Chapter 1. Introduction

Man's increasing demand on the natural world has combined with technological advances to result in an increased use of the ocean environment. The majority of marine applications require knowledge of the physical, or geotechnical, properties of seafloor sediments. Typical users include; sedimentologists and environmentalists who examine the transportation and deposition of sediment and their affects on human activities in the coastal zone (Holland and Osler, 2000; Leeder, 1982); marine engineers who require knowledge of the strength of sediment to site offshore structures such as pipelines and oil rigs, and the offshore prospecting industry in its search for hydrocarbon reservoirs (Sheriff and Geldart, 1995) and gas hydrates to potentially supply increasing energy demands (Dasios *et al.*, 2001).

The last three decades has seen significant interest in the development of acoustic reflection and refraction techniques for the rapid, remote acquisition of geoacoustic and ultimately geotechnical properties over large regions of both surface and sub-surface sediment. Conventionally, the geoacoustic properties measured are those corresponding to compressional waves, as these can be more easily measured than those corresponding to shear waves. Integral to such an approach is accurate knowledge of empirical and theoretical relationships between these geoacoustic and both geotechnical properties and frequency.

At present, the underlying physics behind the interaction of compressional waves with marine sediment is not yet fully understood and these relationships are still under debate. For example, a variety of relationships between compressional wave attenuation coefficient and frequency have been presented in the literature, including a linear relationship (Hamilton, 1972), alternative power relationships (Kibblewhite, 1989) and more complex relationships in which the frequency-dependence relies on the frequency range under examination (Stoll, 1974). In addition contention still exists over which energy loss mechanisms dominate in marine sediments and whether compessional wave velocity is dispersive or non-dispersive. Hence more research is required to reliably determine the necessary relationships.

Having identified that there are still questions to ask in terms of both acoustic propagation of sound in sediments and its relationship to the physical structure we have to consider how we reliably acoustically characterise sediments. All acoustical techniques used to examine marine sediments possess inherent limitations. For instance, laboratory techniques, which are frequently used to examine sediment samples, are generally limited to frequencies greater than 200 kHz, with uncertainty existing in the degree of sediment disturbance that the sample has been subjected to. Hence it is uncertain if the compressional wave properties measured in the laboratory are applicable to those *in situ*. Although the ultimate aim for this area of research is the use of remote acoustical methods to examine subsurface sediments, they currently lack a reliable method for the extraction of the geoacoustic properties and possess uncertainty in the volume of sediment examined.

While the use of *in situ* probes minimises sediment disturbance and allows a relatively simple probe geometry to reliably obtain the compressional properties of a well-defined sediment volume, limitations still exist. These are primarily the limited frequency range and restricted range of sediment types which have been examined by a single research project. Though compilations of data from a range of research projects and devices are often used to alleviate this issue (Hamilton, 1972; Kibblewhite, 1989), it is debatable whether like is being compared with like. Additional sources of uncertainty which are commonly not presented in the extant literature include; unquantified alterations to pulse shape, the use of incorrect spreading losses and the repeatability of both the acoustic wave emitted by the source and the coupling of the probes to the sediment.

Considering the uncertainties in the acquisition and study of the geoacoustic parameters it also necessary to re-examine the validity of empirical and theoretical relationships previously derived between compressional wave properties and both geotechnical properties and frequency.

Hence the aim of the present project is to reliably determine the dependence of the compressional wave properties of marine sediments on both the insonifying frequency and the geotechnical properties of the sediment. This will be achieved through the following objectives:

- Perform a suite of *in situ* transmission experiments, which use a specially developed *in situ* device and novel processing techniques, to reliably measure *in situ* compressional wave velocity, attenuation coefficient and quality factor over as wide a frequency range as possible.

- Perform these experiments in a range of sediments, in order to incorporate as wide a range of geotechnical properties as possible, with a range of individual locations examined at a variety of sites in order to examine the variability of the compressional wave properties.
- Develop processing techniques to incorporate spreading losses applicable to the sediment, a thorough error analysis and a detailed investigation of the repeatability of the coupling of the probes to the sediment and the acoustic wave emitted by the source.
- Examine how compressional wave properties are affected by the insonifying frequency and the geotechnical properties of the sediment and determine which geotechnical properties can be most reliably determined from compressional wave properties.
- Compare the compressional wave properties measured to those predicted by selected empirical and theoretical models in order to determine the validity of the models and identify the dominant energy loss mechanisms.

1.1. Thesis structure

A detailed examination of the present understanding of the compressional wave properties of marine sediments is undertaken in *Chapter 2*. This includes the definitions of all properties examined, typical sediment structures and the dependence of compressional wave velocity, attenuation coefficient and quality factor on both frequency and geotechnical properties. Geoacoustic models are also examined, with focus on the three that are most applicable to the frequency range examined within this project.

Chapter 3 reviews acoustical techniques and justifies the selection of *in situ* transmission experiments to examine compressional wave properties. Previous research using *in situ* transmission experiments has been reviewed with the common sources of uncertainty highlighted.

The new device, the Sediment Probing Acoustic Detection Equipment (SPADE), which can emit and detect compressional wave pulses with central frequencies from 16 to 100 kHz is presented in *Chapter 4*. The electronic pulses sent to the source transducer are examined. The modelling approach used to predict the pressure field emitted in a range of sediments is detailed and verified through calibration tests in water and predicted fields in typical sediments are examined. The methodology of fieldwork is presented along with measured geotechnical properties of inter-tidal sediments that are examined.

Chapter 5 describes the processing techniques developed to reliably determine compressional velocity, attenuation coefficient and quality factor. These incorporate the spreading losses predicted in *Chapter 4*, a detailed error analysis and a thorough examination of additional sources of uncertainty.

The dependence of the compressional velocity, attenuation coefficient and quality factor on both frequency and selected geotechnical properties is examined in *Chapter 6*. The validity of basic frequency-dependent relationships are examined, while qualitative relationships between compressional wave and geotechnical properties are presented.

Chapter 7 compares measured compressional wave velocities, attenuation coefficients and quality factors to those predicted by Biot Theory, with the manner in which the Biot Theory was implemented incorporating the interrelated manner of certain groups of input parameters. This allows the validity of the Biot Theory and the global viscous loss mechanism to the inter-tidal sediment to be determined.

Conclusions and recommendations for further work are presented in *Chapter 8.*

Appendix A presents the empirical relationships used to calculate the required geotechnical and geoacoustic properties of water, while *Appendix B* presents details of the fieldsites examined. *Appendix C* presents the standard techniques used to measure the geotechnical properties of the sediment, *Appendix D* details anomalies in the received pulses and *Appendix E* presents the chi-squared distribution from which the validity of hypothesised frequency-dependences were tested.