Ascendancy of Continuous Profiles of Grain-Size Distribution for Depositional Environment Studies*

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Abstract

Knowledge of structure, composition and texture, the three fundamental attributes of sedimentary deposits, is necessary for a robust analysis and interpretation of depositional environment. In the absence of core information; borehole images, “elemental-capture spectroscopy” and NMR logs all contribute to understanding the structure, composition and grain-size attributes. Grain-size is considered the most important textural parameter because it reflects the processes and energy levels active at the time of deposition. Early studies show that depositional processes and environment can be inferred from size distributions of Krumbein (1934) and Sahu (1964). These inferences are based on deductions and experimental data and deliver acceptable accuracy, although Krumbein (1941) shows other textural (e.g. shape, roundness, roughness) and compositional information enhances certainty).

Building on early work, we present a methodology and examples where NMR derived grain-size distributions are used to infer depositional environment. In contrast to spot-core analysis, NMR provides a continuous along hole profile of grain-size-distributions. This study is the first to utilize a continuous grain-size-distribution profile. The study was conducted blindfolded, without initial reference to core studies, to test the robustness of the methodology.

By using statistical parameters from grain-size distributions that are characteristic of depositional environments, and applying Sahu (1964) linear-discrimination functions, depositional systems for two wells were inferred to be shallow marine-to-fluvial deltaic. Linear-discriminate analysis of geostatistical variables showed bimodal distributions of sediments dominated by fine-grain sands and silts. The studied sandstones were concluded to be mainly fine grained, moderately to poorly sorted, fine skewed, mesokurtic, leptokurtic occasionally platykurtic in nature.

Our conclusion was “shallow-marine deposition” and was compared and confirmed with core-driven studies as “shallow marine”. In summary, profiles of grain-size-distributions from NMR logs provide important information about changes in depositional energy level from which we infer depositional setting and reservoir quality. A precise depositional environment interpretation is crucial for optimal/economical field development.

Introduction

Historical studies have shown that sediments with different physical characteristics (size, shape, textural properties) are transported and deposited uniquely different, but in correlatable modes. Therefore, profiles of grain-size distributions in pivotal wells are one of the main elements in the studies of genesis and evolution of sedimentary environments. The trends in grain-size distributions of a field exhibit mutual or reciprocal relation between the sediment itself and its depositional environment. Although, the process of deposition and the environment can be inferred from the statistical elements of the size distribution, these inferences are based on deductions of statistical nature and historically proven to provide acceptable accuracy when the actual sedimentological data are missing. However, the accuracy of deductions on depositional environment and processes are largely based on the adequacy of number of core samples and their representativeness.

With the advent of NMR (Chen et al., 2007), wireline technology (acquisition, processing and interpretation of data), it has become possible to attain continuous grain-size profiles for the entire log coverage of the zone of interest, providing continuity of the required data that was not available earlier. The information driven from the NMR data leads not only the depositional environment deductions, but also the types of processes and energy levels that originated the transport of sediments. With the mineralogical information that can be gathered from elemental capture spectroscopy logs, it will be possible to derive newer discriminate functions to further evaluate and classify the mode of transportation, weathering undergone, or simply, the nature of the depositional basin. Few control wells with the aforementioned data in a field with the processes explained in this study can yield more reliable deductions of depositional environment leading to better field development and better realization of the projected field economics.

We derived continuous profiles of grain-size distribution from NMR logs for two wells (X & Y) to interpret the depositional patterns. By using the inter-relationship of size-distribution and its statistical features with various types of depositional environments and applying Sahu discrimination functions (Sahu, 1964), the depositional systems were inferred as shallow marine to fluvial (deltaic). Linear discriminant analysis of geostatistical variables showed bimodal nature of sediments having dominance of fine grain sands and silts. The sandstones were concluded to be mainly fine grained, moderately to poorly sorted, fine skewed, mesokurtic, leptokurtic occasionally platykurtic in nature. The study was conducted independent of the sedimentological/geological study and in a blindfolded manner with no prior knowledge of the actual sedimentological study of the field. Our conclusion was “shallow marine deposition” and were compared and confirmed with core-driven studies of the field as “shallow marine”.

Methodology

Grain size distribution is one of many descriptive measures of sedimentary rocks. It provides information about the intrinsic properties of the sediments and their environment via yielding probable nature and energy of the transporting means that supplied the sedimentary basins. Understanding the grain size characteristics and its variation from well location-to-location sheds a light on the depositional environment. We have used profiles of grain-size distributions with Linear Discriminate Function (LDF) (Sahu, 1964) formulations to evaluate potential depositional environments for the case studies, and then compare our conclusions with independently done sedimentological analyses and results. In the heart of our study, there lies the advance NMR Wireline technology that provides continuous profile of grain size distributions (Gladkikh, 2005) of the zone of interest (Figure 1). The technology relies on innovative use of NMR experiments together with pore-network modelling that lead to the creation of synthetic NMR responses. Synthetic NMR responses are created by honouring the porosity, mineralogy and the anticipated degree of packing and compaction, then, are compared against the actual NMR tool responses. The convergence of modelled and actual NMR responses is attempted by iterating on the degree of compaction and packing order of the modelled pore-network. Continuous grain size distributions for the vertical resolution of NMR tool are created upon the convergence of NMR responses and by deconvoluting the geometrically definable pore-network.

Numerous attempts have been made toward discriminating depositional environments from textural parameters that include grain size distribution, shape, and texture of the grains (Figure 2). However, in our study, the deductions were made based on LDF outputs by using the statistical elements driven from continuous profile of grain size distributions. We have used Udden-Wentwort Grade scale as the expression of our size-classes (Figure 3).

The statistical features studied from the NMR acquired set of grain-size profiles were; mean, median, sorting, skewness, kurtosis and the standard deviation. Historically, exhaustive studies of correlations between these features and transport-means and the depositional environments have been the basis of the LDF driven deductive logic that produces the depositional processes and the environments. The “Mean Size” is an indication of fine-sands depositing at moderately low energy environment while the “standard deviation” yielding information on the level of ever-changing kinetic energy or the transport velocity of the transporting mean.

Skewness or asymmetrical distribution profile indicates the input mode and/or transport channel and energy environment as a function of direction and the absolute value of it. On the other hand, kurtosis is a reflection of the degree of change in flow characteristics of the depositing medium, and; therefore, it is a more subtle element to watch as it also has implications on the maturity of the sand. In his classical paper, Sahu (1964) states and shows that depositional environment and the process of deposition have high degrees of correlations with all of these statistical elements; and there from, can be de-convoluted. In our study, we applied the statistical formulations used in sedimentology to compute the aforementioned parameters and used them in LDFs for semi-deterministic analysis of grain size profiles. These analyses provided the information on energy environment of the sedimentation process, and then guided us in concluding probable depositional environments and processes for the studied cases.

Statistical parameters of the distributions were calculated, and classified by using the templates given in Figure 4. Then, by employing a set of Linear Discriminant Functions (LDF) published by Sahu (1964) (formulae given below), the depositional environments and the processes for the case studies were surmised. The comparison and confirmation of shallow marine environment from fluvial one is made by Y3 formula.

Aeolian or Beach: $Y1 = -3.5688 \cdot M + 3.7016 \cdot r^2 - 2.0766 \cdot SK + 3.1135 \cdot KG$ If Y1 $>$ -2.7411 ➔ Beach; if Y1$<$-2.7411 ➔ Aeolian
Back shore or subtidal: $Y2 = 15.6534 \cdot M + 65.7091 \cdot r^2 + 18.1071 \cdot SK + 18.50435 \cdot KG$ if Y2 $\leq$ 65.365 ➔ Beach (back shore); if Y2$>$65.365 ➔ Shallow agitated marine (subtidal)
Shallow marine or fluvial (deltaic): $Y3 = 0.2852 \cdot M - 8.7604 \cdot r^2 - 4.8932 \cdot SK + 0.0482 \cdot KG$ If Y3 $\leq$ -7.5190 ➔ Fluvial (deltaic); if Y3$>$-7.4190 ➔ Shallow marine

Our study for the Case 1 yielded the following conclusions that are depicted in Figure 5 and Figure 6. Further evaluation of depositional features that are useful in final deduction are presented in Figure 7 for Case 1.

Conclusions

Grain size distribution data from NMR logs with proper modeling and the application of LDF to the statistical parameters provide a template for inferring depositional environment and the processes as a tool for sedimentological studies. Case studies indicated that the sediments were deposited under "shallow marine environment" by beach and fluvial processes by a near shore agitated turbidity action of water. Bivariant plots present an overlapping of the near shore samples of the study area. Consensus of the evaluations was that the depositional environment was "shallow marine".

Acknowledgment

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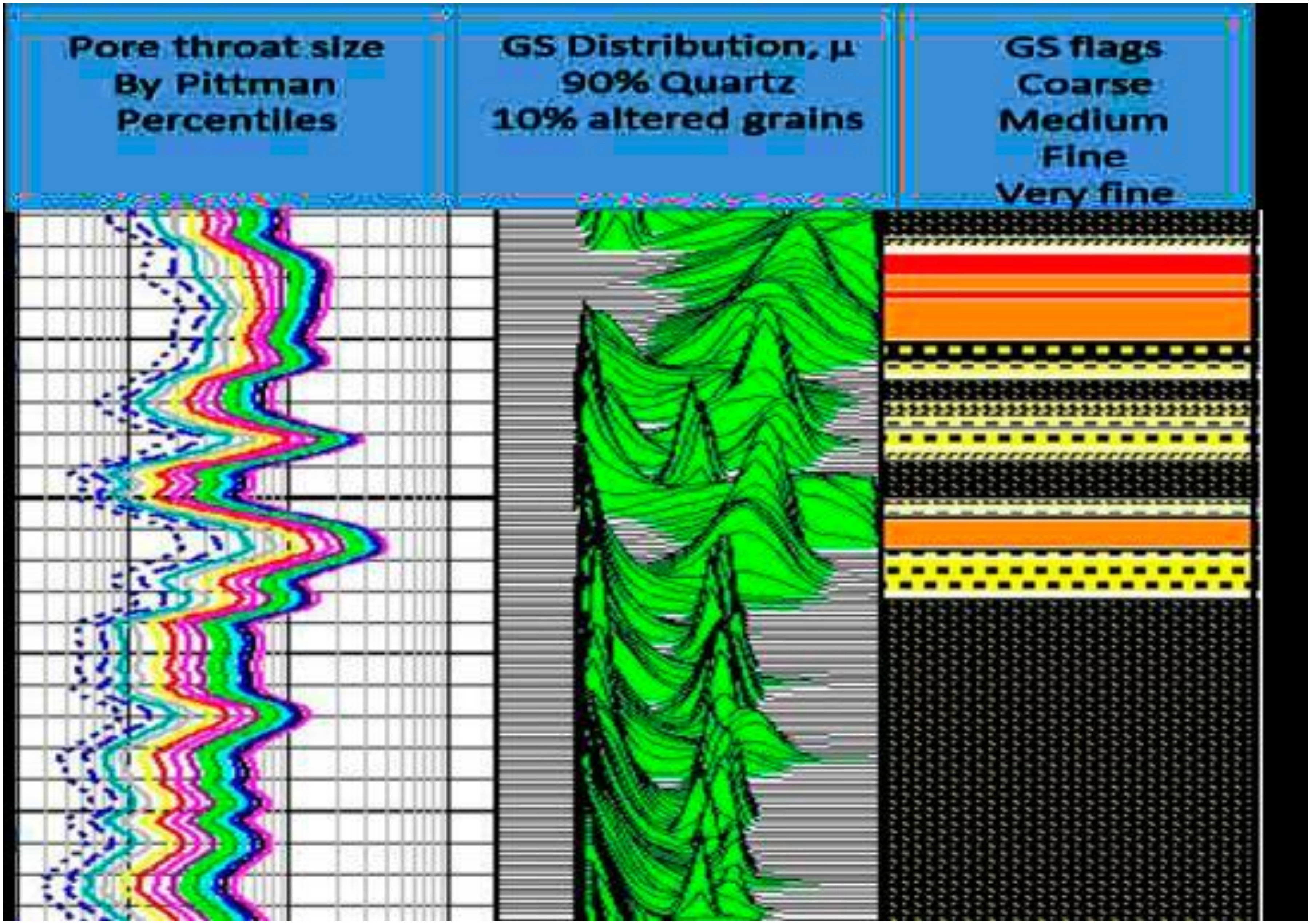


Figure 1. NMR-driven grain-size distribution.

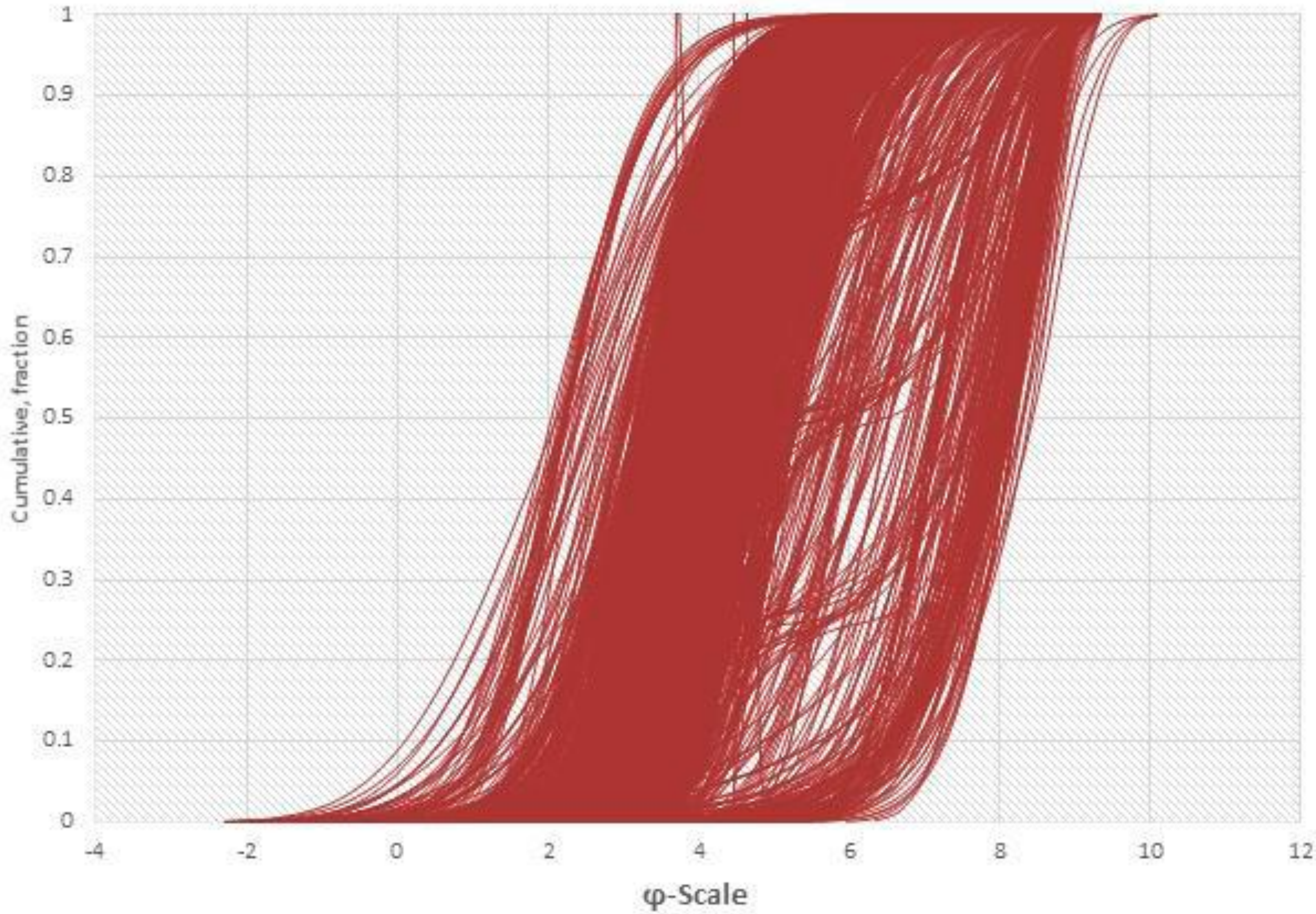


Figure 2. A wide range of grain sizes computed from NMR data for the subject zone in Case 1.

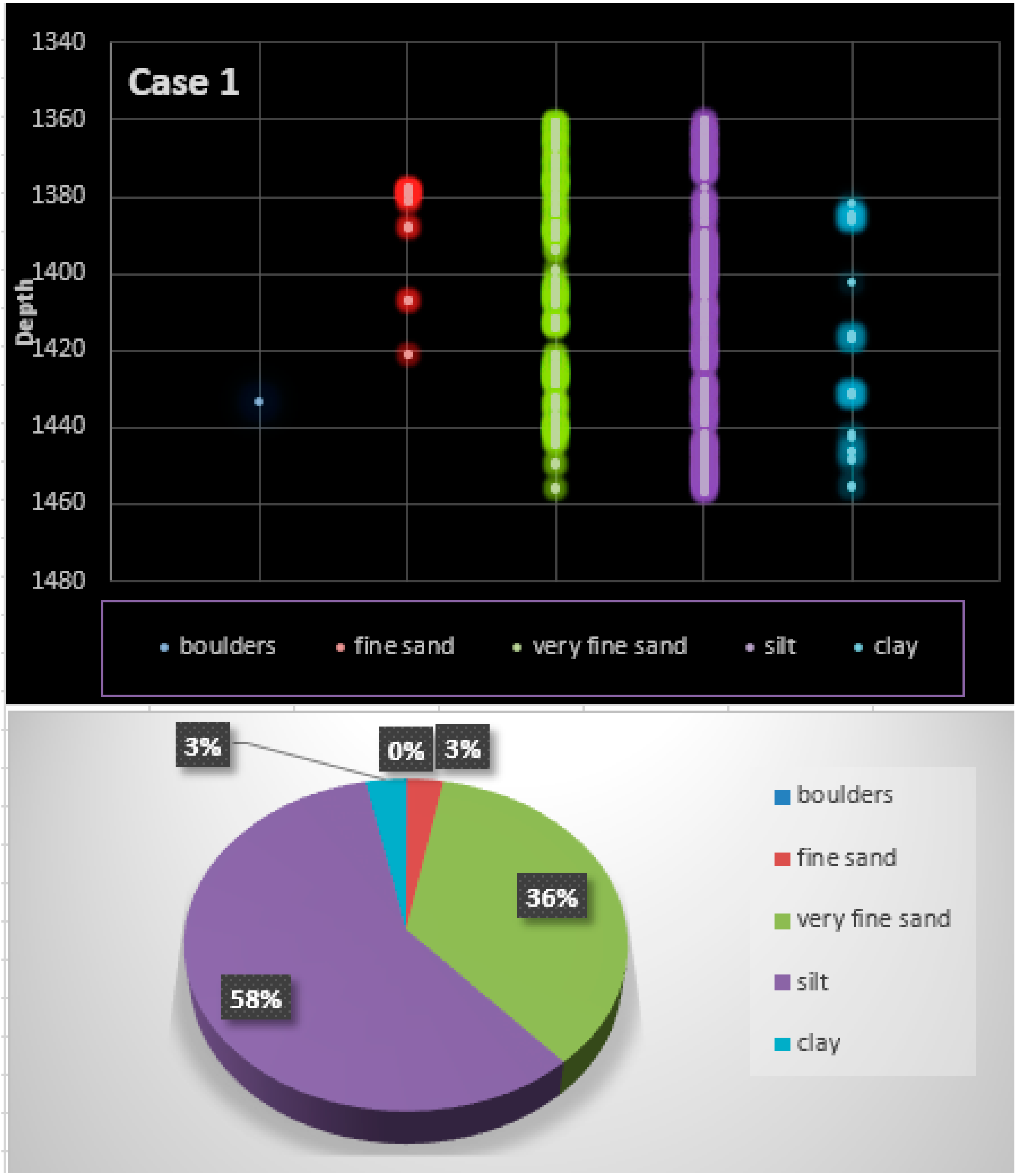


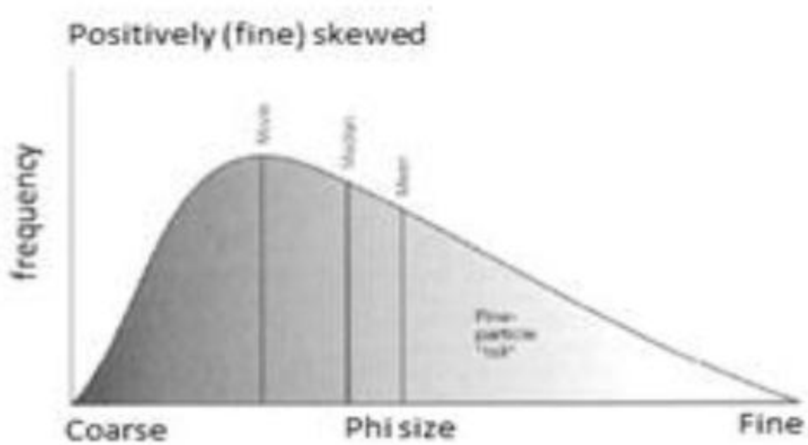
Figure 3. Grain size classification for Case 1.

Sorting: (from inclusive graphic standard deviation)

very well sorted	under 0.35 phi
well sorted	0.35 to 0.50 phi
moderately well sorted	0.50 to 0.71 phi
moderately sorted	0.71 to 1.0 phi
poorly sorted	1.0 to 2.0 phi
very poorly sorted	2.0 to 4.0 phi
extremely poorly sorted	over 4.0 phi

Sorting skewness: (from inclusive graphic skewness)

strongly fine- skewed	+1.00 to +0.30
fine- skewed	+0.30 to +0.10
near symmetrical	+0.10 to 0.10
coarse-skewed	0.10 to 0.30
strongly coarse-skewed	0.30 to 1.00



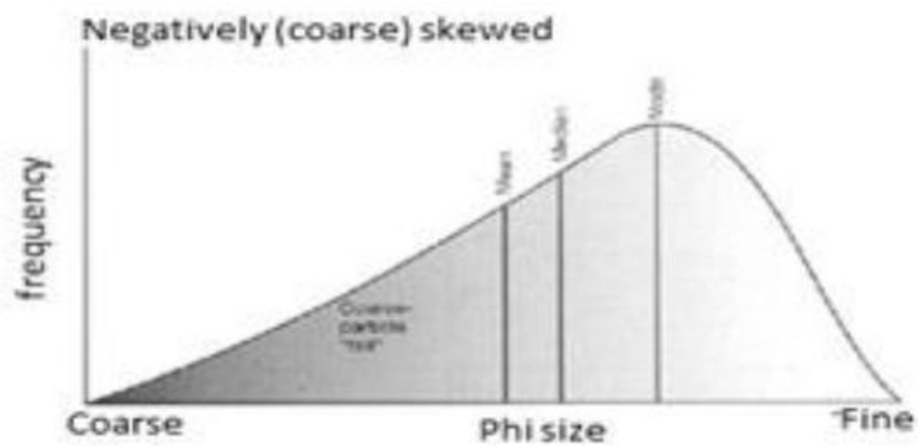


Figure 4. Criteria of sorting and sorting skewness.

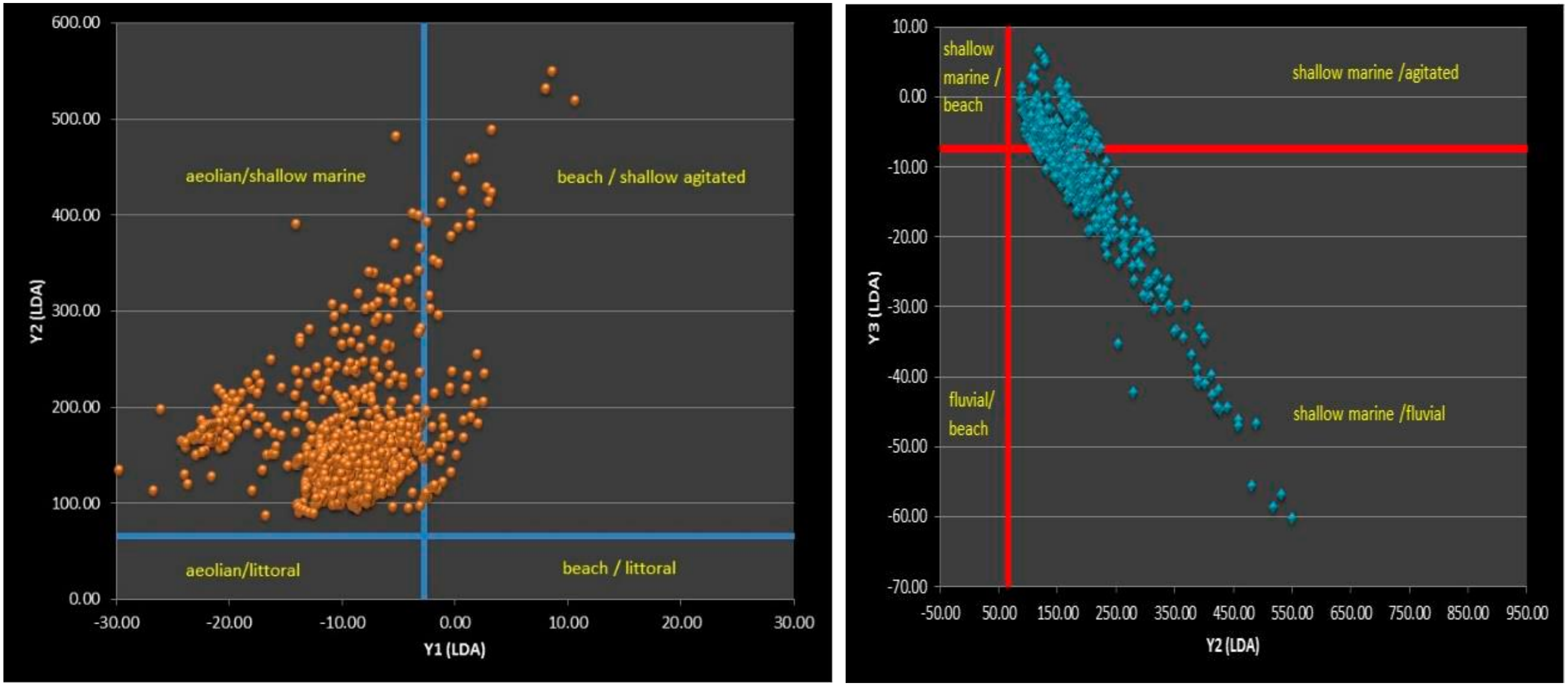


Figure 5. Aeolian /Shallow and agitated marine are the dominant environment for Case 1.

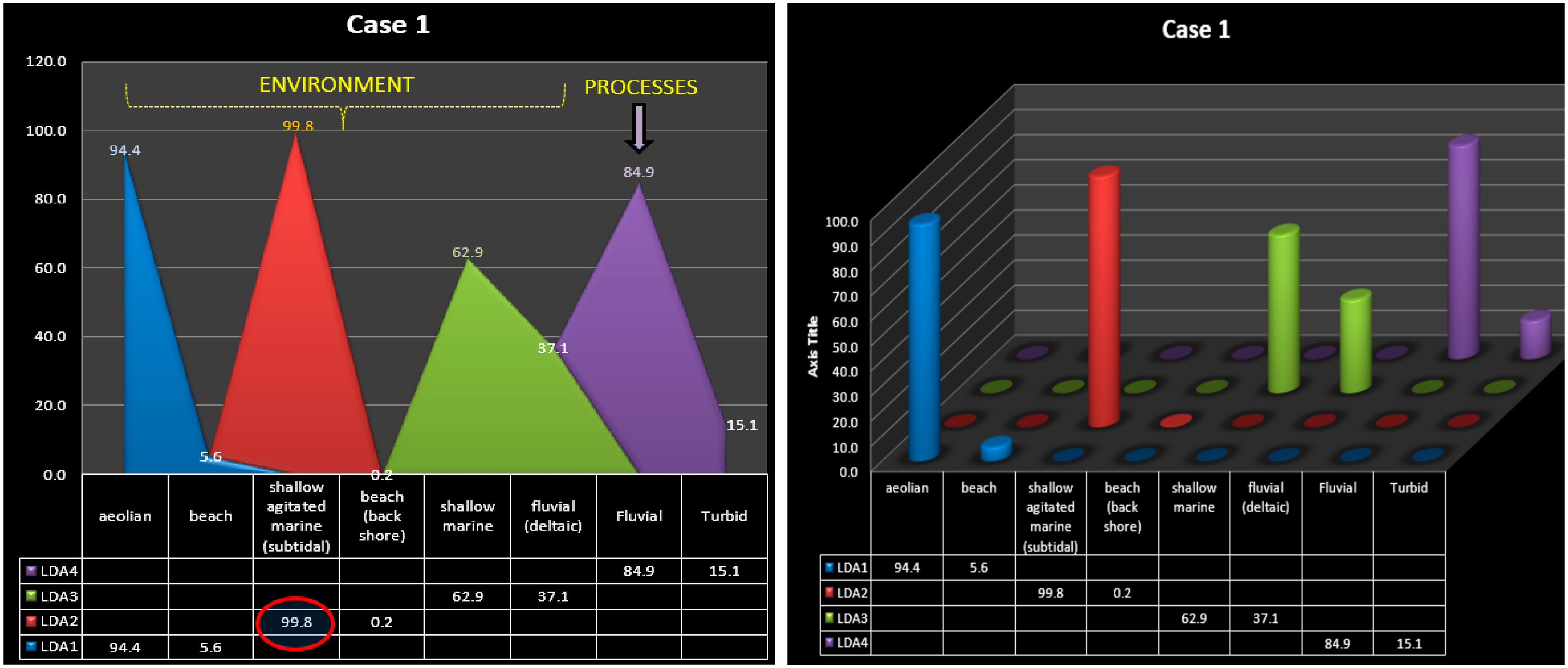


Figure 6. Shallow agitated marine environment and fluvial deposition are determined from LDFs.

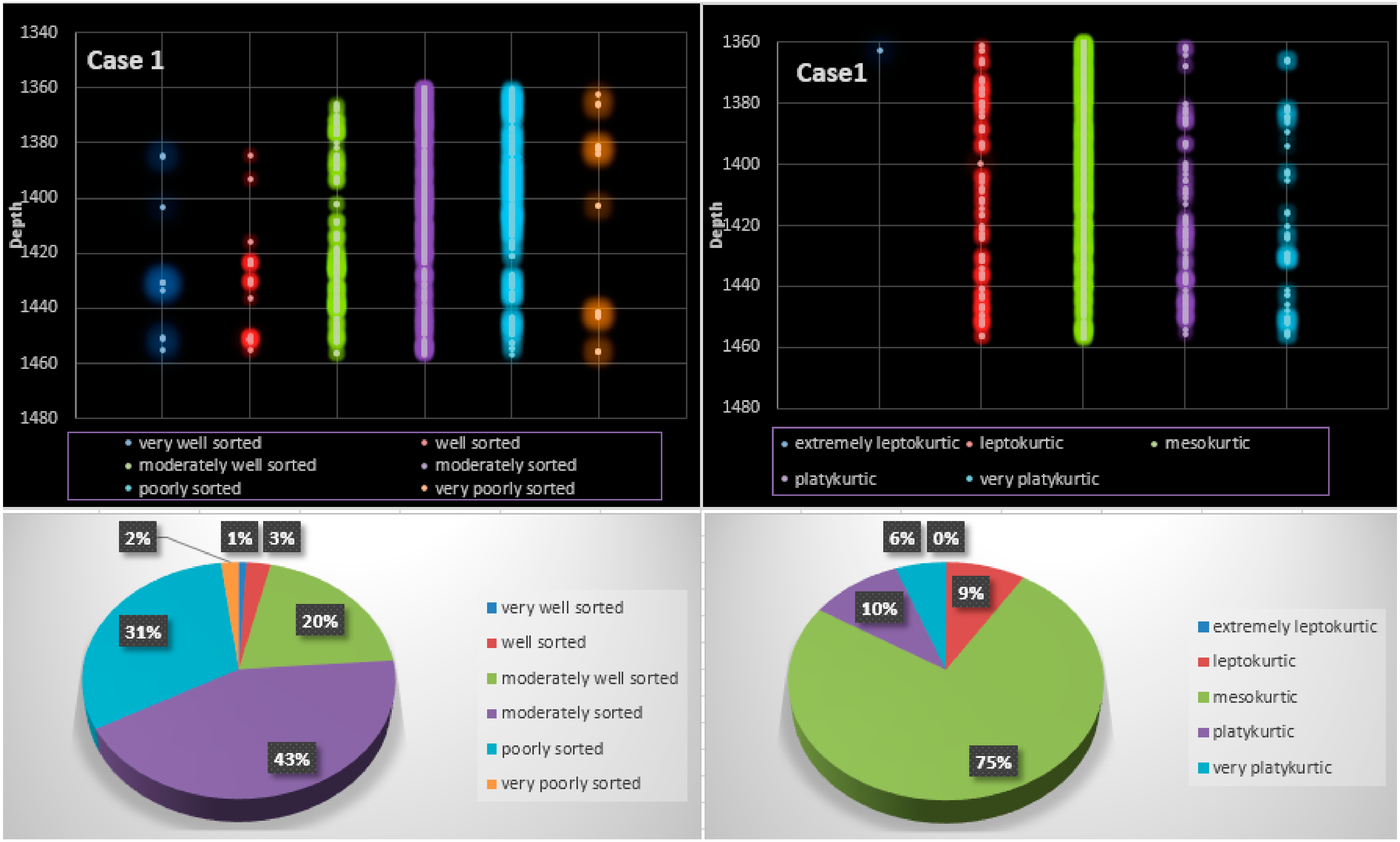


Figure 7. Mostly “moderately to poorly sorted” and “leptokurtic to platykurtic” and dominated by “mesokurtic” accumulation of the sediments make up the Case 1.