Research Article

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A grain size auto-classification of Baikouquan Formation, Mahu Depression, Junggar Basin, China

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Abstract: The borehole electrical imaging log offers general visual borehole wall, leaving no doubt that the conductivity contrast is sufficient to obtain a qualitative grain-size distribution of rocks. In this study, an automatic grain-size classification method is proposed using gray values of borehole electrical images from Baikouquan Formation in Mahu Depression. The first stage is comparing electrical images with cores. Gravels, sands, silts and clays are all discovered in the cores. The gravels are “mottled” in electrical images, and the bigger the spots, the coarser the gravels. The images of sands are homogeneous bright colored, and the coarser the sandy grains, the brighter the images. The electrical images of silts and clays are homogeneous brown and dark-brown colored. The second stage is auto-discriminating four categories of grain sizes roughly using averages and variances of gray values. The variances of gray values of gravels are high, whereas those of sands are medium. The gray averages of silts are between 160 and 220, whereas those of clays are larger than 200. The third stage is auto-classifying three kinds of gravels or sands finely using frequency distribution of gray values. The gray values of frequency peaks of cobbles are less than 50 and frequencies are larger than 15%, whereas those of pebbles are less than 50 or larger than 200 and frequencies

are between 10% and 20%; almost gray frequencies of granules are less than 10%. The dominated gray values of coarse sandstones, medium sandstones and fine sandstones are less than 50, between 50 and 160 and ranged from 160 to 240, respectively. The proposed method is demonstrated to be useful and fast to auto-classify grain size of various rocks in conglomeratic environments.

Keywords: borehole electrical image, auto-classify, grain size, conglomerate, Baikouquan Formation, Mahu Depression

1 Introduction

The buried rocks are the direct materials to uncover the geological formation, such as grain size, sedimentary structure, facies and depositional sequence. Normally, the only available real rocks are cores, but cores cannot offer uncored section information. Due to the low-resolution and non-image, the conventional logging programs are not able to resolve the grain size or sufficiently identify the centimeter-scale lithostrome. The borehole electrical imaging tools sample the formation every 0.2 inch, measure variations in micro-resistivity along the borehole wall and leave no doubt that the conductivity contrast is sufficient to reflect the grain size of rocks. The borehole electrical images provide a wealth of geologic data obtainable only from cores previously. Even though spatial resolution of features visible on the images (down to 0.2 inch) is lower than that on a core, borehole images can offer major geologic information where core is absent [1–5]. However, the generated image essentially provides numerical data in the form of log curves which may be useful to quantify the images and classify grain size of rocks [6]. The only related literature is that of Sovich (1993), who picked conductivity thresholds of Formation MicroScanner (FMS) image to quantitatively define the facies of cobbles, sand matrix, silty sand and non-reservoir rock [6]. His purpose was to estimate the proportion of grain sizes roughly by the conductivity

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Figure 1: Geological setting of Lower Triassic Baikouquan Formation in Mahu Depression. (a) Map of China. The Junggar Basin locates in northwestern China, indicated by red rectangular. (b) Tectonic map of Junggar Basin. Mahu Depression is in the northwestern margin of Junggar Basin, indicated by red rectangular. (c) Depositional setting of Baikouquan Formation in Mahu Depression. Six coarse-grained fan-deltas are developed on slope of the depression.

threshold values, but not to classify grain size. Then, to know the grain size from borehole electrical images, the usual approach is only qualitative by the geological and logging workers, not automatic.

In Lower Triassic Baikouquan Formation, Mahu Depression, Junggar Basin, fan-delta deposits were developed, and the lithology is mainly conglomerate. As one of the most important petroleum formations, the borehole electrical images are acquired to realize the vertical change rules of grain sizes. The qualitative way is obviously too slow and with subjective factors in a number of identification tasks. A new automatic method is warranted to provide a solution to the location and grain size of rocks and to better distinguish rock type in complex lithologies. Taking Baikouquan Formation as an example, the goal of this study is to propose an automatic and fast way to classify various grain sizes of rocks. First, borehole electrical images of various grain sizes are qualitatively compared with cores. Second, four categories of grain sizes are discriminated by averages and variances of the gray values of electrical images. Third, three kinds of gravels or sands are classified by frequency distribution of gray values. Furthermore, auto-classified result is compared with that of core descriptions and experimental grain size distributions in a cored interval of one well.

2 Geological setting

Located in northwestern China, Junggar Basin is one of the most significant oil producing regions in this country (Figure 1a). Several large-scale oil-fields have been built in six hydrocarbon generation depressions. As one of the principal hydrocarbon accumulation sags, “hundred-mails oil-fields” are being established around Mahu Depression [7,8]. Tectonically, the Mahu Depression is located at the front of a foreland in the northwestern margin of the Junggar Basin (Figure 1b), which developed due to the collision and subduction between the Junggar–Turpan and Kazakhstan Plates during the Late Paleozoic [9,10]. Sediments were denuded in the northwestern margin and transported by gravity and flow into the Mahu Depression, which takes the Carboniferous Formation as the basement. These numerous coarse sediments accumulated on the slope to form alluvial fans, fan-deltas or fluvial delta deposits from Permian to Quaternary. In Lower Triassic Baikouquan Formation, the coarse grains stacked as fan-deltas, named Zhongguai, Karamay, Huangyangquan, Xiazijie, Xiayan and Dabasong Fan-delta around the depression (Figure 1c) [11–13]. The data used in this article are from Huangyangquan and Xiazijie Fan-delta. In addition, later

Figure 2: Open-hole conventional logs and mud logging lithology of Baikouquan Formation in Well M154. The T₁b₁ and T₁b₂ are main thick grayish-green conglomerates. Gray sandstones and gray-brown mudstones are more developed in T₁b₃. GR: natural gamma ray; SP: spontaneous potential; RT: deep-investigation resistivity; RI: middle-investigation resistivity; AC: acoustic-time; CNL: compensated neutron.

tectonic activities were weak in this formation, which resulted in poor natural fractures in conglomerates.

Since 2010, the Baikouquan Formation gradually became a key petroleum exploration target zone, and multiple high-yielding intervals were found in conglomerates. Abbreviated as T₁b, Baikouquan Formation is divided into three members, T₁b₁, T₁b₂ and T₁b₃ upwards in stratigraphy. With a thickness of 30–50 m, T₁b₁ is mostly thick gray, grayish-green and brown conglomerates; with a thickness of 60–100 m, T₁b₂ is mainly thick grayish-green conglomerates embedded thin brown mudstones; with a thickness of 40–90 m, T₁b₃ is dominantly thick gray

sandstones and gray-brown mudstones embedded thin grayish-green conglomerates (Figure 2) [14–16]. The coarse grains are major lithology of reservoir.

3 Databases and methodologies

3.1 Databases

Borehole electrical imaging logs have been used to resolve lithologies, sedimentary structures, depositional microfacies

Figure 3: Gray-scale used in borehole electrical images. Dark-brown color indicates high conductivity and bright color represents high resistivity.

and environments in petroleum geology successfully [17–21]. To understand the depositional system of Baikouquan Formation, borehole electrical imaging tools were run in 21 wells. The following two kinds of tools were used: (1) Fullbore Formation MicroImager (FMI) served by Schlumberger Corporation, with 196 buttons distributed on eight pads in contact with the borehole wall; and (2) Extended-Range MicroImager (XRMI) developed by Halliburton Corporation, with 150 buttons distributed on six pads. A number of resistivity data are converted into electrical images by the following two filters: (1) static normalization, rescaling resistivity to the highest and lowest values of the logging run; and (2) dynamic normalization, rescaling the data in a narrow interval (1 m in this article). For the higher contrast, the dynamic image artificially enhances the geological textures [4]. The images are scaled in gray values ranging from 0 to 255, and bright indicates high resistivity and dark-brown color indicates high conductivity (Figure 3). In this article, the gray values of two-dimensional dynamic electrical images are extracted to classify grain sizes of rocks.

Cores were obtained from 15 wells where the borehole electrical imaging tools were run. Cores were described and the diameters of gravels were measured by straightedge to classify the grain sizes. Cores were photographed or scanned into computers to digitally confirm the characteristics of lithology. The core works were done independently of the image analyses and compared later with the auto-classification of grain sizes. Based on the diameter range, grain size of rocks in the Baikouquan Formation has been classified in

many literature studies, which is divided into four categories (gravel, sand, silt and clay) and nine classifications (boulders, cobbles, pebbles, granules, coarse sandstones, medium sandstones, fine sandstones, siltstones and mudstones) (Table 1) [22,23]. Individual boulders are rarely observed in core samples as well as in electrical images. Hence, boulders will not be considered in this study.

3.2 Methods

Ultrahigh-resolution digital information derived from borehole electrical images provides detailed grain size characteristics and plays a key role in understanding the depositional environments of the overall formation. Taking the fan-delta deposits of Lower Triassic Baikouquan Formation in Mahu Depression for example, the method using borehole electrical images to auto-classify grain size of rocks requires knowledge of primary lithological features and comprises three stages in this article.

The first stage, comparison of borehole electrical images with descriptions and photographs of cores, involves (1) eliminating the depth error between images and cores and (2) summarizing the borehole electrical image feature of the four categories and eight classifications qualitatively. This is conducive to the general sight for different grain size rocks.

The second stage, extraction of the gray values of dynamic borehole electrical images, consists of (1) calculating the average and variance of gray values at each depth point and (2) discriminating four categories of grain sizes using averages and variances. At individual depth point, average of grays is the sum of all grays divided by the total number of values, and variance of grays is defined by the quadratic sum of difference between gray and average divided by the total number of values:

$$\begin{cases} \text{Average} = \frac{\sum_{i=1}^N g_i}{N} \\ \text{Variance} = \frac{\sum_{i=1}^N (g_i - \text{Average})^2}{N} \end{cases}$$

Table 1: Four categories and nine classifications of grain size of the Baikouquan Formation [22,23]

Categories	Gravel					Sand		Silt	Clay
Classifications	Boulder	Cobble	Pebble	Granule	Coarse	Medium	Fine		
Diameter (mm)	>128	32–128	8–32	2–8	0.5–2	0.25–0.5	0.06–0.25	0.004–0.06	<0.004

Diameters of boulders are even larger than those of cores and they are hard to be observed in electrical images.

Figure 4: Scanned photographs, dynamic electrical images, averages and variances of gray values and gray frequency profile of cobbles, Well M152. (a) Scanned photographs. Individual grain is clear. (b) Dynamic electrical images. They are coarse mottled and the spots indicate the grains. (c) Gray averages and variances of electrical images. Averages are middle and variances are high. (d) Two-dimensional gray frequency profile of cobbles. The frequency curves are unimodal at one depth point.

Figure 5: Scanned photographs, dynamic electrical images, averages and variances of gray values and gray frequency profile of pebbles, Well M19. (a) Scanned photographs. Individual grain is clear. (b) Dynamic electrical images. They are coarse mottled and the spots indicate the grains. (c) Gray averages and variances of electrical images. Averages are middle and variances are high. (d) Two-dimensional gray frequency profile of pebbles. The frequency curves are unimodal or bimodal at one depth point.

where g_i is the gray value and N is the total number of gray values at each depth point. This procedure allows the grain size of rocks to be roughly distinguished.

The third stage, based on the above identified result, embraces (1) calculating frequency distribution of 25 gray class intervals and (2) dividing three classifications of grain sizes in gravels or sands according to the gray frequency distribution. The gray frequencies of each depth are defined

by the number of values falling into each interval which was then divided by the total number of values:

$$\text{Frequency}_i = \frac{\text{Number}_i}{N},$$

where Number_i and Frequency_i are the number and frequency of grays in the i th interval, respectively, $i = 1, 2, 3, \dots, 25$. One-dimensional gray frequency curves and two-

Figure 6: Scanned photographs, dynamic electrical images, averages and variances of gray values and gray frequency profile of granules, Well AH1. (a) Scanned photographs. Individual grain is clear. (b) Dynamic electrical images. They are fine mottled and the spots indicate the grains to a certain extent. (c) Gray averages and variances of electrical images. Averages are middle and variances are high. (d) Two-dimensional gray frequency profile of granules. The frequency curves are not obvious peaks at one depth point.

Figure 7: Scanned photographs, dynamic electrical images, averages and variances of gray values and gray frequency profile of coarse sandstones, Well M152. (a) Scanned photographs. Individual grain is clear. (b) Dynamic electrical images. They are homogeneous bright colored. (c) Gray averages and variances of electrical images. Variances are low and gray averages are nearly 0. (d) Two-dimensional gray frequency profile of coarse sandstones. The grays of peaks are less than 50.

dimensional gray frequency profiles of electrical images are adopted here. Grain sizes of rocks are classified finely in the end.

4 Results

4.1 Comparison of borehole electrical images with cores

Individual gravelly grain is very obvious on the core cylindrical surfaces and their photos. According to the

laboratory quantitative identification of clastic components, volcanic tuff, felsite, andesite, granite and rhyolite are the dominated rock types of gravelly grains [15]. These grains within different volcanic materials present different conductivity, which corresponds to different gray values in borehole electrical images. Therefore, the gravels are elaborate “mottled” in two-dimensional electrical images. Benefitting from the ultrahigh-resolution, the grain sizes are clear to be classified in the visualized images. The spots within different gray values indicate the approximate gravelly grains: the bigger the spots, the coarser the gravels (Figures 4a, b, 5a, b and 6a, b) [24–27].

Figure 8: Scanned photographs, dynamic electrical images, averages and variances of gray values and gray frequency profile of medium sandstones, Well M152. (a) Scanned photographs. Grains are well sorted. (b) Dynamic electrical images. They are homogeneous yellow-bright colored. (c) Gray averages and variances of electrical images. Variances are low and gray averages are mostly between 75 and 125. (d) Two-dimensional gray frequency profile of medium sandstones. The grays of peaks are mostly between 50 and 160.

Figure 9: Scanned photographs, dynamic electrical images, averages and variances of gray values and gray frequency profile of fine sandstones, Well M136. (a) Scanned photographs. Grains are well sorted. (b) Dynamic electrical images. They are homogeneous yellow colored. (c) Gray averages and variances of electrical images. Variances are low and gray averages are mostly between 125 and 160. (d) Two-dimensional gray frequency profile of medium sandstones. The grays of peaks are mostly between 160 and 240.

The sands transported by braided rivers or distributary channels of the fan-delta system are usually well sorted. The sizes of sands range from 0.06 to 2 mm, which is below the resolution of borehole electrical imaging tools. As a result, the individual sandy grain could not be observed in electrical images. Being different from gravels, the images of sands are homogeneous bright colored. However, the coarse sandstones are bright (Figure 7a and b), medium sandstones are bright-yellow

(Figure 8a and b) and fine sandstones are yellow (Figure 9a and b). It means that the coarser the sandy grains, the brighter the images [24–27].

The silts and clays accumulated in quiet water have well conductivity, and silty and muddy intervals have medium-low and the lowest resistivity, respectively. Correspondingly, electrical images of both are homogeneous brown (Figure 10a and b) and dark-brown colored, respectively (Figure 11a and b) [24–27].

Figure 10: Scanned photographs, dynamic electrical images, averages and variances of gray values and gray frequency profile of siltstones, Well FN10. (a) Scanned photographs. Grains are well sorted. (b) Dynamic electrical images. They are homogeneous brown colored. (c) Gray averages and variances of electrical images. Variances are low and gray averages are mostly between 160 and 200. (d) Two-dimensional gray frequency profile of siltstones. The grays of peaks are nearly 220.

4.2 Auto-discrimination of four categories

In general, the gravelly formations have low conductivity, whereas silts and clays have low resistivity in

open-hole conventional logs [28,29]. The borehole electrical images are composed of a number of gray points, which can be extracted gray averages and variances of images at each depth point. For the whole

Figure 11: Scanned photographs, dynamic electrical images, averages and variances of gray values and gray frequency profile of mudstones, Well M152. (a) Scanned photographs. Grains are well sorted. (b) Dynamic electrical images. They are homogeneous dark-brown colored. (c) Gray averages and variances of electrical images. Variances are low and gray averages are mostly between 200 and 255. (d) Two-dimensional gray frequency profile of mudstones. The grays of peaks are nearly 255.

Figure 12: Cross-plot of gray averages and variances of four grain size categories' borehole electrical images. Averages of gravelly grays are middle and variances are high. Averages and variances of sandy grays are both middle-low. Averages of silty and muddy grays are high and variances are low.

Baikouquan Formation in one well, gray average and variance curves are processed to auto-discriminate four grain size categories.

Electrical images of gravels are inhomogeneous mottled, mixed with various gray values. The averages of gravelly grays are medium and variances are high (Figures 4c, 5c and 6c). Electrical images of sands are homogeneous bright or yellow colored, within similar gray values. Averages and variances of sandy grays are both middle-low (Figures 7c, 8c and 9c). Electrical images of silts are homogeneous brown colored, and gray averages are high and variances are low (Figure 10c). Images of clays are homogeneous dark-brown colored, and gray averages are the highest and variances are low (Figure 11c). For the aforementioned features, gray averages and variances of gravels, sands, silts and clays are drawn in cross-plot, which is effective to auto-discriminate four grain size categories of rocks (Figure 12). The gray variances of gravels are about larger than 3×10^3 , whereas those of other grains are lower than this threshold. The gray averages of sands are less than 170, those of silts are between 160 and 200 and those of clays are larger than 200.

4.3 Auto-classification of gravels or sands

After grain sizes of rocks are distinguished into four categories in the previous step, the third step is auto-classifying grain size in gravels or sands internally. The corresponding two-dimensional gray frequency profiles of eight grain size classifications are plotted (Figures 4d, 5d, 6d, 7d, 8d, 9d, 10d and 11d). In addition, at each depth point, the one-dimensional frequency distribution curves are also derived from frequency profiles (Figure 13). These two-dimensional profiles and one-dimensional curves could be used to auto-classify three kinds of gravels or sands.

In gravels, the gray frequency curves of cobbles are unimodal. The gray values of peaks are less than 50, and the corresponding frequency percentages are larger than 15% (Figures 4d and 13a). The gray frequency curves of pebbles are unimodal or bimodal, one peak at low gray, less than 50, and another peak at high gray values, larger than 200. The frequency percentages of both peaks are between 10% and 20% (Figures 5d and 13b). The gray frequency curves of granules are without obvious peaks; gray values are widespread; and the almost gray frequency percentages are less than 10%

Figure 13: One-dimensional gray frequency distribution curves of gravels and sands. Data come from Figures 4d, 5d, 6d, 7d, 8d and 9d. (a) Gray frequency curves of cobbles. (b) Gray frequency curves of pebbles. (c) Gray frequency curves of granules. (d) Gray frequency curves of coarse sandstones. (e) Gray frequency curves of medium sandstones. (f) Gray frequency curves of fine sandstones.

Figure 14: Cross-plots of peaks' gray values and frequency percentages of frequency distributions of borehole electrical images. Data are from Figure 13. (a) The peaks' gray values of cobbles are less than 50 and frequencies are larger than 15%. The peaks' gray values of pebbles are less than 50 or larger than 200 and frequencies are between 10% and 20%. The frequencies of granules are less than 10%. (b) The dominated gray values of coarse sandstones, medium sandstones and fine sandstones are less than 50, between 50 and 160 and ranged from 160 to 240, respectively.

Table 2: Auto-classified criterion of different grain size rocks using borehole electrical images

Categories	Average	Variance	Classification	Peak's gray	Peak's frequency (%)
Gravel	50–175	$>3 \times 10^3$	Cobble	<50	>15
			Pebble	<50 or >200	10–20
			Granule	0–255	<10
Sand	0–170	1×10^3 – 3×10^3	Coarse	<50	
			Medium	50–160	
			Fine	160–240	
Silt	160–200	1×10^3 – 3×10^3			
Clay	200–255	$<1 \times 10^3$			

Average and variance of grays are used to auto-discriminate four categories. Frequency distributions of gray values are used to auto-classify three kinds in gravels or sands.

(Figures 6d and 13c). All these features are shown in the cross-plot of gray values and frequency percentages of peaks (Figure 14a). Centralized regions of cobbles, pebbles and granules are distinguished from each other.

In sands, the gray frequency curves are unimodal. However, the gray values of peaks are different from each other: the primary gray values of coarse sandstones are less than 50 (Figures 7d and 13d); the main gray values of medium sandstones are between 50 and 160 (Figures 8d and 13e); the dominated gray values of fine sandstones range from 160 to 240 (Figures 8d and 13f). In the cross-plot of gray values and frequency percentages of peaks, these three types of sandstones are

differentiated by the distribution of dominated gray values easily (Figure 14b).

5 Discussion

Borehole electrical images have been primarily used for the qualitative recognition of grain sizes and depositional structures. The excellent resolution of the borehole electrical imaging log makes it possible to discriminate features that are not seen in conventional logs. The ability to discriminate grain size leads to the capability to quantify the image through gray values of

Figure 15: The photographs of core, grain size of core description, depth of experimental grain size distributions, dynamic borehole electrical image, gray average and variance curves of electrical images, auto-classified result and two-dimensional gray frequency profile, 2775.45–2777.59 m interval of Well FN10. The result of auto-classified method is without qualitative influence of core observer's knowledge, and integral and continuous depth in the whole interval. GSD: grain size distribution; Cl: claystone; Si: siltstone; Fs: fine sandstone; Ms: medium sandstone; Cs: coarse sandstone; Gr: granule; Pe: pebble; Co: cobble. In the sixth channel, Cl: clay; Si: silt; Sa: sand; Gr: gravel.

Figure 16: Six experimental grain size distributions. The grain size results of auto-classification are same as that of grain size distributions. M_z : mean of grain size distribution; M_d : median of grain size distribution.

digital images. The auto-classified criterion of different grain size rocks using borehole electrical images is summarized in Table 2. Four categories of grain sizes are auto-discriminated by the averages and variances of gray values. Three kinds of gravels or sands could be auto-classified by the frequency distribution of the gray values. This auto-classified method has been successfully applied to identify the grain sizes of fan-delta deposits in Baikouquan Formation, Mahu Depression. Taking 2775.45–2777.59 m interval of Well FN10 for example, the photographs of core, grain size description of core, dynamic borehole electrical image, gray average and variance curves, two-dimensional gray frequency profile and auto-classified result are shown in Figure 15, and six experimental grain size distributions are given in Figure 16.

The first channel shows the core photographs, and core recovery was near 100%, despite that very few cores are broken and lost by sampling (Figure 15). The second channel shows the core description result which is made in the core library (Figure 15). Because of the understanding level of grains, the observer considered that the gravels are all pebbles. Besides the depth error with logs, the depth of artificial results is not entire. The third channel is the depth of experimental grain size distributions. The fourth channel is the logging depth. The fifth channel shows the borehole electrical images collected by XRMI (Figure 15). The average

and variance curves of image's grays are shown in the sixth channel (Figure 15). According to the auto-discriminated criterion of the categories, silts, sands and gravels are identified, which is shown in the seventh channel (Figure 15). The result of auto-discriminated categories is close to that of core description: in the gravelly interval of cores, the rocks are gravels as well (2776.12–2777.18 m and 2777.31–2777.58 m). The eighth channel gives the two-dimensional gray frequency profiles of images (Figure 15). Cobbles, pebbles, granules, coarse sandstones and medium sandstones are recognized, respectively, at different intervals in the ninth channel, according to the auto-classified criterion of three kinds of gravels or sands (Table 2). In addition, the grain sizes of six samples were analyzed (Figure 16). Grain size results are gained from the grain size distributions, and they are in accordance with the auto-classified results (Figure 15). Therefore, same as experimental grain size distribution results and more elaborate than core description results, the auto-classified results demonstrate the availability and feasibility of this method.

Compared to the result of core description, the auto-classified result has the following two advantages: (1) no qualitative influence of core observer's knowledge; and (2) integral and continuous depth in the imaging logging running intervals. In addition, the method of this study would be applied to the near provenance conglomeratic deposits, such as alluvial fans and fan-deltas. For the short

transportation distance, the grain sizes of gravels within different mineral components are usually larger than the resolution of borehole electrical images. Their conductivity must be different from that of interstitial matters filled in the spaces of grains. These borehole electrical images of conglomeratic formations are visualized to identify the grain sizes of rocks, and digital attributes derived from high-quality images can be certainly used to auto-classify grain sizes by this proposed method.

6 Conclusions

Taking Baikouquan Formation in Mahu Depression for example, an automatic method is proposed to classify the grain size of various rocks using borehole electrical images, which includes comparing electrical images with cores, auto-discriminating four categories roughly and auto-classifying three kinds of gravels or sands finely. The gravels are “mottled” in two-dimensional borehole electrical images, and the bigger the spots, the coarser the gravels. The images of sands are homogeneous bright colored, and the coarser the sandy grains, the brighter the images. The electrical images of silts and clays are homogeneous brown and dark-brown colored.

The gray averages and variances of electrical images are calculated to auto-discriminate gravels, sands, silts and clays. The variances of gray values of gravels are high, whereas those of sands are medium usually. The variances of gray values of silts and clays are both low, but the gray averages of silts are between 160 and 200, and gray averages of clays are larger than 200.

The two-dimensional gray frequency profiles and one-dimensional gray frequency distribution curves of borehole electrical images are counted to auto-classify cobbles, pebbles and granules, or coarse sandstones, medium sandstones and fine sandstones. The peaks’ gray values of cobbles are less than 50 and frequencies are larger than 15%. The peaks’ gray values of pebbles are less than 50 or larger than 200 and frequencies are between 10% and 20%. The almost gray frequencies of granules are less than 10%. The dominated gray values of coarse sandstones, medium sandstones and fine sandstones are less than 50, between 50 and 160 and ranged from 160 to 240, respectively. In a cored interval, the availability and feasibility of the proposed method are verified by core descriptions and experimental grain-size distributions, and it can be used to auto-classify grain size of rocks in near provenance conglomeratic environments.

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