Chapter 8. Conclusions and future work

8.1. Conclusions

In this thesis, a series of well-constrained *in situ* transmission experiments (*Section 4.4.1)* were performed on a wide range of inter-tidal sediment using a new acoustic device, the SPADE (*Section 4.1).* The compressional wave velocity, attenuation coefficient and quality factor of saturated sediments were measured from 16 to 100 kHz using specially developed processing techniques, which account for oversights in previously published work that uses *in situ* probes. This processing included the incorporation of *in situ* spreading losses (*Section 4.3),* a thorough error analysis (*Sections 5.2.3* and *5.3.3)* and an investigation of the repeatibility of the coupling of the trandsducers to the sediment (*Section 5.3.3*).

The compressional wave properties for the inter-tidal medium to fine sands and medium to fine silts examined are presented in *Chapter 6*. Group velocities were greater in sands (1590 to 1880 $m \cdot s^{-1}$) than in silts (1260 to 1472 $m \cdot s^{-1}$), while attenuation coefficients ranged from 2 to 52 $dB \cdot m^{-1}$ in sands and 1 to 23 $dB \cdot m^{-1}$ in silts and quality factors were less in sands (14 to 120) than in silts (66 to 400). The low velocities observed in silts either arise from a significant fraction of organic material lowering the grain bulk modulus or are suspect.

While velocity was observed to be independent of frequency in sands, no reliable frequency-dependence could be determined in silts, owing to the variability in the measured values. An attenuation coefficient which was proportional to frequency was confirmed for the majority of the sand and silt locations examined, with constants of proportionality k_A greater in sands (0.19 to 0.52 $dB \cdot m^{-1} \cdot kHz^{-1}$) than in silts (0.06 to 0.2 $dB \cdot m^{-1} \cdot kHz^{-1}$). No conclusions could be drawn concerning the frequency-dependence of quality factor in either sands or silts.

Qualitative trends between compressional wave properties and geotechnical properties were also examined. Observed trends indicate that compressional wave properties can be used to determine porosity, bulk density and sand fraction. The large degree of variability observed in plots of compressional wave properties against mean grain diameter indicate that this geotechnical property cannot be reliably determined from these acoustic properties. The ability of sand fraction to describe grain size distributions more accurately than mean grain diameter justifies the decision to retain all materials that can affect compressional wave propagation in marine sediments in the geotechnical analysis undertaken (*Appendix C*).

Within the sand sites, the variability of compressional wave properties agreed with spread of the geotechnical properties over each site, with significant variation introduced owing to the non-unique nature of marine sediment. Within the silt sites, no direct link could be made between the observed spread of geotechnical and compressional wave properties, implying that geotechnical properties can be more reliably obtained from compressional wave properties in sands than in silts.

In *Chapter 7* measured compressional wave properties were compared to those predicted by Biot Theory, in order to examine the validity of this accepted baseline geoacoustic model. Biot Theory was implemented using the original version (Biot, 1956b; Biot, 1956a) in such a manner that the compressional wave properties predicted are applicable to the sediment examined at each site. This was achieved by separating the input geotechnical properties into three groups (namely fluid properties, grain properties and frame properties), obtaining a suitable range of values for each property and only using combinations of values that incorporate the inter-related nature of the properties within each group.

In sands, the velocities predicted by Biot Theory agree with those measured. Predicted absorption coefficients are less than measured attenuation coefficients in sands, with the discrepancy between predicted and measured values increasing with frequency. Either acoustic scatter or squirt flow are promoted as additional loss mechanisms, with both equally valid within the data available. An additional issue is whether the increased losses occur from individual grains or sediment heterogeneities. In the case of scattering losses the more likely source are the larger scale heterogeneities observed within the sediment (*e.g.* shells, pebbles, root channels, rubble or patches of sediment heterogeneity), rather than scatter from individual grains.

In silts, predicted velocities are greater than those measured, while absorption coefficients generally agree with or are greater than measured attenuation coefficients. The discrepancy between the measured attenuation coefficients and absorption coefficients predicted by Biot Theory can be explained through the over-estimation of *in situ* porosities by the geotechnical measurement techniques adopted, which results in over-estimates of pore size parameter, permeability and under-estimates of tortuosity. The discrepancies between measured and *in situ* porosities cannot be used to explain the difference between the measured velocities and those predicted by Biot Theory. Hence, alternative explanations for the discrepancies in measured and predicted velocities are either that the measured velocities in silts are suspect or that the bulk moduli used for the silts are too great.

Over the examined frequency range of 16 to 96 kHz it is impossible to distinguish between the complex frequency dependence predicted by Biot Theory and a linear relationship. Hence a frequency range of greater than 1 decade is required to examine frequency dependence of attenuation coefficient.

8.2. Future work

Several possible avenues of future work can be developed from the present research. The primary route involves the identification and examination of additional inter-tidal sites which would complete the sediment range from coarse sands to fine clays. The dependence of compressional wave properties on geotechnical properties could then be more thoroughly examined. The collection of sediment cores would permit the analysis of less disturbed samples and increases confidence that the geotechnical properties measured are directly relevant to the *in situ* sediment.

Alternatively the SPADE could be modified to permit the examination of sub-surface marine sediments. This allow both the frequency-dependency and variability of compressional wave properties in inter-tidal sediment to be compared to those for submerged sediments, while permitting the examination of a wider range of environments.

The underlying experimental principles applied within this project could also be used to examine and constrain the compressional wave properties of gassy sediments. These principles include:

- An assessment of the reliability of the acoustic wave emitted by the source.
- An assessment of the effects of variable coupling between the transducers and the sediment on the received signal.
- A thorough error analysis.
- The use of spreading losses which are directly relevant to the sediment under examination.