6.1.2. Silty sediments

Velocities, attenuation coefficients and quality factors are displayed for the four sites which possessed silty sediments, *i.e.* Needs Ore *(Figure 6.4)*, Mercury (*Figure 6.5*), Saltern (*Figure 6.*6) and Universe (*Figure 6.7*). As for the sandy sites certain anomalous compressional wave properties were omitted from the following analysis, see *Appendix D* for details.

The velocities from the remaining locations and frequencies range from 1260 to 1472 m·s^{-1}, with errors less than $\pm$ 25 m·s^{-1}. These are both lower and more tightly constrained than for the sandy sites, with errors reduced due to the larger S-R separations examined and the resulting increase in arrival times, *Section 4.4.3.* The velocities of the pore water were calculated from the salinities and temperatures in *Table 4.4,* (see *Appendix A* for details) and ranged from 1420 and 1476 m·s^{-1}. Hence, the sediment velocity is less than that of water for the Universe and Mercury sites and less than or equal to the velocity of water for the Needs Ore and Saltern sites, a phenomenon that has been previously observed in fine-grained sediments with porosities greater than 70 %, *Section 2.4.1.* The extremely low nature of the velocities measured in silty sediments are called into question, see *Section 6.2.1* for a more detailed discussion.

Values of attenuation coefficient from the selected frequencies and locations were less than those measured at the sandy sites and ranged from 1 to 23 dB·m^{-1} (with errors from $\pm$ 1 to $\pm$ 7 dB·m^{-1}), *Figures 4.4E, 4.5E, 4.6E* and *4.7E.* Measured values in silts are greater than those published for fine-grained sediments over the same frequency range, which vary from 0.5 to 10 dB·m^{-1} (Bowles, 1997).

Quality factors display a large range of values (66 to 400) and errors ($\pm$ 5 to $\pm$ 200) with quality factors greater than 200 limited to frequencies less than 50 kHz. Once again these reflect the manner in which quality factor was calculated (*Section 5.4*), with the relatively large errors in the lower values of attenuation coefficient resulting in large errors in quality factor. Measured values are considerably greater than previously published values for medium to fine silts at frequencies from 1.5 to 100 kHz, which vary 2 to 80 (see *Figure 2.12*). However, the omission of errors from the published values in the literature prevents the significance of this discrepancy from being determined.

A significant degree of variability is observed in both the geotechnical and compressional wave properties across each silt site examined. No such ranges of values can be obtained for the Mercury site due to the examination of only one uncorrupted location. Unlike the sand sites, no direct link can be made between the observed spread of geotechnical and compressional wave properties, with the Universe site displaying the largest range of velocities, attenuation coefficients and porosities and the Needs Ore site displaying the largest range of mean grain diameters and quality factors. This implies that geotechnical properties can be more reliably obtained from compressional wave properties in sands than in silts, with variations due to the non-unique nature of sediment more pronounced in silts.

Site	Variability of property				
	Porosity (%)	M (ϕ)	Velocity ($m \cdot s^{-1}$)	Attenuation coefficient ($dB \cdot m^{-1}$)	Quality factor
Needs Ore	9.9	1.33	80	7.5	280
Saltern	0.2	0.24	100	3.5	25
Universe	14.3	0.06	115	12.0	160

Table 6.4. Variability of geotechnical and compressional wave properties at silt sites, including range of porosity and mean grain diameter across uncorrupted locations and maximum range of compressional wave properties at a single frequency.

The basic relationships between the compressional wave properties and frequency were tested as for the sand sites, Section 6.1.2. In the case of velocity the confidence in both the weighted mean and weighted linear fit are both extremely poor, with only Mercury 2 possessing a confidence greater than 95 % (*Table 6.5).* Hence, within the reduced errors of the measured velocities from the silty sediments, neither the hypothesis that velocity is independent of frequency or is proportional to frequency are acceptable. The sharply oscillatory nature of the deviations in the measured velocities from the weighted mean, *Figures 4.4.D, 4.5D, 4.6D* and *4.7D,* implies that these deviations arise from spread in velocity, rather than a fundamental frequency-dependent trend.

Location	Mean velocity ($m\cdot s^{-1}$)	Confidence in weighted mean (%)	Confidence in weighted linear fit (%)
Needs Ore 1	1440 $\pm$ 1	> 90.0	> 90.0
Needs Ore 2	1404 $\pm$ 1	< 80.0	< 80.0
Needs Ore 3	1455 $\pm$ 1	< 80.0	< 80.0
Mercury 2	1414 $\pm$ 2	> 99.5	> 99.5
Universe 1	1346 $\pm$ 2	< 80.0	< 80.0
Universe 2	1363 $\pm$ 2	< 80.0	< 80.0
Saltern 1	1408 $\pm$ 3	< 80.0	< 80.0
Saltern 2	1345 $\pm$ 3	< 80.0	< 80.0

Table 6.5. Weighted mean velocity for nine uncorrupted silt locations examined. Confidence in weighted mean and weighted linear fit are included for comparison purposes.

As for sandy sediments, only the hypothesis that attenuation coefficient was proportional to frequency was tested, with the resulting fits plotted in *Figures 6.4E, 6.5E, 6.6E* and *6.7E* and the corresponding values and statistics presented in *Table 6.6.* For six out of the eight silt locations examined, confidence in the weighted linear fit was greater than 95 %. At all locations except Needs Ore 1 and 2, where confidence in the linear fit was less than 80 %, the weighted linear fits are observed to agree with the measured attenuation coefficients within errors. This supports an attenuation coefficient which is proportional to frequency for the majority of silt locations examined. Values of k_A are less than those in sands, ranging from 0.06 to 0.2 $dB\cdot m^{-1}\cdot kHz^{-1}$ with errors typically less than or equal to $\pm$ 0.02 $dB\cdot m^{-1}\cdot kHz^{-1}$. These values display no site dependent trends and are lower than those observed in sands.

In the case of quality factor, the weighted fit resulted in a higher confidence than the weighted mean, with confidence in the weighted linear fit greater than 95 % for four of the eight locations examined (*Table 6.6* and *Figures 6.4F, 6.5F, 6.6F* and *6.7F*). For Needs Ore 2 and Universe 2 errors are comparable to the absolute value of the constant of proportionality Q_A and so a weighted linear fit and weighted mean are equally valid. The observation of negative constants at a further two locations prevents any reliable conclusions being drawn concerning the frequency-dependence of quality factors in silty sediments.

Location	Weighted linear fit in α		Weighted mean in Q		Weighted linear fit in Q	
	k_A $(dB \cdot m^{-1} \cdot kHz^{-1})$	Confid-ence (%)	Mean Q	Confid-ence (%)	$Q_A \cdot 10^{-2}$ (kHz^{-1})	Confid-ence (%)
Needs Ore 1	0.19 ± 0.01	< 80.0	101.1 ± 1.5	< 80.0	18.2 ± 9.3	< 80.0
Needs Ore 2	0.13 ± 0.01	< 80.0	143.9 ± 4.2	> 90.0	0.1 ± 2.7	> 90.0
Needs Ore 3	0.20 ± 0.01	> 99.5	158.6 ± 4.4	< 80.0	-296.2 ± 50.4	> 99.5
Mercury 2	0.17 ± 0.02	> 99.5	151.7 ± 7.2	> 99.5	-160.4 ± 59.7	> 99.5
Universe 1	0.06 ± 0.01	> 99.5	62.2 ± 1.2	< 80.0	86.9 ± 5.2	> 99.5
Universe 2	0.16 ± 0.02	> 99.0	145.6 ± 3.6	> 99.5	28.2 ± 29.1	> 99.5
Saltern 1	0.13 ± 0.04	> 99.5	67.2 ± 2.0	< 80.0	62.4 ± 11.2	> 90.0
Saltern 2	0.18 ± 0.01	> 99.0	77.0 ± 1.7	< 80.0	31.2 ± 6.1	> 90.0

Table 6.6. Investigation of frequency-dependence of attenuation coefficient and quality factor for eight uncorrupted silt locations examined including; constants of proportionality k_A and Q_A, weighted mean of quality factor and corresponding confidences.

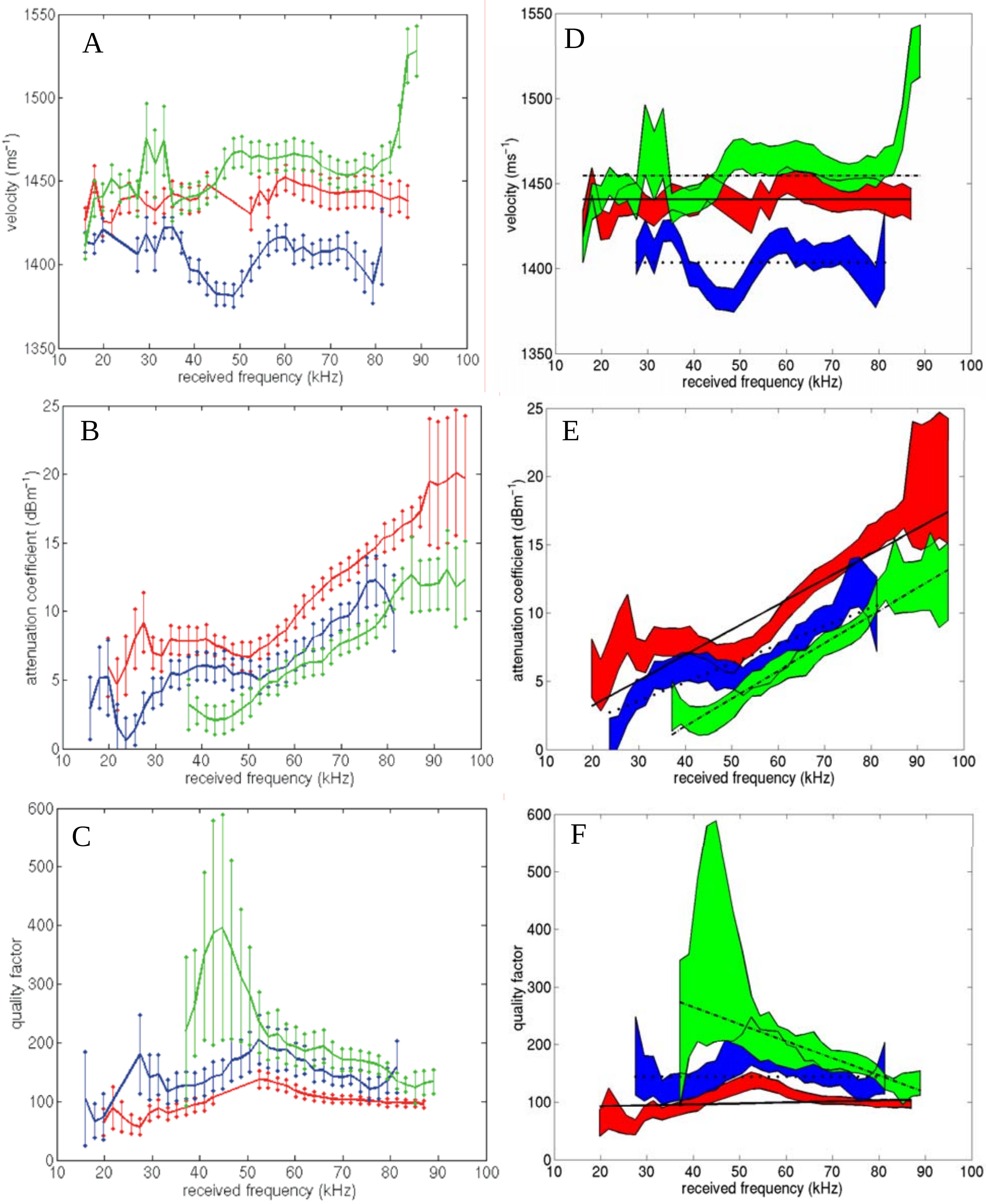

Figure 6.4. Compressional wave properties of sediment examined at the Needs Ore site including; velocity (A and D), attenuation coefficient (B and E) and quality factor (C and F) from Locations 1 (red), 2 (blue) and 3 (green). Selected fits are plotted for Location 1 (solid line), Location 2 (dotted line), and Location 3 (dash-dot line). Errors are denoted by vertical bars (A, C and E) and shaded regions (B, D and F).

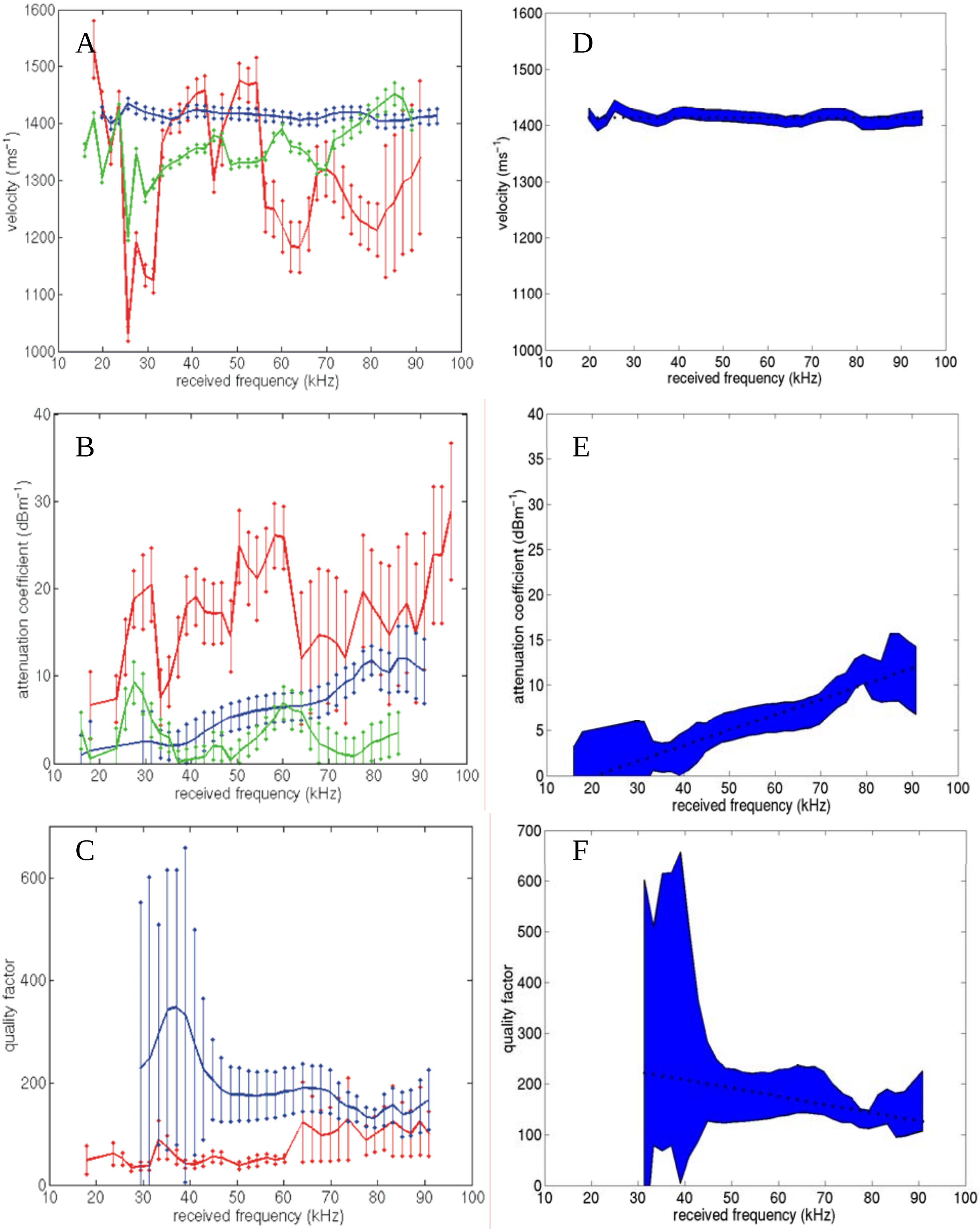

Figure 6.5. Compressional wave properties of sediment examined at the Mercury site including; velocity (A and D), attenuation coefficient (B and E) and quality factor (C and F) from Locations 1 (red), 2 (blue) and 3 (green). Selected fits are plotted for Location 1 (solid line), Location 2 (dotted line), and Location 3 (dash-dot line). Errors are denoted by vertical bars (A, C and E) and shaded regions (B, D and F).

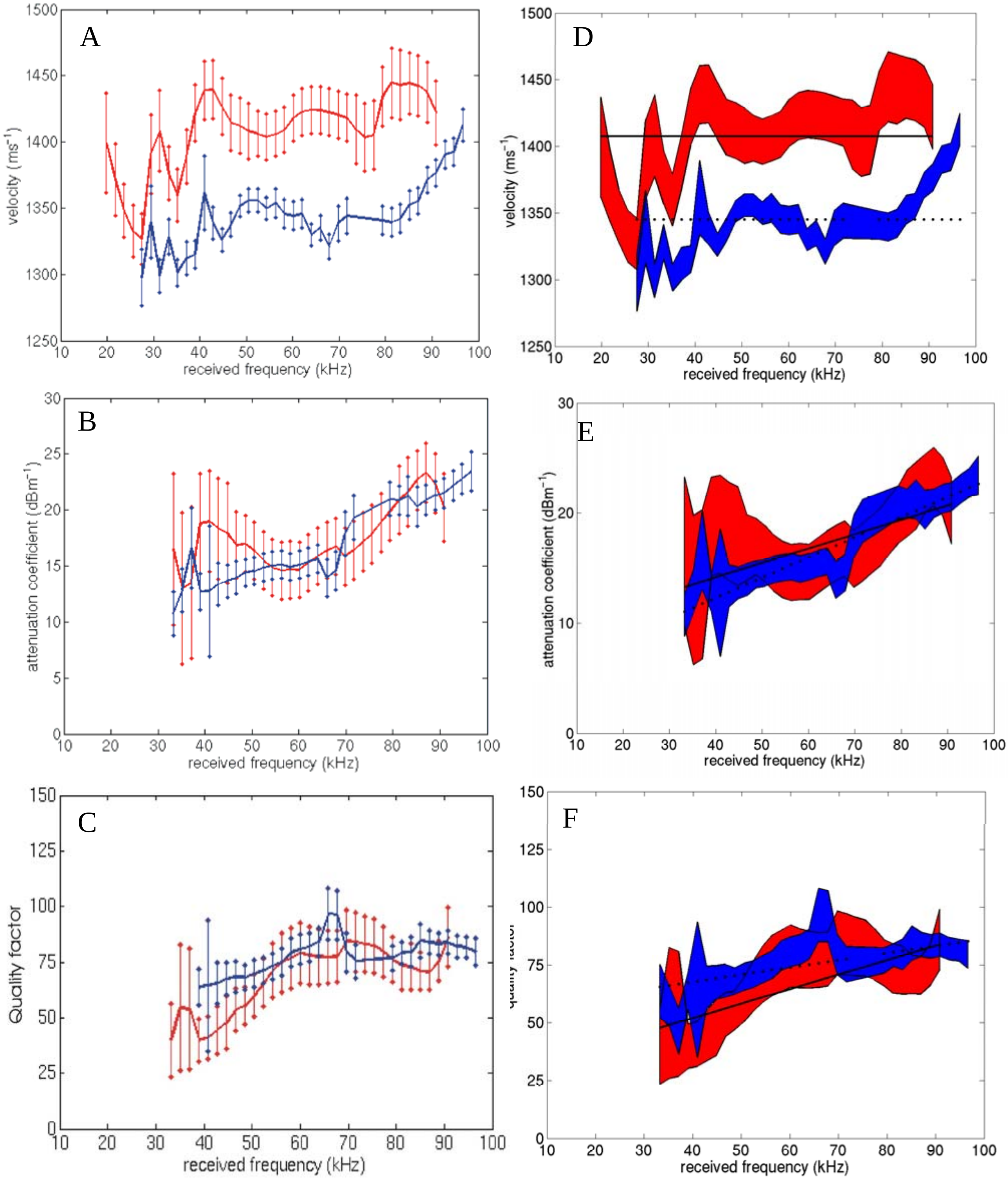

Figure 6.6. Compressional wave properties of sediment examined at the Saltern site including; velocity (A and D), attenuation coefficient (B and E) and quality factor (C and F) from Locations 1 (red) and 2 (blue). Selected fits are plotted for Location 1 (solid line) and Location 2 (dotted line). Errors are denoted by vertical bars (A, C and E) and shaded regions (B, D and F).

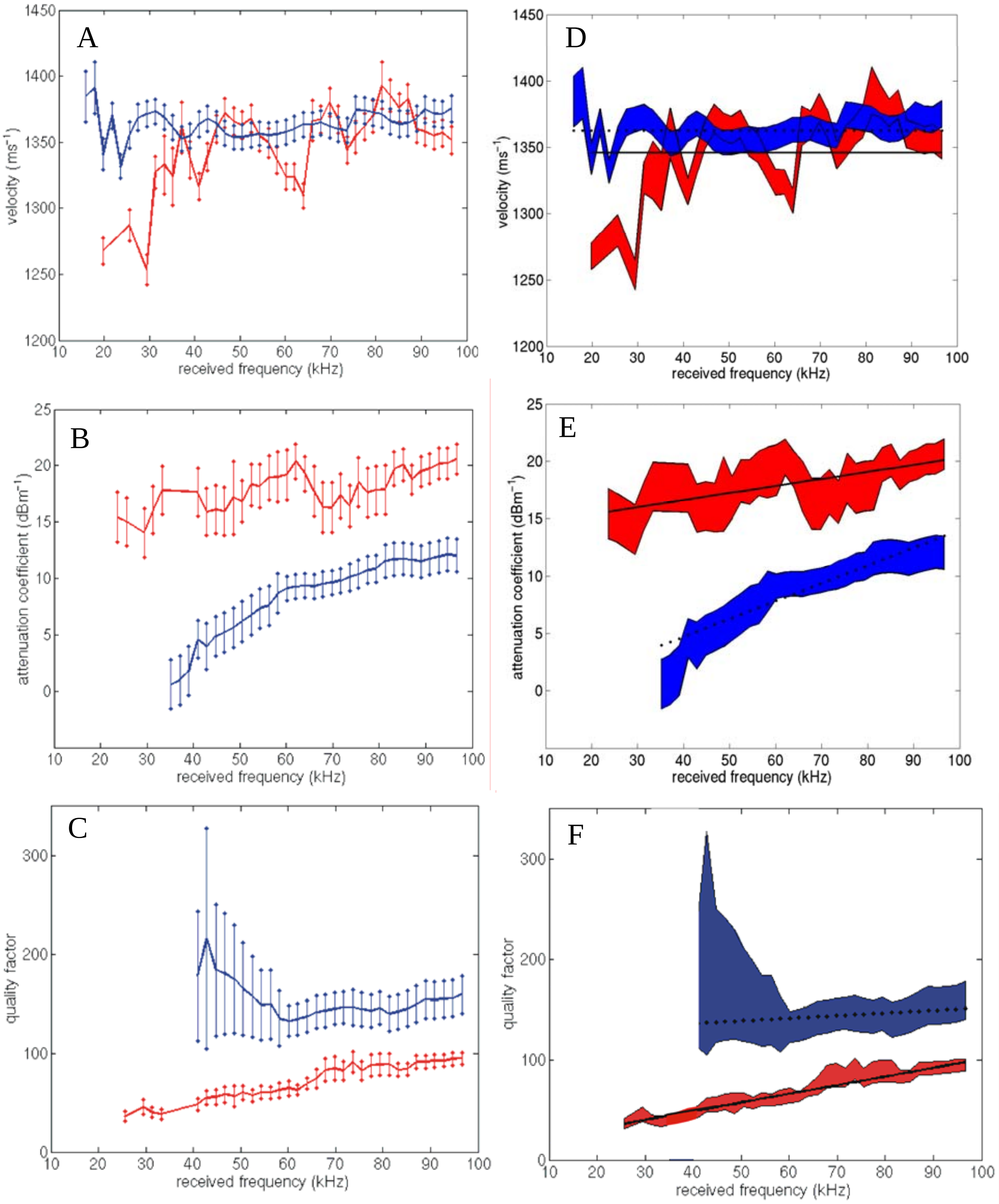

Figure 6.7. Compressional wave properties of sediment examined at the Universe site including; velocity (A and D), attenuation coefficient (B and E) and quality factor (C and F) from Locations 1 (red) and 2 (blue). Selected fits are plotted for Location 1 (solid line) and Location 2 (dotted line). Errors are denoted by vertical bars (A, C and E) and shaded regions (B, D and F).