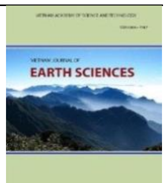
Vietnam Journal of Earth Sciences, 41(2), 182–199, Doi: 10.15625/0866-7187/41/2/13798

(VAST)

Vietnam Academy of Science and Technology

Vietnam Journal of Earth Sciences

http://www.vjs.ac.vn/index.php/jse



Environments of upper miocene sediments in the Hanoi depression interpreted from grain-size parameters

Mai Thanh Tan, Dinh Van Thuan, Nguyen Dich Dy, Nguyen Van Tao, Le Duc Luong, Trinh Thi Thanh Ha, Ngo Thi Dao

Institute of Geological Sciences, VAST, Hanoi, Vietnam

Received 26 October 2018; Received in revised form 26 January 2019; Accepted 26 April 2019

ABSTRACT

The grain-size analysis is carried out for 49 samples of Upper Miocene sediments taken from three boreholes in the Hanoi depression. The statistic parameters of the grain size distributions such as percentiles, median, graphic mean, sorting or inclusive graphic standard deviation, inclusive graphic skewness, and graphic kurtosis are used to decipher the depositional environments and transportation mechanisms of sediments. Bivariate plotting of these parameters, the discriminant functions with four basic parameters of graphics mean, sorting, inclusive graphic skewness and graphic kurtosis, and the CM pattern with the one percentile (C) and median (M) diameters are applied for this determination. The plots of graphics mean versus sorting suggest 14% of samples being the sand sheet, 46% related to rivers and 40% of the estuarine environment. The sorting - inclusive graphic skewness plot shows a river-related environment for all samples. Linear discriminant functions show the sandstone of upper Miocene in Hanoi depression are deltaic sediments formed in unstably transporting and depositional environment, impacted by turbidity current in the coastal river-mouth. The CM pattern shows sediment transportation for most of the samples in three modes: rolling, suspension and rolling, and uniform suspension. The environmental dynamics are relatively complex and change over time.

Keywords: Grain-size parameters; bivariate plots; discriminant functions; CM pattern.

1. Introduction

Grain-size analysis has long been used in sedimentology for interpreting transportation mechanism and depositional medium of sediments. The grain-size distribution is characterized by several statistical parameters such as percentile values, median, mean, sorting, skewness, kurtosis, etc. These parameters were once used as a set of separate data for deciphering depositional environment but later interpretations are based on the quantified relationships among these grain-size characteristics. Using the variation of mean in relation with sorting to characterize different environments is mentioned by Starkel et al. (1982), Florek et al. (1990), Sarre and Chancey (1990); Ruz and Allard (1995), Rizzetto et al. (1998), Mycielska-Dowgiałło and Ludwikowska-Kędzia (2011). Bivariate correlations between mean, sorting,

*Corresponding author, Email: maithanhtan@igsvn.vast.vn

skewness, kurtosis, etc., are plotted to distinguish different environments by Friedman (1961), Moiola and Weiser (1968), Tanner (1991), Lario et al. (2002), Switzer et al. (2005). The discriminant functions with four basic parameters namely mean, sorting, skewness, and kurtosis are used for sands to discriminate aeolian, beach, backshore, shallow agitated, shallow marine, deltaic, fluvial and turbidity environments (Sahu, 1964; Rajganapathi et al., 2012; Rashedi and Siad, 2016; Maity and Maiti, 2016). Grain-size parameters are used not only for deciphering depositional environments but also for interpreting the mechanism of sediment transportation with the pattern of C (one percentile) vs. M (median) introduced firstly by Passega (1964).

In Vietnam, granulometric analysis has also been applied to determine sedimentary environments. Grain sizes in millimeters and their parameters calculated by Trask (1930) such as mean equal to median, sorting coefficient calculated by square rooting the ratio between 1st and 3rd quartile values, skewness obtained by dividing the product of 1st and 3rd quartile to the square of mean, are used for study Cenozoic sediments in the Hanoi depression (Tran Nghi et al., 1986; 1991). The particle size parameters introduced by Trask (1930) are used as a set of separate data, combined with other methods, to interpret the depositional environments. Based on the grain-size analysis of samples taken from three recent boreholes, the Upper Miocene sediments of Hanoi depression are interpreted not only from separate parameters of grain size, determined by Folk's method (1974), such as graphic mean (M_Z), sorting or inclusive graphic standard deviation (σ_I), inclusive graphic skewness (SK_I) and graphic kurtosis (K_G) but also from their quantitative interrelationships. The grain size parameters, their bivariate plots, discriminant functions of Sahu (1964) and CM pattern of Passega et al. (1969) are used for this interpretation.

2. Geological setting

The Upper Miocene sediments for sampling are situated in the Hanoi depression, belonging to northwestern part of Cenozoic Red River basin. Cenozoic sediments in this depression have been studied by many authors such as Golovenok and Le Van Chan (1966), Do Bat and Phan Huy Quynh (1983), Nguyen Dich Dy (1987), Tran Nghi et al. (1986, 1991, 2004), etc. As a result of many recent studies, these sediments evolve from Eocene to Late Holocene.

The Red River basin with over 14 km thickness of Cenozoic sediments is a pull-apart basin initially formed by left slip of the Red River Fault Zone (Nguyen Manh Huyen and Ho Dac Hoai, 2007) during Eocene - Early Oligocene collision between Indian and Eurasian plates (Tapponnier et al., 1990; Phan Trong Trinh et al., 2004; Leloup et al., 1995; Schoenbohm and et al., 2005). Up to Middle Oligocene, this movement was no longer large and stopped at the northern part of Red River basin (Phan Trong Trinh, 2012). In the Red River basin, Middle Oligocene tectonic inversion, marked by an angular unconformity, limiting sinistral slip within a narrow zone between the Lo River fault and the boundary fault of East Vietnam (Rangin et al., 1995; Nielsen et al., 1999; Phan Trong Trinh, 2012). In Miocene, left-lateral motion continued in the above-mentioned zone with an offset not exceeding a few tens of kilometers, but there was a change from trans-tension into trans-compression at the Early/Middle Miocene (Rangin et al., 1995), resulting in Middle-Late Miocene tectonic inversion (Lee and Lawver, 1994; Hutchison, 2004; Nguyen Manh Huyen and Ho Dac Hoai, 2007; Li et al., 2015), horizontally compressing sediments to form folds within branching systems of faults (Tran Nghi et al., 2004). Pliocene-Quaternary right-lateral motion has not been found in Red River through its presence in vicinities such as onshore part of Red River Fault Zone (Replumaz et al., 2001; Schoenbohm et al., 2006; Trinh et al., 2012), Bach Long Vy area (Replumaz et al., 2001; Fyhn and Phach, 2015).

According to Tran Nghi et al. (2004), the Cenozoic sediments in the Red River basin develop in 7 cycles, each cycle is characterized by temporal facies-associations with lateral change in direction from continent to the sea, oriented by paleo flow of the Red River and direction perpendicular to the basin axis, corresponding to sediments of following formations: Phu Tien Formation (E2 pt) and the lower of Dinh Cao formation (E3 dc) in cycle I; upper of Dinh Cao formation (E3 dc) in cycle II; Phong Chau Formation (N11 phc) in cycle III; Phu Cu formation (N12 pc) in cycle IV; lower of Tien Hung formation (N13 th) in cycle V; upper part of the Tien Hung Formation (N13 th) in cycle VI; and 6 formations namely Vinh Bao (N2 vb), Le Chi (Q11 lc), Hanoi (Q12-3 hn), Vinh Phuc (Q13 vp), Hai Hung (Q21-2 hh) and Thai Binh (Q23 tb) in cycle VII.

The Upper Miocene sediments belong to Tien Hung Formation, which is firstly introduced by Golovenok and Le Van Chan (1966). Its holostratotype is described in borehole GK4, drilled in Tien Hung district (Thai Binh province), from 250 to 1010 m depth. This formation is composed of sediments in 15 to 18 distinct rhythms, beginning with gritstone, sandstone grading upward to siltstone, claystone, coal shale and many brown coal seams. In these rhythms, the coarse-grained part is usually thicker than the fine-grain part. Sandstone and gritstone with poorly sorted and rounded grains are usually feebly cemented or friable, bearing garnets. In the lower part of the formation, the beds are usually compressed and contain interbeds of grayish sandstones bearing siderite concretions. The thickness of the formation in this holostratotype reaches 760 m (Tong Duy Thanh et al., 2005). The Tien Hung Formation is found in most boreholes drilled in Hanoi depression and Tonkin Gulf with a composition mainly of sandstone, in the upper part often coarse-grained interbedded with gritstone, claystone, siltstone intercalated with brown coal seams. However, the Tien Hung formation contains less brown coal than the underlying Phu Cu formation due to the submergence of deltaic sediments whose marine characteristic increase towards Tonkin Gulf. Sandstone is light grey to greenish grey colored, fine to coarse-grained, thick-bedded to massive structure, moderately to poorly sorted, carbonate and clay cemented and bearing fauna and brown coal debris. Mudstone is greenish grey to light gray, locally brownish grey, dark grey, containing coaly debris and fossils, locally, glauconite and pyrite. The thickness of the formation ranges from 760 m to 3000 m. The Tien Hung Formation is formed mainly in the deltaic plain environment (Khoai Chau-Tien Hai band), deltaic plain intercalated with marine littoral phases (Dong Quan depression) and submerged delta developing towards the Tonkin Gulf (Tong Duy Thanh et al., 2005).

Samples are taken from three boreholes situated in Thai Binh province, concretely: LK51SH with 1100 m deep in Phu Luong commune of Dong Hung district, LK97SH deep with 1050.2 m in Tay An commune of Tien Hai district and LK102SH with 1100 m deep in Nam Thang commune of Tien Hai district (Fig. 1). The Upper Miocene sediments are unfinished in all of these three boreholes, their tops are situated from the depth of 268.3 m in LK51SH, 364 m in LK97SH and 369.6 m in LK102SH, so the segments from above-mentioned depths to bottom of respective boreholes are sampled. These borehole segments are mainly composed of gray fine-to-medium grained sandstone, intercalated with siltstone, claystone and brown coal (Fig. 2).

Figure 1. Borehole locations

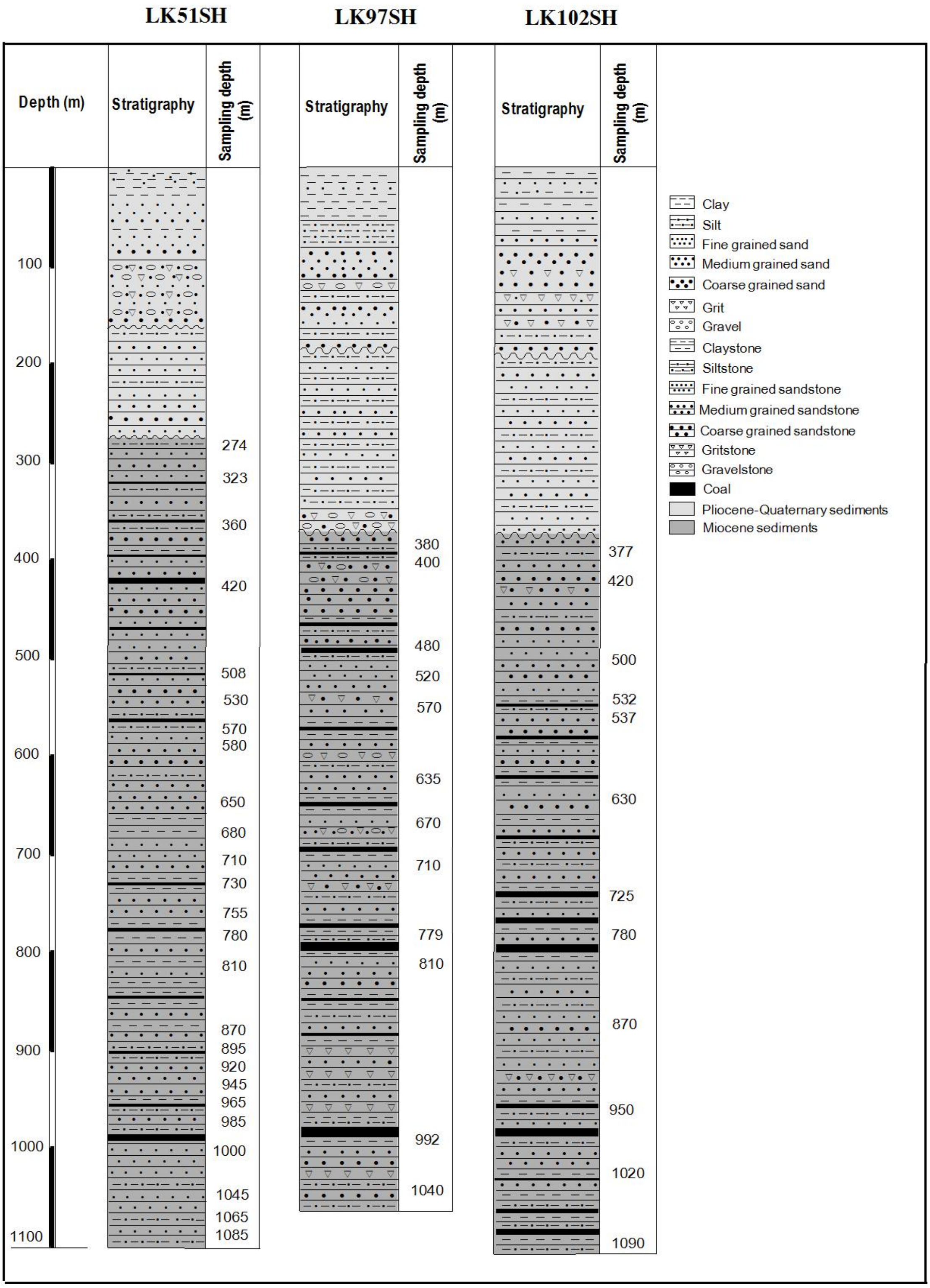


Figure 2. Stratigraphy in boreholes

3. Methods

Sampling is taken from the Upper Miocene sediments of Tien Hung formation in the following boreholes:

- LK51SH: 25 samples, depth from 274 m to 1085 m;
- LK97SH: 12 samples, depth from 380 m to 1040 m;
- LK102SH: 12 samples, depth from 377 m to 1090 m.

All of these samples are weakly consolidated, relatively friable and easily saggregated for granulometric analysis. Grain-size analysis is carried out by Horiba LA-960 laser scattering particle size distribution analyzer. This device can analyze grain size in the range from 10 nm (0.01 µm) to 5 mm (5,000 µm). Its built-in software helps to plot the grain-size distribution in form of both frequency and cumulative curves and to determine percentile values.

Based on grain-size distributions, the obtained statistic parameters are coarsest size (C) used at one percentile value, median size (M), graphic mean (M_Z), sorting or inclusive graphic standard deviation (σ_I), inclusive graphic skewness (SK_I) and graphic kurtosis (K_G). The M_Z, σ_I, SK_I and K_G values are calculated from grain size in phi unit Φ5, Φ16,, Φ25, Φ50, Φ75, Φ84 and Φ95 at 5%, 16%, 25%, 50%, 75%, 84% and 95%, respectively in the cumulative grain-size curve. Grain size Φ in φ unit is converted from size D in millimeter unit as follows: $\Phi = -\log_2 D$. Parameters M_Z, σ_I, SK_I and K_G are defined by Folk (1974) as follows:

Graphic Mean: $M_Z = (\Phi16+\Phi50+\Phi84)/3$

Sorting or Inclusive Graphic Standard Deviation - σ_I:

$$\sigma_I = \frac{\Phi84 - \Phi16}{4} + \frac{\Phi95 - \Phi5}{6.6}$$

σ_I classification: Very well sorted (<0.35φ); Well sorted (0.35–0.50φ); Moderately well sorted (0.5–0.71φ); Moderately sorted (0.71–1.0φ); Poorly sorted (1.0 – 2.0φ); Very poorly sorted (2.0 – 4.0φ); and Extreme poorly sorted (>4.0φ).

Inclusive Graphic Skewness - SK_I:

$$SK_I = \frac{\Phi16 + \Phi84 - 2\Phi50}{2(\Phi84 - \Phi16)} + \frac{\Phi5 + \Phi95 - 2\Phi50}{2(\Phi95 - \Phi5)}$$

SK_I classification: 1 to 0.3 - Strongly fine skewed; 0.3 to 0.1 - Fine skewed; 0.1 to -0.1 - Nearly symmetrical; -0.1 to -0.3 - Coarse skewed; -0.3 to -1.0 - Strongly coarse skewed.

Graphic Kurtosis – K_G:

$$K_G = \frac{\Phi95 - \Phi5}{2{,}44(\Phi75 - \Phi25)}$$

K_G classification: <0.67 - Very platykurtic; 0.67 to 0.90 - Platykurtic; 0.90 to 1.11 - Mesokurtic; 1.11 to 1.50 - Leptokurtic; 1.50 to 3.0 - Very leptokurtic; >3.0 - Extremely leptokurtic.

From the M_Z, σ_I, SK_I and K_G parameters, the bivariate plots expressing their pair relationships are used to determine the depositional environment of sediments as suggested by Friedman (1961), Moiola & Weiser (1968), Tanner (1991), Lario et al. (2002), Switzer et al. (2005), etc.

The discriminant functions taking into account of these four parameters, introduced by Sahu (1964) are applied for interpreting environments of sand sediments. Based on the assumption that the grain size distribution reflects the fluidity (viscosity) factor of the depositing medium and the energy factor of the environment (site) of deposition, Sahu (1964) quantitatively discriminated different depositional mechanisms and environments for coarse clastic sediments (gravels, sands, silts and their lithified equivalents) taken from different environments such as turbidity current, delta, floodplain, river channel, shallow marine (as deep as 90 m), littoral, aeolian flat, aeolian dune deposits. As a result of his study, 4 discriminant functions determining the different sedimentary environments are expressed as follows:

- $Y_1 = -3.6888M_Z + 3.7016\sigma_I^2 + 2.0766SK_I + 3.1135K_G$ to distinguish between aeolian process Y_1 <-2.7411 and littoral (intertidal zone) environments (Y_1 > -2.7411).

- $Y_2 = 16.6534M_Z + 65.7091\sigma_I^2 + 18.1071SK_I + 18.5043K_G$ for discrimination between beach (backshore) deposition (Y_2 <65.3650) and shallow agitated marine or subtidal environments (Y_2 >65.3650).

- $Y_3 = 0.2852M_Z - 8.7604\sigma_I^2 - 4.8932SK_I + 0.0482K_G$ for distinguishing shallow marine (Y_3 > -7.419) from fluvial or deltaic environments (Y_3 < -7.419).

- $Y_4 = 0.7215M_Z - 0.403\sigma_I^2 - 6.7322SK_I + 5.2927K_G$ for discriminating between environments influenced by river (Y_4 < 10.00) and turbidity (Y_4 > 10.00).

The CM pattern of Passega et al. (1964), plotting particle size of one percentile (C) versus value of median (M) in logarithmic scales, is also used to determine the modes of sedimentary transportation and deposition.

4. Results and discussions

4.1. Grain-size parameters

Graphic Mean grain size (MZ) is a function of (1) the size range of available materials and (2) amount of energy imparted to the sediment which depends on current velocity or turbulence of transporting medium (Folk, 1974). Normally coarse-grained sediments are deposited in high-energy conditions while the fine grains are associated with low energy. The MZ of Upper Miocene sediments in Hanoi depression ranges from coarse sand (-0.02ϕ) to clay (8.18ϕ), but most of the samples falling to sand and silt, except 2 clay samples LK51SH- 680 m depth and LK102SH- 725 m depth with MZ slightly over 8φ (Table 1). Generally, MZ in each borehole tends to decrease from older to younger with the rhythmic characteristics.

Sorting (σ_I) depends on at least four major factors: size range of the material supplied to the environment; type of deposition; current characteristics; and time - rate of supply of detritus compared with the efficiency of the sorting agent (Folk, 1974). For the study area, sediments are moderate to very poorly sorted. Most of samples (ca. 80%) are poorly sorted with σ_I value of 1φ - 2φ; the very poorly sorted samples (σ_I >2φ) accounts a significant part with 16%, belonging to the boreholes of LK51SH and LK102SH; there are only two moderately sorted samples (4%) of medium sand LK51SH at 965 m depth and LK97SH at 400 m depth. Sand samples have values of moderate to poor sorting whereas do silts and clays poor to very poor. The poor and very poor value indicates very little sorting in transportation and deposition of materials, probably due to strong disturbance, strong variability of energy or lack of stable unidirectional energy.

The inclusive graphic skewness (SKI) and the graphical kurtosis (KG) represent the closeness of grain-size distributions compared to the Gaussian normal distribution. The positive value of SKI exhibits the curve of grain-size distribution skewed toward finer grain and the negative value is for the coarser skewed curve. Sign of skewness is related to the environment energy. Negative skewness (coarse skewness) is correlated with high energy and winnowing action (removal of fines) and positive/fine skewness with low energy levels (accumulation of fines) (Friedman, 1961). Positive skewness of sediment probably indicates the unidirectional transport (channel) or the deposition of sediments in sheltered low energy (Ramanathan et al, 2009). Generally, dunes tend to be positively skewed and beaches are negatively skewed (Friedman, 1961), but this characteristic may be modified by the source of supply (Hayes, 1964). In the study area, SKI values range from -0.31 to 0.68. The majority is positive expressing the frequency distribution curve of grain size skewed to finer side. The results compared to classification of Folk (1974) show nearly 67% strongly fine skewed, 14% fine skewed, 12% nearly symmetrical, 4% coarse skewed with 2 samples of LK51SH-depth 780 m and LK97SH-depth 810 m, and only 2% strongly coarse skewed in the sample of LK51SH at 1045 m depth.

Table 1. Results of grain-size analysis

Borehole	Depth (m)	Grain size (φ)								Mz (φ)	σ_I (φ)	SK_I	K_G
		Φ1	Φ5	Φ16	Φ25	Φ50	Φ75	Φ84	Φ95				
LK 51 SH	274		-2.41	-0.81	0.34	1.15	2.06	2.91	4.11	1.09	1.92	-0.07	1.55
	323	-0.11	0.37	0.86	1.10	1.60	2.28	3.36	5.87	1.94	1.46	0.48	1.90
	360	4.69	5.36	6.29	6.76	7.76	9.12	9.87	11.18	7.97	1.78	0.17	1.01
	420	-1.06	-0.59	0.00	0.30	0.95	1.79	2.43	5.34	1.13	1.51	0.35	1.62
	508	3.23	4.10	4.67	4.94	5.83	8.48	8.85	9.46	6.45	1.86	0.40	0.62
	530	-0.69	-0.22	0.24	0.46	0.91	1.57	2.17	4.91	1.11	1.26	0.43	1.89
	570	2.35	2.98	3.65	3.99	4.80	7.02	8.25	8.97	5.57	2.06	0.45	0.81
	580	-0.26	0.20	0.69	0.93	1.48	2.22	2.96	5.87	1.71	1.43	0.43	1.81
	650	-1.08	-0.61	-0.02	0.32	1.09	1.86	2.20	3.26	1.09	1.14	0.06	1.03
	680	2.35	5.44	6.28	6.80	8.00	9.59	10.27	11.32	8.18	1.89	0.13	0.86
	710	-0.87	-0.40	0.19	0.51	1.25	1.96	2.29	3.32	1.24	1.09	0.05	1.05
	730	3.87	4.33	4.78	5.01	5.72	8.24	8.68	9.31	6.39	1.73	0.48	0.63
	755	-0.69	-0.22	0.20	0.40	0.84	1.46	1.98	4.04	1.01	1.09	0.39	1.64
	780	2.72	3.74	5.19	6.17	7.80	9.12	9.82	11.09	7.60	2.27	-0.12	1.02
	810	2.38	3.21	4.03	4.39	5.15	8.16	8.61	9.17	5.93	2.05	0.43	0.65
	870	-0.29	0.17	0.59	0.79	1.22	1.81	2.30	5.32	1.37	1.21	0.43	2.07
	895	2.36	3.04	3.77	4.12	4.88	7.80	8.56	9.21	5.74	2.13	0.47	0.69
	920	0.13	0.54	0.93	1.13	1.59	2.23	2.84	5.86	1.79	1.28	0.45	1.99
	945	2.36	3.12	3.99	4.39	5.19	7.97	8.52	9.15	5.90	2.04	0.39	0.69
	965	-0.22	0.20	0.57	0.75	1.14	1.64	1.93	3.62	1.22	0.86	0.30	1.57
	985	2.22	2.70	3.34	3.72	4.60	7.08	8.57	9.24	5.50	2.30	0.47	0.80
	1000	0.58	1.03	1.55	1.78	2.30	3.45	4.98	6.61	2.95	1.70	0.55	1.37
	1045	2.13	2.85	4.11	4.89	6.06	6.76	7.08	7.76	5.75	1.48	-0.31	1.07
	1065	2.93	4.16	4.74	5.02	6.03	8.59	8.92	9.50	6.56	1.85	0.34	0.61
	1085	2.82	3.74	4.35	4.63	5.26	8.29	8.70	9.23	6.10	1.92	0.51	0.61
LK 97 SH	380	3.45	4.01	4.52	4.76	5.37	7.97	8.49	9.11	6.13	1.76	0.52	0.65
	400	-1.17	-0.71	-0.26	-0.08	0.30	0.79	1.15	2.83	0.40	0.89	0.31	1.67
	480	0.36	0.81	1.24	1.43	1.81	2.26	4.01	5.07	2.35	1.34	0.56	2.12
	520	-0.22	0.25	0.75	0.97	1.46	2.04	2.44	4.39	1.55	1.05	0.29	1.58
	570	0.78	1.28	1.78	2.01	2.55	3.64	4.87	6.48	3.07	1.56	0.51	1.31
	635	0.27	0.71	1.24	1.50	2.04	2.79	3.48	5.71	2.26	1.32	0.38	1.59
	670	-0.30	0.13	0.54	0.73	1.22	1.99	2.59	5.05	1.45	1.26	0.45	1.61
	710	-0.62	-0.17	0.30	0.55	1.20	2.25	2.80	5.24	1.43	1.44	0.39	1.31
	779	0.50	0.96	1.53	1.82	2.57	4.02	5.40	6.69	3.16	1.84	0.45	1.07
	810		-1.35	-0.58	0.10	1.56	2.47	3.06	4.11	1.34	1.74	-0.12	0.94
	992	3.23	4.33	4.98	5.31	6.91	8.64	9.11	10.20	7.00	1.92	0.09	0.72
	1040	-0.03	0.44	0.96	1.20	1.71	2.38	3.10	6.19	1.92	1.41	0.43	1.99
LK 102 SH	377	-0.01	0.48	1.00	1.24	1.73	2.28	2.72	4.80	1.81	1.08	0.29	1.70
	420	-0.08	0.39	0.85	1.08	1.60	2.17	2.55	4.53	1.66	1.05	0.27	1.57
	500	-0.52	-0.07	0.43	0.66	1.23	2.06	2.54	4.66	1.40	1.24	0.34	1.39
	532	3.24	4.15	4.74	5.03	6.16	8.38	8.78	9.48	6.56	1.82	0.27	0.65
	537	2.10	2.57	3.09	3.35	4.02	5.60	6.19	6.92	4.43	1.43	0.37	0.79
	630	0.96	1.44	1.89	2.08	2.52	3.37	4.61	6.41	3.01	1.44	0.55	1.59
	725	4.04	5.08	6.16	6.75	8.00	9.48	10.06	10.99	8.07	1.87	0.03	0.89
	780	1.34	1.70	2.02	2.19	2.66	5.18	6.31	7.29	3.66	1.92	0.68	0.77
	870		-1.66	-1.43	-1.15	-0.26	1.06	1.64	3.56	-0.02	1.56	0.35	0.97
	950	3.34	4.18	4.75	5.04	6.32	8.64	9.02	9.69	6.70	1.90	0.24	0.63
	1020	2.36	3.42	4.39	4.76	5.76	8.76	9.10	9.66	6.42	2.12	0.33	0.64
	1090	2.74	3.67	4.78	5.20	7.02	8.76	9.30	10.40	7.03	2.15	0.01	0.77

The graphical kurtosis (KG) expresses the shape of the frequency curve of grain size with the relationship between the concentration level in the center and in the two tails. The extreme high or low value of kurtosis imply that a part of the sediment achieved its sorting elsewhere in a high energy environment (Friedman, 1962); variation in the kurtosis values is a reflection of the flow characteristics of the depositing medium (Ramanathan et al., 2009). KG values of Upper Miocene sediments range from 0.61 to 2.12 with 36.7% Very leptokurtic, 20.4% Platykurtic, 18.4% Very platykurtic, 16.3% Mesokurtic and 8%. Leptokurtic.

4.2. Depositional environments and bilateral relationship between grain size parameters

For the relationship between graphic mean (M_Z) and sorting (σ_I), most sediments of sand size are well to moderately sorted (Edwards, 2001) and the best sorting belongs to fine sands with size of 2–3φ (Griffiths, 1967; Folk, 1974; Tucker, 1990). Based on the correlation of mean and sorting, depositional environments of sediments are suggested by Mycielska-Dowgiałło and Ludwikowska-Kędzia (2011) as follows:

The increase of MZ accompanied with decrease σ_I characterize for the environments with high variability of transport energy such as for riverbed sediments. Phases of low-energy, during which the sorting of deposited materials takes place, alternate with brief phases of higher-energy transport which-when rapidly declining-result in the accumulation of coarse-grained materials, forming poorly sorted sediments.

- Decrease MZ coincided with σ_I decrease refers to media with prevalent sorting within the range of a coarser fraction (sand) and with a periodical supply of a poorly sorted finer fraction (silt) transported in suspension. Such depositional environments are usually found in aeolian deposits of hot deserts, floodplain deposits, fluvial channel lag deposits, and slope wash-out deposits without sorting in very rapid accumulation.

- Constant σ_I with variable MZ characterize for less dynamic environments with the small variation in energy as well as the low density of transporting media. This is usually found in aeolian deposits of temperate zones, deposits in stagnant water, e.g. in the oxbow lake.

- Constant MZ with variable σ_I is characteristic of wash-out deposits on the slope where rain splashing is the dominant process.

The MZ-σ_I relationship could be expressed by bivariate plots to determine the depositional environment (Tanner, 1991; Lario et al., 2002; Switzer et al., 2005). However in the study area, the MZ - σ_I plot proposed by Switzer et al. (2005) indicates unidentifiable for most of the samples and only seven samples (ca. 14%) belonging to sand sheet environment (Figure 3). These sand sheet sediments are sampled from two boreholes LK51SH and LK97SH, characterized by poorly-sorted medium sands with the graphic mean size of 1.09-1.34 φ and sorting of 1.09–1.92 φ. The logarithmic MZ - σ_I plot, suggested by Tanner (1991), Lario et al. (2002), for 48/49 samples, logarithm cannot be used for one rest because of negative value of very coarse sand (MZ = -0.02 φ) in sample of LK102SH-870 m depth (Table 1), shows 46% related to the river, 40% estuary, and 14% undetermined (Fig. 3). This MZ-σ_I plot clearly distinguishes river and estuary environments. Sediments in river are characterized by σ_I in 0.86–1.92 φ range and MZ in 1.22–5.75 φ; sediments in estuary are less sorted with narrower σI value in 1.76–2.3 φ and smaller size with MZ in 5.57–8.18 φ; notably, there is a relatively clear threshold in graphical mean size at about 5 φ, most of the fluvial sediments are below this value and the estuarine sediments are in contrary.

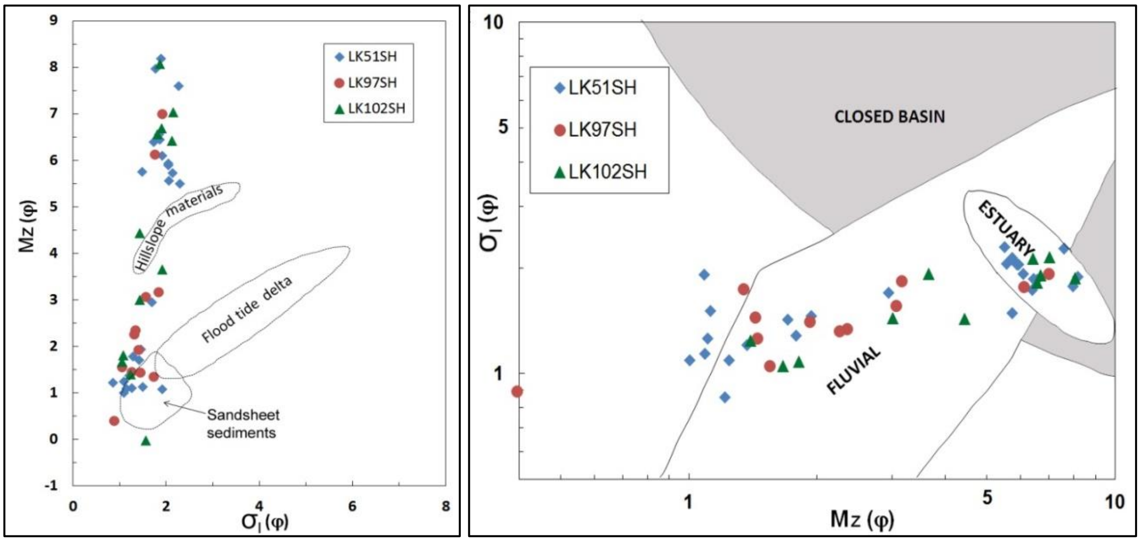


Figure 3. Graphic mean (M_Z) versus Sorting (σ_I) plots.
Environments based on Switzer et al. (2005) (left); based on Tanner (1991), Lario et al. (2002) (right)

For the SKI - σI relationship, in relatively fine-grained unimodal sediments, beach sands are well sorted and negatively skewed while river sands are less well sorted and usually positively skewed, dune sand typically has positive skewness but is finer grained than beach sand (Tucker, 1990). For the study area, the environmental determination by SKI - σI plots of Tanner (1991) and Lario et al. (2002) indicates all of the samples in the river environment, none in a beach environment (Fig. 4).

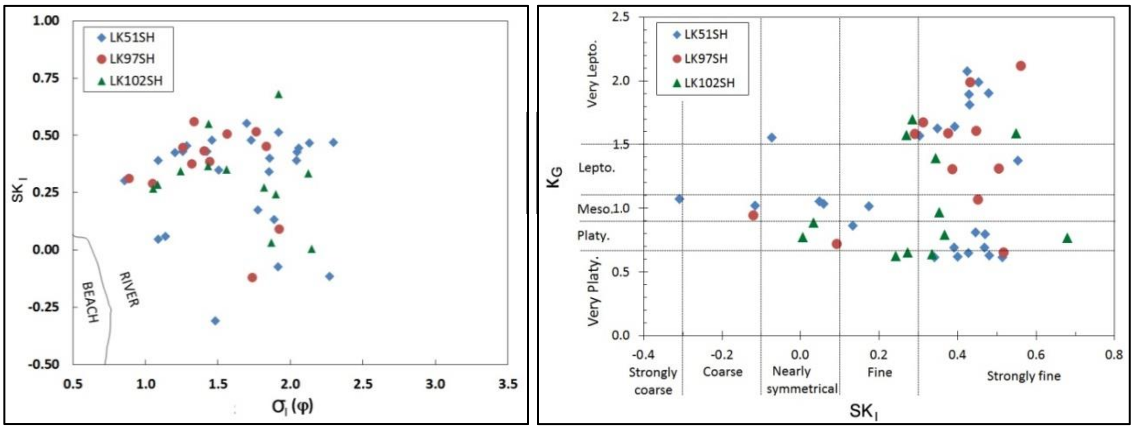


Figure 4. Inclusive graphic skewness (SK_I) - Sorting (σ_I) and Inclusive graphic Skewness (SK_I) - Graphic Kurtosis (K_G) plots Enviroments based on Tanner (1991), Lario et al. (2002)

In term of KG - SKI relation, most sands are leptokurtic either negatively or positively skewed probably because they consist of two population, one predominant and the other very subordinate, coarse (leading to negative skewness) or fine (leading to positive skewness) (Friedman, 1961). In the case of Mutstang Island, beaches give nearly normal curves, dunes are positively-skewed mesokuric, and aeolian flats are positively-skewed leptokurtic (Mason and Folk, 1958). Fluvial environments consisting mainly of traction load (coarse grains) with some infiltrated suspension load (finer grains) are commonly positively-skewed leptokurtic (Folk, 1974). For the study area, grain size analysis of 49 samples shows (Fig. 4):

- 3 (6%) mesokurtic and negatively skewed samples;
- 1 (2%) very leptokurtic and slightly negatively skewed;
- 4 (8%) leptokurtic, positively skewed;
- 5 (10%) mesokurtic and positively skewed;
- 10 (21%) platykurtic and positively skewed;
- 17 (35%) very leptokurtic and positively skewed;
- 9 (18%) very platykurtic and positively skewed.

Thus, most of the analyzed samples have grain-size distribution in very leptokurtic, platykurtic, very platykurtic and positively skewed forms. For the sand samples, quite consistent with Friedman (1961), most them belong to mesokurtic, leptokurtic and very leptokurtic, there are only two of platykurtic and none of very platykurtic. In contrary, the silt and clay samples are mainly found in platykurtic and very platykurtic forms with positive skewness. In the study area, the SKI - KG plot, suggested by Tanner (1991) and Lario et al. (2002), cannot determine the depositional environments.

4.3. Depositional Environments of sands determined by discriminant functions

The discriminant functions proposed by Sahu (1964) are used for deciphering deposition environments in many places of the world (Rajganapathiet al, 2012; Rashedi and Siad, 2016; Maity and Maiti developed, 2016). For the study area, all of 28 sand samples taken from three boreholes, namely LK51SH, LK97SH and LK102SH, are analyzed by using these discriminant functions. The grain-size statistics of these sand samples are summarized as follows:

- 93% samples are poorly sorted; only 7%, 2 samples at 400 m depth of LK97SH and 965 m depth of LK51SH, are moderately sorted.
- 93% samples are positively skewed, indicating a dominance of skewness to fine grains, detailedly 72% strongly fine skewed, 10% fine skewed, 14% nearly symmetrical and only 3% (1 sample) coarse skewed.
- Most of the sand samples (62%) are very leptokurtic. The leptokurtic and mesokurtic samples take nearly 14% and 17%, respectively. There are only two samples (7%), at 240 m depth LK51SH and 780 m depth of LK102SH belong to platykurtic.

Based on method of Sahu (1964), Y_1, Y_2, Y_3 values show all of the samples may belong to littoral (intertidal zone) environment ($Y_1 > -2.7411$); environment of agitated shallow water ($Y_2 > 65.3650$); fluvial or deltaic environment ($Y_3 < -7.419$) (Fig. 5). Y_4 calculation presents that most of samples (83%) are affected by turbidity ($Y_4 > 10$) and only 14% samples are controlled by river ($Y_4 < 10$) (Fig. 5). Thus, the analysis of discriminant functions for sand sediments suggests that they are formed in deltaic environment of agitated shallow water, affected greatly by turbidity current and some by river.

4.4. Mechanism of sediment transport determined by CM pattern

- SR: uniform suspension
- RQ : graded suspension, no rolling
- QP: suspension and rolling.
- PO: rolling and suspension
- ON: rolling.

Recently, the CM pattern has been popularly used in South Asia (Rajganapathi et al., 2012; Balamurugan et al., 2014; Kulkarnia et al., 2015, Maity and Maiti, 2016; Bhattacharya et al., 2016), where the natural conditions, especially the climate, are similar to Vietnam. For the study area, the samples, analyzed by CM pattern (Fig. 6), mainly fall into two groups: the first with a median size of 15-40 µm and one percentile value of 90 - 230 µm; the second having a median value of 160-560 µm and one percentile of the diameter of 500-2000 µm. These sediments fall into NO, PQ and RS segments, suggesting that they are mainly transported in three modes: 1- rolling, 2- suspension and rolling and 3- uniform suspension.

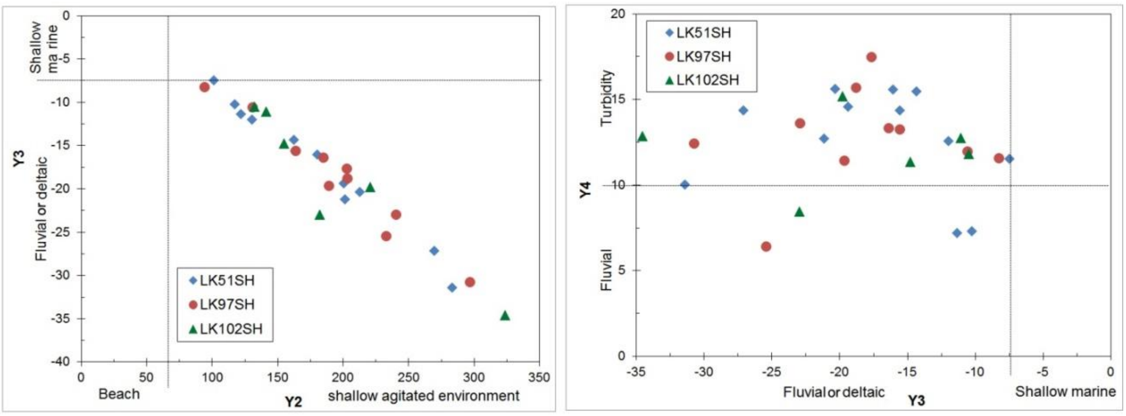


Figure 5. Analysis of the Y2, Y3 and Y4 discriminant functions for sand samples

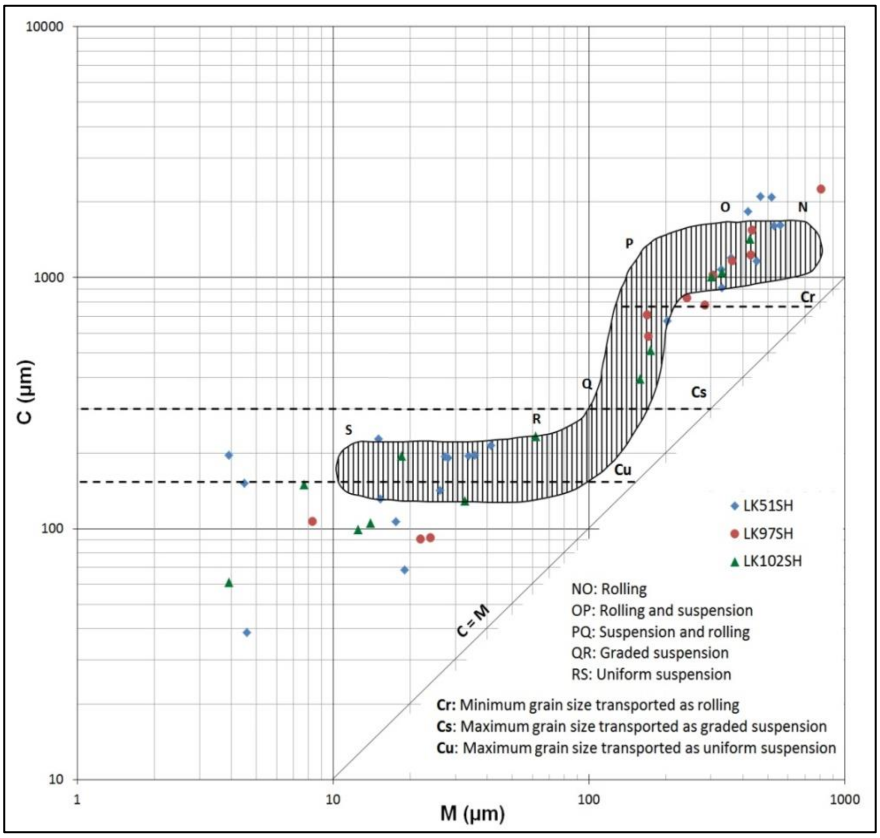


Figure 6. CM pattern for sediment samples in the study area

4.5. Evaluation of analysis results

Environments of sampled sediments are interpreted as sand sheets by MZ-σI plot of Switzer et al. (2005); river and estuary by logarithmic MZ-σI plot of Tanner (1991), Lario et al. (2002); river by SKI-σI plot of Tanner (1991) and Lario et al. (2002); Delta in agitated shallow water, affected by turbidity or river by discriminant functions of Sahu (1964) (Table 2). Summarizing the above interpretations, sediments in the study area are deposited deltaic environment of shallow water.

Previous studies (Tong Duy Thanh et al., 2005) suggest that upper Miocene sediments in this area belonging to Tien Hung Formation are deposited in environments of the delta, intercalated with marine littoral phases and submerged delta developing towards the Tonkin Gulf. The sediments are rich in pollens of *Dacrydium* sp., *Quercus* sp., *Ilex* sp., *Castanea* sp., *Pinus* sp., *Liquidambar* sp., *Tsuga* sp., *Florschuetzia trilobata*, *Fl. levipoli*, Leguminosea, Euphorbiacea, *Carya* sp., *Alnus* sp. and spores of *Cyathea* sp., *Magnastriatites howardi*, *Acrostichum* sp., *Gleichenia* sp., *Stenochlaena* sp., belonging to Assemblage *Dacrdium complex - Ilex - Quercus - Fl. trilobata*. Foraminifera are poor, scattered in depth of 622-664 m of Tien Hai borehole 6, mainly including *Pseudorotalia papuanensis, Ps. gaimardi, Ps. schroeteriana*, and few of *Globigerinoides trilobus, Gl. immaturus*, *Quinqueloculina* sp., *Elphildium* sp., *Textularia* sp., *Ammonia* sp., etc. belonging to the Assemblage *Pseudorotalia - Asterorotalia*.

Thus, the interpretations of depositional environments resulted from grain size analyses are relatively consistent with previous studies. In more detail, the paleontological analyses in the same three boreholes mainly encounter pollen and spores. Foraminifera are also found at 392 m and 650 m depth of LK51SH, 654 m depth of LK97SH, 377 m depth of LK102SH but very poor in species composition. Palynologicaly in the majority of the sample, the Angiosperm takes a large percentage in composition, mangrove accounts for 20-30% and marsh-related species intermittently occur in boreholes, indicating the environment of tidal flat, marsh, coastal river-mouth, matching with grain-size analyses.

The identified Foraminifera are poor in quantity and species composition, but most of them are benthic species such as *Ammonia* sp., *A. beccarii*, *A. tepida*, *Cibicides* sp., *Globorotalia* sp., indicating neritic environment with low water- depth.

At the depth of 392 m in borehole LK51SH, in addition to few neritic foraminifera such as *Ammonia beccarii, A. tepida*, some pollen and spores are also present. Though no grain-size analysis is carried out, this paleontological result may suggest an environment of coastal river-mouth influenced by river, sea and turbidity, which is similar to the results of grain-size analyses at upper depth (360 m) and lower depth (420 m) of the same borehole (Table 2).

For the sample LK51SH – 650 m depth, paleontological analysis is carried out only for Foraminifera, not for pollen and spore, the identified species are Ammonia beccarii, Ammonia tepida and Ammonia sp., indicating a neritic environment. The grain-size analysis shows a sand-sheet environment in the agitated shallow-water delta, impacted by the river (Table 2). Thus, the environment may be neritic marine or shallow water delta where sediments containing neritic foraminifera are brought by special events such as extreme storms or tsunamis similar to suggestion of Switer et al. (2005) on sand sheets in southeastern New South Wale, Australia? This issue needs further research.

In borehole LK97SH at 654 m depth, it is found only 6 individuals, belonging to 2 genera of Ammonia and Cibicides, typical for the neritic marine environment. Furthermore, pollen and spores are abundant. Therefore the environment here could also be estuary or agitated shallow-water delta impacted by river, sea, and turbidity, similar to the results of grain-size analyses at upper depth (635 m) and lower depth (670 m) of the same borehole (Table 2).

Table 2. Depositional environments interpreted by grain size analyses

Boreholes	Depth (m)	Interpretation based on Tanner (1991), Lario et al. (2002)		Interpretation based on Switzer et al., 2005	Interpretation based on Sahu (1964)
		$M_Z - \sigma_I$	$SK_I - \sigma_I$		
LK51SH	274	-	River	Sand sheet	DASW affected by turbidity current
	323	River	River	-	DASW affected by turbidity current
	360	Estuary	River	-	
	420	-	River	Sand sheet	DASW affected by turbidity current
	508	Estuary	River		
	530	-	River	Sand sheet	DASW affected by turbidity current
	570	Estuary	River	-	
	580	River	River	-	DASW affected by turbidity current
	650	-	River	Sand sheet	DASW affected by river
	680	Estuary	River	-	
	710	River	River	-	DASW affected by river
	730	Estuary	River	-	
	755	-	River	Sand sheet	DASW affected by turbidity current
	780	Estuary	River	-	
	810	Estuary	River	-	
	870	River	River	-	DASW affected by turbidity current
	895	Estuary	River	-	
	920	River	River	-	DASW affected by turbidity current
	945	Estuary	River	-	
	965	River	River	-	DASW affected by turbidity current
	985	Estuary	River	-	
	1000	River	River	-	DASW affected by turbidity current
	1045	River	River	-	
	1065	Estuary	River	-	
	1085	Estuary	River	-	
LK97SH	380	Estuary	River	-	
	400	-	River	-	DASW affected by turbidity current
	480	River	River	-	DASW affected by turbidity current
	520	River	River	-	DASW affected by turbidity current
	570	River	River	-	DASW affected by turbidity current
	635	River	River	-	DASW affected by turbidity current
	670	River	River	-	DASW affected by turbidity current
	710	River	River	Sand sheet	DASW affected by turbidity current
	779	River	River	-	DASW affected by turbidity current
	810	-	River	Sand sheet	DASW affected by river
	992	Estuary	River	-	
	1040	River	River	-	DASW affected by turbidity current
LK102SH	377	River	River	-	DASW affected by turbidity current
	420	River	River	-	DASW affected by turbidity current
	500	River	River	-	DASW affected by turbidity current
	532	Estuary	River	-	
	537	River	River	-	
	630	River	River	-	DASW affected by turbidity current
	725	Estuary	River	-	
	780	River	River	-	DASW affected by turbidity current
	870		River	-	DASW affected by river
	950	Estuary	River	-	
	1020	Estuary	River	-	
	1090	Estuary	River	-	

Note: “DASW”: Delta in Agitated Shallow Water; “-“ : undetermined

In LK102SH at 377 m depth, there are 6 individuals of 3 genera, including Globorotalia sp., Ammonia beccarii, Ammonia sp., Cibicides sp. adapting neritic environment with low water-depth. Though no palynological analysis is done, the interpretation from grain-size parameters shows an environment of the agitated shallow-water delta, affected by turbidity. So is it possible that these shallow marine sediments are brought to the delta environment? This issue needs further research. In brief for the study area, the results interpreting depositional environment from grain-size analyses are relatively consistent with the previous general studies and preliminary paleontological analyses of the same boreholes.

5. Conclusions

Grain-size analysis of Upper Miocene sediments in the Hanoi depression shows a range of coarse sand to clay, but from fine sand to silt in the majority, for graphics mean grain size (MZ) of all samples. The mean grain size tends to decrease from older to younger with rhythmic characteristic reflecting the gradual change of depositional environment from inland to coastal river-mouth and neritic element. These samples are moderate to very poorly sorted with over 90% of poor and very poor sorting. Silt and clay are poorly or very poorly sorted. The poor value indicates very little sorting in transportation and deposition of materials, probably due to strong disturbance, strong variability of energy or lack of stable unidirectional energy.

The inclusive graphic skewness (SKI) ranges from -0.31 to +0.68 and the graphic kurtosis (KG) values ranging from 0.61 to 2.12 reflect the intercalation of the river and tidal flat environments.

Plotting the sorting versus graphics mean size shows about 14% samples originated from the said sheet, 46% related to rivers and 40% belongs to the estuarine environment. The sorting-inclusive graphic skewness plot shows a river-related environment for all samples.

The analysis of discriminant functions, based on grain size parameters of sand samples with 93% poor and 7% moderate sorting, suggests the deltaic environment with unstable transportation and deposition impacted by a turbidity current in the coastal river-mouth. The CM pattern shows sediment transportation for most of the samples in 3 modes: rolling, suspension and rolling, and uniform suspension. In all analyzed boreholes, the samples, located in transporting areas of these three modes methods, shows that the environmental dynamics are relatively complex and change over time. The grain-size parameters are grounded for interpreting environments of sediment transportation and deposition the study area. However, the grain size of sediments depends not only on the depositional environment but also on the rock and weathering characteristics of provenance, the distance from the source to the deposition site. Therefore, for more accurate interpretation, in addition to the grain size analysis, the other methods should be required.

Acknowledgements

This work was supported by the Vietnam Academy of Science and Technology (Projects VAST05.04/17-18 and QTPL01.02/18-19). Samples were taken from boreholes, drilled by the International Geological Division under Permission of the General Department of Geology and Minerals of Vietnam.

References

Balamurugan P., Vasudevan S., Selvaganapathi R., Nishikanth C.V., 2014. Spatial Distribution of Grain Size Characteristics and its Role in Interpreting the

Sedimentary Depositional Environment, Kodaikanal Lake, Tamil Nadu, India. J. Earth Sci. Clim. Change, 5, 217. Doi:10.4172/2157-7617.1000217.

Bhattacharya R.K., Chatterjee N.D., Dolui G., 2016 Grain size characterization of instream sand deposition in controlled environment in river Kangsabati West Bengal. Model. Earth Syst. Environ, 2, 118. Doi 10.1007/s40808-016-0173-z.

Do Bat, Phan Huy Quynh, 1983. Stratigraphy and stratigraphical corelation of Tertiary sediments in Hanoi depression. Vietnam Petroleum Institute (in Vietnamse).

Florek W., Mycielska-Dowgiałło E., Starkel L., 1990. Lithology and facies of fluvial deposits. [In:] L. Starkel (Ed): Evolution of the Vistula River valley during the last 15 000 years, Part III. Geographical Studies Special (Ossolineum, Wrocław), 5, 111–126.

Folk R.L., 1974. Petrology of sedimentary rocks, Hemphil, Austin, TX, 159 p.

Friedman G.M., 1961. Distinction between dune, beach and river sands from their textural characteristics . Journal of Sedimentary Petrology, 31(4), 514–529.

Friedman G.M., 1962. On sorting coefficient and log normality of the grain size distribution of sandstones. J. Geol., 70, 737–753.

Fyhn M.B.W., P.V. Phach, 2015. Late Neogene structural inversion around the northern Gulf of Tonkin, Vietnam: Effects from right-lateral displacement across the Red River fault zone, Tectonics, 33, 1–24. Doi: 10.1002/2014TC0036.

Golovenok V.K., Le Van Chan, 1966. Sediments and forming conditions of Neogene-Quaternary sediments in Hanoi depression. Vietnam Petroleum Institute (in Russian).

Griffiths L.C., 1967. Scientific methods in the analysis of sediments. New York: MCGraw-Hill, 508 p.

Hayes M.O., 1964. Grain size modes in Padre Island sands, in Depositional environments, south-central Texas coast: Gulf Coast Assoc. Geol. Socs., Ann. Mtg.,1964. Field trip Guidebook, Austin, Tex., 121–126.

Kulkarnia S.J., Deshbhandaria P.G., Jayappa K.S., 2015. Seasonal Variation in Textural Characteristics and Sedimentary Environments of Beach Sediments, Karnataka Coast, India. Aquatic Procedia, 4, 117–124.

Lario J., Spencer C., Plater A.J., Zazo C., Goy J.L., Dabrio C.J., 2002. Particle size characterisation of Holocene back-barrier sequences from North Atlantic coasts (SW Spain and SE England). Geomorphology, 42, 25–42.

Lee T.Y., Lawver L.A., 1994. Cenozoic plate reconstruction of the South China Sea region. Tectonophysics, 235, 149–180.

Leloup P. H., R. Lacassin, P. Tapponnier, U. Schärer, Z. Dalai, L. Xiaohan, Z. Liangshang, J. Shaocheng and P. T. Trinh, 1995. The Ailao Shan-Red River shear zone (Yunnan China), Tertiary transform boundary of Indochina, Tectonophysics, 25, 3–84.

Li C.-F., J. Li, W. Ding, D. Franke, Y. Yao, H. Shi, X. Pang, Y. Cao, J. Lin, D.K. Kulhanek, T. Williams, R. Bao, A. Briais, E.A. Brown, Y. Chen, P.D. Clift, F. S. Colwell, K. A. Dadd, I. n. Hernández-Almeida, X.-L. Huang, S. Hyun, T. Jiang, A.A.P. Koppers, Q. Li, C. Liu, Q. Liu, Z. Liu, R.H. Nagai, A. Peleo-Alampay, X. Su, Z. Sun, M.L.G. Tejada, H.S. Trinh, Y.-C. Yeh, C. Zhang, F. Zhang, G.-L. Zhang, X. Zhao, 2015. Seismic stratigraphy of the central South China Sea basin and implications for neotectonics. Journal of Geophysical Research.

Maity K.S., Maiti R., 2016. Analysis of sedimentation in connection to grain size and shear stress at lower reach of the Rupnarayan river, West Bengal, India. Indian Jour. of Geo-marine, Sci., 45(9), 1128–1137.

Mason C.C., Folk R.L., 1958. Differentiation of beach, dune and aeolian flat environments by size analysis, Mustang Island, Texas. J. Sediment. Petrol., 28, 211–226.

Moiola R.J., Weiser D., 1968. Textural parameters: an evaluation. J. Sediment. Petrol., 38(1), 45-53.

Mycielska-Dowgiałło E., Ludwikowska-Kędzia M., 2011. Alternative interpretations of grain-size data from Quaternary deposits. Geologos, 17(4), 189–203.

Nguyen Dich Dy, 1987. Stratigraphy and paleogeography of the Cenozoic sediments of Vietnam. PhD Thesis. Kharkov Univ, 380 p. (in Russian).

Nguyen Manh Huyen, Ho Dac Hoai, 2007. Red river sediment basin and petroleum resources . In Nguyen Hiep (ed), Geology and petroleum resources. Scie. and Tech. Publ., 187–240 (in Vietnamese).

Nielsen A., Mathiesen T., Bidstrup O.V., Vejbaek P.T., P.T. Dien, P.V. Tiem, 1999. Modelling the hydrocarbon generation in the cainozoic Song Hong basin, Vietnam: a highly prospective basin. Journal of Asian Earth Sciences, 17, 269–294.

Passega R., Byramjee R., 1969. Grain-size image of clastic deposits. Sedimentology, 13, 233–252.

Passega R., 1964. Grain size representation by CM patterns as a geological tool. Journal of Sedimentary Petrology, 34(4), 830–847.

Phan Trong Trinh, 2012. Recent tectonic and geodynamics in Vietnamese waters and adjacent areas. Natural Scie. and Tech., Publ., Hanoi, 331p. (in Vietnamese).

Phan Trong Trinh, Hoang Quang Vinh, Leloup H., Julian G., Garnier V., Tapponnier P., 2004. Cenozoic deformation, thermodynamic evolution of Song Hong fault zone and ruby formation in Cenozoic. In: Song Hong fault zone, geodynamic, metallogeny and natural hazards. Sci. and Tech. Publ., Hanoi, 5–74 (in Vietnamese).

Rajganapathi V.C., Jitheshkumar N., Sundararajan M., Bhat K.H., Velusamy S., 2012. Grain size analysis and characterization of sedimentary environment along Thiruchendur coast, Tamilnadu, India. Arab Jour. Geosci. Doi 10.1007/s12517-012-0709-0.

Ramanathan A.L., Rajkumar K., Majumdar J., Singh G., Behra P.N. Santra S.C., Chidambaram S., 2009. Textural characteristics of the surface sediments of a tropical mangrove sundarban ecosystem, India. Indian Jour. of Mar. Sci., 38 (4), 397–403.

Rangin C., Klein M., Roques D., Le Pichon X., Trong L.V. 1995. The Red River fault system in the Tonkin Gulf, Vietnam. Tectonophysics, 243, 209–222.

Rashedi S. A., Siad A., 2016. Grain size analysis and depositional environment for beach sediments along Abu Dhabi coast, United Arab Emirates. International Journal of Scientific & Technology Research, 5(7), 106–115.

Replumaz A., Lacassin R., Leloup P.H., 2001. Large river offset and Plio-Quaternary dextral slip rate on the Red River fault (Yunnan, China), J. Geophys. Res., 106, 819–836. Doi:10.1029/2000JB900135.

Rizzetto F., Mycielska-Dowgiałło E., Castiglioni G.B., 1998. Some aeolian features in the Po plain near Este (North Italy). Geografa Fisica e Dinamica Quaternaria, 21, 245–253.

Ruz M.H., Allard M., 1995. Sedimentary structures of cold-climatic dunes. Eastern Hudson Bay, Canada. Sedimentology, 42, 725–734.

Sahu B.K., 1964. Depositional mechanisms from the size analysis of clastic sediments. Journal of Sedimentary Research, 34(1), 73–83.

Sarre R.D., Chancey C.C., 1990. Size segregation during aeolian saltation and sand dunes. Sedimentology, 37, 357–365.

Schoenbohm L.M., Burchfiel B.C., Liangzhong C., Jiyun Y., 2005. Exhumation of the Ailao Shan shear zone recorded by Cenozoic sedimentary rocks, Yunnan Province, China, Tectonics, 24, TC6015. Doi:10.1029/2005TC001803.

Schoenbohm L.M., Burchfiel B.C., Liangzhong C., Jiyun Y., 2006. Miocene to present activity along the Red River fault, China, in the context of continental extrusion, upper-crustal rotation, and lower-crustal flow, Geol. Soc. Am. Bull., 118, 672–688. Doi:10.1130/B25816.1.

Starkel L., Klimek K., Mamakowa K., Niedziałkowska E., 1982. The Wisłoka river valley in the Carpathian Foreland during the Late Glacial and the Holocene. Geographica Studia Special, 1, 41–56.

Switzer A.D., Pucillo K., Haredy R.A., Jones B.G., Bryant E.A., 2005. Sea level, storm, or tsunami: Enigmatic sand sheet deposits in a sheltered coastal embayment from southeastern New South Wales, Australia. Journal of Coastal Research, 21(4), 655–663.

Tanner W.F., 1991. Suite statistics: the hydrodynamic evolution of the sediment pool. In: Syvitski, J.P.M. (Ed.), Principles, Methods and Applications of Particle Size Analysis. Cambridge University Press, Cambridge, UK, 225–236.

Tapponnier P., Lacassin R., Leloup P.H., Schärer U., Zhong D., Wu H., Liu X., Ji S., Zhnag L., Zhong J., 1990. The Ailao Shan-Red River metamorphic belt: tertiary left-lateral shear between Sundaland and South China. Nature, 343, 431–437.

Tong Dzuy Thanh, Dang Vu Khuc, Dang Tran Huyen, Doan Nhat Truong, Do Bat, Nguyen Dich Dy, Nguyen Huu Hung, Pham Huy Thong, Pham Kim

Ngan, Ta Hoa Phuong, Tran Huu Dan, Tran Van Thang, Tran Van Tri, Trinh Van Long, 2005. Stratigraphic units of Vietnam. Hanoi National Univ. Publ., 504 p (in Vietnamese).

Tran Nghi, 1991. Evaluation of quality of the reservoir rock of the deep horizon of Ha Noi Depression on the basis of lithophysics. Proc. 2nd Conf. Geol. Indochina, Hanoi, 219–230.

Tran Nghi, Tran Huu Than, 1986. History of evolution of Neogene sediment in Hanoi depression on the basis of quantitative lithology. Geol., 174–175, Hanoi, 19–23 (in Vietnamese).

Tran Nghi, Tran Huu Than, Nguyen Thanh Lan, Dinh Xuan Thanh, Dam Quang Minh, Tran Thi Thanh Nhan, Pham Nguyen Ha Vu, 2004. Developing stages of Cenozoic sedimentary of Red River basin in relation to Geodynamic activities**.** J. Sci. of the Earth, 26(3), 193–201 (in Vietnamese).

Trask P.D., 1930. Mechanical analyses of sediments by centrifuge. Economic Geology, 25(6), 581–599.

Trinh P.T., N.V. Liem, N.V. Huong, H.Q. Vinh, B.V. Thom, B.T. Thao, M.T. Tan, N. Hoang, 2012. Late Quaternary tectonics and seismitectonics along the Red River fault zone, North Vietnam. Earth Sci. Rev., 114, 224–235. Doi:10.1016/j.earscirev.2012.06.008.

Tucker M., 1990. Techniques in sedimentology. Blackwell Scietific Publications, 63–86.