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AUTOMATIC SEA BED CLASSIFICATION USING SIDESCAN SONAR

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1. INTRODUCTION

An expert operator can inspect a sidescan sonar record and, given a knowledge of the general characteristics of the sea bed site, determine the nature of the bed (sand, mud, rock etc.). However, this approach is time-consuming and susceptible to subjective errors. Computer analysis of the sidescan sonar returns can provide faster and more reliable classification of the sea bed. This paper presents the results of a classification method based on differences in the spectra of the envelope of the sidescan sonar return amplitude. Several independent data sets and some special cases, such as a sea bed with ripples, are considered.

2. THE BASIS OF THE SPECTRAL ANALYSIS METHOD OF SEA BED CLASSIFICATION

When a sidescan sonar insonifies the sea bed, the acoustic returns, which may be called backscatter or reverberation, have an amplitude which is a function of time t within the transmission interval and can be written A(t). Pace and Gao[1] have shown that the spectral (or frequency) analysis of A(t), involving taking its Fourier transform, reveals information on the nature of the sea bed, allowing its classification as either SAND, MUD, CLAY, GRAVEL, STONES or ROCK, with, in most cases, a probability of misclassification of less than 2.5% (subject to certain assumptions). The low frequency content of the averaged normalized log power spectrum, PNL (f), obtained after taking the Fourier transform of A(t), is shown to increase through the above sequence of six sea bed types. Thus sand tends to have the least, and rock the most, low frequency content in its reverberation profile A(t).

The A(t) function must be corrected for range-dependent effects unless the sections of the A(t) profile on which the Fourier transform is performed are short enough for such effects to be disregarded. The averaging of the spectrum referred to above relates to an averaging over several successive transmission intervals (the same 'range bracket' of the A(t) profile being used in each).

3. DEFINITIONS

Let the highest frequency in the spectrum be fMAX. Then two parameters, Df1 and Df2, which express the relative areas under the averaged normalized log "power" spectrum between certain frequency limits, are defined as follows:

$$\mathrm{Df1} = \frac{\int_0^{\frac{1}{2}\mathrm{fMAX}} \mathrm{PNL(f)\,df}}{\int_{\frac{1}{2}\mathrm{fMAX}}^{\mathrm{fMAX}} \mathrm{PNL(f)\,df}}$$

$$\mathrm{Df2} = \frac{\int_0^{\frac{1}{16}\mathrm{fMAX}} \mathrm{PNL(f)\,df}}{\int_{\frac{1}{2}\mathrm{fMAX}}^{\mathrm{fMAX}} \mathrm{PNL(f)\,df}}$$

where f denotes frequency. These definitions are effectively the same as in Pace and Gao [1] (except that a specific value of fmax is used there). Figure 1 shows a typical plot of PNL(f) for an area that is thought to be sand (a 100 kHz sidescan sonar was used).

The remainder of this paper deals mainly with results obtained at Marconi Underwater Systems Limited using the 'Df' spectral analysis method.

4. RESULTS FOR SIX DIFFERENT SEA BED TYPES

Figure 2 shows values of Df1 and Df2 for 48 kHz sidescan sonar data (and the case fMAX = 3.1 kHz). Both Df1 and Df2 tend to increase through the sequence SAND, MUD, CLAY, GRAVEL, STONES, ROCK. There is seen to be quite a lot of overlap between the Df1 values for sand and mud, but little overlap between the Df2 values for successive sea beds from the above sequence. Hence Df2 for the case fMAX = 3.1 kHz seems to be an effective parameter for classification purposes.

A major advantage of the frequency analysis method of sea bed classification is that it is insensitive to the absolute levels of the return amplitude, being based on the relative levels of the returns at different times. Thus it can be applied without the need for accurate calibration of the sonar.

5. FURTHER RESULTS

The key objective in this work has been to identify a 'robust' classification parameter which proves effective when applied to any available data set. Data for the full range of sea beds, with good ground truthing, is however hard to find. Where comparisons have proved possible, encouraging agreement has been found. Consider the ratio (Df2/Df1), which appears less sensitive to the value of fMAX than the Df1 or Df2 values separately. Values of (Df2/Df1), for fMAX = 6.85 kHz, in the range approximately 0.174-0.193 have been found for sandy sea beds in two independent sets of sidescan sonar data, one for an area off the south coast of England at 100 kHz sidescan sonar frequency and the other for an area near the Shetland Isles at 50 kHz.

The value of (Df2/Df1) for rock in the 100 kHz data set referred to above was about 0.21 i.e. significantly higher than any of those for sand. Figure 2 is for different geographical areas again, a different fMAX and 48 kHz sonar frequency, but it clearly shows that the (Df2/Df1) values for rock (around 0.24) are higher (by typically 30%) than those for sand (around 0.19), the data points for rock lying well to the right of the main trend line.

In the 50 kHz data another very high (Df2/Df1) value at fMAX = 6.85 kHz, about 0.23, was found for an analysis area in which a pipeline is located. It seems that the hardness and diameter of the pipeline cause its reverberation profile, A(t), to resemble that of rock in some respects. This reinforces the consistent picture that is emerging.

In order to provide a test of the robustness and universality of the 'Df' approach, it was applied to some data for the Scotian Shelf (off Nova Scotia) as published in [2]. In that paper the amplitude of the signal reflected from the sea bed as a result of insonification by a broadband seismic 'boomer' pulse is given. The median 'incoherent' reflectivity coefficient for the returns, 'r_2', namely the reflectivity corresponding to the total of the sea bed returns received between 0.64 ms and 1.60 ms after the first return, is given separately from the 'direct' coefficient which relates to the total of the returns in the first 0.64 ms. The incoherent component was used in this analysis because it includes scatter at the sea bed, and it was considered that its behaviour was more likely than that of the direct component to resemble backscattered sidescan sonar signals. The scale of the graphs in [2] is such that r2 could reasonably be read off only at rather long intervals of about 87 m along the sonar track. Fortunately the boomer source was highly repeatable, and normalization was applied to correct for spreading losses etc., so returns from widely different positions along the track may be compared as if they were all returns received during one transmission interval. Then the Fourier transform was applied to the r2 values, and normalized log power spectra obtained. The following Df1 values were obtained for three cases in which a just sufficient number of sufficient data points (about 15) was available:

clay	1.189
gravel	1.342
bedrock	1.643

i.e. the same 'order' and similar relative increments of increasing Df1 as are seen in Figure 2 where the frequency of the sonar source was much higher and the geographical locations were quite different (the absolute values of the Df1's are different from those in Figure 2 which is as expected because of the much lower digitization frequency for the data read off from [2]).

In general the digitization frequency of a data set, and hence the value of fMAX, is closely related to the sonar bandwidth and hence the transmitted pulse length. Data obtained using different sonars will in general involve different digitization frequencies. If the value of fMAX is standardized it tends to be at the expense of not fully utilizing the data sets at the highest digitization frequencies.

6. SPECTRAL ANALYSIS FOR AN AREA OF RIPPLES

Figure 3(a) is a binary grey level plot for a generally sandy area off the south coast of England which was insonified by 100 kHz sidescan sonar. Ripples are evident at the top of the plot. Figure 3(b) is the log power spectrum for the part of the area indicated (it took 50 transmission intervals to insonify this part of the area, so the spectrum in Figure 3(b) is the average of 50 spectra, one for each transmission interval). The spectrum has a high resolution because 450 pixels are included for each transmission interval. The high resolution allows a spectral peak at non-zero frequency to be seen clearly. The position of the peak has been found to be consistent with the ripple spacing in the across-track dimension. Even the width of the peak (it extends over about a 2:1 range) can be accounted for, by the range of measured ripple spacings (spanning about a 2:1 range) as shown in Figure 3(c). Clearly, high resolution spectral analysis offers the prospect of identification of ripples running parallel or at an acute angle to the sonar track, and estimation of their dimensions. If the ripples run at an angle to the sonar track, the component of their spacing orthogonal to the track would be measured. Spectra should be examined for evidence of ripples because their presence could perturb the Df values and lead to misclassification of sea bed type unless allowance is made for them.

7. THE SPECTRAL ANALYSIS OF AN AREA OF MIXED SEA BED TYPE

If the Df values are to be used for sea bed classification, their behaviour at the boundary between areas of different sea bed type is of interest. No suitable data for an area containing a well-defined boundary between two different ground-truthed sea beds was available. Consequently two of the 48 kHz sidescan data files for different sea beds, e.g. mud and rock, were spliced together to create a sharp, straight boundary between them. All the amplitudes on one side of the boundary were then multiplied by an appropriate factor so that the ratio of the mean amplitude on one side to that on the other side was similar to that which would be found at a natural boundary e.g. a 1:6 ratio for a mud:rock boundary giving $20 \log_{10} 6 \simeq 15$ dB contrast between the reverberation levels. Figure 4 shows the trend of the Df2 values for two different boundaries. In Figure 4(a), as the amount of rock in the analysis area increases to the right, the Df1 and Df2 values rapidly approach those for 'pure rock'. In the transition, the Df's assume values appropriate to sea beds other than mud or rock. In Figure 4(b) the transition for a gravel:stones boundary is seen to be more gradual. Where boundaries between different sea beds may occur, the Df method should not be used in isolation for classification purposes. Additional parameters, such as the standard deviation and other statistical moments of the amplitude distribution, may have to be used.

8. CONCLUSIONS

Work carried out with a number of independent data sets confirms the conclusion reached in [1] that the spectral analysis of the profile of reverberation from a sea bed insonified by sidescan sonar provides a basis for determining the nature of the bed. If used in isolation, however, spectral analysis of the sea bed in an area containing a boundary between two different types of bed (e.g. mud and rock) can give misleading information.

Special results have been obtained for a pipeline and for an area containing ripples. High resolution spectral analysis offers the prospect of identification of ripples running parallel or at an acute angle to the sonar track and estimation of their dimensions.

REFERENCES

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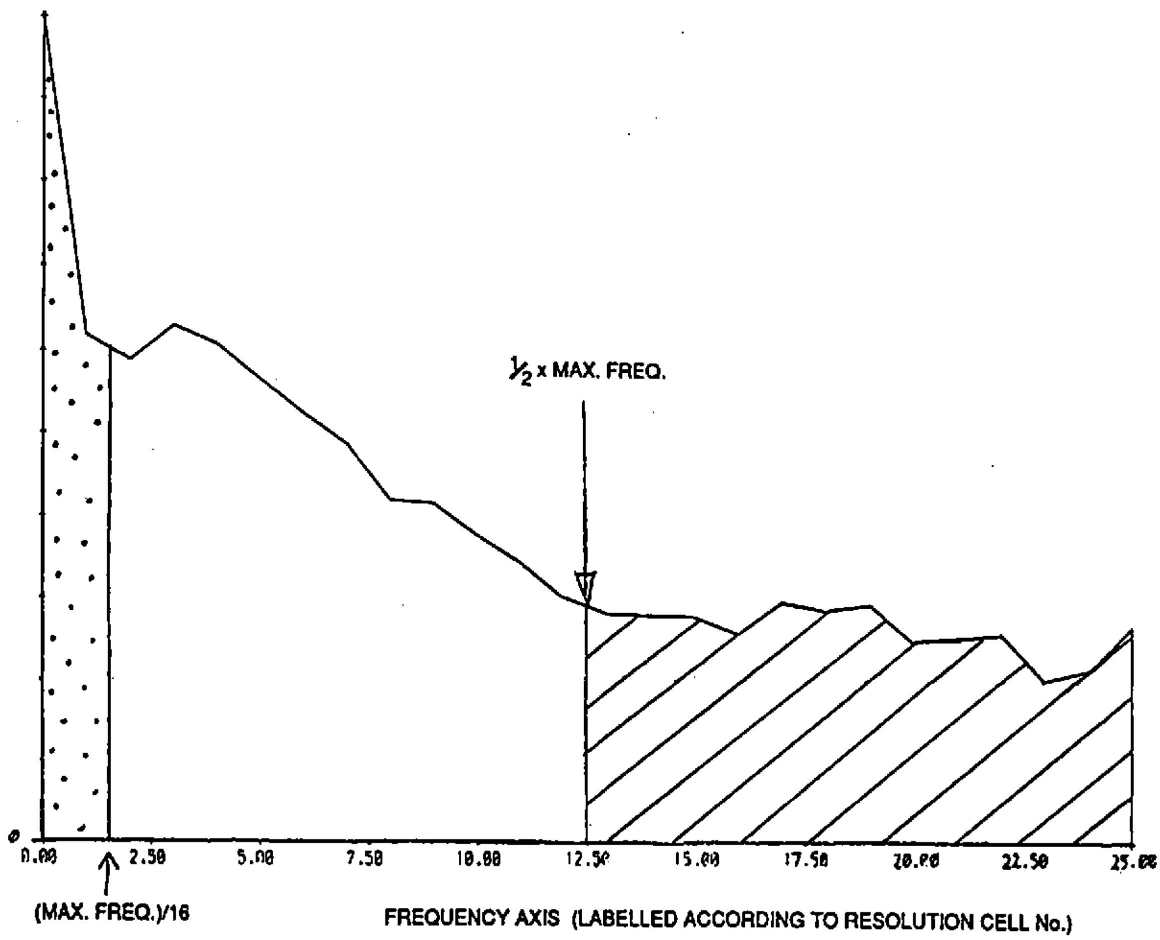

Figure 1 A Typical Frequency Analysis Plot

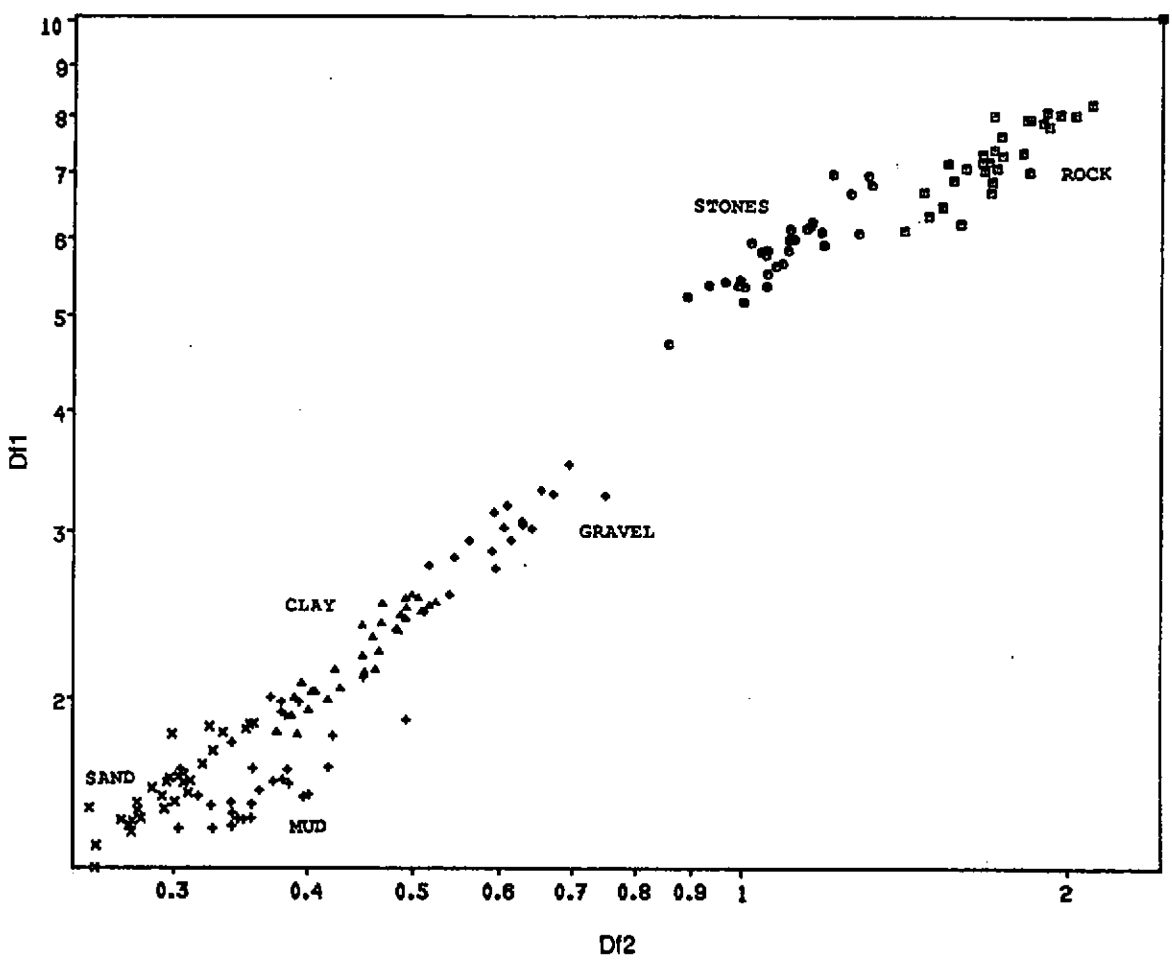

Figure 2 The Df1 and Df2 Values (for fmax = 3.1 kHz)

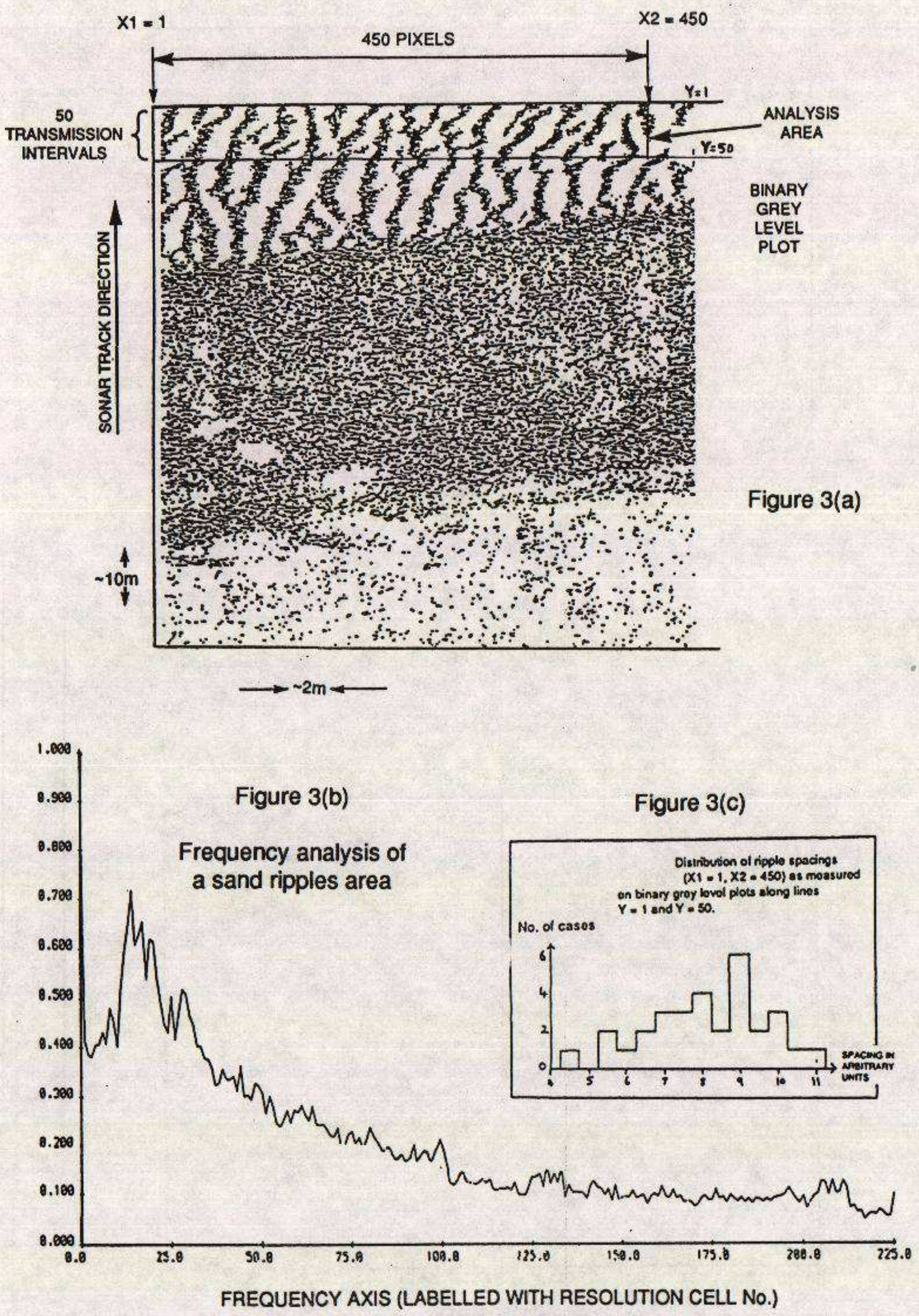

Figure 3 Analysis for Area of Ripples

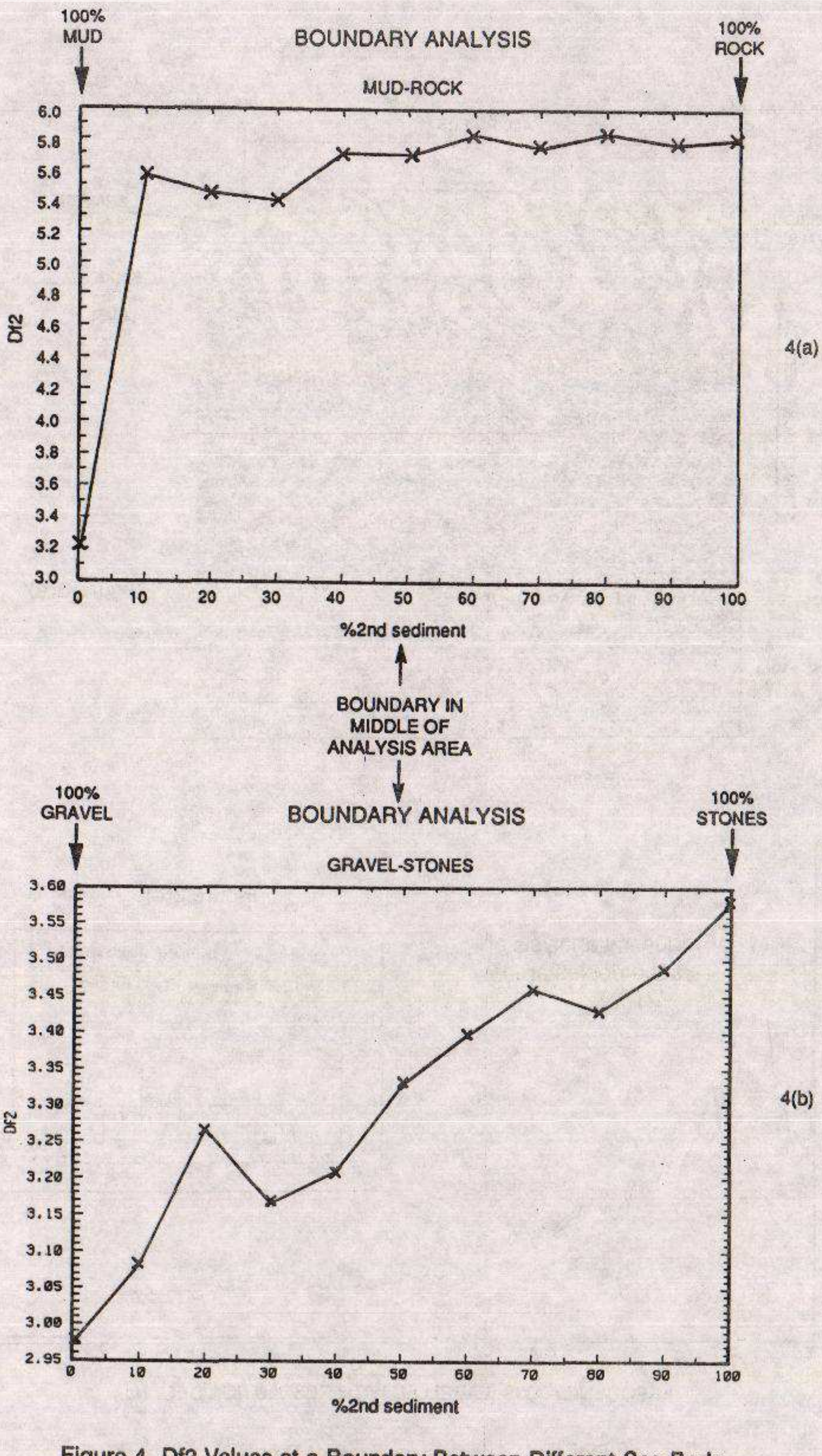

Figure 4 Df2 Values at a Boundary Between Different Sea Beds