Oil Sands Fabric: The Grain Component and Influences on Reservoir Properties*

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Abstract

The grain component of the oil sands fabric was explored from three Canadian oil sands depositional settings from the McMurray Formation to determine grain morphology and weatherability, along with 'sourcing grains' to confirm depositional environments. In reservoir management studies, it is well known that accurate predictions of reservoir quality have a major influence on the success of a recovery program. Inherent characteristics of grains can be directly observed, including textural properties (such as grain size, grain shape, and sorting) and pore scale properties all which control reservoir properties. For the pilot study, 1000 grains were analysed from each of the three depositional environments, a transition environment, including a depositional setting, estuary reservoir proper, and the main estuarine reservoir. They were observed by SEM and results analysed with an image analysis package. For the overall study, 18,000 grains from cores, 6000 from each of the three depositional environments were analysed. Preliminary results from SEM analysis revealed that grains from the three depositional settings displayed markedly different characteristics. Grains from the transitional depositional setting ranged from coarse to very fine sand (according to the Udden-Wentworth grain scale), although grains were predominately medium and fine sand sized. Grains from the estuary reservoir proper changed to be predominately medium and fine sand sized, as were those from the main estuarine reservoir. These shifts in grain sizes between depositional environments are indicative of sorting differences which greatly influence reservoir characteristics and quality. Weatherability and fracturing of grains that also control reservoir conditions were observed to vary between the three depositional settings. Grains from the transitional depositional setting displayed the least amount of weathering; whereas weathering significantly increased in the estuary reservoir proper and significantly increased again in the main estuarine reservoir. Few grains of the transitional depositional setting were observed to be fractured either along the edges or across grain surfaces. Whilst grain fracturing significantly increased in the estuary reservoir proper, change although to it slightly decreased in the main estuarine reservoir. Fractured and weathered grains can introduce a secondary porosity to the reservoir and impact reservoir productivity. Mechanical grain features observed from the three depositional settings confirmed that sources of the grains are derived from the logged distinct environments.

Introduction

In reservoir management studies, it is well known that reservoir characteristics allow for insight into reservoir quality and reservoir characteristics have a major influence on a success recovery program. Geological factors that control reservoir quality include: texture or grain size and shape, sorting, packing, any cementation if present, and silts and clays. These fines can be directly observed in 2D thin sections allowing a wider field of observation for constituents and their spatial arrangements than SEM analysis, and findings can be checked in 3D. Key reservoir characteristics which affect reservoir quality can be observed in thin sections during oil sands fabric studies. These characteristic include reservoir quality, grain morphology, sorting, roundness for packing; grain weatherablity, introduction of fine components including silts and clays into the reservoir system; and fractured grains that can alter reservoir properties such as wettability, if grains are infilled with the oil phase (Bell et al., 2012; Bell et al., 2013). A 3D SEM study, of oil sands fabric coarse components, was carried out on core samples from three depositional settings from the Upper McMurray Formation from Alberta, Canada. The goal was to explore reservoir characteristics observed during the oil sands fabric studies that affect reservoir quality. This paper presents the results of the pilot study carried out on 3000 grains from three oil sands depositional settings: a transition depositional setting, estuary reservoir proper, and the main estuarine reservoir.

When discussing depositional environments, it is important to periodically check and ensure that the proposed depositional environments are in fact correct and this can be done by sourcing of grains by SEM analysis. The mineral grain most suitable for sourcing of grains from different depositional environments is quartz due to its resilient nature and resistance to chemical weathering, thus making it easy for surface texture to be preserved in the grains (Mahaney, 2002). The ability of quartz sand grains to resist both mechanical abrasion and chemical solution results in it surviving erosion, transportation, and alterations during deposition. Therefore, quartz is an ideal mineral grain from which information such as the surface features and grain morphological characteristics can be obtained. The predominant mineral constituent from the Upper McMurray Formation is quartz. Previous studies on quartz grains using the SEM have shown that each of the sedimentary processes in which quartz grains are subjected to, brings about modification to the grain surface features and morphology (Margolis and Kennett, 1971; Krinsley and Doornkamp, 1973). The frequency with which these characteristic features occur can thus be used to infer the sedimentary history of quartz grains (Culver et al., 1983). In essence, results obtained from analysis of these features, if properly analysed and interpreted, tell us the story of various erosional episodes and characteristic energy conditions found in the different environments to which the grain has been subjected. Even if grains have passed through several cycles, newer episodes might superimpose features upon older surface features and thus add to the specific chronology of events to be recognized from studying quartz grain surface texture and morphology. Obtaining results of this nature before the advent of computers was a laborious task and took a considerable amount of time to achieve, but today, the convenience of the SEM and image analysis software, such as image J, made the task much easier and faster. The use of image analysis makes it easy to generate morphological data and results from thousands of grains within minutes.

Material and Methods

The core samples used in this study were obtained from the University of Alberta for research purposes and shipped to the London South Bank University for analysis. The core samples were from three depositional settings including a transition depositional setting, estuary reservoir proper, and the main estuarine reservoir from the Upper McMurray Formation.

- Sample A - collected from the depth of 81.4 m and taken immediately below a depositional environment transition. On preliminary examination, coarse grained sands are saturated with bitumen and some fine lamina.
- Sample B - collected from the depth of 85.0 m in the estuarine depositional reservoir. Preliminary examination showed medium to fine grained sands, consolidated with bitumen, and some very fine grained lamina.
- Sample C - collected from the depth of 89.2 m in the main estuarine reservoir and on preliminary examinations is fine to very fine grained sands, consolidated with bitumen.

To carry out successful and more accurate SEM analysis of the quartz grains, bitumen was separated by a Soxhlet extraction technique and toluene was used as a solvent. After washing the quartz grains, they were dried and in order to mount grains in rows on an aluminium specimen stub, coated with double sided scotch tape in such a way that grains adhere strongly to the scotch tape. A total of 3000 grains were analysed in this pilot study with 1000 grains from each of the three depositional environments, whereas for the overall SEM study 18,000 grains will be analysed with 6000 from each of the three depositional settings. In order to obtain 1000 images per depositional setting, an average of three stubs were needed and 350 grains were mounted onto each stub. Each stub was then divided into lines with four grids to enable accurate point counting. The grains, once mounted, were sputter coated to avoid charging and ensure that SEM images obtained were of the best quality. The sputter coating machine used for the coating was the polarox E 51100 model. Stubs were positioned in a rotating vacuum evaporator within the machine for coating by gold for a period of 2 minutes at a pressure of 2 torrs and current of 20 mA and a thin, uniform layer of gold was deposited over them. This setting ensured that the correct quantity of gold was deposited on the surface of the grain as a gold coat that is deposited too thickly or distributed unevenly can cause image distortion.

Once SEM images were taken, they were analysed by Image J; a free, open and widely used, multi-platform java image processing and analysis software package which is currently well-documented and well-supported globally (Rasband, 2009). It could either be found running as an online application or as a download application and has the flexibility of being able to run on any computer. To ensure that the best image quality in terms of particle resolution and focus was employed, a combination that resulted in a minimum of 10 pixels per particle was chosen at different times to increase the level of accuracy in determining particle size and magnification.

Information obtained from image analysis included standard deviation (StDev)/ sorting and mean, grain size distribution, grain roundness, and cumulative frequency curves. Standard deviation (StDev)/ sorting were obtained by plotting the grain diameter (in phi) on cumulative frequency plots while values obtained were inputted into the Folk and Ward (1957) logarithmic graphical formula to determine standard deviation and mean values. The standard deviation is a measure of the grain sorting and StDev results were compared to a sorting scale developed for the logarithmic graphical method in order to determine the degree of sorting for the three depositional settings. Grain size distribution was obtained by plotting grain diameter on a normal frequency plot in an Excel spread sheet which allows for a good understanding of how grains were distributed within the three depositional settings. Grain roundness was determined by plotting the roundness value on a normal frequency curve and the value obtained for the most frequently occurring roundness value is compared to a combination of the power's roundness class interval corresponding to the Wadell's classification chart to determine the class of roundness for grains. Cumulative frequency curves are curves that make use of the original histogram from the supplied data and are constructed by plotting the total amount of grain diameter, the larger minimum diameter value and smaller maximum grain diameter values within the sample. Using

Excel, grain sizes were plotted on the horizontal axis and the cumulative frequency on the vertical axis with a scale running from 0 to 1, thus 0-100 percent.

Results

The results from grain sourcing of the three depositional settings will be presented first. A table with a total of 36 surface features adapted from Bull (1978) and Higgs (1979) was used to track quartz surface features (refer to Table 1). After which from grain morphology analysis will be presented which include: sorting values represented by the grain standard deviation; grain size distribution using normal frequency statistical analysis; grain roundness; and cumulative frequency curves for each of the three depositional settings. Important theory to study grain morphology results was the ferret diameter generated by the petrographic image analysis software ***image J,*** as this standardized grain diameters was used to determine all grain size distribution parameters.

Sample A - Immediately below of depositional environment transition

The quartz grains of the depositional setting immediately below a depositional environment transition are comprised predominantly Chemical 'V' pits/indentations with rounded grain outlines, also common are large to medium irregular pits as well as small and medium conchoidal fracture. Any conchoidal fractures greater than 100 µm regarded as large and anything between the range of 10 and 100 µm is regarded as medium to small conchoidal fractures. The mechanical 'V' pit has varied spatial distribution from one grain to another (refer to Figure 1) and the volume along with relative abundance of these 'V' pits are greatly tied to duration of exposure and intensity in subaqueous impact as well as the degree of agitation as these features are usually associated with high energy environments. Dish-shaped depressions of varying sizes are also common grain features, as well as solution pits in varying size, shape and abundance. A considerable amount of grains have precipitation features appearing as silica globules and thus modifying the grain relief. Linear groove plates (LG) of different dimensions, breakage blocks, and abrasion edges were also observed. Located in Figure 2, are charts showing relative abundance of surface textures observed in the depositional environment transition.

Grain sizes within the depositional environment transition were discovered to be slightly evenly distributed with all grain sizes present in varying proportions and ranging from fine to coarse according to the Wentworth scale (Wentworth, 1922) move up. The fine sands are found to make up 35% of the total grain population, while the medium grained sands are about 41% of the total grain population, and coarse sand the remaining 24% (refer to Table 2 and Figure 3). Over 76% of the grains fell into the very rounded category, 20% rounded, and the remaining 4% subrounded (refer to Table 3 and Figure 3). This shows that the sample contains texturally supermature grains on the basis of roundness. A total of 160 grains were observed for weathering and fracturing with 1% showing weathering and 8.75% displaying fractures on grains or edges.

Sample B - Estuarine Depositional Reservoir

Surface features observed to be abundant amongst the estuarine depositional reservoir are chemically acted upon mechanical 'V' pits/indentations (highly ubiquitous) of varying sizes, and large to medium irregular grooves and pits, with grains ranging from sub-rounded to rounded. Other features commonly observed were dish shaped and solution pits (refer to Figure 4, Figure 5, and Figure 6). Occurring together with the solution pits are a number of crevasses found traversing numerous grain surfaces, with some areas around the crevasses showing previous impact features. Located in Figure 7 are charts showing relative abundance of surface textures in the estuarine depositional reservoir environment. In many grains, precipitation features are highly abundant in the form of globules, thereby modifying the grain relief. A good number of grains display conchoidal fracture patterns that have been smoothed and breakage blocks of large size were also observed. Impact V's found in this depositional setting are usually oriented in different directions and at times appearing wider and deeper (due to dissolution). Straight steps and regular fracture plates are also quite common features. Some of the grains also seem to have undergone a high degree of chemical weathering,

The grain sizes in the estuarine depositional reservoir are not spread across various size ranges and distribution of grain diameters are not widely spaced. Grains are predominately medium sized which constitute about 80% of the total grain distribution, fine sand making up 8%, and coarse sand constitute the remaining 12% of the grain population (refer to Figure 8 and Table 2). This depositional setting is dominated by rounded grains with about 63% being very round, 32% rounded, and 5% subrounded (refer to Figure 8 and Table 3) indicating that the depositional setting contains texturally supermature grains on the basis of roundness. A total of 116 grains were observed for fracturing and weathering with 19.8% showing weathering and 23% displaying fractures on grains or edges.

Sample C - The Main Estuarine Reservoir

The main estuarine reservoir contains an abundance of well rounded quartz grains with varying sizes of solution pits (refer to Figure 9 and Figure 10), and an abundance of mechanically etched small and large V pits present in different sizes. Located in Figure 11 are charts of the relative abundance of surface textures in the main estuarine reservoir. Medium to large irregular pits or impact grooves of varying size with shapes ranging from linear to semi-circular were observed, as well as fresh conchoidal fractures, and solution crevasses were commonly observed. Dished shaped depressions observed as step like furrow and block breakages were also observed in some grains though not abundant.

Grain sizes are closer in size in the main estuarine reservoir, falling into two main categories: medium grain sand that constitutes about 62%, fine sand fraction at 32%, and the remaining 6% coarser materials (refer to Figure 12 and Table 2). Rounded grains are dominate with a range of 0.8 as the dominant roundness class, thus very rounded. In all, the very rounded grains constitute 72%, while rounded grains are 25% and 3% being subrounded (refer to Figure 12 and Table 3). Thus grains of the main estuarine reservoir are texturally supermature. A total of 124 grains were observed for fracturing and weathering with 31% showing weathering and 17% displaying fractures on grains or edges.

Discussion

Further exploring by SEM key reservoir characteristics that can affect reservoir quality observed in 2D thin sections during oil sands fabric studies for a detailed grain study in 3D. Studies of grain morphology including, sorting, roundness for packing, grain weatherablity, and fractured grains further enhance the understanding of reservoir quality. Provenance and characterization of oil sands depositional setting, also a main aim of this study, is important as lateral heterogeneity of depositional setting has a profound effect on the reservoir quality and consequently, bitumen recovery. As variation in the nature of the grains that constitute the reservoir is tied to the different environments of deposition, it is believed that reservoir quality and bitumen recovery varies from one depositional environment to the other.

Samples from all three depositional settings contain grains that show varying types of features tied to diverse sediment sources, as well as the transporting agents. Grains were subjected to preceding depositional settings prior to their deposition. Analysis of quartz surface features from the three depositional settings showed the dominant grain surface features indicating transport within a subaqueous environment. From SEM analysis, grains from the depositional environment transition were mainly reworked sediments of aeolian origin (accounting for the grain roundness). These became reworked in the marine environment with little resident time in this environment and finally transported and deposited under fluvial conditions. The freshest features today are those that are peculiar to fluvial environments such as fresh fracture and edge abrasion on rounded grain. Grains from the estuarine depositional reservoir were sourced from multiple provenances; though initially deposited under aeolian conditions, where resident time was interpreted to be short lived, grains were then subjected to fluvial conditions and finally deposited under marine conditions. It is believed that residence time and exposure to marine conditions are very high due to the high intensity of chemical weathering on grain surface. The main estuarine reservoir contains grains from multiple provenances, although initially deposited under aeolian conditions where resident time was interpreted to be short. Grains were then subjected to marine conditions. It is believed that residence time and exposure to marine conditions were very long due to the presence of almost complete dissolution of quartz globules. These grains from the main estuarine reservoir were finally deposited under fluvial conditions.

Conclusion

Grains from all three depositional settings (a transition depositional setting, estuary reservoir proper, and the main estuarine reservoir) have features that portray deposition in all three aeolian, fluvial, and marine environments. From a combination of both grain surface features and grain morphology, it was conclusively inferred that the current depositional setting for the overlying transition depositional setting and underlying main estuarine reservoir are fluvial in nature, whereas the estuary reservoir proper is marine which suggests an estuarine where mixing of marine and fluvial waters occurs, or fluxuating tides.

Based on grain morphology, the best reservoir quality was associated with the main estuarine reservoir as grains are being better sorted, well rounded, and of medium grain sand, followed by the estuary reservoir proper and transition depositional setting. Weatherability and fracturing of grains can control reservoir conditions and these vary between the three depositional settings. Grains from the transitional depositional setting displayed the least amount of weathering; whereas weathering significantly increased in the estuary reservoir proper and significantly increased again in the main estuarine reservoir which can introduce both silt and clay sized fines into the reservoir. Few grains of the transitional depositional setting were observed to be fractured either along the edges or across grain surfaces, although fractured grains significantly increased in the estuary reservoir proper and slightly decreased in the main estuarine reservoir. Fractured and weathered grains can introduce a secondary porosity to the reservoir and impact reservoir properties, increasing porosity and permeability thus impacting reservoir quality.

References Cited

Bell, J., O. Eruteya, and O. Oono, 2012, Application of Petrographic Image Analysis and Multivariate Statistical Techniques for Textural Studies of Oil Sand Samples: Search and Discovery Article #80212, p. 1-14. http://www.searchanddiscovery.com

Bell, J., K. Kulkarni, and M. Maraj, 2013, Novel Approach to Determining Unconsolidated Reservoir Properties: Fabric and Flow in Oil Sands: OnePetro Article, ID SPE-168803-MS, p 1-8. https://www.onepetro.org/conference-paper/SPE-168803-MS

Bull, P., 1978, A quantitative approach to scanning electron microscope analysis of cave sediments, *in* W. Whalley, (ed.), Scanning Electron Microscopy in the Study of Sediments: Norwich, Geobooks, p. 821-828.

Culver, S.J., P.A. Bull, S. Campbell, R.A. Shakesby, and W.B. Whalley, 1983, Environmental discrimination based on quartz grain surface textures: a statistical investigation: Sedimentology, v. 30, p. 129–136.

Folk, R.L. and W . Ward, 1957, Brazos River bar: a study in the significance of grain size parameters: Journal of Sedimentary Petrology, v. 27, p. 3-26.

Higgs, R., 1979, Quartz grain surface features of Mesozoic-Cenozoic sands from the Labrador and Western Greenland continental margins: Journal of Sedimentary Petrology, v. 49, p. 599-610.

Krinsley, D.H. and J.C. Doornkamp, 1973, Atlas of Quartz Sand Surface Texture: Cambridge University Press, London, 91 p.

Mahaney, W., 2002, Atlas of Sand Grain Surface Textures and Applications: Oxford University Press, Oxford, 237 p.

Margolis, S.V. and J.P. Kennett, 1971, Cenozoic paleoglacial history of Antarctica recorded in subantarctic deepsea cores: American Journal of Science, v. 274, p. 1-36.

Momoh, A., 2012, SEM analysis of Grain Morphology of the Upper McMurray Formation, MSc Thesis, London South Bank University, London, UK.

Morris, O.L., 2012, Sourcing of Grains for Understanding of Reservoir Architecture for the Upper McMurray Formation: MSc Thesis, London South Bank University, London, UK.

Rasband, W.S., 2009, ImageJ: U.S. National Institutes of Health, Bethesda, MD.

Wentworth, C., 1922, A scale of grade and class terms for clastic sediments: Journal of Geology, v. 30, p. 377–392.

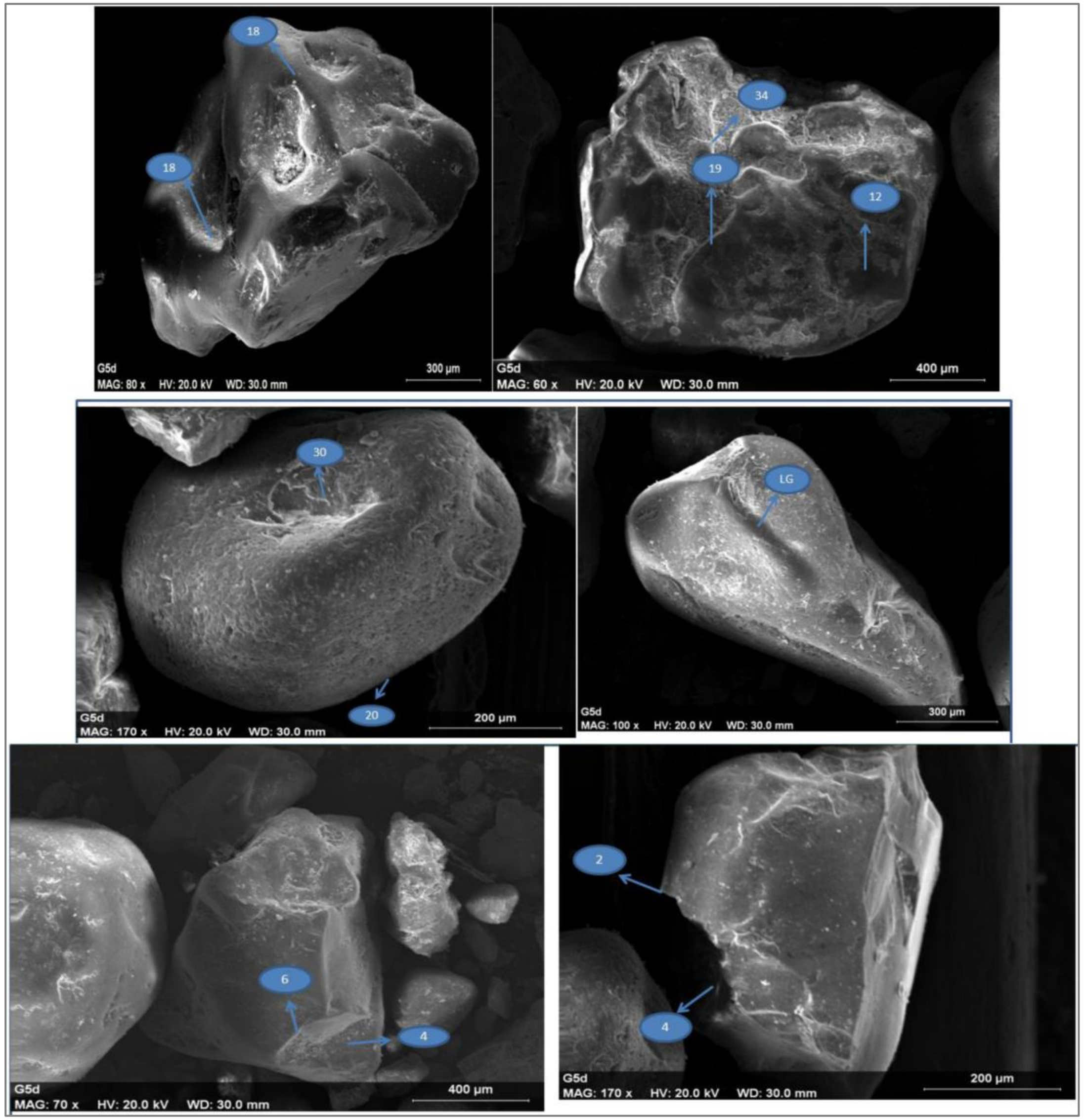


Figure 1. SEM photomicrographs showing the different surface features observed in the transition depositional setting. Locations (2) showing edge abrasion; (4) breakage blocks; (6) fresh conchoidal fracture; (12) irregular pit; (18) showing mechanical v-pit; (19) showing evidence of dish shape; (20) roundness; (30) solution pit, LG lateral groove; (31) solution crevasses; and (34) amorphous precipitation (silica).

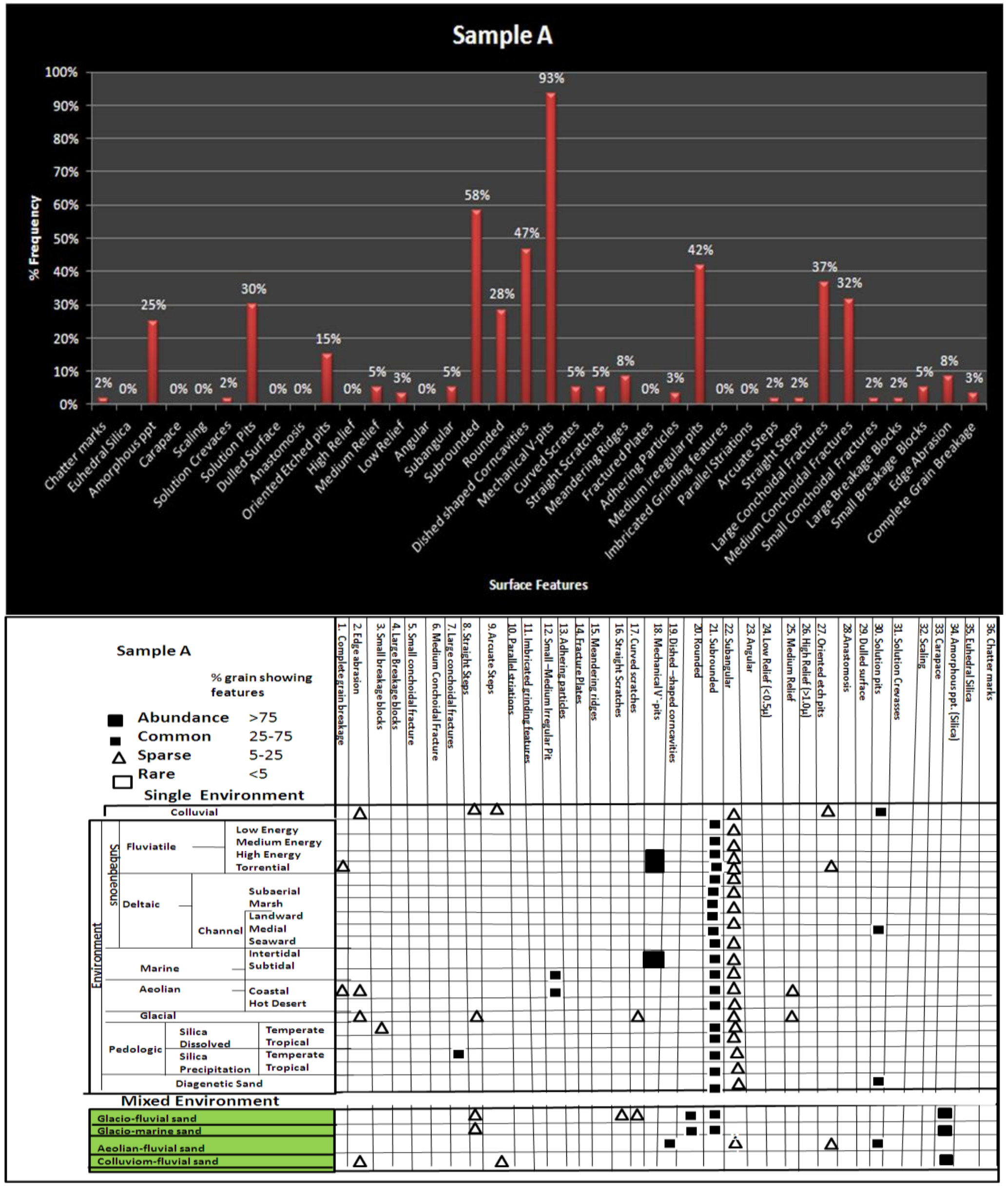


Figure 2. Surface textures used in analysis and their relative abundance. Surface texture abundance chart for the transition depositional setting.

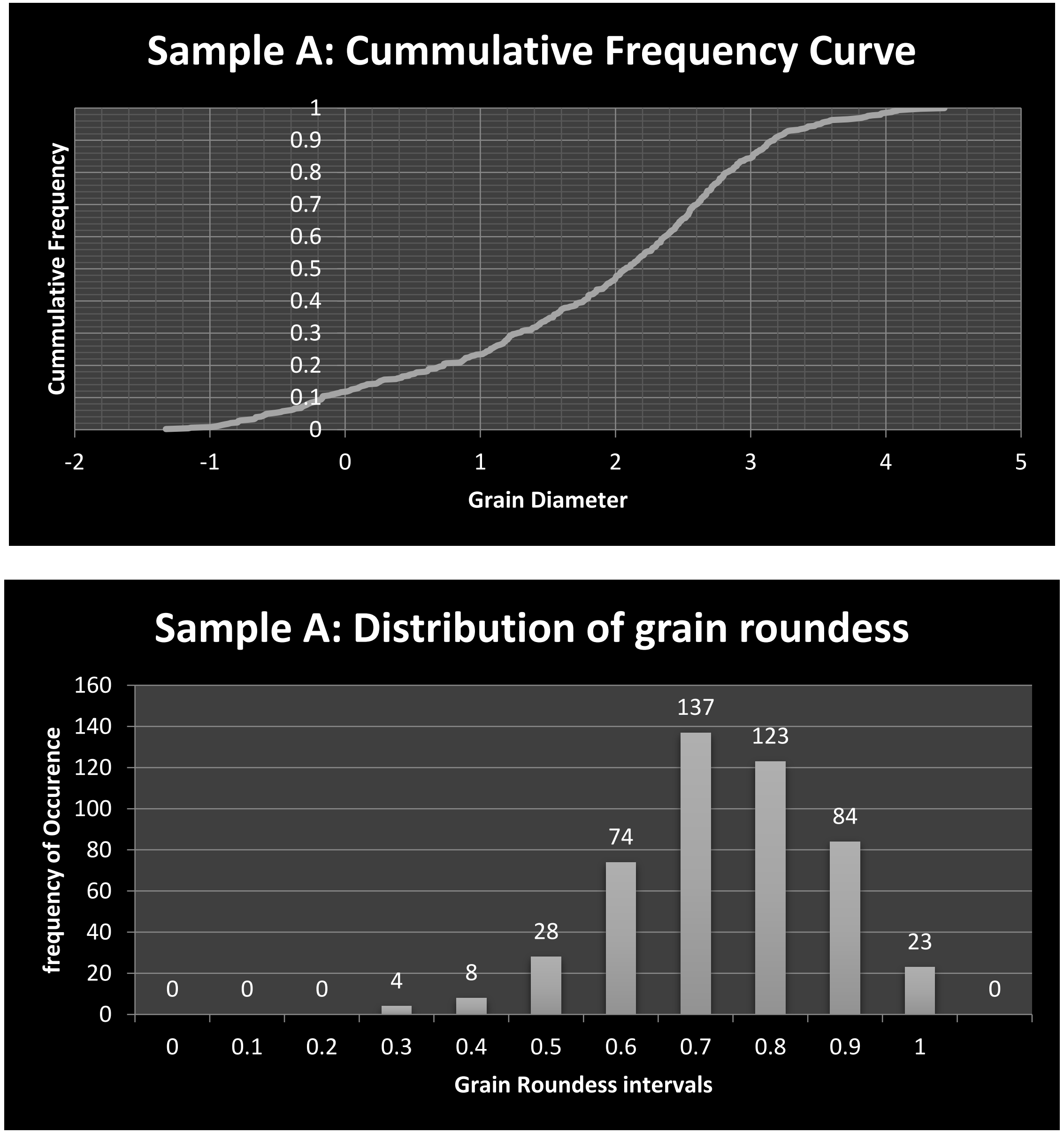


Figure 3. Cumulative frequency curve showing grain distribution and grain roundness distribution for the transition depositional setting.

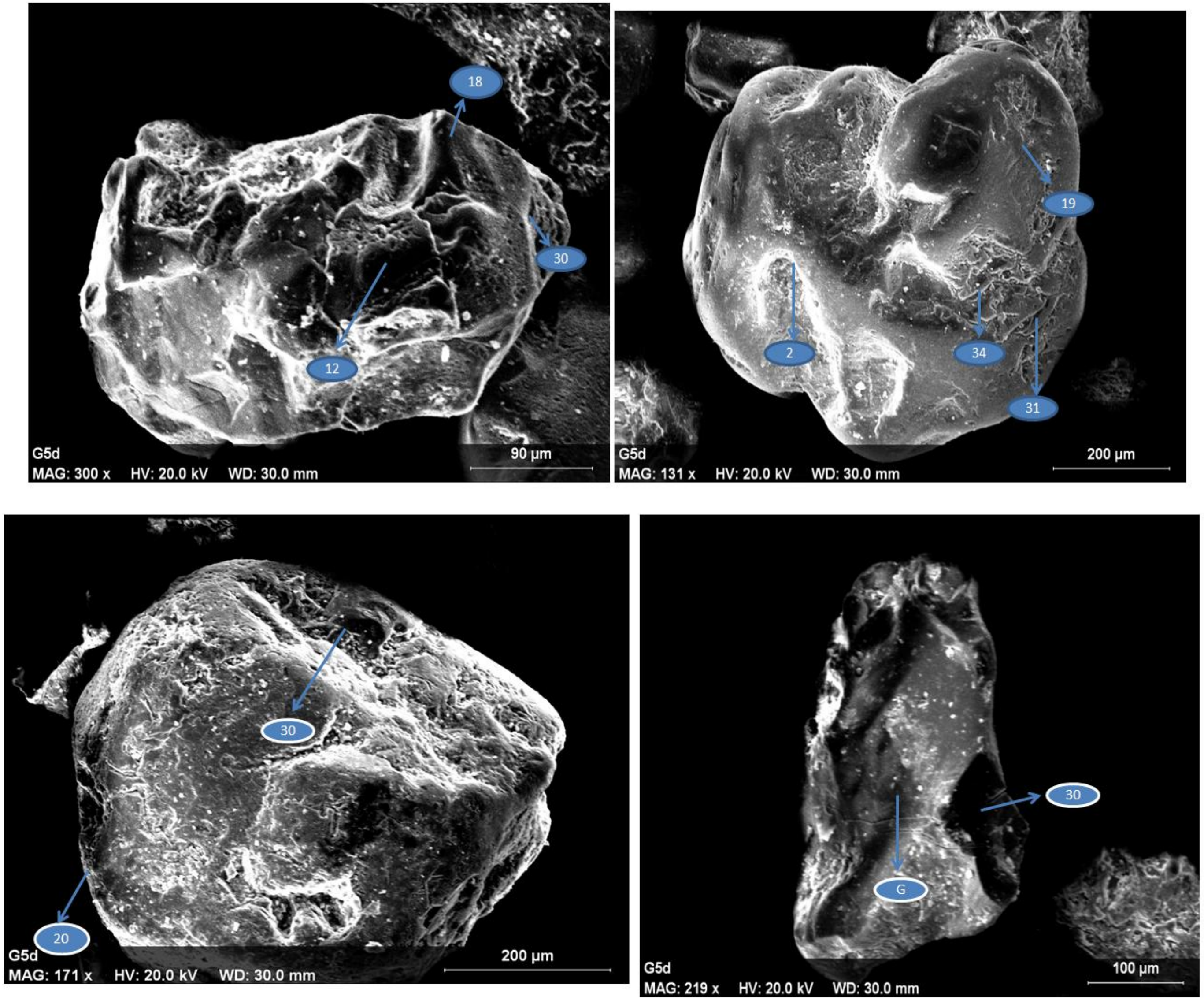


Figure 4. SEM photomicrographs showing the different surface features observed in the estuary reservoir proper. Locations (2) showing edge abrasion; (12) irregular pit; (18) showing mechanical v-pit; (19) showing evidence of dish shape; (20) solution pits; (30) roundness, G-grooves; (31) solution crevasses and W–highly weathered grain; and (34) amorphous precipitation (silica).

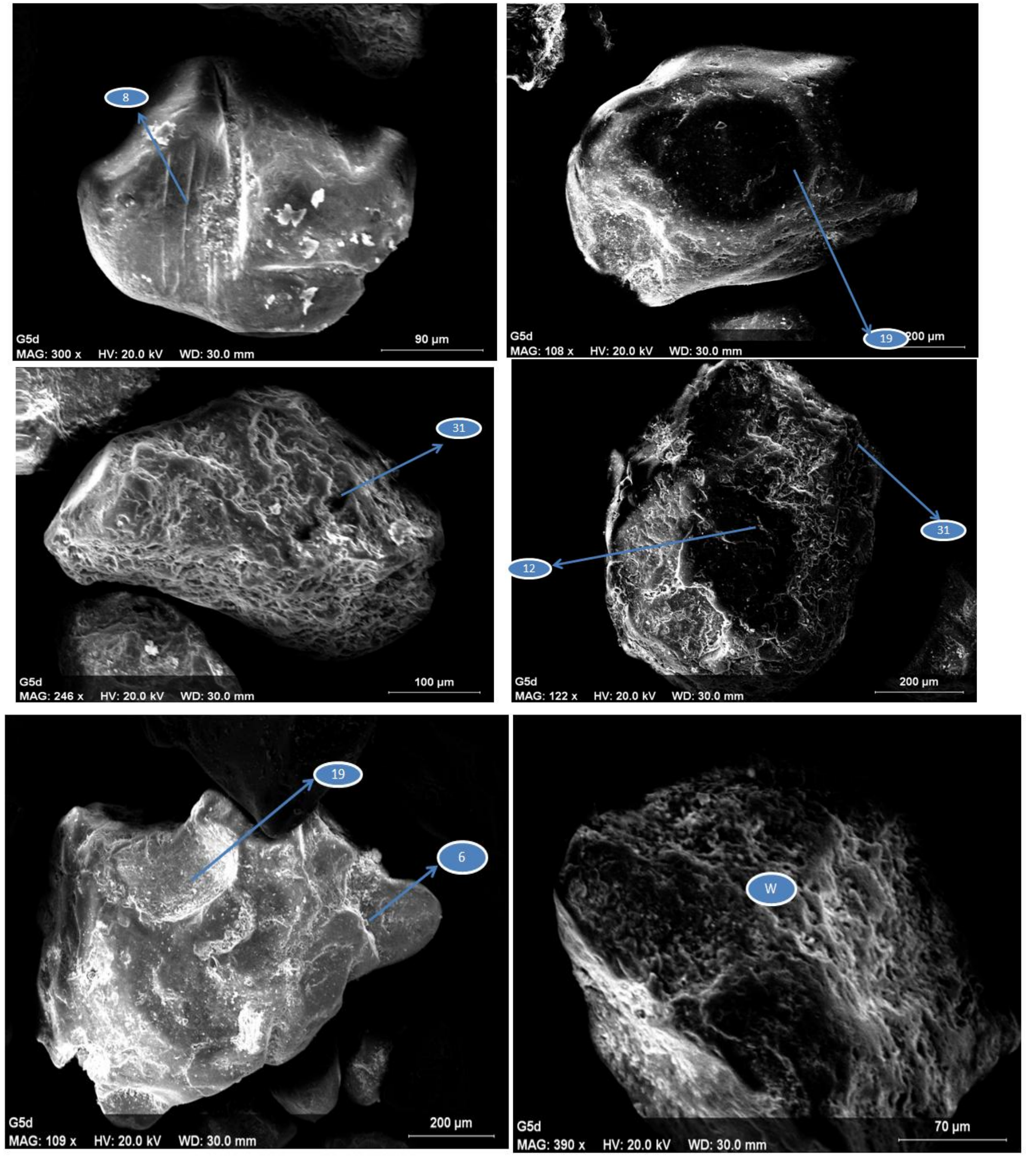


Figure 5. SEM photomicrographs showing the different surface features observed in the estuary reservoir proper. Locations (6) smoothened conchoidal fracture; (8) straight steps; (12) irregular pit; (19) showing evidence of dish shape; and (31) solution crevasses and W–highly weathered grain.

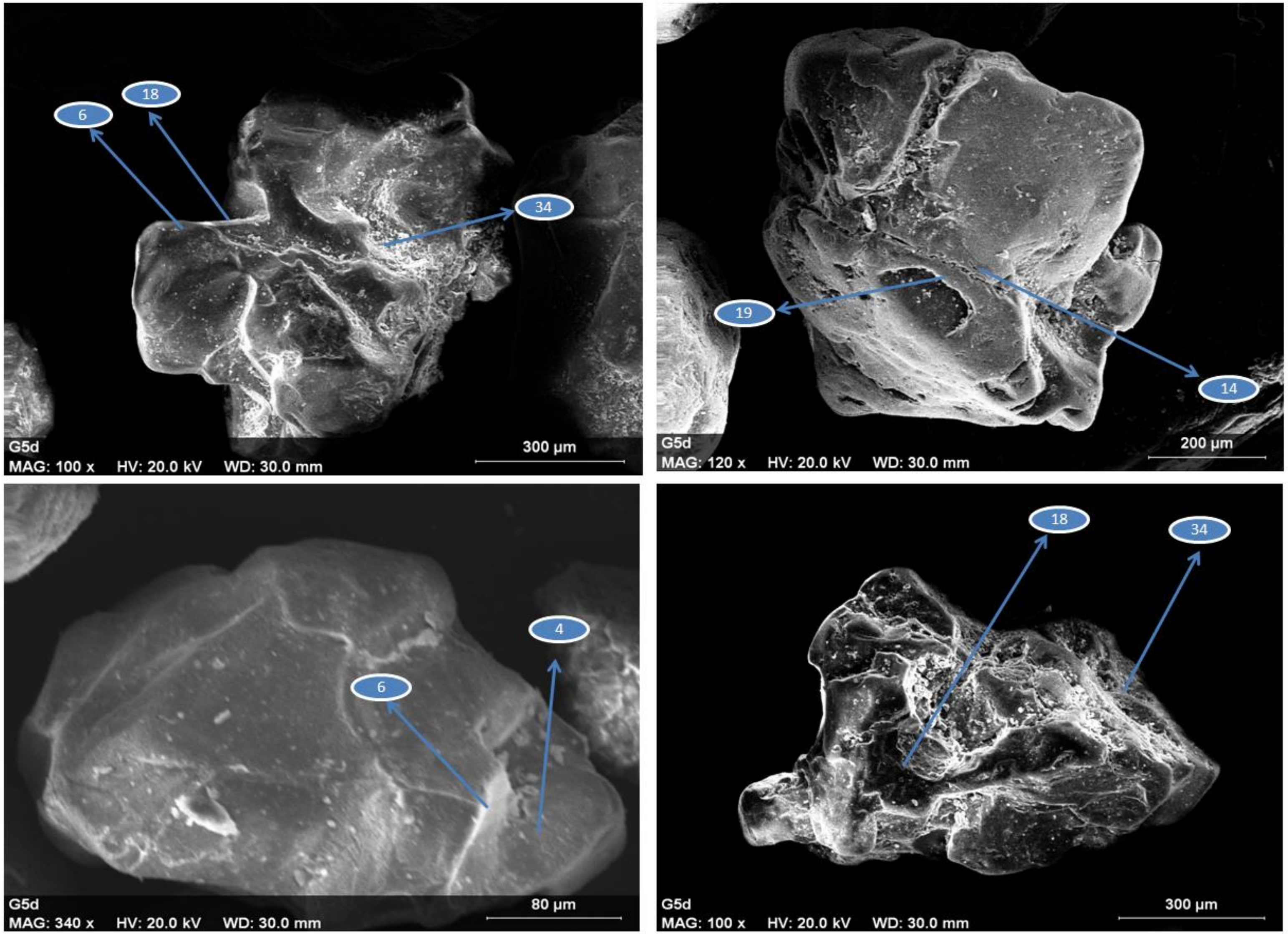


Figure 6. SEM photomicrographs showing the different surface features observed in the estuary reservoir proper. Locations (4) breakage blocks; (6) smoothened conchoidal fracture; (14) fractured plates; (18) showing mechanical v-pit; (19) showing evidence of dish shape; and (34) amorphous precipitation (silica).

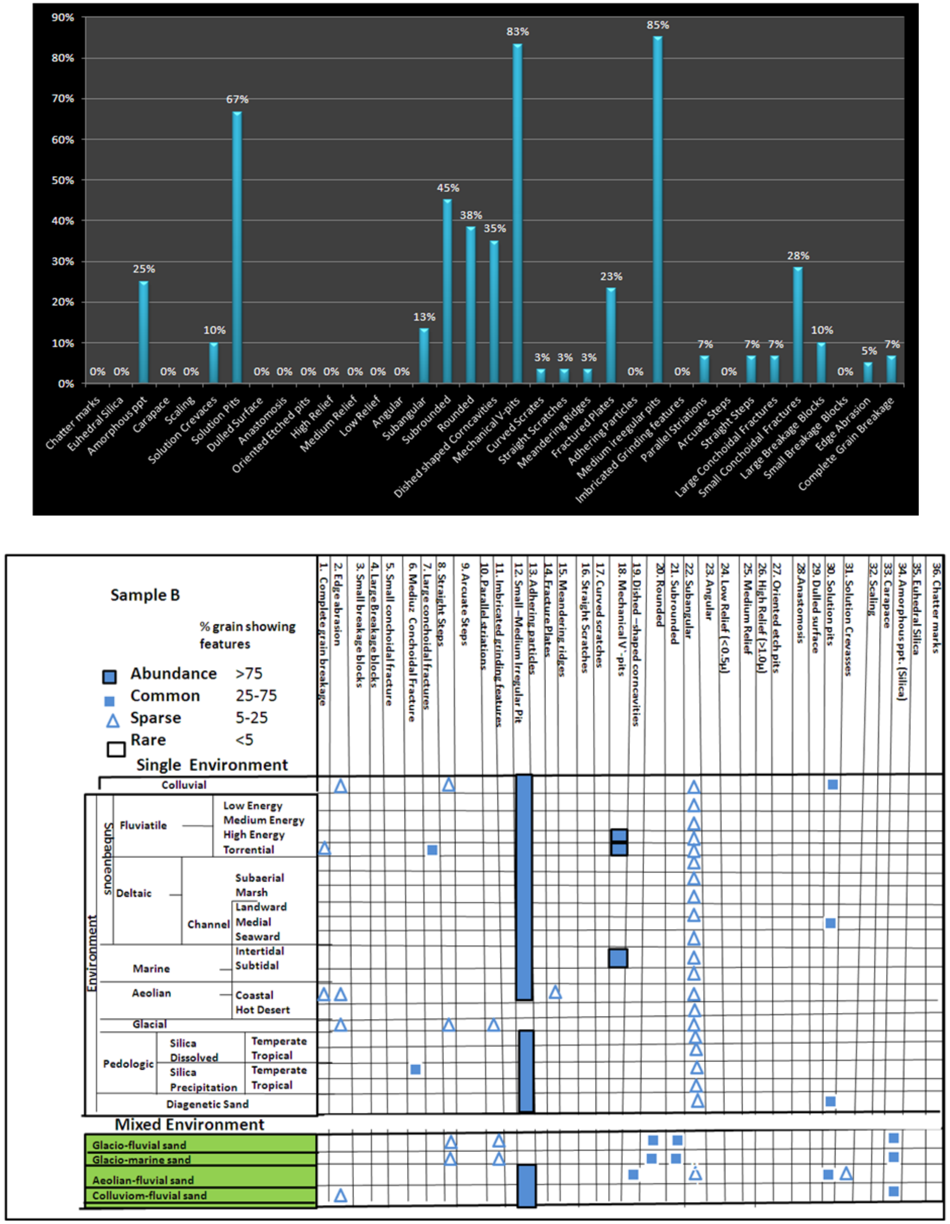
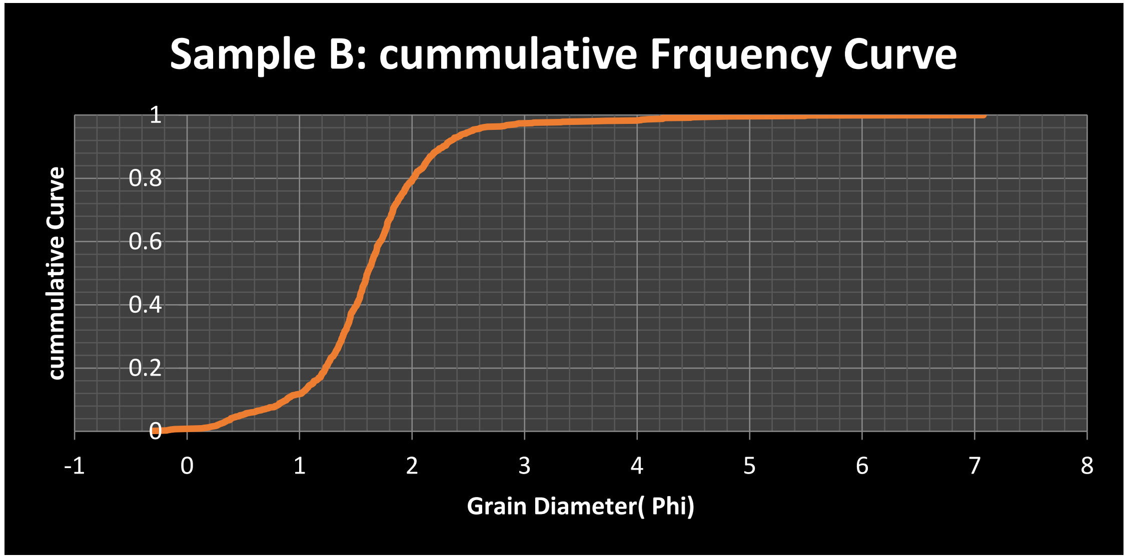


Figure 7. Surface textures used in analysis and their relative abundance. Surface texture abundance chart for the estuary reservoir proper.



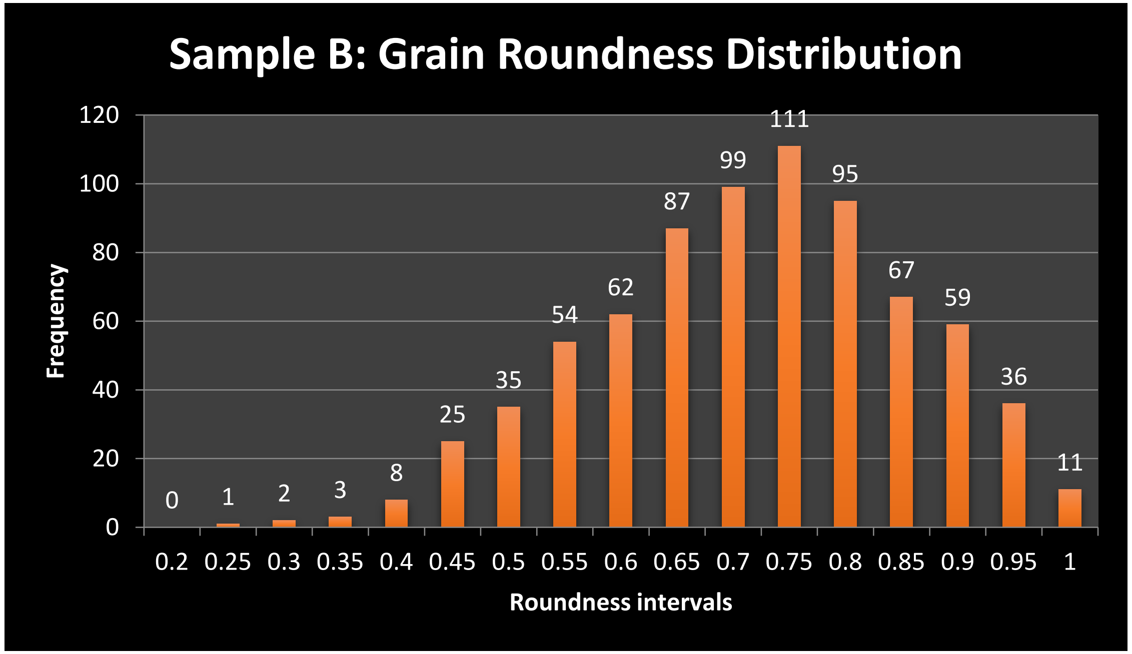


Figure 8. Cumulative frequency curve showing grain distribution and grain roundness distribution for the estuary reservoir proper.

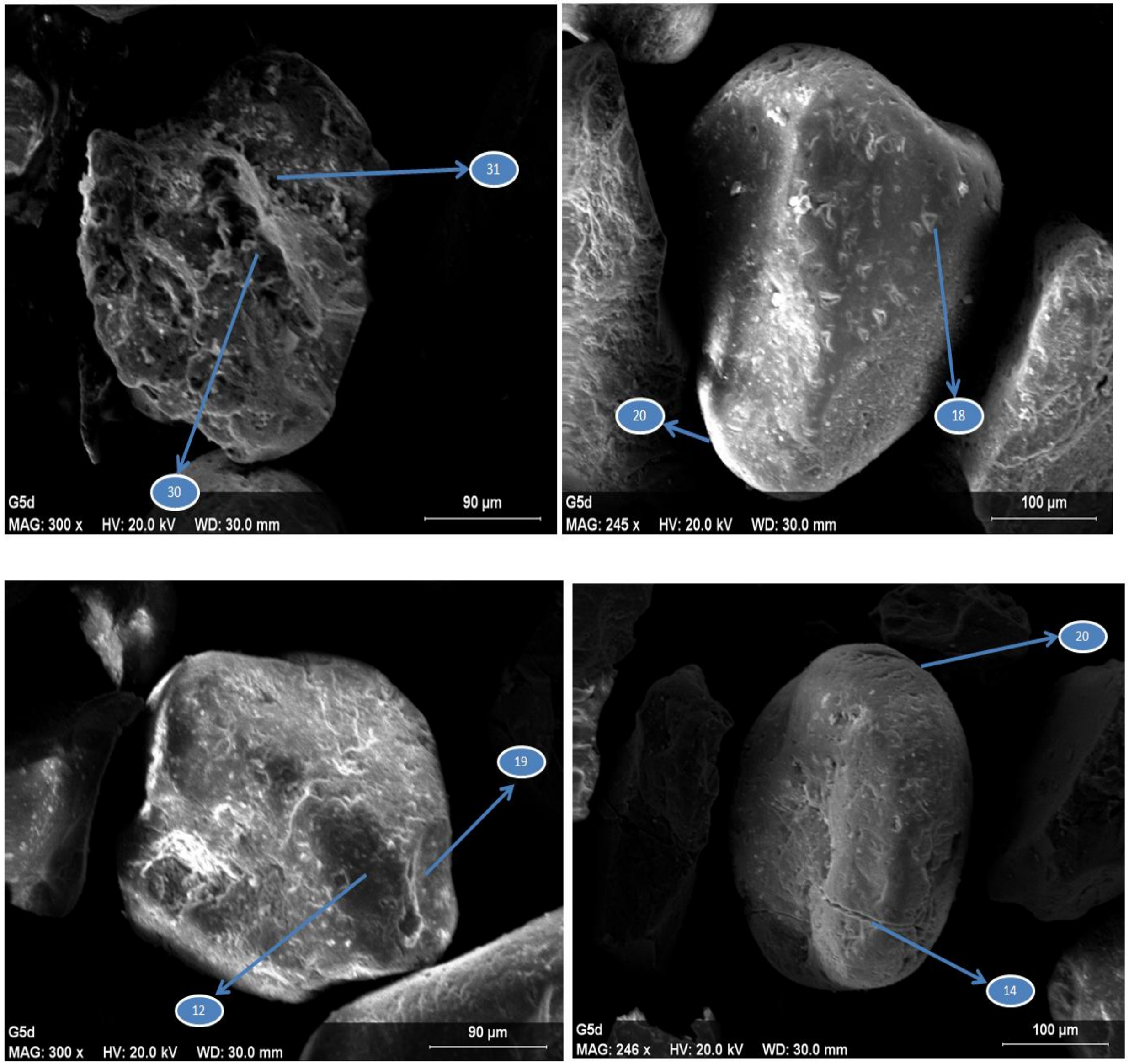


Figure 9. SEM photomicrographs showing the different surface features observed in the main estuarine reservoir. Locations (12) irregular pit; (14) fractured plates; (18) showing mechanical v-pit; (19) showing evidence of dish shape; (20) solution pits; (30) roundness, G-grooves; and (31) solution crevasses.

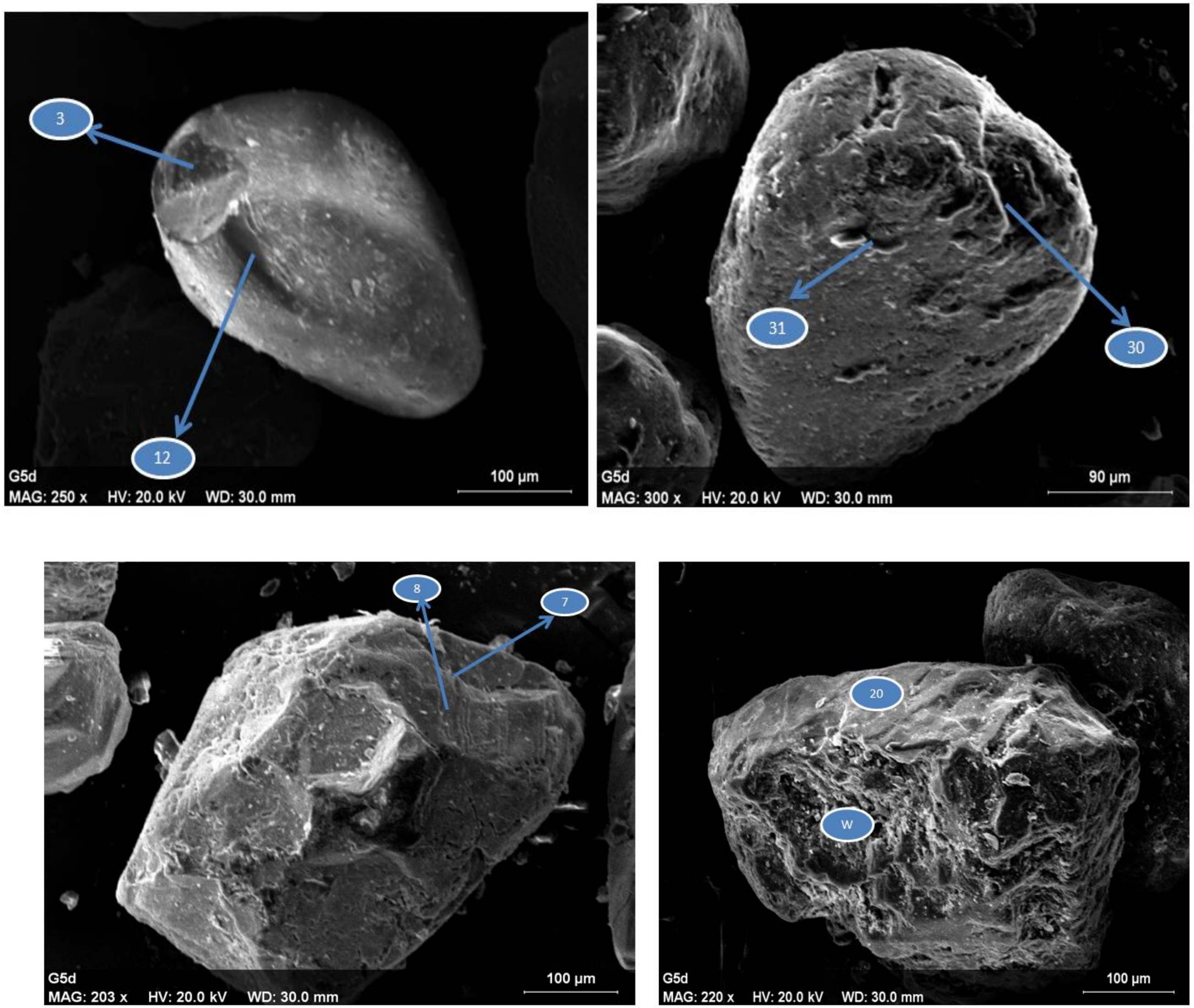


Figure 10. SEM photomicrographs showing the different surface features observed in the main estuarine reservoir. Locations (3) breakage blocks; (7) fresh conchoidal fracture; (8) straight steps; (12) irregular pit; (20) solution pits; (30) roundness, G-grooves; and (31) solution crevasses.

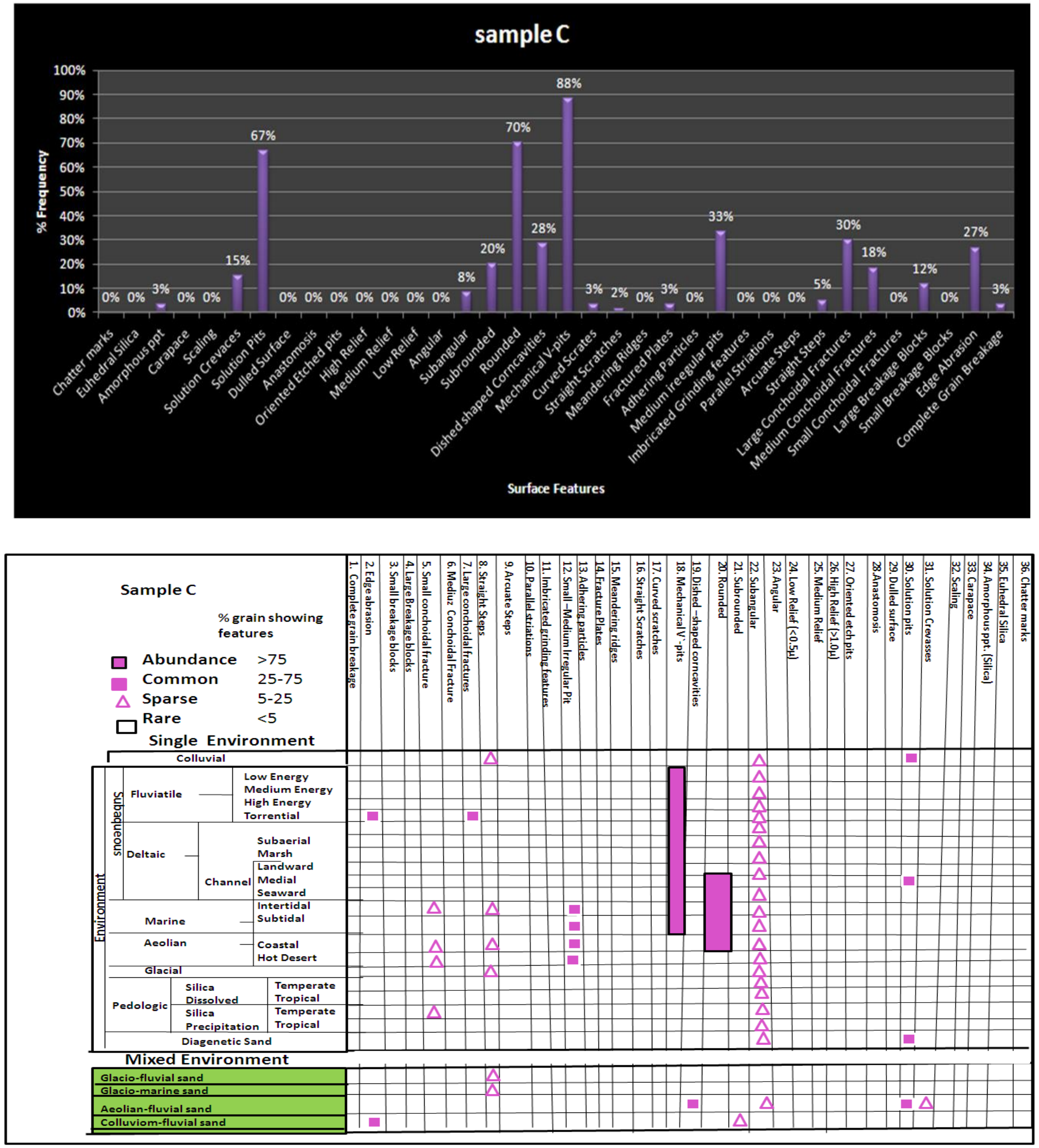
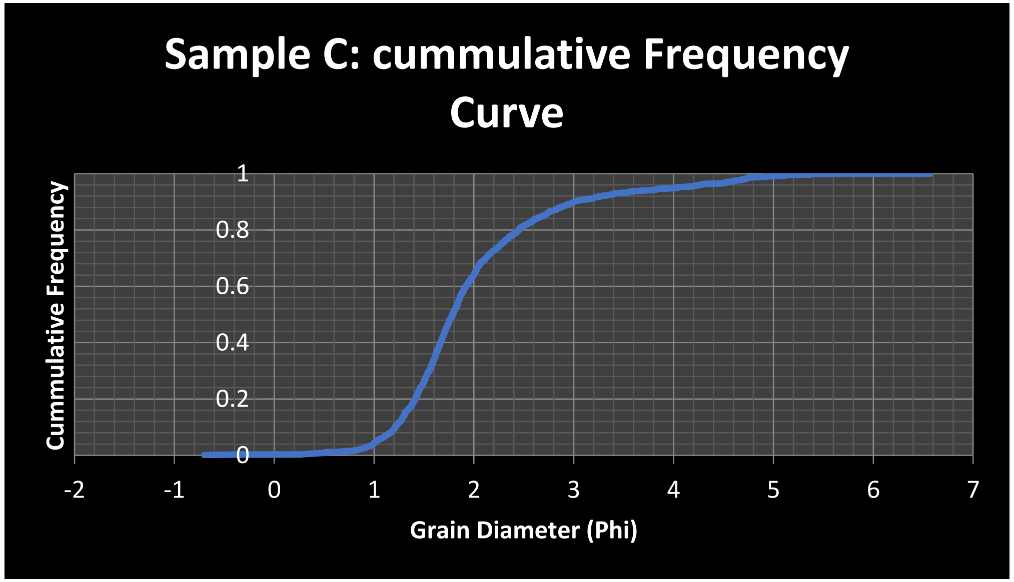


Figure 11. Surface textures used in analysis and their relative abundance. Surface texture abundance chart for main estuarine reservoir.



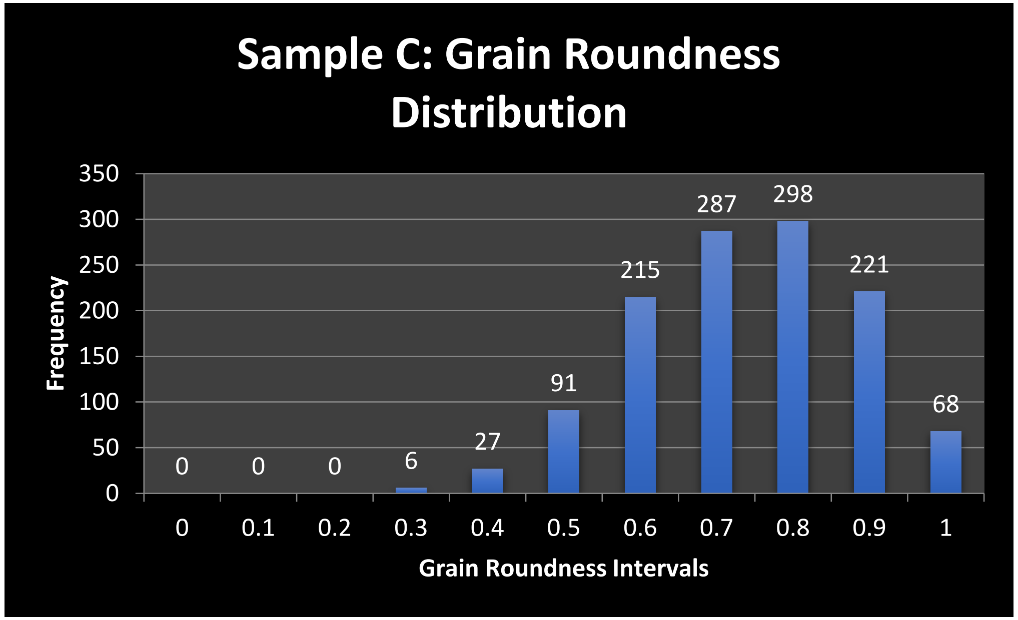


Figure 12. Cumulative frequency curve showing grain distribution and grain roundness distribution for the main estuarine reservoir.

Group	No.	Surface Features
Mechanical Features	1	Complete Grain
	2	Edge Abrasion
	3	Small Breakage Blocks
	4	Large Breakage Blocks
	5	Small Conchoidal
	6	Medium Conchoidal
	7	Large Conchoidal
	8	Straight Steps
	9	Arcuate Steps
	10	Parallel Striations
	11	Imbricated Grinding
	12	Medium ireegular pits
	13	Adhering Particles
	14	Fractured Plates
	15	Meandering Ridges
	16	Straight Scratches
	17	Curved Scrates
	18	Mechanical V-pits
	19	Dished shaped
Morphological Features	20	Rounded
	21	Subrounded
	22	Subangular
	23	Angular
	24	Low Relief
	25	Medium Relief
	26	High Relief
Chemical Features	27	Oriented Etched pits
	28	Anastomosis
	29	Dulled Surface
	30	Solution Pits
	31	Solution Crevaces
	32	Scaling
	33	Carapace
	34	Amorphous ppt
	35	Euhedral Silica
	36	Chatter marks

Table 1. Check List for Grain Surface Features. Adapted from Bull (1978) and Higgs (1979).

Grain size parameters	Results A	Results B	Results C
statistical Mean	1.84	1.61	1.92 (Medium Sand)
Standard Deviation (σi)	1.26	0.55	0.8
Sorting category	Poorly Sorted	Moderately Well sorted	Moderately Sorted
Ø5	-0.542	0.47	1.03
Ø16	0.39	1.14	1.34
Ø50	2.18	1.6	1.79
Ø84	2.95	2.1	2.62
Ø95	3.49	2.54	4.03

Table 2. Standard deviation and statistical mean for the three depositional settings.

Grain Parameters	Sample A abundance	Sample B abundance	Sample C abundance
Coarse Sand Fraction (>0.5)	24%	12%	6%
Medium Sand Fraction (0.25-0.5)	41%	80%	62%
Fine Sand Fraction (<0.25mm)	35%	8%	32%
Min Grain Diameter	0.046308	0.007399	0.010541
Max Grain Diameter	2.507145	1.23502	1.625

Table 3. Summary of grain size distribution for the three depositional settings.