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Mapping Navigational Hazards as Areas of Maritime Archaeological Potential:

The effects of sediment type on the preservation of archaeological materials

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Title:
Mapping Navigational Hazards as Areas of Maritime Archaeological Potential:
The effects of sediment type on the preservation of marine archaeological materials

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Summary:
The Conservation Department of the National Museum of Denmark was contracted to contribute to Bournemouth University's *Mapping Navigational Hazards as Areas of Maritime Archaeological Potential* research project, funded by the English Heritage Archaeological Commissions Program under the Aggregate Levy Sustainability Fund. As part of this project, a sediment model was to be developed using sediment maps from the British Geological Surveys offshore *Digital Geological Map of Great Britain (DigSBS250)*. These sediment maps are broadly divided up into 15 different sediment types based on a modified Folk Classification (1954) with 11 additional classifications for seabed sediments that are absent or undifferentiated, and areas where other seidment calssification shcemes have been adopted (non-UK) waters. The different sediment types in this classification were given a ranking in terms of their possible effects on preservation of submerged archaeological materials. The limitations of the sediment ranking are discussed in terms of general deterioration processes affecting submerged archaeological sites and future developments of the GIS model.

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Table of Contents

1. Introduction

The Conservation Department of The National Museum of Denmark was contracted to contribute to Bournemouth University's *Mapping Navigational Hazards as Areas of Maritime Archaeological Potential* research project, funded by the English Heritage Archaeological Commissions Program under the Aggregate Levy Sustainability Fund.

The overall aim of the pilot study was to create a GIS based model which sought to use the extensive archives, including charts, sailing directions and pilotage notes, and modern seabed geology mapping to identify and map Areas of Maritime Archaeological Potential (AMAP), areas where high potential for shipwreck losses coincide with areas of high preservation potential (Merritt et al., 2006, page 3).

As part of this, a sediment stability model was to be developed. The National Museum of Denmark should make a "geological statement" (Merritt et al., 2006, page. 12) on the preservation conditions of sediments encountered around Britain, which could be incorporated into the GIS model. The British Geological Survey's *Digital Geological Map of Great Britain (DigSBS250)* was used for the model and the author was provided with the 1:250 000 scale information. The *Sea Bed Sediment theme* (SBS) provides information on the lithology of the offshore sediment types, based on a modification of Folks (1954) classification plus additional classifications.

The deterioration of shipwrecks is complex involving many processes, of which sediment typology is just one parameter. Nevertheless the overall project is an holistic approach to understanding the formation of archaeological sites. To this end, development of a robust GIS model incorporating many kinds of data is an ambitious yet innovative undertaking. The use of the BGS sediment typology data is a good starting point in this development yet should be used cautiously, as will be discussed. This report provides a simple classification of the sediment types of the DigSBS250 maps in order of the likelihood of them providing preferential preservation of archaeological materials. A rationale for this classification is given along with its limitations and suggestions for future development of the GIS model.

2. British Geological Survey's Digital Geological Map (DigSBS250)

The Sea Bed Sediments (DigSBS250) theme is a map of offshore sediment types and their distribution around Great britain. It is pertinent at the outset to note the potential limitations of these data when considering the implications for their preservation of archaeological materials in the marine environment. As noted by the BGS in their supporting documentation:

- Most recent sediments commonly form a **veneer** on the sea bed, i.e the sediment types presented may not be representative of the overall stratigraphy in an area.
- The map is based on seabed grab samples of the top 0.1m, combined with cores and dredge samples **as available**.

The BGS data are available as a series of colour coded maps, where the boundaries between different sediment types shown on the map are generally transitional and have been drawn taking bathymetry and other factors, such as tidal currents, into consideration. A typical example is shown in Figure 1

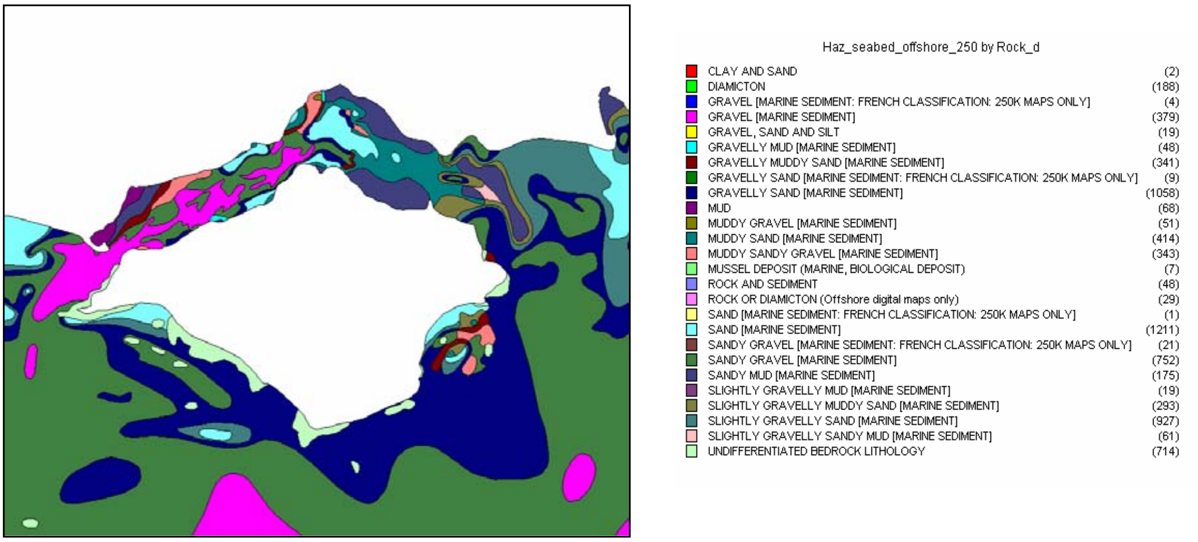


Figure 1: BGS map of sediment classification around the Isle of Wight, England
© British Geological Survey

Classification of the sediment types is based on a modified Folk ternary diagram (1954), whereby mud – sand-gravel grain size distributions are divided into 15 discrete categories as shown in Figure 2 and Table 1.

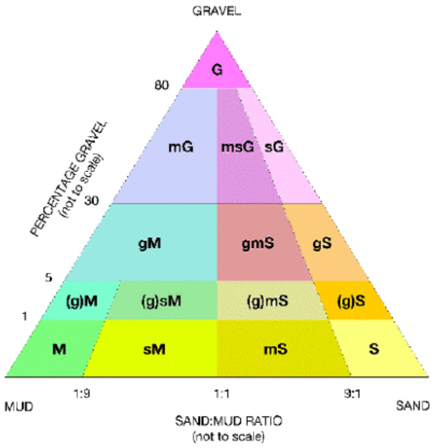


Figure 2: Modified Folk (1954) ternary diagram of mud-sand-gravel sediments

Folk Classification (Modified)	**Lithology Description**
M	Mud
sM	Sandy Mud
mS	Muddy sand
S	Sand
(g)M	Slightly Gravelly mud
(g)sM	Slightly gravelly sandy mud
(g)mS	Slightly gravelly muddy sand
(g)S	Slightly gravelly sand
gM	Gravelly mud
gmS	Gravelly muddy sand
gS	Gravelly sand
mG	Muddy gravel
msG	Muddy sandy gravel
sG	Sandy gravel
G	Gravel

Table 1: Lithology of modified Folk ternary diagram.

The modified Folk classification uses the collective term “mud” to describe the texture of fine-grained (particle size < 0.053mm), mainly non-biogenic sediments that essentially consist of a mixture of silt and clay (Schulz and Zabel, 2000). Furthermore sands and gravels include a wide range of sediments from very fine to very coarse sands in the former (particle sizes 0.0625 – 1.68mm) and granules, pebbles, cobbles and boulders in the latter (particle sizes 2 – 4096mm) (Leeder, 1982).

Apart from the Folk classifications, there are also areas where seabed classifications are absent or undifferentiated, and areas where other sediment classification schemes have been adopted (non-UK waters) as listed in Table 2.

Additional Classifications	Comment
Clay and sand	Pre-Holocene deposit
Diamicton	Pre-Holocene deposit
Gravel (Marine sediment: French classification)	
Gravel, sand and silt	Unclassified
Gravelly sand (Marine sediment: French classification)	
Mussell deposit	
Rock and sediment	Undifferentiated
Rock or Diamicton	Pre-Holocene deposit
Sand (Marine sediment: French classification)	
Sandy Gravel (Marine sediment: French classification)	
Undifferentiated mud	Undifferentiated

Table 2: Additional classifications used for Sea Bed Sediment classification

Before ranking the BGS sediment types in order of their effects on preservation, a brief overview of the preservation of archaeological materials will be given. This will give a better understanding of the rationale in the ranking of the sediment types that follows.

3. The preservation of archaeological materials in marine environments

When a shipwreck, or other maritime structure, is deposited or submerged in the marine environment, its' physical survival is primarily dependent upon whether it comes to lie on or within the seabed. Should it lie exposed to seawater, it may be attacked by wood boring organisms. Even in the absence of these organisms' saprotrophic organisms, that is to say bacteria, fungi and protozoa, which utilise non-living organic material, will still cause deterioration. In the event of the wreck sinking into the seabed or being covered due to sediment transport, deterioration will still occur, albeit it at a slow rate, due to the activity of saprotrophic organisms. The rate of deterioration in sediments will be generally much slower due to the absence of dissolved oxygen, which is rapidly depleted by microbial activity. However even in the absence of oxygen other chemical species in the marine environment, such as sulphate and methane, will be utilised by saprotrophic micro-organisms.

This section considers the fate of archaeological material when it is deposited in the marine environment in terms of the likelihood of settling on or within the seabed, effects of sediment transport and biological processes of deterioration in open seawater and buried environments.

3.1 Physical post depositional processes

3.1. Settling on or within the seabed: Bearing capacity of sediment

The physical properties of marine sediments depend on the properties and arrangement of the solid and fluid constituents. Generally speaking, sediment is a collection of particles – the sediment grains- that are loosely deposited on the seafloor. The voids between the sediment grains – the pores – form the pore space. In water saturated sediments it is filled with pore water. Porosity describes how densely the sediment is packed. It is defined by the ratio:

$$\phi = \frac{V_p}{V_m}$$

where V_p is the non-solid volume (pores and liquid) and V_m is the total volume of material, including the solid and non-solid parts. Unconsolidated deposits, as we are dealing with here, have the following porosities: Gravel 0.25-0.4; Sand 0.25-0.50, Silt 0.35 – 0.50 and Clay 0.40 –0.70. That is to say that gravels and sands are less porous than silts and clays. On the other hand permeability; the ability to transmit fluids, is high for gravels and sands and low for silts and clays because of the differences in pore size. Porosity and permeability are amongst the sediment parameters that affect the ability of sediment to support a load; termed its bearing capacity. Although the data shown in Table 2 (British Standards: BS8004: 1986) is for the bearing values of various undrained soils (not necessarily waterlogged) they indicate that the finer grained and less compacted the material the lower the bearing capacity.

Category	**Types of soil**	**Presumed bearing value**
Non-cohesive soils	Dense gravel or dense sand and gravel	>600 kN/m²
	Medium dense gravel, or medium dense sand and gravel	<200 to 600 kN/m²
	Loose gravel, or loose sand and gravel	<200 kN/m²
	Compact sand	>300 kN/m²
	Medium dense sand	100 to 300 kN/m²
	Loose sand	<100 kN/m² *depends on degree of looseness*
Cohesive soils	Very stiff bolder clays & hard clays	300 to 600 kN/m²
	Stiff clays	150 to 300 kN/m²
	Firm clay	75 to 150 kN/m²
	Soft clays and silts	< 75 kN/m²

Table 2: Bearing capacity of undrained sediment

In the terms of UK wrecks, the *Amsterdam* (1749) (Figure 3) is a fine example of how, in the right circumstances, a ship can sink relatively deeply within sediments.

Figure 3: The wreck of *Amsterdam* (1749), which sank to the upper gun ports

Marsden eloquently describes the sinking of the ship into the beach at Hastings, "…it was only then that the thick layer of clay just below the sand was discovered. This yielded under the pressure of the ship itself, her 150 tons of ballast, and the water that filled her decks. As she sank lower, sand washed in with the water and ultimately came to fill her interior completely, and it is this sand alone that becomes a true "quicksand" when disturbed by digging" (Marsden, 1974; 69). Boreholes and probes taken in the sediment around the wreck site indicated that the ship was lying in a thick bed of clay, with its bottom resting at a depth of eight to nine metres, on a bed of sandstone.

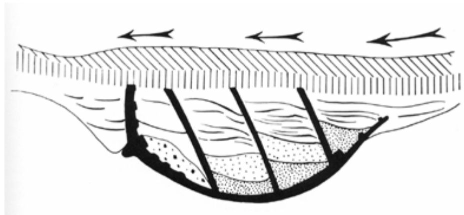
3.1.2 Sediment Transport

Even if archaeological material is deposited within sediment, localised currents, either tide or wind induced, may be sufficient to transport sediments, which may result in further covering (or uncovering) of archaeological remains. The ability of a sediment type to be transported is dependent upon its grains size and the strength of the current acting upon them - the finer grained the sediment, the more easily it will be transported. The effects of sediment transport on a wreck site in the UK can be illustrated by the *Mary Rose* (1545), the formation of the wreck site being described by Rule (1982; 44-45) and repeated here:

"After the ship sank, it lay on its starboard side at 60 degrees from the vertical and current born silt was deposited in the relatively calm water within the hull. The ship lay broadside to the strongest currents that run from the east and from the west interspersed by minor currents from the northeast and southwest. As these currents hit the hull exposed above the seabed, they vortexed and eroded a deep wide scour pit on the port side and a narrow scour pit on the starboard side of the hull. The starboard scour pit quickly filled with silt and young oysters, which had settled on the exposed hull, were smothered and killed. The portside scour pit remained open for much longer and the planks and frames were thinned and weakened by the abrasive action of the silt laden currents."

"After a period of time, the exposed structure became so weak that it collapsed downwards, filling the scour pits and thereafter only small secondary scour pits were formed around the ends of the deck beams and the tops of the eroded frames."

"A hard layer of shelly clay was deposited over the site, sealing the Tudor levels, some time in the late seventeenth century or early eighteenth century and above this a mobile "modern" seabed was formed which was wholly or partially removed from time to time. It was probably as a result of these temporary exposures that the Mary Rose was discovered in 1836 and rediscovered in 1971."



3.2 Biological post depositional processes

The major threat to organic materials, particularly wood, left exposed in the marine environment is the action of wood boring mollusca and crustacea. These organisms are active around the majority of the UK coastline (almost ubiquitous) and require dissolved oxygen in the seawater for their respiration – without this they cannot survive. Near-shore sediments are often bereft of dissolved oxygen, i.e. anoxic, due to the action of micro organisms and it is this fact that prevents wood boring organisms attacking organic archaeological materials buried within the seabed. Even though micro organisms utilise dissolved oxygen, normally within the upper millimetres to decimetres of most sediments, they use this oxygen as part of a process to oxidise organic matter. Furthermore, oxygen is only one of a range of chemical species used by micro organisms in sediments as part of their respiration. Therefore even in the absence of oxygen, deterioration (oxidation of organic matter) will occur but at a much slower rate. In microbial respiration, the aforementioned chemical species are termed electron acceptors and their utilisation within sediments occurs sequentially with increasing sediment depth. Close to the sediment surface (the oxic zone), dissolved oxygen is usually transported from the bottom water into the sediment either by molecular diffusion or, biological activity (bioturbation) or advection and is the first electron acceptor to be utilised. Below the oxic zone (i.e. the zone where all oxygen has been used) the following electron acceptors are utilised sequentially:

manganese oxides, nitrates, iron (III) oxides and hydroxides and sulphates. This sequence of utilisation yields ever-decreasing amounts of energy for the bacteria. Below the sulphate zone methane fermentation occurs and this reaction yields the lowest amount of energy.

All these processes are directly or indirectly connected with the deterioration of organic matter. This organic material is primarily produced by algae in the euphotic zone of the water column by photosynthesis but other organic matter such as dead plant and animal matter and culturally produced debris (including archaeological materials) in sea water will be incorporated into the sediment where it becomes one of the driving force for microbial activity. Thus the organic content of a marine sediment – of any type – will have an effect on the metabolism of micro organisms and the preservation potential of archaeological material. It is hypothesised that the higher the organic content of the sediment (certainly those sediments overlying a wreck site), the better the preserving effects of the sediment. The *Mary Rose* serves as a suitable example to illustrate this; the deposits overlying and capping the wreck and the Tudor seabed contained numerous lenses of seaweed and the organic content of the sediment was determined to be between 7 and 8% (Jones, 2005; 25). Although profiles of the above electron acceptors were not measured in the *Mary Rose* sediments, measurements in sediments with an organic content of approximately 6% from the Baltic, showed that all dissolved oxygen and sulphate had been utilised within the top 5 – 10cm of sediment and thus thereafter methane fermentation was the predominant process (Matthiesen et al, 1998). As noted above methane fermentation yields the lowest amount of energy and is a slow process.

Research assessing the total numbers of saprotrophic bacteria (those that utilise non-living organic matter) in sediments of different grain size has shown that the finer grained the sediment the higher the saprotrophic bacterial content (Table 3).

Sediment	**Grain size (μm)**	**Water content (%)**	**Saprotrophic Bacterial count ($x\ 10^3\ g^{-1}$)**
Sand	50-1000	33	22
Silt	5-50	56	78
Clay	1-5	82	390
Colloidal	<1	>98	1510

Table 3: Relationship between particle size and saprotrophic bacterial numbers (after Rheineheimer, 1992).

Particularly low saprotrophic numbers have been found in constantly disturbed sands where organic material cannot accumulate. The highest numbers of bacteria and fungi are almost always found in the top few centimetres of the sediments, and mostly on their surface. Even 10cm below the surface, the numbers of bacteria are, not infrequently, already reduced to a few percent; below 100cm from the sediment surface, the total bacterial and saprotrophic numbers hardly change over the next several meters. However, where the sediments are layered unevenly zones of low bacterial content may be followed by others with a high one, though only within the top 100cm (Rhenheimer, 1992; 105) These results should be considered with caution as the source of the data does not quote the organic content of the sediment or the depths of the sediment samples; both of which, as has been discussed, have an effect on the bacterial population.

4. Classification of sediment in terms of preservation of archaeological material

To summarise the potential limitations of the BGS data:

- Only information of the top 10cm of sediment.
- No information on the thickness / stratigraphy to underlying bedrock.
- No indication of current data which may induce sediment transport
- Chemical composition (for instance organic content) of sediments is unknown

Nevertheless, the 15 types of sediment in the Folk ternary diagram and the 11 additional classifications used by the BGS were graded as shown in Table 3:

Lithology Description	Folk Classification (Modified)	Gravel (%)	Theoretical Grade of preservation
Mud	M	1	1
Undifferentiated Mud			1
Sandy Mud	sM	1	2
Muddy sand	mS	1	3
Clay and sand			3
Sand	S	1	4
Sand			4
Slightly Gravelly mud	(g)M	5	5
Slightly gravelly sandy mud	(g)sM	5	6
Gravel, sand and silt			6
Slightly gravelly muddy sand	(g)mS	5	7
Slightly gravelly sand	(g)S	5	8
Gravelly mud	gM	5-30	9
Gravelly muddy sand	gmS	5-30	10
Gravelly sand	gS	5-30	11
Gravelly sand			11
Muddy gravel	mG	30-80	12
Muddy sandy gravel	msG	30-80	13
Sandy gravel	sG	30-80	14
Sandy gravel			14
Gravel	G	80	15
Gravel			15
Mussell deposit			16
Diamicton			17
Rock and sediment			18
Rock or Diamicton			19

Table 4: Grading of the BGS sediment data (Text in blue denote the additional classifications)

The rationale for ranking the sediment types is essentially based upon their particle size. Thus sediment types with a higher proportion of finer grained sediments, and conversely lower proportion of coarser grains, offer the best preservation. As has been discussed this is because they tend to have lower bearing capacities and thus may envelope archaeological materials more readily. Finer grained sediments are also more mobile in the event of sediment transport so may more easily cover archaeological materials. However, this is a “double edged sword” in as much they may also be more easily transported ***away*** from a site leaving it exposed. Finally, the finer grained sediments are less prone to advective oxygen transport so the oxygen penetration is lower than in sand or gravel (Riedl and Ott, 1982).

It was deemed presumptuous to classify the sediments in terms of their “preservation properties” based purely on the BGS information, as further information is required to make this meaningful. Suggestions for development of the GIS model to achieve this will be discussed as part of the AMAP1 project.

5. Further development of the AMAP project

Seabed typology is just one of many complex parameters affecting the preservation of archaeological materials in the marine environment. A GIS model to assess the potential for the preservation of archaeological material is extremely useful to assess the potential of an area to preserve these materials. However, as has been discussed the current data and interpretation has its limitations. More data is required to shed light on these complexities, both in terms of processes on going in the open seawater environment and the seabed. The current GIS would benefit from being expanded to incorporate:

- The likelihood of attack of exposed archaeological materials by wood borers
- Current information and sediment transport
- Detailed information about sediment type and their depths / stratigraphy.

It may be that much of this data is already available, having been collected by other academic or governmental institutions, and can be applied to the GIS. For example the National Museum of Denmark is in the process of preparing a GIS model to assess the spread of shipworm in Danish waters, based on data freely available from the Danish Environmental Agency.

An assessment of the environment is only one side of the equation in terms of archaeological material preservation – the material itself being the other side. An archaeological site is the product of the various pre- and post depositional processes acting upon it. An understanding of the processes of deterioration should enable their effects on the submerged cultural heritage to be better understood, interpreted and used to protect these remains.

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