildings of the Early Christian burial ground. The building of the Archaeology Museum received its present form after a history of many centuries. According to the first land register, in 1687 the house of Ibrahim Csór, a janissary agha, was given to the Jesuits to be used for education purposes and it became a grammar school. In 1725 the building functions as a school of the Jesuits. From 1752 it became the house of a wine-merchant then in 1773, the house of the chamber. Between 1774 and 1822 the house was owned by the Országh family. Later it also functioned as an orphanage. In 1871 the Baranya County Savings and Credit Bank owned it and operated its bank there. In 1877 the building came into the possession of Kálmán Nádasdy who built the stone fence that can be seen today along the western side of the garden. In 1898 a new storey was added to the house that was designed and constructed by Imre Schlauch. The county purchased the house in 1941 in order to use it as a museum. Finally, in 1951 the house became

Fig. 15. Building of the Archaeology Museum in Pécs

government-owned and in addition to a department of archaeology, the Directorate of the Baranya County Museums was also located in the building. At the beginning of the 1960s a new wing was built along the northern part of the garden to house the Anthropology Collection. Towards the end of the 1970s, part of the attic was converted and the ceiling on the first floor was strengthened and the storerooms were modernized. The Anthropology Collection was placed into the storeroom in the attic while the Archaeology Collection was placed in the storeroom on the first floor of the east wing. The history of the house shows the various functions the building filled over the centuries when all of them played an important role in the life of Pécs for some reason or other.

5.2 Concept for the reconstruction

Over time the building of the Archaeology Museum has fallen into a derelict state. The overall superstructure is in a very good condition but it was obvious that this protected historic building needed renovation. The concept the architects had has always been about preservation and making connections. Preservation in the course of planning, the architects wanted to preserve everything possible and that which had not been added to the building arbitrarily. The word connection may have several meanings as roads, walkways, ages, buildings and underground spaces also intersect here. Underneath the museum there are ramifying tunnels connected to the cellars still existing under Széchenyi square. According to the original architectural concept the planners would not only create cellars under the periphery of the building to establish new exhibition halls, but this work would also have been extended to the south, towards the mosque. This way the ruins of the St. Bartholomew church could be presented (see Fig. 16).

Unfortunately, this southern extension did not fit into the financial framework provided by the investor. The architectural concept was thus limited to using the present cellars of the building and also to making new cellars under the periphery of the building. This does not mean that in the case of a future reconstruction of the building, the architects will not be able to use this underground world offering many great opportunities for improvement. As part of the building's reconstruction, the inner yard will have a glass ceiling, making it a multifunctional exhibition hall. By reconstructing the building of the museum, the planners can also make it accessible for disabled people, although within the limitations a historic building may have. The concept of the museum is also adjusted to the preserving-connecting philosophy of the architectural concept. Széchenyi square and the area west of it formed the historic centre of the town of Pécs. During the reconstruction works of the main square of Pécs in 2010, a burial chamber was found in front of the museum. For financial reasons this chamber was documented by the archaeologist and then reburied. It is quite probable that in the course of excavating the cellars, archaeologists could find several artefacts from the Roman period, which could then make the museum even more attractive. If there are interesting finds under the building then these could be displayed 'in situ' so the museum itself could become part of the exhibition. In this connection the museum, the exhibits, the attraction and its framework are all united. The various ages could also mean a further point of connection in the concept of the museum, as visitors will take a journey in time in the museum. Starting from the 21st century show rooms on the first floor, visitors will be able to reach the time of the Roman Empire in the cellars through the Baroque period and the Middle Ages. A museum concept of this kind helps visitors connect the various archaeological finds to their periods and also understand them. In addition to these ideas, the architects wished to give the museum yet another role. Owing to its location and

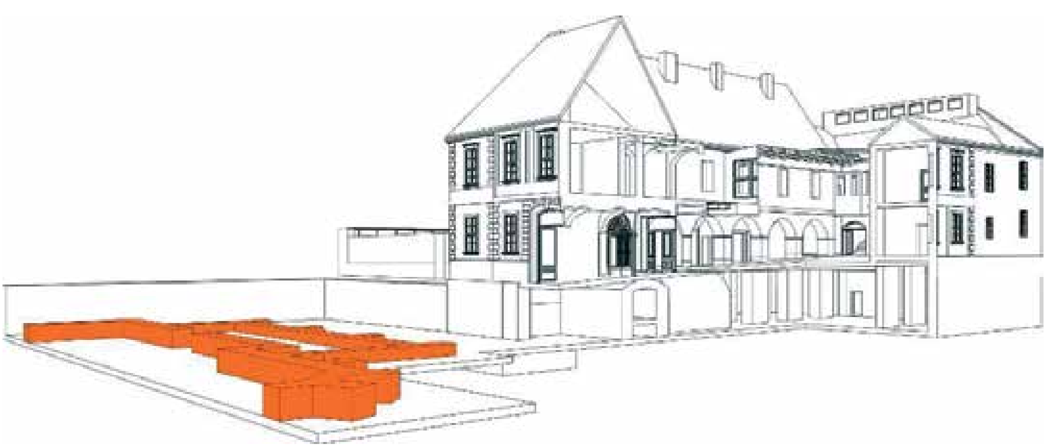

Fig. 16. The ruins of the St. Barholomew church in front of the Archaeology Museum

because it is close to the walkways popular among tourists, the building could become the information centre of the World Heritage site. The tourists visiting Pécs can get the necessary information they need to discover this colourful town, which has been influenced by several cultures.

A row of arcades along the western side of the courtyard was walled up in the course of an earlier reconstruction. By undoing these, an architectural solution could be restored that could function really well, reducing the amount of sunlight the showrooms receive and meaning the employees would not have to use any additional shading. The geometry of the glass ceiling covering the inner yard of the museum would not be simple, as the height of the moulding, on parts of the building constructed over the various ages, are different from each other. The architects managed to design the geometry of the ceiling in a way that would ensure ventilation of the exhibition hall with the help of shutters. The designed architectural solutions are always separated from the existing structure under protection, ensuring faithfulness to the building and its didactic introduction. In the new spaces created by the enlargement of the underground level the vaulted cellars would appear as houses in the house providing the visitors with an interesting, new perspective. (Molnár, 2009)

The garden plays an important role in the architectural concept for various reasons. On one hand it is a green oasis in the museum, in the town and also in its main square; on the other hand the architects wish to display exhibits here that look like an open-air place, like a separate museum of stonework finds. At the same time, however, the youngest ones, the children should not be forgotten. Small interactive spaces in the garden were designed for them where they could get acquainted with the finds of the various periods in more intriguing, playful manner.

Unfortunately, the reconstruction of the Archaeology Museum in Pécs ground to a halt because of financial pressures of the investor. The architectural solutions to be implemented guarantee a framework for the concept of a museum where the architectural and archaeological remains of the early Christian period of the Roman Empire, the Middle Ages and the Turkish times as well as those of various ethnic groups (German, Croatian, Serbian, Turkish, Bulgarian) having inhabited the region since the beginning of the 19th century can be introduced. Hopefully the designed concept will be constructed in the near future.

6. St. Bartholomew’s bell-tower

One of Europe's most beautiful pasha mosques decorates the main square of Pécs and is used as a catholic church. The congregation wanted to build a tower, a belfry, a campanile. This would have resulted in a rather strange architectural formation if the congregation had been called to mass by the peal of a relatively high campanile standing by the mosque. The architects finally had the idea of creating a sculpture composition, a bell sculpture, which rises like a tower while the bells are ringing and then sinks back to the size of a bell sculpture (Bachman, 2010).

The congregation of the City Centre Catholic Church, in Pécs’ Széchenyi Square were longing for the ringing of bells for their church. It is quite understandable when you take into consideration that this is the square where János Hunyadi’s statue reminds us of the Pope’s call for all the bells of Europe to ring in remembrance of János Hunyadi, the Turk Conqueror. It is not a simple task to erect a tower; it could even be sacrilegious in this case for a mosque, even if it does serve as a catholic church today. A mosque can have a minaret, but it would be strange to hear bells from it. The mosque of Ghazi Kasim pasha was built from the stones of the St. Bartholomew's Church. In 1939 Gyula Gosztonyi excavated it and found the walls of the church's sanctuary.

6.1 Concept of the bell tower

Now anybody can experience the medieval treasure world of the missing church as the structure has been reconstructed and is now visible at a seated bench level. The square is neutral, very simple and can accept an almost undecorated tower. Three bells suspended from three slender steel columns, which statue-like guard the area to the north-east of the mosque with the statue of St. Bartholomew. It is a moving telescopic statue, which can hydraulically rise to become a tower (see Fig. 17). Technically, it consists of a thirteen meter

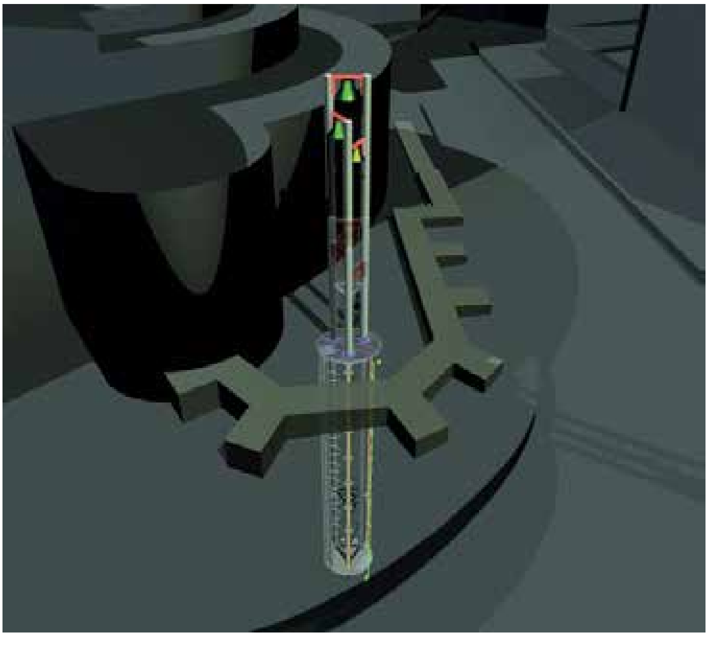

Fig. 17. Structural system of the moving bell tower

vertical shaft, two meters in diameter, which hides the steel structure of the tower, until it is raised the thirteen meters by a hydraulic drive with a five ton capacity.

The groundwork and creation of the shaft was done by a mining company. Erecting towers and statues, as well as the casting of the bells themselves have always been demanding communal activities. They have a symbolic power, expressing the unification of the settlement, they serve to protect, guard, sound the alarm, celebrate, mourn, orientate and are meeting points. (Bachmann & Bachman, 2010)

It is an unforgettable, shocking and imposing experience to design and build a tower. It is a work giving faith and a test of professional competence, the power of soul and the omnipotence of fantasy. The erection of the tower was a determining moment for the design team. Work of the planners was guided by the love of the people, starting with the abbot, Pál Kele, through to the bishop and the congregation, their caring and protective concern, and sometimes their anxiety. It also inspired János Gulácsi, the classical master of bell ringing, who dreamt about a previously non-existing and invisible way of moving the bells. The sculptor, Sándor Rétfalvi's statue of St. Bartholomew is a significant piece of art: it is incredibly difficult to mark a point in space, perhaps impossible (see Fig. 18).

This point is the statue of St. Bartholomew, the martyr, who overcomes the torture of the fleeced, suffering man. The tower music was inspired by the movement of the sinking and rising sculpture-tower, the ringing of bells. The fresh rhythmic music, reminiscent of the striking and ringing of hammers in blacksmiths shops, is accompanied by the bass of a roar-like Gregorian song preaching timelessness. When reaching the final height, there is sparkling metallic music again to complete the 65-second rise, giving over to the magnificent ringing of bells, in the morning, at noon and in the evening.

Fig. 18. St. Bartholomew bell tower with the sculpture of the martyr

7. Conclusion

During the projects some important principles of planning and research were laid down that are essential for the preservation and reconstruction of historical city centres.

The underground burial chamber renovation project needed special technical, architectural solutions. It was with the help of mining techniques that enabled the architects to protect these 1600 year old treasures. The burial buildings had to be isolated from the surrounding soil and buffer-zones were used to separate the painted burial chambers from the visitors, as the paintings need a constant temperature and humidity to remain preserved in a good condition.

I am of the opinion that these projects really represent the most important principle of monument protection, namely that the protected heritage should be presented in a way that everybody can understand it. In cases where only remnants of the original buildings remain, artistic effects should be used to present them. Special architectural solutions are needed to make visitors feel the atmosphere of the place.

Sustainability is also very important with such buildings and monuments. It is significant that these places are alive nowadays and that they are used for a variety of programmes not only as museums.

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11

Homage to Marcel Proust – Aspects of Dissemination and Didactic in a Museum and a Science Centre: Science Communication Visions for the Third Generation Museums

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1. Introduction

In this essay focus is upon some experiences from the run of the science centre and the university museum in Trondheim, Norway, and dissemination of research and science to the school. It debates how the institutions increasingly may adapt to school programmes and the new aspect in the new curricula for Norwegian primary and secondary schools: the *budding researcher* – the young student that got the possibility for to have a closer touch of research and science. Hence, the essay display some examples of archaeological public work towards what may be can be said to represent aspects of the third generation museum. Finally – it discuss some science communication visions for the years to come. And: what motivation and benefit may the archaeologist derive from spending time imparting research?

2. The significance of the idea

Within science studies there is an examination question which goes something like this; "Progress in research is determined by the development of new techniques and equipments. Discuss". If the answer were a straight "yes", one may have to report that the frontiers of the field had not moved much. Fortunately, the answer is not a simple "yes". While it is of course true that one point to fields of science which opened up because of new techniques and equipments, it may be even more often that new fields opens up because of new *ideas* rather than new techniques. And also behind new equipment, like the electron microscopy for the study of small elements in nature – and radiotelemetry for monitoring of the behaviour of large animals, one can imagine an idea behind the initiative and what kind of data that will emerge. Typically, and as one example of idea-making in practice, the 1973 receiver of the Noble Prize for Physiology and Medicine, Niko Tinbergen (1907-1988) most preferred skills was his ability to observe animals and ask four questions; 1) immediate causation for their behaviour, 2) technically development of anatomic traits, 3) looking back for evolutionary explanations, and 4) how it all function connected to succeed in surviving and reproduction. Tinbergen used his eyes and his imagination as central tools for his voyage of discovery (Tinbergen 1951, 1958). One may suppose that this way of reasoning is useful in general within science.

Is the reflections above relevant to the topic of this paper - the educational role towards the public of museums and science centres? And for subjects as archaeology? Obviously, an idea, or a notion or thought, can serve as a technique or method of performance or manipulation. A new way of thinking about a problem can become a useful way to solution, just as a new device for measuring can reveal new knowledge. This ability to intellectual action and the possibility for to direct participate in reasoning around a question or a hypothesis is of great value for individuals and society, and should be promoted during dissemination work by scientists. Daily activities, school and studies, and science centres and museums, must encourage this essential quality and capacity among pupils. Hence, science centres and museums should be a tool to stimulate imagination (Pedretti 2002).

Providing the public with information on history and archaeology is well established, and in recent decades the practice has developed into a separate discipline (e.g. Somers 1979, Colin Renfrew 1983, Kwas 2001, Watkins 2006). Books containing collections of articles dealing with how to communicate archaeology to a wider public have begun to appear and the discipline of Science Communication, which is touched upon later in this essay, is growing rapidly (e.g. Beavis & Hunt 1999, Hørnig Priest 2010). These authors stress the importance of publishing research in the best possible way and even question the validity of carrying out much of the research if it is not imparted to the public in an easily understandable fashion. In the last ten years or so, the use of the Internet has also become increasingly important for imparting archaeological research, for instance by presenting exhibitions and dissemination projects (e.g. Hembrey 2001, Warwick & Meckseper 2002, Brughmans 2010). Such activity also directly enters into the role of museums to be socially including in quite general terms (e.g. Sandell 2003), and this is expected to become an increasingly important task for museums in the years to come.

The challenge is to communicate effectively towards the public. By the science centres interactive pedagogy, they are considered as an important supplement to the formal schools, and a contribution to understanding of research (Falk & Dierking 1992, 2000, Persson 2000a). One reason to the establishments of the Norwegian centres is the recruitment swab to science subjects within the education system. One main objective for the science centre is therefore to inspire youths to keep on with science subjects in further studies and employments. One may say that classical museums within archaeological- and natural science moves in much the same direction.

In this essay focus is upon: **1)** some experiences from the run of the science centre and the university museum in Trondheim, Norway, and dissemination of research and science to the school, **2)** debates how the institutions increasingly may adapt to school programmes and the new aspect in the new curricula for Norwegian primary and secondary schools: the budding researcher, and **3)** display some examples of archaeological public work – hence some science communication visions for the years to come: what motivation and benefit may the archaeologist derive from spending time imparting research?

3. The science center and the classical museum

The science centre in Trondheim, Norway, was founded in 1988, and was from 1991 to 1997 localized together with the Museum of Natural History and Archaeology, which is an integrated part of the University of Science and Technology in Trondheim. From 1997 and onwards it has been localized in Bank of Norway's old building in the city, but plans for another localization together with the university museum is now worked out. The exhibition area represent approximately 700 square meters respective around 200 objects that focus upon physics, anatomy and technology. 50 000 people and more have visited the centre yearly, whereas between 60 -70 % represent school classes. The potential customer group are stipulated to be around the 300 000 people living within a 100 km radius around Trondheim. Visitors are mainly from schools in the nearby surroundings of the city. Most objects are adapted to the curriculum within the school programme from age 6-15 years. Several of the models presented are given as examples in the school textbooks. Formal collaboration with some schools and groups of teachers has been accomplished.

The Museum of Natural History and Archaeology at the Norwegian University of Science and Technology (NTNU) dates back to the 19th century and is located in the centre of the same city as the science centre – that is Trondheim, central Norway (Steffensen et al. 2008). Its focus is on research on natural history and archaeology with dissemination of research results to the public and to school pupils (Overskaug et al. 2010, and see also Ross 2004). The schools, on their part, incorporate museum visits as means of educating their pupils in compliance with their curricula. Hence, the first archaeological exhibition made at this museum, and one that is still widely used by schools, is the prehistoric exhibition that dates from as long ago as 1955. The exhibition spans the entire period from the earliest settlements in Norway some 10 000 years ago up to the Viking Age, and to medieval time about 500 years ago. It is located in a quiet part of the museum and has seating to give people an opportunity to sit down and absorb the historic atmosphere the rooms attempt to impart. The aim has been to get all school pupils in central Norway to visit this exhibition at least once in the course of their period at school. The exhibition and the presentation of its content made by archaeologists has been extensive and very good. Nowadays, many people will probably say that the exhibition appears old-fashioned, since it largely comprises glass cases containing objects, but the museum have received responses that it is precisely the good atmosphere that prevails in this exhibition that invites people to visit it. However, good empirical data are still lacking to show how widespread this view is. Furthermore, the trend in recent years has been that it has been more difficult to attract pupils to permanent exhibitions than to new, temporary exhibitions.

Obviously, there are ideas that best can be realized by a co-operation between classical museums and interactive centres. One such project initiated in 2001 focus on *communication*, where the university museum presents how animal communication are figured out by postures and sound, and the Science centre build an interactive model which demonstrates principles behind communication technology like TV and radio waves. Another inter-museum project initiated in 2002 deals with *geology*. The new geology lab in the science centre serves the interactive part of this project. Furthermore, visits to the geology exhibits given at the university museum were arranged.

Finally, a fellow-actor for the museum and the science centre is the School Centre for Science Education at the Norwegian University of Nature and Technology. The School Centre is a link between the primary schools, Colleges, the University and the industry and commerce. The goal is in particular to renew and strengthen the education in mathematics, natural science and technology in the school. Consequently, the basic structure seems well.

However, as i. e. Macdonald (2003) point to in here stimulating paper on museum identities, one main challenge for future museum work is also to focus on the concept of identity, and which represent an underlying factor in the following discussion.

4. The budding researcher

New curricula for the 10-year (pupils aged 6-16 years) compulsory primary and lower secondary education and the succeeding 3-year (pupils aged 16-19 years), optional, upper secondary education was introduced in Norway from 2006. The curricula are comprised of three parts, a general normative part, principles for education, and specific syllabuses for the subjects taught. Central principles in the education are to stimulate personal development and pave the way for involving the local community in school activities. The syllabuses for the subjects mention, for instance, basic skills such as expressing oneself orally and in writing, being able to read and to do arithmetic, and the use of digital tools.

The new curricula do not lay out the same regulations, so to say, as the former ones as regards teaching methods. Nor do they mention, or place emphasis on, special historical events, or list examples of topics in science to the same extent as former curricula and syllabuses have. One intention with this is to give teachers freedom to chose the best form and content in their teaching. However, under the topic of the *budding researcher*, the new curricula place greater focus than earlier on the need to understand research processes and scientific reasoning and maturity. The budding researcher is a compulsory aspect of science subjects, i. e. the pupils must be given grounding in and practice the principles of scientific work. Here, science emerges in the teaching in two ways, as a product that illustrates current knowledge and as a process that builds on knowledge. In the curriculum for social studies, which includes history and archaeology, developing scientific reasoning in accordance with the same pattern as in the budding researcher of science subjects is implicit. The challenge facing the university museum and the archaeological work in their effort to impart knowledge will be how to best organize their dissemination work towards pupils to fit the lines laid out in the curricula.

A distinguishing feature of the university museum is that its exhibitions and the manner the museum communicate them to the public are based on research and collections, while the public service department act as intermediarie to make research and research processes available to the public through exhibitions and other forms of presentation. The combined activity of research and communication in the university museum should therefore be tailored to support the vision behind the introduction of the budding researcher – concept presented in the new curricula, aimed at providing insight into the building up of knowledge and maturity in scientific reasoning.

The university museum in Trondheim has larger natural history and cultural history collections and exhibitions, and the scientific expertise attached to the museum is particularly concerned with those two subjects. The museum organizes activities aimed at the general public and school pupils, providing them with insight into what takes place right from the initiation of research processes to half-completed products and reflections around more long-term perspectives. For instance, it is possible to arrange that school pupils can visit archaeological excavations and follow these excursions up with another visit to the museum when the material has been processed and interpreted. The purpose is to incorporate meetings with researchers and work on assignments and the solving of various problems during visits in the field and to the museum as a compulsory part of the education of pupils in ancient and modern history. Hence, school pupils, through the museum, have a unique opportunity to gain insight into the process linked to the research, from idea to realization, and also to meet researchers who are at various stages along that line. The new curricula therefore increase the role of the museum in the current arena of education.

After going through the first generation museums consisted of artefacts in glass cases (Fig. 1), followed by the second generation encouraged interaction and hands on (Fig. 2), future activity may encourage visitors to redefine the exhibits and its contents. They may themselves participate in developing dissemination projects and in discussions with researchers – and that may be can be said to represent some kind of a third generation museum (Fig. 3, 4). While the science centre in many ways already touch the third generation, also Trondheim university museum has taken steps towards that goal by running dissemination projects where school-teachers- and children participate in the process towards the final product. An example are the production of middle-age clothes based upon what research said about the design of that time costumes (Fig. 3), and then by wearing the costume and perform a "pilgrimage" from the museum to the large medieval cathedral in Trondheim and discuss the history behind the building (Fig. 4). For this specific project information about the life and clothes of *The Bockster Man* - the remains of a medieval male body found in a bog in Sweden in 1936 and dated to 14th century – were used as background information (see for example Durrani 2006). The man had been killed and knocked to the bottom of a lake which later became a bog. He was recently reconstructed to show what he may have looked like when he was alive. Depending on the interpretation of the clothing, and in particular the hood, different conclusions can be made about the man's social background. The hood he wore was usually worn by the more prosperous classes and it has therefore been suggested that he was a tax collector or a soldier recruiter. The type of hood was also used within the church. Definitely, this story attracts teachers and young students – from it was initiated based upon available literature and the design of the costumes (Fig. 3) – and through further studies of the middle-age time and the history of the medieval cathedral in Trondheim (Fig. 4).

5. Discussion and further visions

5.1 Research as guide to development

Although the justification of science centres are debated (Bradburne 1998), they seem to represent a kind of institutions of informal learning that public calls for (Borun et al 1996, Persson 2000b). Fully satisfying data that clearly demonstrates long-time effect concerning learning from museums are lacking. But for visitors, museums and science centres represent meaningful experiences (Falk 2000, Sheppard 2000). Studies shows that more than 50 % of the public could precisely repeat the principles behind exhibits one year after the visit.

In Finland, Salmi (1993) presents studies from *Heureka* Sciènce Centre of school children that had both single stays and visited the centre several times, respectively. The conclusion was that an optimal strategy for learning is to motivate the visitors for several visits, establish

Fig. 1. First generation museums – exhibitions in glass cases. This may still function very well, in particular if there are possible to tell a story behind the exhibition and the artefacts. When were they sampled? Under what conditions – accidentally or as a result of a larger project? What was the background for the project? (Photo: K Overskaug).

Fig. 2. Second generations museums – hands-on and minds on. Visits behind the exhibitions, and stay for a day with the archaeologist – in the museum and maybe it sometimes also is possible to go with him to the field-work. Get even deeper insight into his way of working. Exhibitions were student do their own experiments are figured out in a number of more classical museums – and are among the essential ideas behind the science centers. (Photo: K Overskaug).

Fig. 3. The tunic of a medieval man from Sweden (see for example Durrani 2006) is among the best-preserved medieval tunics in Europe, and made of wollen fabric. He was wearing a hood with a 90 centimetres (35 in) long and 2 centimetres (0.79 in) wide "tail". On his upper body he wore a shirt and a cloak, while his legs were covered by hosiery. The photo shows a simple copy made on information from *the Bocksten Man* and other sources, and made by and for students and used for a dissemination project of some of the human life during parts of the medieval time (see Fig. 4). (Photo: G. Holt/K Overskaug).

Fig. 4. Maybe characteristics of the third-generation museum, and popularizing of archaeological subjects towards the public and school, is to involve children and students in themselves making dissemination projects under supervising of the museum? Hence in the university museum in Trondheim, Norway, - and exemplified by the design of a collection of middle-age-costume – and then take a "pilgrimage" from the museum to the cathedral and the amazing 1000 – year history behind the building (se also figure 3). (Photo: K Dahl).

pre-lectures that prepare students for the visit, and post-lectures that further put the exhibits into a broader context. That approximately 80 % of the first-year students at the University of Helsinki had visited Heureka before they had started their studies, may support the impression that informal learning sources can represent a motivational factor, and create active attitudes towards science, research and technology among young people (Salmi 2000). The importance of integrating the object of the visit towards the textbooks on school can also be stressed by that there at least in some museums and dissemination projects is more or less even compulsory for teachers to participate in a workshop at the centre in front of the visit with their students.

Yet, published empiric and specific visitor data for the science centre and the university museum focused upon here is mostly lacking (but see for example Overskaug et al. 2010), the overall positive response from school-children and groups from kindergarten may, however, indicate that the centre and the museum play a growing role in informal learning. For example have approximately 15 – 20 000 pupils annually visited the university museum during the last years. However, this is nevertheless a fairly small proportion of the total number of pupils in the region that can be considered the museum's natural catchment area. One of the challenges seems to be to reach teachers effectively with the information that are distributed. And an important goal is to work further to design studies that verify the educational effect. A more formal co-operation towards schools, and attention around their needs, will make it possible to present offers that increase the use of the centre by schoolchildren. It is often also a question about time and economy – how to bring schoolchildren from the school to the museum and back again? And who pay?

5.2 What's in it for the archaeologist?

During an ordinary working day, when researchers are often snowed under with urgent tasks and under pressure to write reports and scientific publications, it can often be difficult to find time to carry out popular scientific dissemination work. Moreover, as such work often gives no purely scientific gain in expertise, nor necessarily proves gainful for project applications, it may be difficult to see how it will be attractive for archaeologists and natural scientists. There are, however, tendencies in the academic world that passing on information to school pupils, students, the general public and non-specialists in political and community management, is strengthening its position as a separate discipline and in several ways will develop into an attractive field. This is because the need for quality-assured knowledge and a knowledge-based approach to current issues is increasingly urgent, and active researchers should be among the foremost to attend to this important task for society since such knowledge may otherwise be quite unattainable for most people, for instance ”hidden away” in specialised scientific journals or published in other ways that are difficult for ordinary people to gain access to. Science Communication is a disciplinary tool to make, for example, such knowledge more widely available and put it into a broader social context. Several articles have been published in recent years that sum up the essence of Science Communication (e.g. Weigold 2001, Burns et al. 2003) and, according to one of the most recently presented definitions (Hørnig Priest 2010), it concerns presenting science to non-scientists (”the public”) – that is, imparting research from researchers to the public at large. Researchers refer to this as ”outreaching” or ”popularization”, and it has evolved into the profession of popular science – that is, interpreting science to the man in the street. Hence, Science Communication includes research exhibitions, research policy and journalistic and other media productions about science. Science Communication may, however, also describe communication between researchers as well as between non-researchers (”the public”).

The motivation to focus on popular science is therefore multifaceted. A prime aspect is that imparting research may be valuable for knowledge-based decisions taken by individuals, for social and political decisions, and not least to improve the research itself through the possibility it has to be presented and feedback received from the general public and other users. In this way, Science Communication has achieved increasing publicity in daily newspapers and research journals (e.g. Sherwood Rowland (1993) who gave the topic broad publicity in *Science*)). ”Science Communication” (first published in 1979) and ”Public Understanding of Science” (published since 1992) are important specialist journals in this field. Some of the more classical articles written about the topic, and summing up the characteristic content of the discipline, were written about the end of the 1980s. Hence, Geoffery Thomas and John Durant are two often-cited authors who addressed the various social benefits derived by increasing public interest for research and science (Durant & Thomas 1987). For instance, the authors point out the following justifications for carrying out popular scientific dissemination – and actual for the archaeologist who may be out on an excavation, in the museum, at a school or on a stand of one sort or another, or by way of popular scientific articles and news stories:

- valuable for research (and society) in itself since, if people in general acquire a broader interest for the science, the science too will achieve more progress and also contribute to a more robust society,
- by being imparted, research has the possibility to put important questions on the society agenda and help to legitimize its own activity. A classical example for archaeology is the frequently posed question of how essential and useful archaeology is for society– do we not already know enough about bygone times?,
- knowledge is advantageous for the individual by directly supplying insight that can be utilized in everyday life,
- some production of knowledge may also have an aesthetic perspective and stimulate art and culture (examples are various scenarios regarding social development), and/or may stimulate an improvement of mental and physical health,
- the broader the knowledge, the better the basis for taking vital political and social decisions,
- dissemination can improve recruitment to the discipline,
- the ultimate benefit is an improvement of the individual's participation in and attitude to social issues, thereby strengthening democracy.

Durant et al. (1989) also had a follow-up paper in *Nature* in 1989 where they referred to a study which showed that the public in both England and the USA were more absorbed by knowledge and science than by sport, for example, but compared with the latter it is more difficult to create just as general excitement for science among the population at large and in the media. Nevertheless, still by the end of the last decade less than 1 % of published scientific work was being referred to or made available for the public in other ways (Suleski & Ibaraki 2009).

5.3 The active visitor

There may be at least four challenges that should be solved; **1)** science centres may still struggle for to be somewhat more than a "fun fair". To try to steer this, there is worked out a guide for teachers with cross references to the curriculum, and the staff made suggestions to activities and approach to problems and projects. **2)** when interactive models are presented - how can we stimulate the public to take a closer look below the surface? To arrange this, each model is first described in depth in the exhibition area. Second, books and booklets on special subjects are written so the public have the possibility to look into the world of knowledge hidden behind each model. Third, and may be the method that function best, is to have a researcher or guide that in a proper pedagogical way can tell the story about the model, the research project, the persons behind – and how they once in the time come up with the idea, **3)** To make enthusiastic pupils we have to make enthusiastic teachers! One may meet this challenge by making lectures and organize special courses for teachers and their classes, and **4)** finally, how can we give the visitors a "heart" for science? Hence, the science centre and the museum may made do-it-your-self-laits, simple scientific toys and arrange different science-clubs keeping children at the centre every day in a week. In many ways this is also already figure out.

The conclusion may be that there is no single solution to those questions. The challenge is to stimulate the active, intelligent visitor, which is hidden in every visitor, when they all have their own special abilities and interests. Consequently, we are back at the point of departure for this essay; much of the philosophy behind the discussion above may be recognized from the heading - in the way it is expressed by Marcel Proust (1871-1922). Brilliant and simple, but certainly true, the novelist probably goes strict to the heart of pedagogical alternatives by the formulation "*The real voyage of discovery consists not in seeking new landscapes, but having new eyes*". It requires a lot of courage to produce your own, new ideas, to have new eyes on science, or even redefine old truths. Science centres and museums may stimulate, arrange and prepare for to realize this potential in visitors. I welcome suggestions, and a fruitful and stimulating discussion and debate from students, researchers, teachers and the museum community upon how to reach and realize a vision about being a significant and maybe more formal contributor to educational goals.

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