# THE ENVIRONMENT OF HISTORIC SHIPWRECK SITES: A REVIEW OF THE PRESERVATION OF MATERIALS, SITE FORMATION AND SITE ENVIRONMENTAL ASSESSMENT

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"It is probable that a greater number of monuments of the skill and industry of man will in the course of ages be collected together in the bed of the oceans, than will exist at any one time on the surface of the continents." (Lyell 1832).

## Declarations

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## Abstract

Consideration of the environment is a fundamental aspect of any archaeological activity and it is particularly important for effective cultural resource management (CRM). Physical, chemical and biological conditions at (and in the vicinity of) any archaeological site strongly influence, amongst other things, practical strategies of site investigation, options for recovery and conservation of archaeological materials, and the viability of likely future *in situ* preservation proposals. Furthermore, environmental factors are of primary importance for understanding differential site formation. The subject of this thesis is the environment of historic shipwreck sites, paying particular attention to the historical base of this sub-discipline of maritime archaeology; examining major themes such as material preservation, site formation and *in situ* management, site monitoring and assessment. The research sets a consideration of historic wreck site environment in context, reviewing past history and current trends, concluding with recommendations for future research directions.

Table of Contents

## List of Figures

## Acknowledgements

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Despite all this assistance all the errors remain mine.

## 1. Introduction

An appreciation of the environment can be regarded as being fundamental to any marine archaeological activity or any aspect of marine cultural resource management (CRM). Past and present day conditions at, and in the vicinity of, any site strongly influence the techniques and methods that will be most effective throughout archaeological investigations, from the initial survey stage to the post-excavation analysis[1].

The subject of this thesis is the marine environment of historic shipwreck sites; the implications of the nature of those environments and the potential for greater understanding of the processes involved in their formation and development. The aims of the research are to:

- Identify the main categories within the subject of marine archaeological environmental studies reviewing their status and benefits to archaeology as a whole;
- Recommend the future development for marine archaeological environmental studies by identifying major omissions, outstanding research questions and fieldwork opportunities within each of the categories.

The initial approach to achieving these aims has been to review the main landmarks in the development of marine archaeological environmental studies concentrating on selected categories (preservation, site formation, management *in situ* and site assessment and monitoring), and (as the research into marine archaeological environments is believed to be important) to suggest ways in which further research can be encouraged. Although essentially a brief, and inevitably incomplete, treatment of the subject, it is hoped that insights can be gained which can lead to targeted research for the

[1]In order to best treat an object a conservator ought to know what the artefact was buried in, how it looked when found, surrounding conditions, proximity of other metals and organic materials (Lawson 1978).

benefit of present and future generations. This latter objective is central to the discipline of archaeology as a whole.

In the past archaeologists have periodically stressed the importance of environmental studies[2], and various attempts at including an assessment of the natural environment in an archaeological investigation have been made but the challenge has not been taken up universally. Furthermore, the development of archaeology underwater (and all its constituent parts - marine, maritime and nautical) has appeared to lag behind its terrestrial counterpart and this is particularly true in the case of environmental awareness[3].

The most common reason, and one of the earliest to be apparent, for including environmental information in a report of a submerged archaeological investigation is to illustrate its effects on the way work was carried out[4]. In particular much is made of adverse surface or underwater conditions[5].

General trends in the focus of marine archaeological research can be discerned. The investigation of drowned terrestrial sites necessitates a methodology that utilises not only those involved with archaeology, but those involved with geology, sedimentology, coastal geomorphology and geophysical technology (Koski 1988). Furthermore, prehistorians studying such sites have long had an appreciation of the burial environment and consequently the importance of oceanography (see Figure 1)(Watters 1985).

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[2] "....a true picture of a site cannot be appreciated without reporting the depth, type of sea-bed, visibility, tide variations, surface and underwater currents, as well as prevailing wind and weather conditions" (Bacon 1974: 1). Furthermore, a reasonably accurate assessment of the pedoturbatory history of the soils and sediments at every archaeological site is absolutely pre-requisite to valid archaeological interpretations (Wood & Johnson 1978). See also Muckelroy (1977), Nagelkerken (1985), Dumas (1972).

[3] A recent major study (*England's Coastal Heritage: A Survey for English Heritage and the RCHME*) excluded areas lying below the Low Water Mark and stressed the lack of information regarding the submerged archaeology (Fulford *et al* 1997).

[4] The licensees of the Church Rocks designated Historic Wreck Site comment on the depth and mobility of the sand, combined with the shallowness of the site, making excavation a "time-consuming and tiresome business" (Preece & Burton 1993: 258).

[5] See Zacharchuk 1971, Green 1975, Stenuit 1977, Ingelman-Sundberg 1977, Mazel 1981, Albright 1984, Koski-Karell *et al* 1984, Needles Underwater Archaeology Group 1985, Blake & Green 1986, Green 1986, Reedy 1987, Einarsson 1990.

The situation in relation to marine wreck sites illustrates a different focus. Starting with an early realisation of the importance and description of general factors of the influence of the marine environment (Weier 1973, Hamilton 1976), followed by attention to specific artefact types (MacLeod & North 1980, MacLeod 1987, 1991) recent research has concentrated on more detailed analysis paying particular attention to micro-environments (Nord *et al* 1993, MacLeod 1989d, Fox 1994, Gregory 1995 and 1996).

At a very basic level, past environmental factors are of primary importance for differential archaeological site formation, and for the differential preservation of the structures, objects and materials which constitute the site itself. However, more sophisticated aspects of the past can be elucidated using site environmental studies such as those carried out by Ross on the *Le Machault* site (1981) who considered the deposition history of an entire group of tools from the wreck, assessing the unique set of cultural events and activities which predetermined the original assemblage which sank with the ship. This was followed by a study of the alteration or reductions caused by immediate and long-term environmental factors (*e.g.* organic material floating off, iron objects corroding, tidal and ice movements, subsequent cultural activities such as contemporary and later salvage).

Maarleveld (1995) puts forward the view that a consideration of environmental factors has always been an important part of the underwater archaeological discipline, tracing the origin from the development of SCUBA diving in the Mediterranean and the special character of many of the sites which were explored.

Archaeologists overseas have also adopted specifically environmental approaches such as Smith *et al* (1981) in Puget Sound who included the assessment of regional sediment types, organisms and physico-chemical parameters (salinity, temperature, dissolved oxygen) to be used in predictive survey (Figure 1). Pettus *et al* (1981) at Fort Guijarros inundated terrestrial site similarly incorporated site description, geology, biology and water chemistry (nutrients, salinity, dissolved oxygen, trace metals, pH) into the project.

The study of marine archaeological sites can also benefit from developments in related disciplines. Stephenson (1984) notes that underwater archaeological research can be improved by increasing knowledge of geomorphological processes because problems relating to geochronology, *in situ* preservation, the nature of pre-burial environments, and subsequent geomorphologic processes, can be addressed. It is thought that underwater archaeological research can be improved by promoting the investigation of geomorphological processes[6].

A focus on environmental aspects of marine sites can also contribute to the raising of standards and the improvement of efficiency in archaeological practice as Bell & Nowak (1993) illustrate in relation to archaeological geophysical surveys. The latter require systematic detailed planning based upon an assessment of the anticipated cultural resource material which may exist within the site, the site conditions, and the characteristics of commonly available remote sensing and off-shore positioning instrumentation.

Conservation science will gain an advantage from an increased knowledge of the burial environment of objects and materials as more effective conservation treatments will be developed if the properties of the environment which surrounded an object (and which contributed to its deterioration) have been carefully considered (Florian 1987a). Similarly, in archaeological finds handling practice it is most important to minimise the damage caused by moving the object from one environment to another, completely different one, during the recovery process. This can be attempted by reproducing the characteristics of the burial environment of the object, or by applying holding treatments to help the object survive until it can be safely transported to a conservation laboratory. In order to construct and maintain correct storage

[6] "...if the initial environment is important, if the sequential natural processes are important; if chronology is important; and if predicting possible future environmental conditions is important; then the contribution of geomorphology to underwater investigations is of significance" (Stephenson 1984: 140).

environments the conservator must have objective information about the conditions of burial[7].

## 1.1 Archaeology

The main focus of the discipline of archaeology is the study of the material record which survives from the past activities of the human race. Clarke (1979) defined five bodies of theory that archaeologists intuitively employ in their interpretative steps from excavated data to final report:

- *Pre-depositional* and *depositional* - the relations of human activities, social patterns, and environmental factors with each other and with the samples and traces that are deposited in the archaeological record,
- *Post-depositional* - the natural and human processes that affect the archaeological record, such as erosion, decay, ground movement, plundering, ploughing, and the re-use of land,
- *Retrieval* theory - the relations between what survives in the archaeological record and what is recovered (sampling, excavation procedures and flexible response strategies),
- *Analytical* theory - the operational treatment of recovered data including classification, modelling, testing, and experimental studies,
- *Interpretative* theory - the relations between the archaeological patterns established at the analytical level and directly unobservable ancient behavioural and environmental patterns.

Archaeological sites provide unique opportunities for learning about the past and, most importantly, they form part of mankind's global heritage (Dean *et al* 1995). Present day society inherits sites from former generations who contributed to formation of the archaeological resource. That society has a moral obligation to ensure that it hands on, in its turn, a common heritage which is in the best possible condition to subsequent generations.

[7] One example is the experimentation with soil stabilising gel media in the conservation of large artefacts recovered from shipwrecks (Carpenter 1987).

Archaeological investigation takes many forms ranging from non-disturbance surveys to complete excavation and recovery[8]. Excavation can be defined as disturbance of archaeological items suspended in the earth or soil and it is another irregularity in what Ascher called "the long, unbroken curve of disorganisation" (1968: 46).

An archaeological site consists of the patterned distribution of artefacts, features, and ecofacts in three-dimensional space and time. Components of sites include a wide range: remains of artefacts and structures; organic, inorganic and composite materials - bone, shell, plant remains, charcoal, crystalline and granular lithics, ceramics, and metal artefacts. All have geographic relationships to each other which include soil and stratigraphic attributes, site micro-topography, general site context, and archaeological features (Mathewson 1989).

Because some sites have been in place for centuries, and even millennia, it is easy to fall into the trap of assuming that they exist as relatively constant entities whereas in fact all sites are located along continua of change over time. Excavation is one such process of change involving the destruction of the site which should be undertaken only when all other options have been considered[9]. After excavation the site will no longer exist and there will be no further opportunities to investigate it even if archaeological techniques improve in the future.

Marine archaeology is fundamentally the same as land archaeology (O' Keefe 1996, Dean *et al* 1995) and it has been recognised slowly (particularly from the point of view of terrestrial archaeologists) that archaeology can be performed underwater to the same standard as on land. Similarly wreck sites are, in principle, no different from any other archaeological site. They are similarly unique and non-replaceable stores of information about our past. Such information can be exploited now and be made available for the future.

[8] "Archaeology in essence....is the discipline with the theory and practice for the recovery of unobservable hominid behaviour patterns from indirect traces in bad samples" (Clarke 1979: 100).

Wrecks also contain artefacts, many of which relate to the lives of ordinary people and which do not often appear in modern museums or collections. The structure of the vessel may also be the only remains of ship types which have completely vanished. Certain vessel types may not be preserved in maritime museums and documentary evidence may be absent, scant or faulty.

### 1.1.1 Archaeological methods and techniques

Archaeologists must continually strive to improve what they do as their "experiments" are unrepeatable (Frost 1962). Furthermore, they need to continually examine their procedures to ensure that they are efficient and using the archaeological resource economically (Wildesen 1982).

The archaeological discipline has developed techniques for maximising the return from the investigation of sites. This enables good quality data to be collected which will be available for the future benefit of everyone in whatever form, be it education, museum display or academic research. In common with forensic science archaeological investigation may build up an adequate record through painstaking attention to details which may at first seem mundane or unimportant.

Methods which aim to ensure that the investigation, identification and interpretation of the physical remains of the past begin even before a single object has been exposed. Objective data collected at this pre-disturbance survey stage will indicate the most effective techniques which should be used on the site. The development of quantified measurement and monitoring techniques for the environment of the site are important to the success of any further work.

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[9]One of the primary sources of information for archaeology (*i.e.* excavation) involves the destruction of unique specimens (Green 1995).

### 1.1.2 Maritime, nautical, marine or underwater archaeology

There is something of an identity crisis in submerged archaeology. Gale (1993) promotes the use of the term "Hydroarchaeology" as embracing all methods of archaeological investigation relating to water, in preference to other terms which have drawn their definition from only one such factor; "underwater archaeology" a type of environment, "shipwreck archaeology" a type of site, "nautical archaeology" a topic of study. Further definition of *Hydroarchaeology* includes consideration of preservation as one of nine constituent *Processes of Study*. The archaeological resource is the *Source for the Study* and can be divided into different environments; *Data Environment*, *Dry Environment* and *Wet Environment*. The *Wet Environment* can be divided into;

- Surface Waterlogged (*e.g.* bog, marsh)
- Sealed Waterlogged (*e.g.* buried peat layers)
- River-bed
- Lake-bed
- Inter-tidal
- Seabed

Thus we see a consideration of the environment as an integral part of study of archaeology and yet it can be argued that marine archaeology has suffered, and still labours in some quarters, because it is not accepted as a serious discipline, and it is not perceived as scientific.

Furthermore, marine archaeology has suffered from a lack of specific identity. This problem is outside the scope of this research but Watters (1985) provides a diagram showing aspects of maritime archaeology at several levels of integration but admits that the interrelations are much more complex than those shown (see Figure 2). Other workers have attempted to propose acceptable definitions for the various sub-divisions such as maritime, nautical, marine and underwater (Gale 1993, Dean *et al* 1995). However it seems that the umbrella term of "maritime archaeology" is preferred (Muckelroy 1978, Gould 1983, Gibbins 1990). Such work can be seen to refute the claim that modern maritime archaeology is specifically historical- or artefact-orientated[10].

The low level of attention paid to the burial environment is analogous to a similar lack of importance given to non-artefactual (or ecofact) evidence from shipwreck sites (Oxley 1984, Kenchington *et al* 1989).

### 1.1.3 History of the development of submerged archaeology

The history of archaeology underwater in all its many manifestations - nautical, marine, maritime - has been summarised many times (*i.e.* Muckelroy 1978, Gawronski 1986). Since World War II the widespread use of self-contained breathing apparatus (SCUBA) has encouraged appreciation of, and inevitably interference with, the marine archaeological resource. It was obvious from the earliest explorations that the particular characteristics of a site's environment had affected the state and amount of surviving material[11]. There was an early recognition of the preservation of organics, particularly ecofacts (olive stones, nut shells, leafy material)(Frost 1973), and factors such as depth and a typically heavy cargo (thousands of amphorae) are given as the principal factors in the formation of the wreck "mound" or "tumulus" (Dumas 1962, Frost 1962).

The foundation of modern underwater archaeology was laid during the 1950s in the Mediterranean where a high concentration of easily accessible wrecks were found. They were mainly derived from the Classical period whereas attention in the Caribbean focused on 16th and 17th Century wrecks.

Interest in underwater sites began with recreational divers exploring a new environment followed by small numbers of land archaeologists becoming involved principally in the collection of objects or artefacts. From the 1960s organised underwater excavations in Western Europe increased to include

[10] "Marine archaeology does not involve the study of the natural environment, but involves the study and recovery of man-made objects present on and in the seafloor which are relevant from a historical point of view" (Soons 1982: 275).

shipwrecks, buildings, settlements and ship blockages from a wide range of cultures and dates in environments such as tropical oceans, mountain lakes, sandy beaches, muddy riverbeds.

Differential research criteria have been created (concentrating on historic wrecks as opposed to Neolithic settlements) but they have often stagnated because of attempts to use the underwater environment of the site or the technology as a common denominator for the discipline as a whole (Gawronski *et al* 1992). From the 1970s independent fields of study have been distinguished and gradually a profession of archaeologists capable of working underwater has established itself[12].

There was a very early tendency on Australian sites to stress environmental difficulties (Green 1975) and a complementary co-operation with marine scientists (North 1976). Australia is currently the location of the most integrated approach to marine archaeology where management plans are common, development control has also stimulated assessment and monitoring methodology (Bower 1994, Boyd *et al* 1995, Kentish 1995, Kenderdine 1995b). In the USA Clausen & Arnold (1976) heralded a methodological advance in integrating environmental data and Lawson (1978) demonstrated an early recognition of the importance of environmental parameters to the conservator, and the role of bacteria in sediments. Recently there has been the emergence of the use of environmental and preservation factors to influence archaeological research designs (Manieri 1982).

### 1.1.4 Cultural Resource Management (CRM)

The aim of culture resource management is to identify, evaluate, protect and manage (Coles 1995). Archaeological sites represent both a cultural heritage resource and a contemporary cultural resource available for access, use,

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[11] Early diving and salvage on Florida shipwrecks revealed iron guns, heavily concreted and encrusted with marine life (Brookfield 1941).

[12] There are probably as few as ten professional full-time marine archaeologists at the present time in the UK, and over sixty members of the Institute of Field Archaeologists' Maritime Affairs Group. The Institute of Field Archaeologists is the UK professional body for the discipline.

exploitation, management and preservation through initiatives such as public exhibitions, shipwreck trails, education projects, and recreational diving. Studying the nature and impact of the environment on a site is vital to understanding the quality of the evidence that is eventually recovered, an aspect of great importance to heritage resource managers with limited budgets and time scales.

An archaeological site can be damaged in many ways including by the forces of nature and by the activities of mankind. It is doubly unfortunate if the latter is unnecessary or not carried out in ways which result in some gain (such as new information and well-preserved archaeological remains) to compensate for the impact. Such is the impact of salvage on wreck sites and also archaeological excavation which is not comprehensively recorded. Shipwreck sites, like all archaeological sites, are complex mixtures of clues, information, objects and structures.

The lack of background data, both archaeological and of natural habitats or ecosystems, is a major problem given the rapid increase in the commercial development of marine environments. There is insufficient knowledge to enable appropriate management decisions to be made about adequately conserving the marine archaeological heritage and to fulfill those archaeological ethics referred to above. In comparison with their terrestrial equivalents, relatively little is known about marine environments (particularly their interaction with archaeological remains), and about the extent and nature of the archaeological resource.

There is considerable potential here for furthering understanding and scientific knowledge if data recovery is conducted within an appropriate interdisciplinary framework (Cummings 1987). Relevant information from related disciplines, such as marine biology, history, geography, soil sciences and others, should be considered.

However, in some overseas cases national and regional CRM initiatives that do not include environmental and preservation parameters have been proposed (Lawrence & Wilde-Ramsing 1984, Bush 1984).

The inconsistencies in the management of archaeology underwater in the UK are described by Firth (1993) and it is against this unsatisfactory background that effective strategies in resource management are being developed. Current initiatives include; the development of evaluation and assessment techniques; site stabilisation and reburial proposals; predictive survey and conservation science treatments. The effectiveness of any of these strategies depends upon the quality of the data known about the environment of the archaeological site, or sites, in question.

However, at the present time the integration of environmental studies with archaeological investigations is proceeding rapidly, spearheaded by the initiatives sponsored by publicly funded national bodies such as the Submerged Cultural Resources Unit (USA National Parks Service), Canada's Parks Service and the Archaeological Diving Unit of the UK.

#### 1.1.4.1 Archaeology in the wider perspective

Archaeologists have begun to recognise wider environmental responsibilities in the hope that future projects which emphasise the recovery of submerged cultural resources will consider the impact which excavation poses to biological communities. Hall (1991) stated the goal to replicate the dimensions of the extant hull in an area close to a wreck site in order to construct an artificial reef to relocate flora and fauna removed from the wreck structure.

The problem of the destruction of the global cultural heritage is cumulative, continuous, near-exponentially progressive and dangerously extensive (Burns 1991). In response to this threat there has been an increase in initiatives to involve the general public, interested persons and sport divers in collecting information about the marine environment, on the basis of understanding marine ecology, "green" issues (Foster-Smith 1995). Curiously, although research into maritime subjects such as shipping, fishing and naval history etc. has a long tradition in many so-called sea-faring nations. The level of knowledge about the nature and location of marine archaeological sites is universally very limited (Christoffersen 1994). The promotion of the care and protection of the marine environment generally may be a key factor in raising awareness about the submerged cultural heritage.

### 1.1.5. The structure of this dissertation

In order to consider all the relevant aspects of the environment of marine archaeological sites the dissertation is divided into the following chapters:

#### 1.1.5.1 The preservation of archaeological materials

As soon as objects or structures have fallen out of use or are lost to become part of the archaeological record, the nature of the burial environment becomes an important factor in determining what evidence or material will survive, in what form and in what position to make up the archaeological resource. Certain specific conditions will promote the survival of particular material types. In simplistic terms the more aggressive the environment the less well delicate materials may survive.

The dangers of exposing archaeological materials to altered environments are well-known but the processes are not well-understood. This chapter aims to illustrate how studying the environment of marine archaeological sites is a vital component to furthering understanding of site and artefact preservation by summarising what is known about the deterioration of materials in marine environments. This process should improve the quality of the information about the past that can be derived from marine sites and future management strategies can be similarly refined.

#### 1.1.5.2 Archaeological site formation studies

The study of the burial environment and related impacts on archaeological resources can provide a scientific, theoretical, and methodological underpinning for the future of the maritime archaeological discipline. The development or formation of a site can be investigated through an understanding of the attributes of a site. This approach is essential if the observed remains are to be related in some way to the society which originally produced them.

It has become apparent that the nature of the micro-environments to which an artefact has been exposed (what it was buried in, how it looked when found, surrounding conditions, proximity of other metals and organic materials) will have had a direct bearing on its degradation.

Because they are remote and far from mankind's usual environment, most underwater sites will not have been subjected to the wide variety of other anthropogenic formation processes such as re-development, subsequent occupation, and post-abandonment agricultural practices such as ploughing. Nevertheless, despite this favoured situation marine sites are subject to impacts or, as they may be termed, formation processes. This chapter seeks to identify the main strands of site formation theory and to summarise the benefits of such study, and to suggest further areas of research.

#### 1.1.5.3 Management *in situ*

Management *in situ* strategies are recognised alternatives to preservation by record (*i.e.* excavation) or allowing archaeological sites to deteriorate. In many cases it is desirable to protect and preserve the site in place, rather than to undertake costly archaeological excavation which can recover only part of the total cultural value of the remains (Mathewson & Gonzalez 1988). Yet, well documented examples of the *in situ* management of marine archaeological sites are rare. Although there has been limited research into the effectiveness of the strategies used, further studies are necessary to identify the most appropriate and cost effective strategies for the widest range of marine archaeological environments. Such studies should be prefaced by an investigation into the nature of marine archaeological environments, site monitoring procedures and systematic trials of stabilisation techniques.

The management *in situ* chapter seeks to further characterise the status of such research and practice in maritime archaeology and to offer profitable directions for future studies.

#### 1.1.5.4 Monitoring and assessment of the environment of marine archaeological sites

The assessment of the environment of a site has become recommended practice on any archaeological project. Indeed, McCarthy (1986) argues that there is a need for physical, biological and chemical pre-disturbance analyses to be carried out as a routine on all submerged sites being considered for further study.

### 1.1.6 Discussion

The present study shows that there is some recognition of the importance of marine archaeological environmental studies but there is a general lack of an accepted methodology, a reluctance to translate theory into practice, and an absence of the implementation of any kind of routine assessment or monitoring of environmental parameters. In addition the substantial research potential across a wide range of related marine disciplines of such studies remains largely unrealised. For example, Gibbins (1990) implies that environmental data from shipwreck sites is not being used as essential stepping stone to theorising and making inferences about past maritime cultures - and it should be. Maritime archaeology has much to learn from the experience of larger and older sub-disciplines - such as wetlands archaeology (Coles 1995).

However, it can be predicted that marine archaeologists will continue to slowly incorporate other environmental sciences into their studies in an increasing way in the future. This will be partly because of society's increased interest in broad environmental issues and archaeologists need to justify their existence. The archaeological discipline can offer special insights into the changes which occur in marine environments as well as contributing to the preservation, study and enjoyment of our unique cultural heritage.

This research is probably the first time such varied topics have been considered together and it concludes with recommendations that paying attention to the environment of historic wreck sites is profitable and should become common practice. The subject has a great deal of topicality. Marine archaeological research features among the topics discussed in international conferences, and legal scholars appear to be increasingly interested in the problems that the preservation of the underwater heritage poses to the law of the sea on a global scale (Strati 1995, O' Keefe 1996). It may be argued that the single most serious problem facing cultural heritage preservation at this time is protecting and investigating sites in international waters. The presence, evaluation and future protection of such sites depends upon a better understanding of their environment. If nothing else this research seeks to inform such an understanding.

## 2. The preservation of marine archaeological materials

### 2.1 Introduction

Archaeological materials are those forms of matter which have been exploited by humans in the past and they now provide present and future generations of archaeologists with the potential for finding out about past societies. The preservation of such remains could be defined in terms of material or evidence that has survived site formation processes and is now available for research and study. The term "preservation" could also be used for the techniques for actively treating or managing what has survived for the benefit of present and future generations[13]. However, complete preservation is ultimately un-attainable and such intervention techniques should be referred to as "management *in situ*" rather than preservation. The possibilities of management *in situ* are explored later in this dissertation. In this chapter the nature of the survival of various materials commonly found on historic shipwreck sites will be discussed. Particular attention will be paid to wood, metals and marine concretions. Further information on other materials can be found in texts such as Pearson (1987), Florian (1987b) and Weier (1975).

Ultimately the stabilisation of objects recovered from marine environments is said to be dependent upon the principles of materials science[14]. Yet the range of interactions of material with environment are seemingly infinite and many examples have been studied in the past from the effect of the environment on one artefact type such as guns (McBride 1976); marine concretions (MacLeod 1982, North 1976); sediment analysis (Adams 1985), and topographical survey and sedimentology (Gibbins & Parker 1986).

[13] A conference held at the Museum of London from the 1st – 3rd April 1996 was entitled "Preserving Archaeological Remains In Situ" (see Oxley 1998).

[14] "It does not matter what the object is, or what it is made of or from which shipwreck it was excavated - ancient or modern - the processes to be followed for preserving the object are similar and based on material science, *i.e.* the study of the properties and deterioration of materials." (Pearson 1981: 80).

Studies have been carried out on particular processes and materials in archaeological environments in different parts of the world (Pearson 1987, Weier 1974, Tylecote 1977).

## 2.2 Differential preservation

It has been apparent for many decades that some materials survive and others do not. The fact that the survival of organic matter tends to be greater in extremely wet or extremely dry conditions is now widely accepted. Organic materials underwater such as wood, textile and leather are subject mainly to degradation by anaerobic organisms and thus decomposition is considerably slower than in most land environments where the influence of aerobic fungi, bacteria and insects means that usually inorganic materials (stone, bone, pottery) survive (Cronyn 1990).

This organic preservation means that the consequent potential for the survival of archaeological information in marine environments is generally very good. Because of this enhanced preservation completely submerged sites have the potential to yield a greater quantity and variety of archaeological information than do archaeological sites situated in dry environments (Coles 1987, Bocquet *et al* 1987).

This differential preservation has advantages other than archaeological. In research prompted by the requirement of British Nuclear Fuels Ltd to determine materials which might be selected for the construction of radioactive waste disposal containers capable of lasting around 1000 years in a seawater environment a review of marine archaeological preservation was carried out by Tylecote (1977)[15].

[15]Further metallurgical analysis to study the long-term corrosion behaviour in seawater of a variety of metals and alloys using material from the wreck of HMS *Association* and comparing the results with data from the Swedish wreck *Vasa* (Campbell & Mills 1977).

## 2.3 Perceptions of preservation in the past

In the early 1960's Frost (1963) made generalisations that sand burial is common in the Mediterranean where ancient ships are found almost intact. Furthermore shipwrecks are better preserved on, or in, sandy seabeds than on rock; and that in those sandy environments the levels of preservation can differ markedly according to the chemical properties of the surrounding sand, which may vary "every few hundred metres" (Frost 1962: 84)(see Figure 3). Bascom (1971) predicted greater chances of survival of wooden shipwrecks and any fragile contents in deep waters (greater than 1000 metres) because of:

- low temperatures;
- chemical reactions proceed slower;
- absence of light;
- currents are minimal;
- the wreck will be beneath the influence of wave action, trawling and divers.

Subsequently, Wilkes (1977) referred to the immersion in water (especially salt water) and the influence of marine life, but not effects of burial environments.

In making explicit the recognition that seabed environments are complex, Florian (1987) attempted to describe the interaction of the chemical, physical and biological aspects of the marine environment with the material of an artefact considering the nature of seawater, the nature of the sediment and interstitial water and the nature of the biota (Figure 4). A staged system is presented focusing down from regional, to site, to artefact, to surface interface - a classification for marine underwater archaeological wreck sites according to biozone (biotope)(see Figure 5) as a simplified approach to unify the variety of geographical (but similar environmentally) wreck sites. That is switching from biology to chemistry with the change in scale. Yet, because of the importance of marine chemistry on artefact material, a classification of marine chemical environments is presented for artefact sites within a wreck site.

## 2.4 Materials decay models

For the purposes of management and the mitigation of impacts, decay models have been proposed (Figure 6). An *Interdisciplinary Workshop on the Physical-Chemical-Biological Processes Affecting Archaeological Sites* (Mathewson 1989b) concluded that:

- each of the components (artefacts, features and ecofacts) and the spatial relationships between them - all of which make up an archaeological site - react differently to changes in the physical, chemical and biological environment surrounding the site,
- basic scientific information required to develop a quantified site decay model was unavailable,
- it would eventually be possible to develop a quantified decay model but it would be extremely complex due to site component variability (*i.e.* numbers, types and interactions between artefacts, features and ecofacts), physical variability (in global environments), biological variability (in distribution and effects of numerous impacting organisms) and chemical variability (in the complexity of the physical and organic chemistry processes which are dependent upon the environment of the site).

It was thought unrealistic to suggest that a generic, quantitative site decay model could be generated and that a more reasonable approach would be for such models to be developed for specific sites (if they are to be impacted by development). An example of a regional approach might be the model put forward by Raban (1973) for the preservation of shallow wreck sites in the Eastern Mediterranean (see Figure 7).

## 2.5 The concept of equilibrium

The concept of sites reaching a relative equilibrium with their environment was recognised at an early stage in the development of marine archaeology[16]. At the same time the fragility of the balance of that equilibrium was also realised:

Objects and materials on a marine site, if left undisturbed, will have reached a state of relative equilibrium with their environment, and deterioration processes will either be very slow or have completely ceased (Leigh 1973). The rate of deterioration of objects slows down to a level thought go be lower than practical means of measurement[17].

“An equilibrium is reached. It is the disturbance of this equilibrium through removal or recovery from this stable environment which starts further decomposition.” (Arnold 1978a: 174)[18]

This point is re-iterated by Pearson that "If conservation is not employed the object is best left alone on the seabed where it will probably safely survive many more years than if raised without being properly conserved" (1987: Preface).

Severe and irreversible changes can occur if artefacts are moved from their resting place on or under the seabed (normally referred to as the burial environment)[19]. Frost (1962) reiterates the point that once the equilibrium of the bottom has been disturbed, objects will become displaced or float away if they are left for any length of time. Even minor disturbances (as opposed to complete removal into air) will also have an effect. Excavation or exposure

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16 “....at the bottom of the sea, one false move........can destroy, in the fraction of a second, some delicate find preserved for centuries in marine conditions.” (Frost 1963: xiv).

17 “It is probably safe to say that once a shipwreck has reached the consolidation stage, it will last for ever with very little deterioration unless disturbed or uncovered”. (Throckmorton 1965: 317).

18 Arnold states this as a scientifically established fact, citing Lawson (1978) who actually said (author’s italics): “During long emersion (*sic.*) in seawater, the artefacts’ rate of deterioration slows down as the object *almost* reaches a state of equilibrium with its surroundings”. (Lawson 1978: 70).

19 Bitter experience of an amateur archaeologist/recreational diver leads to conclusion that: "An object that has been buried in the seabed for a couple of centuries will not alter very much if left undisturbed for a few more years. But bring it up into the atmosphere and in a matter of days, decomposition will commence." (Wilkes 1971: 249).

for whatever purpose (archaeological or otherwise) might constitute the major cause of such disturbance.

Furthermore, it is known that deterioration processes at the artefact level will continue after excavation or removal from the burial environment, and they may even promote accelerated degradation[20].

## 2.6 Processes of deterioration

Many factors (and the interactions between them) promote deterioration which in itself is accelerated by fluctuations. For example wetting and drying, influxes of salts, alterations in pH and changes in temperature. Decay, or deterioration, processes are often categorised into chemical, physical and biological topics (Mathewson & Gonzalez 1988), a list of agents (Cronyn 1990), or assessed in relation to a particular archaeological artefact type (Pearson 1987).

Attempts have been made to correlate time with factors affecting preservation. Mills Reid (1986) speculates that the extent of degradation of organic materials at 25°C for 200 years may be comparable to that occurring at a temperature of 5°C over 500-1000 years.

Smith *et al* (1981) produced a flow chart of environmental factors which lead to increased artefact preservation (see Figure 3). In general reactions increase when temperature increases, light is present, water movement increases, and salinity increases.

Chronological age, however, appears to have little to do with the survival or otherwise of archaeological materials (Florian 1987, 1990). Frost in the early Sixties makes the observation that "it is the conditions surrounding a wreck on the seabed rather than the time element that govern its state of preservation" (1962: 83) having seen wood from a Bronze Age vessel and from Sixteenth

Century ship remains in the Mediterranean, both being equally well-preserved.

### 2.6.1 Sequence of colonisation

The sequence of colonisation of newly-exposed or newly-introduced materials on a marine site has been studied. Freshly exposed timber on the *Mary Rose* site was colonised as quickly as adjacent steel, concrete and plastic surfaces (by-products of the excavation activities)(Collins & Mallinson 1984). The main destructive macro-organisms in this case were boring isopods (*Limnoria* spp.).

### 2.6.2 Exposure or burial

If materials are buried (by sand, silt or mud) or protected by the hull structure it is possible that very fragile materials can survive - *e.g.* glass, textiles etc.. In such buried environments there is very little oxygen, a substance which is essential for the majority of deterioration processes to occur. Reduced oxygen levels in sandy sediments were known from an early time to favour preservation (Frost 1962[21]). If left undisturbed such materials can survive for centuries.

Wrecksites situated in sedimentary environments are commonly well-preserved, and can be categorised according to their degree of exposure to seawater. In Bay Bulls, Newfoundland, Barber (1977) reports on three sites in the same vicinity - Wreck 1 almost completely covered by silt with little wood exposed but three cannon, Wreck 2 partly exposed wood, concretions and cannon, and Wreck 3 fully exposed and consisting of a pile of stone ballast and some surrounding hull.

The typical situation of partially buried wood on the seabed can be depicted (see Figure 4). Seawater is aerobic and therefore it will support the growth of algae, fungi, bacteria, *Teredo* spp. and *Limnoria* spp., resulting in extensive

[20]For example the observation that some attached corals which had been pushed off the surfaces of amphora during handling and this had removed a thin layer of the ceramic which was adhered to their attachment faces (Florian 1994).

decay of any timbers protruding from the seabed. Mechanical erosion would also help to remove decayed wood thus exposing new surfaces to decay and allowing decay organisms to penetrate deeper into the wood. Those timbers, or parts of them, well buried in the seabed sediments will only be subject to the relatively slow action of anaerobic bacteria. Therefore the integrity of archaeological waterlogged timbers will be governed by the length of exposure to free-running seawater they have been subjected to.

Two identical halves of a cast bronze capstan bearing, recovered from the wreck of the *Rapid*, exhibited differences in patina attributed to their relative levels of exposure (MacLeod 1992). Against expectation the casting which had been lying on the surface of the seabed was better preserved having a patination of the original as-cast surface. The buried counterpart had a roughened, mottled surface. It is thought that the thermodynamically more reactive phases of a buried bronze object (as opposed to the copper phases) are preferentially attacked because the level of dissolved oxygen is lower than that present in seawater. An indication of the importance of the level of exposure is that this factor is a primary element in decay modelling (*e.g.* Ward *et al* 1997).

### 2.6.3 The influence of micro-organisms

Bacteria are thought to represent the most important single factor in establishing the micro environment of the seabed (Lawson 1978, Ward *et al* 1997). One example is that of the decomposition of the hull of the *Pandora* (about one third of the original structure is said to survive buried in sediment) is thought to be largely due to the action of anaerobic microbial community (Guthrie *et al* 1995).

[21] After Brourdel & Vernet (1958).

### 2.6.4 Water movement

The Australian site of the *Lively* (1810) is situated in shallow water and subjected to heavy swell and severe tidal conditions, so oxygen availability is always high for utilisation in biological degradation (Mills Reid 1986).

Differential corrosion on historic iron shipwrecks in Port Philip Bay in Australia has been attributed to differences in water movement associated with their position within the bay (MacLeod 1992). Wrecks at the same depth and in the same biological zone exhibit a ten-fold difference in corrosion rate which has been interpreted from corrosion potential and hull thickness measurements.

### 2.6.5 Erosion

"Erosion" is a common term given applied to degradation of archaeological sites and it is often categorised according to whether the causes are natural or anthropogenic (see Figure 21). In reality the cause may be more complex because there are a number of examples of recreational divers (intentionally or otherwise) exposing previously buried archaeological materials and causing the site to be de-stabilised. Subsequent damage is then continued by natural forces (Martin 1995a). In fact, in the case of the *William Salthouse* wreck, the de-stabilisation sequence may have been triggered by a reduction of the sediment cover over the site as a result of nearby channel dredging; the site then became visible to local sport divers who started to loot the wreck causing further deterioration (Elliget & Breidahl 1993)

In relation to erosion on land archaeological sites it has been said that the main problem is that once de-stabilised the site will usually continue to deteriorate (Rees 1994). This is perhaps borne out on a marine site by the fact that, even though the area under immediate risk on the Duart Point site was sand-bagged further erosion continues to occur periodically around the margins of the sand-bagged area (Martin 1995a). More sand-bags could be installed to reduce this "toe scouring" but this process cannot be carried on indefinitely for reasons of cost and practicality. As discussed later, other more environmentally acceptable solutions (such as encouraging protective kelp growth) may be more suitable for such sites.

#### 2.6.6 Hydration

Artefact materials of an organic origin are usually made up of fibrous polymers which formerly performed a structural function in the original organism (*i.e.* lignin in plants or collagen in animals). Such fibrous polymers in the living organisms are maintained in a hydrated state by the movement of water through osmotic and hydrostatic pressure. Before use of the materials for artefacts they are usually dried which involves some shrinkage. On immersion in seawater as part of the formation of the marine archaeological site they undergo re-wetting and hydration. This process is accompanied by some swelling which involves particles of the solid being pushed apart, increasing the volume and introducing an excess of solvent (*i.e.* water). For example the waterlogged oak timbers of the Swedish warship *Vasa* had a 1 per cent increase in tangential dimension after 333 years immersion (Cronyn 1990).

#### 2.6.7 Water quality

Research has been carried out to observe and quantify the direct and indirect effects of nutrient rich and microbiologically contaminated water and sediments upon the integrity of the fabric of marine archaeological sites. The species and level of wood-borer attack varied considerably between the sites and this correlated with local water quality conditions (Merritt-Jones & Pedley 1998).

### 2.7 Organic materials

There is very little published research relating to, or meaningful interpretative analysis of, organic materials from marine archaeological sites other than wood. Reviews of the deterioration of organic materials, especially those materials other than wood, has had to rely on published literature on the physical, chemical and structural aspects of the natural unaltered materials and to then speculate on the changes that may occur due to immersion and burial in seawater (Florian 1987). This speculation must be tempered by knowledge of the implications of the alterations which may have occurred during the use of the artefacts.

Thus marine burial can preserve the shape and dimensions of an artefact but this often gives a misleading impression of the overall state of preservation and stability of the object. Chemical and bio-deterioration may have occurred even if the integrity of the whole has been maintained.

### 2.7.1 Wood

There have been a number of studies of the deterioration of waterlogged wood on marine archaeological sites (Grattan 1987). Waterlogged wood means that all the air spaces in the cells of the wood have been filled with water and although its condition may appear to be extremely good the object will be very weak, probably unable to hold its own weight and the soft surface will be easily damaged. The degree of decay and water-logging of a piece of wood is also dependent upon species and tissue type. Some species (*e.g.* alder, beech) waterlog within a few hours and together with ash, birch and willow have poor survival in water. Oak heartwood and yew survive well and even if there is surface deterioration there is usually a sound, well-preserved core[22].

Few workers have been willing to estimate the expected survival of archaeological sites in the marine environment. Experience with wreck sites of the mid-18th Century in the Florida Keys indicates that the life expectancy of the exposed timbers is about ten years, and will not exceed twenty (Skowronek 1984).

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[22] Investigations, carried out *in situ* on the seabed, into the condition of structural timbers of the hull of the Mary Rose showed that the majority of the wood consisted of a soft, decayed outer layer of variable thickness surrounding a core of relatively sound material (Squirrell & Clarke 1987).

During the time that its immersion in sea water the structure of the cells of the wood will also have been weakened due to chemical degradation of the cell walls. Cellulose, even though normally protected from fungal and most bacterial decay, will have undergone hydrolysis and anaerobic bacterial attack, leaving the cells composed mainly of lignin and supported by water, organic debris and sediment.

Completely exposed wood rarely survives. In aerated environments above seabed level, wood will be attacked by a variety of animals (see Figure 9). Molluscan borers such as the shipworm (*Teredo navalis*) are characterised by long, worm-like bodies (from 10cm to 2m in length) with only the head of a bivalve shell which has become a cutting tool. They enter wood as minute embryonic forms thus making only small holes in the surface. Rapid burrowing follows within the wood as the animals increase in length. The interior can be completely riddled with tunnels whereas the surface shows only a few pin-holes.

The marine gribble (*Limnoria lignorum*), the main crustacean borer, is around the size of a rice grain and the damage can be readily seen at the surface. Burrows are narrow, interlacing and branching, seldom extending more than 1cm below the surface thus the outer layers of the wood become finely honeycombed and spongy. This degraded surface is susceptible to mechanical erosion, exposing a fresh surface for attack. Destruction is therefore progressive. Bacteria and marine fungi will also contribute to the degradation of the wood (Leigh 1973).

Wood buried in marine environments for considerable periods of time can be said to be waterlogged, *i.e.* the pore spaces in the wood (capillaries and micro-capillaries) have become filled with water. Wood can be termed degraded at the same time if micro-organisms have had the opportunity to attack the wood by consuming various components so that physical weakening occurs (Hedges 1990).

In an archaeological object a false impression of the structural integrity and strength can be given because water filling and giving support to the cells of the wood - the object may appear little altered from the time it was lost. However, if waterlogged wood is allowed to dry in an uncontrolled manner, it may collapse, shrink, distort, split, embrittle, check, de-laminate, or even disintegrate completely (Grattan 1987).

Bacteria and fungi are the two microbial groups which have been shown to degrade wood. Guthrie *et al* (1995) state that on the *Mary Rose* erosion and tunnelling bacteria were significant, and to a lesser extent soft-rot fungi, whereas the *Kronen* suffered from erosion bacteria with tunnelling bacteria and soft-rot occurring to a lesser extent. The authors suggest that unlike fungi, bacteria can also degrade wood slowly under anaerobic conditions.

## 2.8 Inorganic materials

### 2.8.1Metals

Relatively few metals have been extensively used by man - principally iron, tin, copper, lead, silver and gold - either individually or in combination as alloys. Most metals (except for gold), from the moment of manufacture, begin a process of corrosion which converts them to more stable compounds and minerals. Exposure to different burial environments causes the formation of corrosion products the identification of which can determine the techniques or procedures necessary to stabilise the metal. In any environment water, porosity, temperature, pH, presence of aggressive anions are critical variables that determine the rates and types of corrosion.

Metals suffer from galvanic corrosion where two dissimilar metals are in contact whilst immersed in a solution such as seawater which acts as an electrolyte. A corrosion cell is established whereby one of the metals becomes an anode (or negative side of the cell) and the other metal a cathode or the positive side. The anode metal will corrode at a much faster rate and the cathode metal will be protected and its corrosion rate reduced. The same principle applies to dissimilar metals in the same object. The creation of a potential (voltage difference) can also be caused by localised variations in temperature, stress, fabrication or the environment (*e.g.* marine growth or siltation).

This model of metallic corrosion is recognised as being over-simplified[23]. Leigh (1973) summarises the role of bacteria, particularly sulphate-reducing variants, in up-setting the equilibrium between pH and dissolved salts in sea water, a process which encourages the formation of concretions. Most ferrous materials are thought to gain a certain degree of protection from continual corrosion by the formation of encrustations. The corrosion rate for unprotected steel in seawater is commonly given as .005 inches a year (Murphy 1987). The lack of quantified experimentation and the variability of factors involved in the formation of concretions on marine archaeological sites means that such predictions would be unreliable

Cast iron corrodes by graphitisation, usually leaving behind a metal core, but with a surface crust of graphite-containing iron corrosion products. Such "concretions" will usually retain the shape of the original object but they are often in a very unstable state, and if exposed to the atmosphere, new and rapid corrosion will occur (at the graphite layer/metal core interface) potentially forcing off the surface layers.

Metals can survive for considerable periods of time (MacLeod 1989a). Tylecote's research on potential metals for the construction of radioactive waste disposal containers (1977) determined that copper (or copper based alloys) and pure lead survived markedly better than any of the other metals available over the last 1000 years.

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[23] Hamilton (1998) explains that electrochemical cells may also form on a chemically homogeneous metal in areas of mechanical stress, such as a dent or a bend (*e.g.* iron fastenings damaged during the sinking event). In addition, the effects of different oxygen concentration, temperature, and pH at a metal surface will also cause corrosion.

The copper alloys of bronze are normally mixtures of other metals and elements other than the usual copper and tin. Additional substances may only be present in small amounts but they will react to immersion in sea water in different ways. There will also be variations in the mixture throughout the object and certain impurities will also be present.

Many of the cannons recovered from the sea are made of cast bronze. After immersion in seawater bronze objects will continue to corrode if they are not kept wet or stored in a stable environment as soon as they are raised.

Copper alloys are toxic to many forms of marine life and as such they have formed the basis for marine anti-fouling throughout maritime history (*e.g.* copper sheathing on the hulls of wooden ships). Bronze cannon are usually discovered with very little marine fouling and concretion.

Bronze and other copper alloys are however subject to corrosion and attack from the chlorides present in sea water. Bronze objects are resistant to oxidation because the thin surface corrosion product layer (or patina) forms a protective barrier. Cannons recovered from beneath seabed level (*i.e.* from within sediment) may be in poorer condition and covered in a blackish layer.

Corrosion products on the surface of the object, and deep within cracks and crevices, will contain chlorides. These chlorides will continue to promote degradation after the cannon is raised from the sea bed.

**2.9 Marine archaeological concretions**

Generally iron objects are encrusted with a layer of hard concretion which forms a semi-permeable barrier between the iron and the seawater. An investigation into the properties, composition and mode of formation of concretion found on marine iron lying on or above the seabed in regions of active epi-faunal growth was carried out by North (1976). The study, concentrating on material from the *Batavia* (1629), fully described the seabed environment of the wreck site and concluded with a description of the concretion formation process.

When artefacts are recovered from the sea, they are commonly encrusted with thick layers of calcium carbonate, magnesium hydroxide, metal corrosion products, sand, clay, and various forms of marine life such as shells, coral, barnacles, and plant life. Such conglomerates may range in size from a single coin to masses weighing several thousand kilograms containing hundreds of individual objects made up of many different kinds of materials (Leigh 1973, Hamilton 1978).

Carpenter (1990) states that the presence of concretion on marine archaeological artefacts should be viewed positively as the benefits outweigh the main negative aspect which is the difficulties involved in its removal. Concretion can also provide information about the changing wreck environments and corrosion processes.

Artefact detail can be retained as an accurate mould of the original surface. The first observation of the phenomena that some concretions can form perfect moulds, and that casts can be made of the original object from them, was made on the Roman wreck lying at the foot of the rock called Balise de la Chretienne (Frost 1963).

On the Spanish shipwrecks of 1554, off Padre Island in the Gulf of Mexico, artefacts rarely occurred individually as they were concreted together in large clusters. In some cases the contents of shipping containers had been trapped as a group by encrustation after the container had been crushed by shifting ballast. Alternatively, objects like stray nails, spikes, and barrel hoops from the disintegrating wreck were gathered together by chance currents, perhaps in shallow depressions in the Pleistocene clay together with a few coins or other non-ferrous items which had become trapped in the encrustation, a product of mainly iron corrosion products (see Figure 10 and Arnold III & Weddle 1978). Ironically, on these sites, which have suffered the depredations of treasure hunters, the only location context with even a small chance of producing any meaning is the scant information that can be gleaned from the interrelationships of artefacts within conglomerates which were encapsulated relatively soon after the wreck.

As concretion forms, corrosion processes are altered and the rate of corrosion activity, in the case of iron, is considerably reduced. This point is critical to the continued preservation of the *Monitor*, a US National Marine Sanctuary. The structure of the iron vessel is continuing to deteriorate from natural galvanic corrosion because of its continued exposure to the marine environment. The *Monitor* has been exposed to a highly corrosive environment because of the relatively high temperature, the oxygen content of the seawater and the current velocities experienced on the site. The latter factor enables the transport of abrasive bottom sediments to erode away corrosion products (concretions) which would normally tend to decrease deterioration over time (Miller 1985).

In some cases substantial areas of wreck sites can be covered with an obscuring concretion matrix such as that found on the *Pandora*, 1791, (Carpenter 1990). This can be beneficial to archaeological investigation as delicate organic materials can often be preserved by encapsulation in the concretion[24].

Concretions are still a relatively un-researched area in marine archaeology and they are in need of further investigation (Leigh 1973)[25].

### 2.10 Benefits of studying preservation characteristics

In terms of shipwreck sites conservation has been defined as the analysis of the material recovered to discover the causes, mechanisms and extent of its corrosion and degradation, and the application of techniques and processes to arrest its corrosion and impose a satisfactory set of equilibria appropriate to the world of light and air (Petersen 1984).

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[24] For example fragments of lace from the *Batavia*, 1629 (Carpenter 1990).

Conservation science will benefit from an increased knowledge of the burial environments of objects and materials as more effective conservation treatments will be developed if the properties of the environment which surrounded an object have been considered *e.g.* sediment type, pH (Pearson 1980)[26]. The conservator will be better able to judge the type of interference to be expected from the artefact having been exposed to certain pollutants, bacteria and chemical substances (Lawson 1978).

In a similar way, the study of the effects of freshwater inundation on various kinds of cultural resources has promoted the design of experiments in preservation which are orientated towards mitigating the effects of adverse natural impacts and structural problems inherent in aboriginal buildings (Nordby 1982).

The classification of shipwreck sites has been based on levels of preservation. It has also been shown that careful search and systematic survey can produce results which allow an interpretation of sites which apparently lack any pattern and are heavily contaminated by modern material *e.g.* Mediterranean sites by Parker (1981). Cederlund (1980) attempted to define the factors which determine the preservation of old ships on the seabed in Swedish waters:

- geographical appearance of the coast,
- situation of the wreck in relation to the water surface (depth),
- type of sea bed (geographical (hard, sandy) or geological (sedimentation, erosion),
- height differences on bottom (movement of sand),
- existence of ice, currents, heavy wave movements,
- special biological conditions (*e.g.* presence of *Teredo* spp).

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[25] Leigh (1973) also admits that his estimate that concretions can grow at a considerable rate is a subjective judgement based on a few random experiments.

The zonation of the seabed into areas of specific environmental conditions thought to have affected the preservation of particular artefact types has also been used to analyse finds distributions in Orange Bay, St Eustatius, as described by Nagelkerken (1985).

### 2.11 Discussion

"... because so little analytical work has been done on artefact material/marine environment from wreck sites it is difficult to predict what is important (Florian 1987: 1).

There are clearly great gaps in our understanding of why some types of archaeological materials are preserved in preference to others. It is also clear that there are many variables and parameters which have an effect. In addition new strands of evidence remain to be discovered. For example the discovery of spionkopite in the inner corrosion layer on a copper alloy compass ring recovered from the *Kronan* wreck site (Nord *et al* 1993). Spionkopite was not previously known as a corrosion product of copper.

To date most of the research into preservation has been driven by the needs of conservators to stabilise objects which have been removed from their burial environment, mainly objects of wood and iron. It may be that research into the nature of the burial environments themselves, and *in situ* monitoring, will prove more useful to a wider range of and number of disciplines - both related to marine archaeology and related disciplines - in the future.

Field research into the behaviour of archaeological materials on marine sites has recently been taken forward (Gregory 1996). The practical aspect of the research was carried out in two parts. First, a series of controlled laboratory experiments was set up involving the placing of a range of artefact materials

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[26] Leigh (1973) uses an medical analogy in that an understanding of what causes an illness is a pre-requisite of diagnosis and treatment. In a similar way knowledge of decay and corrosion is needed before it is possible to diagnose and to suggest a suitable treatment for submerged remains.

(*e.g.* wood, bone, ivory, bronze) into a series of simulated sea water and sea bed environments, these environments having varied chemical criteria (*e.g.* temperature, salinity, pH, Redox potential and dissolved gas content). The resultant effects of the criteria on the different materials will be measured over one year. Second, having ascertained in the laboratory a hypothesis regarding which kinds of chemical environment affects artefacts in the marine environment, materials similar to those used in the laboratory experiments, have been placed onto selected wreck sites[27]. The various criteria have been measured on the sites over a year along with their effects on the artefact materials. By correlating the results obtained in the laboratory and in the field it has been possible to predict (with an accepted degree of confidence) what effect a given chemical environment will have on a particular type of material.

This work reinforces a trend which can be seen in recent shipwreck investigations and post-excavation analysis of attention being paid to smaller and smaller types of evidence. Led by the conservation sciences there is an increasing focus on detail – ranging from specific biozones and inter-faces between artefacts and burial environments (Florian 1987) to a concentration on micro-organisms which clearly play an important role in the development of submerged archaeological sediments (Guthrie *et al* 1995). This trend has clearly been influenced by the emergence of archaeologists with specific scientific expertise who promote the use of analytical methodologies which are recognised, and acceptable to, the traditional marine sciences (Ferrari 1994, Gregory 1996).

It is likely that useful techniques could be imported from related disciplines but it is important to consider their relevance carefully. Methodologies for determining the state of deterioration of materials in marine environments exist in other disciplines (studies of fouling of offshore structures, cable and pipeline stabilisation, preservation of harbour and foreshore structures) but they may not be directly transferable to archaeological environments and

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27 This approach was suggested by Leigh (1973) in order that information collected from samples recovered from marine archaeological sites could be supplemented by the results of controlled

deposits as they have been developed with a view to producing new materials which are *least* likely to corrode or deteriorate. In contrast, archaeological scientists will be interested in materials which are most likely to deteriorate, and the consequent stabilisation and conservation of those materials (Oxley 1995a).

experiments in the deliberate submergence of modern disused boats and of typical archaeological materials.

# 3. Archaeological site formation studies

## 3.1 Introduction

Formation processes can be broadly defined as how archaeological evidence (in the form of artefacts, structures etc.) came to be buried, and what events distorted or destroyed it subsequently, regardles of whether those events were of human or natural origin (Renfrew & Bahn 1991). Knowing what happened at each of these stages is vital for understanding the limitations and significance of the archaeological record (Trigger 1989). Therefore the study of site formation and post-deposition processes is a pre-requisite for good archaeological practice and it influences all aspects of that practice from survey, excavation, sampling, theoretical studies and CRM.

The archaeological record available to us is necessarily incomplete. Complex and little understood processes have altered the artefacts, structures and sites which were abandoned or lost by our ancestors (see Figure 22). The data available to the archaeologist, who is attempting to interpret these events in retrospect, is always biased and incomplete. It is the purpose of site formation studies to try and identify the biases, and subsequently compensate for them in the analysis and interpretation of the site.

Murphy states (1990), in relation to the Douglas Beach site, that the *specific* examination of formation processes and the formulation of general principles enhances archaeological inference and interpretation. Archaeologists had earlier assumed that inundated sites would be preserved only on low-energy coastlines like parts of the Gulf of Mexico[28]. Other workers go further. The understanding of the effects of formation processes on the archaeological record cannot be reached without reference to both natural and cultural processes - an axiom often stated in the introductory remarks of any treatise

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[28] The Douglas Beach site demonstrates that barrier-island migration can preserve sites and the model for early site location offshore can now be expanded to include submerged, remnant barrier features. Previous site location models for the region focused on relic riverine features in low-energy areas (Murphy 1990).

on impacts, formation processes or archaeological interpretation (Wood & Johnson 1978, Wildesen 1982).

An analysis of the site's formation is essential for meaningful definition, and the interpretation of individual shipwreck assemblages should begin with environmentally-based models (Parker 1995). Also the site formation processes at each individual site must be considered separately, usually within the context of different deposits within it. The fundamental point is that they have to be identified before behavioural or environmental inferences can be made from any archaeological evidence.

Site formation studies have been the mechanism used to analyse finds distributions such as the zonation of seabed into areas of specific environmental conditions thought to have affected the preservation of particular artefact types (Orange Bay, St Eustatius described by Nagelkerken 1985). The latter study involved the possible identification of an historic anchorage using environmental parameters linked to archaeological survey. A further example is the environmental assessment and remote sensing surveys employed in relation to site formation, followed by test excavation on the Padre Island surveys (Clausen & Arnold III 1976, Arnold III 1977).

One example is *Archaeological Formation Processes*, (Kristiansen 1985a) which is an attempt to systematise but one aspect within an overall theory of the formation processes of the archaeological record on a regional and national scale (Kristiansen 1985b). Site formation studies can provide a framework for identifying the types of site (or cultural remains) which might be preserved. The assessment of the archaeological formation processes of Denmark (Kristiansen 1985a) concentrates on the effects of historical post-deposition factors for archaeological representation at regional and national scales, unusually including maritime environments and nautical archaeological sites (Crumlin-Pedersen 1985).

Research on the site of the *Xantho* has shown that, after taking into account many variables including site formation processes, the behaviour of a steamship owner and the ship's crew can be elucidated from the material record (McCarthy 1997). The same process has been carried out by Souza (pers. comm.) in relation to wreck sites in the Dry Tortugas as part of research into the persistence of sail in the age of steam - assemblages and associations have been identified which reflect the behaviour of the crew just prior to the wrecking event. A particularist approach (research into the technology of steam auxiliary equipment, deck machinery and ground tackle) has been combined with a behaviourist approach interpreting the evidence in relation to risk-taking, technological adaptation, resistance to change, and changing concepts of acceptable risk.

### 3.2 The archaeological record

Archaeological evidence results from two processes - initial human behaviour (*i.e.* the phenomenon of a shipwreck which is a culturally-derived event) and subsequent transformational actions (effect of natural processes and subsequent human activities).

Archaeologists on land have long understood that past human activities are reflected in the distribution of artefacts on a site, *i.e.* Childe's (1956) assertion that human behaviour is "fossilised" in the archaeological record. More recently consensus has emerged in terrestrial archaeology on the need to study the formation of the archaeological record as a prelude to drawing inferences based on archaeological data (Renfew & Bahn 1991). Archaeologists have come to recognise that the archaeological record has a complicated history - various types of forces have transformed the original assemblage deposited by the inhabitants of the site or contained in the wreck into the assemblage observed now.

However, site formation theory is not often explicitly dealt with in the marine archaeological literature. Furthermore, site formation studies have since the earliest years of the development of the sub-discipline been recognised by only a few workers as significantly important for studying the processes which underlie the development of submerged sites. There is an even wider gulf between the acceptance of theoretical concepts and the delay in developing such concepts between marine archaeology and its parent discipline. Similarly, there is distance in the relationship between field practice[29] and theoretical research and development.

This is in contrast to land archaeology where although it took some time for prehistorians and archaeologists to accept the dynamic nature of soil and to apply it to field situations[30], it did become widely accepted. Similarly, the principle of stratigraphic superposition can be traced back to Steno in 1669, but archaeologists did not consistently make use of this important law until the last 70-80 years (Schiffer & Rathje 1973).

### 3.3 Site formation processes

The archaeological record which exists at a place is a mixture of temporally discrete occurrences compressed into a single, spatial distribution (Gladfelter 1981). Coles (1995) described an archaeological site as cultural evidence surrounded or embedded in a matrix which also contains contemporary environmental evidence.

Schiffer (1972) postulates that all elements of a site (*e.g.* artefacts and structures) enter a system, they are then modified, broken down, or combined with other elements, used, and eventually discarded. This concept can be equated to the wear and tear effects which would have taken place during the working life of a ship before it is wrecked.

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[29]It is essential that excavators gain an understanding of the many processes involved in the formation of a particular site - how structures decay, how occupation layers accumulate, how depressions become filled with sediment etc. (Greene 1995) - for them to perform effectively and to investigate the archaeological resource economically.

[30] Soils are not static - they are open systems in which numerous processes operate to pedoturbate profiles, and to move objects vertically and horizontally within them. These processes may operate singly or in combination in additive or subtractive fashion, in all environments and at all latitudes (Wood & Johnson 1978).

Site formation processes alter archaeological burial by gradually degrading the total resource. Such processes, whether physical, chemical or biological, can also cause acceleration or deceleration of the degradation but even in the latter case they are not thought to cease entirely. The archaeological patterning which results from natural formation processes will also be modified by post-deposition human activities such as trawling, contemporary and later salvage.

Natural formation processes will be the first to act on an original archaeological record structured (in part) by cultural behaviour associated with shipboard life (*i.e.* where things are on any given ship). Frost (1963) suggested that to be preserved at all wrecks must lie in deep water beyond the ravages of winds and currents, and they must be buried in sand; on a rocky bottom wood is broken up or eaten by sea animals. Furthermore, sand holds both wood and cargo together in a significant relationship, and since oxygen is reduced in certain layers of sand, it also helps to preserve organic matter.

The marine environments, in which archaeological sites develop, exhibit differences providing additional variables - from the macro scale in terms of temperature, depth, and local topography; to the microscopic variations of chemical parameters within burial sediments . The environmental parameters or preservation characteristics themselves will also be dynamic and change over time as Florian (1987) describes when discussing the differentiation between artefact/environment interfaces (Figure 4).

Many underwater archaeological sites consist of extensive areas of wooden structure exposed to free running water. Such structures are also vulnerable to degradation from many sources, ranging from fungi, bacteria through to larger wood-boring organisms. Deterioration is further enhanced if there are repeated cycles of exposure and covering. At each new exposure organisms will attempt to re-colonise the structures (using a variety of attachment methods from chemical secretions to physical mechanisms) causing further damage to the surface of the wood.

The extent of the risk and the speed of the attack can be seen from experience on the St Peterport Gallo-Roman wreck where it took only twelve months to obliterate surface detail from the exposed ship's timbers and only two years to reduce the size of a timber by 50% (Rule & Monaghan 1993).

A second common characteristic of marine archaeological sites is the presence of large iron objects. On wreck sites these objects are often guns and anchors with a greater or lesser amount of surface concretion. However in the case of the designated Historic Wreck Site the *Iona II*, a paddle steamer which sank in 1864, extensive areas of machinery and boilers are preserved in addition to iron frames and structural elements. Iron objects and structures can survive on the seabed for many years substantially unchanged at least visually, provided that the surface layers of concretion remain intact.

### 3.4 Definition and understanding

Site definition and an understanding of site formation processes have proved to be the most intractable problems in archaeological method and theory (Gould 1989). The overriding problem is how can a controlled approach to the study and preservation of archaeological sites be achieved that will ensure scientifically acceptable results suitable for under-pinning research designs and workable management practices?

In terms of maritime archaeology, and specifically in relation to wreck sites as sources of information of value to the study of the maritime past, Anuskiewicz (1992) restricts the term "site formation" to describing the initial factors which contributed to how each site was formed: poor navigation, natural floundering, storms or hurricane, accidental fire, economic abandonment, warfare scuttling or battle damage)[31]. Subsequent alteration of the site as a result of natural or cultural processes is not considered in Anuskiewicz's work.

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[31] See Parent's (1988) Ship Concentration Criteria (Figure 11).

The effects of contemporary salvage and post-deposition salvage are often predicted and even cited as the cause of unexpected disturbance, but they remain little understood particularly compared to some terrestrial post-deposition processes. For example in the case of the *Mary Rose* site the effect of the Deane brothers salvage in 1836, *i.e.* 291 years after the sinking was relatively slight, especially in relation to the effort required to excavate and raise the entire ship and contents in 1982 (Bevan 1996).

## 3.5 Defining the processes

The first stage in any attempt to rigorously examine the most fundamental archaeological problem *i.e.* the relationship between the operation of past cultural systems and the location (and interpretation) of the data that remains, should be to explicitly outline the physical and cultural processes that have led to the present state of the archaeological record (Schiffer & Rathje 1973). This sequence would involve a description of the natural background and the history of its formation then the subsequent input represented by the cultural component of the site. For example, the physical characteristics of the deposits in which they were found tell us that fast-running waters of the River Thames rolled dozens of prehistoric hand axes downstream from where they were originally dropped by their makers and deposited them in river gravels, to be recorded by archaeologists thousands of years later.

### 3.5.1 Relative survival of evidence

It has long been recognised that the archaeological record normally contains a far from complete sample of the material remains of the past. Elements of the sites (features, contexts, structures, deposits, artefacts) have been destroyed or modified after abandonment or wrecking and material can also be added to sites. On a 16$^{th}$ Century wreck off Bermuda, protection was seen to be afforded by accreted sediments, iron features were completely destroyed but extensive organic preservation (ecofacts which became important in interpreting the origin of the vessel) was noted under undisturbed ballast and sediments within the surviving hull remains (Watts 1993).

### 3.5.2 The trend of site deterioration

Schiffer (1987), whilst recognising the position of Ascher's "time's arrow"[32] as a statistical generalisation, points out that there are three important exceptions -all of which have relevance to shipwreck formation studies:

1. Because degradation can be caused by specific processes, and not necessarily simply by the passage of time, deposits formed at the same time but subject to different formation processes, vary in their degree of preservation. An example is the protective properties of marine concretions which can also, with or without surviving artefact material, provide evidence of changing wreck site environments and corrosion processes (Carpenter 1990).

2. Useful information can be derived from badly degraded deposits. Muckelroy's analysis of the distribution of finds from the *Kennemerland* (1976) caused him to make the strong suggestion that such close study should prove worthwhile. This possibility is often ignored by over-pressured cultural resource managers and others (*e.g.* treasure salvors) when making claims that "scattered" sites are likely to be unproductive archaeologically.

3. Some information of archaeological interest actually accumulates through time *e.g.* materials, principally ecofacts, are added through environmental mechanisms. The latter may be of interest to other disciplines, perhaps as temporal benchmarks. Dumas (1972) postulated that the seemingly widespread phenomenon of the formation of a uniform layer of aggregation on amphorae sites in the Mediterranean might be of benefit in determining a chronology of deposition and change in seabed environment. Recent work on deep sites has recorded phenomena such as the sea floor depressions (interpreted as products of the feeding habits of pilot whales) which contained amphorae, and the fact that the whole area was heavily bio-turbated (McCann

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32 Ascher (1968), in one of the first general examinations of archaeological formation processes, conceived the "time's arrow" which progressively reduced the quantity and quality of evidence surviving in the archaeological record.

& Freed 1994). Such investigations also provide further feedback to the marine biology as it was observed that each amphora had its own unique ecology.

### 3.5.3 Generalities

In general terms formation processes can range in scale and magnitude from massive (sea level change, coastal erosion), extensive (sewage related nutrient enrichment) to minute (burrowing of micro-fauna). They can operate on a global (climatic and sea-level change), national, regional, site, object or micro-environmental scale.

Processes can also work over a variety of time-scales, perhaps 10, 20 or even 50 years but cumulative effects of even a small impact, multiplied many times, may be considerable *i.e.* micro-faunal disturbance over 450 years.

### 3.5.4 Regularities

If formation processes were completely changeable in their time and manner of operation then the task of inferring past cultural behaviour would be hopeless. However Schiffer (1987) postulates that all transformations effected by cultural and non-cultural formation processes (*i.e.* c-, and n-transforms) are quite regular in two important aspects, and it is possible to put forward marine archaeological examples as follows:

Causes: - the occurrence of specific formation processes is determined by specific causative variables, making these processes highly predictable. For example, in sedimentary, shallow water, marine environments we can anticipate that marine fauna will be present which will significantly disturb archaeological remains (Ferrari & Adams 1990).

Effects: - the results or consequences of specific processes, their traces, are themselves regular and predictable. For example, disturbance of the burial environment of archaeological remains will alter bacteriological ecologies which may accelerate deterioration (Gesner 1992). Because these effects are regular they can be used to identify the formation processes of specific deposits or even environments.

The latter premise underlies the research currently being undertaken by Gregory (1995) in creating a better understanding of the initial dynamic phase of deterioration within a shipwreck environment.

### 3.5.5 Categorisation of processes

A typology has been suggested by Wood & Johnson (1978) for clarifying various processes of soil mixing (pedoturbation):

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

No equivalent exists for the disturbance of marine archaeological burial environments. In general, it is important to recognise that all processes are significant whether their effects are judged to be positive or negative. Additionally, all processes must be considered simultaneously although their apparent interaction may pose problems for identification and interpretation since several may produce similar impacts, and therefore prove difficult to define.

### 3.5.6 Migration of artefacts

The phenomenon of "artefactual migration" was reported by Shomette as part of the investigation of a 17$^{th}$ - 18$^{th}$ Century tidal river port complex at Londontown (1978) where the cyclical movement of smaller artefacts or objects in shallow water around a larger, stationary object, in a measurable rhythm caused by repetitive motion of tides, currents and wave activity striking a poised balance of movement. In addition, the observation was made during the salvage of the *Debraak* that "Zacharchuk.....claimed it was his experience with ships carrying quantities of coins and bullion that these materials migrated down through the matrix of a site and became lodged beneath the hulls" (Beard 1989: 48). Moreover, Murphy (1990) suggested that artefacts whose specific gravity is greater than the surrounding sand, which are deposited in sand deeper than the wave base, will migrate downwards to the wave base and stabilise.

This process is further described by Ferrari & Adams (1990) in terms of burrowing marine organisms transferring soil to the seabed surface and collapsing burrows causing subsidence. Buried objects will continue to sink through these disturbed sediments through the influence of gravity until a substrate is reached which is no longer affected by burrowing (see Clausen & Arnold 1976, Cantelas & Rodgers 1994).

### 3.5.7 Transforms

Transforms are essentially best limited to post-deposition. A distinction between two basic types of transformation (or formation) process, suggested by the general regularities observed above, has been provided by Schiffer (1987):

- *"c"-transforms* can be defined as the processes of human behaviour that affect or transform archaeological materials (*e.g.* artefacts, structures or sites) after their initial period of use in any given activity.

- *"n"-transforms* are non-cultural formation processes or the events and processes of the natural environment that impinge upon archaeological materials and evidence.

*n-transforms* can be used to refine predictions of likely survival and representivity, predictive survey and studies of preservation.

Schiffer & Rathje (1973) foreshadow marine archaeological site formation theory by illustrating the dangers of over-generalising *c-transforms* and utilising them in an immature form. Their example describes the situation where more specimens of classical Greek art have been recovered from shipwreck sites that from land excavations. Although most of these wreck sites have been found by accident, careful study of *n*-transforms and *c-transforms* promise more efficient site location in the future - a theory taken up and developed by Bascom (1976) who focused on the Mediterranean and Black Sea marine environment as a preservation medium and as a mechanism for optimising any search strategy.

Muckelroy (1978) after Clarke (1968) proposed the term "extractive filters" to attempt to distinguish between the effects of natural processes and cultural ones[33]. Muckelroy's discussion of the evolution of a shipwreck and the relationship between filters (elements which operate to extract materials from the assemblage) and scrambling devices (which rearrange the patterns of these associated materials) applies similar reasoning (to Schiffer's *n-*, and *c-transforms*) to the problem of evaluating underwater sites, although the cultural and natural processes he refers to cross-cut the distinction between filters and scramblers (Gould 1989)(see Figure 12).

Vrana & Mahoney (1995) after Wildesen (1982) discuss the difference between *impact* and *effect*. For example one of the causes for the differences

[33] Ross in 1981 discussed the concept of identifying "filters" which served to reduce the site - since an assemblage lost with the ship is further reduced by immediate and long-term environmental factors (organic material floating off, iron objects corroding, tidal and ice movements etc.) - "researchers should ...... seek to explicitly identify the environmental factors affecting the preservation and destruction of original cultural assemblages" (Ross 1981: 73).

in corrosion potential of similar metals on an Australian wreck appears to have been the presence of the sea urchin (*Heliocidaris tubercolta*) which burrowed into the marine growth on the concreted artefacts. The surface of recovered artefacts, such as a carronade and cast-iron ballast pigs, featured shallow hemispherical depressions which are thought to have affected the electrical resistance of the concretion layer, increasing the corrosion of the underlying object (MacLeod 1993)[34].

An impact can be termed an *effect* if a professional judgement is made about the measurable alteration *i.e.* what change has been occasioned on the characteristic or property of the archaeological site in terms of an outside philosophical, methodological, or regulatory standard. It is important to remember that measurable changes can also be of a positive nature.

### 3.6 Interpreting the evidence

The interpretation of evidence presented by archaeological site is seldom straightforward. Patterns produced by natural formation processes have been mistaken for cultural patterning and this can lead to the misinterpretation of site chronologies, stratigraphy, spatial organisation and function (Erlandson & Rockwell 1987).

Wood & Johnson (1978) point out that since debris (or artefact) distribution is the result of purposeful human activity, it may be patterned but it does not follow that the patterning of the debris and the patterning of the human behaviour that produced it are identical. And before such demonstration of artefact/behaviour isomorphism is complete, the processes must be known that may have acted on the matrix in which the debris was incorporated, and their effects assessed. The matrix (usually soil) is subject to modification and transport by numerous chemical, biological and mechanical processes.

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[34] A further example of the effect of environmental processes is indicated by the widespread distribution of containers on the Varazze site which has been linked to conger eels dragging octopuses (which cling to the insides of pots) towards their den before killing them. This activity can leave the containers far from their original location (Riccardi & Chamberlain 1992).

Curiously, given the dislocation between terrestrial and shipwreck site formation studies (see below), a review of Schiffer's often cited *Formation Processes of the Archaeological Record* could be describing the current state of shipwreck formation process studies almost ten years on. Rick (1989) states that: some significant advances have occurred; more processes, principles and effects are known, and thus there are more avenues of explanation for those who recognise formation processes approach. However, at the same time as being conscious of more variety there is a feeling of a struggle to discover general principles. This is combined with an inability to generate a systematic theory.

Rick further suggests that, because there are so many context-sensitive qualifiers, sophisticated analysis of formation processes will always be directed towards specific circumstances. Moreover formation processes will not be capable of being generalised into law-like statutes. Most formation processes will increase in complexity on closer examination thus reducing our chances of developing general principles that can cope with all site types.

Maximising the effectiveness of archaeological interpretation is predicated upon attaining a sound appreciation of site formation processes. This principle has not found widespread explicit acceptance in shipwreck archaeological fieldwork despite workers over the last forty years periodically suggesting that it is an appropriate pre-requisite to any shipwreck investigation (Dumas 1962, Frost 1962, Throckmorton 1965). Calls have also been made for a unifying methodology and theory for maritime archaeology based, amongst other things, on a comprehensive treatment of site formation theory (Gibbins 1990).

Few publications of wreck site investigations pay any attention to site formation. Those that do exist do not often include reference to theoretical concerns and specific site formation considerations are even scarcer. In addition treatises on general archaeological formation processes rarely include marine sites and references to shipwreck sites are even scarcer, an exception being Schiffer & Rathje (1973).

The relationship between field practice and theoretical research in shipwreck archaeology can be characterised by the delay between the development, acceptance and integration of theoretical concepts into mainstream shipwreck archaeological practice. An undoubted factor is that most maritime archaeological sites are still only reported at interim level. Few sites, world-wide, are comprehensively published.

By contrast, in the last four decades site environmental assessment has been far more common on submerged settlement, drowned landscapes and even foreshore sites (including wrecks) than on completely submerged wrecks. There has been little convergence between land and submerged site formation studies despite notable initiatives that span the wet/dry divide such as the inundated reservoir work carried out under the auspices of the US National Parks Service (Lenihan *et al* 1981).

Greene (1995) states that most archaeologists would give credit to 'New' archaeology for improving the recording and description of archaeological information, because any attempt to reconstruct social and economic systems demanded high quality data. This resulted in rigorous analysis of archaeological sites, partly through better techniques of excavation, but principally through an improved understanding of how sites were formed.

In their initial enthusiasm, 'New' archaeologists tended to assume that the archaeological record, if adequately interpreted, offered a relatively complete and undistorted picture of the society that had produced it. Gradually, however, following Ascher (1968), these archaeologists became aware that artefacts were made, used, and frequently discarded in different contexts, not all of which were equally represented in the archaeological record.

They began to think about why a conclusion was valid. Any activity creates a specific distribution of material, specifically a *pattern*. Patterns can infer behaviour but formation processes alter patterns therefore equal concern is required for formation processes which were determined to not be random but have predictability in effects. Furthermore, there were additive as well as subtractive formation processes, cultural and natural processes, emphasis was on traces and distributive effects (*e.g.* ploughing).

During the 1970s archaeologists began to ask questions like "how do we know what we know?" and some developed models of how sites form, and how the process of site formation and the developmental history of a site affect what is archaeologically detectable (*e.g.* Schiffer 1976). The main thrust was to determine regularities, for example through experimentation.

Wood & Johnson (1978) identify a sequence beginning with the theory that all patterning observed on an archaeological site is as a result of human or cultural activity. This was followed by the realisation that some other processes (*i.e.* of natural origin) may have had an influence; progressing to attempts to categorise and differentiate between causes and effects of all site formation processes (Ascher 1968, Schiffer 1972, 1976).

## 3.7 History of marine archaeological site formation theory

### 3.7.1 The early years

Shipwreck archaeology is slowly emerging from a past tainted by indiscriminate artefact collection, treasure salvage and the unrecorded destruction of sites. However, from the earliest decades it was evident that the destructive effects of marine life were more pronounced on rocky substrates as opposed to the more sterile sandy environments (Nesteroff 1972). Frost (1962) and Dumas (1962) pioneered studies of wreck formation putting forward generalised models for the sinking and wrecking of Classical ships, the so-called "tumulus" sites (see Figure 13). Throckmorton (1965) developed empirical models using a series of dated and documented sites at

Methone in south west Greece. Most early studies concentrated on Mediterranean sites, especially "amphora wrecks" and was mainly concerned with site categorisation according to preservation and to excavation methodology (Dumas 1973). Such authors, among others, gave the sub-discipline its theoretical foundations (Gibbins 1990). Further highlights in the development of marine archaeological site formation studies are as follows:

### 3.7.2 The 1970's

In the Seventies the requirement to identify suitable materials to contain nuclear waste buried under the sea provided an unusual impetus for marine site formation studies (Tylecote 1977) whereas in terrestrial archaeology this period saw the introduction of the concept of transforms.

The late Seventies included the further filtering through of such concepts to shipwreck archaeology. Clausen & Arnold (1976) discovered remains of colonies of benthic organisms adhering to the upper two thirds of large concretions providing evidence that the depth of the sediment in the area had fluctuated over the period of deposition. At least once in the past the conglomerates were largely, or perhaps entirely, exposed long enough to permit these organisms to flourish.

In terms of regionally-based initiatives Bascom (1976), as referred to earlier, concentrated on the marine environment of the Mediterranean and Black Sea as preservation media for the purposes of optimising any search strategy, and Raban (1973) suggested a model of wreck preservation in the Eastern Mediterranean based on personal experience (Figure 7).

Muckelroy (1975), developed models for addressing what he felt were the basic conceptual concerns in the archaeology of shipwreck *i.e.* the event that took place between the ship's existence as a functioning entity and the discovery of shipwreck remains by the archaeologist. In a further refinement (1978) he represented the evolution of a shipwreck as a flow diagram (see Figure 12) comprising five subsystems: the process of wrecking; salvage operations; the disintegration of perishables; sea bed movement; and the characteristics of excavation methodologies. The inputs to the system are the ship itself and any material subsequently deposited on the site whereas outputs are the material which has floated away, been salvaged or disintegrated. Within the system the subsystems of sea bed movement, disintegration of perishables and salvage are linked by positive feedback loops *i.e.* salvage operations will disturb the sea bed and material will deteriorate due to the loss of the state of relative equilibrium.

Muckelroy put forward a site classification system based on an environmental model which ranked physical attributes (*e.g.* topography, particle size of deposit, slope, sea horizon and fetch) and interpreted the results on the basis of the completeness of the archaeological record. He acknowledged the role of natural formation processes (*i.e.* chemical and biological) stating that explanation must lie in variations in the composition of the objects concerned, in the chemistry of the sea bed deposits, in the quality of the sea water in the area, and other such chemical and biological factors. Muckelroy's system is still regularly cited[35], almost two decades on, and it has yet to be satisfactorily tested (Gregory 1992, Maarleveld 1995).

Concentrating on post-Medieval wrecks from Northern Europe, Muckelroy attempted to construct an analytical theory for shipwreck site formation which would be applicable to a wide variety of site environments (1978). His work represented an important step forward in reviewing the state of theory at the time and in identifying areas that required further study.

### 3.7.3 The 1980's

The Eighties saw a resurgent interest in archaeological "knowability" (*i.e.* how do we know what we know?) and a parallel urgency in most Western countries for archaeologists to participate in government planning and CRM. There was also an increased emphasis on the study of impacts to archaeological sites (Wildesen 1982), site formation as an aid to predictive modelling and survey, and general concepts of management archaeology.

Parker (1981) advocated a flexible approach concluding that even "tumulus" sites may be the subject of contamination. So-called jumbled "ships graveyard" sites could also be of value and individual wrecking events identified with detailed recording and careful analysis, even when the remains are scattered, mingled and denuded by illicit excavation. Also there was an increasing awareness of processes and inter-relationships between site formation, materials preservation and site assessment (MacLeod & Killingley 1982).

Around the same time Lenihan (1983) said that two primary developments needed to take place. Research on ships should be conducted with the benefit of well-planned, explicit research designs no matter what orientation is used, and shipwreck studies must be carried out with a much more inter-disciplinary approach. Murphy (1983) reiterated that the application of a multi-disciplinary approach is long overdue and that little is known about the environmental impact on wrecks, and of wrecks on the environment. Following this direction Skowronek (1984), claimed that his intra-site analysis of the Legare Anchorage site was the first statistical intra-site analysis of a shipwreck in the Western hemisphere.

That marine sites are heavily influenced by natural processes (specifically seabed movement in this case) was clear from the investigation of the stratigraphic record of the Red Bay, Labrador, by Parks Canada (Stevens 1984). A key element in the study was the presence of the 16th Century wreck site of a Basque whaler. It was evident when the shore excavation trench was extended underwater to the wreck site that the wreck had acted as a barrier with an associated collection basin not only for the natural waterborne sediments but also for debris from contemporary industrial

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[35] In relation to specific sites (Henderson 1989, Nayton 1989, Hardy 1990, Nash 1990, Owen 1991) and referring to marine/maritime archaeology theoretical studies (Lenihan & Murphy 1981, Hunter 1994, Parker 1995, Vrana 1995), particularly in North American and Australian shipwreck archaeology.

workings (whale products processing) on the nearby island. There was substantial accumulation of materials near the southern extent of the wreck - an ongoing event that began after the sinking of the ship and continued until the wreck site no longer acted as a major barrier to water movement.

Placing shipwrecks in a wider context has been a productive direction for maritime archaeological research. For example in the assessment of the archaeological formation processes of Denmark (Kristiansen 1985) concentrated on the effects of historical post-deposition factors for archaeological representation at regional and national scales, unusually including maritime environments and nautical archaeological sites.

With reference to the latter, in a comprehensive study of the factors which affect that archaeological representation of ship finds and ship blockades (AD 800-1200) Crumlin-Pedersen (1985) determines a series of factors which have contributed to the preservation and discovery of nautical archaeological finds: changes in coastline; conditions of deposition; dredging and harbour construction; diving techniques; context of ship finds (sacrificial, sunk, wrecked); and loose finds. The incidence and significance of the finds are reviewed in the context of Denmark and its adjacent waters. Crumlin-Pedersen points out that it is not only the presence and state of preservation of maritime sites that is governed by environmental factors but also their discovery.

Gould (1989), to enable a controlled approach to the study and preservation of archaeological sites to be achieved, recommends considering the nature of archaeological sites and their formation from several different points of view:

- The Geographical Framework
- The Stratigraphic Framework
- The Ethnographic Framework

The latter comprises residue-oriented studies of contemporary human behaviour, which should provide a convincing framework for explanations of the cultural component of site formation processes in the archaeological record.

Observations of the biophysical environment surrounding the wreck site have been included as part of the collection of non-artefactual data at the Terence Bay site in Canada. The fact that the wrecking event and the subsequent development of a site can be reconstructed from observations of the biophysical environment was demonstrated by Kenchington *et al* (1989) concentrating on the sediments within the wreck, the surrounding bathymetry and the biological species present (Figure 14). Evidence from stratigraphic analysis revealed that a bed of Eelgrass (*Zostera marina*) covered the wreck soon after the sinking (Carter & Kenchington 1985).

### 3.7.4 The 1990's

To give an example of potential complexity which shipwreck sites may involve there are instances where a shipwreck lies on top of prehistoric remains (Murphy 1990). Other avenues of research have proposed the zonation of the seabed into areas of specific environmental conditions thought to have affected the preservation of particular artefact types thus informing the analysis of finds distributions (Nagelkerken 1985).

Finally, it has been shown that inter-disciplinary site evaluation can be successfully linked to traditional historical research after controlling for certain variables. In the case of the *Xantho* the latter include site formation processes, the behaviour of a steamship owner and the ship's crew. It has been shown that such factors can be discerned through a comprehensive study of the history of the vessel and the careful analysis of the archaeological record (McCarthy 1996).

General statements regarding methodology have been made periodically[36]. A further approach, specifically tailored to the Dutch situation[37], is taken by Maarleveld (1995) which stresses that the overall environmental situation in the Netherlands has changed dramatically over time. Dynamic fluvial, estuarine and tidal conditions, unrestrained by solid substratum have ensured continuous change. Therefore the assessment of formation processes , preservation and archaeological potential becomes, necessarily, an assessment of geology, of the physical genesis and continuous metamorphosis of the area concerned.

Murphy (1990), in one of the few marine archaeological publications specifically relating to site formation studies (*Natural site formation processes of a multiple-component underwater site in Florida*), suggested two new principles to the growing body of natural formation processes influencing archaeological enquiry, and he offered them for further testing: that artefacts in certain substrates will migrate downwards and that barrier island migration preserves archaeological sites from subsequent impact of inundation.

Parker (1992) cites the early work of F. Benoit who was already reporting wrecks as sites or groups of material in the 1950s but his interest was more in the collections of finds than in the actual dynamics of the underwater site. More than a decade earlier Parker dismissed two basic assumptions underlying Benoit's work (1981). The first was is that true wrecks can only be found in deep waters and the second was that "ship graveyards" which lie in shallow water, are of no scientific concern.

The observations of maritime archaeologists and the collation of *in situ* conservation data has indicated that the state of preservation of a shipwreck is dependent on several basic factors: the condition of the vessel before wrecking, the nature of the wreck event itself and the preliminary exposure to wind and water movement. All are significant in the initial stabilising process. As a wreck site ages features of the burial environment increase in

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36 See Ferrari & Adams (1990), Firth & Ferrari (1992), Gould (1991).

importance. In recent years wreck site environmental assessment has been recognised as vital to effective programmes of CRM (Kenderdine 1995b).

Ferrari (1994) states that the initial acceptance of a continual reduction in both the quantity and quality of data over time has been replaced by the assertion that these patterns can be detected and inference refined accordingly. Therefore the archaeological deposits retain data potential and we can therefore estimate what has been lost and allow for this in the interpretation phase of archaeological study.

### 3.8 Concretions

The analysis of concretions and associated corrosion products (with or without surviving artefact material) from non-ferrous artefacts from Australian wrecks, together with a characterisation of the marine environment for each site, contributed towards establishing the previous history of the artefacts for the period between the wreck and the excavation of the vessel (Carpenter 1990, MacLeod 1991). A range of formal oxidation states in the copper sulphides were found on the coins which indicated variations in the anaerobic conditions during the years of burial. Some of the coins showed a banded structure of layers of silver chloride and silver sulphide which is consistent with periodic burial and exposure (MacLeod 1991).

A typical description[38], of a marine archaeological concreted mass which enveloped *Debraak*'s hull - created by ferrous oxides from the ship's shot, describes corroding cast-iron ballast and armament which, when combined with natural sediments and calcareous concretions, formed a cement-like matrix (Beard 1989).

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[37] Other regional approaches include: Western Australia (McCarthy 1986), Israel (Raban 1973).

[38] Marine archaeological concretions have been described many times (see MacLeod 1982, 1987, 1995, North 1976, Muncher 1991, McCarthy 1988).

### 3.9 Post-deposition processes

"...we have never had any 'intact pristine resources', strictly speaking, because all archaeological sites have been subject to natural and human-caused impacts since their creation" (Wildesen 1982: 83).

The net destructive effects of disturbance for the purposes of archaeological excavation has been assessed by Gesner (1993)(see Figure 26). Wreck material exposed by changes to coastal dynamics and marine sedimentation caused by marina construction (Negueruela *et al* 1995).

It is very difficult to define all the processes which might result in material being removed from the site, but it is important to consider as wide a range of potential disturbances as possible. Use of the seabed for fishing, anchorage, dredging, sport diving and salvage will remove and add material (see Figure 8). Shipwreck sites can be complex involving more than one wrecking event[39] and there are instances where a shipwreck lies on top of prehistoric remains producing the effect of later activity on a site blurring the clues left by earlier occupation (Murphy, 1990, Cockrell & Murphy 1978).

In antiquity those wrecks which were situated in suitable locations would have been more or less extensively salvaged immediately after the sinking and in subsequent years *e.g.* the activities of the Deane brothers on the *Mary Rose* site (Bevan 1996). A further example is the salvage operations carried out on the Jutholmen wreck in order to recover the rig and cargo (Cederlund 1983). This involved most of the masts and spars being pulled up, the deck broken up, deck beams sawn off to gain access to the cargo, upper hull planks torn out, after-castle and stern torn down.

#### 3.9.1 Fishing

It may be possible to identify if a site has been disturbed and by what fishing method thereby enabling an interpretation of spatial distribution of artefacts -

[39] Often referred to as 'ship traps' where particular environmental conditions from antiquity to the present day have represented a hazard to shipping.

similar to plough-zone archaeology? However, Ferrari (1994) has shown that where areas which were formally extensively trawled are left for a considerable period (ten years) then the traces of the former fishing activity can effectively disappear.

The considerable extent of the potential impact on archaeological remains can be seen in the example of sponge fishing which led to the discovery of the Cape Gelidonya Bronze Age shipwreck (Bass 1967). Using the technique of dragging a net is hauled along the seabed using a winch and the boat's engine, usually on flat, muddy bottoms to depths of several hundred metres. The draggers often found the remains of shipwrecks in the nets including structural elements and amphorae. The latter were usually thrown back but only after being smashed to prevent them tearing other trawler's nets.

### 3.9.2 Dredging

Modern dredging operations represent a significant threat to archaeological remains. The archaeological potential of submerged deposits is such that even material displaced by dredgers is seen to be of sufficient importance to warrant study (US Army Corps of Engineers 1988b). Many highly significant historic wrecks have been discovered through the activities of dredging - principally maintenance work on harbours and navigation channels.

Extraction dredging or maintenance spoil dumping may also have an un-quantified effect in the form of suspended solids settling on submerged structures and thus altering the burial environment characteristics (Bower 1994). The feasibility studies considered the potential impact of dredging including:

- De-stabilisation of sediments and structures,
- Erosion,
- Altered corrosion rate,
- Siltation from dispersion of fines causing changes to marine growth.

Shipwreck sites have also been disturbed by shell dredging for lime (Kenderdine 1995a).

### 3.10 General models of shipwrecks

Modelling an environmental (and archaeological) resource means constructing a map of how various components are interrelated, how a change in one component can instigate a change in another, the conditions that must be met for this change to occur, and the rate at which it occurs.

One model of land archaeological site formation is that after a site is abandoned natural processes begin and the objective of the archaeologist of recognising and recording man's purposeful arrangements depends on distinguishing between the action of natural agents and the action of human agents (Ascher 1968).

Most submerged settlements reflect this general model but wreck sites do not undergo the formation sequence of typical land sites. That is a period of post-abandonment decay. Wrecks are usually the result of a catastrophic event which happens quickly. The deposition (or the original cultural contribution to the equation) happened at one time on a shipwreck "instantaneous abandonment" (Gould 1989). However, the broad relationship between the natural and the anthropogenic is still present *i.e.* the area of seabed as opposed to the ship which is wrecked on it, the structures of the submerged settlement site and the surrounding natural environment.

Necessarily, because of the incomplete nature of archaeological sites, a variety of clues can be used to reconstruct missing elements. Cargo distribution can reveal hull size and the shape of the hold, and artefact location can indicate living or galley areas. Steffy has stated that usually something can be learned about a ship's hull on a wreck site, even where nothing of the hull itself survived (1994). It is through the growing confidence in, and knowledge of the increasing diversity of, site formation that such interpretations are possible and credible.

The "time capsule" model can be refuted as a popular misconception. Marine archaeological sites (including shipwrecks) are dynamic - archaeological remains may re-surface to be further re-worked before they are buried again. Diagrams or representations have often been produced as working hypotheses of type and rate of disintegration processes (Figure 15). Examples date to as early as the mid-19$^{th}$ century, such as the *Birkenhead* (Kayle 1990)(see Figure 23). The gradual deterioration the *Pandora* underwent several stages before it reached its present condition (Gesner 1993).

### 3.10.1 Wreck marks and alignment to current direction

Caston (1979) describes the shapes created in front and to the rear of obstacles to a dominant current flow whilst stressing that full details of flow patterns are largely unknown. Generally a current crescent is scoured near the upstream side of the obstacle and longitudinal features, including ridges and furrows, are formed downstream parallel to the flow (Figure 16). The latter features have been used to indicate net transport direction and they could also contribute to the search for new sites and predictive survey.

### 3.10.2 Ballast mounds

Rugged nature of ballast stones overlying hulls wrecked in Dor harbour, Israel, accelerated the process of pottery disintegration yet the mound formed a catchment preserving pottery fragment. Other items were swept towards the beach after the disassembly of the upper structure of the vessel (Raveh & Kingsley 1992).

### 3.10.3 "Scattered" or "discontinuous" sites

Muckelroy (1975) clearly demonstrated, in refutation of Dumas' assertion[40] that scattered wreck sites were not valuable as sources of archaeological information, that meaningful excavation was possible if post-deposition processes were accounted for. Successive workers have reinforced this view that good recording can be justified even on shallow sites commonly regarded as jumbled (Cockrell & Murphy 1978). Murphy (1990) suggested that the late Seventies represented a turning point in dispelling the assumption that high energy coastline shipwrecks break up, randomly scatter and continually degenerate.

Gibbins (1990: 382) takes the view that the fact that there is a greater relative "distance" between the wrecking event and the current assemblage on such sites in comparison with well-preserved sites, provokes a greater need to concentrate effort on controlling for site formation and post-deposition factors. However, the concept that scattered sites are not worth saving as heritage is still put forward, *e.g.* on designated sites like *Schiedam*, forces of environment have altered the distribution so much that recording context etc. would be counter-productive (Randall pers. comm.). Schiffer (1987) suggest that the entropy view of site formation processes as the reason why cultural resource managers and others can attempt to "write off" heavily disturbed sites.

### 3.10.4 The grounded ship

The Slufter project showed that the remains of a ship run aground can get dispersed over an extremely large area - parts of the same vessel being recovered over 1 km apart quickly (Adams *et al* 1990).

A grounded ship that cannot be recovered can deteriorate where it is, or it can slide (partly re-floated) into deeper water. In situations where mobile

[40] Such "....scattered wreckage is of scant interest to the archaeologist" (Dumas 1972). This view was not unique in the 1970's: "Shallow wrecks can often be found near dangerous rocks but such wrecks

sediments can envelop wreck structure then it is possible that large fragments or entire ships can become embedded and preserved (Maarleveld 1995). Differences in preservation will be apparent according to depth. Shallow sites are subject to severe mechanical forces whereas in deeper water exposed remains will be more at risk from chemical degradation and attack by marine organisms.

### 3.10.5 Mobile wreck structures on beaches

Bright (1993) describes one large piece of wreckage, washed out of the beach during a storm near Whale Bone Junction 10 December 1977, which moved northward two miles before being deposited upon the beach again. The following year it was vandalised by souvenir hunters before being placed under state ownership. After three months of fruitless efforts to find the means to remove the wreck from the beach for its protection a new storm moved the structure again in southerly direction, knocking out nine pilings at a fishing pier before travelling 15 miles and beaching itself[41].

### 3.10.6 Evolution of a shipwreck

Various models of the wrecking of ships have been put forward and research has been carried out on classifying the wrecking event itself and the environmental characteristics which might have influenced the wreck (Bascom 1971, Parrent 1988, Anuskiewicz 1992)[42]. With reference to the general development of a wreck Dumas (1972) asserts that it is very unlikely that a ship would sink upside down and that the parts of a shipwreck structure in direct contact with the seabed are usually very well preserved. A large number of sinking ships are thought to settle in an upright position and the keel structure often survives on wooden wrecks (Steffy 1994). The weight of the cargo can push bottom planks into the seabed, waterborne silt settles

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are liable to be broken up by succeeding storms with the result that they have little or no interest to the marine archaeologist"(Hall 1970).

41 Kenchington & Whitelock (1996) postulate similar long distance movement of wreck structure, in this instance completely submerged, in the case of the *Humboldt*.

42 " most sink quickly, carrying down everything except minor flotsam.......a sort of underwater Pompeii" Bascom (1971: 262).

over the wreck and smothers oxidation[43]. The wreck reaches a state of relative equilibrium until disturbed.

Muckelroy (1978), represents the evolution of a shipwreck as a flow diagram comprising five subsystems (as referred to earlier and see Figure 12). As the structure degrades and collapses its influence on the environment (and *vice versa*) will change. For example a less prominent obstruction will be less able to induce scour (Ferrari & Adams 1990).

It has been suggested that there is a generally rapid (*i.e.* within ten years) evolution of the wreck to a situation of relative stability (Dumas 1972). No significant objective studies exist to support this hypothesis.

One approach on the *Queen of Nations* wreck which occurred in 1881, was to use archaeological and historical evidence to reconstruct the wrecking event and subsequent post-deposition impacts (Smith 1992). A suggested disintegration pattern was put forward based on contemporary newspaper accounts, photographs and sketches which documented the major phases of collapse (Figure 17). This was supported by survey of the remains present on the seabed.

### 3.10.7 Site formation models

Site formation models are becoming an increasingly common features of shipwreck studies as tools to help workers understand the formation of sites and the effect the formation processes have had on the nature and quantity of archaeological evidence contained in the site (Martin 1978, 1979).

Frost (1962) refers to Dumas (see Dumas 1962) as pioneering the rationalisation of wreck formation, and she postulates the sinking and wrecking of a Roman merchant-ship with a cargo of amphorae, striking a

[43]A phenomenon suggested by Bascom (1976) as a "mud cloud" thrown up by sinking ship which may, upon settling, act as a protective layer over the structure. The latter may not be a protective feature as noted in recent environmental impact assessments relating to the possibilities of mineral dredging activities generating plumes of sediment which settle over wreck sites (Bower 1994).

rock, filling with water, planing to the bottom, and then coming to rest. If this is on a sandy bottom it is likely that the lower parts of the structure, in whatever aspect the wreck finally settles (*i.e.* upright or tilted to port or starboard), will be better preserved. The model continues with the movement of the cargo; the loss of buoyant items; the degradation of organic elements of the wreck structure and contents by marine organisms; the formation of sediments containing the detritus, and bodies, of these organisms coupled with the obstructing effect the structure has on sedimentation characteristics of the tidal currents. The wreck becomes a "tumulus", or mound, over which sediment stops being deposited when the gradient of the sides becomes too shallow to obstruct the natural flow of sediment across the bottom. Finally, this model postulates that once stabilised the site will not alter for centuries (Figure 13).

Using direct observation and recording of excavated sections Throckmorton developed empirical models on a series of dated and documented sites at Methone in south west Greece (1965); *HMS Columbine* which foundered within two hours of striking the rocks in 1824; an unnamed Austrian brig lost in 1860; and the schooner *Heraclea* sunk in 1940. These sites provided the possibility of studying similar types of ships sunk at almost identical depths, in the same harbour and on the same kind of seabed. In the case of the *Heraclea*, after twenty-three years only a small portion of the wreck protruded above the seabed. Although the buried components were in good condition, Throckmorton considered that the reason for the *Heraclea*'s poorer preservation than the Austrian brig to be due to its shallower location and that she sank in an upright position. The *Columbine* had sunk on a thin layer of mud over rocks, thirty yards from the eventual resting place of the Austrian brig, and had been almost completely destroyed except for fragments of planking with copper sheathing attached. The Austrian brig was situated over on its starboard side, in a depth of around 10m, close to the shore.

The *Heraclea* and the Austrian brig were sectioned providing evidence of the destructive processes that occur in relatively sheltered shallow waters near enough to shore so that sediment can be washed into the water, and the wrecks, during rains. Throckmorton investigated a third wreck, the *Asia* (sunk in 1825 and partially salvaged in the 1830's), and he used the information (particularly the sections) to illustrate the time-intervals involved in the destruction-consolidation process of a wooden ship sunk in quiet water on a muddy bottom in the Aegean. In the case of the Austrian brig, the first stage, in which the wreck lay intact on the bottom, cannot have lasted more than ten or fifteen years, until the hull, weakened by Teredos on the starboard side, was pushed outwards. The second stage, during which the disintegration of the wreck must have been much accelerated until the fore-and-aft members collapsed of their own weight, cannot have lasted more than five to ten years. Thus the third stage, during which the wreck gradually fades into the seabed, will have been reached twenty years after the sinking (*i.e.* the condition of the *Heraclea* during the survey). At this point the exposed timbers are becoming weaker and weaker, and will soon disappear.

As referred to earlier Muckelroy (1976) developed a system which describes the development of a wreck site, from the moment of wrecking through to modern excavation, within which all available data can be assembled, and from which more information can be extracted on matters for which the direct evidence is inadequate. He was addressing what he felt were the basic conceptual concerns in the archaeology of shipwrecks *i.e.* the series of events that took place between the existence of the ship as a functioning entity and the discovery of shipwreck remains by the archaeologist.

Work on testing Muckelroy's model was carried out on the *Sirius* wreck site situated off Norfolk Island, Australia (Henderson 1989, Nayton 1989). By analysing oceanographic and geomorphological variables relating to the distribution and state of preservation of archaeological material, it was also aimed to test whether the *Sirius* wreck site conforms to a predictive model as proposed for European wreck sites by Muckelroy in 1978, and whether a degree of correlation can be established between the biophysical environment in which a ship is wrecked, and the condition of the shipwreck remains on the seabed, for Australian waters. Specific aims were the testing of the model's validity (whether a shipwreck can be viewed as a system); its viability (whether the processes can be successfully identified and their effects measured); and the claim that the model is general and applicable to all shipwrecks. Relevant environmental attributes were recorded and the site was assigned a class according to Keith Muckelroy's European model then the condition of the site was assessed to see whether it matched the classification. It did so and therefore the Muckelroy model was determined as being valid for this site. Modifications of Muckelroy's original flow diagram were proposed and the importance of the physical site formation processes emphasised (Henderson 1989, Nayton 1989).

Finally, a model for the extent of the *Monitor* site, named the Peterkin Footprint Model, attempted to depict transformational processes which were thought to determine the distribution of artefacts and fragments of the wreck structure across the seabed (Nordby 1988)[44].

### 3.10.8 Site decay modelling

Understanding of the real effects of natural degradation and related impacts will be gained from modelling site deterioration. Recent research on quantifying site deterioration models has explored innovative ways of depicting such processes on the scale of the site as a whole.

Mathewson & Gonzalez (1988) offer a concept of an archaeological site decay model which is based on models of forest succession accepting that a forest is renewable whereas archaeological sites are not (see Figure 18). The archaeological model shows a uniform decay rate for a specific component of a site and external impacts can either increase or retard this rate. Factors which complicate the decay model are given as site component, physical, chemical and biological variability (Figure 6). Whilst admitting that the work

[44] The model takes into account the possible depth-charging of the site by the US Navy in World War II, modelling the explosive force of the depth charges and the mass of the hull plates used to build the *Monitor*.

required to generate a generic, quantitative site decay model is felt to be excessively complex and economically unrealistic, it is claimed that it is reasonable to propose the development of a logic-based, qualitative decay model that relates to the impact of an induced change in the site environment for each site component and spatial relationship (Mathewson 1989).

General shipwreck preservation factors have been summarised by Parrent (1988) as "Shipwreck Site Preservation Factors" (see Figure 8):

- Shipwrecks coming to rest on hard sea bottoms are not protected from the ravages of teredo worms, micro-biological agents and existing energy levels. Unless they are in very deep water all exposed organic material will be destroyed.
- Sites covered with sand are protected from the destructive forces mentioned above. However, sand cover is often temporary and unpredictable.
- Cohesive sediments, such as muds and clays, offer best protection for wreck sites. Once sites are covered they are protected from damage by teredo worms, microbiological agents and wave and current forces.
- In warm waters with high oxygen content unless organic components of a shipwreck are buried in sediment they will be damaged by microbiological organisms.
- Colder water and less oxygen reduces microbiological activity. Therefore, organic components are more likely to survive with or without sediment covering.

In an alternative approach Ward *et al* (1997) point out that most existing models for wreck disintegration are based on the form of the wreck at various phases of breakdown and the identification of generalities about factors affecting wreck formation (see Figure 8). In addition the environmental processes that influence wreck disintegration at the various stages have not, as yet, been used as the basis for formation models. A process-based model for wreck evolution is proposed utilising the influence of wreck deposition history on such processes as biological decay and chemical corrosion of wreck materials, and on wreck evolution itself.

Using the site of the *Pandora* (whose development was earlier modelled by Gesner, see Figure 6), a scheme is outlined in which the major environmental processes operating at a wreck site are divided into physical, biological and chemical, each of which can be linked to wreck deposition history. These processes and linkages are incorporated into a model for wreck disintegration where the main environmental processes (physical $\delta P/\delta t$, biological $\delta B/\delta t$, and chemical $\delta C/\delta t$) are plotted against the relative sedimentation rate ($\delta S/\delta t$), to attempt to quantify the rate of wreck disintegration ($\delta D/\delta t$).

Rather than attempting to classify wreck sites by looking at their environment and predicting what current state of preservation a shipwreck will be in, perhaps the problem should be approached from the opposite direction and seek to understand what effect the environment will have in terms of the *future* preservation of a wreck site. Thus when considering any newly discovered site both the wreck and the environment should be assessed systematically on their own merits (Gregory 1992).

### 3.10.9 Classification of sites

Classification models for shipwreck sites were suggested by Dumas (1972) based on the type of sea bottom and relationship with coastal geomorphology. Later, Muckelroy (1977) put forward environmentally-based site classification models which ranked physical attributes (*e.g.* topography, particle size of deposit, slope, sea horizon and fetch). Results were interpreted on the basis of completeness of the archaeological record but the acknowledgement was made that other factors (*e.g.* chemical and biological) were also influential[45].

45 "...explanation must lie in variations in the composition of the objects concerned, in the chemistry of the sea bed deposits, in the quality of the sea water in the area, and other such chemical and biological factor" (Muckelroy: 1977: 56).

Muckelroy's work was also important in identifying the complexity of site environments although he concluded that there are several types of 'intermediate' site on which the remains are neither perfectly preserved nor smashed to pieces. Muckelroy understood the importance for the survival characteristics of a site of the variety of forces acting on it, as reflected in the relatively high correlation between the survival of material and location factors *e.g.* the extent of the sea horizon open to the site.

However, as Gregory (1992) and Maarleveld (1995) point out, Muckelroy's hypothesis, although frequently cited (Owen 1991, Nash 1990, Hardy 1990, Vrana 1995), has not been substantially developed by succeeding workers (Hunter 1994, Parker 1995, Lenihan & Murphy 1981) and some have questioned the feasibility of statistical analysis using environmental factors. Such criticism has been suggested by workers who have substantially greater populations available to them than Muckelroy had access to (Cederlund 1983).

Classification systems have much to offer in terms formalising vague ideas and theories within a framework. Site assessment studies provide a fundamental role in improving the viability of site classification systems (Gibbins 1990). Few such studies have been carried out. Despite the fact that of the 1189 Mediterranean sites recorded as many as 25% have been so briefly reported that neither their condition nor depth is known, Parker's classification of Classical wrecks (see Figure 19) based on depth and condition (Perfect, Coherent, Scattered, Hull only, Unknown) served to emphasise that wrecks which are well preserved lie mostly in deeper water (30-60m) (Parker 1992).

Muckelroy is extensively referenced in this subject area but his statistical approach fails on the assignment of the variables and scoring methodology. In addition, the work could be criticised for:

- Paying too little attention to the complexities of the wrecking process. No two ships will be wrecked in exactly the same way thus numerous variables are introduced early in the site formation process.
- Not considering the difference in date range for the various sites used in the analysis - earliest *Mary Rose* (1545) and latest *Evstafi* (1780). This leads to questions as to whether we can be certain that the environment on the sites has remained stable or constant since the wrecking event.
- Many of the sites used in the analysis were subjected to salvage attempts, both immediately after the wrecking and in the following years. In Muckelroy's model other possible impacts such as commercial fishing, dredging, sport diving and pollution were not considered.

Muckelroy based his analysis on observed sea bed distribution of materials - which is now recognised as having a very complex origin (Gregory 1992), notwithstanding the problems of achieving objective recording of underwater sites.

Finally, Cederlund attempted to define the factors which determine the preservation of old ships on the seabed in Swedish waters: geographical appearance of the coast, situation of the wreck in relation to the water surface (depth), Type of sea bed (geographical (hard, sandy) or geological (sedimentation, erosion), height differences on bottom (movement of sand), existence of ice, currents, heavy wave movements, special biological conditions (presence of *Teredo* spp) (Cederlund 1980).

### 3.11 Experimentation

As has been referred to above, the process of archaeological site formation is irreversible, but it must be figuratively reversed when inferring past human behaviour (Ascher 1968). With reference to land archaeological sites Ascher states that it should be possible to look at contemporary communities with the aim of learning how the path of disorganisation starts.

Sites and artefacts have also been subject to impacts during their original manufacture and working history and the effects of these processes must be recognised. An important aspect of experimental archaeology is the study of natural and cultural processes which have shaped sites and artefacts during their acquisition, manufacture, use and disposal (Renfrew & Bahn 1991). Such processes have their equivalents in shipwreck archaeology where study of the use of particular modern day vessel types may shed light on processes which occurred on board ships in the past, and which subsequently determined the nature of wreck sites.

Freshwater studies show that scientific experimentation is required similar to that which was introduced for reservoir inundation mitigation studies in the early Eighties (Nordby 1982). Further developments of this work include taphonomic studies on preservation and identifying impacts (Garrison *et al* 1981).

Gladfelter (1981) describes the types of experimentation *i.e.* based on changes to spatial distribution of artefacts by formation processes or alterations to artefact attributes, to contextual variables and conditions such as surface cover and degree of effects on near-surface materials. Designing effective site formation experiments has proved problematical in relating the life-span of the experimentation to the time scales of processes that were probably taking place on the real sites. For example, it is still regarded as being too soon to judge whether the Experimental Earthworks Project is worthwhile although it has in place since 1960 as the intervening 36 years are only a quarter of the intended span of the experiment (Bell *et al* 1996).

Experimentation in marine archaeological site formation processes has occurred only intermittently. Modern objects were placed on the *Batavia* site to model concretion formation. House bricks were found to have a 25% coverage of coralline algae after three months and an iron mooring anchor was covered with a 0.01m thick layer of coralline algae which supported a prolific secondary growth after three year's immersion (North 1976).

Experiments in artefact movement on the Moor Sand and Langdon Bay prehistoric designated Historic Wreck Sites were never followed through or published.

Recognising that attempts to identify seeds that might have reached a wreck site in a random way are likely to be unproductive, an experiment was set up to establish how local flora and plant remains carried by the sea might affect contamination on the Late Bronze Age site at Ulu Burun (Haldane 1993). In 1984, a wide-mouthed jar with nearly 500 olive stones, placed upslope of the wreck for 90 days, accumulated only a few cubic millilitres of sand and broken shell despite airlifting and intense activity on the site. By the end of the excavation season, three olive stones had disappeared. This short term experiment suggests that transport processes for plant material on this site are relatively weak and consequently sea-borne contamination is probably not a primary factor in the composition of archaeo-botanical samples on shipwrecks.

### 3.12 Site formation and Cultural Resource Management (CRM)

Natural processes are an inevitable factor in the formation of sites and in a sense what is currently perceived as erosive or destructive is just the latest stage in the site formation process (Schiffer 1987). The task of the archaeological resource manager is to attempt to arrest, or at least slow down as much as possible, these processes. Such specialists, by necessity, have a sensitivity to the rapidly eroding archaeological resource base. Moreover, as effective management is dependant upon high quality information so opportunities to better understand and better manage that resource including site formation studies.

This has long been recognised in the maritime archaeological CRM sector and the importance of shipwreck site formation research has been repeatedly stressed by organisations in countries with relatively mature CRM structures. The latter are usually associated with central government and examples include the work of the US National Parks Service Submerged Cultural

Resources Unit (Lenihan & Murphy 1981), the UK Archaeological Diving Unit (Oxley 1992, 1998) and Australia's State maritime archaeologists (McCarthy 1996).

In the early 1960s Frost (1962) stated that it was evident that a knowledge of general principles of site formation can identify the probable levels of preservation at an early stage during a site investigation. Thus helping the likely return of archaeological data compared with the resources required for the investigation. This cost-benefit analysis is becoming increasingly important in CRM shipwreck archaeology but little attention is paid to site formation theory in reality - which is particularly perplexing as the trends are towards management *in situ*, predictive survey, and the consideration of archaeological areas rather than individual sites.

This trend is further illustrated by the significance of high profile sites (*e.g. CSS Hunley*, *USS Arizona*, *Resurgam*, *Monitor*, and *SS Xantho*) which have required detailed research designs and comprehensive management plans which pay specific attention to site formation (*e.g. Monitor* National Marine Sanctuary 1997).

The Slufter project demonstrated the that archaeology can be integrated into the highly commercial objectives of dredging and marine engineering (Adams *et al* 1990). In the late 1980s a large scale, contaminated dredged material disposal site was constructed by displacing 37 million cubic metres of sediment. To accommodate for the possible destruction of archaeological remains and data preliminary survey indicated possibilities or potential and archaeologically sensitive areas. A series of appropriate actions were then proposed in order to cope with various types of discovery during the construction project itself. Wreckage from some sites was also recovered in sediments far below what would have been expected suggesting that scouring must have been considerable and have occurred quickly (Adams *et al* 1990).

Archaeologists still have much to learn about how natural and cultural impacts affect the archaeological record - we know very little about the actual type of impact resulting from the action of a specific natural or cultural impact agent. We know even less about the characteristic features of each impact type, including degree, duration, extent, and distribution in time and space from the day the archaeological site was created until archaeologists discover it again[46]. More importantly, archaeologists know little about the degree of distortion introduced by those impacts into the archaeological record (Wildesen 1982). Following studies for the purposes of sedimentology Caston (1979) notes that contrary to experimental work carried out no relationship is apparent between either the width and shape of wrecks and the depth of associated scour features, or between the height of the wrecks and the depth of scour. This would be a potentially useful area of study because of its relationship to the management of iron and steel wreck sites, particularly regarding their progressive collapse.

Finally, Vrana & Mahoney (1995) stress the need to extend impact assessment research in underwater cultural resources from the mere description of impacts to actually assessing the underlying causes. They conclude that impact assessment concepts and methods developed by other disciplines (especially applied social sciences) can enhance the management of underwater cultural resources. Archaeologists must develop a greater appreciation and understanding of them and how they can apply to submerged cultural resources.

It is useful to determine/postulate the process of wrecking of the vessel or mode of deposition when making significance assessments and to formulate recommendations (*i.e.* correlating with historical records or oral sources)(Kenderdine 1994). The ability of the archaeological community to further refine archaeological practice and CRM pivots upon achieving a fuller understanding of site formation and post-deposition processes, and a well-reasoned methodological and theoretical approach to their study.

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[46] See Figure 22, Summary of Impact Processes.

### 3.13 Complexity and need to understand

Ward *et al* (1997) stress the importance of understanding the dynamics of inter-actions between positive and negative feedback operating between processes in the seawater, sediment and the wreck materials, as part of wreck formation. It could be said that the marine archaeological discipline is only just becoming aware of such complexities. This is evident in the lack of organising principles for the many specific interactions between processes and patterns. Certain materials can be shown to go through specific processes (e.g. the biodeterioration of organics or the corrosion of metals), but other than variations in scale (artefact, deposit, site, region) or domain (culture or environment), there is no evident pattern to this data that will suggest general predictions or support modelling of formation processes (Rick 1989).

Schiffer (1987) shows that formation process research still lacks an objective methodology for determining *which* processes can be reliably blamed for which complexes of archaeological phenomena. Furthermore, because there are so many context-sensitive qualifiers, sophisticated analysis of formation processes will always be directed towards specific circumstances and they (formation processes) will not be capable of being generalised into law-like statutes. Most formation processes will increase in complexity on closer examination, thus leading *away* from general principles (Rick 1989).

### 3.14 Discussion

Intermittent work on theory and modelling has attempted to define common strands to what is clearly a vastly complex relationship between the multitude of material types contained in the hundreds of thousands of archaeological sites, which sink (as in the case of wrecks), or become inundated by seawater (*e.g.* submerged settlement sites), over the thousands of years of mankind's interaction with the sea. Specific research into site formation and post-deposition processes has been limited and theories based on intuitive assumptions rather than rigorous scientific measurement or observation.

While archaeologists are often concerned with pattern-recognition involving material remains at archaeological sites, the interaction between natural and cultural processes to account for such patterning is complex and requires an organised and controlled approach (Gould 1989).

Despite the erratic development of shipwreck site formation research several topics look likely to have particular potential for future study. Refinement and acceptance of theory will depend upon selective and comprehensive recording. This process may not be possible by evaluating wrecks surveyed and recorded in the past but upon new research, based on new fieldwork and targeted towards specific topics. A selection of the latter might be:

- Testing the proposition that meaningful distribution data exist within all sites, with special reference to "scattered" sites.
- The theory that careful examination of the stratigraphic sequence around and adjacent to the wreck structure can reveal the history of the phases of the destruction of the ship (Foerster Laures 1986) should be further tested.
- Examining the apparent migration of materials (usually artefacts) through sediments (see Cockrell & Murphy 1978).
- Further identification of "transforms", particularly the recognition of the effects of contemporary and later salvage, and clarification of the implications of the wrecking event itself.
- Reviewing the formation of shipwreck sites in relation to other marine sites (*e.g.* drowned landscapes) and the consideration of "ship traps" and "ship graveyards".
- Appraisal of the utility of marine environmental impact assessment methodologies in relation to shipwreck sites.
- Evaluating approaches to site classification and predictive survey.
- Experimental archaeology in relation to shipwreck formation processes.

- More research on fouling of archaeological remains on marine sites would be recommended taking into account artificial reefs and studies into the colonisation of new marine environments (*i.e.* new seabeds generated by submarine lava flows).

The more complex the question asked of the evidence, the more rigorously must be the attempt to evaluate the biases within the evidence, and to achieve this a careful study of processes which interact to form the archaeological record is necessary (Dean *et al* 1995).

# 4. The management *in situ* of marine archaeological sites

## 4.1 Introduction

The management of archaeological sites *in situ* is recognised as being an important component of CRM in that it enables some archaeological sites, or parts of them, to be protected from deterioration processes (Thorne 1991b). Furthermore, this methodology represents a viable and increasingly acceptable alternative to the essentially destructive practice of excavation.

With relation to maritime archaeology however, the subject is not well-researched. Strategies are often implemented as short-term, stop-gap measures which frequently do not get followed up by further studies and longer-term solutions. Moreover, it is not universally accepted that an environment for protecting one archaeological material or context will not necessarily be conducive to preserving another (Hamilton 1989). Furthermore, we do not fully understand the real effects of even simple stabilisation strategies such as sand-bagging. No comprehensive, comparative studies of *in situ* management strategies for shipwreck site deposits have been carried out (Oxley 1995b).

Although such techniques are often utilised (especially the simple variations such as sand-bagging), they are infrequently mentioned in detail in publications. Stabilisation methods have often been carried out in the past then for one reason or another, they are forgotten or they become enshrined in "folk memory".

Research on site preservation technology in the United States was conducted by means of a questionnaire sent to over 400 archaeologists and cultural resource managers in the Federal Service (Thorne *et al* 1987). Responses indicated several overriding factors. Most respondents had not actually been involved in site preservation activities. Those who had been so involved reported that whatever preservation actions had been taken were, for the most part, unpublished and had not been subsequently evaluated as to effectiveness.

A notable exception is the "Bibliography of Corps of Engineers Research Related to Cultural Site Protection and Preservation", published by the US Army Corps of Engineers (1992), which recognises that little compilation of relevant sources has been carried out.

Some consolation can be drawn from the careful and well-research approach taken by Parks Canada to the intentional reburial of the Red Bay wreck timbers subsequent to total excavation and comprehensive recording (Waddell 1994). The construction of the reburial pit (which contains over 3000 timbers) incorporates facilities for the periodic collection of interstitial seawater and representative wood samples for analysis. Over the coming years this work will provide important data on the utility of reburial strategies and the behaviour of archaeological materials in seawater. As reburial strategies are normally based upon mimicking the original burial environment this work will inform all the required stages of assessing, replicating and monitoring that environment.

Deterioration cannot be completely avoided and therefore absolute preservation *in situ* is not achievable. Furthermore, it can be concluded from the earlier discussion on site formation that all sites are dynamic and they are still forming in the sense that degradation processes are continuously altering the material remains albeit at slow rates. In addition, materials can be added to sites at any stage as part of the formation process, and such materials will themselves start to deteriorate as soon as they are deposited.

The covering of archaeological sites is itself not a new phenomenon. The natural burial of sites is common, often as a result of colluvial and/or alluvial processes - other dramatic examples include the sealing of Herculaneum and Pompeii by volcanic activity. This natural covering results, in the same way as artificial covering, in some archaeological materials to be well-preserved while the loss of other types can be accelerated.

A site to be protected or preserved must incorporate preservation of both the components of an archaeological site (the physical remains *i.e.* artefacts, features and ecofacts) and their spatial relationships (Mathewson 1989b). "Preservation" cannot be defined as the absence of change but only as procedures which reduce or eliminate detrimental changes resulting from specific, defined impacts (Mathewson & Gonzalez 1988).

In addition to their importance for long-term protection various types of conservation *in situ* techniques are often deployed on underwater and inter-tidal archaeological sites during periods when archaeological work is not taking place in order to protect the whole site or parts of a site, for example between excavation seasons[47].

This chapter seeks to describe the main characteristics of conservation *in situ* on marine archaeological sites, under the main headings of Cultural Resource Management, Differential Preservation of Shipwrecks: Iron versus Wood, Strategies, Physical Stabilisation, Reburial, Cathodic Protection, and Negative Aspects of Management *In Situ*. Examples from a variety of different site types located in a range of marine environments around the world will be used to support the discussion.

### 4.2 Cultural resource management (CRM)

Techniques are beginning to be increasingly necessary on archaeological sites to mitigate unavoidable threats where preservation by excavation and record is not a viable alternative to allowing the sites to be destroyed. On those wreck sites in the UK afforded statutory protection, but where no government funding is available for actual daily management, site stabilisation (or protection) has recently been identified as a significant issue requiring immediate attention (Saunders 1994, Oxley 1998).

[47] For example on the *Water Witch* site stabilisation, using sandbags and re-deposited ballast, was implemented after recording (Jeffery 1992).

*Ad hoc* site protection strategies common on designated sites have not been accompanied by continuous monitoring - *e.g.* the *Invincible* wreck is assumed to generally remain covered with sand, or to be more exact, assumed to have been *continually* covered (see below). Therefore, in common with most site stabilisation strategies at this time, there is no quantified evidence to support the assumption that the measures implemented are working effectively. In the case of the *Invincible* there may have been many covering and uncovering events, each providing opportunities for agents of degradation to attack the structures.

In the case of the *USS Arizona* - ramifications of the research on the Pearl Harbor shipwrecks go far beyond those sites. Many important iron and steel vessels are submerged world wide, and the management of those vessels *in situ* may be the only viable alternative to their eventual disintegration (Murphy 1987).

*In situ* preservation is an important management option in the case of the US National Oceanic and Atmospheric Administration's (NOAA) responsibilities towards the *Monitor* National Marine Sanctuary. Alternatives such as recovery of the wreck represent formidable logistical, technological and financial burdens. The turret alone is more than 7m in diameter, 3m high and weighs in excess of 100 tons, not counting the two cannons. Cathodic protection and physical stabilisation of portions of the armour belt are being considered to prevent further deterioration (Office of Ocean and Coastal Resources Management 1992).

There is evidence that other countries have taken on board the necessity to carry out site stabilisation and accept long-term management responsibilities for marine archaeological sites. Strategies such as the taking of baseline information followed by periodic monitoring form a fundamental part of the management plans for underwater heritage parks in many parts of the world. In the United States, as a result of the support of the centrally-funded

National Parks system, a National Clearinghouse For Archaeological Site Stabilization was established in 1983 (Thorne nd) with the following aims:

- to develop a bibliography that identifies potentially useful stabilisation techniques and site stabilisation project case histories which is to be made available on an unrestricted basis,

- to prepare technical briefs to explain various techniques that might be applicable to archaeological conservation problems.

Another example is the policy enshrined in the *Guidelines for the Management of Archaeological Resources in the Canadian Parks Service* produced by the Canadian parks authorities to deal with archaeological remains within their park boundaries:

"The first step in applying CRM Policy to archaeological resources is to undertake surveys of lands and waters under CPS (Canadian Parks Service) administration to inventory and record *in situ* resources.... Beyond this stage, other stages of treatment of the archaeological resource will be determined by a weighting of such factors as national/regional/local importance, research significance, interpretative potential, accessibility, vulnerability to natural or human impacts and the presence of valued ecosystem elements and valued natural resources" (Environment Canada 1993).

### 4.3 Differential preservation of shipwrecks: Iron versus Wood

In recent years it has become apparent that particular attention needs to be paid to the management of wreck sites from the iron/steel era. These sites are in danger because of the deterioration of metals in seawater and they are more prone to impacts, they are in general larger and currently more numerous than wooden wrecks and they have better documentation about location and contents. Therefore they are at greater risk relative to wooden wrecks from potential impacts such as irresponsible sport divers, commercial fishing methods and accidental damage of dredgers. McCarthy points out that many important iron and steel vessels are submerged world wide, and the preservation of those vessels *in situ* may be the only viable alternative to their eventual disintegration. It is well known that artefact deterioration on site can be lessened by action based on an understanding of the chemical and physical processes of the marine environment (McCarthy 1982).

It is also clear that the remains of iron ships in the marine environment suffer much more decay, relatively speaking, than wooden ships because of the relative instability of the metals in seawater. Metal structures (unless of massive construction) exposed to the effects of free running seawater are degraded whereas wooden elements appear better preserved, particularly if they are located in anaerobic environments (McCarthy 1986).

Iron and steel wrecks may not achieve the same state of equilibrium that we have come to expect from their wooden counterpart and there are some doubts, as yet unresolved, as to whether the wrecks of iron vessels will last the thousands of years that we know wooden sites in anaerobic environments are capable of (McCarthy 1989).

### 4.4 Strategies

Management *in situ* methods can be categorised according to the approach utilised for example hard or soft. In the United States, hard approaches include such techniques as stone covering (rip-rap), earth burial, wooden or concrete retaining walls etc.. Soft techniques include the use of geo-synthetic materials and re-vegetation. Hard techniques are typified as costly, engineering-based, and in the long-term more likely to require expensive maintenance. One example is Hurricane Mound, a Mississippian Period (c. 1100 AD) sub-structure platform mound situated in the flood plain of the Tallahatchie River. The mound had been subject to erosion cycles and, at the time of stabilisation, had been reduced to about half its original height. The top of the mound was cleaned and all features recorded. The entire surface was covered with a woven filter cloth which was embedded around the edges into a 15cm wide trench. The mound was then covered with rock riprap of varying weights (4.5kg - 68kg). Over the years some additional riprap has been added, in addition to a buoy that marks the location of the rip-rap during periods of high water (Thorne 1994).

Alternatively, management *in situ* strategies could be classed according to the physical, chemical or biological basis of their operation.

4.4.1 Avoidance

Preliminary surveys can indicate areas and sedimentary sequences which are of no archaeological importance but they cannot unequivocally predict what will be found elsewhere. Nevertheless a potential will be indicated that can inform decision-making and the setting of priorities. Surveys carried out prior to the dredging of the Slufter project was partly practical - including the assessment of existing acoustic and seismic records, and lithostratigraphic and palynological analysis of cores - and partly theoretical - site formation theory and inferences on archaeological potential (Adams *et al* 1990).

### 4.5 Physical stabilisation

Physical stabilisation methods are usually relatively unsophisticated[48] and involve the pinning down of unstable archaeological contexts and features. The use of some techniques brings an uncertainty about whether compressing the surface is in fact damaging buried archaeological deposits beneath, thus representing a net loss of archaeological potential (US Army Corps of Engineers 1988a, 1989b).

Physical protection may also be achieved by covering over the archaeological deposits or structures and thereby inhibiting aerobic agents of deterioration by reducing their access to oxygen in free running seawater.

[48] On the Varazze wreck the site was sealed off with some synthetic felt held down by the tubes of the reference grid (for survey purposes during the excavation) and finally covered over with sandbags Riccardi & Chamberlain (1992).

The following sections discuss a number of individual methods of physical stabilisation. However, it is important to note that one particular strategy is rarely limited to a single objective. In relation to land sites Mills Reid (1986) suggests that the most common means of protecting residual organic material was to cover the site with rocks, ballast bricks or similar heavy materials designed to act as sediment traps to offer physical protection and create an anaerobic environment.

Successful stabilisation depends upon high quality information about the environment of the site so that remedial work can be specifically designed to mitigate the de-stabilising processes. Nevertheless, it is salutary to note that in a major bibliography of site stabilisation references there are no examples relating to underwater archaeological sites (Thorne nd).

On the *Amsterdam* project, the fact that the site was exposed for extended periods, depending upon the state of the tide, proved to be a significant advantage both in terms of conducting the excavations and in stabilising the site upon their completion. When excavation seasons were completed the exposed area was covered with plastic sheeting and sand-bags, then sand was purposely back-filled into the site in order to prevent the effects of winter storms causing damage. In 1984 this back-filling was allowed to occur naturally and sediment covered the wreck within a few weeks. However, a large amount of refuse was also deposited which caused delays at the beginning of the next season's work (Gawronski 1986). In 1985, after the excavation was completed, exposed sediment surfaces were sealed by filter fabric which was laid down and weighted with loosely-filled, elongated sand-bags before the whole deposit was covered with clean beach sand placed on site by mechanical excavator at low water (Adams pers. comm.). Internal structural elements were also strengthened through a programme of hull reinforcement (Figure 24)(Adams 1987).

Unfortunately, since the mid-1980s and the reduction in activity on the site, the *Amsterdam*'s location in a highly public inter-tidal area has proved to be a source of problems. It has been suggested that the condition of the site represents a hazard to bathers and that the site is in need of stabilisation. In addition there is evidence to suggest that the girders and sheet piling installed to facilitate the excavations might be encouraging current patterns over the site which are steadily removing the sediment overburden and exposing the structure and archaeological deposits to degradation.

Typical strategies employed on land, riverbanks or foreshores for stabilisation of deposits such as the use of filter fabrics and geo-textiles, barrier layers and stabilising mats have also been used on underwater archaeological sites. Moreover, the use of stabilising fabrications are well-researched in the coast protection industry employing sand-bags, gabions and concrete shapes (US Army Corps of Engineers 1992).

In an alternative strategy a local slowing of current speed is sought in order to encourage the settling out of suspended sediment. The fact that dense algal growth can alter current flow and lead to localised reduction of energy levels and thus increased sediment deposition is well known (Eckman *et al* 1989).

Work on the inland crannog in Llangorse Lake in Wales can be used as an example of a "soft" strategy that also typifies the difficulties in determining an effective solution to erosion (Redknap & Lane 1994, Rees 1994)[49]. The pilot project was unsuccessful probably because of the seasonal fluctuations of water level in the lake and the inherent buoyancy of the bales. Alternative methods of protection are currently being considered (Coles 1995).

In the Netherlands site stabilisation techniques have included the use of barrier textiles and sand-bags as emergency responses to erosion, *e.g.* on the Scheurrak SO 1 and Burgzand Noord III sites (Maarleveld 1990).

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[49] A relatively simple and low cost scheme of installing a staggered barrier of barley straw bales around the perimeter of the eroding area was proposed to form a stilling basin, and even the wash resulting from leisure activities (such as water skiing) would be dissipated. The protected area would promote the settling out of suspended sediment, thereby covering and protecting exposed archaeological deposits and promoting re-vegetation of indigenous species (Coles 1994a).

Burgzand Noord III has been covered with a synthetic textile and 6000 sand-bags because of its importance.

On the wreck site at Marsala in Sicily the stabilisation of mobile elements of the site during and after excavation was achieved in a number of ways. Planks were fastened to the frames by inserting softwood dowels, bedded in silicon mastic, into convenient holes left by degraded metal fasteners. The protection of the structure comprised a spread layer of about 5 - 10mm of elastomer (RHODORSIL RTV 1600) on cloth sacks measuring 50 - 70cm. The sacks were then laid over the external surface of the wreck structure. The final covering of the site was achieved by placing PVC sacks of different dimensions, filled with sand, on top of the wreck structure treated with silicone rubber. The smallest sacks (150mm diameter) were placed between the frames whilst the largest (50 x 70cm) were located to produce a continuous layer over the site. At this point a final layer of sand about 20cm thick was deposited on top. The above methods were considered to be cost effective and the silicon rubber used is thought to be unaffected by immersion in seawater (Meucci 1986).

On inundated terrestrial sites in California three protective measures ("gunnite" or spray-on cement, rock riprap and concrete) are described together with a report of the monitoring process (Taylor & Cooley-Reynolds 1982).

On the Glenrose Cannery shell midden site (DgRr-6) near Vancouver, dating to 4600 BP, basketry, wooden tools, fish traps etc. were found to be eroding and an assessment of engineering solutions was carried out (Eldridge 1991). Funding was secured to treat about half of the site involving the use of geo-textiles and rock riprap. The treatment was rapidly executed despite requiring both high and low tides to complete the various phases. The work consisted of laying geo-textile filter cloth (at low tide) which was secured temporarily by long metal spikes topped by washers. The following morning a barge containing rock rip-rap was brought in and the barge-mounted crane dropped the rock at high tide, so that the water provided some cushioning to the falling rock (Eldridge 1994).

### 4.5.1 Sediment "drop"

This strategy has been attempted on a number of sites, perhaps because it is perceived as being relatively cost effective. It may appear attractive because in theory large areas of a site can be dealt with at one time. However, several examples suggest that it is only effective if extensive forward planning is carried out. For example, it has been said that the "sand drop" method failed on the *Day Dawn* site due to the dispersal of the sand sideways as it hit the seabed, yet on the *William Salthouse* the sand drop was judged a success (McCarthy 1986).

On the *Mary Rose* site gravel was released from a hopper barge on the surface in preparation for the winter of 1978. This was judged to have been moderately effective (bearing in mind the costs in time and effort to re-establish the excavation surface when work resumed) but in hindsight more comprehensive research and planning, particularly into the choice of material and the method of maintaining the position of the deployment vessel, would have provided benefits (Adams pers. comm.). With this method, if there is no barrier layer between the stabilisation material and the surface of the site, there must be an implicit risk of contaminating and damaging the archaeological deposits beneath.

### 4.5.2 The use of artificial sea grasses

Later strategies on the *William Salthouse* site in Australia included the application of a system known as "Cegrass" to create a pattern of artificial seagrass beds around the site. The buoyant plastic strips of the Cegrass remain upright in strong currents and reduce the velocity of the water and encourage deposition of suspended sediment. Forty-six Cegrass mats were constructed by clipping fronds of the artificial grass to mats of concrete reinforcing mesh. The mats were shackled together and then transported to the site, positioned by divers and held down with sections of old railway track

(Figure 25). After only two months substantial sand accumulation was noted around the wreck (Elliget & Breidahl 1991).

Such systems are very sensitive to environmental change. The Dutch Department of Public Works and Trade have found that the effectiveness of artificial seagrass mats is severely compromised when the fronds are colonised by marine organisms such as mussels. In this situation the weighed-down fronds collapse and current velocities regain their original levels. Thus the fronds tend to lose buoyancy and cease to function as sediment traps. It has also been found that the mats have to be very carefully oriented in terms of the prevailing current and that they are much less effective when deployed on a slope as opposed to a near horizontal seabed (Maarleveld pers. comm.).

Similarly tests were carried out with natural and artificial seagrass, as part of the Legare Anchorage Shipwreck Project, to inhibit erosion by trapping enough sediment to mitigate the effects of surge. Sprigs and seedlings of two plant species, *Syromgodium* (manatee grass) and *Thalassia* (turtle grass), together with plugs of mature plants, were installed on the site. Only the turtle grass was successful after two months. Natural seagrass proved a failure in the initial application probably because of the toxic effects of the galvanised nails used to anchor the grass strands. Results from the transplanting proved mixed, shoots collected from shallow water were unable to survive at 10m, while thalassia from adjacent deep water beds appeared to be thriving (Skowronek 1984). The artificial seagrass called "Seascape", which had proved effective in protecting shorelines from erosion in high energy areas of the Cape Hatteras National Seashore, comprised inert fibreglass tubes with floating styrofoam fronds. The tubes are filled with sand and sealed onshore. At the site they are placed counter to the normal, winter, tidal flow. Approximately fifty units of Seascape were installed but problems were encountered with assessing the effectiveness of this method as sediments on the site were "blasted" away by treasure salvors using prop-washes (devices attached to the propellors of their vessels which funnelled the thrust of the engines down to the seabed)(Wild 1984). Eventually the experiment was deemed unsuccessful because, at the low energy Legare Anchorage site, micro-organisms and crustaceans colonised the fronds causing them to lose buoyancy (Skowronek *et al* 1987). The seagrass did not then provide an effective barrier to slow the current enough for sediment to settle from suspension.

#### 4.5.3 Natural back-filling

As an example of a wreck site situated in an estuarine or river environment, experience on the *Grace Dieu*, supported by extensive experimentation and monitoring, suggests that natural deposition as a means of back-filling any excavation of the wreck would be a long and unpredictable process, and it might leave certain areas of the site exposed to increased deterioration. Experiments were carried out to determine whether natural protection of the hull remains could be induced. Artificial groynes (measuring 1.2 x 0.6m) were constructed of 3mm marine-grade plywood attached to oak stakes. In order to assess the apparent migration over the site of soft deposits from the eastern river bank, marker poles were used to monitor the changing profiles. The poles consisted of 13mm diameter galvanised conduit driven into the riverbed with 0.4m remaining exposed. The passing river traffic on the Hamble caused considerable damage to both the groynes (installed to deflect the current) and the marker poles, so much so that these experiments and assessment techniques had to be abandoned (Clarke *et al* 1993).

As referred to earlier the *Invincible* site is one on which, practically since the site was discovered, there has been a policy of allowing natural processes to back-fill excavation areas. At the end of the various excavation seasons airlifts were used to physically deposit sand and shingle into the trenches from the nearby seabed. This strategy was thought to provide a protective layer between the structure and decaying seaweed which was deposited naturally. In a typical year, excavations up to 2m deep were completely back-filled within a month, usually with layers of seaweed. It is not known with any certainty how effective this strategy was. On this site the licensee considers it unrealistic to attempt to control the natural forces without resorting to vast capital expenditure (Bingeman pers. comm.).

### 4.5.4 Deflection

On the site of the *Maple Leaf*, a barrier was required to divert the continuous flow of gelatinous bottom sediment that would quickly fill up the excavation area. The barrier had to be rigid enough to withstand changing tidal currents and a fence-like structure of small heavy-gauge wire panels (normally used for temporary livestock pens) proved easiest to assemble underwater and strong enough to withstand currents. The panels were covered with a geotextile to block the flow of sediment and then they were mounted on pre-placed steel poles set around the work area. The silt barrier effectively kept the excavation open and provided 15-60cm of visibility on the deck of the wreck (Stoltman & Cantelas 1993, Cantelas & Rodgers 1994).

### 4.5.5 Protection from impact

Site protection, in the sense of preventing damage from impacts such as trawls and anchors, is common in industrial sectors in the marine zone. In the oil and gas extraction industry various techniques are employed to defend structures such as pipelines and well-heads. In this situation sophisticated deflective structures are often used at great financial cost. Further areas where research has been carried out which may be relevant to developing applications in archaeological site stabilisation include experimentation in gravel dumping to determine the optimum particle size having the least tendency for re-distribution by currents (The Crown Estate & MAFF nd).

### 4.5.6 Covering to inhibit micro-organisms

Physical protection may also be achieved by covering over the archaeological deposits or structures and thereby inhibiting aerobic agents of deterioration by reducing their access to oxygen in free running seawater. For organic materials in marine deposits it is imperative that anoxic conditions are achieved in as short a period of time as possible (Mouzouras 1994).

The physical covering of archaeological deposits is common, often with polythene sheeting although there are problems with the establishment and maintenance of an effective covering. This is most true of extended, high relief, three-dimensional sites, such as wooden wreck structures. Such an exercise may also have very substantial financial and practical problems. An example is the difficulty experienced in trying to implement the strategy of covering the *Mary Rose* structure with the geotextile "Terram" for the over-wintering of 1980-1981 (Barak pers. comm.). On the Legare Anchorage shipwreck site a thin layer of sand was hand-fanned over the exposed timbers in the hope that it would inhibit attack by marine organisms, as well as camouflage the wreck from divers (Skowronek 1984, Skowronek *et al* 1987).

### 4.5.7 Use of toxins

The covering of ships timbers on the *Rapid* site by rocks and ballast blocks was discovered to have been unsuccessful because after one year significant marine borer attack was apparent (Mills Reid 1986). Following on from this the projecting frames and keelson of the *Rapid* were covered with chemically impregnated cloth (hessian with tri-butyl-tin oxide, TBTO), now a widely-restricted, environmentally hazardous chemical (McCarthy 1986). The cloth was then covered with many tons of the original overburden, in this case excavated ballast. Not surprisingly this strategy was not liked by the site workers who were concerned about ingesting toxic substances. Despite these fears the cloth was successfully applied and further covered with ballast. The site is now considered to be stable, largely on the evidence of reduced corrosion activity of concreted iron objects (McCarthy pers. comm.).

### 4.5.8 Reinforcement of wreck structure

The archaeological investigation of a marine site which involves the excavation and removal of internal deposits can cause extensive damage to a wooden wreck structure. The integral strength of wood will usually have been compromised by the deteriorating effects of natural organisms and chemical attack. The strengthening of the hull by the insertion of three iron braces (to replace missing deck beams) has been attempted on the wreck at Jutholmen to counter the damage caused by contemporary salvors (Cederlund 1983), and the stern has been reinforced by running a chain around it from the aft iron brace. Similar techniques have been employed on the *Amsterdam* site (see Figure 24) and "Acro-props" were widely used on the *Mary Rose* to support deckbeams isolated after the excavation of between deck sediment.

### 4.5.9 Sand-bagging

Sand-bagging has often been used in the past as the unit costs are low. Although, when employed in great numbers, the costs can rise along with problems of identifying a suitable source suitable material. For small applications the material to fill the bags (often gravel or sand) is often found locally as on the *Sydney Cove* (Nash 1991) and Duart Point sites (Martin 1995a).

On the *William Salthouse* site in Australia initial techniques used to stabilise the site included wooden fences, intentional back-filling and the dumping of large quantities of sand on the exposed wreck. Emergency sand bagging was deployed while more expensive, long-term engineering possibilities were researched. Sand deposition was encouraged by placing barriers, across the path of the current, consisting of a bio-degradable and removable system of sand bag walls (pre-mixed sand and cement in hessian bags) (Hosty 1988, Elliget & Breidahl 1991). The *Sydney Cove* site was covered with an undulating mound of sandbags designed to smooth the flow of current over the wreck (McCarthy 1986).

It is appropriate to suggest that, as the method is under-researched, sand-bagging can only be considered as a *temporary* site stabilisation method. Perhaps it should be limited to emergency stabilisation only until such times as a fully considered strategy can be implemented. Empirical observation suggests that sand-bagged areas usually seem to be assimilating well into the local environment in that they are often readily colonised by flora and fauna, and they often become indistinguishable from the surrounding seabed to casual observation. The latter can be a useful advantage in CRM terms in that exposed areas are less likely to attract the attentions of recreational divers.

At Duart Point in the Sound of Mull, an eroded area of the site which contained fragile organic material was consolidated by the application of (what was assumed to be) archaeologically-sterile gravel as an emergency response. As a further measure a single layer of sandbags, covering some $30m^2$, has been laid on top of the eroding deposits, and similar protection has been applied to abrading areas of exposed hull structure (Martin 1995a, 1995b). A total of 400, loosely filled, polyester weave bags were used.

Sand-bags were used on the *Santo Christo de Castello* (1674) site in Cornwall as temporary bulwarks to hold back shingle from re-filling excavation areas overnight. In the short-term this proved effective provided that there were no heavy seas overnight (Larn pers. comm.). Similarly, on a wreck in the Sea of Galilee, excavated in 1988, 1,350 sand-bags were placed as a wall in a horse-shoe shaped trench around the perimeter of the wreck. This prevented sand from re-filling the excavation trenches (Cafiero 1993).

At Caesarea Maritima, Israel, sand bags (made of synthetic material half-filled with sand) have been used to cover parts of the excavated Roman wooden caissons constructed to hold concrete as part of the original construction. The sand bags are moulded to the exposed form-work and they act as a datum allowing the working level to be quickly reached after high energy conditions have filled the site with sand during non-working periods. The sand bags also protect the structure from exposure during these sand movements. Sand bags have been found to be cheap and effective in this high energy environment (Reinhardt pers. comm.).

In St Peter Port, Guernsey, sixteen tons of sand bags were temporarily placed over the Gallo-Roman wreck structure (which extended over an area of about

6m$^2$) as protection for the winter of 1984 - 5, between excavation sessions (Rule 1990).

### 4.5.10 Filter fabrics

Otherwise known as geo-textiles, these fabrics have been available for many years in the construction (particularly roads) industries. They can be woven or non-woven and advantages for archaeological applications include sufficient elasticity to be moulded around irregular surfaces without massive surface preparation that would require removal of part of the archaeological layers. Since the material is synthetic it is resistant to erosion and the permeability can be controlled to some degree by careful fabric selection. The placement of steel pins (or similar) to anchor the fabric may adversely affect the cultural deposits. It must be realised that these fabrics are relatively expensive and have a finite useful life (Thorne 1989).

In the marine archaeological context, the annual monitoring of the 60 x 40m sheet of geo-textile (covered by 6000 sand-bags) installed over the wreck Burgzand Noord III has shown that this strategy has proved successful (Maarleveld 1990).

### 4.5.11 Protection from human interference

The site of the schooner *Sweepstakes*, situated in the Fathom Five National Marine Park in Canada, has been subjected to heavy recreational diver use. Recent assessments identified considerable cause for concern despite stabilisation efforts in the early 1980s (such as supporting the hull with iron tie bars and beams placed under the deck) carried out by volunteers. One unusual source of concern was the accumulation of divers' exhaled air under the decks which appeared to be the cause of a softening of the structure. As well as assessing the hull, the area of lake bed adjacent to it was also surveyed as erosion was occurring (McLellan 1994).

Sediment cover (see Legare Anchorage wreck above) has been used to camouflage sites (Skowronek 1984). In the case of the late 18th Century British vessel, located off Chubbs Head Cut in Bermuda, after the excavation and uncovering of surviving structure the site was reburied by reverse dredging excavation spoil in order to protect the timbers from accelerated deterioration and disguise its location from future salvage efforts (Krivor 1994).

### 4.6 Reburial

Reburial (or the transplanting and intentional burying of previously excavated material) is an important technique for the recovery of information from archaeological sites without incurring the substantial costs of conservation and storage is the reburial of archaeological material after suitable recording has been carried out[50]. It is likely that variations on this method of resource management will become increasingly popular in the future but its effectiveness depends ultimately on how well the reburial environment mimics the original burial conditions (Stevens & Waddell 1987), and this clearly depends upon how precisely the preservation conditions of the site are known.

In any reburial strategy there is a requirement to know what conditions are going to be created, what condition is going to predominate. Then there is the need to predict what is going to be preserved and what will be adversely affected. Hamilton (1989) stresses the difficulties of determining the effects of any given reburial strategy.

Reburial attempts to duplicate the conditions of the original burial site. Mouzouras (1994) gives examples of where this techniques has been used to store archaeological timbers in the past, for example Jespersen (1985).

[50] The observed failure of the covering of exposed structure with plastic sheeting and sand after the 1968 season on the Kyrenia wreck was a material fact which influenced the decision to recover the entire wreck the following year (Swiny & Katzev 1973).

Intentional archaeological site reburial is a technique used to retard the degradation processes on a site (Thorne 1991a).

The reburial of the ship timbers from the Red Bay site (referred to earlier) is recognised as one of the largest undertaking of its kind ever attempted. Over 3000 timbers were installed in a burial mound measuring 14x16m and up to 1.5m deep. The covering comprised 315 metric tonnes of sand overlain by a artificial fibre tarpaulin pinned down by concrete-filled tyres. To help establish the effectiveness of the reburial various procedures were put in place to enable buried wood and the inter-stitial seawater to be periodically sampled and evaluated (Waddell 1994).

McCarthy (1986) states that the accepted, and general, procedure on wooden ship excavations has been to re-bury the excavated site with the original overburden (*e.g.* ballast, sand, coral etc.) with the qualification that problems occur as it is rarely as impervious to marine organisms and oxygen as before.

To date, the impact of reburial upon archaeological site components is largely unknown yet it must be acknowledged that the process of removing the objects from their environment and the uncovering of structures, even for the briefest of time to record and photograph, exposes sites and features to some environmental changes. This is sufficient to restart the process of deterioration which will continue for some time after the object has been reburied, even in its original sediment type, before gradually slowing down again as near equilibrium is reached (Lawson 1978)[51].

Sampling has taken place to assess the effects of previous excavation on as yet un-excavated artefacts and hull remains which lie in deeper areas of the site (Gesner 1993), and excavation and back-filling (see Figure 26). In addition, attempts were made to determine if, as a result of previous excavation, environmental conditions have been created where marine

[51] Recent research supports this proposition *e.g.* the assessment of apparently stimulated micro-biological communities present in previously excavated and back-filled areas of the *Pandora* site (Guthrie *et al* 1995), and the evaluation of past preservation efforts on the wreck of the *Defence* (Reiss & Daniel 1997).

worms, borers or other microbes can thrive and have caused an acceleration or renewed process of disintegration and deterioration within the wreck (Guthrie *et al* 1995).

### 4.6.1 Faunalturbation[52]

On the Studland Bay wreck strategies to prevent the erosive activities of lobsters and crabs (which seem to prefer to burrow against a solid surface) involved the implementation of woven polypropylene sheeting extending well beyond the edge of the structure and secured with a double row of sandbags (Ferrari & Adams 1990).

Side burrowing activities of crabs damaging vertical faces, destroying stratigraphical relationships, necessitating further cutting back of section faces - observations on *Kennemerland* showing changes overnight (Ferrari & Adams 1990). The protection of an exposed excavation face was attempted by the construction of a barrier of large, flat stones acquired from the site and its vicinity. The barrier was still discernible a year later and thus was judged to be a successful strategy (Dobbs & Price 1991).

In a similar way small boulders (weighing less than 100-150kg) and exposed during excavation) were positioned as additional protection for vulnerable areas on the designated Historic Wreck Sites situated off The Lizard in Cornwall (*St Anthony*, *Schiedam* and Rill Cove) (Randall pers. comm.). This strategy only proved effective in the short-term until seas of sufficient energy moved the boulders into a new position.

## 4.7 Cathodic protection

Corrosion protection works on the basis of inhibiting one or more of the four requirements of the corrosion cell (cathode, anode, electrolyte and a metal) and it can be achieved by modifying the environment to reduce its conductivity and/or eliminating the cathodic reactants. Alternatively, a coating

52 Faunalturbation is defined as the effects of animals, particularly burrowing forms by Wood & Johnson (1978).

system which separates the metal surface from the environment will prevent the cathodic reactions occurring. Sacrificial anodes or impressed current can be used to ensure that the entire metal surface (which previously included anodic and cathodic areas) remains cathodic relative to a remotely located anode (Kentish 1995, Bump & Muncher 1987, Jobling 1990).

In the case of sacrificial anodes potential differences exist between electrically connected dissimilar metals which can provide the driving force for the cathodic protection providing the materials are carefully selected. The sacrificial anode must be more active than the metal it is to protect and it must not be allowed to passivate (form a protective oxide layer). Anodes must corrode actively for their entire life in order to function satisfactorily. When protecting steels and wrought irons suitable metals are zinc, magnesium and aluminium. The latter metal can passivate in stagnant environments and may not be effective in estuaries and harbours. Zinc anodes tend to be chosen where stagnant conditions may exist. Therefore the selection of alloy composition and the assessment of the electrolyte (*e.g.* water quality and movement, temperature, dissolved oxygen) is critical to the success of the corrosion protection strategy.

A useful example of the *in situ* treatment options for large, corroding iron objects has been demonstrated on the wreck of HMS *Sirius* which was wrecked off Norfolk Island, Australia, in 1790. Extensive studies were made of the rates of corrosion of the cannons and anchors on the site. After some three and a half years of pre-treatment with sacrificial anodes one extensively corroded carronade was raised in a largely stabilised condition (MacLeod 1993). Experience on this, and other, Australian sites indicates that the pre-treatment of artefacts on the seabed prior to excavation and recovery suggests that post-excavation treatment time can be minimised. Not only is corrosion halted during the remaining time on the sea bed but active conservation treatment can be carried out at the same time (MacLeod 1989).

### 4.8 Negative aspects of management *in situ*

There is a very great gap in terms of the strategies which might be installed and what they might cost between archaeology and the construction or marine environmental industries. Sophisticated bio-technical solutions common to destabilisation problems in the oil industry are very expensive to manufacture and install - costs of the order of £50 per $m^2$ , with suitable installation vessels costing up to £50,000 per day, are known. Installations requiring non-standard units or delicate placement will be comparably slower and even more expensive (Ferrari 1994).

Installation of the seagrass initiative on the Legare Anchorage Shipwreck site was budgeted at $1435 (1983), employing three persons for seven days (Skowronek 1984). Twenty-two Cegrass mats were placed on *the William Salthouse* at a cost of A$100,000 (approximately £50,000) (Harvey pers. comm.), excluding the many hours of work contributed by volunteers. The price of the Cegrass artificial mats themselves have been quoted as in excess of A$175 (c. £85) per $m^2$ (Hosty 1988).

Although it is acknowledged that the estimation is very difficult, the costs of the limited sand-bagging on the Duart Point site are thought to be in the region of £1500 for labour and £250 for materials (Martin pers. comm.). Sandbagging on the *William Salthouse* involved $18m^3$ of sand and 800kg of cement to fill 1500 x 35kg bags. Twenty-three working dives were made on the site with a total bottom time of 129 hours (100 hours constructing the sand-bag walls and 29 hours on measuring sand movement) (Hosty 1988).

As an example of how extensive and costly (in money, manpower and resources) sand-bagging can be, on the south bank of Lake Neuchatel in Switzerland, the lakeshore receded 15m between 1982 and 1992 causing half-submerged Neolithic sites to be exposed in the wave-zone. With the support of the Swiss army an area of 180 $m^2$ at Font, and another 125 $m^2$ at Forel was stabilised. A layer of geotextile covered with 1,450 sacks (each filled with gravel and weighing 110kg) was installed over two days. It is believed that the sacks, made to measure in a very thick and robust geotextile, will help to protect the sites for ten to twenty years or until a definitive solution is found to the problem of the erosion (Ramseyer 1993).

In terms of the way in which operations on most UK designated Historic Wreck Sites are currently funded, comments from licensees authorised to investigate the sites suggested that the costs that stabilisation methods are likely to incur are completely beyond the means of the local amateur group (Randall, pers. comm.). Other licensees commented that high costs inhibited them from constructing site protection methods to facilitate excavation - in the case of the Church Rocks site proposals involved a cofferdam (Burton pers. comm.).

Some preservation *in situ* strategies can be implemented on underwater environments for relatively modest sums (*e.g.* sand-bags) but they should only be employed in the full knowledge that their effectiveness may only be short-term, probably measurable in years rather than decades.

Depending upon the scale of the stabilisation, some methods represent significant barriers to any future archaeological research or survey. Access will be reduced and the site will be less visible for the purposes of heritage appreciation. Many methods of physical protection (*e.g.* sand-bagging) will significantly reduce the amenity value of a site by masking areas of interest. On the *William Salthouse* site a significant disadvantage is the cost of removing the material on site where further intrusive work is planned in the future (McCarthy 1986). There may also be an adverse effect on the natural environment, particularly from methods such as sand-bagging and the various types of layers (*e.g.* polythene) affecting underlying and adjacent marine ecosystems (Elliget & Breidahl 1991).

During the planning of the Llangorse Lake stabilisation strategy, the potentially negative effects of the plan to encourage re-vegetation of eroded areas were appreciated. Plant roots and rhizomes can damage archaeological deposits so the progress of the re-vegetation sequence would need to be monitored closely and it may be necessary to delay colonisation by plant species until sufficient sediment has accumulated (Coles 1994a).

Preliminary work on the rates of bacterial activity in various contexts on the *Pandora* site indicate that the bacterial population is adversely affecting the timbers of the wreck at the backfill site (Guthrie *et al* 1995). However although initial results indicate increased levels of bacterial activity around the backfill site this may be due to many contributing factors as the research was unable to determine if the excavation and backfilling processes were actually causing rapid decomposition of the hull. It is thought that improvements to the sampling techniques will enable this question to be answered as part of future expeditions.

#### 4.8.1 Recommended procedures for *in situ* management

Mathewson (1989b) proposed that any initial step in the planning, design and implementation of a management project involves preliminary archaeological investigation including:

- definition of the specific characteristics and components of the site which are to be protected,
- consultation of the decay matrix (see Figure 6) to select the desired environmental change to be induced through burial, including determining priorities between materials or characteristics which may be differentially preserved,
- determination of the existing physical, chemical and biological conditions pertaining on the site,
- design of concepts to determine whether the desired environmental changes will occur,
- monitoring of the buried sites to ensure the changes have taken place.

In designing an effective *reburial* project the following processes should be carried out (Thorne 1991a):

- evaluate the components of the site;
- measure potential impacts, including decay processes against the goals for protecting the site;
- assess the benefits of intentional site burial;
- specify the methods and procedures to be used.

4.8.2 Experimental methodology

In order to make decisions as to the best sedimentary medium for *in situ* preservation and subsequent monitoring an understanding of the processes of deterioration within sediments is required. Related research has been carried out on the effects of compressing archaeological deposits on land and this may prove a starting point for similar studies focusing on marine sites (US Army Corps of Engineers 1989a, 1989b).

In addition, experimentation is underway to identify the suitability of sand as a medium for *in situ* preservation and what parameters should be monitored in the reburial environment (Gregory, pers. com.). A series of field experiments will examine the deterioration of modern wood and canvas in open seawater and buried within sand. The former represent a "worst case scenario" for a submerged artefact and the latter are designed to simulate a reburial strategy.

Monitoring is essential to facilitate the maintenance of site stabilisation strategies and add to existing information of the condition of sites and the effectiveness of site stabilisation remedies[53]. Results can be useful even if monitoring is only carried out infrequently *e.g.* Playa de la Isla wreck in Spain, after exposure due to effects of marina construction given a protective covering of successive layers of sand, mesh and gravel in 1991 and checked as effective in 1993/1994 (Negueruela *et al* 1995).

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[53] Coroneos (1991) recommends the preparation and initiation of a monitoring programme for any stabilisation method implemented.

Inappropriate strategies which do not take account of the actual factors governing the stability of the site will inevitably fail. The following chapter addresses the nature and extent of monitoring and assessment procedures carried out on marine archaeological sites.

**4.9 Discussion**

The continued existence and cultural resource potential, of many submerged archaeological sites are threatened by de-stabilising factors such as erosion. Parrent states that, in general, if left alone historic ship archaeological sites are not in peril from their environment but only when man disturbs them (1988). There is a need for the quantified assessment of the stability of such sites, followed by the design and implementation of suitable mitigation strategies as required.

Throughout the discipline as a whole there is a distinct lack of established, well-proven methodologies for the planning and installation of site management strategies.

Underwater and marine archaeologists are benefiting from the experience of land archaeologists, in particular those dealing with wetland environments. Recent discussions amongst wetland and underwater archaeologists at a conference in Marigny, France stressed the importance of studying the factors which cause erosion or de-stabilisation, and the necessity for co-operation between the archaeological community and nature conservation interests. All participants admitted that they should have carried out more detailed recording of the sites before intervening so that subsequent monitoring had greater meaning, and to enable the success or otherwise of the protective measures to be gauged sooner (Coles 1994b).

The available knowledge concerning site stabilisation methods and techniques in marine archaeology is limited and experience is lacking. There has also been limited research into the effectiveness of the strategies used therefore it is difficult to assess whether value for money has been achieved.

Ensuring that protection measures are effective requires baseline data that is capable of supporting rigorous research, analysis and comparison in the future. This in turn demands recognition of the need to develop a co-ordinated policy based on the results of relevant research now. Little research has been undertaken to assess the actual long-term implications of *in situ* management and most methods are likely to involve significant expenditure.

There is a need for an adequately funded research programme to ensure that any money spent in the future is spent as effectively as possible. Without comprehensive research in advance of protective measures (and there is clearly some experience of specific methods which could be collated and analysed as part of this effort) there is a risk of endorsing methods with highly unpredictable results. Furthermore, efforts should be made to assess stabilisation experience in the environmental sectors, and the offshore oil and gas extraction industries.

Fulford *et al* (1997) state that more detailed consideration will need to be given to the specific survey, recording, and management needs of the submerged, marine archaeological resource. Comprehensive study is necessary to identify the most appropriate and cost effective strategies for the widest range of submerged archaeological burial environments. Furthermore, there is a need for clarification of the minimum requirements for monitoring and there is a basic lack of research into the effectiveness of protection measures (McGrail 1993). The programme must also encompass studies into the nature of submerged archaeological environments, site monitoring procedures and systematic trials of stabilisation techniques.

# 5. Monitoring and assessment of marine archaeological sites

## 5.1 Introduction

A full characterisation of the physical, chemical and biological environment of a site should be considered an integral part of any investigation. Such an assessment should consider the site as it was when it was occupied or active as well as through the later stages which brought it to the condition in which it was found (Dean *et al* 1995). This chapter looks at the conception, planning and execution of shipwreck site assessment and monitoring procedures in the light of actual examples from the UK and overseas.

Studies of the marine archaeological environment are known for specific purposes such as collecting data on current speeds and sediment suspension (Fischer *et al* 1984, Wild 1984, Skowronek *et al* 1987). The utility of site assessment has been demonstrated by the *Xantho* where a comprehensive pre-disturbance survey (including biological and chemical analysis) revealed the extensive fragility of the wreck (McCarthy 1984, 1996). One example of area survey is the work carried out on the Goodwin Sands by Marine Archaeological Survey, a short-lived group of individuals (formed to further the use of geophysical survey in marine archaeology and to foster links with the hydrographic sector (Redknap & Fleming 1985).

Site assessment has a far-reaching importance in archaeology. A principle aim of archaeological conservation is to ensure that the evidence of the past is retained for the future, by minimising the damage caused by the change of environment during and after recovery. Using the techniques of passive conservation, this is attempted by reproducing the characteristics of the burial environment of the object, or by applying holding treatments to help the object survive until it can be safely transported to a conservation laboratory. In order to construct and maintain adequate environments for transport and storage the conservator requires accurate information about the conditions of burial (Carpenter 1987).

Despite this recognised importance, environmental assessments have not become an accepted part of archaeological investigations. The emphasis has often been on particular artefacts (*e.g.* the guns from *HMS Dartmouth*, see McBride 1976) or particular environmental attributes (*e.g.* sediment evaluations, grain and pore size related to preservation qualities and site formation (Lawson 1978, Smith *et al* 1981, Gibbins & Parker 1986) rather than attempting to understand the environment as a whole.

A more important factor might have been the recognition that site environments are complex systems which are too difficult to understand. There are significant variations in the composition of archaeological objects, in the chemistry of the sea-bed deposits, in the quality of the sea water in the area, and other such chemical and biological factors (Muckelroy 1977). Moreover, there is considerable variation in the survival characteristics of various sites, and also between different areas on any one site.

The perceived reluctance by archaeologists who have worked underwater to carry out site environmental assessments may be due to the lack of accepted methodologies, or perhaps it was due to an in-built wariness when relating data and vocabularies which are derived from the natural sciences (such as pH or the measurement of obscure chemical species) to archaeological problems. In addition, most previous work has been individual site based and there has been little objective data published which might be useful for comparing one site against another, with regard to factors such as the differential preservation of the materials present, therefore the opportunity of building up a useful corpus of evidence on the nature of archaeological sites underwater as a whole has been lost (Wildesen 1982).

Therefore, although the benefits of environmental assessments have been recognised widely they have not been universally taken up probably because there is a lack of clear methodologies for determining objectively which attributes or factors are important and how they can be measured on archaeological sites underwater. It would seem that there has been a lack of consistency in the past. Environmental assessments might have been carried out on a single site basis whereas what is required is a broader view.

### 5.2 The history of the assessment of the environment of underwater sites

In the 60s and 70s a general doctrine emerged from early diving in the Mediterranean, stating that only on shores with submerged cliffs are coherent archaeological remains likely to be found, on rocky shores in shallow water no important remains will be found (Dumas 1962, Dumas 1972).

The first interim report of the Moor Sand Bronze Age site near Salcombe is unusual in that an appendix is devoted to a biological assessment of the site (Muckelroy & Baker 1979) and in a later paper which documents the next season's work includes an assessment of the results in the light of any significant changes (Muckelroy & Baker 1980). Furthermore, the evidence suggests that there has been a process of slow progressive enlightenment. Early investigations of wreck sites were principally interested in the recovery of artefacts, ship-structure remains came second, then consideration was finally given to non-artefactual material and evidence.

If it was done at all, consideration of environmental factors was often limited to their relationship to preservation. Even so the recorded information regarding the nature of the burial environment and its effects on artefacts is often confined to a few brief lines in an excavation report (Robinson 1982). Also site environmental studies have always been more common on submerged settlement sites (Muche 1982) particularly inland sites *e.g.* Warm Mineral Springs - Cockrell 1988, Fischer & Gerrell 1990). Such projects are still providing useful test-beds for innovative techniques as illustrated by the use of digitised video for survey purposes at Little Salt Spring (Gifford 1993).

Recently observations of the biophysical environment surrounding the wreck site have been included as part of the collection of non-artefactual data at the

Terence Bay site in Canada. This assessment had three elements: sediments within the wreck, the surrounding bathymetry and the biological species present (Kenchington *et al* 1989). There has also been a progression to environmental aspects being included in deep water exploration for archaeological remains - increased data on context of sites together with emphasis on greater depth as environmental factor which caused difficulties in working (McCann & Freed 1994).

### 5.3 Cultural resource management (CRM)

Site environmental assessments should form a fundamental part of any CRM scheme as such evaluations provide the basis for achieving a better understanding of the site and its' formation, and indicate ways in which it can be better managed and preserved for the benefit of future generations. Strategies such as the taking of baseline information followed by periodic monitoring form a fundamental part of the management plans for underwater heritage parks in many parts of the world.

What CRM archaeologists need to know is how quickly cultural materials decay in a site, and whether any identifiable decay products might remain to help determine the nature, quantity and distribution of former cultural materials in the site matrix. Proposals for long-term monitoring and management of the *Abemama* site in Western Australia recommended regular (six months to one year in this case) intervals between sediment level recording and assessment of biological communities (Nash 1987). It is anticipated that this data would identify threats from environmental changes and indicate mitigation strategies. In addition it may provide a basis for a predictive model of site formation processes that could be useful in elucidating how and why particular wreck distributions occur. Furthermore, it may allow for a database of information to be established recording deterioration in the integrity of structure, and for comparative analysis with other sites (see McCarthy 1982).

The investigation of the *USS Arizona*, one of the battleships sunk at Pearl Harbour, represents a major landmark in site assessment studies as no-one had previously confronted the problem of developing a long-term preservation program for a whole ship *in situ*. The programme included collecting a baseline inventory of biological communities on the structure of the 600 foot battleship which would help determine the biochemical processes impacting the vessel fabric. The programme also included the development of a series of degradation hypotheses which can be tested together with a description of fouling layers and their effects on corrosion, the effect of fanning by egg-laying fish which exposed teak decking to wood-boring molluscs. Stations around the vessel were also established to enable quantified measurements of the state of deterioration of structural elements to be collected at periodic intervals. It was determined that corrosion and the biofouling process are affected by numerous water quality attributes chiefly oxygen, pH and motion. Samples of the water inside the wreck were also collected and chilled for determination of the presence of sulphides and hydrocarbons (Murphy 1987, Lenihan *et al* 1989).

As part of a wreck inspection programme devised as an aid to the co-ordinated management of a large number of wreck sites McCarthy nominates "the conditions on site" (comprising weed cover, bottom type, visibility, surge, depth, sea state, currents and tide) as one of six categories of information required. Temperature, salinity, pH, dissolved oxygen content, water movement and purity, bottom-type and analysis, corrosion products and marine concretions are also seen as of importance (McCarthy 1982).

The wreck site of the iron steam-ship *Xantho* has provided a model for how a marine archaeological site can be managed. Pre-disturbance surveys of the marine biology, electrochemical and physical environment established reference data for monitoring changes in the site's conditions. The installation of a cathodic protection system prevented further deterioration of the historically significant engine whilst conservation facilities were being established. Finally site assessments after the excavation and recovery of the engine showed that these activities had not significantly affected the micro-environments of the rest of the site (MacLeod *et al* 1986, McCarthy 1996).

On the CSS *Chattahoochee* site, it was necessary to ascertain the physical processes and the environmental conditions at the site, attempt a description of the historical aspects of the wrecking and the geographical setting. This information serves as the basis for the analysis of site formation processes which can be grouped into early fluvial processes, the more recent anthropo-limnologic processes and the observed conditions during the on-site investigation programme. It was pointed out that the relationship of water quality to the *in situ* preservation or destruction of wooden hulls and various metals is not well understood (Stephenson 1985).

A detailed pre-disturbance survey can be a powerful tool (Adams *et al* 1990) in ensuring that, as far as is practicable, flexibility can be introduced into development projects so that archaeological concerns can be taken into consideration. However, the crucial irony is that it is those sediments and contexts that are untouched, and thus of unknown content, that determine their actual archaeological importance.

On a terrestrial waterlogged site three main monitoring and analytical components of microbial research were recommended (Cox *et al* 1995). For such structures as the Sweet Track monitoring during periods of hydrological and management change were proposed to:

- to evaluate the degree of decay of timbers sampled from the archaeological structures,
- to evaluate the physical and chemical conditions that might affect the rate of decay of organic archaeological material so samples of various types of wood should be buried and assessed at various time intervals,
- to establish the feasibility and potential role of the irradiation of archaeological waterlogged timbers followed by reburial.

Monitoring studies on the *Sweepstakes* have included the use of current meters, temperature probes and sediment sampling. Parks Canada, in their efforts to manage the sites included within the Marine Park, are using techniques such as periodically re-measuring specific distances, angles of inclination, stress and strain gauging, photography (still and video), as well as artefact monitoring. Selected loose artefacts were recovered, photographed, weighed, moulded and returned to the site and secured in place. The moulds were used to cast detailed reproductions which are retained as reference materials. At specific intervals (*e.g.* 2 - 5 years) the original item will be recovered and compared with the reproduction to determine if any changes have occurred. The original will then be returned to the site. In addition, new samples of similar materials have been placed on the sites and will be checked at regular intervals to monitor any changes. Potential chemical changes are also monitored together with dissolved oxygen, temperature profiles and metallic reactions (McClellan 1994). The involvement of Parks Canada personnel to assume most of the monitoring process can be seen as a major advance in encouraging greater presence on-site (Parks Canada 1997).

In CRM common strategies involve formal statements as to future strategies for any particular resource *e.g.* management plans or conservation plans. An example of the latter for the wreck of the *Clarence*, 1850, (the oldest and best preserved Australian-built coastal trading vessel), derived in part from an extensive programme of environmental monitoring. Categories assessed were significance, current status, identification of threats and opportunities (including site interpretation and access), culminating in proposals for management. A primary recommendation of the *Clarence* Conservation Plan was to write a complete report on the interractions of the wreck and its environment based on data collected during the monitoring programme and elsewhere (Coroneos 1991a).

## 5.4 The development of monitoring strategies

Archaeologists should know how to recognise both the material of an object and its likely condition (Pearson 1981)[54]. Some knowledge of the likely condition after prolonged exposure to seawater is necessary. Cast iron can be reduced to graphite, pewter and brass completely mineralised or corroded within a surface crust, leather degraded and fragile. Stone (1993) produced a guide for the recognition of 19th century sailing ship artefacts discovered on the seabed contrasting their present and former condition (Figure 20a and b).

The US National Parks Service has pioneered the training on non-specialist personnel to take part in monitoring exercises[55]. Techniques are de-mystified so far that significant tasks can be achieved (*e.g.* the characterisation of the largest structure ever mapped underwater, the *USS Arizona*.

### 5.4.1 Use of commercial geophysical data

Draper-Ali (1996) in a review of archaeology and commercial geophysical survey stated that it is possible to retrieve archaeological information from commercial survey data but opportunities vary considerably according to the specific aims of the survey exercise. It is imperative to apply archaeological criteria derived from a clear understanding of archaeological objectives. Although substantial archives of geophysical survey data are held by institutions (*e.g.* British Geological Survey, local authorities and commercial survey companies) the archaeological potential of this data is highly variable and generally limited. Despite these existing limitations the very rapid rate of refinement of equipment and survey techniques over the last decade suggests that in future geophysical prospecting for archaeological purposes will become an exact science and will therefore become a vital part of archaeological resource assessments.

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54 It has been suggested that the perception that some materials survive and others do not may be an artefact of assessment methods used (Wildesen 1982).

Surveys conducted by the oil industry prior to the placement of any kind of installation represent the highest level of information that is currently available and corridor surveys undertaken by cable and pipeline companies are conducted to extremely high standards. There is often a minimal amount of verification of contacts as commercial surveys are primarily aimed at identifying features which are then avoided. Survey undertaken during prospecting for marine aggregate extraction contained the least amount of archaeological data as their principal aim is to identify large areas of sedimentary material suitable for extraction. Consequently area coverage is more important than resolution.

### 5.4.2 Marine biological survey of wreck sites

Assessment of the marine life which colonises archaeological sites can provide important information for management and interpretation. Biological organisms can be used as indicators of physical characteristics of the sediment (*e.g.* Garrison *et al* 1981, May *et al* 1978, Gould 1991). On the Late Bronze Age site at Moor Sands a biological assessment was carried out specifically to provide an indication of the nature of water movement over the site (Muckelroy & Baker 1979)[56].

Marine biological survey of the *Mary Rose* site over a three year period indicated that an effect of excavation was the increase in the diversity of species present (Collins & Mallinson 1984). Survey by routine diver observation, collection and photography showed that over the previous ten years of archaeological work a new range of habitats had been exposed.

A similar survey of the historic wreck *Iona II* (1864) provided, in conjunction with an assessment of a much more recent wreck the *MV Robert* (1975),

[55] Lenihan (1989) describes the submerged site responsibilities and activities of over 200 National Parks Service rangers and maintenance personnel from a number of US National Parks situated across the world.

[56] Exposure scales produced by biologists were used. The scales relate wave exposure to the presence and abundance of certain species.

useful information on the latest stage in the natural faunal succession of the sites (Irving 1995)(see Figure 23). Further work on the Gull Rock site, which consists of a scatter of artefacts encrusted with marine growth on a seabed of muddy shell gravel at the base of a rocky slope, identified three distinct biological communities[57]. The limestone cannon balls supported a distinctly different faunal assemblage than that found on adjacent hard substrata, in fact one highly characteristic of limestone bedrock in other parts of the country.

As part of analysis of corrosion measurements of iron objects on the *HMS Sirius* site MacLeod (1989a) found no differences in samples of weed collected from various substrates in and around the wreck (*e.g.* ballast pigs, area around the anchor, growth on anchor ring and reef top) due to the presence of iron or its corrosion products. The colouration of the concretion on the wreck site is essentially that of the surrounding coralline environment, with no characteristic iron stains, and the species present are essentially those to be expected from a shallow high energy habitat.

### 5.4.3 Geomorphology and geology

In the case of the Richmond River in New South Wales, Australia, knowledge of the present geomorphology, survey of past changes in geomorphology, historical records of shipwrecks - all combine to enable modelling the possibilities of shipwreck preservation at any locality in the river mouth area (Boyd *et al* 1995). This provides an essential input to the development of shipwreck heritage management by extending the current NSW Department of Urban Affairs and Planning practice of site assessment by identifying whether wrecks of a given age are likely to occur at a location, and the degree of protection or risk to the preservation of a wreck afforded by the present geomorphological and land use characteristics of that location.

[57] Firstly the circa-littoral bedrock and artificial substrata (iron cannon) with a sponge, hydroid and bryozoan turf at 13-26m below chart datum. Secondly, circa-littoral limestone in the form of cannon shot including horseshoe worms, sponges and bivalves at 23m below chart datum. Thirdly, lower circalittoral muddy shell gravel plain with crabs and burrowing anemones.

A sedimentological study of the coastal sand used the wreck at Ma'agan Mikhael as a temporal bench-mark in the reconstruction of the local paleogeography (Mart 1994).

The 1995 field trip to Atherley Narrows National Marine Park involved the second year of implementation of a project - setting up an additional row of Depth of Disturbance Rods, taking measurements on silt movement and location, and the tagging and assessing the preservation of the stakes in the monitoring programme (Parks Canada 1987).

Describing the occurrence of scour patterns (scour shadows and sand plumes) downstream of recent wrecks Caston (1979) considers the differences between patterns created around wrecks located on sand and gravel seabeds. Duck (1995) details the importance of side-scan sonar techniques in assessing such features which are of interest because they can provide evidence of sediment mobility, and the directions of currents and sediment transport.

### 5.4.4 Predictive survey

Predictive surveys are aimed at identifying areas which might have a high potential for containing archaeological sites. A principal necessity for such initiatives in relation to shipwrecks is to take into account the variable conditions in which vessels come to grief, such as the geographical and/or topographical factors. Furthermore, the conditions which are favourable for preservation (*i.e.* sandy seabeds adjacent to rocky coasts) are important for defining a survey with the highest probability of locating previously unknown sites.

The development of quantified measurement and monitoring techniques is crucial to the success of any study. Various physical, chemical and biological parameters have been determined to be important for wreck site location as well as for predicting expected states of preservation (see Figures 2 and 3)(Smith *et al* 1981).

There is general agreement as to the burial site characteristics which give best preservation (*e.g.* rapid burial at depth in sediment, elimination of light, oxygen and anaerobic bacteria)(Florian 1990). Several workers have used such criteria as the basis for predictive surveys[58].

**5.5 What is going to be measured?**

Marine environmental systems are comprised of individual component parts (*e.g.* temp., fish) together with the interactions between them (*e.g.* corrosion of exposed iron objects). Moreover, careful consideration should be given to what level of precision and accuracy is required in order to make predictions[59].

A parameter can be regarded as any single characteristic of the total marine archaeological environment that can be measured (by objective methodologies *e.g.* pH or subjective methodologies *e.g.* aesthetic value. Environmental criteria are selected parameters based on current understanding of importance[60]. Furthermore, environmental standards are those criteria that have been specified for control within certain limits. The dynamics of the system will also be important. Furthermore, there may be important formal or informal organisations which have specific knowledge *e.g.* recreational divers.

Thorne (1991a) suggests that in order to complete the evaluation of a site components, that is necessary for the development of a design for the burial of a particular site, additional information on components other than artefacts will be required such as pH, ongoing and potential Redox processes, and soil samples.

[58] Predictive survey: for a given seabed type targeting the finds which will probably be preserved in such conditions and in what state of preservation? (Raban 1973). Lawson (1978) discusses the importance of sediment evaluations for developing a comprehensive conservation plan.
[59] Kenderdine (1995b) proposed a wreck inspection programme which included the collection of conservation data including: temperature, salinity, pH and dissolved oxygen content, water purity and movement, bottom type analysis and corrosion products.
[60] For example those parameters which describe sedimentary environments thought to be important for preservation.

The latter will allow the development of reasonable estimates of how a site's artefact and ecofact components have reacted to their physical and chemical environments through time. A model can then be derived to predict how artefacts, structures and ecofacts will behave beneath an artificial covering. This process may prove problematic as Pearson (1981) states that it is possible to predict to some extent how well different types of materials will survive underwater but a variety of factors will affect the *rate* of deterioration and this is a fundamental parameter where the future management of marine archaeological sites is concerned.

Can sediments on marine archaeological sites be classified along the lines of Krumbein & Garrels (1952) "Origin and classification of chemical sediments in terms of pH and oxidation-reduction potentials"? Florian (see Figures 28a and b) adopts their lists of characteristics of normal marine, open-circulation and restricted (humid), anoxic environments to illustrate extremes of marine environments.

Muche discussing inundated aboriginal sites includes a site description and measurement of currents, temperature, visibility, local geology and biological communities. The site was described as being still in the process of recovering from massive pollution and some "biologically dead" areas were noted (Muche 1978, 1982).

### 5.5.1 Inter-relationships

Site environmental assessments should identify and measure the processes which contributed to the formation of the site, in particular the preservation or degradation of the materials or deposits that make up the site (*e.g.* Yorktown shipwreck surveys, Broadwater 1981, Broadwater 1985, Hazzard 1982, MacLeod & Killingley 1982).

There is clearly a need to develop and test models of marine archaeological environments to try and understand how various components of these environments are interrelated; how a change in one component can instigate a change in another; the conditions that must be met for the change to occur and the rate at which it occurs.

Various strategies have been employed in the past. As part of a study of the effects of freshwater inundation on various kinds of cultural resources Nordby carried out experiments in preservation oriented towards mitigating the effects of adverse natural impacts and structural problems inherent in aboriginal buildings (Nordby 1982). On the site of HMS *Vixen* Gould carried out a controlled biological survey to compare marine growth with that on adjacent natural reef (Gould 1991) and on the Legare Anchorage Shipwreck Project the bottom topography and vegetation patterns were mapped as part of the initial survey to determine the placement of excavation units (Skowronek 1984). Watson & Gale's excavation strategy (1990) was determined after assessing the depth and character of surviving stratigraphic layers and the assumed optimum conditions for preservation.

### 5.5.2 Factors to be included in evaluation

Mapping on the Legare Anchorage Shipwreck site included plant life (as well as conventional archaeological parameters such as structural elements, *in situ* artefacts and metal detector readings)(Skowronek 1984). Each survey unit was also surveyed for information on the seabed such as nature of sediment (loose, unconsolidated etc.), turtle grass and sea fans.

Garrison (1975) sought to carry out a systematic assessment by using data and theory from hydrology and engineering studies to describe the expected impacts on archaeological resources due to inundation in a reservoir. The main causes of impacts are determined to be waves, currents, seiches, temperature, water quality, erosion, and sedimentation. These forces also appeared to behave differently in the active (upper), transitional and static (lower) zones of any specific reservoir. Lenihan *et al* (1977) extended Garrison's work to develop a series of hypotheses for a National Reservoir

Inundation Study which has proved to be a useful model for site environmental studies.

### 5.5.3 Assessment of scour depth

In attempting to assess the scour depths around large wrecks Caston (1979) used Hydrographic Department data derived from echo-sounder survey. Some depths were considerable (maximum recorded was 15m) but the number of surveys for each wreck was insufficient to determine whether the initial rate of scour was greater or whether an equilibrium depth was reached in a given time.

### 5.5.4 Microstratigraphy

Arguing that different categories of evidence from archaeological fieldwork devoted to site and/or context formation processes is either irreversibly separated or bulked together during routine processes of extraction or sample preparation (employed in many analyses of organic, inorganic or artefactual remains), Matthews *et al* (1997) suggest the utility of microstratigraphic techniques. The principal contribution would be the simultaneous analysis of diverse sediments, artefactual and bio-archaeological components together with precise details of their deposition and contextual relationships.

### 5.5.5 Lack of comparative data

In various parts of the world work has been carried out on the problems of developing effective sampling methodologies. MacLeod & Killingley (1982) reiterate that in order to fully understand the nature of the many factors which determine the survival of artefacts on an historic shipwreck a detailed knowledge of the site conditions is essential. However because of financial constraints information on such important factors as the annual variations in salinity, temperature and oxygen content have to be obtained from the literature rather than from actual measurement on site. In Australia this modern reference data is rarely available for remote sites but an interesting aspect of the work is the use of the ratio of oxygen isotopes to assess changes in temperature during the growth of barnacles and therefore to changes in the nature of the environment during the formation of the archaeological site.

### 5.5.6 How is preservation to be assessed or measured?

Site environmental assessments should identify and measure the processes which contributed to the formation of the site, in particular the preservation or degradation of the materials or deposits that make up the site (*e.g.* Yorktown shipwreck surveys, Broadwater 1981, Hazzard 1982). However, feasibility studies for determining the decomposition rates of shipwreck sites by Brown *et al* (1988) (including measurement of electromotive potentials on shipwrecks using reference electrode probes, to observe if shipworms were active in newly exposed areas of ship's timbers, and to look for evidence of anaerobic bacterial activity) were not regarded as a success as the readings were difficult to interpret.

Although archaeological sites may be situated in many different geographical locations they could be classified by marine characteristics based on the broad environmental similarities. Florian (1987a) suggests chemical properties of seawater and the nature of the biota to act as a guide to the recording the variable parameters of importance in marine archaeological sites (Figures 28a and b).

### 5.5.7 Micro-organisms

On the *Pandora* site monitoring of bacterial populations to ascertain whether archaeological retrieval of the wreck's contents would adversely affect the condition of the hull remains. It is not planned to recover the latter. Accepted that given the large grain size of the sediments, degree of physical and biological disturbance, high input of organic matter, remoteness of the sites - although it is clear that bacteria play an important role in cycling organic carbon in reef sediments it is a very difficult environment to characterise and study.

The method is detailed in Guthrie *et al* (1995) and the aim was to measure microbial growth rates *in situ* in order to quantify the decomposition rate of the food source, *i.e.* the wooden wreck structure.

The results suggested that the bacterial population was adversely affecting the *Pandora* and that there appeared to be increased activity in the back-fill area implying that archaeological work may involve the introduction of negative processes to the overall stability of the wreck site (Guthrie *et al* 1995). Therefore, although in this case the results of the analysis recommended that alterations should be made to the method, overall it appeared to be a useful way of obtaining data on the current condition of the wreck and the likely effects of potential disturbances in the future.

The relationship of water quality parameters to *in situ* preservation or destruction of wooden hulls and various metals is not well understood (Stephenson 1985). Redox potential is considered to be an important measurement of the physico-chemical variables which if monitored can give an indication of the aerobic/anaerobic condition of the substrate and its capacity to carry out physical, chemical and biological processes upon which a range of function depends including microbiological activity.

### 5.5.8 Assessing and monitoring iron corrosion

The assessment of iron corrosion has involved on-site measurement of corrosion potentials together with the use of sacrificial anodes to continually 'treat' metal objects. For example studies of cannon on sites in the John Pennekamp State Park (Bump & Muncher 1987), and at Chandeleur Islands (Jobling 1990), have demonstrated the link between the assessment of the burial environment and the benefits of *in situ* conservation methods in CRM.

The development of new conservation treatments can also benefit from effective assessment. For example, on the *SS Xantho* project the successful recovery and stabilisation of the vessels engine was only carried out after comprehensive pre-disturbance biological, chemical and electrochemical assessments had been made of the site (McCarthy 1988). Other examples include the treatment of the anchor from *HMS Sirius* and the cryogenic de-concreting of the *Trial* cannon (McCarthy 1982, MacLeod 1987).

### 5.6 Strategies for predicting states of preservation

The observation of states of preservation of artefact types and the projecting of these onto other artefacts can be a useful strategy for predictive survey. Manieri states that environmental conditions were used to justify the proposition that archaeological remains would be preserved in the likely location of the shipwreck. Factors assessed included tolerance of salinity by shipworm, silting processes in the Cape Fear, metal corrosion and coral growth. The assessment of the local current regime was a major reason for extension of the designated search area (Manieri 1982).

Parrent regards predictive models as an important component of a CRM plan for identifying areas that have a high potential for containing archaeological sites. Figures 8 and 11 demonstrate the many varied elements to be considered (Parrent 1988).

### 5.7 Intrusive sampling

At Kyholm joint archaeological-geological investigation was carried out and a corer over one metre in length was specifically designed for sampling sandy sediments and to be diver-placed and recovered (Crumlin-Pedersen *et al* 1980). Techniques of remote assessment on deep sites are discussed by Nelson including site environmental studies utilising bottom core sampling and water analysis (Nelson 1979). The physical problems of sampling underwater sites have been discussed such as the extraction of coring devices (Anuskiewicz 1978, Murphy 1978, Ruppe 1978, May *et al* 1978).

Methods for collecting subsurface data on historic shipwrecks in environments such as coral reefs have also been investigated such as coring to assess the bedrock geology for factors such as the degree of cementation of formerly unconsolidated strata by the presence of iron, a common metal on shipwrecks that readily reacts with the surrounding environment (Raymond 1984). Keith *et al* on The Molasses Reef Wreck discuss the application of sclerochronology (the assessment of the annular growth rings in coral heads) which may provide a means for determining a *terminus ante quem* for the wreck site. Corals also offer a potential for dating the sinking of the ship by radiocarbon analysis (Keith *et al* 1984).

In a further overseas example Clausen & Arnold (1976) discuss environmental assessment and geophysical survey in relation to site formation, and test excavations have been proposed as part of a verification or evaluation process (Arnold 1977).

There is a need to develop recommendations for the conduct of archaeological geophysical surveys in underwater environments covering such parameters as minimum accuracy of position fixing systems, survey line spacing and sensor deployment details. Realistic guidance is required for the minimum requirements necessary for geophysical surveys of archaeological sites as well as environmental assessment.

### 5.8 Environmental assessment consultative procedures for development proposals relating to underwater environments

The rapid growth of environmental assessment requirements has led to an increased awareness of archaeology and a steady increase in the numbers of desk based assessments of developments in underwater environments. The pace of the change is such that it is only within the last eighteen months that consideration of the archaeological resource underwater has been taken into account on anything like a consistent basis. However there is no established network of sources of archaeological advice available to assist the developer and the current legislation and statutory requirements for the marine zone illustrate that inadequate consideration is given to archaeological concerns in procedures controlling offshore development (Firth 1993).

This rapid rise in awareness has been actively encouraged but it has ironically also served to highlight deficiencies within the discipline of field archaeology in its ability to supply suitable practical advice and expertise within an accelerated time scale because of problems with the availability of experienced manpower, resources and tested methodologies.

It is also instructive to examine the environmental assessment process which has emerged from the recent implementation of environmental impact regulations in many parts of the world. Those organisations which have been forced to carry out environmental assessments because of statutory obligations have had cause to examine the fundamental basis of assessment methodology (National Research Council 1990).

### 5.9 The assessment of threats or impacts

Impacts, of human and natural origin, on underwater environments have received relatively little attention compared to those on land where the procedures of environmental assessment of archaeological sites are relatively well established.

It has long been known that commercial interests, such as dredging, have an impact on underwater sites, particularly in the accidental discovery of sites, and there are numerous examples of dredgers accidentally locating wreck sites (*e.g.* Frost 1973). The level of data on such impacts on the underwater archaeological heritage is poor *e.g.* what effect would the extraction of gravel at the rate of millions of tonnes annually have on the stability of wreck sites in the vicinity? What are the differences in impact with increased distance from the extraction area? Recent attempts have been made to carry out pre-dredging surveys and set terms for appropriate action to various kinds of discovery (Adams *et al* 1990).

Within the underwater archaeological literature there is a wide variation in the amount of detail given to site environmental subjects. On the site of the paddlewheel steamer the *John Fraser* VandenHazel tabulates such information on the site as substrate and solid geology, temperature, depth and the variation of the oxygen content of the water throughout year, particular attention is paid to the effect of water and oxygen penetration of cast iron machinery (VandenHazel 1987).

Pettus *et al* investigating the coastal site of Fort Guijarros in San Diego Bay included a site description covering factors such as depth, surge, temperature and solid geology yet little attention was paid to biological communities. However it was pointed out that the determination of the water chemistry of a site is essential in promoting the later preservation of recovered materials and that primary data should include nutrients, salinity, dissolved oxygen, trace metals and pH (Pettus *et al* 1981).

As part of the United States National Parks work to assess the effects of inundation upon archaeological sites Garrison *et al* (1981) discussed the research design and data recovery techniques, the problems of recognising and measuring chemical and biological impacts, laboratory experiments and subsequent fieldwork. The question is posed as to what are the impacts that result from water chemistry changes and the introduction of new biological forms on various classes of cultural remains *e.g.* ceramics, wood, bone, glass, shell, lithics, etc..

An interesting aspect of assessing impact on the site of *HMS Pandora,* on the Great Barrier Reef in Australia, is the proposal to study the effects of any (prior) 'excavation –back-filling' cycle on the (deeper lying) hull remains and artefact assemblages of the wreck. The work would determine if such activities have altered the bacterial communities in the sediment leading to increased or decreased metabolic activity or changes in species composition.

Additional studies are aimed at assessing whether the *status quo* is reached within a specific number of years after excavation/back-filling (Gesner 1992).

There is a need for more research to compile detailed information in order to effectively evaluate risks and potential impacts on the archaeological resource. Important advances being made in marine environmental monitoring research may be applicable to the identification of impacts and the monitoring of change[61].

5.9.1 The classification of impacts

Once the nature of the underwater environment has been assessed then any potential alterations must be considered. These alterations provide the key to understanding the development of the environment and can be categorised into five basic ways: introduction, transformation, trans-location, sequestration and dissipation (after Erickson 1979). All site formation processes, whether cultural or natural, can be categorised in terms of these alteration types but to date this methodology has not been attempted for underwater archaeological environments.

In order to study, manage and even mitigate the effects of impacts it is important that some kind of classification framework is devised. Vrana & Mahoney (1995) summarise the history of the classification impacts to underwater cultural resources illustrating the approach taken by public resource managers (ranking impacts according to their perceived cause *e.g.* natural or cultural), whereas impacts can also be classified according to the physical outcomes from natural or cultural processes (*i.e.* alteration, transfer or removal of artefacts). Therefore cause, type and outcome have been used, Wildesen (1982) also stresses the importance of degree, extent and duration.

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61 For example research into the *Detection of alterations in aquatic continental and marine habitats by means of bioindicators* (Record Control Number 19638) Referenced in CORDIS (http://apollo.cordis.lu).

Lenihan (1981) developed a Relative Sediment Impact Prediction Index (Figure 30) when investigating the impacts of reservoir inundation on a range of archaeological sites. The Index relates sediment competence to a variety of freshwater erosion processes. Long & Roberts (1997) considered that the Index would be applicable to marine and inter-tidal sites after some adaptation. The same authors presented a summary of impact processes and the modification of the archaeological resource for inter-tidal sites (Figure 22).

### 5.9.2 Detecting faunalturbation

Faunalturbation refers to the mixing of soil by animals referred to by Wood & Johnson (1978) to include burrowing mammals (from small squirrels and gophers to foxes and prairie dogs) to insects and earthworms. On marine sites aspects of the interaction between biological activity and cultural material with special reference to species which burrow into relatively soft sediments were reviewed by Ferrari & Adams (1990) concluding that the cumulative effect of potentially erosive biological activity should be taken into account[62].

Visible depressions throughout the area of the Late Roman wreck site, situated at a depth of around 750m between Sicily and North Africa, have been interpreted as being caused by the noses of diving whales. These are considered to be a recent disturbance as many amphorae had appeared to have rolled into the depressions. In addition, the whole area was heavily bioturbated and a variety of marine animals were observed on the site such as crabs, shrimps, eels and groupers.

The existence of faunalturbation on marine archaeological sites and the realisation of its effects on the material remains may not be readily visible. The possible effect of marine worm burrowing carrying along oxygenated

[62] Mechanical damage can also be caused to wreck structure through widening of crevices chosen for habitation by marine animals (Collins & Mallinson 1984).

water thus changing a burial environment from anaerobic to aerobic was considered on the Bai Jiao I site (Kenderdine 1995).

In appropriate conditions disturbed areas of sediment may be differentiated from undisturbed contexts but it may only be upon excavation (*i.e.* through sectioning of contexts) that a true picture is gained.

### 5.10 Future research directions

For many hundreds of years seabed classification has relied upon the interpretative skills of hydrographers and their ability to take accurate, sampled manual soundings for mud, sand, or rock in areas chosen to be charted. Recent demands for greater sensitivity, objectivity, and above all scale have promoted developments in capability:

- objective and unambiguous recording (unlike diver's reports, video recording or side scan imagery)
- non-intrusive recording (in contrast to coring or grab sampling),
- efficiency - capable of consistent underway surveying, weather resistance (no longer dependent upon slow speeds or calm conditions),
- wide-ranging adaptability (non-specialist operators using small vessels, inexpensive software and hardware) (Murphy *et al* 1995).

It is proposed that additional research at the wreck site should include, but not be limited to, additional mapping and excavation of the wreck, a study of the substrate at the site, a detailed chemical analysis of the substrate and the stream, and a chemical analysis of the gunboat hull material above and below the stream bottom (Stephenson 1985).

- The impact on the underwater archaeological resource of assessment techniques.

- The formulation of site environment characterisation models and their uses in predictive modelling and survey.

- The assessment of existing geophysical data sources for archaeological information (*e.g.* survey data deposited with institutions like the British Geological Survey).

- The development of geophysical survey techniques for the purposes of archaeology in shallow water environments, for example seismic profiling.

- The assessment of the archaeological potential of environmental data acquired during commercial surveys of the underwater environments *e.g.* sea bed characterisation, sediment mobility and distribution.

- Coastal Zone Management. SHOALS (scanning hydrographic operational airborne lidar survey) (Lillycrop & Estep 1995).

- The role of the sciences in their broadest sense to the development of the discipline of archaeology underwater and the management of the archaeological resource in underwater environments.

- The contribution of defence industries. Marine sciences stimulated by defence requirements are taking this a further step - the Key West Campaign project represented a unique opportunity to assess mine burial, sediment classification technologies, high frequency bottom-interracting acoustics, and prediction of sea floor engineering properties in a well-understood and characterised environment (Tooma & Richardson 1995).

**5.11 Regional audit initiatives**

These can be important and useful for determining which areas might require special management or protection. These strategies are often based on environmental variables *i.e.* sedimentary environments are thought to offer enhanced archaeological preservation, environmental factors can influence where ships were wrecked etc.. An example is South Carolina's Underwater Antiquities Management Plan which monitored human impacts on cultural resources along the Atlantic coast of South Carolina. The potential impacts of proposed construction projects are assessed and the initiative has shown that some of the counties in the state with the greatest potentially harmful activity are those with the highest number of known underwater sites (Simmons 1988).

Similarly in South Australia through the accumulation of environmental and archaeological data it was possible to show which shipwrecks will provide the maximum and most pertinent information (Jeffery 1992), and the assessment of the *Grace Dieu* is an example of the environmental and archaeological audit of inter-tidal wreck (Clarke *et al* 1993).

Kenderdine (1994) carried out an audit of the River Murray which given the changeable nature of wreck-site environment (post-fieldwork floods created new set of environmental parameters on each site - burial, siltation) concluded that it was better for comparative purposes to assess the status of vessels in relation to the relative level of submergence.

### 5.12 Integration

One of the main advantages of studying environments of marine archaeological sites, and one which has yet to be sufficiently exploited, would be the provision of information to other marine sciences[63]. There have been major technological advances in studying the marine environment as a whole in recent years - development of faster, more effective remote sensing methods, concentration on environmental impacts etc.. Archaeology can play its part in these advances. Archaeological sites can provide well dated phenomena and materials providing a time scale for events and features. Wrecks of different periods within the same area are important, not only to archaeologists but to marine geologists and biologists. For example cargo and concretions constitute a unique time-scale for dating marine sediments (Frost 1962).

In outlining the site environment analysis objectives for the *Pandora* fieldwork Gesner (1993) subscribes to the existence of a relatively new sub-discipline of archaeology and a branch of environmental science. The new sub-discipline, called "eco-archaeometry" by Burns (1991), concerned the studies of physico-chemical phenomena which lead to the deterioration of ancient materials with a view to understanding and mitigating them. The initiative would carry out studies of the fundamental phenomena which lead to deterioration of ancient materials. Deterioration processes must be understood at a molecular level and all archaeological explorations should be preceded by an investigation of physico-chemical processes (and change of rates of these processes) at a potential site - not the least because archaeological activities can, in many cases, actually accelerate degradation. The current problem is seen as one of multi-disciplinarity and of weakness of the links between the relevant disciplines.

In the context of establishing effective evaluation methodologies inter-disciplinary co-operation will increase confidence in environmental evaluations (both statutory requirements and others) as well as increasing knowledge of underwater environments as a whole. It is recommended that the marine archaeological sector take a lead from the EIA approach (after Erickson 1979) to:

- utilise a systematic interdisciplinary approach
- identify and develop methods and procedures which will be acceptable to other marine scientists[64].

The obvious benefits of inter-disciplinary co-operation have been stated on a number of underwater sites (in particular shipwreck projects) such as in Yorktown in the United States where wide variations in the state of

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63 For example the discovery of barstowite (a mineral formed by the action of seawater on other lead minerals) identified as a corrosion product on a lead object recovered from the Mahdia wreck site (Kutzke *et al* 1997).

64 Recommendations were made in the *Clarence* Conservation Plan for *appraisal* by marine science practitioners of strategies and data for monitoring and stabilisation (Coroneos 1991).

preservation of the wrecks in the area were observed. Studies conducted by related scientific institutions of present erosion patterns in the river revealed differences in local sedimentation patterns indicating varying preservation conditions (Broadwater 1981, 1985). Alternatively, a Technical Advisory Committee with representatives from the fields of underwater archaeology, naval and maritime history, conservation, engineering, oceanography, geology and museology has been set up to assist the USS *Monitor* project (Watts 1982)[65].

Recognition of the importance of interdisciplinary co-operation in the investigation of drowned terrestrial sites necessitates a methodology that utilises not only those involved with archaeology, but those involved with geology, sedimentology, coastal geomorphology and geophysical technology (Koski 1988). The necessity for co-operation in underwater work in mainland Europe (Boquet *et al* 1987) is also recognised as water-saturated sediments require new investigation methods.

In the corrosion assessment of *Monitor* wreck it was shown that equipment developed to evaluate cathodic protection levels on offshore platforms and pipelines is sensitive enough to provide meaningful data concerning corrosion activity on metallic archaeological structures (Arnold III *et al* 1991).

Finally, interesting work is being carried out on marine fouling. Perspex plates, specially adapted with sampling mechanisms, were placed on the seabed for fouling organisms to colonise. Such research will have significant results for the study of the effects that organisms have on exposed archaeological materials (Woolmington & Davenport 1983).

## 5.13 Archaeology and commercial geophysical surveys

Areas where improvements could be made have been suggested by Draper-Ali (1996) and they include enhancing the utility of commercial surveys for

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[65] Sheridan (1979) describes the range and extent of the geological and oceanographic techniques applied to the Monitor wreck, including magnetometry, piston coring and sub-bottom profiling.

archaeological purposes by focusing on equipment selection, line spacing, position fixing, interpretation and data storage. In addition there is a need for a more refined interpretation of data to facilitate differentiation between modern debris and archaeological material, techiques to assess and monitor the condition of sites, and to develop a catalogue of "signatures" from known site types to aid future detailed interpretation. Commercial survey data can be of use to archaeologists dependent upon the survey parameters, equipment deployed and the methods of interpretation.

Archaeologists could also benefit from work on wreck marks and scour patterns (Caston 1979) and studying evidence of commercial fishing disturbance of benthic communities (Hall *et al* 1993).

Evidence from research into cemented gravels, found in association with an 1857 wooden wreck off Islay carrying machinery, suggested that corrosion of the iron occurred in an anaerobic environment and that sulphate-reducing bacteria were the agents causing the carbonate cementation (Adams & Schofield 1983). This work indicates that further co-operation between marine geologists, archaeologists and conservators would be useful in furthering understanding of the formation of marine concretions.

It is also important that the archaeological discipline maintains a close relationship with allied research. The innovation of CHIRPS, where the emphasis is on non-intrusive survey, generates evidence for a variable deposition history. In some situations buried scours may be more evident than the wreck itself (Quin *et al* 1997).

### 5.14 Growth of integrated marine environmental databases

A recent development in information technology is the availability of geographic information systems not the least for overcoming "land topocentricity" evident in existing maritime archaeological studies (Hunter 1994). The availability of large quantities of data in easily managed formats enables widely differing environmental parameters to be directly compared in relation to archaeological sites.

## 6. Conclusions

This thesis has taken as a subject the environment of historic shipwreck archaeological sites and by reviewing the status of knowledge in this area several broad conclusions can be made:

- The nature of the marine environment is a critical factor in the preservation of archaeological materials of all types.
- In comparison with their terrestrial equivalents, relatively little is known about marine environments, and particularly their interaction with archaeological remains.
- In most cases only a minimum of attention is paid to this area despite repeated calls for more integrated fieldwork and increased theoretical debate.
- In general ideas, models and procedures for marine site formation, artefact preservation, site management are based mainly on generalisations and empirically-derived information.
- What is done is not supported by extensive field testing or a sound theoretical base, or accepted science of monitoring.
- More often than not strategies are based on short-term expediency, minimal costs and time-scales, and absence of resources for adequate monitoring and maintenance.
- Recent developments, pressures and influences have not come from within the discipline but from effects of the growing interest in environmental concerns in society as a whole.

It can be predicted that the trend of increased impact to the submerged cultural resource will continue as exploitation of seabed environments continues. Therefore, there is an urgent requirement for explicit research and assessment strategies which will under-pin procedures for the survey, stabilisation, excavation or monitoring of all marine archaeological sites.

There are some promising initiatives in research programmes aimed at a better understanding of archaeological sites in underwater environments but there is a need for co-ordination so that significant gaps or overlaps can be identified. All significant historic shipwreck sites should be positively managed using the benefit of an inter-disciplinary advisory body and/or a comprehensive management plan that has been prepared as a result of multi-disciplinary consultation. A more detailed description of the types of sites and the implications for site interference may produce a useful tool for predictions about the preservation of remains for as yet unlocated sites, and the long-term preservation of the resource.

Useful comparable material and techniques could be imported from related disciplines but it is important to consider its relevance. For example, developments in the manufacture of specialised coatings for submerged structures indicate that particular characteristics of controlling fouling and even encouraging it to stimulate the creation of habitats can be catered for[66].

There is a great potential for co-operation. In 1978, the description of sub-littoral zones was incomplete and assessments of species which indicate levels of exposure to waves were limited to inter-tidal zones[67]. It is likely that such habitat description will have been subsequently advanced. Research in the marine biological sector, often derived from environmental impacts, can also provide useful archaeological information[68]. Leigh (1973) suggest that the controlled collection of archaeological material from a range of different environments could be beneficial not only to archaeologists and conservators but to oceanographers and corrosion scientists who will have the use of samples of a known date showing the effects of marine processes that have occurred over known, and often very long, time periods, much longer than those that can be simulated in the laboratory.

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66 *Special coatings for marine environments* (Record Control Number 18274), *Improved, environmentally harmless anti-fouling coating for marine objects* (Record Control Number 18620) Referenced in CORDIS (http://apollo.cordis.lu).

67 See Muckelroy & Baker (1979).

68 The assessment of the possible effects of fishing disturbance derived from an analysis of spatial patterns in community structure around a wreck (Hall *et al* 1993).

Informed archaeological judgements, made to further archaeological resource management aims, rely upon the existence of accurate and comprehensive information gathered by monitoring the condition of sites and monuments, recording, sampling and investigation. It is also apparent that site stabilisation strategies are unlikely to be effective if comprehensive assessment of the existing marine archaeological environment is not carried out prior to intervention. Such an assessment would also improve the viability of subsequent monitoring exercises. What is required is a broader discussion of what is necessary to be measured; how the data is to be collected, manipulated and interpreted on all sites.

On a broader scale maritime archaeology is a recent development and the rate of generation of new information about submerged sites has been considerable. More and more *c-transforms* will be published and available as archaeologists become increasingly aware of the sensitivity of the link between cultural formation process concepts and the nature of extinct cultural systems. Hopefully the set of past excavation reports and the results of all future excavations will provide archaeologists with a data bank for developing and testing generalisations about the processes responsible for forming the archaeological record.

Finally, the ultimate business of archaeology *i.e.* learning about and from the material remains of past societies must be our paramount aim. There is a worrying trend towards environmental assessment and CRM which address not questions of research but to the concerns of clients (Lenihan & Murphy 1981). In addition, there is a need to foster the concept of cultural heritage interests being given attention in areas where the natural heritage is often the prime concern. To paraphrase Coles (1995) “historic shipwreck archaeology **needs** management. It cannot be simply left alone”.

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*IJNA* = International Journal of Nautical Archaeology

*Bull. AIMA* = Bulletin of the Australian Institute for Maritime Archaeology

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UNDERWATER/SHORELINE SITES: ENVIRONMENTAL DATA

PHYSICAL

GEOGRAPHICAL LOCATION

TIDAL RANGE

CURRENTS

- Seasonal variation
- Strength
- Direction

FETCH

WATER DEPTH OVER SITE

- Highest
- Lowest

BOTTOM TOPOGRAPHY

- Bathymetry
- Slope over site
- Description

BOTTOM SEDIMENT TYPE

- Rock
- Boulder
- Pebbles
- Gravel
- Sand
- Mixed
- Organic deposits

SEDIMENT COLOR

SEDIMENTATION RATES

- Seasonal changes
- Current transport

DEPTH SEDIMENT DEPOSIT OVER SITE

WATER TEMPERATURE

VISIBILITY

- Surface
- Bottom

STORM WEATHER

LOCAL DRAINAGE/EFFLUENT OUTFLOW
HISTORICAL SHORELINE CHANGES

CHEMICAL

DISSOLVED OXYGEN

pH

SALINITY

BIOLOGICAL

SEAWEEDS

Type:

- green algae
- brown algae
- red algae

% Coverage:

- attached to site
- attached to bottom
- evidence kelp rafting

INVERTEBRATES

Type:

Major groups
- Porifera
- Coelenterata
- Echinodermata
- Bryozoa
- Mollusca
- Polychaeta

VERTEBRATES

WOOD SAMPLE

Type of Wood

Infestation

- Teredo
- Bankia
- Xylophaga
- Limnoria

Figure 1 Regional sediment types, biological organisms and chemical parameters (salinity, temperature, dissolved oxygen) to be used in predictive survey (after Smith *et al* 1981)

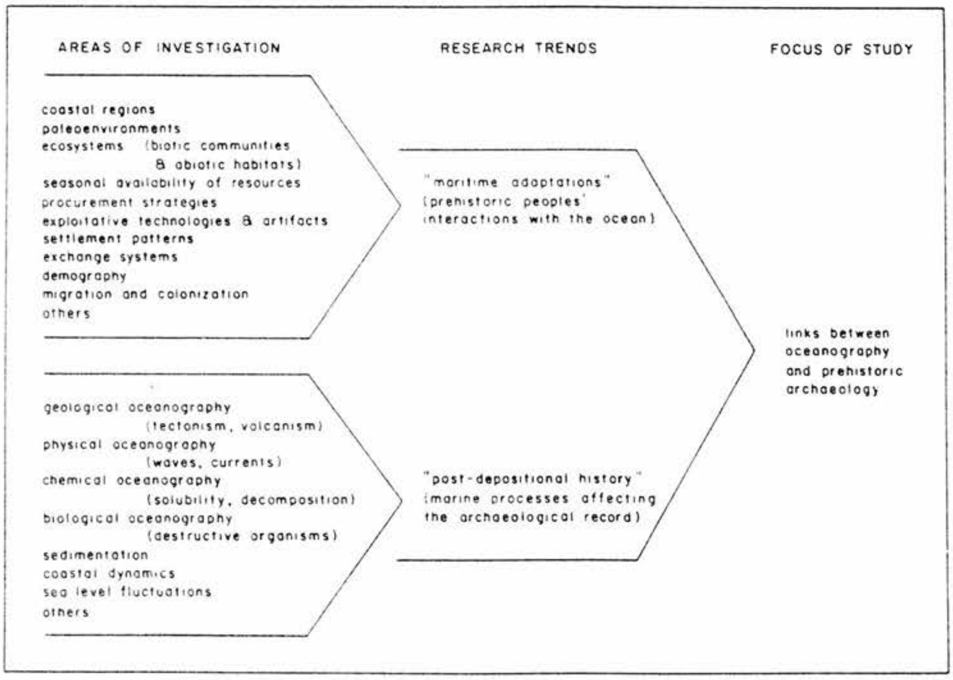



Figure 2 Aspects of maritime archaeology at several levels of integration (after Watters 1985).

**ENVIRONMENTAL FACTORS AFFECTING PRESERVATION**

LOW CURRENTS
↓
MUD/SAND SEDIMENTS
↓
DECREASED INTERSTITIAL WATER CIRCULATION
↓
LOW pH, DISSOLVED OXYGEN
↓
REDUCING ANAEROBIC ENVIRONMENT
↓
SLOW DOWN CHEMICAL/BIOLOGICAL DEGRADATION; INHIBIT GROWTH (LOW SALINITY, TEMPERATURES IMPORTANT AT THIS STAGE)
↓
**INCREASED ARTIFACT PRESERVATION**

Figure 3 Flow chart of environmental factors which lead to increased artefact preservation (after Smith *et al* 1981).

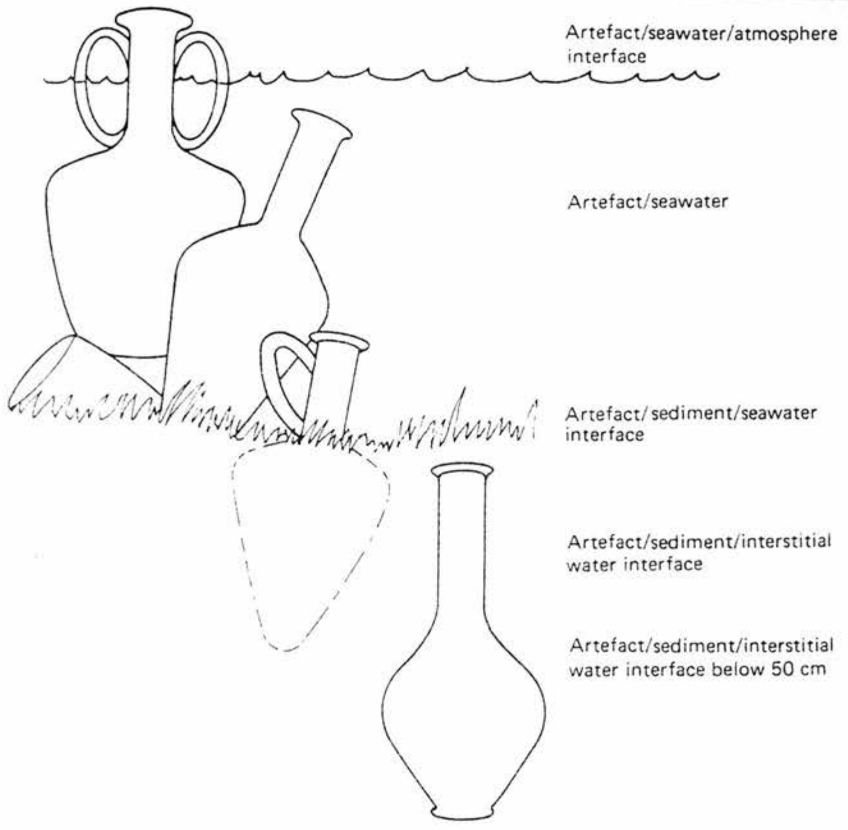



Figure 4 The classification of artefact sites within a wreck site based on artefact/marine environment interfaces (after Florian 1987).

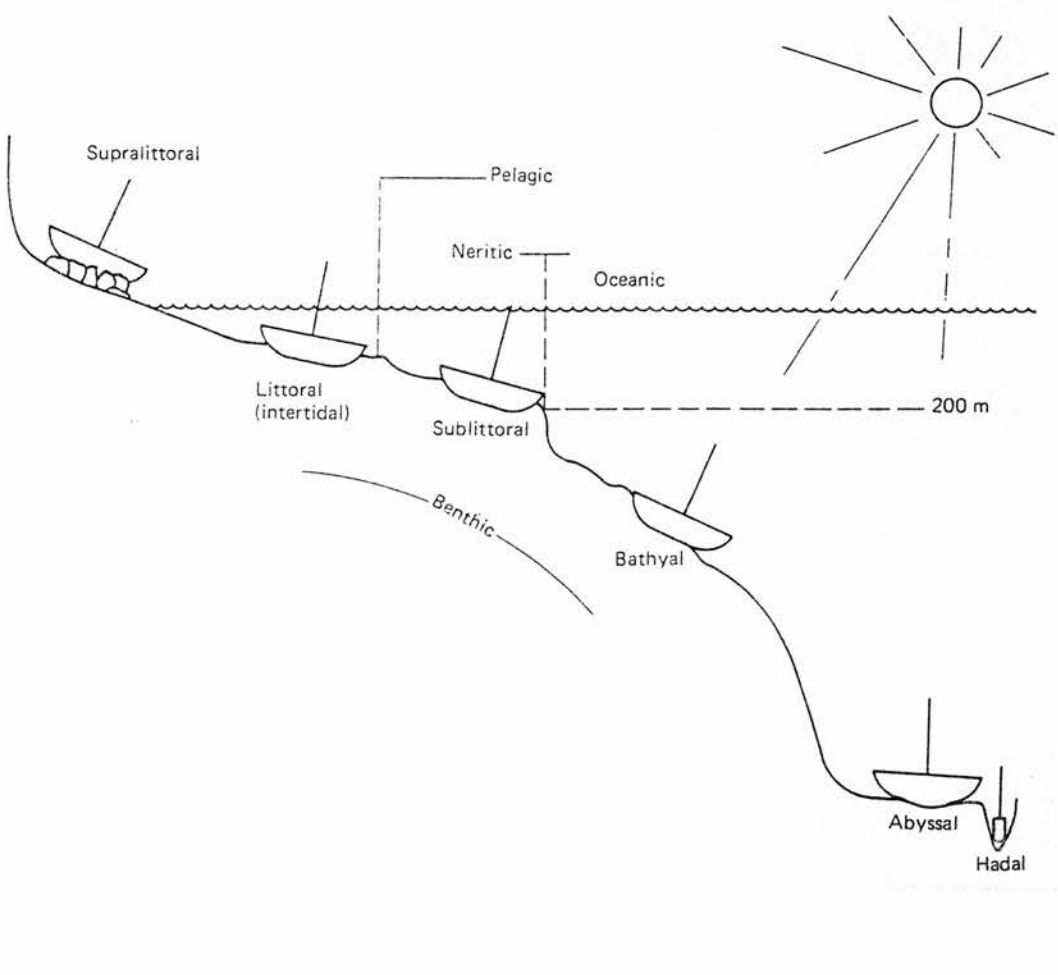



Figure 5 Classification of marine environments for wreck sites based on biozones (after Florian 1987).

**SITE COMPONENTS**

| PROCESSES | ANIMAL BONES | SHELL | PLANTS | CHARCOAL | CRYSTALLINE LITHICS | GRANULAR LITHICS | CERAMICS | ARCHAEO. FEATURES | SOIL ATTRIBUTES | METALS | CONTEXT | ISOTOPE CONTENT | TOPOGRAPHY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ACID ENVIRONMENT | A | A | E | N | N | A | N | N | A | A | N | A | N |
| BASIC ENVIRONMENT | E | E | A | N | N | E | N | N | A | A | N | N | N |
| DRY (CONT.) | E | E | E | E | N | E | N | N | N | E | N | E | N |
| WET ANAEROBIC(CONT.) | E | E | E | A | A | A | A | A | A | A | N | A | A |
| COMPRESSION | A | A | A | A | N | N | A | A | A | N | A | N | A |
| MOVEMENT | N | N | N | A | N | N | N | A | A | N | A | N | A |
| WET-DRY | A | A | A | A | A | A | A | A | A | A | N | A | A |
| MICOORGANISMS | A | N | A | A | N | N | N | N | N | A | A | A | N |
| MACROORGANISMS | A | A | A | A | N | A | N | A | A | N | A | N | N |
| WET AEROBIC | A | A | A | A | N | A | A | A | A | A | N | A | N |
| FREEZE-THAW | A | A | A | A | A | A | A | A | A | N | A | A | A |
| FREEZE | A | A | A | A | N | A | A | N | E | N | A | E | N |
| THAW | N | N | N | N | N | A | N | N | A | N | A | A | N |

E = ENHANCES PRESERVATION
A = ACCELERATES DECAY
N = NEUTRAL OR NO EFFECT

Figure 6 Logic-based archaeological component decay and preservation matrix (after Mathewson 1989b).

| Type of find | Minimum Depth (in metres) correct for the open Sea | Rocky bottom | Pebbles | Fossil mud | Mobile sand cover | Coastal alluvial gravel |
|---|---|---|---|---|---|---|
| Stone Anchors. | Inside a basin, a closed bay, or a small enclosed body of water. | Good preservation Difficulties in identification and detection. | Good preservation Sometimes close to the bottom. | Recovered with marine faunal concretions on upper parts. Good preservation. | Excellent preservation Occasional detection demanding a long follow-up. | Worn and covered b concretions in uppe parts. Difficulty in de tection. |
| Lead anchors. | 2–10 (on sand).<br>3 < (on rock). | Good preservation of the metal parts only. | A light covering of organogenic minerals. | Good preservation including the wooden parts. | Excellent preservation. A little wear but preservation of wood possible. | A light cover of cher cal minerals. |
| Coins | 0 < (on fossil mud or sand). | Low probability. Worn. High level of acidity. | Great difficulty in detection. Medium preservation. | Good preservation. Ionic exchange. Fe-Cu. | Worn. High level of oxidation. Good preservation of silver. | Worn. High level oxidation on face coins. |
| Bronze statuettes | 2 < (on sand or fossil mud).<br>6–7 < (on rock). | Very low probability of preservation. High level of oxidation. | Covered with calcite deposit. Develops corrosion. | Good preservation. | Worn. Some calcite patina; initial stage of corrosion. | Mostly worn, wit patina cover of calc minerals. Advance stage of corrosion. |
| Copper objects. | 0 < | Crushed. Few found, medium preservation. | Concretion to the sea bottom. | Good preservation. Possible ionising processes. | Difficulties in detection. Good preservation. Beginnings of corrosion. | Broken, with advanc corrosion. |
| Wooden objects. | 15 <<br>(With some exceptions). | Low level of preservation. Total lack of context. | Rare | Mostly in decomposed condition. | Rare | Rare |
| Iron objects | 2 < (on sand)<br>4–5 < (on rock) | Very advanced corrosion. | Corrosion. Thick cover of marine fauna, concretion and deposits. | Considerable corrosion. | Little corrosion. Thick cover of marine faunal concretion. | Developed corrosion. |
| Small pieces of pottery. | 0 < | Worn and difficult to identify. | Partly broken and covered by fauna and deposits. | Good prospects. | Worn, decomposed. Small broken pieces. | Rare and hard to dete |
| Cargo of amphorae. | 4–5 < (on Sand)<br>6–7 < (on Pebbles)<br>10–11 < (on Rock) | Single specimens covered by faunal concretion in upper part. | Worn; they tend to break. | High percentage broken into pieces, which disintegrate and tend to decompose. | Mainly worn pieces; single specimens may be found complete. | Worn; single specime in thick cover of orga ogenic material. |
| Cargo of containers (mainly amphorae) | 6–7 <<br>(on sand, rarely even shallower) | Single specimens complete. | Pieces dispersed over a large area. | Many pieces. Pottery decomposed and without faunal concretion. Most difficult to preserve. | Dispersed over large area at different stages of preservation. Mostly broken. | Dispersed over lar area. Advanced state breakage; worn a destroyed. |
| Entire cargo, including hull of vessel. | 15–20 < | Insignificant probability. | Probability close to zero. | Rare, but possible. | Rare, but possible. | Probability tending zero. |

Figure 7 Preservation in shallow waters in the Eastern Mediterranean (after Raban 1973).

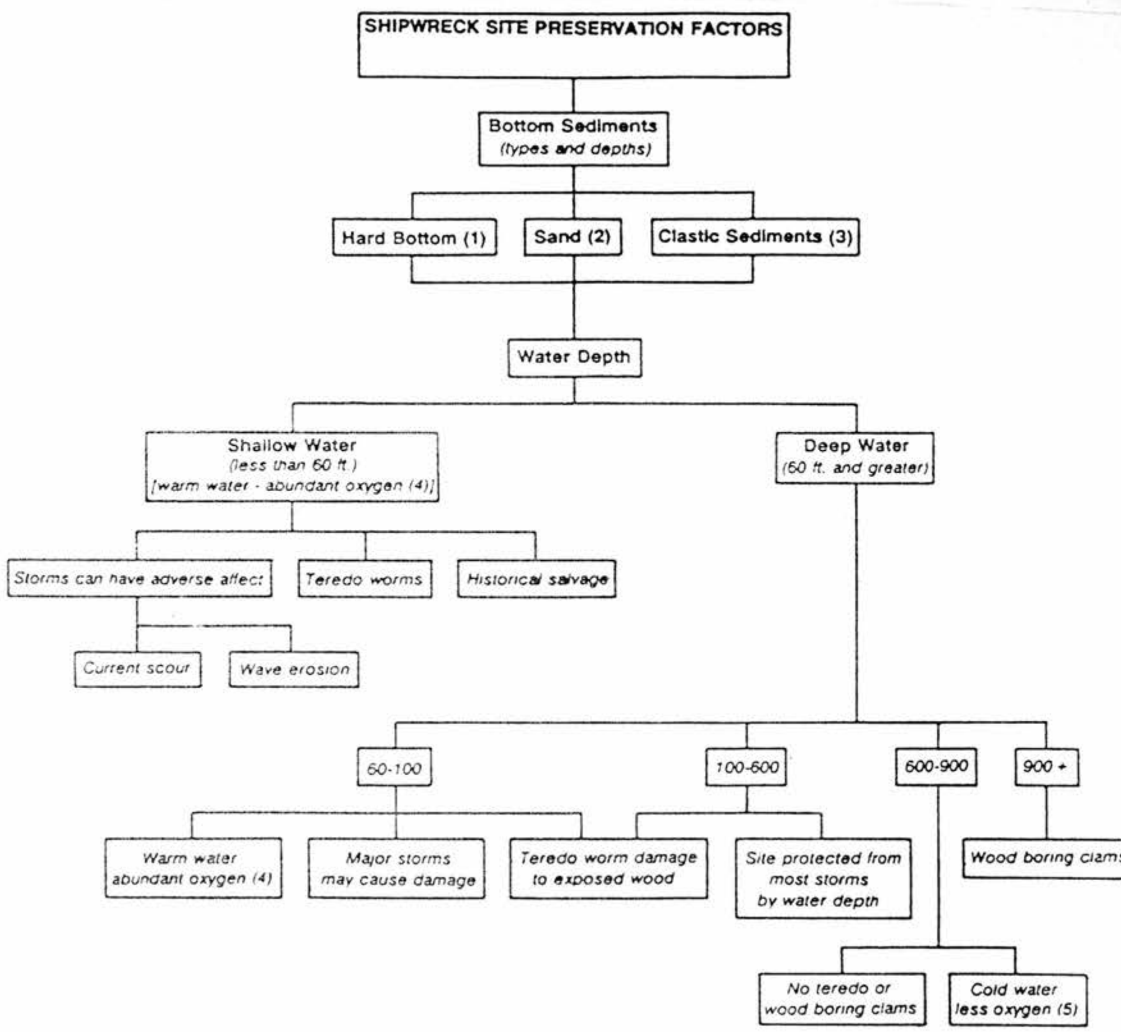



Figure 8 Shipwreck site preservation factors (after Parrent 1988).

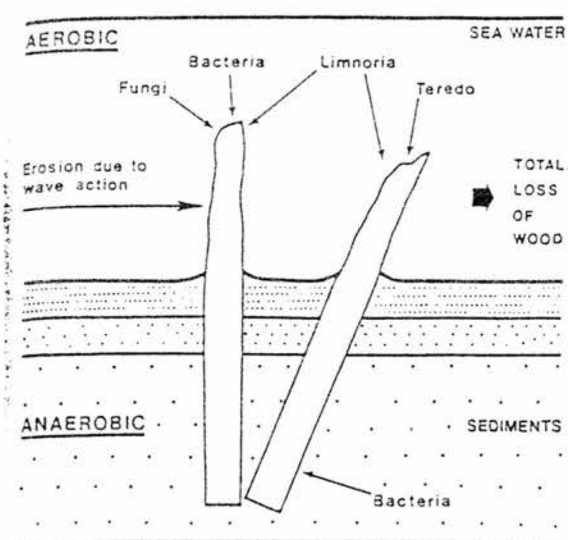



Figure 9 A typical situation of partly buried wood on the seabed (after Mouzouras *et al* 1990).

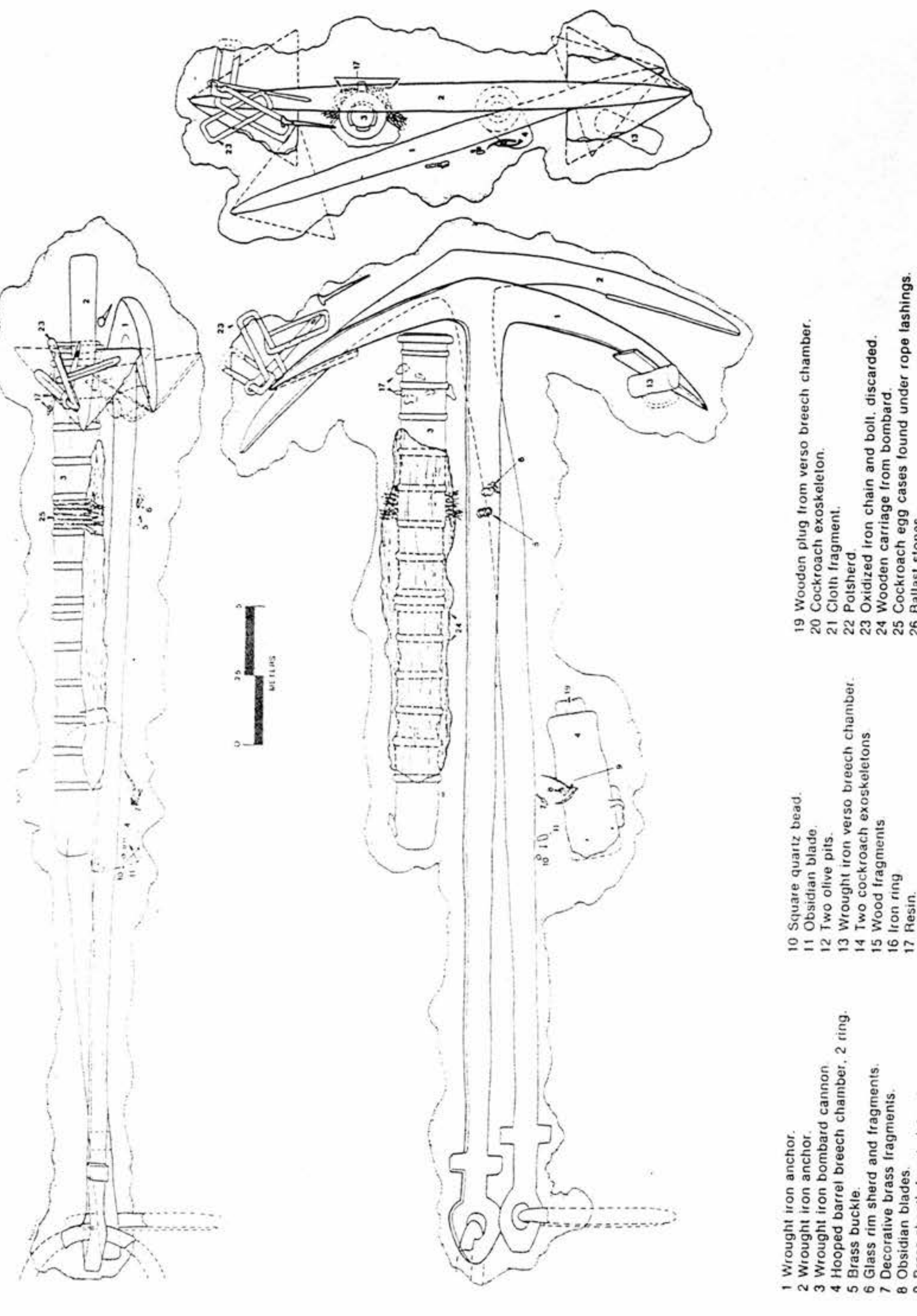



Figure 10 Artefacts from the 1554 Padre Island wrecks embedded in a large concretion (after Arnold III & Weddle 1978).

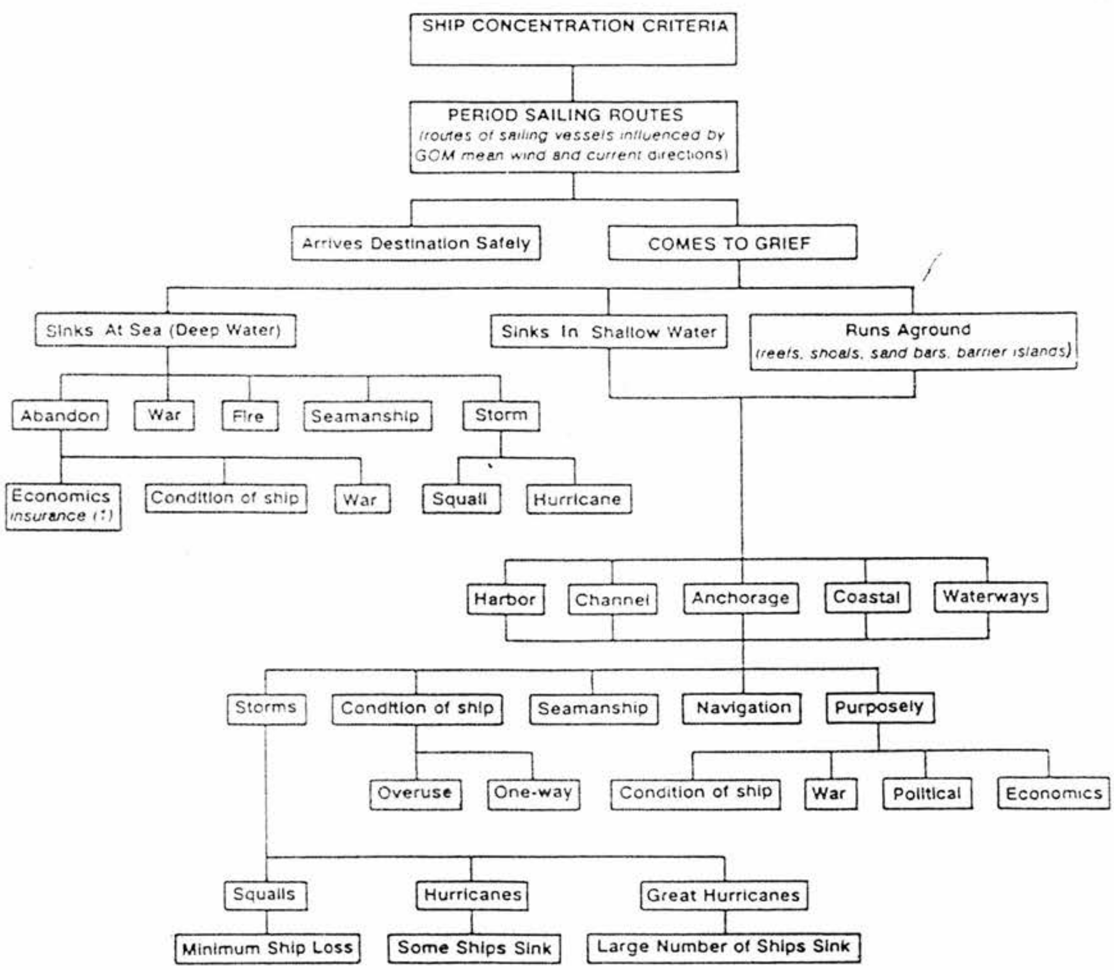



Figure 11 Shipwreck Concentration Criteria (after Parrent 1988).

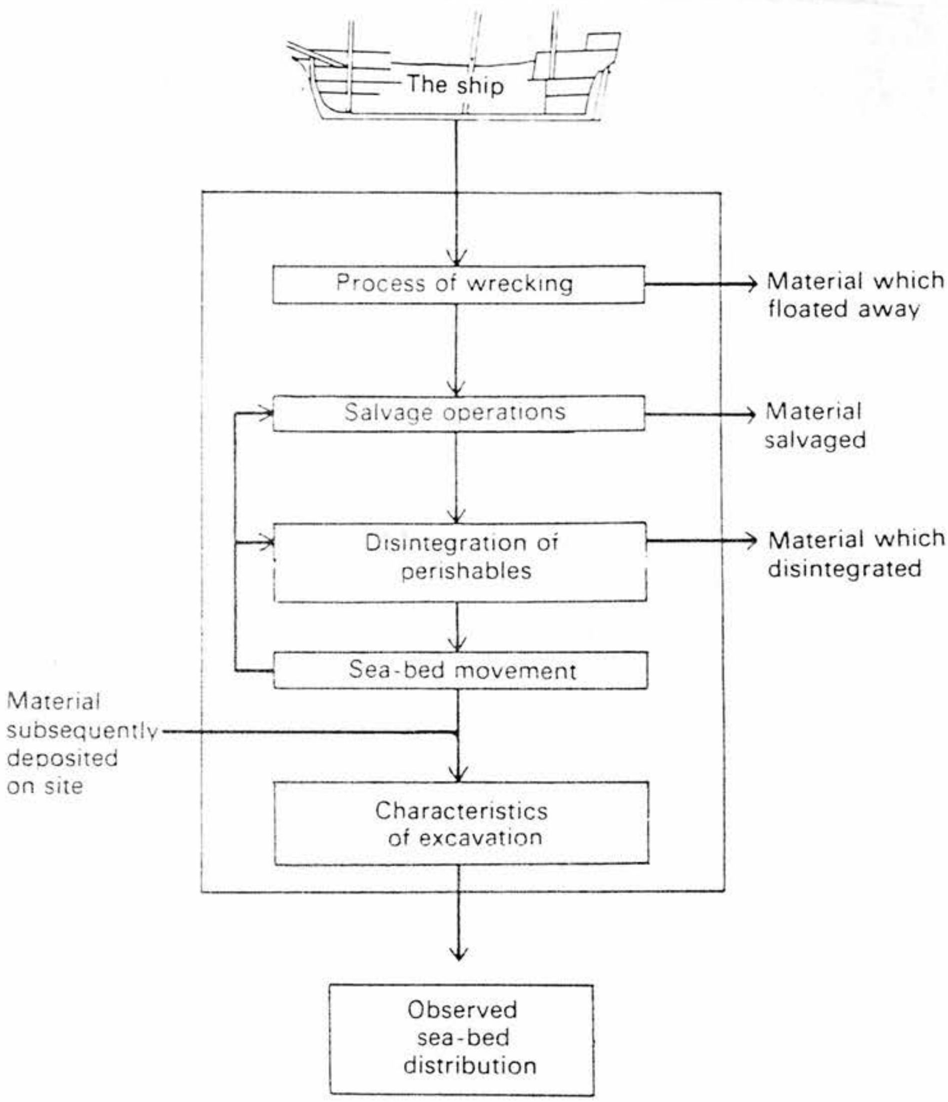



Figure 12 Flow diagram representing the evolution of a shipwreck (after Muckelroy 1978).

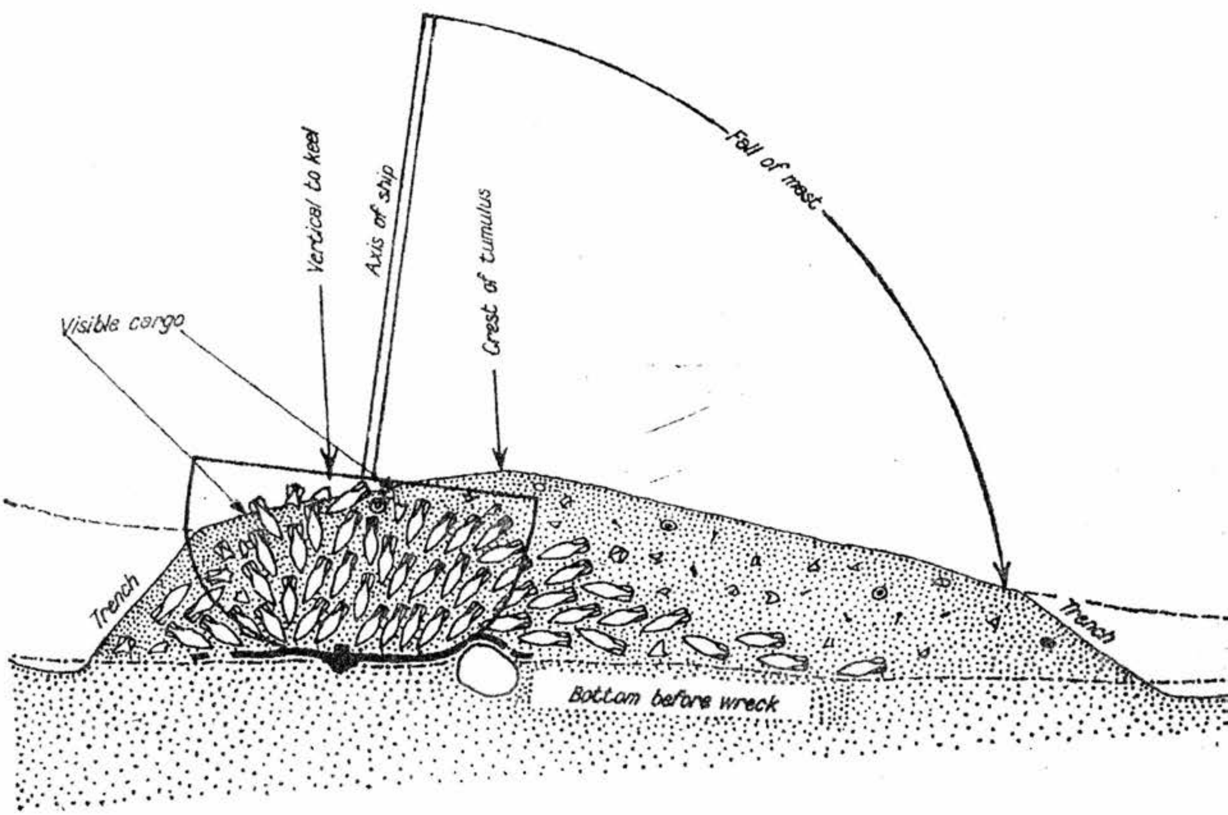



Figure 13 Schematic section showing how an amphora-carrying ship opens (after Frost 1962).

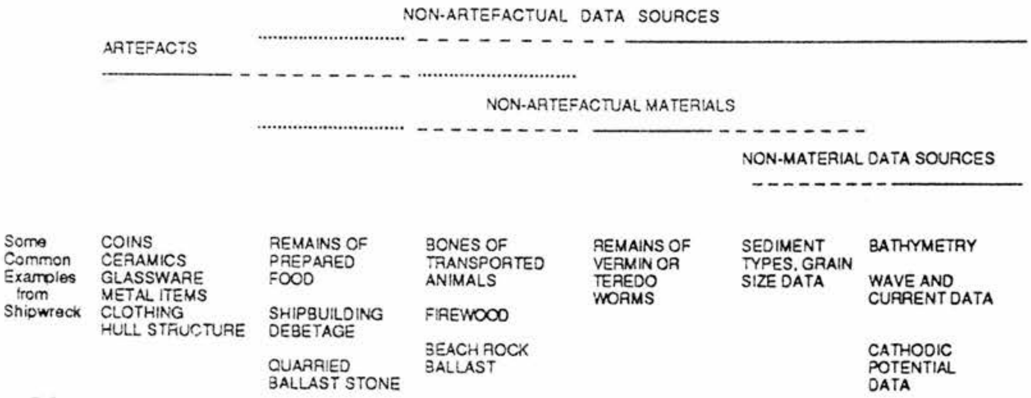
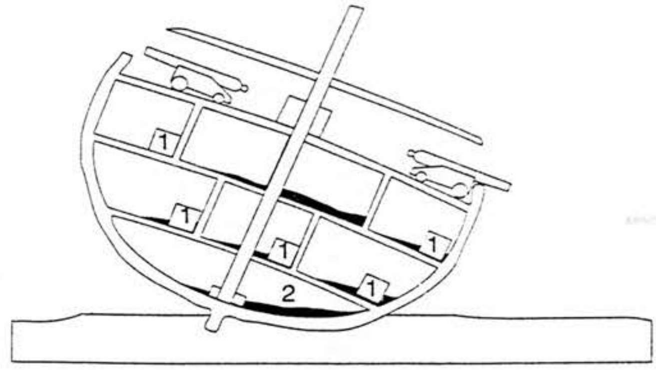
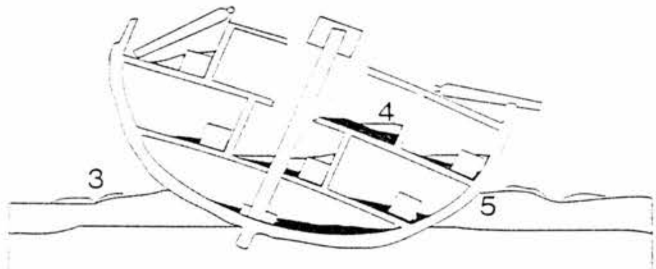


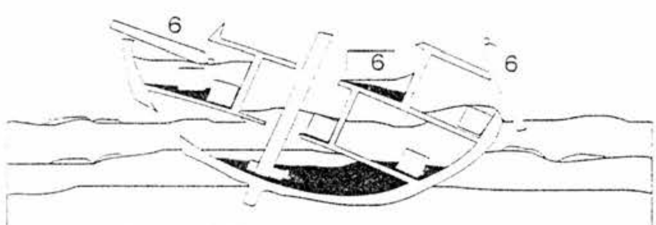

Figure 14 Diagrammatic outline of the artefact/non-artefactual/non-material data source continuum (after Kenchington *et al* 1989).



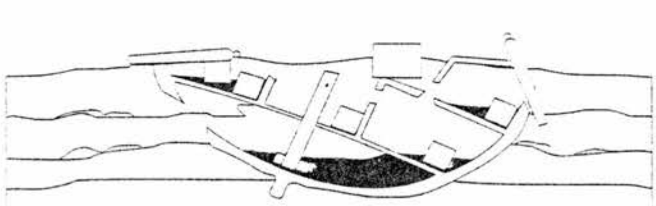

**STAGE 1.** (*Approximately 1 year after sinking*) Masts and rigging have broken off and floated away: weakened quarter—and focsle deck bulwarks have broken off and been dispersed by currents. Small artefacts accumulate in clusters against internal partitions and bulkheads (1). Gradual silting up begins as organic materials decay and fine particles are trapped within enclosed hull spaces (2).




STAGE 2 (*Approximately 1 to 10 years after sinking*) Parts of upperdeck deteriorate and collapse due to marine borer activity. Parts of upperdeck structural timbers fall away onto sea-bed (3). Currents deposit finer sediments into semi-enclosed hull spaces (4) and carry away and disperse light artefacts. Gradual sea-bed build-up occurs under and around hull (5). Fine particle build-up continues within enclosed spaces.




STAGE 3 (*Approximately 10 to 50 years after sinking*) Continuation of process started in Stage 2: more collapse of structural timbers: continuation of fine particle build-up in enclosed spaces and coarse sediment accumulation in semi-enclosed spaces. Sea-bed build-up continues around hull. Heavy iron objects—e.g. cannon and ship's oven drop down into lower areas of hull (6).



STAGE 4 (*Approximately 50 to 80 years after sinking*) Wreckage approaches stabilization. All spaces within hull filled with compacted fine or coarse sediments. Sea-bed build-up has been completed. Marine borer activity ceases due to effective cover by sediments which insulate organic material from oxygen.

Figure 15 Stages in disintegration of the *Pandora* (after Gesner 1993).

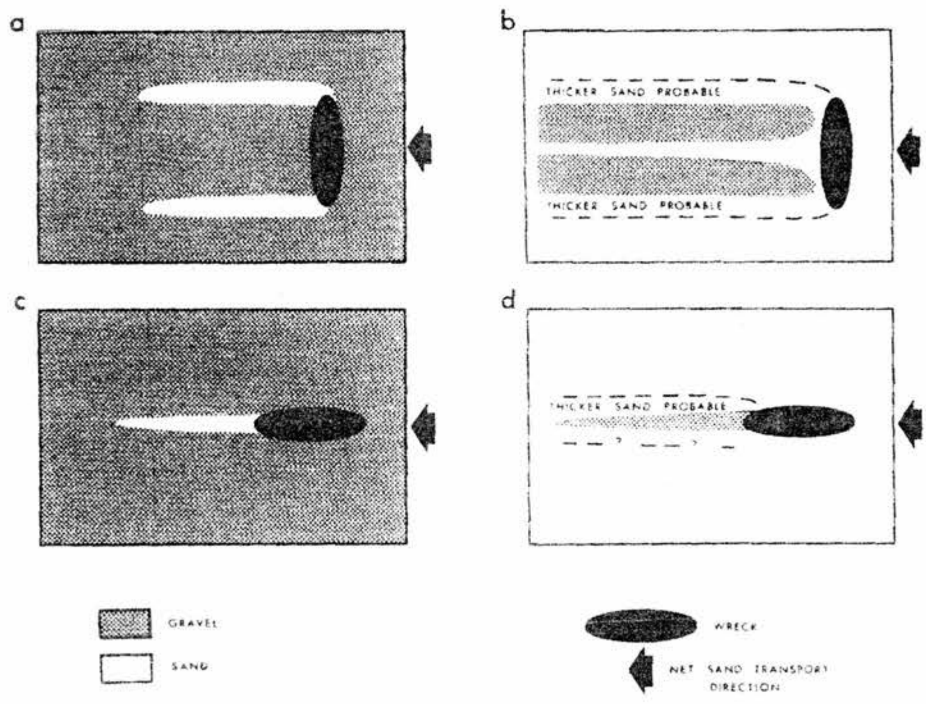
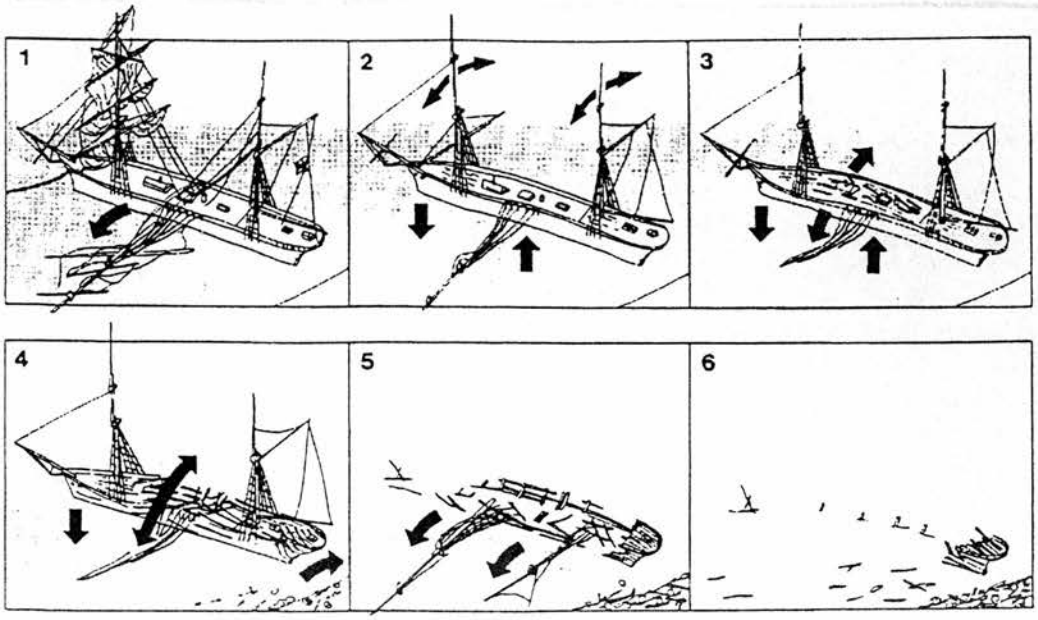
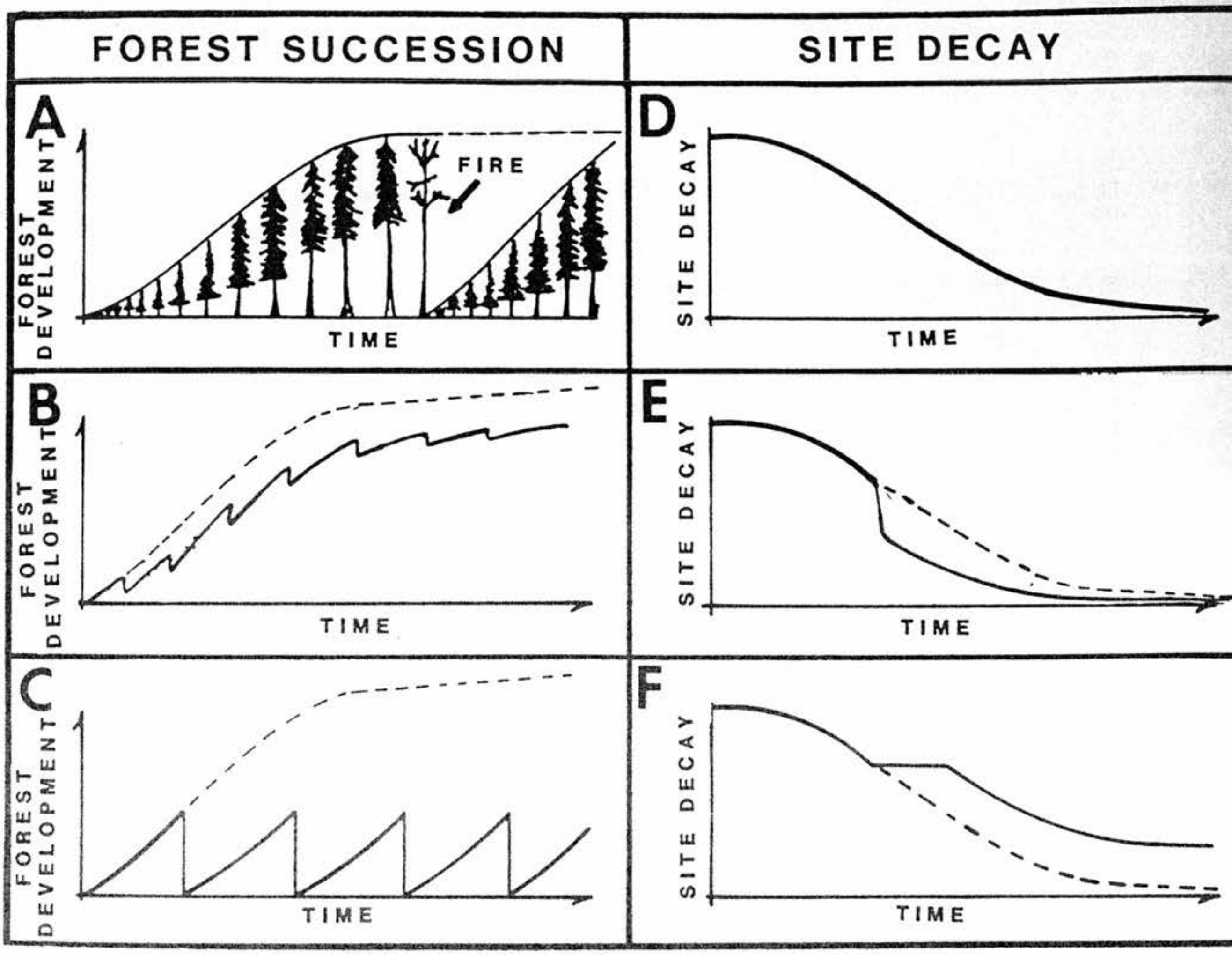



Figure 16 Diagrammatic representation of end members of the gradational series of longitudinal wreck marks (after Caston 1979).




1. The vessel struck the reef on 31 May, bumped several times over it and then settled into the sand. The mainmast went over the port side, taking with it the fore topmast and part of the mizzen. The vessel lay stern-on to the beach, slightly canted to starboard and worked quickly into the sand.
2. By 3 June, the vessel had sunk some 10 ft (3.04 m) and had taken 14 ft (4.26 m) of water in the hold. The *Queen of Nations* had now broken its back, the foremast began to sway one way and the mizzen the other. The bow started to sink as the sea made clean breaches from stem to stern.
3. By 11 June, the swaying masts had seriously strained the decks which soon began to start. The bow continued to sink and shifted from its original line, due in part to the action of waves against the starboard side. A quantity of sand had entered the hold which made salvage of the cargo difficult.
4. By 23-24 June, the vessel was beginning to break up. The hull screwed from side to side and the seas continued to make clean sweeps over the wreck, penetrating the hatches. The weakened decks soon burst open resulting in the beach becoming strewn with wreckage. The poop canted 45° to starboard.
5. On 25 June, the fore and mizzen masts broke off to port at deck level. A small portion of the stern remained intact although the wreck was now complete.
6. The forward part of the hull disappeared the following day, leaving only the point of the jib boom and a few frames above water. The poop was now canted heavily to port with cargo and wreckage widely strewn about.

Figure 17 Disintegration pattern of the *Queen of Nations* (after Smith 1992).

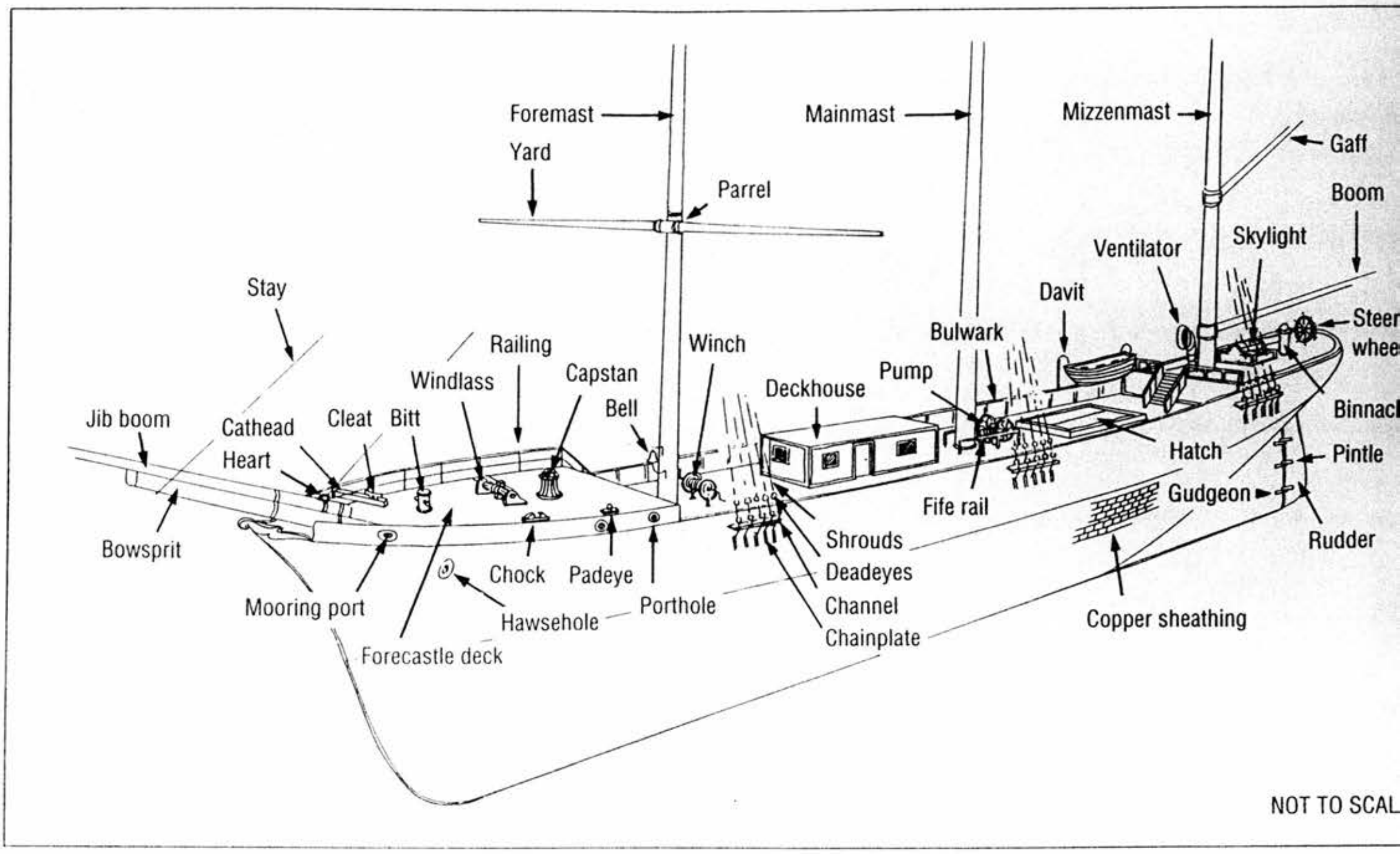


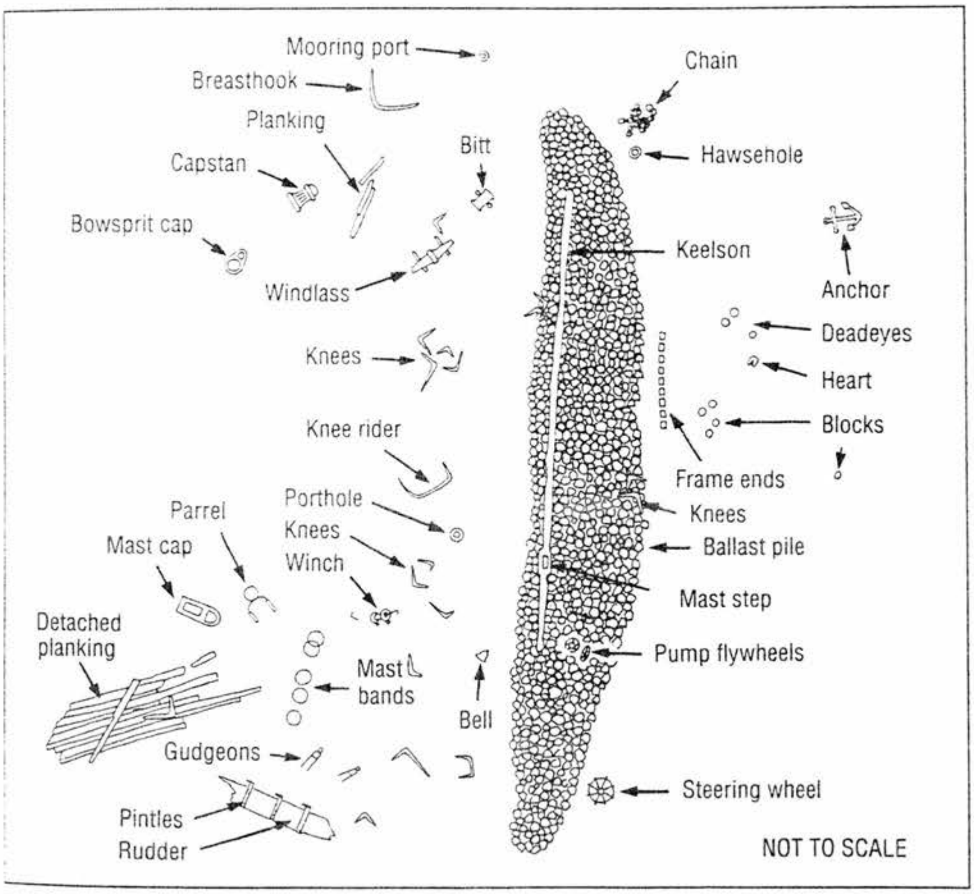

In (A) and (D), the independent variables are uniform and the process-time relationship follows a smooth curve. A significant external, independent variable, fire in (A) causes an abrupt step function change in the process-time relationship. Non-uniform or cyclic changes in the value of the independent variables cause irregular process-time relationships.

Figure 18 Schematic process-time relationship for forest succession and archaeological site decay (after Mathewson & Gonzalez 1988).

| Condition: | Perfect | Coherent | Scattered | Hull only | Unknown | Total |
|---|---|---|---|---|---|---|
| Depth: | | | | | | |
| Silted/dry land | 3 | 3 | 1 | 34 | 7 | **48** |
| Shallow (0–15 m) | 29 | 71 | 154 | 23 | 59 | **336** |
| Medium (15–30 m) | 30 | 44 | 55 | 1 | 36 | **166** |
| Deep (30–60 m) | 82 | 49 | 40 | 0 | 65 | **236** |
| Very deep (60– m) | 16 | 3 | 3 | 0 | 25 | **47** |
| Depth unknown | 10 | 12 | 22 | 4 | 308 | **356** |
| Total: | 170 | 182 | 275 | 62 | 500 | 1189 |

Figure 19 Depth and condition of recorded Mediterranean wreck sites (after Parker 1992).




Figures 20 Top: Schematic view of a typical three-masted wooden barque of the late 19th century. Bottom: A barque as a diver might find it after a century underwater (after Stone 1993).

| Environmental matrix | EROSION FACTORS | | | | | | |
|---|---|---|---|---|---|---|---|
| *(Sediment type)* | *Wave, boat wash, and wind action* | *Site located on the inside of meander bend forming part of tidal creek system* | *Site located on the outside of meander bend forming part of tidal creek system* | *Water velocity in channel controlled by slope and nature of delivery mechanism* | *Water with high carrying capacity eg in tidal channel* | *Periodic drawdown of site – daily wet/dry cycles* | *Freeze/thaw activity* |
| Well graded gravels; gravel-sand mixture; little or no fines | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Poorly graded gravels sand-gravel mixtures; little or no fines | 1 | 1 | 2 | 1 | 1 | 1 | 1 |
| Silty gravels; poorly graded gravel-sand-silt mixtures | 1 | 1 | 2 | 2 | 2 | 1 | 2 |
| Well graded sands; gravelly sands; little or no fines | 2 | 1 | 2 | 2 | 2 | 2 | 1 |
| Poorly graded sands; gravelly sands; little or no fines | 2 | 1 | 2 | 2 | 2 | 2 | 2 |
| Silty sands, poorly graded sand-silt mixtures | 3 | 2 | 3 | 3 | 3 | 2 | 3 |
| Clayey sands; poorly graded sand-clay mixtures | 2 | 1 | 2 | 2 | 2 | 2 | 2 |
| Inorganic silts and very fine sands; rock flour; silty or clayey fine sands with slight plasticity | 3 | 2 | 3 | 3 | 3 | 3 | 3 |
| Inorganic clays of low to medium plasticity; gravelly clays; sandy clays, silty clays | 1 | 1 | 2 | 1 | 1 | 2 | 2 |
| Organic silts and organic silt-clays of low plasticity | 3 | 2 | 3 | 3 | 3 | 3 | 3 |
| Inorganic silts, micaceous or diatomaceous fine sandy or silty soils; elastic silts | 3 | 2 | 3 | 3 | 3 | 3 | [illegible] |
| Inorganic clays of high plasticity | 1 | 1 | 1 | 1 | 1 | 2 | 2 |
| Organic clays of medium to high plasticity | 3 | 1 | 1 | 2 | 1 | 3 | 3 |
| Peat and other highly organic soils | 3 | 2 | 3 | 3 | 3 | 3 | 3 |

Numerical weighting predictions courtesy of Bureau of Reclamation Engineering and Research Center, USA (Adapted from Lenihan, 1981)

1=minimum impact; 2=moderate impact; 3= maximum impact

Figure 21 Relative Sediment Impact Prediction Index which relates sediment competence to a variety of freshwater erosion processes (after Long & Roberts 1997).

| IMPACT PROCESS | MODIFICATION OF ARCHAEOLOGICAL RESOURCE |
|---|---|
| PHYSICAL | |
| ***Wave action*** – increased impact energies and shock pressures. Physical breakdown and removal (swash, backwash, drift aligned) of shoreface material | Exposure/extraction – damage, alteration, destruction |
| ***Current action*** – increased attrition and abrasion of shoreface material, primarily during erosion and transport of material<br><br>***Deposition*** of sediment will eventually occur | Exposure/extraction – damage, alteration, destruction, redeposit, loss of context<br><br>Burial – protection |
| ***Suspended sediment deposition*** – increased rates of erosion will lead to increased rates of suspended sediment deposition either within the intertidal zone or offshore | Burial – protection |
| CHEMICAL | |
| ***Anaerobic conditions*** – generally associated with burial environments and tend to preserve organic artefacts<br><br>***Aerobic conditions*** – once exposed, aerobic macro- and microfauna, bacteria, and fungi rapidly attack organic remains leading to biodegradation. Metal artefacts will undergo oxidation leading to degradation | Preservation<br><br>Exposure – damage, alteration, destruction |
| ***Water chemistry*** – controlling factors include: nutrient levels, pH and salinity leading to cell degradation and breakdown of organic artefacts | Exposure – damage, alteration, destruction |
| BIOLOGICAL | |
| ***Marine borers***<br>Molluscan – *Teredo, Bankia, Martesia*<br>Crustacean – *Limnoria, Chelura* and *Sphaeroma*<br><br>***Fungi***<br>*Basidiomycetes, Merulius Lacrymans, Coniphera cerbella*<br><br>***Bacteria***<br>*Aeromonas, Pseudomonas, Acinetobacter* | Macro- and microfaunal activity tends to lead to biodegradation of organic material, with wooden structures particularly prone to cellulose and lignin breakdown |

Figure 22 Summary of impact processes and the modification of the archaeological resource for inter-tidal sites (after Long & Roberts 1997).

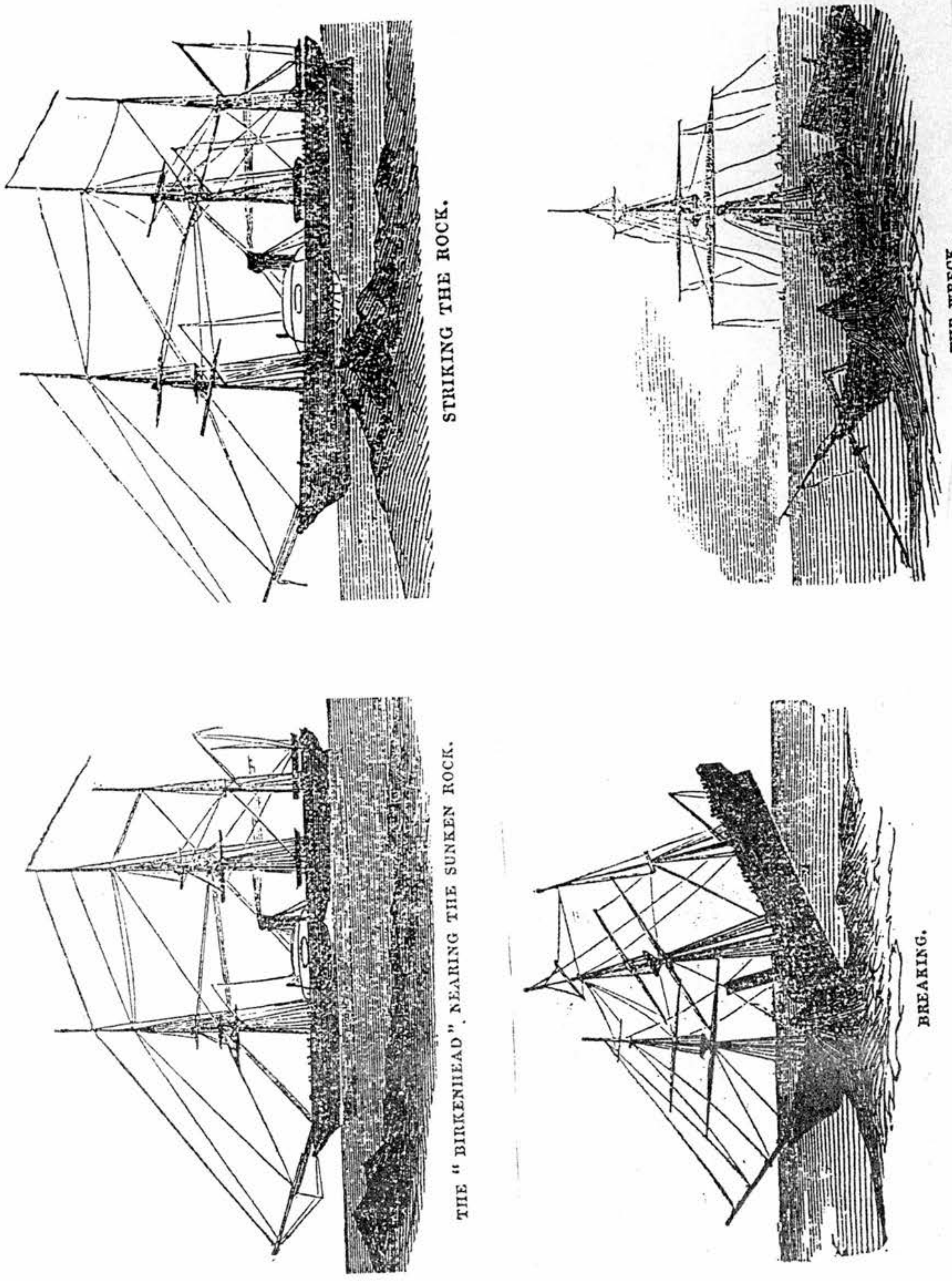
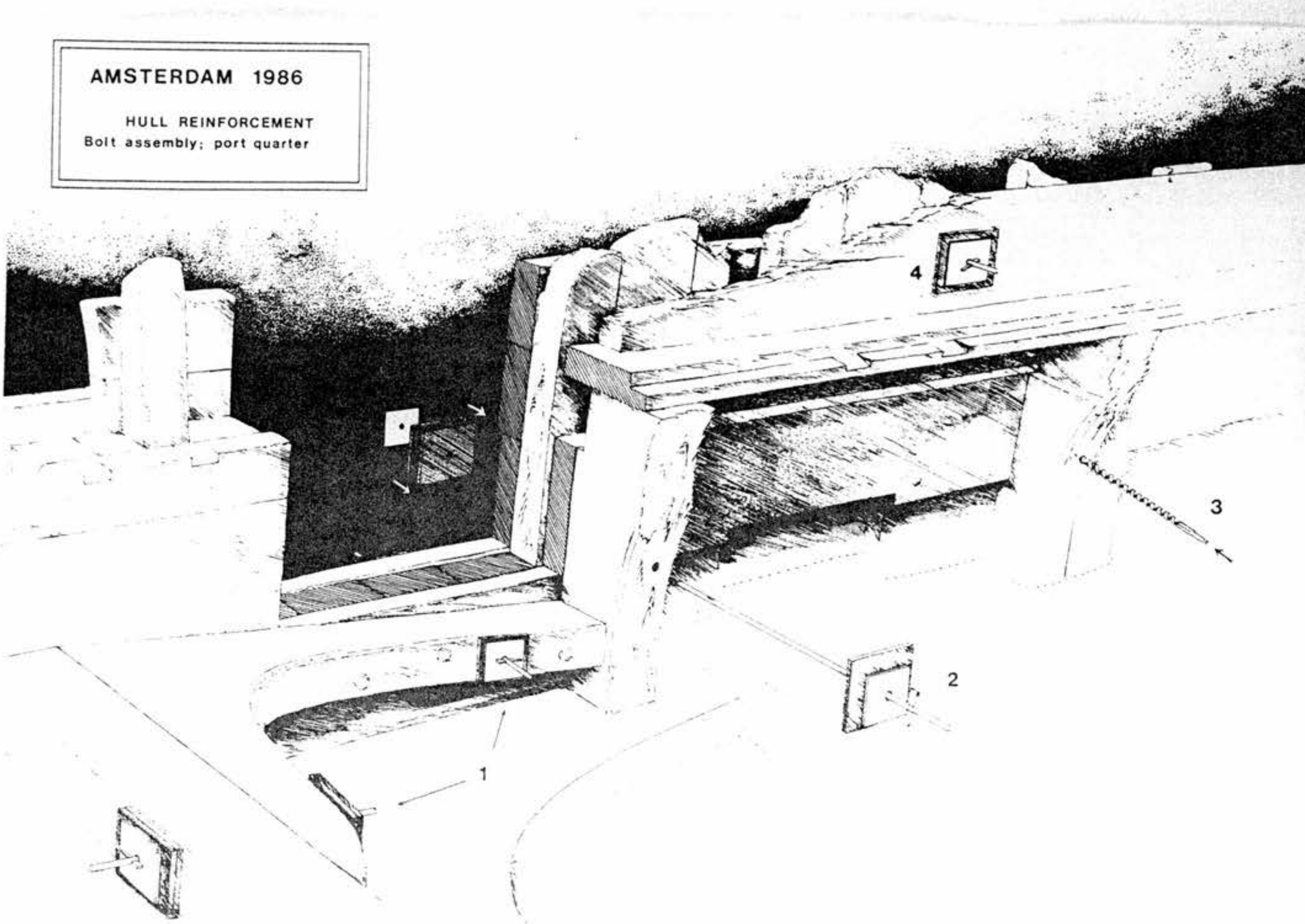



Figure 23 Mid – 19th Century depiction of the formation of a shipwreck site, the wreck of the *Birkenhead*, featured in The London News, 10th April 1852 (after Kayle 1990).




At the start of the season twelve positions were identified as priorities for reinforcement. By the end of the season sixteen positions had been bolted. Figure shows the situation on the port side at the stern. A large lodging knee has two bolts already in place, one in each arm (1). The cutaway section shows the first of a series of bolts reinforcing the hanging knees of the upper gundeck (2). The angle at which the bolthole in these knees is drilled depends partly on the factors discussed above, but was also varied in order to clamp as many of the outer planks as possible (3). Above the waterway is the first of a series of bolts through the spirketing (4).

Figure 24 Bolt assembly used for hull reinforcement of the *Amsterdam* (after Adams 1987).

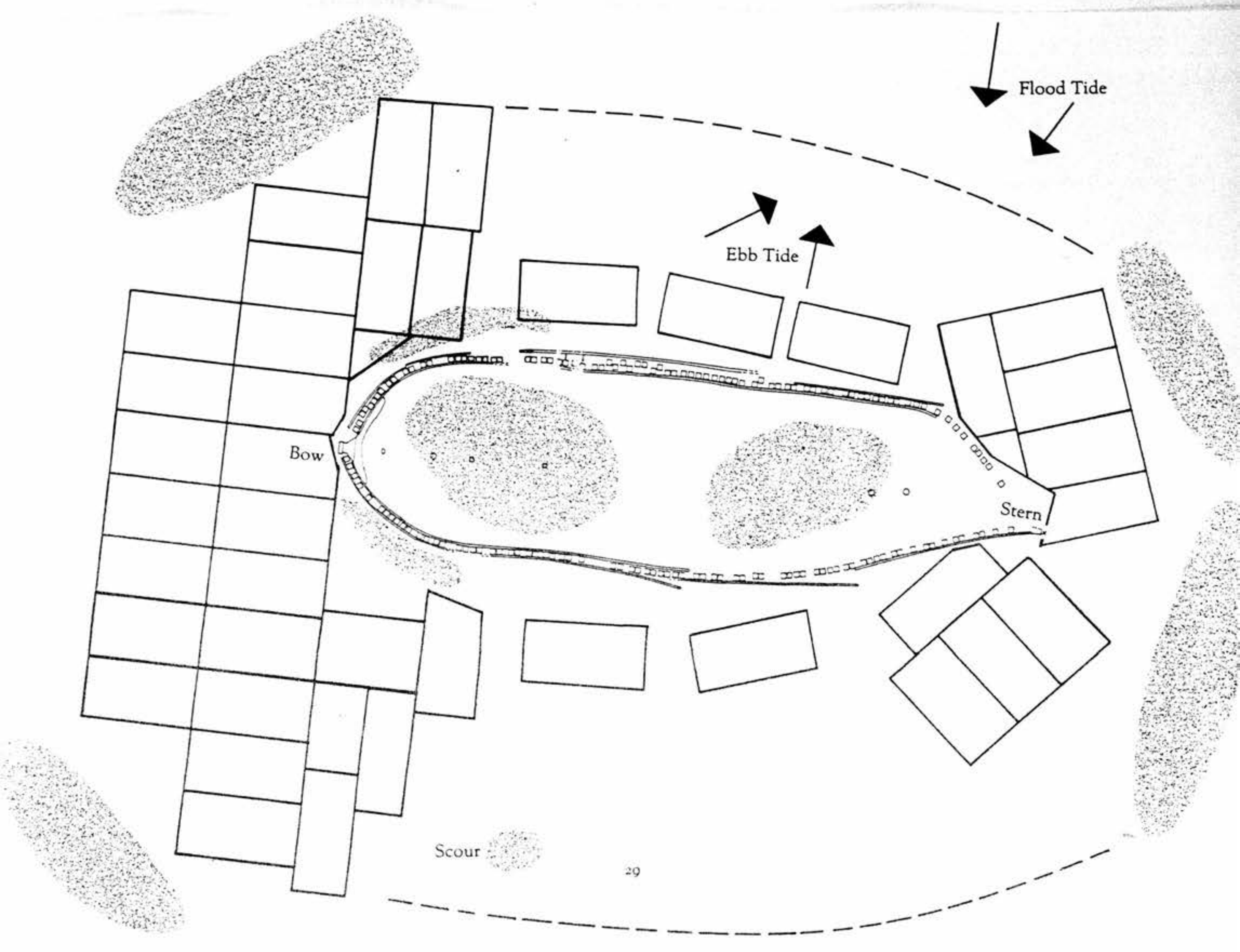
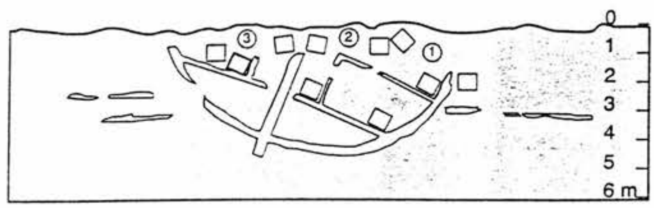
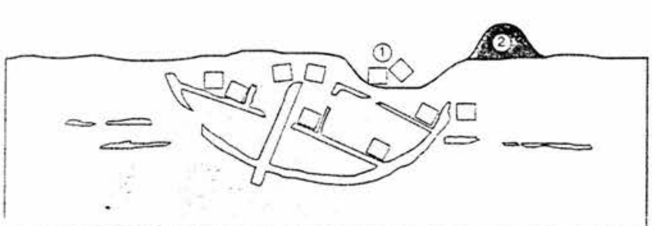


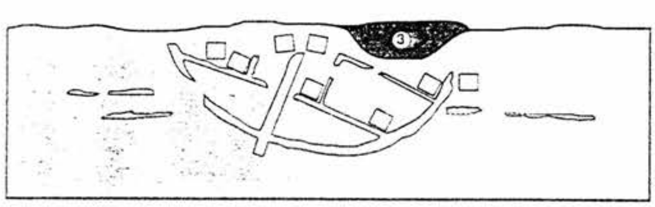

Figure 25 The layout of Cegrass mats on the *William Salthouse* site (after Elliget & Breidahl 1993).




a. Predisturbance situation: artefact assemblages (1) (2) (3) etc. and hull remains sealed from oxygenated waters by compact sediment layer of between 0.5–1 m thick.




b. Excavation of artefact assemblage (1): sediment layer gradually removed and deposited on spoil heap (2). Artefact assemblage (1) recorded in 3 dimensions and retrieved over a period of *c*. 4 to 5 weeks.




c. Back-filled excavation area (3) using sediment from spoil heap. From observation, back-fill of less compact nature and different material composition due to loss of fine sediment.

Figure 26 The alteration of archaeological deposits on a wreck site as a result of excavation and back-filling (Gesner 1993).

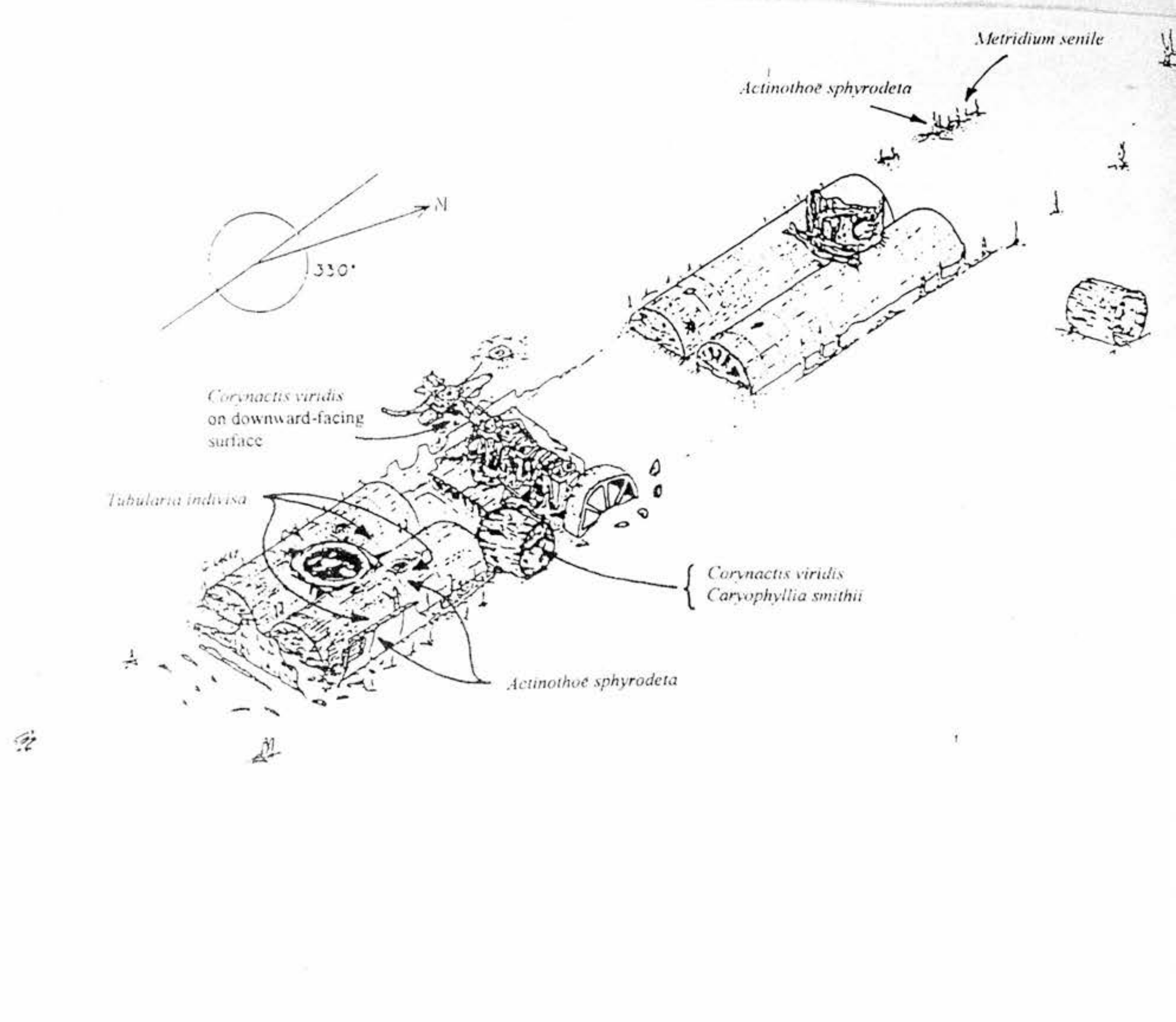



Figure 27 Location of particular biological species on the wreck of the *Iona II* (after Irving 1995).

| Item | Average value | Remarks |
|---|---|---|
| Temperature | Surface: 0°–25°C | Varies with latitude, depth, currents. |
| Pressure | Surface: 1 atm.<br>Bottom: see remarks | Pressure increases 1 atm. for each 9 m of depth.<br>Maximum pressure in ocean bottom is about 1000 atm. |
| Salinity | 35 parts per thousand | Varies from 33 to 37 parts per thousand as function of latitude; highest in tropics. |
| Ions in solution | *Constants (parts per thousand):*<br>$Cl^-$ 19.34<br>$SO_4^=$ 2.70<br>$Na^+$ 10.72<br>$Mg^{2+}$ 1.30<br>$Ca^{2+}$ 0.42<br>$K^+$ 0.38 | Not appreciably affected by organisms; variations introduced near river mouths, etc. |
| | *Variables (parts per million):*<br>Phosphorus 0.001–0.1<br>Iron 0.002–0.02<br>Silicon 0.02–4.0<br>Manganese 0.001–0.01 | Strongly affected by biologic activity. |
| Dissolved gases | *Oxygen:*<br>Surface: 6 cc/l<br>Bottom: 1 cc/l at depth of 610 m | Varies from about 4.9 to 9.0 cc/l. |
| | *Carbon dioxide:*<br>Surface: 46 cc/l<br>Bottom: variable (usually complement of $O_2$) | Surface water in equilibrium with atmosphere; amount at depth a function of photosynthesis, etc. |
| | *Hydrogen sulphide:*<br>Surface: nil<br>Bottom: nil | Usually not present in open-circulation conditions. |
| Hydrogen-ion concentration (pH) | Surface: 8.2<br>Bottom: 7.8 | Ranges from 7.5 to 8.4. |
| Oxidation-reduction potential (*Eh*) | Surface: 0.2–0.4<br>Bottom: 0.1–0.3 | Seawater is mildly oxidizing throughout. |

| Item | Average value | Remarks |
|---|---|---|
| Temperature | Surface: 16°C<br>Bottom: 6°C | Values apply to Norwegian fiords: higher values in tropical basins. |
| Pressure | See Table 1.12 | |
| Salinity | Surface: 19 parts per thousand<br>Bottom: 30 parts per thousand | Probably a wide variation from near-fresh waters at surface to normal salinity at depth. |
| Ions in solution | *Constants:*<br>Relative proportions of ions may remain the same as in Table 1.12, except for $SO_4^=$ conversion to $S^=$ | |
| | *Variables:*<br>Phosphate ion usually high: 0.3 mg/l in fiords | |
| Dissolved gases | *Oxygen:*<br>Surface: 6 cc/l<br>Bottom: nil | |
| | *Carbon dioxide:*<br>Surface: 46 cc/l<br>Bottom: 46 + cc/l | |
| | *Hydrogen sulphide:*<br>Surface: nil<br>Bottom: 9.14 cc/l | Maximum observed in fiords 40 cc/l. |
| Hydrogen-ion concentration (pH) | Surface: 8.0<br>Bottom: 7.0 | Some fiords show pH less than 7.0 near bottom, indicating definitely acid conditions. |
| Oxidation-reduction potential (Eh) | Surface: 0.1<br>Bottom: −0.3 | |

Figure 28 Top: Characteristics of the normal open-circulation environment
Bottom: Characteristics of the restricted humid (anoxic) environment (after Florian 1987).