



## Formation Characterization in a Different Perspective: Drill Cuttings Analysis Revisited

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### Abstract

For years, drill cuttings have been the first contact with real subsurface formation material in drilling operations. They also have been restricted to an information element used by mud loggers and some specific geologic purposes such as microfossil studies. Once used for these purposes, they usually disappear from the scenario of exploration and production upstream activities. Conventional procedures on sample preparation and advanced visualization analysis techniques (Scanning Electron Microscopy, X-ray Dispersive Energy Spectroscopy, Backscattered Electron Imaging and Digital Image Processing and Analysis) enable drill cuttings to supply important information for different end users, including petrophysicists, reservoir engineers and drilling engineers.

This paper presents some examples of the analysis of field samples, showing the wide range of data possible to obtain: modal mineralogy and chemical analysis, lithological classification and provenance, log correlation, textural analysis and pore geometry determination, inorganic mud additives, and metal debris evaluation from wear of BHA. Though less precise in terms of depth origin, the sample supplies a significant amount of information making this approach a valid option when economic restraints cannot consider coring operations but formation characteristics are needed for field development and working fluids design.

### Introduction

During drilling operations, the resulting rock debris becomes the first hand, real representation of formation characteristics taken at surface. Mud logging companies collect this material at the rig site and their activities include sampling, preservation and storage for general lithology description and paleontology support studies.

Besides the wear degree that leads to very small size samples, using the material for additional purposes traditionally has been limited due to the lack of continuity and precise provenance of drill cuttings.

New techniques on sample collection, preparation, and

analysis have not received much attention and conventional practices from 40 years ago are still in use. A literature review of the last 10 years shows an interesting number of applications in petrophysical characterization of reservoir rocks,<sup>1,2,3</sup> geomechanics,<sup>4</sup> and formation evaluation from logging on cuttings.<sup>5</sup> The development of a prototype device<sup>6</sup> to collect and preserve a washed, continuous stratigraphic sequence of drill cuttings is another reference worthy of mention.

The fact is drill cuttings today are still considered a waste material to be disposed of, instead of an invaluable source of information. More efficient operations are continuously seeking savings in well construction and increased well productivity. Drill cuttings analysis may, in many cases, avoid the cost of gathering core material. Also, when coring is not planned due to economic restraints, assessment and control of potential problems for upcoming wells is now an real possibility.

This paper addresses some field examples to show a different perspective with this approach and the potential it has to give a better description of rock systems and information elements leading to geological and petrophysical models and also better design of working fluids.

### Drill-Cuttings-Analysis Process

After the bit makes contact with the rock, depending on the lithology, both isolated grains and clusters are carried throughout the annular hole to the surface (Fig. 1). A filtercake builds up, however its quality will depend on how well the bridging material within the mud matches the exposed rock surface pore geometry.

Since the time required to bring drill cuttings out of the hole is related to flow regime and particle size,<sup>6</sup> a very heterogeneous population of drill cuttings from different depths is collected by the mudlogger (Fig. 2) before the flow line reaches the solids-separation equipment.

Poorly trained personnel in charge of sampling is an additional problem that may be overcome by either

involving more experienced professionals (geologists) or by using continuous automatic collecting devices, that can be correlated to actual lithology logs,<sup>6</sup> with depths uncertainties of  $\pm 3$  feet.

### Experimental

Cuttings were cleaned, dried, labeled, and stored, following conventional mud logging procedures. Resin-impregnated flat and polished casts of non-consolidated and consolidated rock cuttings were prepared to start the formal analysis. Due to the heterogeneous nature of samples, analysis is supported mainly by visualization techniques with capabilities of compositional, structural and textural discrimination.

Scanning Electron Microscopy (SEM), with probes for Back Scattered Electron detection (BSE) and Chemical Element Analyzer (EDS), which are common array in modern instruments, provide the raw digital images that generate the wide set of information for different final end users such as surface loggers, petrophysicists, petrographers, reservoir engineers, geophysicists and drilling engineers. No extensive explanation on the principles of the above-mentioned techniques is provided, but literature reviews are available elsewhere.

SEM-BSE images (Fig. 3) have brightness proportional to the mean atomic number of the target (in the absence of surface irregularities). Black and darker tones are related to organic phases such as epoxy resin, that is filling the porous space, and more brilliant phases are related to higher mean atomic numbers. K-feldspar is more brilliant than quartz and quartz more brilliant than kaolinite.

Mineral composition was provided by element X-ray spectra (Fig. 4), which represent fingerprints for each mineral phase that is spotted as a point or area of interest. Several images per sample for statistical purpose were obtained in a SEM with BSE/EDS detection system. Samples were carbon coated to make them conductive as a conventional procedure.

### Field Case A

A horizontal re-entry was performed on a shallow offshore location, through an Eocene age lithology, having alternate sequences of shales and consolidated sandstones. A curved section was planned to place the shoe on top of a depleted sand pay just a few feet before a shale layer. A water-based mud containing calcium carbonate as the bridging material was used. There was no information about pore geometry and carbonate size was selected based only on permeability information.

Immediately after breaking the cement plug and getting into the pay sand, high fluid losses began and could not

be controlled, resulting in the eventual lost of the well. However, drill cuttings were collected for use in a post mortem study that was initiated. Resin infiltrated and polished samples were prepared and images were obtained.

Low-magnification images (30-60X) showed different compositions, structures and textures (Fig. 5a & 5b). Metal debris, mechanical lube spheres, bridging calcium carbonate, and formation material were observed as isolated and cluster grains.

Digital image processing and analysis of these images made possible the discrimination of the different components in all samples. A particle-size-distribution graph (Fig. 6) from the calcium carbonate bridging material, outlined in yellow after digital processing, was generated. A  $D_{50}$  value of 75 microns was obtained. In addition a shape factor or roundness with a mean value of 1.884 was determined for those particles.

The formula applied by the computer program to calculate this value is:

$$\text{Shape Factor (Roundness)} = \frac{(\text{Perimeter})^2}{4 \cdot \pi \cdot \text{Area}} \quad (\text{Eq.1})$$

Values close to 1.000 indicate regular rounded forms. Higher values suggest prismatic and very angular shapes.

Formation material clusters usually keep original grain arrangement and provide a bi-dimensional (2D) pore-geometry image, referred to as pore throat and pore body size distribution (Fig. 7a & 7b). This study revealed that bridging material used was indeed too big to seal the exposed rock surface, with pore apertures of less than 10 microns. This may be one of the reasons for the well failure.

Clay and clastic grain mineral analysis within the sand matrix were performed. Kaolinite was easily identified by its characteristic EDS spectra and texture. Clastics grain size and cementation were also visualized. Lighter gray tone grains on the figure were identified as potassium feldspar.

Geologists usually do not get this information by conventional thin-section analysis, which is more typically based on the analyst's experience. Conversely, XRD diffraction mineralogy provides possible minerals (qualitative data) and relative abundance (semi-quantitative data) from a bulk sample.

Selecting an appropriated bridging material size for the drilling fluid (rock pore throat size versus bridging

material particle size), allowed later wells to be drilled successfully with no fluid losses reported.

### Field Case B

As part of a mature field development program with a small budget, one operator designated an old field with no cores available. Continuity of Miocene and Eocene sands with potential hydrocarbon in place could not be traced by means of existing logs.

Only drill cuttings were available from a number of offset wells. A cuttings-core correlation was initiated in order to develop completion strategies when coalescence of both Miocene and Eocene sands may occur on the same well, and generate rules for log interpretation in such cases.

Composition and texture of sands and related shale layer information were needed. Samples were prepared for SEM visualization and correlated with reported depths from log traces, as they were collected during mud logging. Images from drill cuttings clearly show these differences. In the case of unconsolidated Miocene sands, clastic granulometric and compositional data can be obtained, in some cases due to siderite cementation appearing as dalmatian grain clusters (Fig. 8). Shale cuttings show also a definite composition, illitic for both the Miocene and Eocene. Eocene sands are consolidated and their cuttings keep their attributes even as fragments in the millimeter-to-micron size range (Fig. 9).

Associated depth error was  $\pm 10$  ft, accordingly to correlated logs. All this information was used to develop drilling fluid design strategies, and geological and petrophysical reinterpretation models of the field were introduced based solely on drill cuttings information. A campaign followed which increased well production on this mature field.

### Conclusions

- Drill Cuttings Analysis has evolved as a powerful tool for information gathering with the support of visualization techniques applied on conventionally prepared polished samples.
- The use of digital image processing and analysis makes possible to obtain attributes such as Particle Size Distribution on clastic grains and other solids like bridging material in a mud.

- Pore Geometry determination has been achieved on consolidated rock fragments.
- Mineral Composition is simpler for interpretation as spatial distribution is shown on sample image, regardless of its size (mm to microns).
- Working fluids can be designed in a tailor-made fashion as presented on the two field cases discussed.
- This approach of analyses is a good alternative of geological information when economic restraints exist and coring operations are prohibitive.

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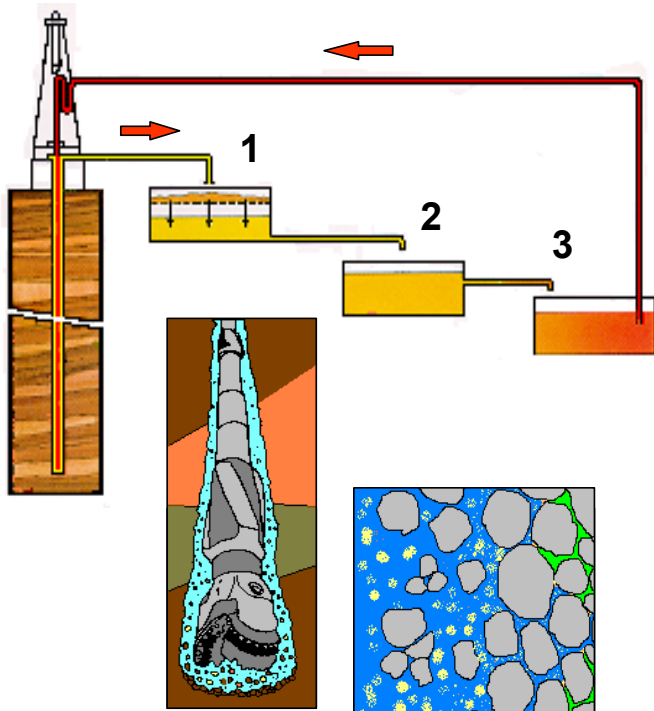


Fig. 1 – Drill-cuttings generation during the drilling process of a well. Solids-control equipment: desander (1), desilter (2), mud pit (3).

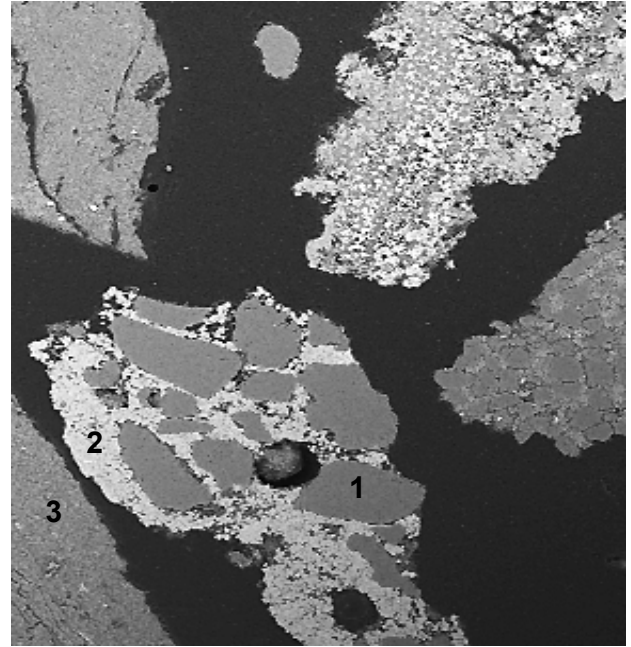


Fig. 3 – Drill cuttings appearance after preparation for SEM-BSE work. Scale bar represents 1 millimeter. Gray tone is related to mineral composition: (1) Quartz, (2) Siderite and (3) Illite.

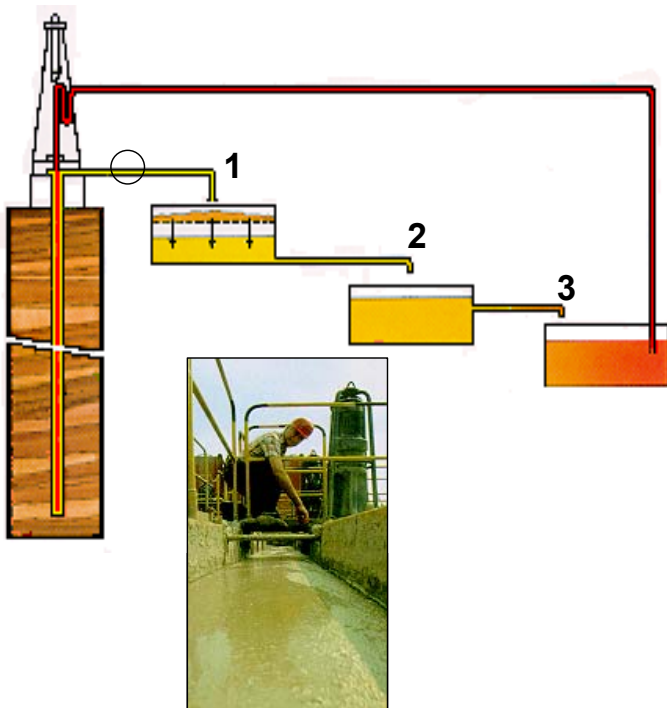


Fig. 2 – Drill-cuttings collection (circle) before flow line enters into the solids-control equipment.

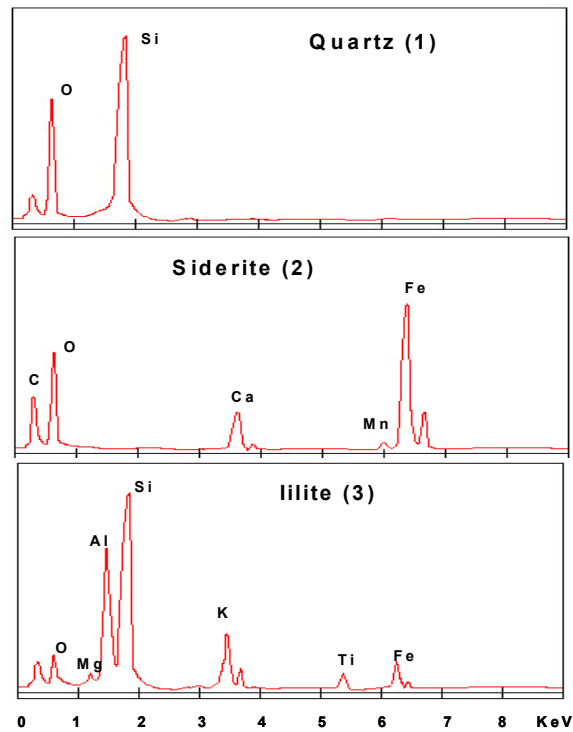


Fig. 4 – EDS spectra collected for the mineral components from Fig. 3. Energy units in KeV. (Kiloelectron Volts).



Fig. 5a – SEM-BSE image of drill cuttings sample from field Example A. Note different textures and gray tones. The last segmented bar scale (left) represents 100 microns.

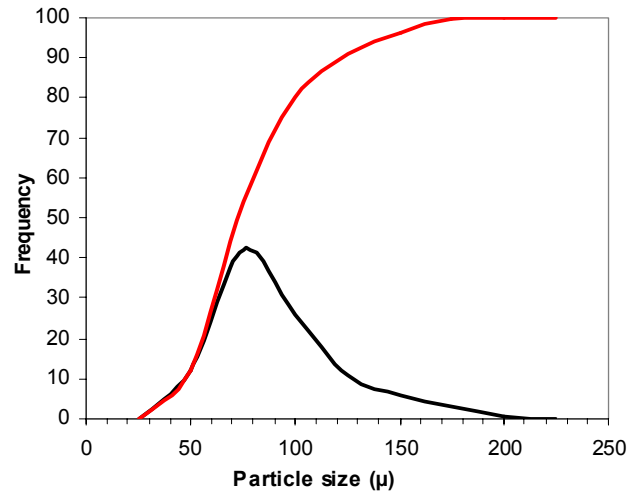


Fig. 6 – Particle-Size-Distribution (PSD) graph of bridging material (yellow) generated from Fig. 5a. Value for  $D_{50}$  was 75 microns. Red line is cumulative frequency and black line represents percentual frequency.

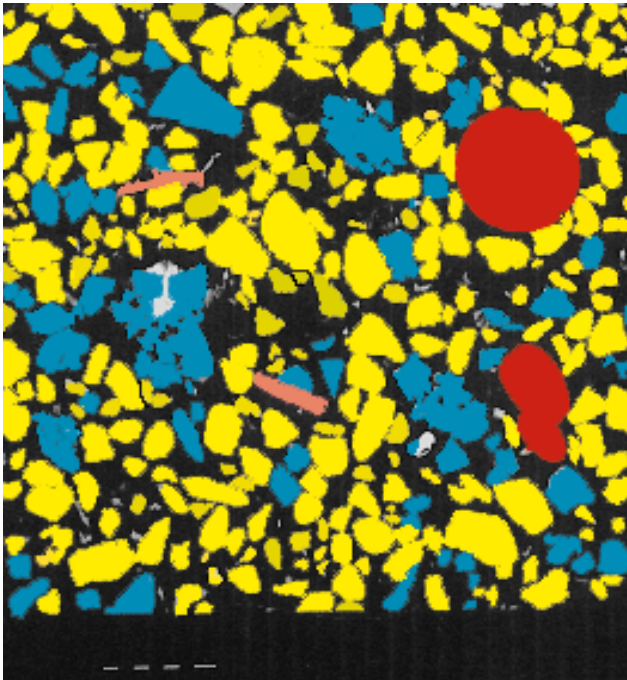


Fig. 5b – Digitally processed image from Fig. 5 showing composition associated with gray tone in a false color mode, bridging agent (yellow), mechanical lube (red), formation material (blue & white), metal debris (tan) and resin cast (black).

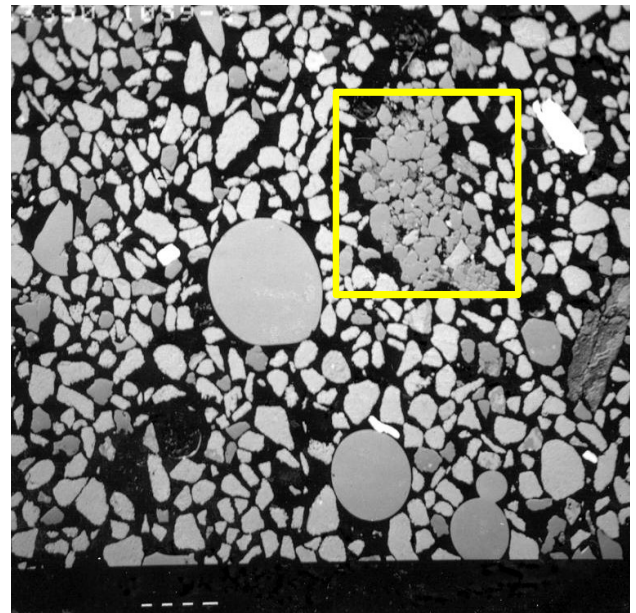
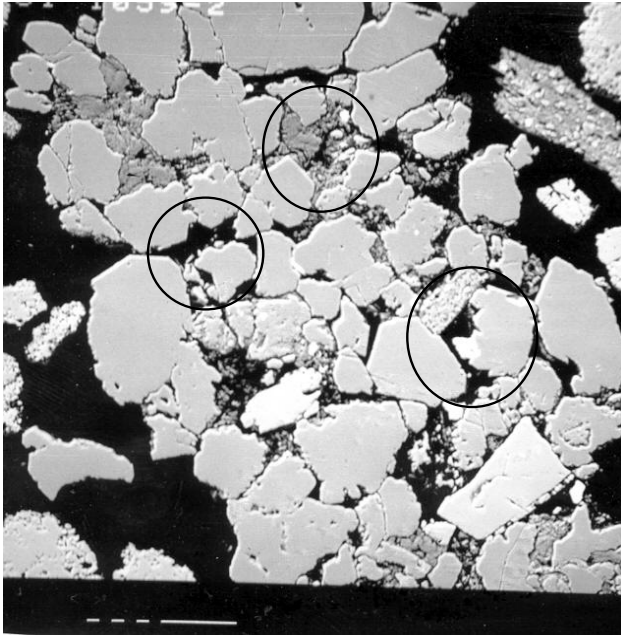
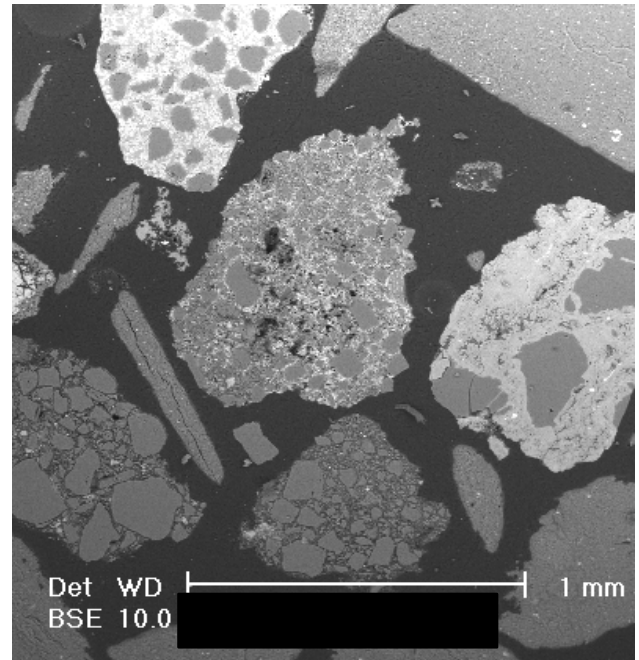


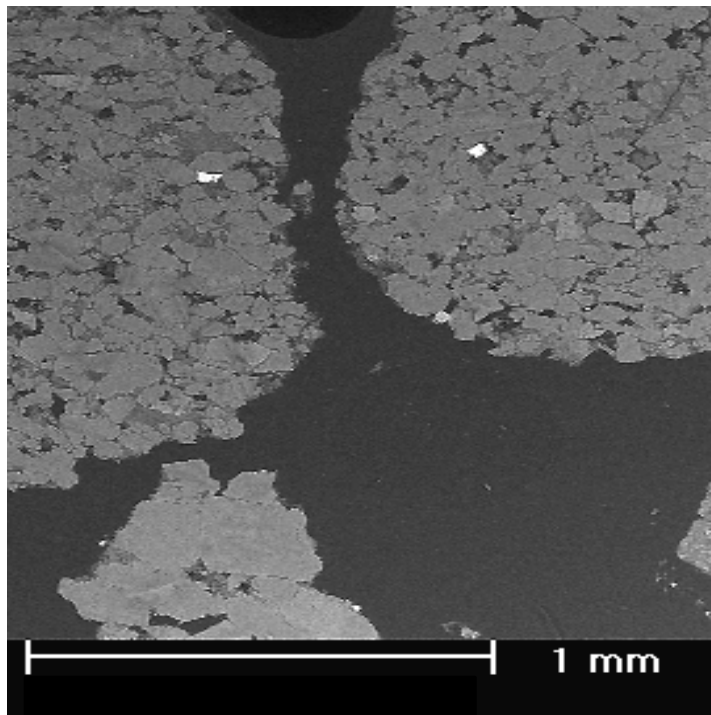
Fig. 7a – SEM-BSE image from Field Case A showing a cluster of grains from consolidated sandstone material of approximate 2-mm length inside a yellow box. Last segmented bar scale (left) represents 100 microns.



**Fig. 7b – Magnified view of yellow box from Fig. 7a. Circles are showing clay material location (kaolinite) and consolidated rock matrix porous space. Pore throats (2D) connecting pore bodies indicate sizes of less than 10 microns. Clastic grains are cemented by silica. Granulometry shows grain sizes ranging from 50 to 200 microns. Last segmented bar scale (left) represents 100 microns.**



**Fig. 8 – SEM-BSE image of drill cuttings sample from Field Case B (Miocene age material). Homogeneous prismatic and elongated shale material shows some microfractures. Clastic material, mostly quartz grains are cemented either by clay or siderite and calcite, showing typical Dalmatian texture (dark gray in white). Granulometry is very variable. Bar scale represents 1 mm.**



**Fig. 9 – SEM-BSE image from Eocene age drill cuttings from field case B. Round shape clusters of grains, cemented by silica, with well sorting. Grains are sub-angular and sizes within each cluster (Top) ranges from 40 to 100 microns. Bottom sample cutting has a range of 250-300 micron indicating a different depth provenance. Scale bar represents 1 mm.**