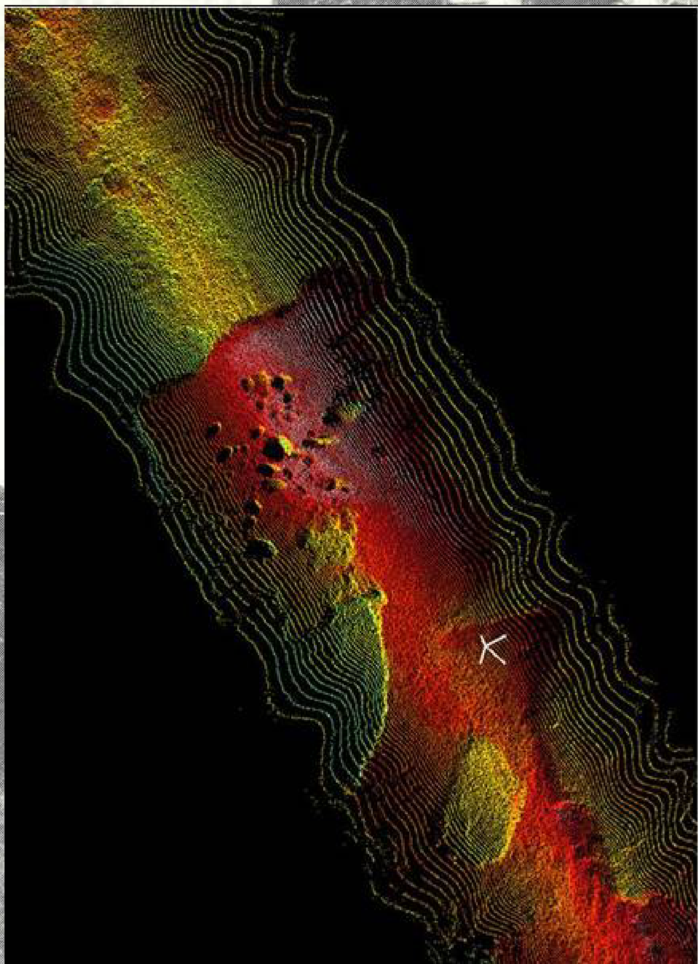
Dunwich 2008
Project Report



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Dunwich 2008 Project Report

GeoData Research Report No. UC1064

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Prepared for

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Executive Summary

The lost town of Dunwich has captured the imagination of people for centuries. The fate of Dunwich is well documented and authoritative collations both factual and fictional have been written over the years. The local Dunwich museum is an important repository of records and artifacts that chronicle the demise of the city.

In 2007/8 Esmée Fairbairn Foundation and English Heritage funded a project with the aim of collating and available historical documentation to guide a side-scan sonar, multibeam and sub-bottom profiler survey of the seafloor in the vicinity of the former city of Dunwich and to display this information via the Dunwich Museum. The objectives of this project were:

1) To collate and georectify historic mapping to support the relocation of major buildings within the former city of Dunwich using remote underwater survey.
2) To evaluate the potential of integrated multi-beam and sub-bottom profiling for visualizing buried structures associated with the former city of Dunwich.
3) To determine the location and extent of remains within the former city that lie buried beneath the Dunwich bank and inshore bars.

The aims and objectives 1 and 2 have been met in full. Objective (3) proved to be outside the seatime funded by the project. However, we were able to collect 4 lines of sub-bottom data and from this we are now able to refine the methodology and to focus the survey on a smaller section of seafloor over the city site. The project was funded under the heritage heading of Esmée Fairbairn Foundation, with the interest being in providing public access to hidden heritage. This we have achieved both through the production and display of new material for the Dunwich museum, but also through the enormous media attention the project stimulated. The impact of the public interest in the work has been measured by the Dunwich Museum Trust who have reported significantly increased attendance and interest in their museum as a result of the project, and extremely positive feedback on the new display materials.

Summary

- Created the most accurate digital mapping of Dunwich Town back to 1587 AD.
- Confirmed the survival of medieval ecclesiastical structures on seafloor after periods of 300 – c.500 years submergence and collapse over cliff.
- Identified the remains of up to four ruins from structures within Dunwich. One positively identified as St Peter’s Church. The other is most probably St Nicholas church. Of the remaining two, one is possibly Blackfriars Monastery and the other remains unknown, though possibly St Katherines Chapel.
- Demonstrated value of integrated Geophysics for locating and visualising debris from medieval structures in low-visibility sites.
- Demonstrated limitations with the survey technology and methodology, highlighting the need for higher resolution geophysical and acoustic technology for identification of worked masonry and for the mapping of structures. Demonstrated the difficulties in interpreting Boomer sub-bottom profiling in sand-overlying gravel when layer of interest is <3m depth.
- Confirmed burial of most of the medieval site under sand bank.
- Review of the historical literature on storms and erosion at Dunwich and within the North sea basin, shows climate forcing of the main phases of decline in the town and particularly in 1250-1350 A.D.

1.0 Introduction

The lost town of Dunwich has captured the imagination of people for centuries and today many tourists visit the small Suffolk village to visit the museum and to walk along the beach, attracted by the story. The fate of Dunwich is well documented and authoritative collations both factual and fictional have been written over the years (e.g. Comfort, 1994, Parker, 1975). The local Dunwich museum is an important repository of records and artifacts that chronicle the demise of the city and is in the process of expansion, including development of a website and online research archive.

The town of Dunwich was located in the county of Suffolk, in the East of the United Kingdom (Figure 1). The town is now an attractive village situated on the Suffolk coast just to the north of Minsmere RSPB reserve and south of the river Blythe estuary at British National Grid TM 47678 70558 (Degrees 52.27731°N, 1.62937°E). It was located on an east facing coast line in the southwest of the North Sea basin.

Figure 1: Dunwich, Suffolk. Located in the Southern North Sea Basin, on an eastern facing coastline of mixed sands and gravel. The yellow line in the right hand figure shows the current parish boundary. (Source Google Earth ™).

2.0 Geology

Dunwich lies on the western margin of the Southern North Sea Basin, an area that is currently experiencing slow subsidence as a result of both regional tectonic factors and the collapse of a proglacial forebulge (Rose 2008; Pye and Blott 2006; Lambeck, 1995; Shennan, 1989). The solid geology of the Dunwich area consists mainly of Pliocene and Pleistocene age (3.75 – 1.5 Million Years) sediments and weakly cemented sedimentary rocks, notably the Coralline Crag (Pliocene) and the Red and Norwich Crags (Pleistocene). These latter deposits are mainly shallow marine, coastal, and estuarine in origin (Rose 2008; Zalasiewicz & Gibbard,1988). The Westleton Beds are particularly coarse (Prestwich 1890; Rose 2008) and represent nearshore beach depositional environments. The northern part of the Dunwich Cliffs is comprised mainly of sands, with scattered, thinner units composed of sandy gravel, forming part of the Norwich Crag. Thus, prior to the glacial events that shaped the North Sea, the area was largely dominated by marine conditions with large rivers bringing sediment in from much of England and the Continent (Gibbard 1988; Rose 2008; Pye & Blott 2006).

During the middle Pliestocene, the area north of Dunwich was subjected to up to four glacial expansions (Hamblin et al, 2005; Rose 2008). The resulting stratigraphy is complex, particularly in the area around Dunwich which lies at the margins of some of the proposed glacial limits (Hamblin et al., 2005). The complexity of the stratigraphy is increased by the provenance of the ice; origins inferred from clast lithology and palynomorphs include the Pennines, Scotland and Scandanavia (Rose 2008). The result is that at the present time, the sediments of the seabed off the coast and the sediments of the cliffed coastal sections, are of very mixed provenance and type. It is from these that the mobile sediments within the present marine environment are being largely derived by erosion.

Drift deposits that lie above the Norwich Crag consist mainly of boulder clay and fluvial deposits belonging to the Lowestoft Till Formation, with deposits of Holocene alluvium and peat within the modern valleys (Figure 2). An estuary existed at Dunwich, deriving fluvial drainage from the river Blyth and Dunwich river catchments. These are now cut off from the sea by shingle and sand barrier systems that migrated shoreward and southwards during the middle ages as a spit developed. The estuaries were formed as a result of early to mid-Holocene flooding of river valleys that were cut to a lower level during glacial low sea level stands (Pye & Blott 2006). Following marine transgression during the early Holocene, deposits of marine, brackish, and freshwater sediments accumulated (Brew et al., 1992) reflecting the processes of barrier breaching and formation. Since the closure of the southern mouth of the estuary at Dunwich, freshwater marshes have developed forming peat deposits. Areas of marsh have been drained and reclaimed over this period. Most recently, rising sea levels have led to increased breaching of the barrier and the deposition of higher energy sands and shingle over the marshes.

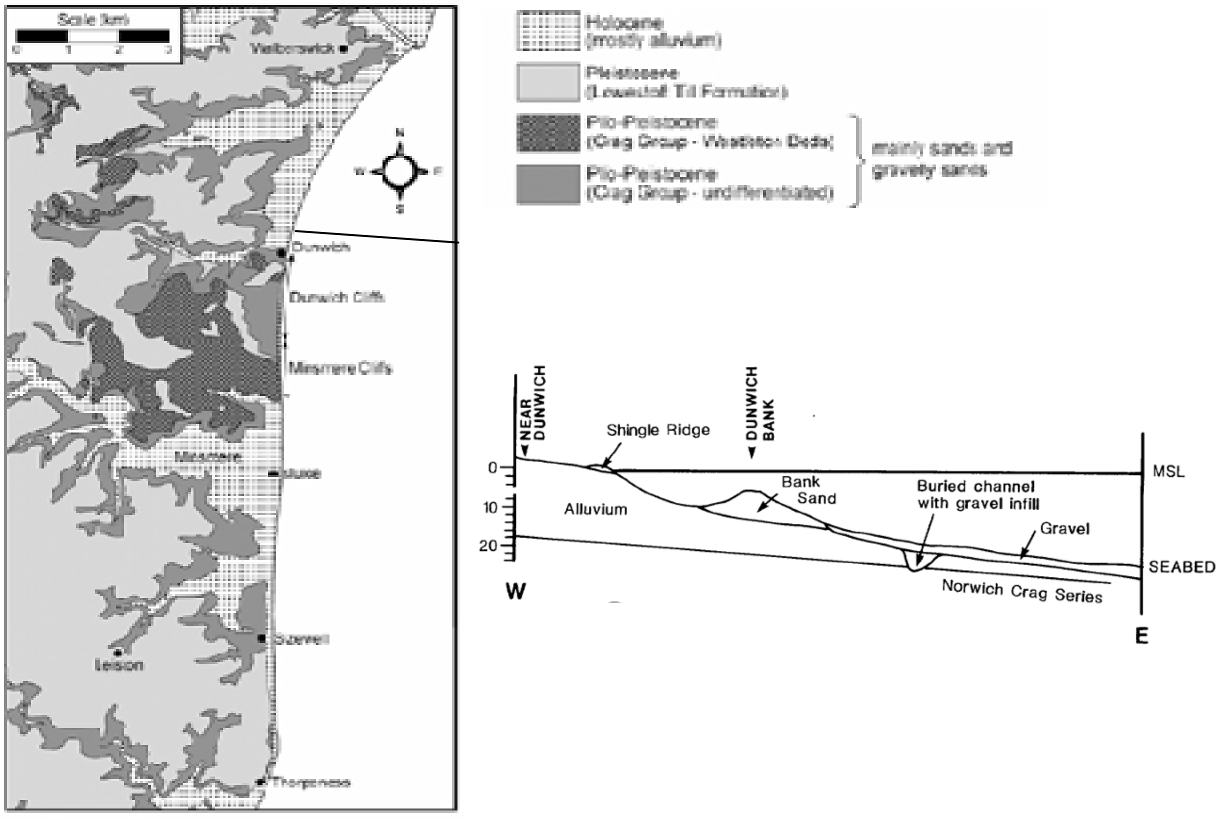

Figure 2: Drift geology in the Dunwich area after Pye and Blott (2006). The Holocene fills extend off shore and contain evidence of former channels of the Blyth and Dunwich rivers. The transect is derived from Lees (1980) IOS survey of the seafloor sediments and underlying geology. The location of the transect is shown on the map.

3.0 History

Most scholars agree that Dunwich was most probably the site of a Roman coastal fort, and was certainly a Saxon settlement (Comfort 1994; Bacon & Bacon 1979). Divers from Suffolk Underwater Studies have tried to locate artefacts from the seabed to verify this theory, but so far without success (Bacon & Bacon 1979). The growth of Dunwich as an important town can be linked to the development of the marine fishing industry in the North Sea. Barrett et al., (2004) report that the incidence of marine fish bones increases rapidly in archaeological middens, from c. 950-1050 AD and probably marks the origins of intensive human exploitation of Europe's marine resources. This dramatic change to marine fish exploitation (particularly herring) was probably driven by Christian fasting regulations, population growth, urbanism and declining freshwater fish resources (Barrett et al., 2004). Dunwich, along with other East coast settlements, was well placed to harvest the near-shore herring shoals, and was already an established site of Christian significance.

The herring, *Clupea harengus*, is an oily fish, between 20 and 40 cm long, that swims in large shoals. It must be cured within 24 hours lest the oils go rancid. When cured, however, it has excellent keeping properties and has long been exported across Europe and beyond, a plentiful and nutritious food that could be eaten during Lent. The need for quick curing initially restricted fishing to ports close by the shoals. Herring shoals swam in close to the shore during the Autumn and were visible from tall wooden towers (condes) of which Dunwich still had two in 1587. The herring fishery ran from 29th September (Michaelmass) to 11th November (Martinsmass), with the fishing nets stretched out on Hen hill to dry. The importance of the herring industry is reflected in the dedication of two of the early Dunwich churches, St Martins and St Michaels. The herring fishery was strongest in the 10th and 11th century, with declines during the 13th century. However in 1463, the Dunwich MP took his pay in fish, so clearly the industry was still important. The cyclicity of herring stocks is well known (Alheit & Hagen 2006) with large catches associated with periods of negative North Atlantic Oscillation. During these periods, herring shoals are larger and school close inshore allowing capture from beach seine nets and relatively small (inshore) boats (Alheit & Hagen 2006). However, the same periods of negative NAO were also associated with the strongest north easterly and easterly storms that brought harbour siltation and cliff recession.

The precise size of the original town is unknown, but was sufficiently important to have once been the seat of the first Bishop of East Anglia, and to have received Royal Charters for a Market and a mint (Gardner 1754; Bacon & Bacon 1979, Chant, 1986). In 1086 Dunwich was one of the ten largest towns in England (Comfort, 1994). The wealth of Dunwich was primarily based on sea trade, fishing and ship building; with substantial investment by different religious orders and at times, the crown.

Until the middle of the 14th Century, Dunwich was a nationally important seaport. In 1225 it was approximately a mile from north to south, with an area similar to London's at that date (Gardner 1754). The town of Dunwich contained up to 18 ecclesiastical buildings (of which two remain Greyfriars monastery and St James - chapel to the Leper Hospital), a mint, a large guildhall and several large important houses (Comfort, 1994, Bacon & Bacon, 1979; Chant 1986). The details of the individual ecclesiastical structures are contained in Table 4. By 1242 Dunwich was the largest port in Suffolk, but this changed dramatically after the great storms of 1287 and especially 1328.

The population has been variously estimated at between 3000 and 5000 at its height, with at least 800 taxable houses, and an area of c.800 acres (Bailey, 1991; Comfort, 1994). Figure 3, summarizes the available data and documents the rise and fall of Dunwich as expressed in terms of the total population and the number of ecclesiastical buildings, itself a crude measure of wealth.

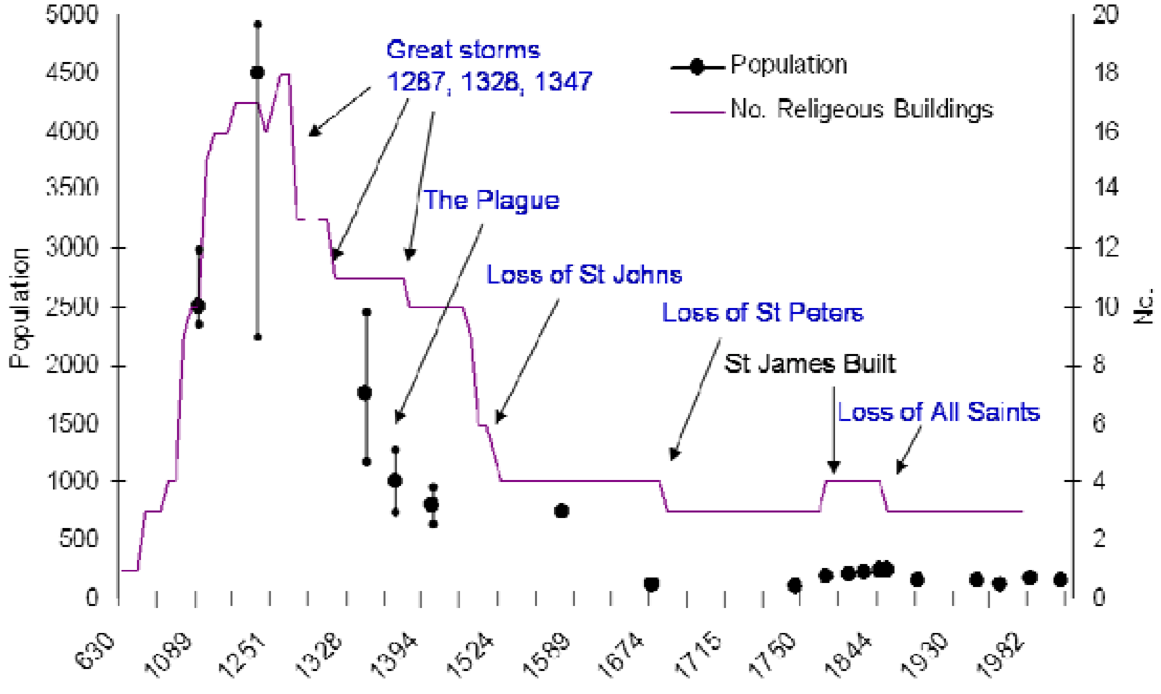

Figure 3: Rise and decline of Dunwich as indexed by the numbers of religious buildings and the total population. Estimates of the population vary and hence ranges are given (Bailey 1992). The growth of Dunwich can be linked to the dramatic growth in marine fish exploitation that occurred c, 1000 AD (Barrett et al 2004), whilst economic stability occurred again with the growth of the Icelandic cod fishery in the late 15th – 16th century.

The demise of the city is as much related to the continual battles to preserve the open harbour as to the physical losses arising from coastal erosion. Loss of land at Dunwich is recorded as early as the Domesday book when over half the taxable farmland was lost to the sea between 1066 and 1086 (Gardnre 1754; Comfort 1994). Major losses were subsequently reported in the storms of 1287, 1328 and 1347, the latter resulting in the destruction of significant property (c.400 - 600 houses) particularly in the low lying portions of the city (Bacon & Bacon 1979; Comfort 1994; Gardner 1754; Bailey 1991; 1992). The minimum rentable values for the property lost in the storms of 1287-88 were £42. Following the storms of 1328, a further loss of equal magnitude resulted in a total of 375 out of 400 houses lost from the parishes of St Leonards, St Martins and St Bartholomew (Bailey 1991; Comfort 1994). Bailey (1991) makes the point that the indirect effects of coastal recession and sedimentation were often as significant as the physical damages themselves. Such costs included the repairs to infrastructure and the cost of rebuilding sea defences. At Dunwich this is exemplified by the sale in 1542, of church plate worth £2 to provide funds for building a pier to protect the Church of St John the Baptist from cliff recession (Gardner 1754; Bacon & Bacon 1979). Similarly, Galloway & Potts (2007) report that climatic deterioration, particularly the increasing frequency and severity of storms, made it increasingly difficult and uneconomic to defend the more vulnerable stretches of coast around the Thames estuary during the period 1250–1450.

The major losses of infrastructure and land at Dunwich during the period 1275-1350 coincided with a period of national economic crisis (Bailey 2007). Increased frequency of harbour maintenance and loss of income due to blockage and diversion of the harbour entrance to the north, would have hit a town economy already weakened by the national crisis. This is reflected in the collapse in market revenue in Dunwich during this period (Bailey 2007) and in the repeated pleas to the Crown for easements on the fee-farm rent (Bailey 1991). This period of climatically driven recession, was reinforced by the arrival of the plague in 1340, which reduced the population still further. An enquiry in 1326 highlights the abandonment of houses by their owners (and hence a reduction in rent income to the town) due to "obstruction and deterioration" of the port since 1278 (Bailey 1991). The economic decline in Dunwich continued into the 15th Century. During the first three decades (1400-1430), the fishing fleet slumped and income from the market stalls fell by 66% - in effect the town was now in financial crisis and continued to petition the crown for easement son taxation. The economic decline over the period c.1230 – 1402 is reflected in the collapse of the annual fee-farm tax to the crown, from £108 to £14. In c.1489, the status as a royal harbour for the Kings ships, was transferred to Southwold following deterioration of the harbour at Dunwich.

The decline of the city was temporarily halted in the late 15th and early 16th Century which saw a resurgence in the fishing industry, notably the long range Icelandic fleet (Comfort 1994; Bailey 2007). This replaced the herring industry, as the main stay of the town's fishing economy (Bailey 2007). In 1533, 22 barks sailed from Dunwich to the Icelandic fishing grounds; by 1640 Dunwich sent 1 bark. The Icelandic fishing fleet in Dunwich was over by 1785.

The decline of Dunwich continued with the dissolution of the monasteries (1536-1545). Monastic houses in the town were already in decline, however, the loss of ready markets for fish and the direct loss of income generated by the monastic complexes of Greyfriars, Blackfriars, and the Templar church of St Marys, would at the least, have added to the sense of decline within the town. Additional physical losses occurred in 1560 and 1570 such that by 1602 the town was reduced to a quarter of its original size (Comfort 1994; Bacon 1982; Chant 1986). Further storms in 1740 flattened large areas of the remaining city, so that only All Saints church remained open, along with the ruins of St James' leper chapel, Maison Dieu hospital and Greyfriars monastery (Gardner 1754; Bacon 1979; Comfort 1994).

The loss of All Saints has been well chronicled since it occurred during the late 19th and early 20th century, finally disappearing over the cliff edge in 1919 (Figure 4). Fragments of All Saints were still exposed on the lower beach in the early 1970's. As of 2007, a final fragment and a single tombstone of All Saints Churchyard remains, and the south east corner of Greyfriars Monastery wall has been removed to prevent it from falling down the cliff.

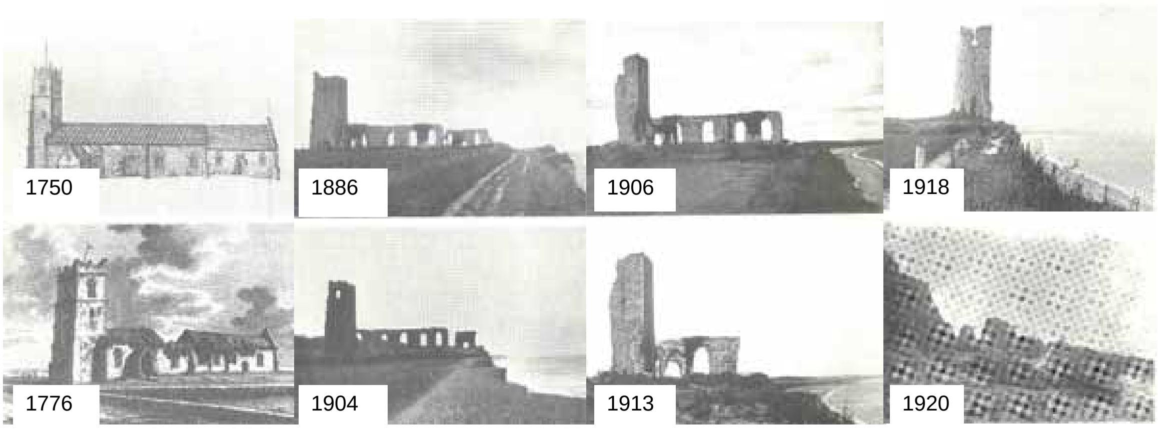

Figure 4: the Demise of All Saints Church, Dunwich. A model for the deterioration of other Dunwich churches.

The remains of the former medieval town now (2009) comprise the precinct, gateways and refectory of the Greyfriars monastery (Boulter & Everett 2009), the 12th Century Leper chapel of St James (Boutler 2008), the north west corner of the churchyard of All Saints Church, and a 150m section of the defensive earthwork around the western extent of the town, called the Palles Dike, including the former Bridge Gate (or 'Lepers Gate' CH 15.502 MS). The archaeological and stratigraphic importance of the former harbour and estuary that form the Dingle marshes is unknown. Outwith these remains, and outside the boundary of the medieval town, the village of Dunwich includes properties that date back to the 18th century including the former Town hall, and School house.

4.0 Coastal Processes

The history of the decline of Dunwich requires a understanding of coastal processes. In turn, these need to be set within the wider context of the coastal sediment system (Pye & Blott 2006; Lee 2008). The coastline of the UK has been divided into sediment cells that are defined as a length of coastline and its associated nearshore area within which the movement of coarse sediment (sand and shingle) is largely self-contained (HR 1995a). Interruptions to the movement of sand and shingle within one cell should not affect beaches in a neighboring sediment cell. Dunwich is located at the southern end of sediment sub-cell 3c which stretches from Lowestoft in the north to Duwich cliffs in the south (Figure 5). This is a smaller part of a sediment cell (3) within which the movement of coarse sediment (sand and shingle) is relatively self-contained (HR 1994; Black & Veatch 2005; Haskoning 2009).

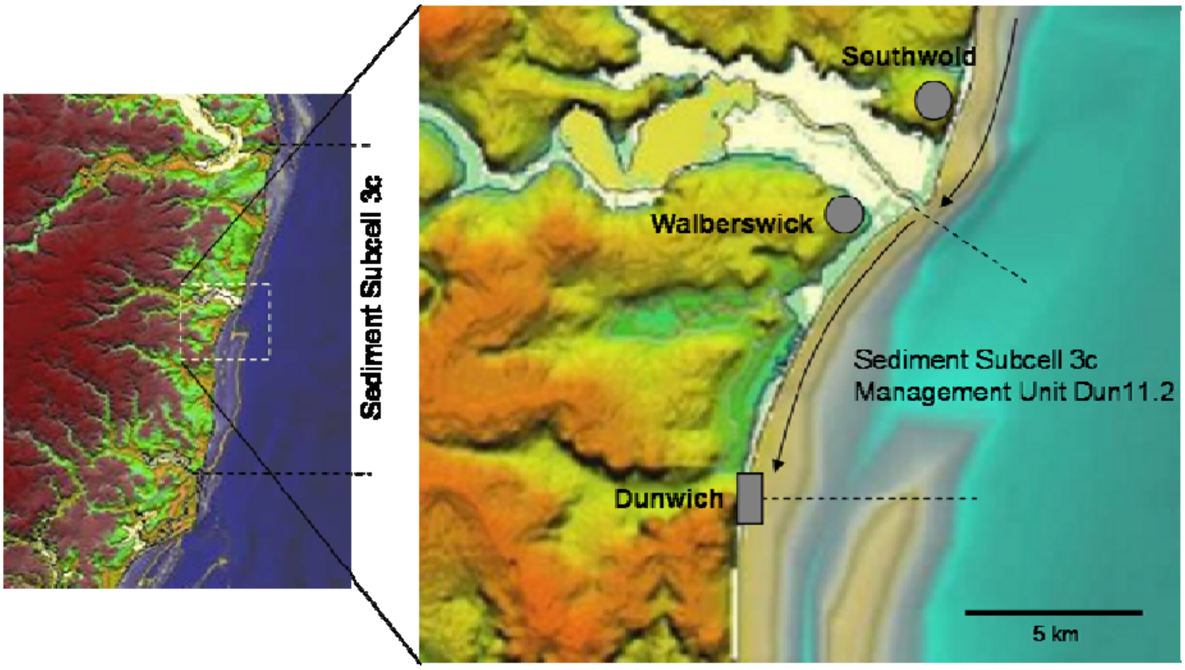

Figure 5: Coastal topography and bathymetry showing the position of Dunwich Town site within the sediment cell framework of the shoreline management planning process. The northern end of the Dunwich bank can be seen off shore. The cliffs at Dunwich fix the southerly end of Dunwich bay, while the harbour structures at the mouth of the river Blythe fix the northerly end of the back-barrier and the morphology of the coast. General direction of drift is shown by the black arrows.

Cliff recession reflects a balance between the strength of the cliff materials and the stresses imposed on the cliff by gravity and the kinetic energy of waves at the cliff foot (Lee 2008). The cliff recession rate (the rate retreat of the cliff profile, from cliff foot to cliff top) is a function of the changing balance between the cliff strength and the imposed stresses (Sunamura, 1992). Wave attack and geological materials are generally the dominant factors controlling the recession process on an open coast like Dunwich (Lee 2008; Sunamura, 1992; Costa et al., 2004). Cliff behaviour is the morphological response of the cliff line to variations in the balance between cliff strength and imposed stresses over time (Lee 2008). This generally involves a combination of mass movement (landsliding), surface erosion and seepage erosion (e.g. Lee and Clark, 2002; Lee 2008). At Dunwich, the geology results in relatively weak (soft) cliff material that is susceptible to erosion by all three processes.

The transport of coarse sediment (sands and gravels) to the beach at the foot of Dunwich cliffs is an important process in the control of cliff recession. Lee (2008) demonstrates that beaches dissipate wave energy and regulate the frequency that the cliff foot is subject to wave attack. The results suggest that over a decadal timescale, there is a non-linear increase in the average recession rate as the beach profile area above High Water Mark (HWM) decreases. Small changes in beach level can result in significant differences in the recession rates. At low beach levels there is high to extremely high recession with considerable variability, whereas at high beach levels there is almost zero recession with limited variability. Historical recession rates are therefore the product of both the past forcing events (storms and surges) and changes in cliff–beach state. This means that the processes of sediment supply and transport to the beach above HMW, are critical to the vulnerability of the cliff to storm and surge action. It follows, that the evolution of the coastline and the history of beach management within the updrift sediment cell (Lee 2008) is critical to understanding cliff retreat at Dunwich.

The Sediment sub-cell model identifies the sources of sediment for the beach at Dunwich and the back-barrier shingle bank to the north of Dunwich as; cliff erosion north of the river Blyth, southerly drift along the shore in Dunwich bay, and offshore seabed material (Halcrow 1995a; b; Black & Veatch 2005). In addition, cliff material at Dunwich adds to the volume of sand and gravel delivered to the critical beach area at the cliff-beach contact point (Lee 2008). Sediment transport along the beach at, and north, of Dunwich is generally to the south. The magnitude of sediment transport is strongly controlled by coastal morphology and storm action (Lees, 1980; Pye & Blott 2006; Lee 2008; Haskoning 2009). During large storms, wave run up is long, and recession velocities high, leading to high rates of beach sediment transport (Lees 1980) and removal of beach material and deposition on offshore sand banks (Lee 2008). Conversely, the beach is built up during periods of swell wave activity on high tides. Maximum vulnerability of the cliff line and barrier occurs a) after repeated of long duration storm action and, b) when sediment supply and transport to the beach above HWM is limited both from cliff processes and drift. The combination of high rates of sediment removal and low rates of sediment supply, creates a net reduction in beach volume at the toe of the cliff, toe erosion at the cliff, over-steepening of the cliff face, and subsequently cliff collapse.

A recent study (Haskoning 2009) has considered the behavior of the shingle bank to the north of Dunwich. The study confirmed previous work that there is only limited net drift along the shore, and that the supply of shingle (gravel) in particular is small, influencing the development of the beach profile. The study also highlighted that during periods of rising sea level and increased storminess, the back-barrier north of Dunwich evolves by roll back through a process of overwash fans, reconsolidation with retreat, and further overwash (Haskoning 2009). This results in regular flooding and eventual inundation of the marsh land behind. Pye & Blott (2006), used historical maps to show that the back-barrier beach has been retreating landwards since at least 1587, at a long-term average rate of c. 1.0 m per year. In recent decades, the central section of the barrier has receded more quickly than the northern and southern ends, creating a more arcuate plan form. This correlates with modeling studies that identify the central section with a discontinuity in drift, further limiting the northerly supply to Dunwich cliffs. In the coastal zone, tracer experiments (Lees, 1980, 1981, 1983) have demonstrated that sediment (sand) is moved landwards by wave action, resulting in a landward shift in the position of the Dunwich bank and inner banks, during stormy conditions.

4.1 Coastal evolution

In the early medieval period, the morphology of the coastline within sediment subcell 3c had important differences compared to the current situation.

Figure 6: Alde estuary showing the spit development south of the town of Aldeborough. This is a model for the situation at Dunwich in the early medieval period prior to 1350. The narrow neck of the spit is probably similar to Dunwich, and explains the frequent formation of a new river mouth both artificial and natural at this point throughout the history of Dunwich.

We know nothing about the offshore bathymetry at this time but by using a combination of the descriptions from contemporary documents, early maps (Gardner 1754) and an understanding of sediment dynamics on the Suffolk coast one can suggest a plausible model for the evolution of the coast at Dunwich. Figure 6 shows what was probably the situation in Dunwich prior to the formation of the current back-barrier system following the cutting of a permanent northern mouth for the river Blyth and Dunwich rivers. As the figure demonstrates, this is typical coastal morphology for the larger Suffolk river estuaries. The land forming the spit that created the sheltered harbour and anchorage at Dunwich was know as Kingsholm, and behind it were estuarine marshes, some of which appear to have been improved sufficiently for grazing (e.g. Leonards marsh, Parker 1975). At this time, drift was uninterrupted from the north, with southerly transport of material supplied by cliff erosion northwards from Southwold. Since it is principally during storms that material is supplied from cliff recession and transported along the coastline, phases of storminess were required to build the spit.

In the south of sediment subcell3c, the movement of sediment would have been interrupted by the harbour entrance and quays that lay along the Dunwich/Blyth river mouth in the north of the town. We know from records that the harbour had extensive infrastructure including piers to prevent sediment blocking the harbour mouth (Comfort 1994; Bacon & Bacon 1979; Parker 1975). The morphology of the harbour mouth was probably similar to that of the current Blyth, with accumulations of sediment on the northern side. Stow, writing in 1573 describes the northern spit and cliff beaches as ‘shynglestone’, indicating that they were similar to the present beach material. The growth and development of harbour infrastructure in the 13th-14th centuries may have created an imbalance in the sediment budget to the south of the harbour. Critically this was the beach area covering the toe of the Dunwich cliffs, hence as the model of Lee (2008) describes, the reduction in sediment supply to this area, increases the vulnerability of the cliff to storm driven erosion.

The history of the decline is Dunwich is characterized not just by cliff recession and the physical destruction of the town, but also by phases of deposition that blocked the mouth of the

Blyth/Dunwich river (Chant 1986). The relationship between the two processes has not so far been made, but clearly, for the spit to prograde southwards, required a supply of sediment and the storms to move it. This explains the frequent description of both harbour blocking and cliff recession at Dunwich during large storms. Initially, the southerly migration of the spit resulted in temporary coalescence with the beach at Dunwich cliffs and the formation of a northern mouth for the River Blyth and Dunwich rivers at Walkberswick (dates for different northerly cuts are given as 1249, 1287, 1464 and 1590). However, once the Blyth had formed a more permanent cut (c.1464 when the port of Walberswick was moved to it's current location), the spit would have narrowed with the interruption of the southerly drift from Southold, exacerbated by the creation of harbour walls at the mouth of the Blyth. To the south, Dunwich cliffs act as a control point on the coast, anchoring the southern end of the back-barrier and allowing a build up of shingle at the southern end. However, the roll back rate of the shingle back-barrier is greater than the rate of erosion of the Dunwich cliff line (Haskoning 2009). It is suggested (Haskoning 2009) that over the longer term, the progress of erosion will occur in a stepwise manner. As the cliffs become increasingly exposed by the progressive roll back of the shingle, they become more vulnerable to erosion (in part due to the loss of sediment supply to the beach at Dunwich cliffs), hence the coastline retreats by back-barrier migration followed by cliff recession. Since the early medieval period, the erosion of the coastline at the town has been driven by storm generated waves, acting on the coastal morphology, with periods of maximum erosion likely during northeasterly winds (distance of longest fetch) and when the back-barrier was located further west than the cliff-line. In addition, recent modeling studies in the Blyth estuary (Black & Veatch 2001) show that management of the estuary influences the formation of the mouth and hence the morphology of the back-barrier to the south. Therefore an additional contributor to the erosion of Dunwich cliffs may have been the enclosure of the Blyth marshes in 1790's when the river was cannelised for navigation and deposition occurred at the mouth of the Blyth.

In addition to the coastal evolution, the landscape of the back-barrier marshes also evolved both through spit coalescence and the diversion of the Blyth, but also as a result of human activity. Once the harbour at Dunwich had been blocked and the main flow of the Blyth diverted to the north, the former anchorage would have rapidly accreted. The Dunwich river has a small freshwater catchment, and is not able to flush out accumulating tidal sediments. Thus rapid sedimentation and saltmarsh colonization would have dominated the changes in the former harbour area post c.1464 and some evidence suggest even earlier, perhaps following the storm of 1328. Corporation Marshes (formerly Kings Holm) to the east of the Dunwich River were already embanked along the river edge by 1587 and the area was dry enough to be used for fairs in the 1380s. To the west, Westwood Marsh (formerly East Marsh and Pauls Fen) was reclaimed from salt marsh by the erection of a sea wall around 1590. Probable early curving drains seem to have been augmented by later straight ones. To the south, Dingle and Reedland Marshes had also been embanked from the river by 1587. The area has a mixture of sinuous and straight drains, suggesting drainage works over an extended period of time.

Pye & Blott (2006), draw together the earlier evidence to create what is probably the most accurate synthesis of the evolution of the Dunwich coastline. Their figure is reproduced in Figure 7. This shows the growth of the spit south across the estuary o the Blyth and Dunwich rivers and the rapid sedimentation and shrinkage of the harbour once the spit had joined the beach and cliffs at Dunwich. The resulting loss of trade was a key factor in he decline of the town.

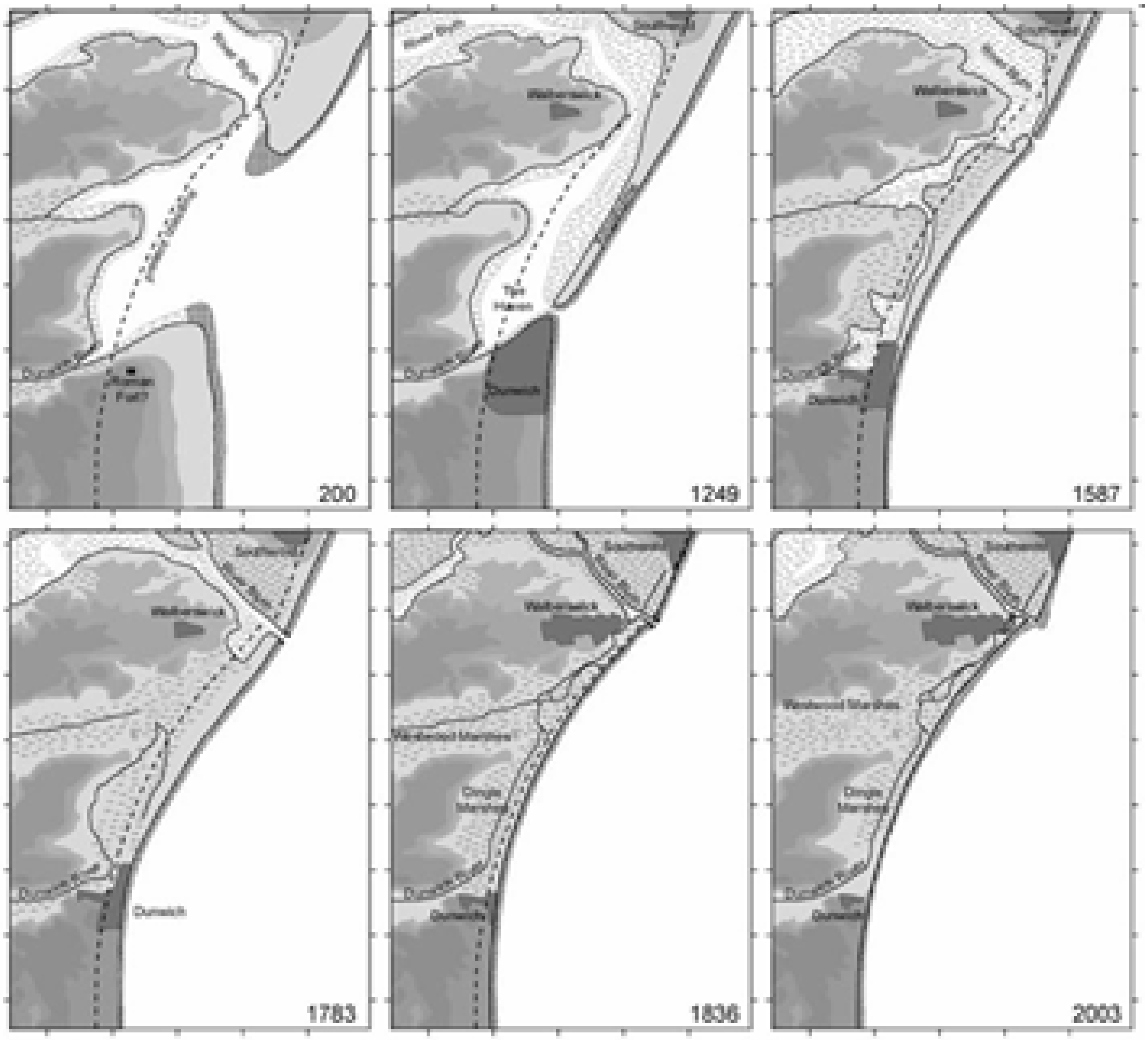

Figure 7: Coastal evolution at Dunwich 200AD – 2003AD showing the evolution of the spit and the closure of the Dunwich harbour entrance that occurred following storms in the later 13th and early 14th centuries. The subsequent shrinkage of the Dunwich river and confounded by drainage of the marshes, resulted in loss of harbour. The map dos not show the sequence of attempts over the period 1280-1500AD to cut new harbour exits closure to Dunwich. Figure from Pye and Blott (2006).

4.2 Climatic drivers of coastal recession and morphodynamics

Climate is a critical driver of coastal processes and morphological evolution at Dunwich (Halcrow 2001; Pye & Blott 2006; Haskoning 2009). To this can be added storm surge activity. Climatic drivers include sealevel rise and storminess, the latter being charaterised by magnitude and direction. The wave climate of Dunwich is bimodal with the majority of waves approaching from the north and northeast or south and southwest (Pye and Blott 2006; Haskoning 2009). Wave energy has been classified as moderate, with 38% of all waves being less than 1 m high and 76% of all waves less than 2 m high. Maximum wave height for 1:100 return period events is calculated as 3.09m OD, rising through 1:500 at 3.45m to 1:1000 as 3.61m OD (Haskoning 2009). The elevation of the back-barrier,and cliff:beach contact point at Dunwich are typically at 3.1 m OD. The highest waves approach from the north and northeast, which is the direction of longest fetch. Local inshore wave heights, period, and approach angle are strongly controlled by the morphology of the coastline, and by the offshore bathymetry, although the importance of the offshore Dunwich bank (Figure 5) in reducing wave energy reaching the coast has been a matter of some debate (Pye & Blott 2006). The most recent studies concluded limited impact during "normal" events but probably a reduction in wave energy reaching the coastline during larger storms (Pye & Blott 2006). The Dunwich and Sizewell banks have been migrating onshore and northwards over the past 140 years, and have grown and coalesced during this time.

Sea level data for the last 2000 years in this area are sparse. In northern East Anglia, the average rate of relative sea level rise since 4000 years BP has been *ca.* 0.61 mm yr^{-1} ((Horton et al 2004, Shennan & Horton 2002; Pye & Blott 2006), but it is uncertain whether this is also representative of coastal Suffolk. However, the available evidence suggests that combined eustatic rise and land subsidence have led to an increase in relative mean sea level of 1.0 - 1.6 mm yr^{-1} over the last 1000 years (i.e. a total of 1.0 - 1.6 m) (Pye & Blott 2006). Data from the Fenland embayment (Brew et al 2000) coupled with climatic inferences (Hulme 1994; Lamb 1995) show a series of changes in sea level over the period during which Dunwich developed and declined. Recent analysis of coastal peats in the Friesian islands in the southern North Sea basin, show a phase of rapid sea level rise around 700-550 uncal.BP (1300 – 1450AD), falling rapidly again around 500-400 uncal. BP (1500-1600 AD) (Freund & Strief 2002). Whilst local factors may have influenced the actual magnitude and timing, this period consistently records an increase in sea level (Table 1).

Period	**Sea Level Trend**	**Coastal Activity at Dunwich**	**Source**
2000 – 1600 BP *0 – 400 AD*	Fall followed by Rise	Building of Roman shore fort??	Brew et al., (2000)
1400 – 1200 BP *600 – 800 AD*	Fall	Establishment of Dunwich as a major religious centre	Brew et al., (2000)
900 – 600 BP *1100 – 1400 AD*	Rapid Rise 1300 – 1450.	Rise then decline of Dunwich. Severe coastal erosion 1250-1450	Lamb (1995) Freund & Strief (2002)
500 – 150 BP *1500 – 1850 AD*	Rapid Fall 1500 – 1600.	Stability followed by coastal erosion in 1540, 1600's, 1750's	Lamb (1995)
150 – 0 BP 1850 – 2009 AD	Rise	Erosion in later 19^{th} Century and early 20^{th} century, followed by relative decline in erosion rates.	Pye & Blott (2006)

Table 1: Trends in sealevel in the vicinity of Suffolk during the period of the rise and decline of Dunwich. Data is derived from stratigraphic interpretation from the Fenland basin, or inferred from periods of warming (rise due to thermal expansion) or cooling (fall due to thermal contraction). Dunwich appears to have developed during a period of relative sea level fall (600-800 AD), with decline coinciding with a period of relative sea-level rise (1300-1450 AD).

Based on an analysis of long-term measured and proxy weather records, Lamb (1995), related periods of slightly higher relative sea level (*e.g.,* 1700–1600 BP and 800–700 BP) with a relative warming of the atmosphere and a northwards deflection of westerly storm tracks. Lamb (1995) proposed that warming phases are associated with an increase in frequency of winds from the southwest, west, and northwest, and cooling phases with a greater relative importance of winds from the north and northeast. The role of physical processes in the decline of Dunwich has been highlighted by Bailey (1991; 2007). However, he notes that although rising relative sea level is generally associated with increased coastal erosion, there is limited evidence for its impacts during the 10^{th} – 12^{th} centuries, suggesting instead that it is increased frequency of high magnitude storms that drive the main phases of coastal evolution (Bailey 1991). However, the erosion events documented in Dunwich during the period 1250 – 1450 are the most severe reported, with similar accounts not occurring until the events of 1540 and 1570 (Table 1). Rising sea level of it's own would not cause the severe coastal erosion reported at Dunwich, although the landward migration of the spit at Dunwich would have been a response driven by sea level rise. Instead, rising sea level would have contributed to the severity of coastal recession by increasing the severity of storm action as waves acted higher up the beach/cliff line removing material from the cliff/beach zone (Lee 2008), cutting into the toe of the cliffs, and overflowing the spit/barrier. Records of storms are therefore required to understand the sequence of erosion and decline within Dunwich.

During a storm or tidal surge event, the increased depth results in larger, longer period waves. Tolman (1991) concluded that in extreme conditions, an accumulation of effects means that relatively small surge currents might have a significant impact on mean wave parameters in the North Sea basin. Storm surges generated by wind set up against the coast produce an onshore water movement at the surface. As water piles up against the coast, downwelling occurs and offshore flowing bottom currents are generated (Hequette et al, 1995). These flows, combined with high-energy wave orbital velocities significantly increase the potential for sediment transport. Indeed, once the waves have supplied the power to mobilize the sediment, the direction and magnitude of the resultant transport will be strongly influenced by the residual surge currents (Hequette et al, 1995). Therefore, considerable offshore sediment transport takes place during storm surge events although factors such as shoreline configuration and seabed topography will also partially control this process.

The frequency, direction and magnitude of storms over the British Isles, and the North sea, has been linked to large scale air mass dynamics in the northern hemisphere (Lamb & Frydendahl 1991; Lamb 1995; Dawson et al 2002; 2006). The North Atlantic Oscillation (NAO) is a large scale pattern of natural climate variability which has important impacts on the climate and weather of the North Atlantic region, and particularly Europe (Hurrell & Deser in press; Lamb 1995). The NAO is a redistribution of atmospheric mass between the Arctic and the subtropical Atlantic, and swings from one phase to other producing large changes in surface air temperature, winds, storminess and precipitation over Europe. The NAO also affects the ocean through changes in heat content, gyre circulations, mixed layer depth, salinity, high latitude deep water formation and sea ice cover (Hurrell & Deser 2009, Trouet et al 2009; Lamb 1995). Thus, indices of the NAO have become widely used to explain variations in storm driven coastal processes (Hurrell & Deser 2009; Clarke & Rendell 2006; Dawson et al., 2002). Changes in the NAO index are important, since they are strongly linked to the direction of storms (Lamb 1995; Dawson et al., 2002). During periods of negative NAO index, temperatures in the British Isles and northern Europe, are typically lower as a result of easterly and north easterly air movement (Lamb 1995; Trouet et al., 2009; Hurrell & Deser 2009). Pye & Blott (2006) relate these to sediment dynamics at Dunwich, suggesting that cooler periods such as the Little Ice Age "*should be associated on the Suffolk coast with greater wave energy, larger and more frequent storm surges, and greater coastal erosion and flooding. Under such conditions, north to south sediment drift along the Suffolk coast should be enhanced. Conversely, during periods of westerly dominance, there should be less erosion, northerly and southerly sediment transport should be more in balance, and the coastline should experience relative stability. During periods of greater storminess and erosion, large amounts of sediment enter the nearshore zone and are available for redistribution, favouring southerly spit extension.*" It follows that an important control on the historical development and decline of Dunwich is the change in climate and specifically periods of negative NAO.

Analysis of storm data for the North sea basin, and specifically for the east coast of England, was undertaken in order to reconstruct phases of storminess. Multi-proxy data sources were used, including evidence from documents (De Kraker 2005; Bailey 1991; 2007; Lamb, 1995; Gardner 1754; Comfort 1994; Bacon & Bacon 1979; Gotteschalk 1971, 1975, 1977; Galloway 2009); sand grain counts from coastal bogs (evidence of increased wind strength – De Jong et al., 2006), climatic data from ships logs (Wheeler & Suarez-Dominiguez 2006) and evidence of large scale climate changes including NAO index during the last millennium (Trouet et al 2009; Dawson et al 2006; Dawson et al 2002). The documentary evidence includes accounts of coastal erosion events in Dunwich allowing reconstruction of the decline of the physical infrastructure of Dunwich to be measured alongside the frequency of storms. The period of record runs from 1000 AD (1000 BP) to 2009 AD. Gaps and disparities in recording of events increases with time, hence the earlier records are both partial and most likely record only the most significant events, where this may relate more to damage than the actual magnitude of the storm (De Kraker 2005; Lamb & Frydendahl 1991). The record, is therefore one of event frequency. Accepting these limitations, the record contains 114 individual storm events, and 46 erosion events specific to Dunwich. Figure 8, presents the data for storms and erosion events as a cumulative trend, that identifies changes in event frequency. Increases in the gradient of the lines equate to periods of increased event frequency, reductions in gradient relate to reduced event frequency while sections of constant gradient equate to periods when no events are documented. Figure 8 shows six discrete periods of storm frequency characterized by clear changes in the gradient of the cumulative frequency curve. The boundaries of these periods were identified by fitting linear trends lines to the dataset and extending these until the next major point of inflexion. Short-term changes (<5 years) were not used as boundaries, hence the periods refer to more general phases of storminess. The decision to adopt this criteria was based on the low resolution of long term climate data available for the period of record (1050-2000), and because the partial nature of the early records precludes finer resolution analysis.

Within the six phases of storminess it is possible to identify three and possibly four phases of rapidly increasing storm frequency; Phase 2 (1230 – 1350 AD), Phase 4 (1680 – 1770 AD), and Phase 6 (1890 – 2009AD). There is some evidence for an increase in storminess post 1980 AD to present. These phases correspond to increases in the frequency of erosion events recorded at Dunwich, and with the exception of the 1540 storm, are associated with the severest erosion events at Dunwich (red arrows in Figure 8). Phase 2, marks the period that witnessed both the peak of population and religious building (up to 1280 AD see Figure 3) and the initiation of the decline of Dunwich as a major British port. Lamb (1995) uses documentary records to demonstrate increased storm frequency in the North sea during this period (1200 – 1300 AD) which is independently confirmed by De Jong et al (2006) using records of aeolian sand grains from Swedish coastal peat bogs. Galloway (2009) highlights the period 1350-1390 as a peak in storm surges reported for the Thames estuary, coinciding with the great storm of 1347 at Dunwich (Bacon & Bacon 1979).

Dawson et al. (2006) use deuterium excess records from the GISP2 Greenland ice core to show that sea surface temperatures during the late thirteenth century and the majority of the fourteenth century were characterized by relatively high amplitude warming and cooling 'events'. The period 1270 AD - 1450 AD featured several short-lived phases of marked air temperature lowering that were rarely ever equaled during succeeding centuries (Dawson et al 2006). These coincide with the severe storms of 1287, 1328 and 1347. Figure 8 shows that this phase is also associated with a sharp decrease in average global air temperature (Moberg et al 2005) and a strong fluctuation in the strength of the (positive) NAO record (Trouet et al., 2009). The persistent positive NAO throughout this period has been suggested to result from prevailing La Niña–like conditions in the Pacific, possibly initiated by enhanced solar irradiance and/or reduced volcanic activity (Trouet et al 2009). Dawson et al., (2006) point to relatively few volcanic eruptions during this period except for one as yet unknown and large volcanic event in 1258. Hence, the major events that led to the decline of Dunwich, starting in the 13th and 14th century, are climatically driven, the precise explanation for which remains uncertain.

Following period 2, a major shift in Northern Hemispheric circulation is thought to have occurred (Dawson et al., 2006), resulting in an increase in the amplitude of NAO index perhaps driven by a change in La Nina like conditions in the Pacific (Trouet et al 2009). Despite evidence for increased north Atlantic storminess during this period 1400 – 1450 AD, there is little correlation with NAO (Dawson et al., 2006). The period is associated with cooling and wetter conditions, leading to depressed agricultural returns (Bailey 2007).

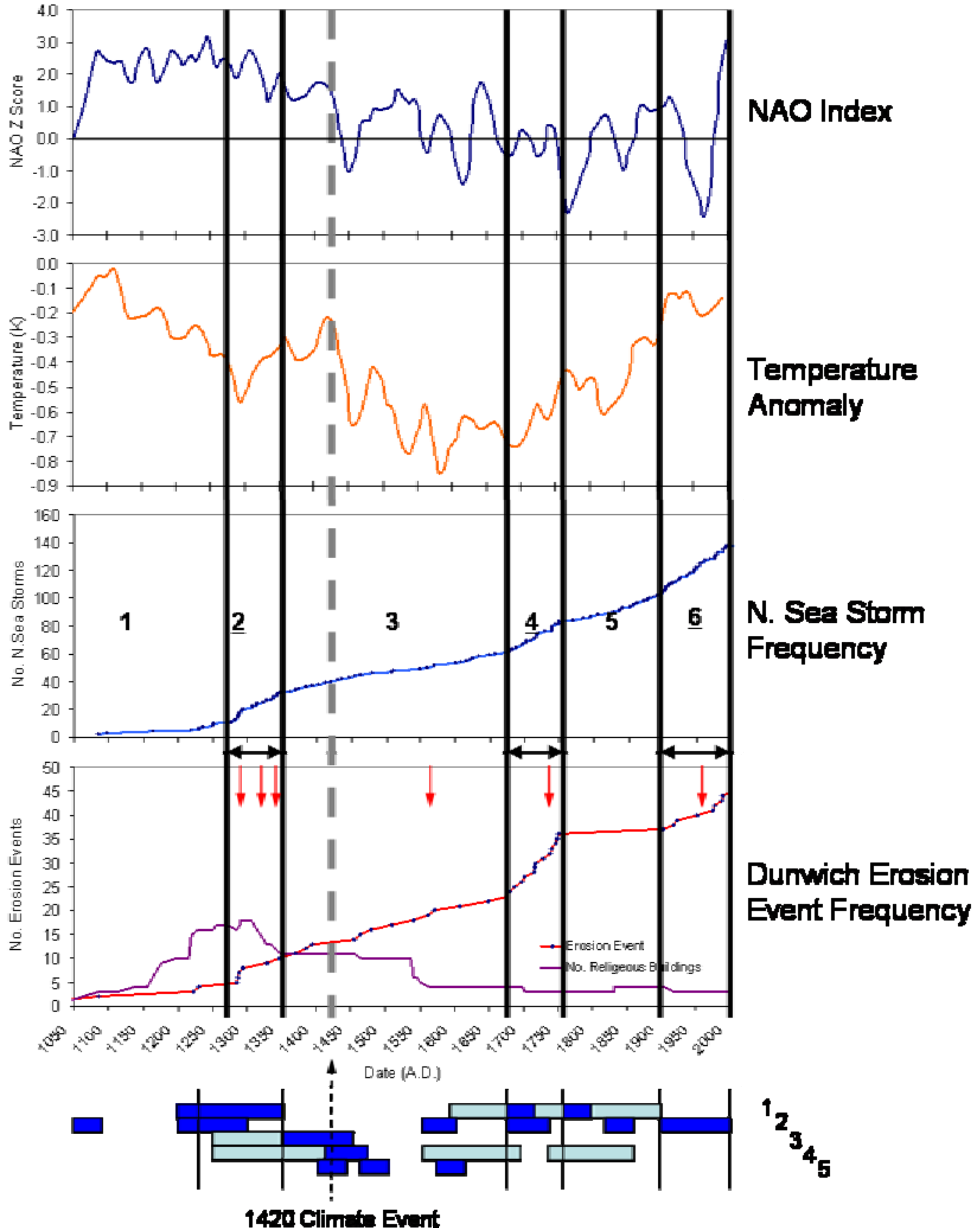

Figure 8: Climate variability over the last 950 years as indexed by NAO index (Trouet et al. 2009); temperature relative to 1961-90 mean (Moberg et al. 2005) and frequency of north sea storms. Lower coloured bars highlight phases on increased storminess reported in 1. De Jong et al. (2006), 2. Lamb (1995), 3. Galloway & Potts (2006), 4. Moberg et al. (2005) and 5. De Kraker (2005). The c.1420 AD change in Northern Hemisphere tropospheric circulation is shown (Dawson et al 2006) which correlates to a switch in NAO index from dominantly positive in the mediaeval Warm Period to fluctuating negative and positive index. The sequence of erosion events and the documented rise and decline in religious buildings at Dunwich are strongly linked to phases of increased storm activity in the North Sea basin. Prior to 1420, there is no clear association with NAO index. Post 1420, increased storminess in the North Sea basin is associated with negative phases in NAO, although this is not so clearly expressed in the erosion event history. Red arrows denote major storms.

The records from Dunwich though recording continued erosion, do not highlight this as a period of exceptional storm or erosion events (Figure 8). Galloway (2009) also shows a decline in reported storm surge inundations following a peak in 1370, although Galloway & Potts (2006) report an increase in storm surge frequency in 1400-1450. At Dunwich the erosion activity in this period runs from c.1455 – c.1560. The lack of reference to the loss of major town structures during this period is in sharp contract to earlier and later records. Several reasons for this include a) either the events were less damaging at Dunwich (the Thames estuary is low lying and flooding is the most commonly reported impact of storms during this period in contrast to the higher land and cliff recession at Dunwich), b) the geography of the town meant that although land was lost there were few buildings of note lost during this period, c) the economic decline in the town at the time resulted in poorer record keeping and hence the recording of events, and, d) there is a differential preservation of records from this period, and hence the records do not reflect the actual frequency of erosion events. The latter point is not correct, and Bailey (1991) comments on the relative lack of reference to inundations and erosion during this period despite extensive records. The most likely answer is that the loss of land did not coincide with major buildings, and the rate of erosion possibly declined in response to the connection of the spit (and hence enhanced sediment transport) to the cliff/beach sediment system that coupled with the high supply of sediment to the foreshore resulted in protection of the cliff toe.

The long period of relatively low storm frequency (3 in Figure 8 and Table 1) spans the period 1360 -1680. Within this period the records from Dunwich show a phase of increased erosion activity around 1455-1570. This period of increased storminess and cooling in the southern North Sea basin is reported by Lamb (1995) and Moberg et al (2005), and in the records of dyke breaching in the Netherlands (De Kraker 2005). Trouet et al (2009) long term NAO record shows this to be a phase of negative NAO.

A peak in erosion severity as indexed by the economic and spatial extent of loss, occurs in the storms of 1540 (Gardner 1754) during which St John's church was threatened and lost sometime around 1550. This period is again highlighted by Lamb (1995) and De Kraker (2005) as a peak in storminess and inundation, Moberg et al 2005, identify this as the coldest period of the Little Ice Age, and Trouet et al (2009) records shows this to be a period of predominantly negative NAO.

The second phase of major erosion (Phase 4 in Figure 8) damage at Dunwich corresponds with a period of increased storminess in the North Sea between 1670-1750AD. De Jong et al (2006) and Lamb (1995) identify this as a period of increased storminess in the southern north sea basin, with cooler temperatures and predominantly negative NAO. Losses during this period include St Peter's church, the market place and town hall, the gaol and the ruins of the Knights Templar church and Blackfriars monastery (Gardner 1754, Comfort 1994). Erosion rates measured from historic maps (1587-1753) average 1.61m yr-1 (IOS 1979) or 140% of long term average.

Period 5 (1750 – 1890) shows a reduction in storm frequency although it is still high relative to period 1 and 3. Erosion events are not reported for Dunwich during this period, with records focusing on the reform of political representation (Pickard 1997). The absence of erosion accounts during a period in which storm activity is known to be increasing (Lamb 1995, Moberg et al., 2005) and in which phases of negative NAO occur, is most likely a result of the absence of major structures and the economic decline within the town that is indexed by the de-population in this period (Figure 3). However, erosion rates for this period derived from overlaying old maps (Pye & Blott 2006; Lees 1978) identify it as a period of relatively low cliff erosion rate (0.6m yr^{-1}). Similarly, within this period St James church is built along with a new school, and the population increases by 50% (Comfort 1994). These suggest that erosion events and inundation though present, were less frequent and severe at Dunwich.

The final phase of erosion activity and losses reported for Dunwich again coincide with an increase in storm frequency and strong negative NAO at the end of the 19th century and continue in phases throughout the 20th century to the present date (2009). The loss of All Saints church (1904-1925) and the additional losses of Middle gate (1969), Temple hill (1925) and in 2006 the start of the collapse of Greyfriars perimeter wall occur within the period. Cliff recession was particularly severe in the 1960's and again in the 1990's. Breaching of the back barrier has been reduced by management throughout the latter half of the 20^{th} century, but has increased in frequency in the early 21^{st} century in response to rising sea levels. Erosion rates from historic maps for this period show average rates of cliff recession of 1.1m yr^{-1}.

The future evolution if Dunwich coastline is predicted to proceed as it has over the preceding 750 years since the spit attached to the cliff/beach system. The draft second Shoreline Management Plan (Haskoning 2008) aims to allow natural evolution of the coastal back-barrier north of Dunwich cliffs. The plan allows the natural shingle bank to overtop and to roll inland in response to sea level change. At Dunwich the plan does not preclude continuation of low level management of the beach at Dunwich, provided that in so doing it does not develop as a significant coastal headland. The intent of the plan is also to improve flood defences to the rear of Dunwich and to allow management and improvement to inland defences behind the front line of the shingle bank. This will provide the best advantage in terms of habitat creation within a more natural defence policy (Haskoning 2009). The trial use of soft beach protection at Dunwich cliffs has resulted in build up of the beach, but downdrift of this work, beach levels have fallen. This includes the cliff line supporting the last of All Saints churchyard and the south eastern section of precinct wall of Greyfirars monastery. Thus the future is one of continual cliff and back-barrier recession, and the loss of the last fragment of the medieval town within the Palles dike. Increased storminess and sea level rise are likely to accelerate the erosion of the beach and cliff line, particularly during north easterly and easterly storms, that are more frequent during phases of negative NAO. Goodkin et al., (2008) have shown how the strength of the NAO has increased in response to global warming.

Based on the historical analysis of storms, the evolution of the coastline at Dunwich since 1450, has been driven by periods of increased storm frequency and intensity associated with easterly and north easterly winds during periods of predominantly negative NAO. Hence, the development and decline of a major medieval port, can be shown to be climatically driven (storms), with impacts modulated by sea level rise, coastal evolution (spit development, sediment balance at cliff toe) and geology (erodibility of cliff line). Economic and social responses followed rather than controlled the physical processes and were inadequate in the face of periods of increased frequency and magnitude of storms.

5.0 Marine Archaeological Context

Relative to early (e.g. Doggerland, Fitch et al., 2005) and later periods there is a lack of information on the archaeological value of medieval sites that have been inundated or eroded by the sea (Fulford et al., 1997). In part this results from the perception that any remains will be "a strew of materials scattered over the sea bed" and of relatively limited archaeological value given a lack of context (Fulford et al., 1997). This is particularly the case for structures that have undergone a process of collapse down a cliff, followed by incorporation and transport within the beach and breaker zone (Allen et al 1997). However there are important heritage as well as archaeological value to submerged sites, where there exists contextual information in the form of historical accounts that enable reconstruction of the social, economic and urban geographies.

The heritage value of the Dunwich Town site is unique for a submerged settlement that spans the medieval period. This value stems from four main factors;

1. Extensive and documented archives for the Town dating back to early medieval period, including data on the urban structure, social structure, economic state, political structures and trade and relationship with hinterland, records of erosion and inundation.
2. Low lying Harbour area with associated sea defences and infrastructure – roll back rather than cliff recession and collapse suggests higher preservation potential.

3. Significant early and post-medieval structures exist that have preservation potential, including nine Churches, four Chapels, and two monasteries.
4. Old course of Dunwich/Blythe rivers provide important sedimentary record of the coastal regression and potential for preservation of early vessel remains. These may extend into the near shore as evidenced by periodic exposure of wooden piles from former harbour structures.

Collectively the combination of archived documents, maps and images provide important information on the nature of the town, however the full value of these, prior to the Ralph Agas map of 1587 is limited by the absence of a reliable urban geography. For example, the interpretation of periods of erosion recorded in documents prior to 1587, is hampered because we do not know the positions of the larger buildings – where they clustered or distributed. Did they lie on low lying ground towards the harbour or on higher land? The locations of these buildings would help historians to understand the many documented disputes between individuals from different parishes, as well as providing important context for the declines in economic value reported for each parish over the period 1280 – 1587.

Prior to the current project, considerable evidence existed that suggested the preservation of larger masonary remains and the potential for higher preservation in lower lying areas of the former city. This evidence is in the form of:

1) Diving surveys and the evidence from photographs document evidence that large structural remains can be preserved and remain close to the point of entry to the foreshore (Figure 4; & Bacon 1974). For example, survival of the ruins of more massive structures (churches/chapels / wells) is evidenced by the preservation of large sections of All Saints and St Peters on the sea floor after 100 and 320 years of submergence respectively (Bacon 1982).
2) Physically, the highest energy conditions within the breaker zone of the beach tend to result in scour around the larger blocks of masonry, resulting in their partial burial. Smaller fragments will be more widely dispersed and incorporated within the beach material following the model of Allen (1997). Off-shore, tidal and wave generated currents have less energy and are therefore less likely to disperse the larger stonework, but instead scour and accretion of sand is known to create periods of exposure and burial at the site (Bacon 1979).
3) The preservation of "soft" landscape features have been demonstrated by Institute of Oceanographic Studies surveys (e.g. Pleistocene or early Holocene river channels) under the surficial seabed sediments (Lees, 1978; 1980; Gaffney et al.,2007).
4) Documentary evidence strongly support the view that the cliff height reduced seawards (see sources cited in Parker, 1975, Comfort, 1994, Bacon & Bacon 1979), increasing the possibility of that some structures were inundated rather than collapsed. For example, Figure 9 shows a view of the Suffolk coast depicted on a Dutch chart of the East Coast, made in 1586 by Waghender (Suffolk Country Archives). Part of the chart shows the sea view of the coast together with the main landmarks. The view of the coastline at Dunwich shows a series of structures that can be corroborated against documentary sources and the 1587 map by Ralph Agas. These include the Conde, a wooden tower erected on Cock hill to assist in the identification of Herring shoals out to sea. Importantly the chart also shows three church towers. The rear one is almost certainly All Saints, and is located on top of a hill behind lower lying ground on which are shown the towers of two further churches. All Saints is known to have been situated on the highest land in Dunwich (Parker 1975; Bacon & Bacon 1979). In addition to this information, it is known from contemporary records, that the north and northeast areas around the quays were low lying. This area was in the Parish of St Martin, a church lost early in the storms of the 14^{th} century.

5) Recent exposure in 2005 of wooden piles on the foreshore to the north of the current car park that may have been associated with earlier attempts to constrain the position of the harbour and quays (Bacon *pers. comm.*).

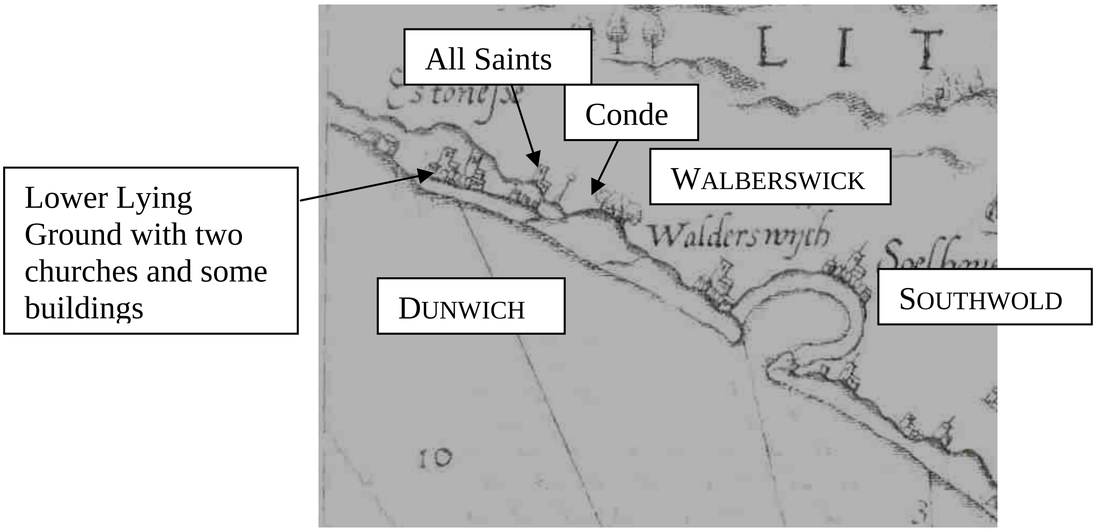

Figure 9: Dutch coastal chart showing the sea view of Dunwich made in c.1586. Lower lying land is shown on which churches and buildings are depicted suggesting that the evidence predates the date of printing (Photo Sear, 2003).

Investigation of the Dunwich site represents a significant challenge to underwater archaeology for three reasons: first part of the site lies buried beneath mobile sand/silt deposits (sediment depths are up to 3m, EA bathymetry 2003). Secondly, visibility across the site is notoriously poor (Bacon, 1982) and thirdly, the remains are often in a poor state of preservation after experiencing collapse from cliff retreat. However several factors suggested that a more detailed survey approach to the site was warranted. First, unusually, the post 1587 plan of the city is known, and can be positioned with relative accuracy. Secondly, extensive sea floor exploration by divers over the period 1971 – 1989; has confirmed the preservation of debris from some of the larger buildings and in positions similar to those marked on early maps (Bacon & Bacon, 1979) and thirdly, technological developments have improved the resolution and positional accuracy of underwater survey including sub-bottom profiling (Phaneuf *et al.*, 1998).

Prior to this project three types of seafloor survey had already been undertaken at the Dunwich site;

1) bathymetric surveys of various dates and coverage;
2) geological surveys of off-shore sediments, and;
3) diver surveys of the sea floor.

The latter has largely been undertaken through the Suffolk Underwater Studies (SUS) since the early 1970's (Bacon, 1988). Bacon (*pers comm.*) the diver with most experience of the site, and head of the SUS, conducted a trial Side-scan sonar survey of the St Peters Church site. He confirmed that structures were visible above the level of the sea floor. In addition Mr Bacon had confirmed that at times, structures project 0.2+ metres above the seafloor and hence would be detectable. A summary of the underwater exploration of the Dunwich town site to the time of this geophysical survey includes the following:

- Reconstruction of previous topography, including former river channels (Lees, 1979; 1980).
- Identification of the remains of historic buildings including four possible Church structures and one chapel (Dunwich Museum; Bacon & Bacon 1979; Bacon 1982).
- Confirmation of the potential for side-scan sonar and multi-beam echo-sounder survey for detecting and mapping some of the larger extant structures of the former city of Dunwich.

- Use of high resolution echo-sounding equipment as part of a TV documentary in 2001 showed some possible structures on the seafloor.

6.0 Aims and Objectives

The aims of the Dunwich 2008 project were to undertake a high resolution, non-invasive multi-beam, sidescan and sub-bottom profiling survey of the former city of Dunwich in order to determine the archaeological potential at the site and to make this information available to the public and other researchers. This overall aim was broken down into four key objectives:

1. To evaluate the value of historic mapping in supporting the relocation of major buildings within the former city of Dunwich using remote underwater survey.
2. To evaluate the potential of integrated multi-beam, sidescan and sub-bottom profiling for visualizing structures associated with the former medieval town of Dunwich.
3. To determine the location and extent of remains within the former city that lie exposed on the sea bed or partially buried beneath the inshore sediments.
4. To document and publish the results of the project for display in the Dunwich Museum, and to make the data available to the public and other researchers.

7.0 Methods

In this section we outline the methods used for deriving the cartographic data used to define the survey area and (post 1587) locating and provisionally identifying ecclesiastical buildings.

7.1 Cartographic Analysis

The approach adopted follows standard cartographic procedures (Longley et al., 2001). The sequence of maps available for Dunwich were screened to determine those that were of sufficient cartographic accuracy to take forward for georeferencing, from those that were inaccurate yet contained important geographical information. Within the latter, were series speculative reconstructions of Dunwich prior to the earliest existing accurate survey undertaken by Ralph Agas in 1587. These included a reconstruction by the Dunwich school teacher Hamlet Watling c. 1852 of the town (Figure 10), a reconstruction by Chant (1986) and one by Parker (1976).

Figure 10: Example of a conjectural reconstruction of Dunwich. Hamlet Watling Map drawn c. 1858 and purporting to be a copy of an earlier map of c. 1300. Largely based on Ralph Agas map of 1587.

All were based on the 1587 Agas map, and used historical documents to attempt a reconstruction. A decision was made to georeference these maps with the sole purpose of defining the geophysical search area since they summarize the available documentary evidence for the extent of the town.

Although Ordnance survey maps exist for Dunwich back to 1882, these were not used for guiding the survey since by that time only the position of one of the lost churches (All Saints) was marked (it's location was taken from the 1882 OS 1:10560 map). Rather, the maps of the lost town were constructed from the 1826 Tithe map and 1587 Ralph Agas map. In addition, a map of the debris fields located by Stuart Bacon and associated divers over the period 197x – 1989 was made available to the project. These maps were based on compass bearing and taped offsets measured from known points on the cliff line (Bacon pers. comm.). The extent of the debris on the seafloor was measured using measured distances from a vertical line attached to a shot. The position of the line was known and the taped offsets from this used to map out the debris fields. In the case of All Saints and St Peter's, a metal grid was laid out over the site and used to map the extent of the ruins. Positional accuracy was limited by the relatively small number of control points available from the map. Table 2 lists the maps selected for georeferencing and summarizes their use in the geophysical survey.

Map	Basemap	No. GCP/No. Test points	RMS Error +/- (m)	Accuracy +/- (m)	Map Use
Bacon (198x) Diver survey map	OS Landline 2000	10 / 5	9.340	11.241	Location of All Saints, St Peters, and unidentified debris.
1826 Tithe Map	OS Landline 2000	23 / 5	8.203m	9.698	Location of All Saints
1587 Ralph Agas Gardner (1754)	OS Landline 2000	10 / 6	10.114	13.311	Location of buildings post 1587
1300 Chant (1986)	OS Landline 2000	12 / 5	38.357	49.708	Define Survey Area Define Potential Building Location
1280 Parker(1975)	1587 Georeferenced	10 / 4	19.882	23.686	Define Survey Area Define Potential Building Location
1300 Hamlet Watling (1858)	1587 Georeferenced	10 / 4	28.225	34.304	Define Survey Area Define Potential Building Location

Table 2: Summary RMS errors and positional accuracy for different maps georeferenced against the OS 2000 Landline. The resulting maps were used for guiding the geophysical survey.

The absence of any topographic data prior to the Ordnance Survey of 1898, made it impossible to account for terrain effects on position, as would be done with Ortho-rectification, Thus the georeferencing was only able to apply planimetric shifts. In reality, the total topographic variability is less than 20m across the site so the positional errors associated with this constraint were therefore assumed to be negligible.

The process of georeferencing the maps is shown in Figure 11. All the historical accurate maps were converted into standard WGS-84 projection coordinates. Each map was scanned at 600 dpi and the digital raster image was used to identify a range of Ground Control Points (GCP's) that were common to both the historical map and the Ordnance Survey Landline 2000 basemap which was used to derive the accurate coordinates for the chosen GCP's. The position accuracy of the Landline map is estimated at 1.1m (Ordnance Survey 2009). Georeferencing was

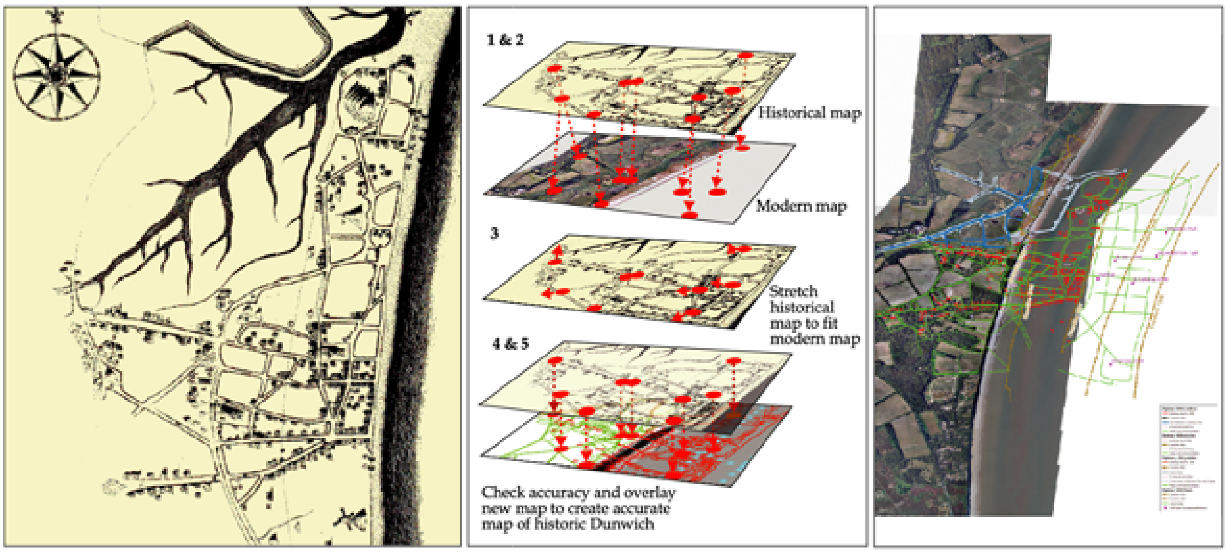

Figure 11: The process of geo-rectifying historic maps to bring them in to modern coordinate systems. Stage 1 – scan and digitize maps. Stage 2, select features common to modern and historical maps, stage 3, rubber sheet map to fit modern coordinates. 4 – Measure accuracy. 5 Overlay maps to create accurate map of historical Dunwich.

performed using a first order polynomial transformation with RMS-errors ranging from 8.2 – 49.7m (Table 2). The georeferenced maps were then overlain with the Ordnance Survey Landline 2000 data to check the alignment of features found in both data sets. If alignment offset was unsatisfactory, georeferencing was repeated with other reference points until alignment errors were as small as possible given the limitations of the mapping (Theiler & Danforth 1994). All the processing was undertaken within ESRI ARCGIS 9.2 using a minimum of 10 GCP's (Hughes et al., 2006). The difference in location between the GCPs on the transformed layer and base layer is often represented by the total root-meansquare error (RMSE) (Hughes et al. 2006). The RMSE for the whole image is the sum of the RMSE for each coordinate divided by the square root of the number of coordinate pairs. These values are given for each map in Table 2. However, the RSME is not a true measure of accuracy, but rather a measure of the georectification process (Hughes et al. 2006). The position accuracy is more appropriately determined by comparing the positions of points between the georectified image and the base map. Owing to the type of maps available for Dunwich, the numbers of independent position points was limited to a maximum of five. Table 2 shows that the positional accuracy is similar to the RMS error, and smallest for those maps that were used for identification of the targets found on the seafloor during the geophysical survey. The values for mapping accuracy are relevant to subsequent discussions concerning the precise origin of the remains found on the seabed during the geophysical survey.

7.2 Geophysical Survey

The geophysical survey was conducted by EMU Ltd. using the vessel *Emu Surveyor*. The *Emu Surveyor* was mobilised for the geophysical survey at Burgh Castle, Great Yarmouth on 4th June 2008 with survey operations commencing out of Southwold Harbour on 5th June. The survey was completed on 7th June and vessel demobilised. The survey was designed to collect contemporaneous swath bathymetry and dual frequency sidescan data from across the whole survey area. In addition, a series of four sub-bottom profling transects were taken to determine the extent of deposition over the site, and hence the potential depth of archaeological remains from the medieval town.

The mapped datasets were used to define a search area for the geophysical survey, and a series of potential targets (ecclesiastical buildings). These were loaded into a GIS on board the *EMU Surveyor* and used to guide the subsequent sidescan, swath bathymetry and sub-bottom profiling (Figure 12). Positional data were provided by a Hemisphere Crescent DGPS system. This receives corrections from the EGNOS differential network via satellite and Trinity House differential stations. This enables the location of seabed information collected by on board sensors to be determined with a high degree of accuracy, typically 2-3 m. The DGPS receiver was configured to receive corrections from the EGNOS differential network via satellite. In the event of loss of differential signal the receiver could be configured to receive corrections from the beacon system operated by the General Lighthouse Authority.

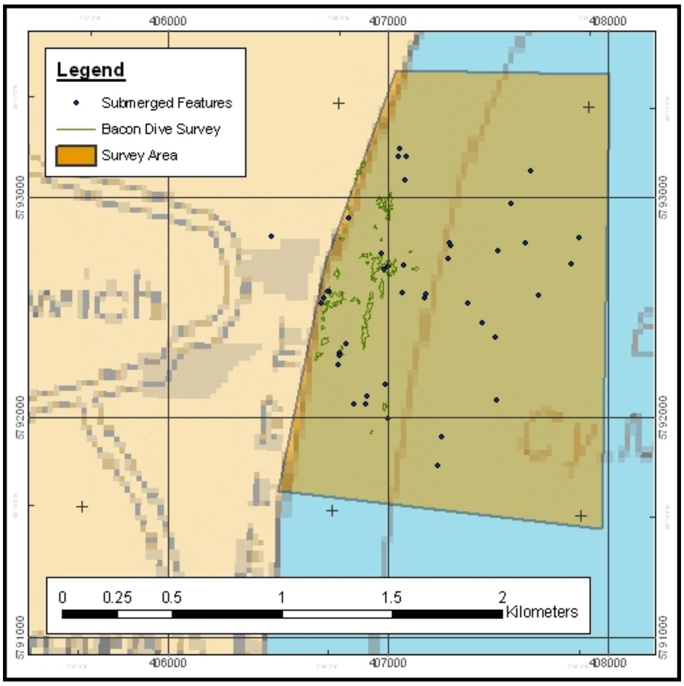

Figure 12: Survey area and positions of potential submerged features (targets) used to guide the geophysical and hydrographic surveys.

At the start of the survey the navigation system was checked against a known reference point. DGPS positions were logged by QINSy software at 1 second intervals for the geophysical and hydrographic survey. Data quality was continually monitored and the system was set to reject position solutions which did not meet the accuracy requirements (< 3m RMS). In the event all positional data fell within this limit.

Swath bathymetry was collected using a fully motion-aided Reson Seabat 8101 multibeam echosounder, a Klein 3000 sidescan sonar system and an Applied Acoustics 200 J boomer system. Tidal information was acquired in the form of Post-Processed Kinematics (PPK) recorded using a Leica GX1230 system and post-processed with RINEX data. All data are referenced to the WGS84 datum and the UTM Zone 31 North projection. The vertical reference for the bathymetry data is to Chart Datum at Southwold. All relevant instrument offsets were measured before the survey commenced and entered into the QINSy version 8 software. Attitude and motion were measured by the MARHS system giving heave, roll, and pitch data. This information was fed directly into the QINSy system for real time corrections of the bathymetry. The swath system was calibrated prior to the survey with a standard patch test operation. This revealed the fixed errors in heading, pitch and roll and also the time delay in the position data. These data were applied in the post-processing.

Data were collected across the survey grid along a line plan designed to give maximum coverage across the site. High tides were utilized to give data as far inshore as was safely possible. The bathymetry data was reduced to Chart Datum at Southwold using Post-Processed Kinematics (PPK) tidal heights. Sound velocity profiles through the water column were taken at the start and end of the survey and applied to the data online. Post-processing was performed by Emu Ltd using QINSy software. At this stage all corrections and filters were applied including the patch test calibration results, removal of outliers with automatic and manual filtering and tides. The cleaned data were then gridded and exported for viewing in ESRI ArcGIS software. Positional accuracy for the swath multibeam was 3m.

Throughout the sidescan survey the Klein 3000 sonar was operated at 400 kHz with a range set at 75m. The surface towfish layback was 25 m. The higher frequency sidescan provides greater resolution of sea bed features and is therefore the preferred frequency for archaeological surveys (Laferty *et al.*,2006). The depths experienced at the Dunwich site are within those identified as optimal by Quinn et al., (2005). All layback values and other relevant settings were recorded in the survey logs. The sea bed features identified in the sidescan sonar data have a horizontal accuracy of approximately 10 m. Inaccuracy is caused by the path of the tow fish not being directly behind the tow point of the vessel, primarily due to tidal currents and differences in cable curvature or tension caused by different boat speeds and use of the layback method of positioning. The Klein 3000 sidescan is a dual frequency system with a pixel resolution of 3.12cm for both high and low frequencies.

At the beginning of the survey the boomer system was tested to determine the optimum site and project specific settings of the system. The trigger interval was set at 250 ms with a sweep length of 50 ms to provide the highest possible resolution of the near-seabed object detection and shallow geology. The boomer catamaran was deployed 20 m astern and layback was subsequently applied to the navigation (GPS) data to provide a boomer XYZ trackplot. All data were logged in the Coda DA2000 system

7.3 Post-Processing the Side scan data for the Church sites

Initial processing of the Dunwich data was done at 50cm for the whole site coverage, but a higher resolution was required for the target areas (St Peters and St Nicholas church sites). To take account of the difference in resolution it was decide to use a grid resolution of 6cm and to interpolate between pings in the along track direction. In the across track direction the raw data provided 2 pixels per 6cm and thus these were averaged. This also has the advantage of increasing the signal-to-noise ratio and improving the imagery, as it is often characterized by high noise content. Simple interpolation often gives a false blocky and smoothed appearance but the interpolation used here added a small amount of random variance to the interpolation based on the surrounding pixels and thus the eye is not drawn to high and low spatial frequency content in the imagery.

The actual processing of the sidescan is a multi-stepped process. Initially two areas were defined that approximately covered the church sites of St Peters and St Nicholas. The data is divided into near-straight line sidescan swaths that cross each specific area. These swaths are then processed individually with the following algorithms to geometrically correct and radiometrically enhance the imagery. This is all done before the geographic registration of the imagery and thus can take account of the sidescan acquisition characteristics. The processing steps used were:

1. Merging of ship navigation and cable data with the imagery and calculation of the sidescan position using an inertial navigation algorithm. A navigation file contains ship position and towed cable values and a layback of 6.3 metre was assumed (calculated from measuring overlapping imagery of a common feature and is assumed to be the distance from the GPS receiver to the zero point of the cable length). Various assumptions are applied: the cable is assumed to be straight, the cable value is assumed to be correct, zero cable is set when the vehicle enters the water, and layback includes the distance between the GPS receiver and the point where the cable enters the water.

2. Set the heading values to the track heading. A five second (50 ping) smoothing filter is also applied to the heading values. The heading values are used in the geographic registration process to angle each ping relative to the sidescan position, and this does not take account of any crabbing of the sidescan vehicle.
3. Slant-range correction assuming a flat bottom. This is a simple Pythagoras calculation assuming that the seafloor is horizontal across-track and sound velocity is $1500ms^{-1}$. Each pixel is 6cm and any pixel gaps on the output file are filled by pixel replication.

4. Median filter to remove any high or bright speckle noise. A threshold is defined for the maximum deviation for adjoining pixels over a small area above which the pixel is replaced by a median value.

5. Dropout removal for large imagery dropouts. When the vehicle yaws excessively it is possible for the transmit and receive phase of each ping to be angled apart. If this exceeds the beam sensitivity value (0.8º) little or no signal is received, creating a dark line on the imagery. The program detects the dropout lines and interpolates new pixel values. If more than 7 dropouts are present concurrently (0.7 seconds) no interpolation is done.

6. More dropout removal but for smaller, partial line dropouts. If more than 7 partial dropouts are present concurrently (0.7 seconds) no interpolation is done.

7. Across-track equalisation of illumination on an equal range basis. This assumes that the backscatter from a particular range should average a given amount for each piece of data. The near-range pixels and far-range pixels are generally darker than mid-range pixels. This is due to the transducer's beam pattern and differences in seafloor backscatter response in terms of angle of incidence. The result of this is to amplify the near and far-range pixels by about 1.5 and reduce the mid-range pixels by 0.8. These values are calculated from the individual segment being processed.

8. As the track spacing was set to between 25 and 35m the amount of overlap on the sidescan imagery (with a range of 75m) was considerable. A track spacing of 135m would have sufficed for a sidescan survey alone, however as multibeam bathymetry was also being acquired simultaneously the tighter track spacing was a necessity. Therefore to improve the imagery only the eastwards looking imagery was considered. This helps with data overlap and creates a uniform shadow direction.

The data was also found to have relatively low pixel variation. The system allows for pixel values between 0 and 65535 whereas the actual data seemed limited between 0 and 60.

Adjoining vehicle swaths are then added segment image by segment image to the final map. As long as the segments do not overlap in geographic position the segments can be added onto the same map. However if two segments of data overlap a new map is created. If there are several segments in a map area it is quite possible to end processing with 2 or 3 maps (or layers) holding the non-overlapping segments, though there can be up to 10 layers (depending on the track lines). These layers are then stacked together and viewed in 3 colour bands (red, green, and blue). If there are more than 3 layers the user must make a choice of which layers to view at any one time.

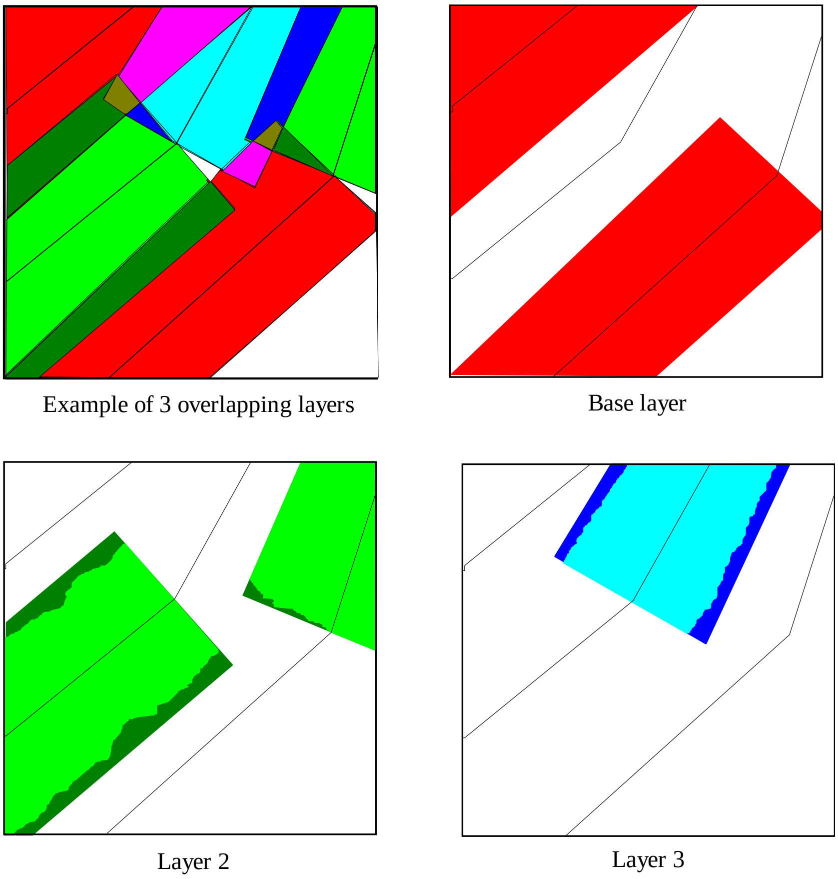

Figure 13: Example of three overlapping layers requiring stenciling and mosaicing. The overlaps of the three layers are shown in the complimentary colours. White represents no data. The trimming required on layers 2 and 3 is shown as the darker coloured areas.

The Dunwich data typically had 8 layers of overlapping data showing the abundance of data available (even after only showing one side of the sidescan). The data was trimmed and mosaiced to show the best imagery. This generally meant removing the near range nadir pixels and the very far range edge pixels. Imagery cannot be averaged from one track to another as there are so many differences in actual acquisition values, such as angle of insonification, angle of incidence on seafloor and the micro-roughness variation with angle. Results from averaged imagery often shows few or blurred features and should be avoided.

Once imagery has been mosaiced then image processing can used to enhance viewing. If viewing on-screen and there are more pixels in the imagery than those available on a monitor it is useful to average the hidden data rather than just sub-sampling the large file. This again increases the signal-to-noise ratio in the imagery. This is why the 50cm resolution imagery appears much smoother than the 6cm resolution imagery.

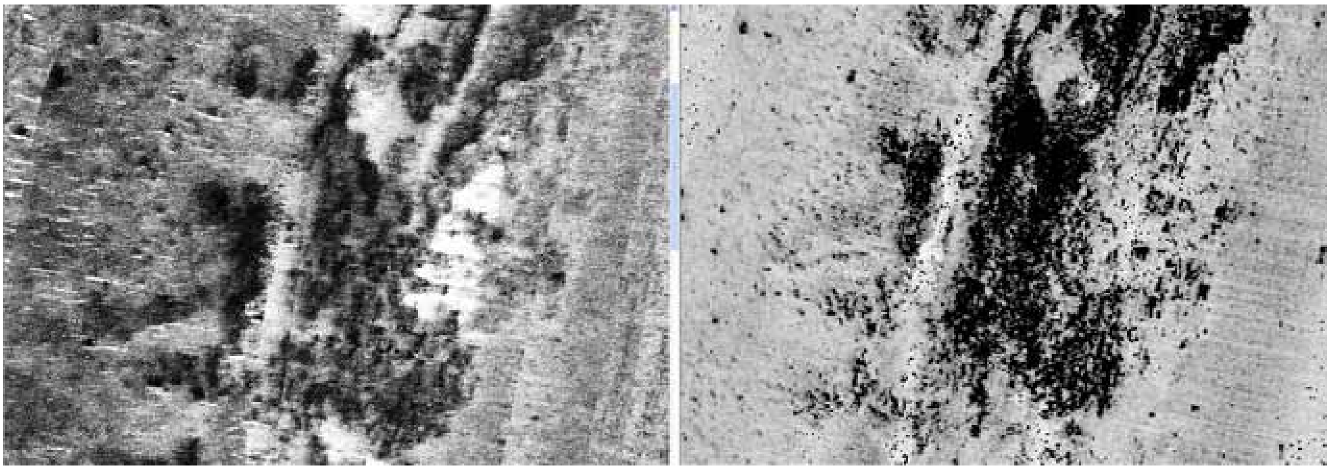

Figure 14: Sidescan sonar enhancement. The right hand image shows 50cm resolution of the original survey. The left hand image shows the enhanced resolution (6cm).

Figure 14 shows an example of 50cm resolution processing (right) and the equivalent area processed and enhanced at a resolution of 6cm (left). The area shows the site of the church of St Peters. The area of each image is $600m^2$.

7.4 Diver Survey

A series of diver ground truthing surveys were undertaken in order to determine the composition of the features identified by the hydrographic survey. An underwater video camera with integral lighting system was used to take film and photographic images of the features. Samples of lose stone from each site were recovered for identification of provenance and evidence of human use. A total of nine individual stones were recovered from positions immediately adjacent to stone structures. Four stones were recovered from the St Nicholas site and five stones from the St Peters site. These were kept in seawater and examined on shore. Three stones from the St Nicholas site had remains of mortar attached to them. A small sample of mortar (5g) was sent off to Sandberg LLP labs for analysis together with an 8g sample of lime mortar recovered from the collapsing southeastern section of Greyfriars monastery perimeter wall. The samples were prepared and analyzed using a combination of hand and chemical separation techniques and the chemical content and grainsize compared.

A series of 11 dives were conducted on the 19th , 21st and 22nd of September 2008 totaling 345 minutes. Dives were controlled by the diving supervisor, with one diver in the water at a time and another acting as a standby throughout. The dives were conducted over the two main target sites. The position of the centre of each target was occupied using GPS and a weighted shot line with surface buoy was positioned as close to that point as possible. Dives took the form of a descent to the bottom followed by a circular offset survey around the shot point out to a maximum distance of 5m. The divers were attached to the shot line at all times. Dive times were restricted to a 2 hours period of slack water on the turn of the tide. Table 3 summarizes the dives undertaken at the site.

Date / Site	**Max. Depth (m)** (Top of Spring tide)	**Surface Sea Temperature**	**Sea State**	**Visibility at bottom**
19/09/08 St Peters Church St Nicholas Church	8.4m	18°C	Calm	Zero with torches
21/09/08 St Peters Church	8.4m	18°C	Calm	Zero – 10cm with torches
22/09/08 St Peters Church St Nicholas Church	8.4m	18°C	Calm	Zero – 30cm with torches

Table 3: Diver summaries for the ground truthing survey of the two Church sites. Divers were from Historic Wreck Recovery.

8.0 Results

8.1 Cartography

The digital mapping of the Dunwich town site is shown in Figures 15, and 16. These show the historical accurate map (Figure 15) back to 1587, and the conjectural mapping (Figure 16) of the earlier town. The mapping is overlaid on colour orthorectified aerial photography dated to 2006 and provided by the Environment Agency of England & Wales. The mapping demonstrates the accuracy of the georectification; the current course of the Dunwich river is shown to follow the historical map, only substantially reduced in width. This reflects the reduction in tidal influence and the reclamation of the former estuary salt marshes during the intervening period. The harbour area (the Dain) is shown to the north of the town.

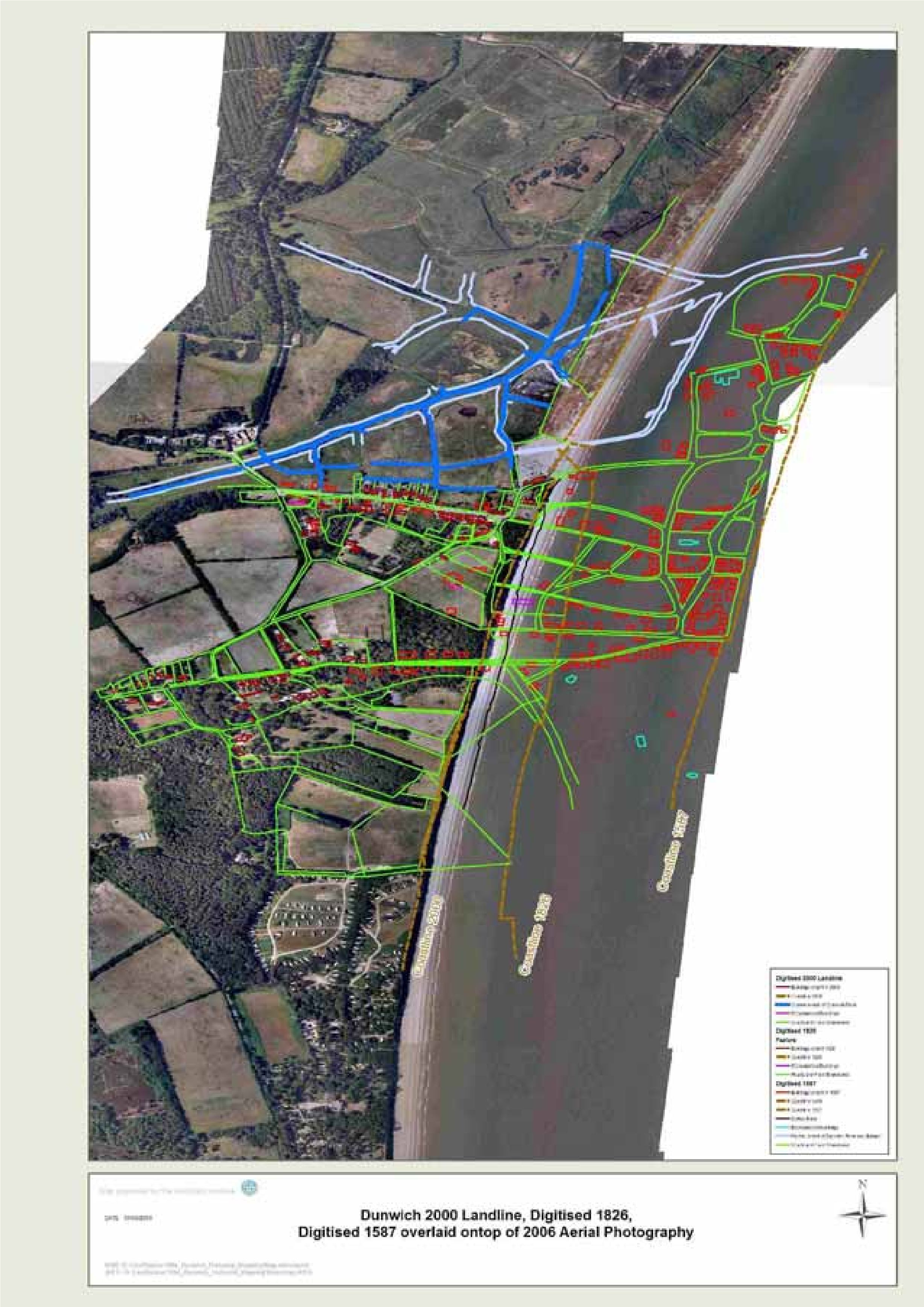

Figure 15: Dunwich Town 1587 digital map. Buildings recorded on Ralph Agas map of 1587 are shown in bright red, and ecclesiastical buildings in light blue. Ecclesiastical buildings present on the 1826 tithe map are shown in purple and buildings shown on the OS 2000 Landline maps are darker red. The

present and former Dunwich river is shown in blue. Shrinkage of the river is evident, and demonstrates the reduction in tidal influence in the intervening period. Shoreline retreat is also shown.

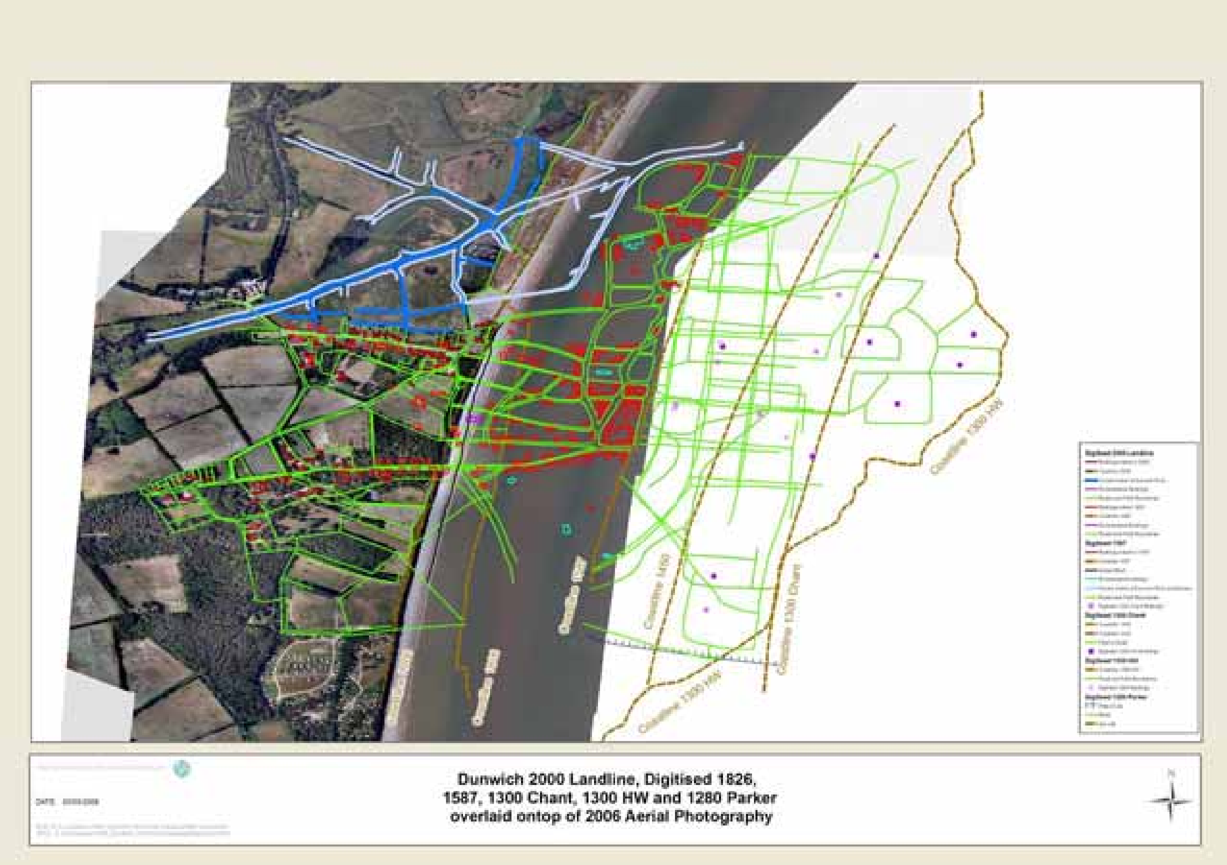

Figure 16: Dunwich Town c.1280 digital map. Buildings recorded on Ralph Agas map of 1587 are shown in bright red, and ecclesiastical buildings in light blue. Ecclesiastical buildings present on the 1826 tithe map are shown in purple and buildings shown on the OS 2000 Landline maps are darker red. The pre-1587 town is based on the reconstruction of Chant (1986) and Parker (1975).

The position of eight ecclesiastical buildings are shown in Figure 15, as depicted on Ralph Agas map. Assessment of the documentary and mapped evidence shows that Black Friars monastery was in ruins, similar to the present state of Greyfriars Monastery. The Knights Templar church of St Mary is also shown on Agas map as a ruin. The Church of St Peter, is shown intact, as are All Saints Church and St Katherines Chapel between the Cock and Hen hills. The location of St Nicholas church is shown to be located close to the shore on a redrafting of the Agas map by Tom Loader (Suffolk County Archaeologist 1979). This position is reported in Gardner (1754), and also by Watling (1858). However, the precise position of this church is not certain, although the churchyard boundary was known to be adjoining the eastern perimeter of Blackfriars.

Pre-1587, the geography of the town is less certain. Documents report relative positions of some buildings. For example, St Johns church is known to have stood seaward of St Peters Church on the eastern side of the Market place (Gardner 1754, Chant 1986, Comfort 1994). St Leonards is reported to have been located east of the Dain (the harbour area) and seaward of St Johns (Chant 1986) giving it a position in the north east of the town. St Martins was located in the east of the town, though again the precise position is unknown. The location of St Michaels and St Bartholomews churches are completely unknown, but their loss prior to 1328 suggests they were further east of any of the other churches. The association of St Martin (Martinmas) and St Michaels (Michalmass) with the herring fishing industry might reasonably place them closer to the fishing harbours in the north east of the town. On the basis of the documentary evidence, the reconstructions generally show a town elongated north-south with a concentration of settlement around the northern harbour and the market place. In part this reflects the absence of buildings shown in the southern part of the town in the Agas map of 1587. A crude estimate of the width of the town can be obtained by extrapolating the average long term erosion rate (1m yr^{-1}between 2006-1587) back to the time of the earliest recorded loss (c.1287) which gives a width of between 700 and 800m. This would support the elongated model for the town at its height, however, the non-stationarity of storms and erosion reported earlier calls this estimate in to doubt. The conclusion must remain that pre-1587, the geography of medieval Dunwich is largely unknown and at best uncertain. Post 1587, we can be more certain, and subject to cartographic errors made at the time of survey and mapping, the locations of the buildings shown on the Agas map, do reflect and accurate representation of the former town at that time. However the distribution of all buildings recorded on the map may not reflect those of pre-1587, since large open spaces exists in the south and southeast of the town which may be a reflection of the economic decline and outward migration recorded in the period prior to the date of survey.

8.2 Geophysical Survey

The spatially integrated geophysical survey results produced the first detailed map of the seabed over the Dunwich town site. When integrated with the cartographic analysis this provided a method for identification of geophysical targets.

8.2.1 Bathymetry and Sediment over the Dunwich town site

The results from the combined multibeam, sidescan and Boomer surveys revealed the site of the town to be covered by an inner sand bank with depths of fine sediment up to 3.3m, sloping down to a platform covered for the most part sand up to 2.7m deep. The composition of the sand can be estimated from IOS sediment grab samples (Lees 1979), diver surveys undertaken by Bacon and others, and from the project diver surveys. All report the fine sediments to be composed of brown coloured fine sands (0.12-0.17mm Lees 1979). To the north and north east of the town site, the bed contains areas of peat, and clay overlain by a thin veneer of fine sand. The IOS studies (1975-1979) were unable to obtain sediment samples over the town site, but report the area of the town as probably being underlain by sticky blue clay (estuarine sediments?) containing organic matter and iron stained. The data from this survey appears to show a progression from sandy gravel mixed beach materials, grading into an inner sand ridge (Figures 17 & 18).

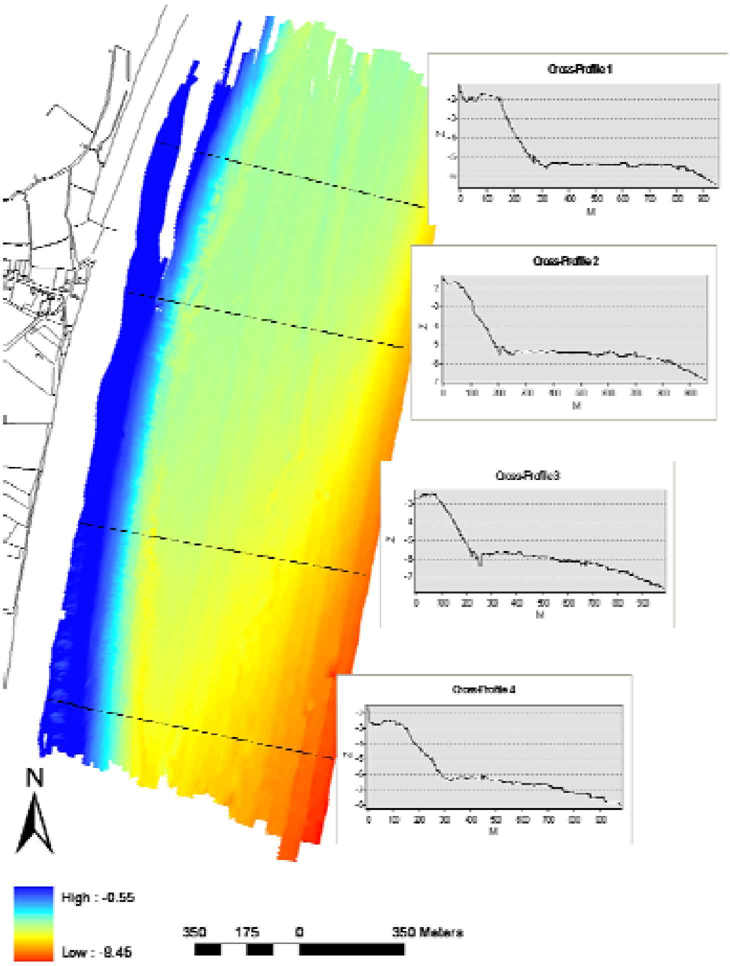

Figure 17: Bathymtery and cross-profiles of the Dunwich town site, derived from Multibeam survey (values are in metres O.D. NewLynn). The shallowness of the inshore area is shown in this Figure, with depths reaching a maximum of 10.4m in the southeast of the survey area. The survey was limited shorewards by rapid shallowing on to an inner sand ridge, before descending into a small trough at the foot of the beach. Cross-profiles show how the seafloor over much of the town site is a flat platform, overlain by sand, that covers any archaeology from the earlier (pre 1587 town).

Haskoning (2008) identify this as a swell-induced bed ridge and trough system. This ridge of sand descends onto a hard bed composed of pockets of clay (see IOS report Lees 1980), with exposures of intercalcated sands and clays typical of the Norwich Crag. The area of exposed bed (no sand cover) has a complex microtopography with linear (north-south) aligned escarpments of up to 0.5m height, and depressions bounded by shallow escarpments. The main exposed archaeological finds lie in this area. The clay/crag surface has a veneer of fine sands,

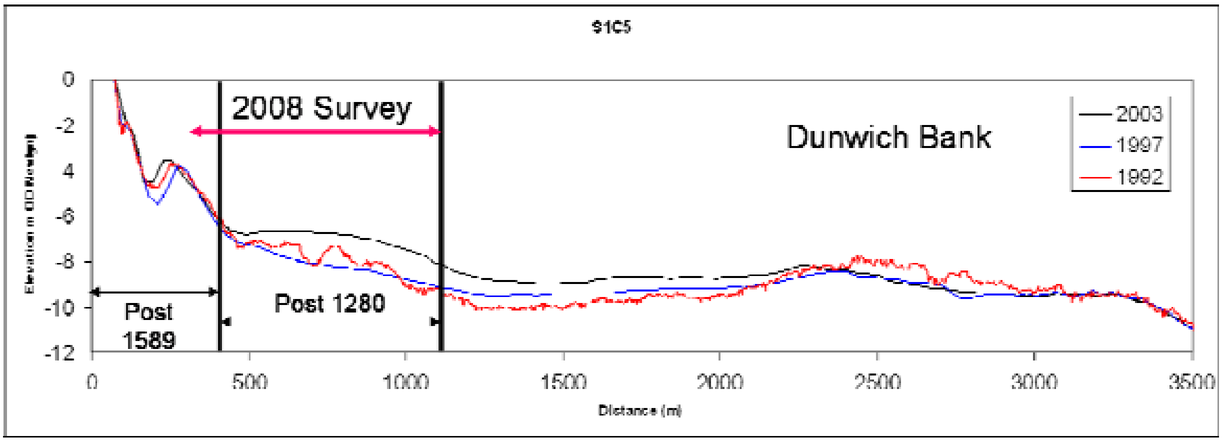

Figure 18: Environment agency bathymetric profiles showing the accumulation of fine sands over the earlier town site and the progression of the inner ridge since 1997 towards the land.

and patches of gravel that are perhaps associated with the decomposition of the church sites. Seaward of this area, the sea bed is essentially a flat plain of sand, dipping gently seawards and to the southeast. This then climbs on to the Dunwich bank as shown in the cross-profiles produced by the Environment Agency (Figure 18).

Two Environment Agency cross profiles pass over the town site. These provide some information on the accumulation of fine sand over the site of the town since 1992. Figure 18 shows the profile that cuts across the centre of the town site. The main features over time appear to be oscillation in the position of the inner ridge and the general trend of accumulation of fine sand over the site particularly since 1997. This is supported but the Multibeam and Sidescan sonar data for this area which shows a plain of featureless fine sand. Over the same period the amplitude of the larger Dunwich bank has decreased as the centre of the bank has eroded.

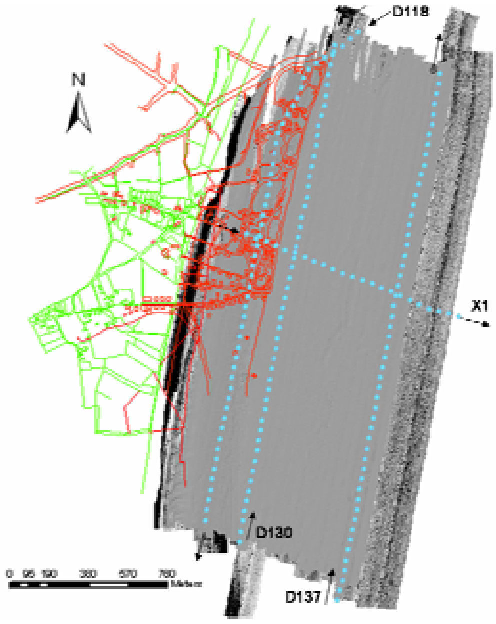

Figure 19: Boomer sub-bottom profile transect lines and directions of survey.

The boomer data collected for the Dunwich 2008 project produced four transects (Figure 19). These showed a shallow layer of sand and strong sub-surface reflections just below the surface. These are interpreted to represent the fine sand layers lying over more consolidated quaternary deposits, that in this area are comprised of intercalcated sands and clays and clay (Lees 1980). To produce a measure of the fine sediment depth, the Boomer survey transects were sampled every 50m (transect X1) and 100m (transects D118, 130, 137) and the depth from the surface reflection to the lower sub-bottom reflection was obtained. Figure 20, shows the resulting fine sediment depths along each transect. Fine sediment depths across the town site (X1) are up to 3.3m where the inner sand bank covers the western area of the town that includes the sites of the Knights Templar Church and St Katherines Chapel (post 1600 AD). Thereafter, sediment depths decrease, reaching a minimum in a narrow zone where the inner sand bank ends. As Figure 20a shows, this is the region where the ruins of the church of St Nicholas and St Peters are exposed above the bed. The site of Blackfriars monastery lies in an area where fine sediment depths are between 1.2-0.67m depth. Seawards (east) of this zone, sediment accumulation increases, resulting in an average depth of 1.35m over the post 1280 area of the town, before increasing to 3.0m at 1km offshore at what might be the start of the Dunwich bank. The Site of St John's church (located approximately 130m east of St Peter's) lies under 1.7m of fine sediment.

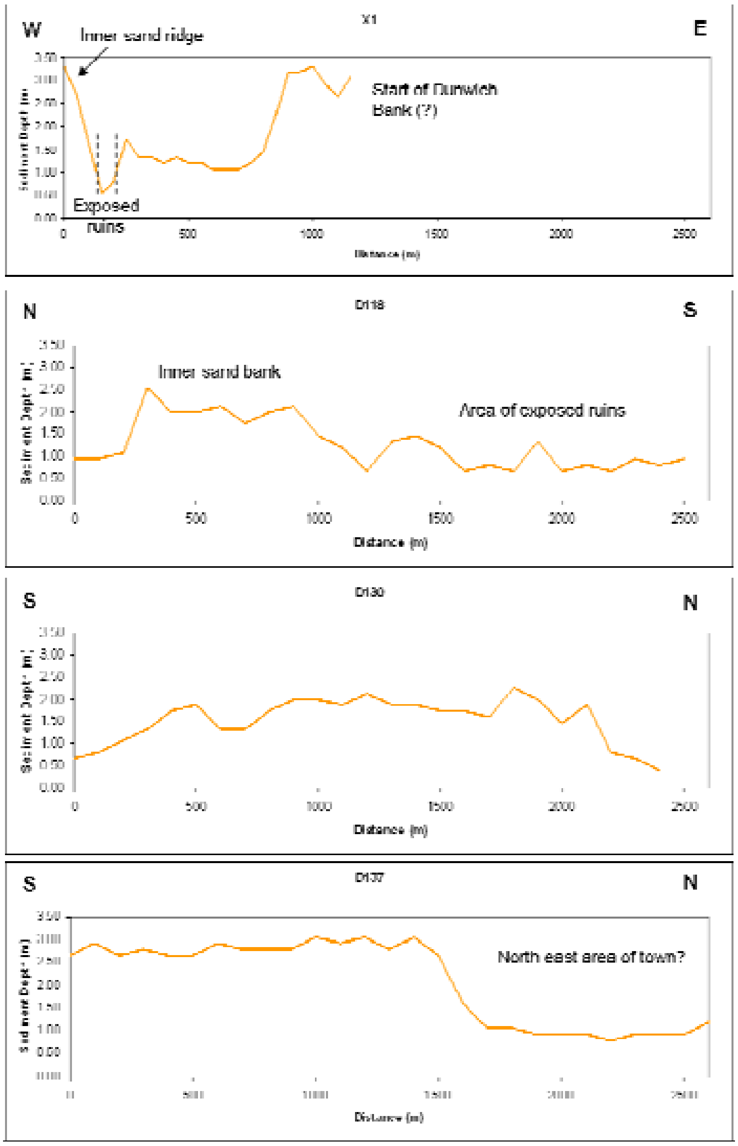

Figure 20: Boomer derived sediment depths along each of the Boomer transects taken over the town site. X1 is the west-east transect across the central part of the town and analogous to the profiles shown in figures 17 and 18 (EA Bathymetry and site bathy). Sediment depths appear to be highest under the inner sand bar, and in the outer (eastern) edge of the site. The area of thinnest sediment depth are over the northern area of the town and along a narrow region in the lee of the inner bank. Sediment depths over the central part of the town are between 1.2 – 2.0m.

At the time of survey, the earlier (pre 1500 AD) central and northern areas of the town lie under 1.20-1.65m of fine sediments, with the northern area (former harbour and river) under < 0.8m fine sediments.

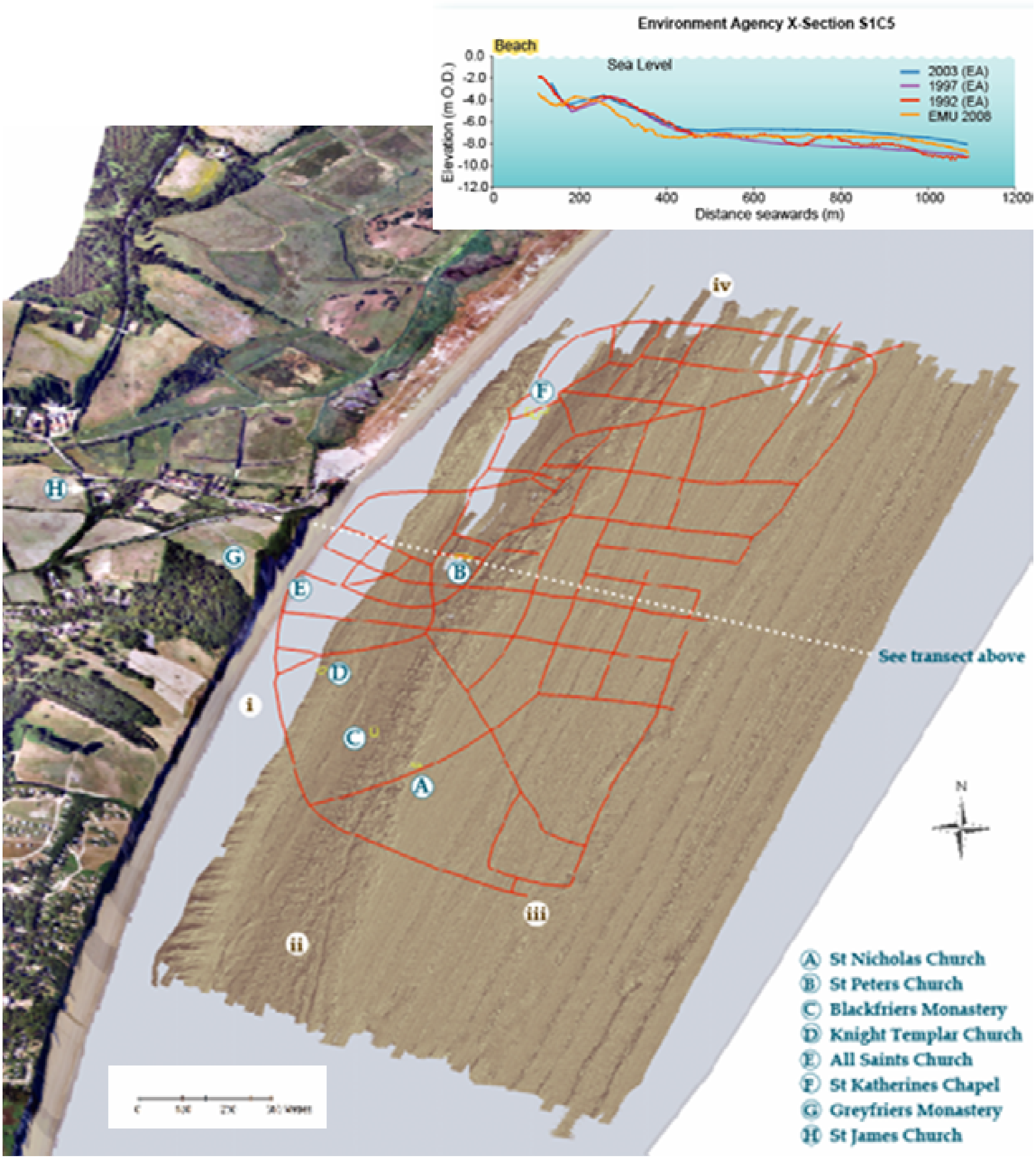

Figure 21: shows the seabed over the area of the former city as revealed by Multibeam sonar The data reveals three main features as you descend off the beach into the sea: i) an inner sand bank separated from the gravel beach by a small gully that parallels the beach, ii) an area where the tide scours the bed of sand and silt to reveal the underlying quaternary sediments and ruins, and (iii) a large plain fine sands that gently dips away to the south east. Further east, this rises into the larger Dunwich sand bank. The area to the north of the town was where the old Dunwich river entered the sea, and where the harbour area lies (iv). We have only partial data coverage is in this area.

Figure 21 shows the multibeam sonar data over the town site together with a transect across the whole site that corresponds to one of the Environment Agency profiles. This shows that the inner sand bank has moved landwards since 2003, and that the depth of the seafloor (fine sediment depth) over the town was lower at time of survey compared to 2003. As described above, the majority of the site of the town lies under the inner sand bank or under the fine sediment east of the scoured zone. No topographic features are evident over this area of the town, rather the site is a featureless plain of fine sand.

In the northern area of the town, towards the harbour and Dunwich river, the sea floor is again partly covered by sediments, but in the area with little sediment accumulation, a series of ridges and scoured basins are apparent, together with some isolated topographic features that might be of archaeological interest. Unfortunately coverage of this important area is poor and / or patchy (Figure 21 iv).

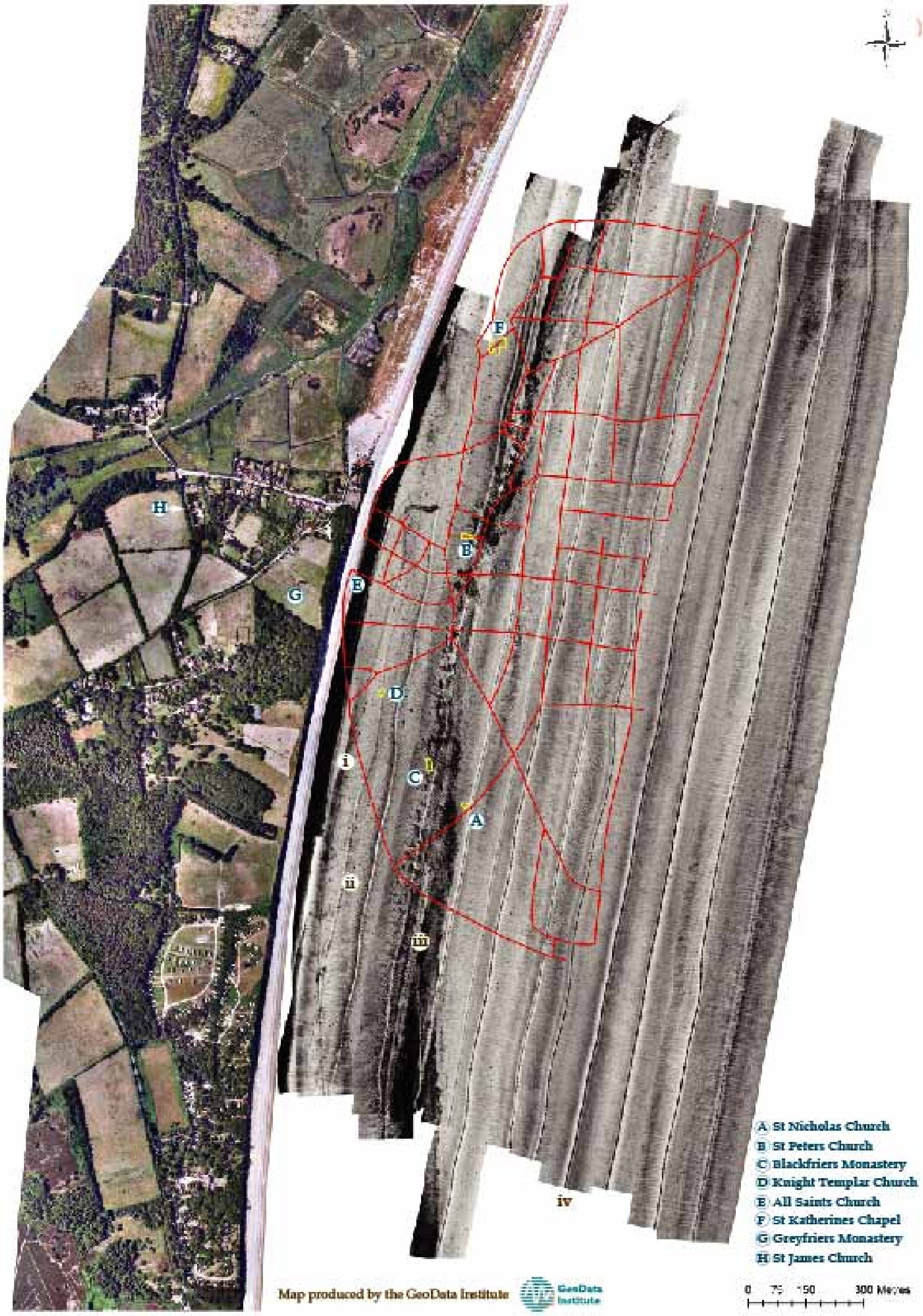

Figure 22: Sidescan mosaic over the town site. The relatively complex seabed in area (iii) is in contrast to the relatively featureless sediment covered area either side. Stronger returns appear as darker areas and occur where masonry, gravels and underlying clay and quaternary deposits are exposed.

Figure 22 shows the sidescan data for the whole town site. This revealed a complex seafloor in the zone of relatively shallow fine sediment along the seaward edge of the inner sand bank. This region is characterized by higher intensity sidescan returns associated with stronger reflecting acoustic materials. These are associated with building debris (gravels, small boulders of erratic material), exposures of underlying Quaternary geology (intercalcated sands and clays) and clays of possible Holocene age (Lees 1980). Other strong reflectors occur where the seabed slopes and the angle of isonification is normal to the slope. The darker band at the shore is partly an acoustic shadow resulting from the small gully at the toes of the beach, and acoustic interference from the waves breaking on the beach. In the north of the site, an area of darker reflection can be seen, that may be associated with deposits from the Dunwich river that is known to have been in this area.

8.3 Identification of Archaeological Targets from Geophysical survey

A conceptual model of the most probable structure of the remains of important stone buildings from the town was developed prior to the geophysical survey. This was based on the evidence already existing from photographs of the ruins of All Saint' church, diver surveys and an analogous site at Walton shore fort. This model hypothesized that:

- the ruins would be in the form of an area of rubble blocks of up to 1m height above the seabed, and of the order of between 1-4m in width or length
- the ruins were expected to show an accumulation of larger blocks towards the west, associated with the more substantial structure of the western tower, or at the centre where the church had a central tower (St Nicholas, St John, Temple).
- the position of the ruins were hypothesized to be offset towards the east from their original (mapped) location as a result of their collapse down the cliff
- the ruins were expected to show a dispersal towards the north-south (drift movement) and east (off-shore movement) during their period within the breaker zone of the beach.
- The ruins were expected to be discrete, and not to be widely dispersed, thus providing a clear area of complex sonar shadows and intense returns, associated with a complex topographic signal from the multibeam.

The multibeam and sidescan sonar surveys over the town revealed four potential targets that contained elements of the conceptual model. The positions of the fours targets are shown in Figure 23, in relation to the digital maps of the town, and diver-based surveys of Bacon (1979).
Three of the targets (T1, T2 and T4) closely matched the model, of which two (T1 and T2) were close to buildings shown on the digital maps of the town in 1587. These two targets were selected for further diver-based ground truthing.

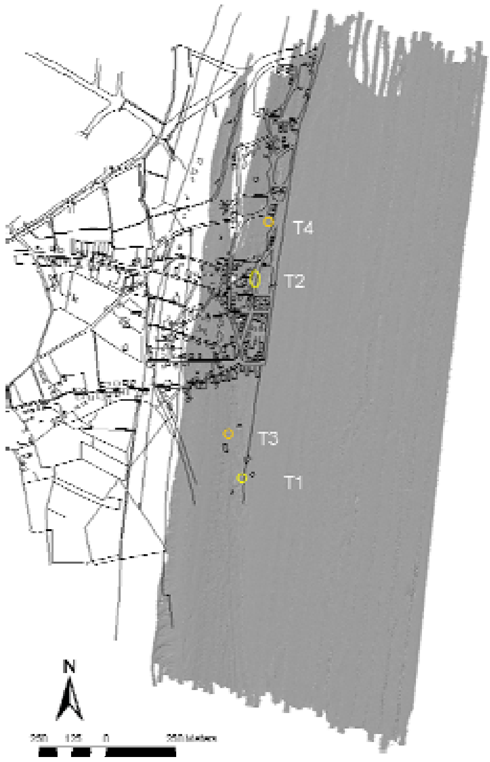

Figure 23: Multibeam hillshaded topography over the town site. The four main targets are shown, colour coded yellow for those that most closely match the expected model of archaeological structures, and orange for those that are not as close to that model. The areas of ruins mapped by Stuart Bacon during his dives on the site are shown as black pecked lines.

8.3.1 Target 2

Detailed images of Target 2 are shown in Figures 23 and 24, below. Target 2 lies 48m east and 20m north of the centre of the mapped position of St Peter's church, and 18m east of the eastern margin of the error box, and within the error box to the north. Bacon's (1979) diver based survey of St Peter's ruins from 1973 are shown to be co-located with the digital position for the church on the Agas map of 1587, suggesting either 1) the ruins revealed in the 2008 survey belong to another structure (St John's Church?) or 2) the Bacon ruin position is inaccurate. The latter is assumed in this instance given the use of weighted rope and compass bearings to obtain the position, and map accuracy of +/- 11.2m. In addition, comparison with his position of All Saints church shows a northern offset of similar magnitude.

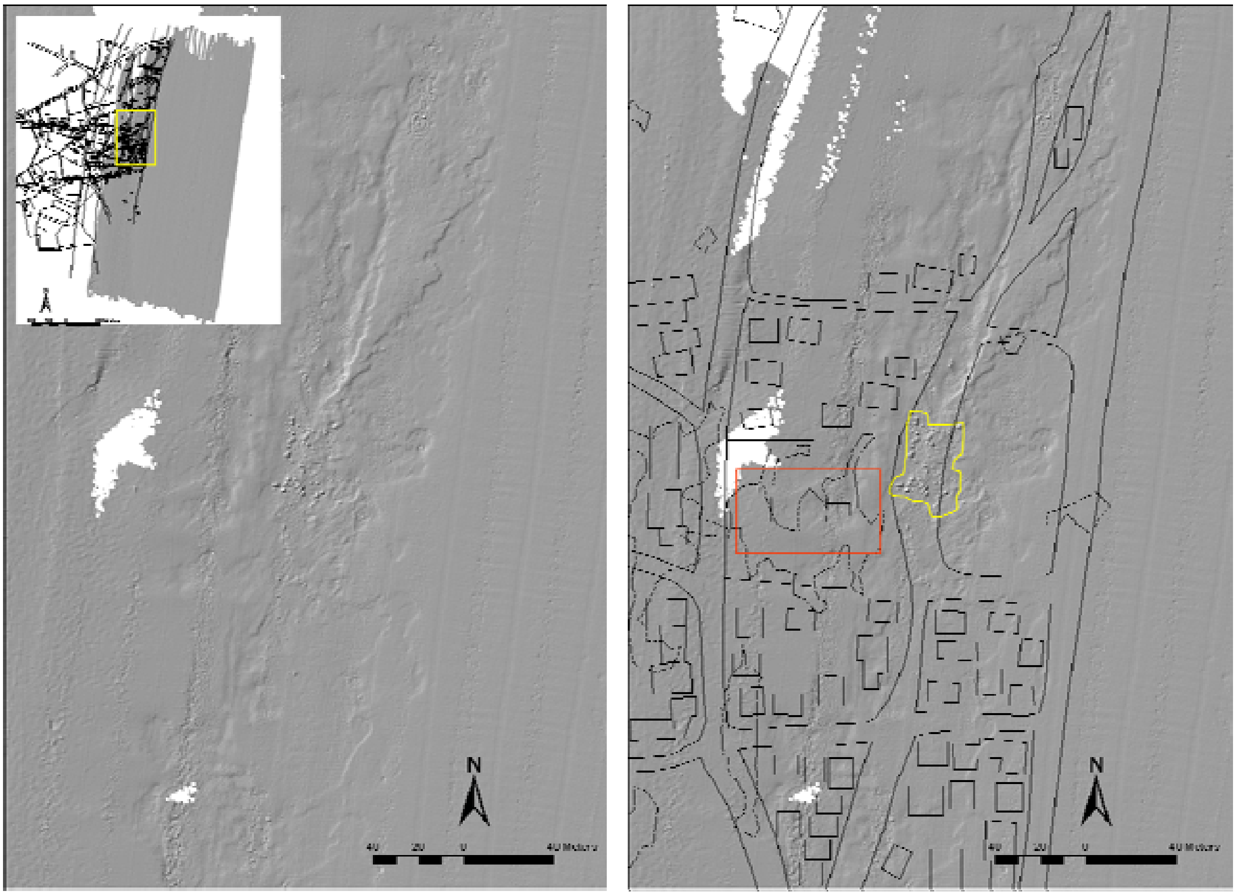

Figure 23: Multibeam hill-shaded topography of the St Peter's Church site. Digital mapping of the 1587 Ralph Agas map is shown together with the error margins around the positions (red box). Yellow denotes the total area of ruins. The ruins are offset to the east and north of the mapped position. Stuart Bacon's diver based survey of St Peter's ruins from 1979 are shown to be co-located with the digital Agas map, suggesting either 1) the ruins revealed in the 2008 survey belong to another structure (St John's Church) or 2) the Bacon ruin position is inaccurate. The latter is assumed.

Klien 3000 Sidescan data is not clear for this site, despite enhancement (Figure 24), thus making it difficult to interpret the archaeology of the site. More recent sidescan data acquired by Wessex Archaeology in June 2009, using a Klein 3900 towfish, have a much higher resolution and enable the larger elements of the ruin to be mapped (Figure 24b).

St Peter's church collapsed down the cliffs during storms around 1688 – 1702, which gives a time of submergence of 307-321 years. Between 1654 and 1690, the church was dismantled much like All Saints, and so what is visible on the seafloor are the ruins of ruins. The site lies some 337m from the present (2000 AD) cliff line, in line with St James Street at a depth of 8.2 metres and covers an area of approximately 934 m^2.

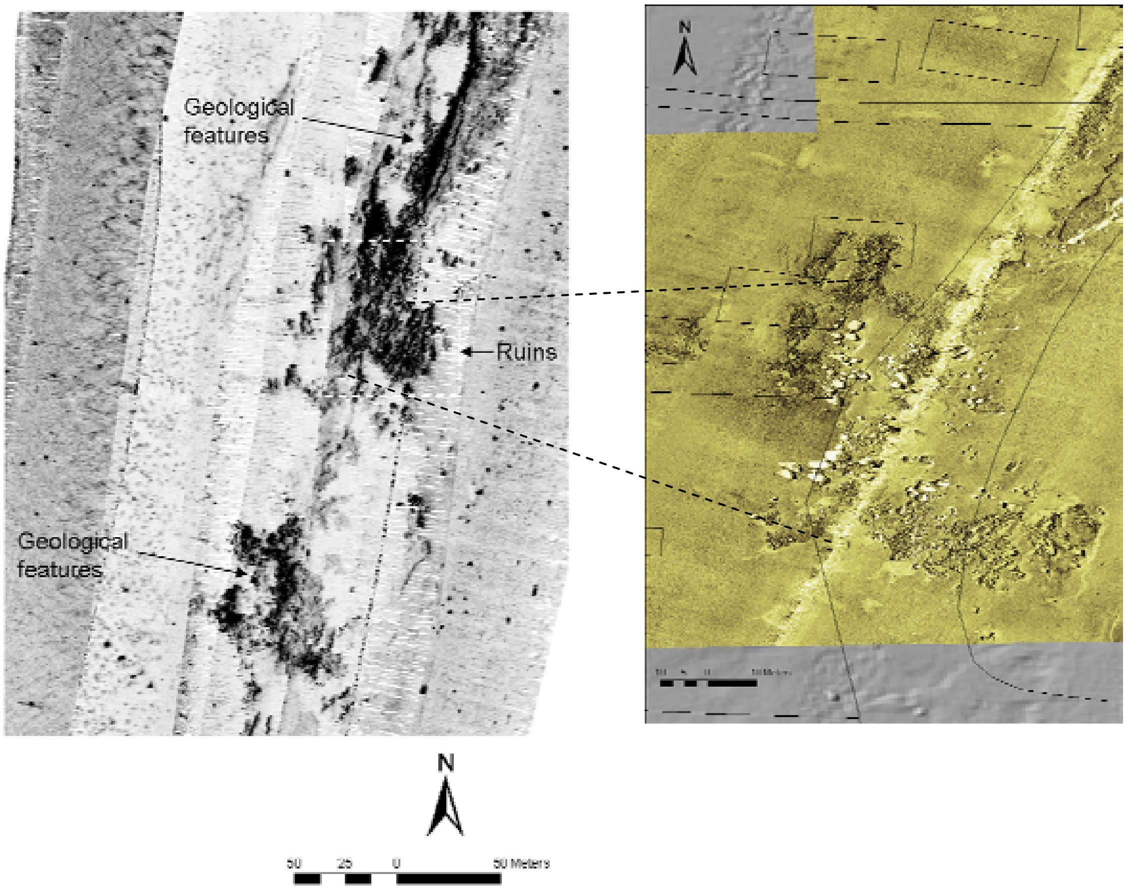

Figure 24: a) Klein 3000 Sidescan sonar image of St Peter's church site. Geological as well as archaeological structures are shown as high reflection areas (dark). b) Wessex Archaeology Klien 3900, 900kHz sidescan sonar image overlayed on Dunwich 2008 swath bathymetry (light grey). Increased resolution with this system enables much clearer visualization of the debris field associated with St Peter's Church. Larger masonry blocks are located at the western end of the debris field as expected for a church with a western tower. Green lines are the locations of buildings and boundaries recorded on the 1587 map of Dunwich (Gardner 1754).

The site is characterised as a series of blocks with concentrations of larger blocks in the western side of the site. The blocks vary in size up to 2.1m in length (based on Wessex Archaeology Klien 3900 sidescan survey) and stand between 0.2- 0.8 m proud of the sea floor (based on swath bathymetry confirmed by diver survey). Average block size is 1.10m by 0.87m, with a tendency to be symmetrical rather than elongated. Figure 25 shows a photograph of the remains of All Saints church tower lying on the beach in 1920. We assumed the dimensions of the flints visible in the image were c. 0.15m based on similar flints in the remaining tower buttress of All Saints. This enables a crude estimate of the size of the blocks to be made at 0.9m height by 1.1.m length which is similar to those of St Peter's.

Diver surveys confirmed the presence of flint and mortar blocks of similar dimensions (estimated) to those measured from the Sidescan and swath bathymetry (See diver reports in Appendix A). A sample of five stones were recovered from this site, all of which were large flints. None showed traces of mortar. An additional artefact was recovered from the northern part of the this site and has been tentatively identified as 20th century piece of ordinance, possible a nose cone from a shell or bomb. Bacon (pers comm.) reports finding ordinance at this site and others. This has implications for the use of magnetometry over the town site. Evidence of worked stones was also reported by the diver surveys though none were recovered.

Figure 25: Ruins of All Saints church on the beach in 1920

Similarly, the blocks in the photograph are more symmetrical than elongated again a feature of the St Peter's ruins, suggesting that this is a feature of the collapse process. The sea floor around the blocks at the St Peter's site is covered in large flints and stones that have fallen out of the walls presumably as the lime mortar dissolves over time.

8.3.2 Target 1

Figures 26 and 27 show the multibeam swath bathymetry over Target 1 and Target 3. Target 1 is in close proximity to the assumed position of St Nicholas Church (Gardner 1754 records it as lying 20 rods (100m) SE of Blackfriars Monastery). Target 1 lies 124m SSE of Blackfriars monastery as recorded on the Ralph Agas map, which is close to the value reported by Gardner (1754). The debris field lies 746m south of St Peter's in the scoured area of seabed east of the inner sand bank. The ruins appear as scattered blocks of masonry in the multibeam images lying in an area of the sea floor that is lower than the surrounding bed. The site lies some 410 m east from the present (2000 AD) cliff line, at a depth of 8.4 metres and covers an area of approximately 630 m^2. The debris field is not extended north-south like that of St Peter's and is instead symmetrical. This is in accordance with the description of the church as a cruciform structure with a central tower. St Nicholas church collapsed over the cliffs sometime in the late 15th Century (c.1480 A.D. Gardner 1754). This gives an approximate time of submergence under the sea of 529 years. The church was almost certainly ruined and stripped of the most valuable materials, including worked stones. Thus the ruins are those of a ruined structure that has collapsed down a cliff (height of cliff unknown, but assumed lower than current cliff height since All Saints occupied the highest part of the town).

Diver surveys were conducted at this site and resulted in recovery of four stones that were adjacent to larger structural blocks. Three of these stones were geologically erratic to the area, being a pink granite, a basalt, a schist. The other was a large un-worked flint. Two of these erratic blocks contained traces of what appeared to be a lime mortar adhered to their surface (Figure 28). Blind analysis of samples of this mortar and samples of mortar recovered from inside a collapsed section of the southern wall of Greyfriars monastery, was undertaken for English Heritage by Sandberg LLP (report 39360/C). This confirmed the sample recovered from the submerged site as feebly hydraulic lime mortar of identical composition to that of the Greyfriars monastery sample. Hence the structures on the seafloor are confidently ascribed to human origin and most likely to be part of St Nicholas Church.

Additional evidence confirming the structures as those from a stone structure came from the diver reports. These confirm the presence of relatively large blocks of flint and rubble scattered over the site, and the possible presence of some worked stone material. Appendix A reports the diver's observations.

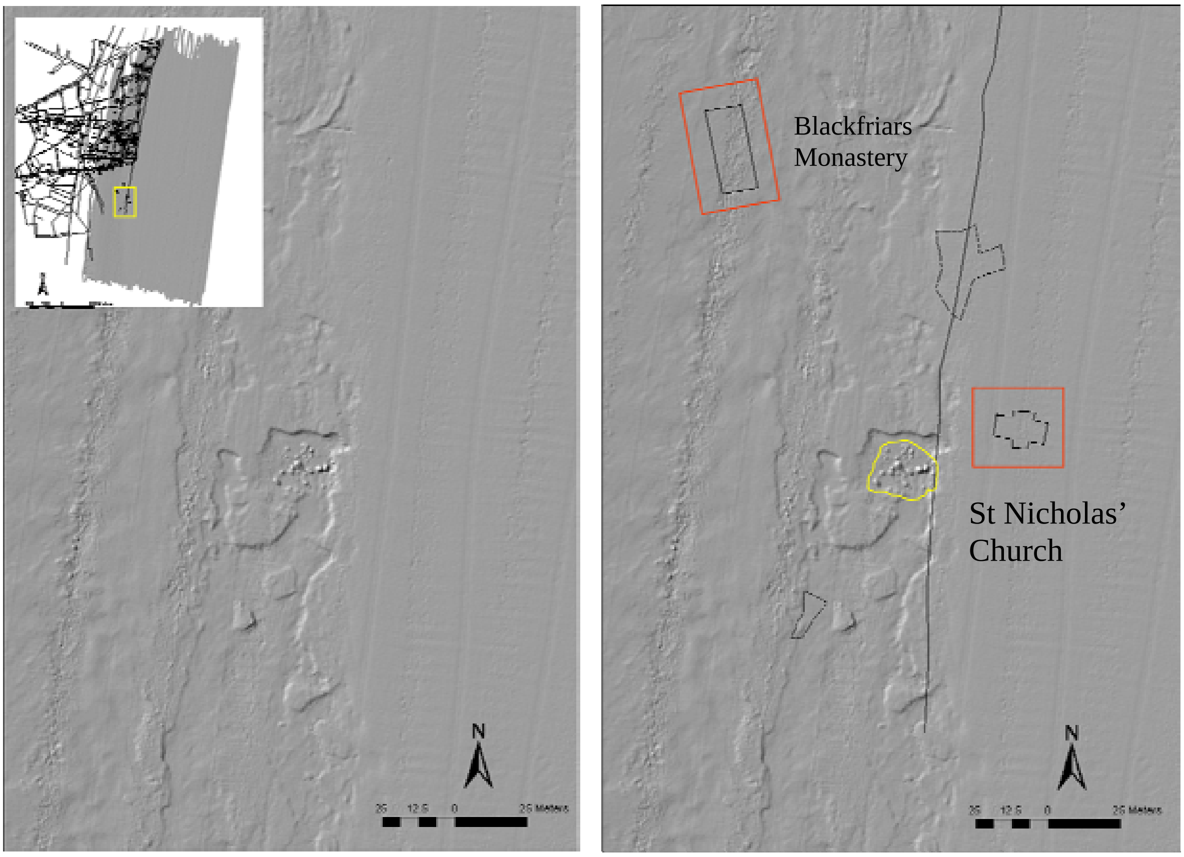

Figure 26: Multibeam hill-shaded topography of the St Nicholas Church site (Target 1) and Blackfriars site (Target 3) . Digital mapping of the 1587 Ralph Agas map is shown together with the error margins around the positions (red box). Yellow denotes the total area of ruins. The scoured area around and to the south of the ruins is evident with a headwall cut into the seafloor to he north of the ruins. The irregular polygon to the north of the ruins is an area of ruins marked on the Bacon diver survey 1979 which corresponds to a geological structure to the north of the ruins.

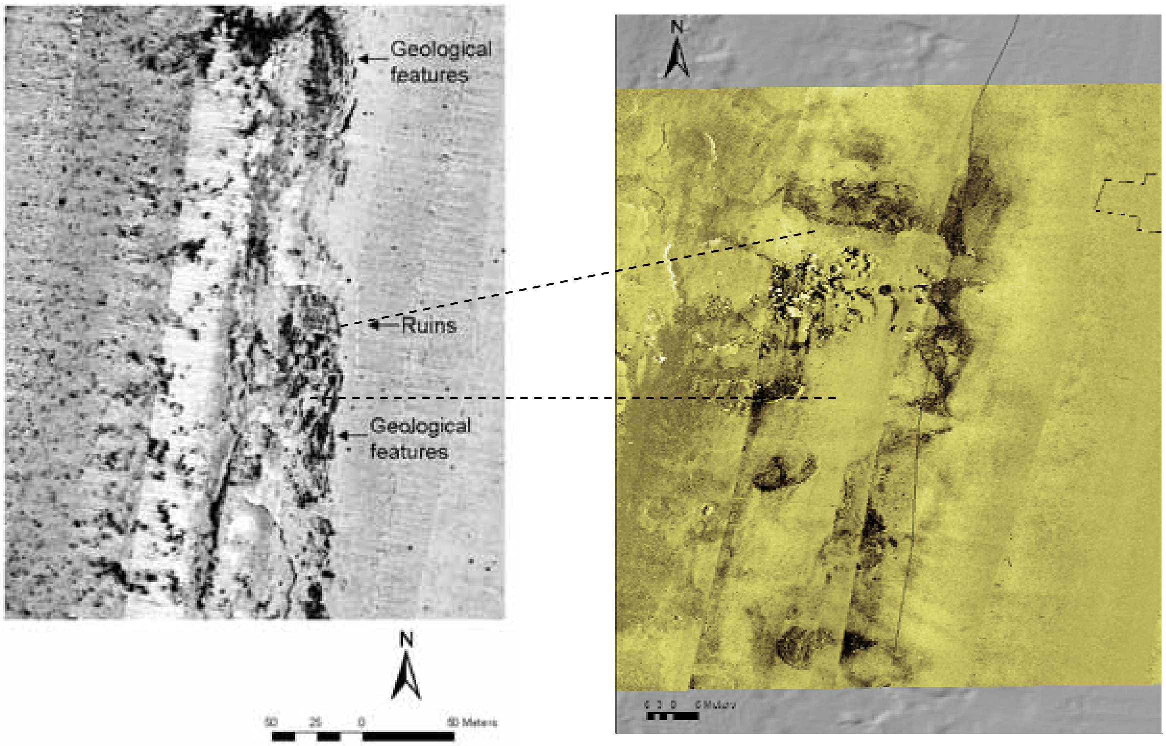

Figure 27: a) Klein 3000 sidescan sonar image of the St Nicholas church site. Geological as well as archaeological structures are shown as high reflection areas (dark). This image demonstrates the problems of differentiating between archaeological structures and natural seabed structures in the site. b) Wessex Archaeology Klien 3900, 900kHz sidescan sonar image overlayed on Dunwich 2008 swath bathymetry (light grey). Increased resolution with this system enables much clearer visualization of the

debris field associated with the church of St Nicholas. Larger masonry blocks are more centrally located within the debris field as expected for a church with a central tower. Green lines are the locations of buildings and boundaries recorded on the 1587 map of Dunwich (Gardner 1754).

These also provide independent estimates of the block sizes 1.4m length and between 03-0.6m height above seabed. The Klien 3900 sidescan survey (Wessex Archaeology 2009), give an average block size of 1.3m length by 0.90m width, and the multibeam survey a height above seabed of between 0.3-0.8m, similar to those at the St Peter's and All Saints sites.

Figure 28: Examples of geologically erratic boulders recovered from the St Nicholas Church site, showing traces of masonry. Top left with detail in bottom left, pink granite boulder. Top and bottom right, Schist. Such boulders were used as ballast by vessels and the ballast was often sold off for building. The use of erratics in Suffolk coastal churches is widespread, and are most often used as part of the external facing (lower photos) as in the example shown from Blythburgh church porch. Both boulders are in the Dunwich Museum.

8.3.3 Target 3

Target 3 (Figure 29) covers and area of 1643m^2, and contains two areas of larger structure, and a field of smaller debris to the east. The site is poorly visualized in the 2008 swath bathymetry and Klien 3000 sidescan sonar survey. However the Wessex Archaeology Klien 3900 sidescan survey reveals more detail. The site differs from all other targets in the absence of large block fields. Instead there are two areas where larger blocks (4.3 x 2.9m) project 0.4m above the sea floor, a more subdued area of seafloor relief to the east of these blocks (possible burial by fines) and an area of relatively high intensity isonification return that appears to result from a strew of smaller blocks (<0.3m x 0.3m). No diver confirmation has been undertaken at the time of writing. The location of the site immediately north and east of the mapped position of Blackfriars monastery suggest a possible association with this structure. The Agas map records Blackfriars as an overgrown ruin similar to that of the current Greyfriars monastery. No tower is shown in the illustration although large masonry structure is present and should have resulted in bocks similar to those found at the other sites. Further investigation of this site is required in order to confirm a human origin to the structures, and to confirm the origin as monastic.

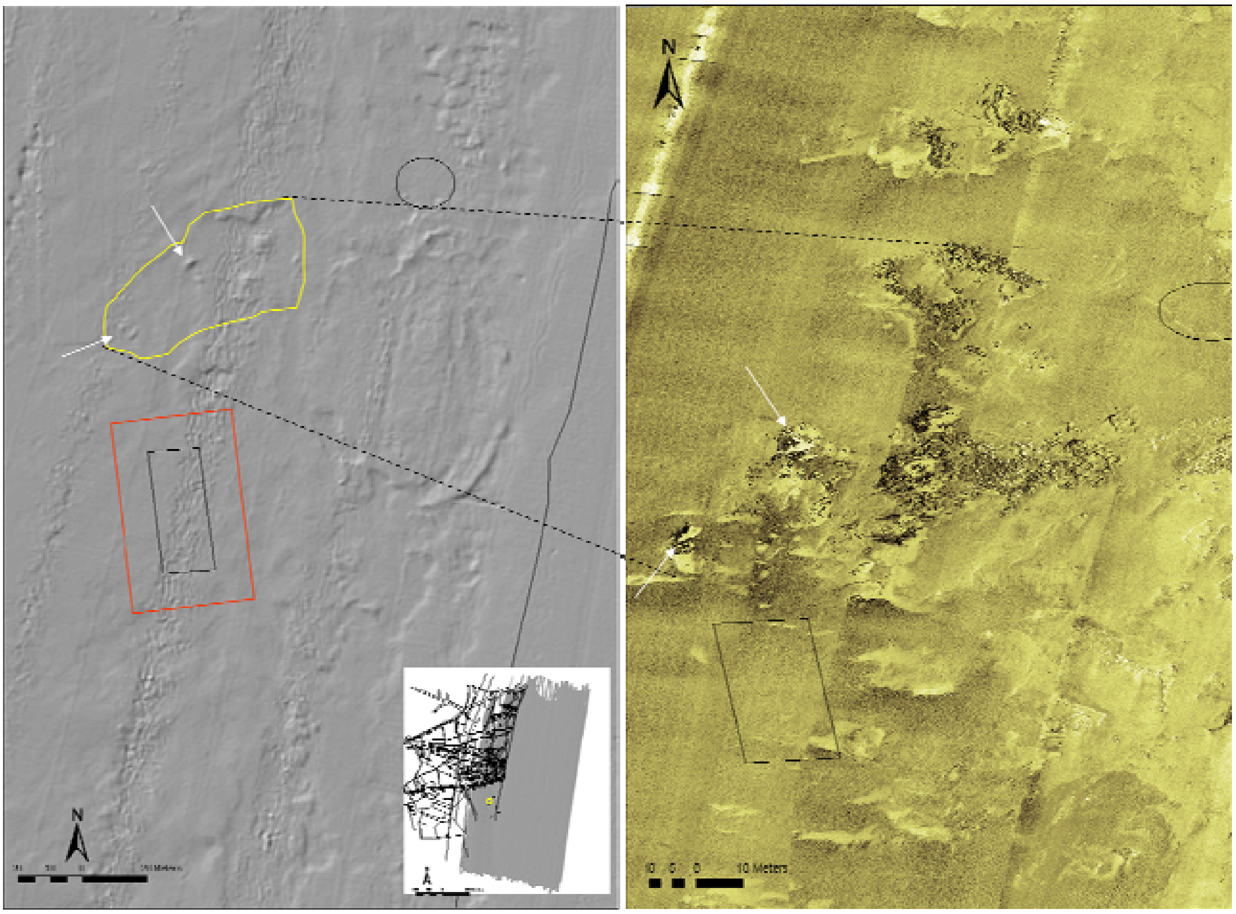

Figure 29: a) Reson 8101 multibean swath bathymetry hillshaded relief of the vicinity of Target 3. White arrows denote structures shown in b) Wessex Archaeology Klien 3900, 900kHz sidescan sonar image overlaid on Dunwich 2008 swath bathymetry (light grey). Increased resolution with this system enables much clearer visualization of the debris field associated with the site. Black lines are the locations of buildings and boundaries recorded on the 1587 map of Dunwich (Gardner 1754). Red shows the map error for the Blackfriars monastery site.

8.3.4 Target 4

Target 4 (Figure 30) covers and area of 183m^2, containing a discrete debris field composed of elongated blocks (3:1 length:width) that average 1.3m by 0.7m, with a swath bathymetry derived height of 0.3-0.6m. No diver surveys have been undertaken at this site at the time of writing. The vicinity of the target is associated with a single unidentified building on the 1587 Ralph Agas map. It lies north of the centre of the town, 226m NNE of the ruins of St Peter's church, and 600m south of the harbour. The small area of the debris field, combined with the relatively discrete and larger blocks are different to the other sites. It is hypothesized that this results from collapse over a shallower cliff and / or a relatively small structure, perhaps associated with a chapel or large house. Bacon (1982) reports finding carved imposts and other worked masonry from a site that fits the location of this structure. The recovered materials suggest an ecclesiastical origin, though this is to be confirmed. Bacon (1981) associates it with the chapel of the Maison Dieu, baed on the location recorded in the Hamlet Watling map. However, this project has cast significant doubt on the validity of this map as a representation of pre-1587 Dunwich. Moreover, the location relative to the position of the Maison Dieu shown on the Agas map of 1587, strongly suggests that it is not associated with this house. At present therefore this structure remains unidentified, though it was clearly present as a building in 1587. It's vicinity to St Johns raies the possibility of it being St Katherines Chapel. This was lost around the same time as St Johns (c.1550+), and was known to be the wealthiest chapel. Further investigation of the site is required in order to confirm its origin and to identify the status of the building.

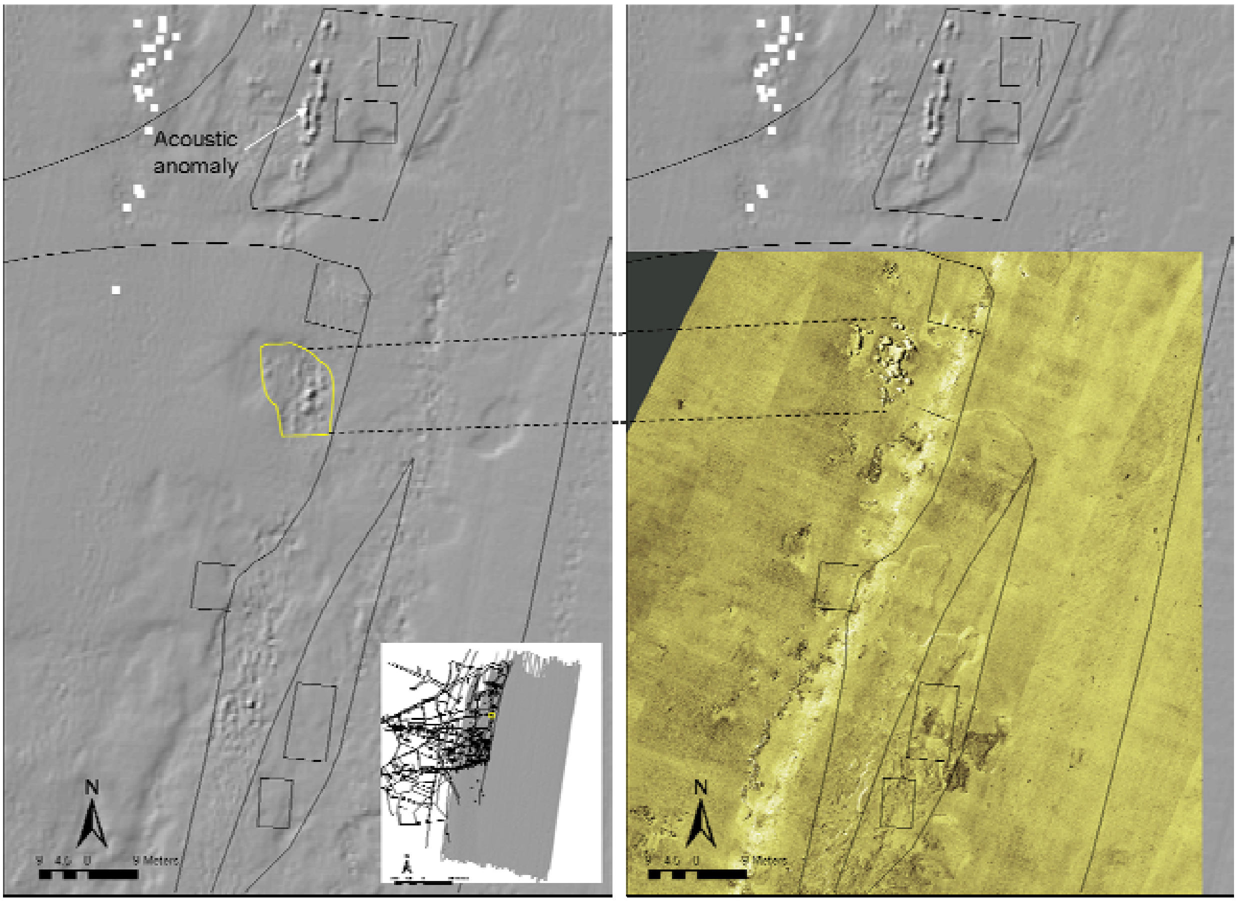

Figure 30: a) Reson 8101 Multibean Swath bathymetry hillshaded relief of the vicinity of Target 4. b) Wessex Archaeology Klien 3900, 900kHz sidescan sonar image overlaid on Dunwich 2008 swath bathymetry (light grey). Increased resolution with this system enables much clearer visualization of the debris field associated with the site. Black lines are the locations of buildings and boundaries recorded on the 1587 map of Dunwich (Gardner 1754). The site is shown close to an unidentified building.

9.0 Discussion

The Dunwich 2008 project has successfully deployed contemporary geophysical and cartographic analysis to positively identify two of the lost churches of the town and possibly two other structures one of which is tentatively identified with the Monastery of Blackfriars. The project has also demonstrated that it is possible to use the 1587 Ralph Agas cartography as a basis for reconstructing the former town and that it is sufficiently accurate to identify larger buildings. This being said, the position of the debris fields associated with the larger buildings are offset from the Agas map by more than the error estimate. This suggests that the surveyed positions of these buildings are inaccurate, and that some limited post collapse movement has occurred (<50m).

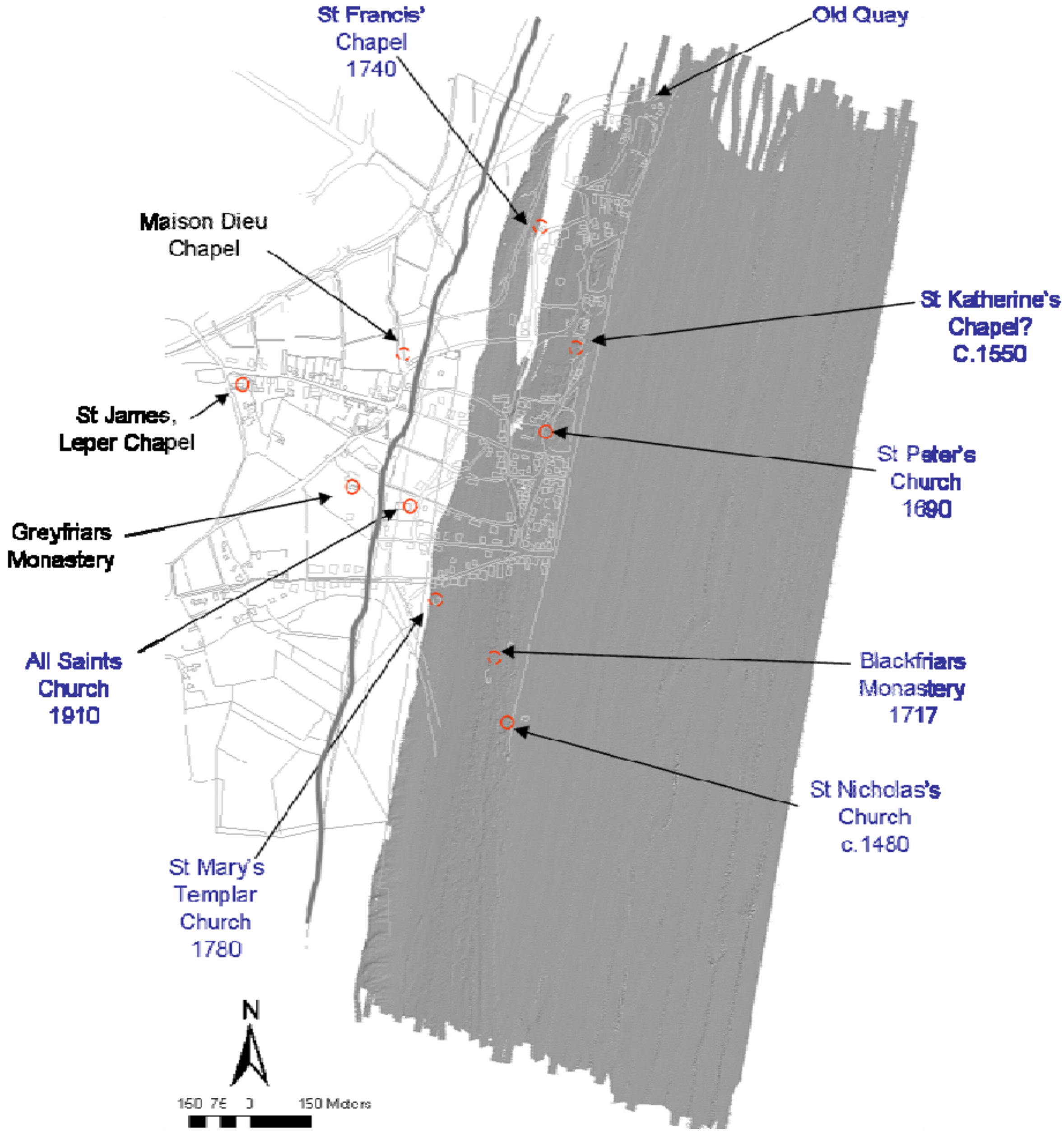

Figure 31: Updated map of Dunwich showing the positions of all known structures. The positions are based on OS Landline 2000 mapping for existing structures, georectified 1587 and 1826 maps, and the geophysical survey of targets 1-4. Dashed circles are sites whose identification or precise position is less certain than solid red circles.

Figure 31 shows the locations of major ecclesiastical buildings in Dunwich identified from the Agas map and from the current geophysical survey. Dates of loss are given. The location of St Nicholas Church is the first of the pre-Agas buildings to be confirmed, and suggests that the remains of earlier buildings can be expected to be detectable given the appropriate technology. Table 4 lists the known ecclesiastical buildings together with a summary of the details known about them. At the end of the Dunwich 2008 project it is possible to state with certainty the positions of 12 out of 22 (54%) of the main ecclesiastical buildings. Of these only one pre-dates the Agas map of 1587. The 10 buildings lost earlier than 1587 (excepting St Nicholas) all lie beneath a dynamic and relatively thin layer of sand (<2m). The preservation of St Nicholas supports the view that the structural remains of these earlier buildings will be preserved, and are therefore potentially detectable. The main targets for detection in order of priority based on highest likelihood of detection are:

1. St John the Baptist (possibly detected in 2008 survey)
2. St Martin (lost c. 1350 AD)
3. St Leonard
4. St Bartholomew
5. St Michael

The relocation of St John's church is a high priority since it's position relative to St Peter's church is relatively well known. Identification would enable the location and dimensions of the central market place of Dunwich to be determined. This was the commercial centre of the mediaeval town for which records of market traders and stall accounts exist (Bailey 2001). The site currently lies under 1.7m of fine sands and silt and will require sub-bottom profiling geophysical survey.

The four churches other represent the earliest and low lying part of the town around the area of the main quayside. Detection of these would enable reconstruction of the north and eastern limits of the town and, given their low lying position, may be in a better state of preservation compared to those buildings that have collapsed down a cliff. This hypothesis is supported by the relatively discrete and larger blocks found at the unknown target 4 site. These buildings lie under relatively shallow sediment depths (0.8-1.5m) and their detection may be possible using shallow sub-bottom profiling technology coupled to magnetometer survey. The concentration of erratic lithology derived from boat ballast associated with stone (church) structures may provide detectable magnetic anomalies. Smaller and earlier buildings are less likely to be detected since the depth of sediment burial increases eastwards (rising to 3m), and the structures themselves may be too small to detect using current technology.

Overall, the town of Dunwich shows concentrations of major buildings along lines of access/ communication, for example the presence of All Saints and St Mary's (Temple) along the line of Kings Street, around the central market place (St Peter's,, St John's and possibly St Katherines chapel). It is less clear why St Nicholas and Blackfriars monastery and the convent gardens were located in the south of the town, though this may relate to later expansion post the development of the other churches. For example, it is highly likely that St Martin's and St Michaels churches were located close to the Quaysides, given their relevance to the herring fishing season, and these are among the earliest churches mentioned. The eastern extension of the town remains uncertain and speculative, but the northern extent is limited by the course of the Dunwich river. Thus the identification of buried structures associate with the eastern part of the town remains a priority.

Building	Founded	Date Last Used	Date of Loss	Location	Date of Re-discovery	Details
All Saints	Pre 1175	1754	1904-1919	Lat:Long 1.63286 52.27512	1979 Stuart Bacon & Colchester Diving Club. Extensive ruins on sea bed. Tower lies over some of ruins. 2008 Survey shows ruins now covered by inner sand bank. Last two graves remaining in 2008. Grave of J.Brinkley Easy lost in 1994.	Last of the parish churches of Dunwich to be lost. Rebuilt in C15th. Nave, Chancel, N. Aisle (built C16th). 147ft long (45m). Western tower. Asset stripped and ruined prior to loss.
St Peter	Pre 1175	1654	11/12/1688 – 1702. Last of the graveyard lost 1734.	Lat:Long 1.63698 52.27667 301m (50 rods – Gardner 1754) NE All Saints. Western side of market place. Gardner reports this as 250m (50 rods) NE of All Saints.	1979 Stuart Bacon. Extensive ruins on seabed. Wall debris, not as tall as All Saints. Site re-located in 2008 survey. Confirmed presence of ruined walls and some worked masonry. Colour film footage of the ruins recorded during good visibility in 2009.	Nave & Chancel. c.40m long. Western tower. Asset stripped and ruined prior to loss.
St John the Baptist.	Pre 1287	1537	Dismantled 1540. Lost to sea by 1550.	Lat Long 1.64178 52.27739 Chant 1.64486 52.27739 HW 1.64288 52.27784 RP 128m East of St Peters. Eastern side of Market place (Bacon & Bacon 1979 taken from Watling inaccurate Map).	Lies under c. 2m sand. Hummocks in sand shown on 2008 survey are in the vicinity of the site.	Second richest parish. Cruciform Church, Central tower, nave, chancel, north and south transepts. Aisles. Asset stripped and ruined prior to loss.
St Nicholas	Pre 1175, post 1100.	c.1352 Ruined by 1413	c. 1450-80. Last of graveyard lost in 1740.	Lat Long: 1.64586 52.2778 Chant 1.65131 52.27689 HW 1.65322 52.27454 HW S.E of St Johns. 100m (20 rods) south east of	Sear & Bacon 2008 survey and diver ground truthing locate walls and stones with masonry attached to them. Possibly located in 1973	Wealthiest Parish in Dunwich. Cruciform Church (Gardner 1754). Asset stripped and ruined prior to loss.

				Blackfriars (Gardner 1754).	by Divers from Bexley Sub Aqua Club who reported a window.	
St Leonard	Pre 1220	c. 1342	1342-1385	Lat:Long 1.64586 52.2778 Chant 1.65131 52.27689 HW North of city, East of the Daine. King's Street in the Parish that stretched westward of the houses of the friars minor to the port.	Not Found. Remains would lie under sand.	No details of church. Northern part of town, with a parish containing part of the Kingsholme spit (St Leonards Marsh). Parts of the parish survived up to1450.Parish
St Martin	Pre 1175	c.1347	Lost c. 1350 or later since Gardner (1754) mentions lost in same century as St Nicholas' church.	Lat:Long 1.64657 52.27975 Chant 1.65095 52.28021 HW Eastern part of city.	Not found. Remains would lie under sand.	No details of church. No mention of ruins so lost quickly? 1287 parish lost many of its houses. Valued at £4 6s 8d in 1291 the parish holding 100 houses. In 1341 valued at 1m with only 7 houses. 1408 some parish land remained – given to Temple.
St Bartholomew	Pre 1175 (possibly one of 3 Domesday Churches)	1328???	Lost pre 1331 possibly in 1328 storm.	Lat:Long 1.64867 52.2717 RP 1.64971 52.27253 HW Eastern / northern city.	Not found. Remains would lie under sand.	No details of church. No records of land in the parish.
St Michael	Pre 1175 (possibly one of 3 Domesday Churches)	1328???	Lost pre 1331 possibly in 1328 storm.	Lat Long 1.65322 52.27454 HW Eastern / northern city. Possibly near quayside since Herring fishery started on Michaelmas.	Not found. Remains would lie under sand.	No details of church. No records of land in the parish.
St Patrick	C7th ?	???	Lost pre 1089	Eastern part of city???	Not found. Remains would lie under sand.	Debate over whether this church existed and was in fact the one founded by Felix.
St Felix	C7th ?	???	Lost pre 1089	Lat:Long 1.65583 52.27718 HW	Not found. Remains would lie under sand.	Debate over whether this Church existed (see St Patrick). Certainly St Felix

				Eastern part of city ???		founded a church and was buried in it in 647. Was it dedicated to him after this?
St Mary & St John (Knights Templar)	c.1189	c.1562	Lost between 1753 (Gardner coastline on Agas map) and 1826 (tithe map). Estimate based on erosion rates is c.1780.	Lat Long: 1.63384 52.27301 RA Western part of city 274m (55 rods Gardner 1754) SE of All Saints. SE of Middlegate.	Stuart Bacon and Divers report base of font / pillar and recovered a tomb top dating from C14th from vicinity. Ruins lie under fist sand bank.	Most important of the 4 templar houses in Norwich Diocese. Circular church, vaulted with lead roof. Knight's quarters surrounded it. Given to Knights Hospitallers in 1322. Asset stripped and ruined prior to loss. Had a small chapel at Dingle. 1562 dissolved. Demolished by 1572.
St Francis (Chapel)	Pre 1220?	c.1545	Ruins lost in storm of 1740 when foundations re-exposed.	Lat Long: 1.63735 52.28129 RA 1.63685 52.28119 RP Northern part of city between Cock and Hen hills.	Not Found. Remains would lie under first sand bank.	Suppressed in 1545. Survived as a house (1595) but fell into ruin. Site remained in 1631 but foundations exposed by 1740 storm.
St Anthony (Chapel)	Pre 1220?	c. 1328	Lost before 1330 (1328 storm?)	Unknown. Eastern part of city.	Not found. Remains would lie under sand on the sea bed east.	Some mention of a Monastery to St Anthony. Lost early on.
St Katherine (Chapel)	Pre 1220?	c. 1545	c. 1550	Lat Long: 1.64379 52.27566 Chant Unknown. In parish of St John the Baptist.	Not found. Possibly the unidentified Target 4.	Possibly the most important of the chapels. Had its own Guild. 1523 John Stone left money for a pair of organs. Dissolved by Henry 8th c. 1545. Went over cliffs about same time as St Johns.
Knights Hospitallers Cell	Pre 1220	???	1328??	Unknown. In Parish of St Leonard.	Not found. Remains would lie under second sand.	Founded by Brothers of the Hospital of St John, later Knights Hospitallers. They may have given it up

						when they acquired the Temple Church.
Benedictine Cell	Pre 1300	???	c.1328	Unknown. SE? part of city.	Not found. Remains would lie under sand.	Small cell linked to Priory of Eye. Left the covent garden bordering Pales Dyke near to Gilden gate.
Blackfriars	1256	1538	1385 sea reaches Eastern perimeter wall. 1717 last of the building lost. Last of the Grounds lost 1754.	Lat Long: 1.63569 52.27133 RA 1.64063 52.27037 HW 603m (120 rods) SE of Greyfriars (II) Monastery. 100m NW of St Nicholas.	Possible remains found 42m north of the position of Blackfriars shown on the digital Agas map. Awaiting diver ground truthing.	Large Monastic building of the Black Friars. Perimeter wall with gates in it, with gardens and houses. Asset stripped and ruined prior to loss.
Greyfriars (I)	1228	c.1290	Ruins lost by 1328.	Lat:Long 1.64666 52.2757 RP Eastern part of city. Possibly in NE of city at seaward end of Dam Street, where Henry III gave it land in 1230.	Not found. Remains would lie under sand.	Built 1228. 1287 sea close to monastic site. Remains lost c.1328. Remnant of the site remained until 1455.Asset stripped and ruined prior to loss.
Greyfriars (II)	1290	c. 1545	SE Corner of perimeter wall collapsing c. 1994.	Lat Long:	N/A	Dissolved in 1545. In 1710 ruins converted into a house by Sir George Downing. Barnes family demolished house in 1815. Asset stripped and ruined.
Maison Dieu (Hospital)	Pre 1220	c. 1545	c. 1740	Lat Long: 1.63276 52.2787 RA 1.63674 52.2792 SB Diver Unknown but around location of current car park. With Chapel to seaward.	Stuart Bacon and Divers recovered carved masonry imposts from what they think is the site in 1981-7.	Chapel paved in 1527. Dissolved in c.1545. Chapel demolished in 1573 except for S wall which survived into C18th. Asset stripped and ruined prior to loss. Lay seaward of the Hospital.
St James (Leper Hospital)	c. 1175	c.1685	N/A	Lat Long	N/A	Possibly one of the pre Domesday Churches.C13th

						references to a parish of St James. Church 33m long. Hospital Founded in Richard 1st reign. Chapel used until 16Survived as a hospital with master into 19th century. Ruined.
St James (Church)	1832	N/A	N/A	Lat Long	N/A	Designed in classical style in 1830 by Robert Appleton. Re-strutured in mid 19th Century with Chancel added in 1881. Last remaining Church in Dunwich.

Table 4: Summary of Ecclesiastical buildings in Dunwich as reported in the literature. Grey shaded rows are those buildings for which no reliable position exists. Positions of these are given based on Hamlet Watling (HW), Katherine Chant (Chant), Rowland Parker (RP) georectified reconstructions of pre-1587 Dunwich. All other positions are given relative to the Ralph Agas (RA) georectified map and the geophysical surveys.

9.1 Archaeological Context

The results of the Dunwich 2008 project enable comment to be made on the on the preservation of ruins from medieval structures in moderate energy coarse clastic coastal environments. These may be summarized as follows:

1) Substantial structural elements from medieval stone buildings remain in the vicinity of their original location though with some dispersal due to storm tide and wave action whilst in the wave zone. The positions are sufficient to enable reconstruction of the relative geography of sites as confirmed by cartographic analysis.
2) Building materials degrade over time with blocks of flint masonry falling apart as evidenced by the strew of flints and loose stones with remnant masonry around blocks seen in the sidescan data and reported by divers. Despite this, detectable blocks of flint and mortar rubble masonry occur even after c. 500 years submergence (e.g. St Nicholas Church).
3) Existence of carved masonry fragments – where protected by sediment or of hard stone, show high preservation of carvings. Others that have been mobile, or subjected to attrition by sand moving over them, show wearing and removal of detail (*cf* Dunwich Museum and Suffolk Underwater Studies collections).
4) Some possible response in the seafloor to the presence of larger masonry blocks inducing scour around the sites (e.g. St Nicholas, Target 4) appears evident. Interactions between the tidal currents (locally attaining $1ms^{-1}$; Lees 1980) and the larger blocks will induce turbulence and vortex shedding. In such conditions, burst and sweep conditions are common, resulting in the potential to create longitudinal scour. This mechanism results in local lowering of archaeological remains into the seafloor, what in time could increase the relative depth of deposition.
5) There is limited evidence to support the hypothesis that cliff collapsed structures present a more dispersed and fragmented assemblage of ruined materials compared to those that have experienced lower or no cliff collapse. Intuitively the fragmentation of masonry structures into smaller blocks during the collapse process renders them more mobile under storm wave and tidal action. This may explain the more widely dispersed remains of St Peter's church (this survey) and All Saints (Bacon 1982) compared to the larger blocks and discrete ruins associated with Target 4.
6) The loss of similar structures over a long period at Dunwich provides an opportunity to explore the affect of different periods of exposure to coastal processes on the preservation of archaeology on the seabed. This is complicated however, by the different architecture (cruciform/western tower) of these buildings and the mode of entry into the beach/littoral zone.
7) The dispersed nature of the sites makes interpretation of the buildings difficult. This is particularly the case for smaller worked fragments whose original position within a building is likely to have been changed by the process of collapse and the subsequent mobility under wave and tidal action.

The results from this survey have wider implications for the preservation of maritime heritage dating from the medieval period along the UK coastline. Dunwich is one (albeit the largest) of the coastal settlements known to have been lost to coastal erosion and inundation (Fulford et al., 1997). Other settlements on the South and East coasts contained churches built of stone, and as the results of this survey demonstrate, their ruins will be extant and close to there original position. Examples where the remains of other church buildings exist, include Church rocks, Shipden-juxta-mare (Cromer, Norfolk) located 300m off shore, and St Helen's, Old Kilnsea in East Yorkshire. The ruins of the latter are marked on the foreshore in the earliest edition Ordnance Survey maps for the East Riding. In addition to medieval heritage, earlier stone buildings are also documented, including a Saxon church at Selsey, West Sussex, the Roman shore fort at Walton, and potentially another Roman shore fort off the coast at Skegness.

Investigation of these structures has archaeological interest since many were lost prior to major architectural changes in the later medieval and post medieval periods.

9.2 Evaluation of the methodology

The survey methodology used in the Dunwich 2008 project has highlighted the limitations of the techniques and methods used as an approach to detailed site investigation. The Reson 8101 MBS and Klien 3000 Sidescan sonar were unable to visualize the necessary detail required to conclusively confirm the origin of the structures or to determine the full extent of the site. Inability to identify features out of context has been reported by Quin et al., (2005). Similarly, the diver surveys were severely limited by the high turbidity at the site. Visibility was typically less than 0.1m and frequently zero. This occurs at the Dunwich site for most of the year. These conditions effectively limit further mapping and recording of the sites. In turn this prevents any quantitative analysis of the sites in terms of a) description of the remains (e.g. site mapping) b) nature of structural preservation; and c) information on the extent and nature of the dispersal of material by initial collapse and subsequent wave/tidal action. Thus the currently deployed technology was suitable for a general assessment of the whole town site, but was unsuitable even with diver ground-truthing at the more local target level. The use of the higher frequency, higher resolution Klien 3900 sidescan soner when focused on specific targets, improved the resolution of imaging to the extent that quantitative analysis of the major structural elements of each target was possible where they are exposed above the seafloor. Despite the improved resolution, it was still not possible to identify individual structural elements within each site. In the future, a higher resolution geoacoustic technology will be required. Candidate technology includes higher frequency Edgetech 4200 dual frequency sidescan sonar, integrated with Reson 7125 high resolution multibeam swath bathymetry. Each target will be insonified from multiple angles to build up a 3-Dimensional DTM over which the higher frequency sidescan mosaics will be laid. In addition, the use of latest generation acoustic imaging systems such as the Soundmetrics Didson system (Belcher et al., 2002) will permit ultra-high resolution (cm scale) investigation of the sites. An alternative approach could include the use of environmental sensing to alert local divers to periods of high visibility (Glasgow et al., 2004). Buoy mounted turbidity probes coupled to telemetry might usefully be deployed to send mobile phone alarm texts to local divers. This has the advantage of maximizing the opportunity to undertake visual identification and mapping of the ruins, but would require rapid mobilization capability.

The Dunwich site bathymetry creates limitations for geophysical survey methodology. Shallow areas particularly in the vicinity of the inner sand bank, preclude the use of larger boat mounted equipment. This limits the investigation of the Temple and All Saints sites. Shallow draft boats might be used at high spring tides, or alternatively a diver towed system (see Plets et al., 2009). Grøn et al., (2007) report application of a Chirp system in 0.5m depths, however, the application of Chirp sub-bottom profiling at the Dunwich site is limited by the presence of coarser sediments.

The main challenge posed by the site remains the burial of structures under shallow sand drapes and the inner sand bank. The Boomer transects used in this survey were unable to resolve details within the shallow sand drapes due to the strong return of the underlying bedrock. An alternative technology such as parametric sonar, that returns data on signal strength and intensity should be tested over the site in order to determine the most effective frequency to penetrate sand whilst returning identifiable reflections from buried structures often resting on seabed material of similar acoustic signature. Integration of a range of novel geophysical technologies will therefore be necessary to further the archaeological investigations at the Dunwich town site.

10: Conclusions

The Dunwich 2008 project has achieved the main aim of undertaking a town-scale survey of the Dunwich site. Integrating geophysical, diver and cartographic methodologies within a GIS, has enabled positive identification of two of the lost churches, and identification of two other potential archaeological sites. The survey has also created the first detailed bathymetric survey of the site, enhancing our understanding of the bathymetry and to some extent the sediments in the vicinity of the archaeology.

The archaeological discoveries have confirmed the existence of substantive ruins associated with medieval church structures even after 500 years submergence. The nature of the sites varies from localized strews of masonry structure, to discrete collections of structure. These suggest different preservation potentials within the littoral zone, that are considered to reflect the mode of entry into the beach environment. Dispersal occurs when structures collapse progressively over larger cliffs. Discrete structural remains occur in the presence of shallow or no cliffs. The preservation potential of earlier stone structures located to the north of the town are therefore considered to be high.

The heritage value of the Dunwich site is significant, representing a mid- late middle ages port of international status and national importance. The ruins on the seafloor have both worked and carved stone, and contain artifacts that are recoverable. However, the interpretation of the remains are difficult because of the loss of context arising from the collapse and mobilization of the materials. Detailed mapping and careful excavation is required to determine what information can be derived from these types of site in terms of the ability to identify their age, use, architectural design and specific dedication.

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12.0 Acknowledgements

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APPENDIX A: Diver Reports