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Application of Dispersion and Regression Analysis for Studying the Relationships of Some Components of Upper Pliocene Sediments of the Indian Ocean

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Abstract—The variance and regression analyses were applied to study the distribution and relationships between organic carbon, calcium carbonate, abiogenic matter, biogenic silica, and their accumulation depth in the upper Pliocene sediments in different structural zones of the Indian Ocean. Analysis of variance allowed us to quantify the influence of diverse facies settings on the distribution of sedimentation components. For the first time, linear and nonlinear regression models of the relationships between organic carbon, calcium carbonate, abiogenic matter, biogenic silica, and the their accumulation depth are presented.

Keywords: bottom sediments, Indian Ocean, Upper Pliocene, organic carbon, calcium carbonate, abiogenic matter, analysis of variance, regression analysis

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INTRODUCTION

One of the widest spread methods of study of bottom sediments and suspended particulate matter of modern seas and oceans is the determination of their component composition, in particular, analysis of abiogenic (lithogenic) mater (AM), $CaCO_3$, SiO_2 biog., and C_{org}. Obtained results are expressed in weight percents or in absolute masses expressed in (g/cm^2) ka. The studies traditionally involve the determination of the components and their relationships, for instance, with primary production, bottom depth, and matter fluxes on the floor, and others (Lisitsyn et al., 1974, 1978; Levitan, 1992; van Andel et al., 1975; Farrell et al., 1995).

The study of relationship of sediment-forming components with each other and with main facies factors of sedimentation environment highlights an increasing need in their complex analysis. The development of numerical modeling provoked numerous publications on multiple correlation of results of component analysis (Costa et al., 2018).

In this work, the analysis of variance and regression analyses were applied to the component analysis of Upper Pliocene sediments from the DSDP cores in the Indian Ocean.

FACTUAL ANALYSIS AND ANALYTICAL METHODS

This paper is based on data obtained during DSDP cruises nos. 22–27 in the Indian Ocean (von der Borch et al., 1974; Whitmarsh et al., 1974; Fisher et al., 1974; Simpson et al., 1974; Davies et al., 1974; Veevers et al., 1974). The contents and mass accumulation rates of the above mentioned components in the Late Pliocene sediments (Table 1) were calculated in (Levitan et al., 2018a, 2018b, 2018c) using data on cores presented in the aforementioned reports on deep-water drilling. In this region (Fig. 1, Table 1), 18 landforms of the Indian ocean floor were studied based on 26 deep-water holes.

It is pertinent to mention that $CaCO_3$ and C_{org} were determined using LECO analyzer during cruises and are expressed in weight percents. The indicated contents of SiO_2 biog. in % were calculated by counting the areas occupied by siliceous organisms (mainly diatoms and radiolarian, with less common silicoflagellates and sponge spicules) in thin sections (smear slides). Special studies showed that starting from 30% the SiO_2 biog. content determined under microscope is approximately 20% higher than the true content of this component determined with chemical analysis (Uliana et al., 2001). The content of abiogenic matter equals the difference between 100% and total $CaCO_3$, SiO_2 biog. and C_{org} in percents. Contents and mass accumulation rates of SiO_2 biog. shown in Table 1 are reported for the first time.

Mass accumulation rates were calculated using data on stratigraphy, humidity, and density of natural sediments and the rate of their sedimentation presented in reports.

Table 1. The average contents (%) and mass accumulation rates (mar, g/cm^2 thou years) of calcium carbonate ($CaCO_3$), biogenic silica (SiO_2 biog.), abiogenic matter (AM), and organic carbon (C_{org}) in the Upper Pliocene sediments of different structures of the Indian Ocean

Structures	Hole, No.	Hole coordinates latitude/longitude	Structure type*	C_{org}, %	C_{org} (mar)	$CaCO_3$, %	$CaCO_3$ (mar)	AM, %	AM (mar)	SiO_2 biog., %	SiO_2 biog. (mar × 100)	Depth, m
Wharton Basin	211	09°46.53′ S l02°41.95′ E	1	0.2	0.00174	1	0.009	39	0.3391	60	52.14	5528
Ninety East Ridge	217	08°55.57′ N 90°32.33′ E	2	0.2	0.00211	62	0.66	38	0.4013	0.01	0.01	3030
Chagos–Lakkadive Ridge	219	9°01.75′ N 72°52.Ó7′ E	2	0.01	0.0001	63	0.69	37	0.4078	0.01	0.011	1764
Arabian Basin	222	20°05.49′ N 61°30.56′ E	1	0.3	0.0872	14	4.07	86	25	0.01	0.29	3546
Continental slope of the Somali Ocean	223	18°44.98′ N 60°07.78′ E	3	2.2	0.0268	21	0.26	72	0.8775	4.8	5.85	3633
Gulf of Aden	232	14°28.93′ S 51°54.87′ E	3	0.6	0.0376	22	1.38	76	3.7571	2	12.52	1743
Gulf of Aden	233	14°19.68′ N 52°08.1l′ E	3	2.1	0.2578	43	5.28	49	6.0152	5.9	72.43	1839
Somali Basin	235	03°14.06′ N 52°41.64′ E	1	0.5	0.0286	53	3.03	42	2.4033	5	28.61	5130
Central Indian Ridge	238	ll°09.2l′ S 70°31.56′ E	2	0.1	0.0001	93	3.59	2	0.0773	5	19.32	2832
Mascarene Basin	239	21°17.67′ S 51°40.73′ E	1	0.1	0.000441	12	0.05	88	0.3881	0.01	0.004	4971
Continental slope of Somali	241	02°22.24′ S 44°40.77′ E	3	0.3	0.00918	54	1.65	44	1.3464	2	6.12	4054
Davi Ridge	242	15°50.65′ S 41°49.23′ E	2	0.2	0.01389	55	3.82	45	3.1248	0.01	0.069	2275
Mozambique Basin	248	29°31.78′ S 37°28.48′ E	1	0.4	0.021427	19	1.02	81	4.339	0.01	0.054	4994
Mozambique Basin	250	33°27.74′ S 39°22.15′ E	1	0.5	0.01797	5	0.18	94	3.3791	1	3.594	5119

Table 1. (Contd.)

Structures	Hole, No.	Hole coordinates latitude/longitude	Structure type*	C_{org}, %	C_{org} (mar)	$CaCO_3$, %	$CaCO_3$ (mar)	AM, %	AM (mar)	SiO_2 biog., %	SiO_2 biog. (mar × 100)	Depth, m
Africa-Antarctic Ridge	251	36°30.26′ S 49°29.08′ E	2	0.4	0.02105	86	4.52	12	0.6314	2	10.51	3849
Krozet Basin	252	37°02.44′ S 59°14.33′ E	1	0.2	0.00297	0.1	0.001	57	0.8464	42.9	42.9	5032
Ninety East Ridge	253	24°52.65′ S 87°21.97′ E	2	0.01	0.0001	97	0.44	3	0.0127	0.01	0.005	1962
Ninety East Ridge	254	30°58.15′ S 87°53.72′ E	2	0.1	0.000182	96	0.175	4	0.0073	0.01	0.002	1253
Naturaliste plateau	258	33°47.69′ S 112°28.42′ E	3	0.6	0.01356	86	1.9443	9	0.2035	5	11.3	2793
Timor deep-water trough	262	10°52.19′ S 123°50.78′ E	3	0.5	0.0209	72	3.51	27	1.1267	1	4.88	2298
Wharton Basin	263	23°19.43′ S 110°58.81′ E	1	0.1	0.003	84	2.93	16	0.5572	0.01	0.04	5048
Naturaliste Plateau	264	34°58.13′ S 112°02.68′ E	3	0.01	0.0001	100	0.64	0	0	0.01	0.006	2876
Southeastern Mid-Ocean Ridge	265	53°32.45′ S 109°56.74′ E	2	0.01	0.0001	7	0.58	1	0.009	90	745.7	3581
Southeastern Mid-Ocean Ridge	266	56°24.13′ S 110°06.70′ E	2	0.01	0.0001	1	0.04	9	0.09	90	360	4167
Australian-Antarctic Basin	267	59°15.74′ S 104°29.30′ E	1	0.01	0.0001	0	0	80	0.63	20	0	4522
Continental foot	268	63°56.99′ S 105°09.34′ E	3	0.01	0.0001	0	0	97	1.15	3	0	3529

* Morphological structures of the Indian ocean floor are shown by numerals: (1) deep-water basins; (2) submarine ridges and rises; (3) continental margins.

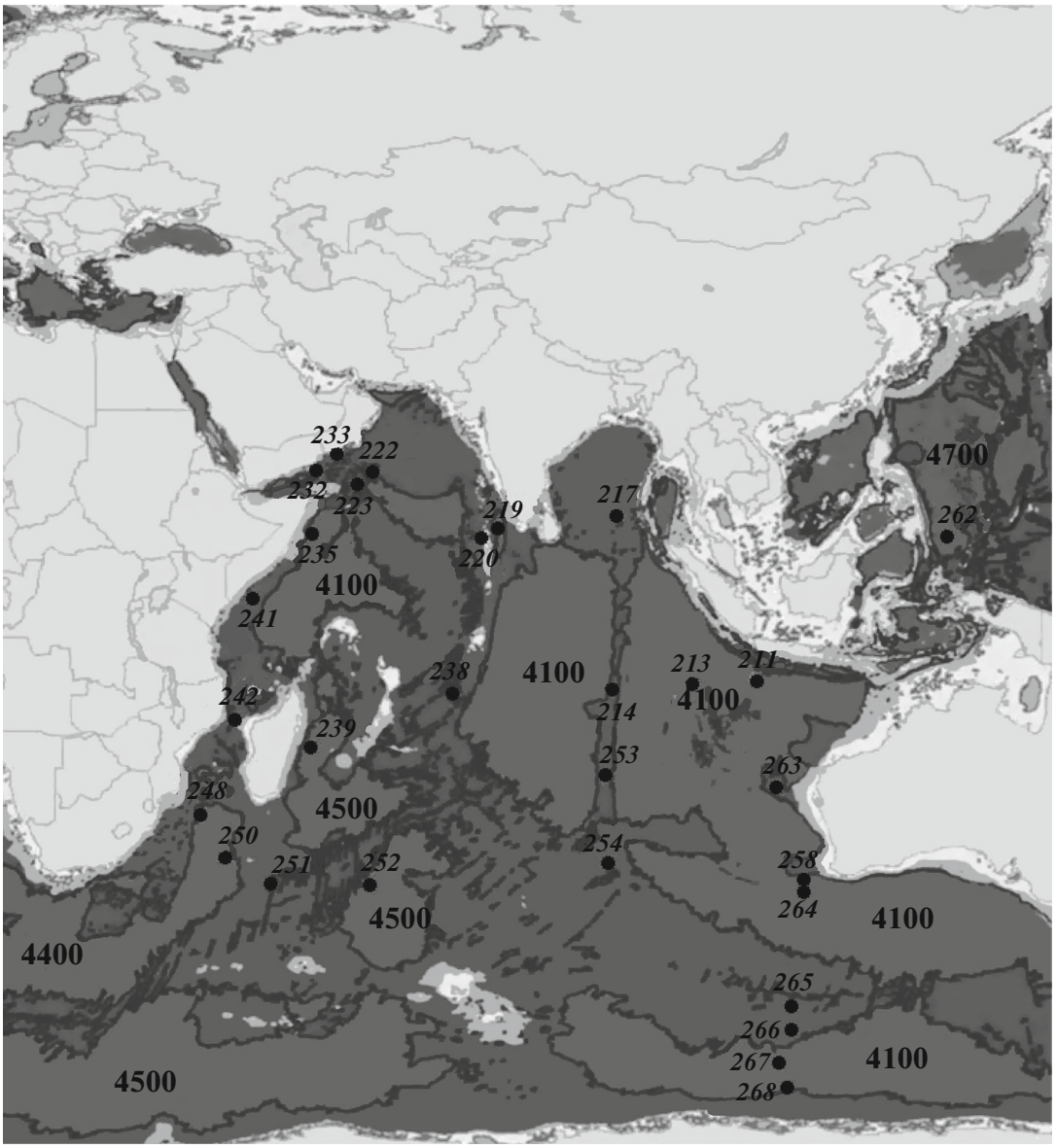

Fig. 1. Location of DSDP holes in the Indian Ocean shown on a fragmentary map of the deep-water basins of the World Ocean from paper (modified after Harris et al., 2014). Italic shows hole numbers, 4100–4700 are depths of deep-water basins (in m).

In spite of the plate tectonic motions, the probable changes of paleocoordinates and bottom depths of the studied holes were taken to be insignificant. Therefore, Table 1 lists the present-day coordinates and bottom depths.

The Upper Pliocene sediments experienced diagenetic alterations, which, however, were much weaker than in older sediments (Levitan, 1992). Therefore, we suggest that sedimentation signal in components reported in Table 1 is expressed much stronger than diagenetic signal.

There is one more important fact related to the qualitative parameters of the studied components. All components are heterogeneous. In particular, C_{org} contains organic carbon of both terrigenous and plaktonogenic origin. A priori clear that the relative role of terrigenous organic matter is higher in the deposits of the Bengal and Indian fans (deep-water fans of the great Ganges and Brahmaputra rivers and Indus River). $CaCO_3$ in sediments in the influence zone of the Zambezi River and so on is mainly represented by planktonic (foraminifers and coccolithophores) skeletons, whereas tropical zones contain pteropod remains at relatively shallow depths, and shelves are abundant in remains of mollusks and echinoderms; Oman shelf contains terrigenous detrital carbonates. The composition of SiO_2 biog. was mentioned above. Abiogenic matter includes terrigenous sedimentary material, volcanogenic-detrital, terrigenous–volcanogenic, as well

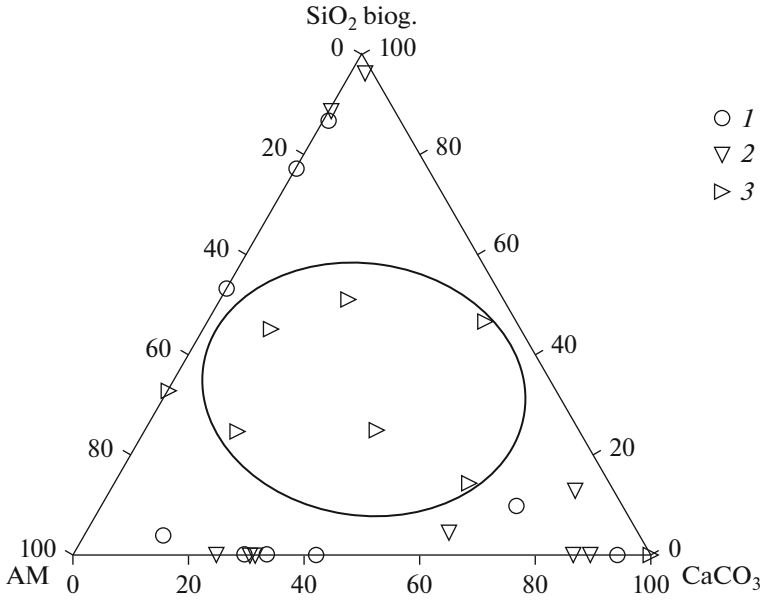

Fig. 2. Triangular diagram of $CaCO_3$, SiO_2 biog. and abiogenic matter (AM) in the Upper Pliocene sediments of the Indian Ocean (in percents). Symbols: (*1*) deep-water basins; (*2*) submarine ridges and rises; (*3*) continental margins.

as abiogenic matter of pelagic red clays. The abiogenic matter represents an insoluble carbonate residue with great fraction of authigenic minerals.

Statistical processing of data was carried out using a Statgraphics plus 5.0 software.

RESULTS

Triangle abiogenic matter, $CaCO_3$, SiO_2 biog. All results presented in Table 1 (except for C_{org}) are shown in percents in the abogenic matter (AM)–$CaCO_3$–SiO_2 biog. triangular diagram (Fig. 2). Analysis of the diagram indicates that only components of Late Pliocene sediments accumulated on the continental slopes of the Indian Ocean form a single cluster (contoured by a solid line). The components of sediments from abyssal floor, i.e., deep-water basins and diverse ridges and rises, are confined in composition to two-component mixtures of abiogenic matter and $CaCO_3$, on the one hand, and abiogenic matter and biogenic silica, on the other. This indicates that the components of abyssal sediments are sharply differentiated into siliceous–lithogenic and carbonate–lithogenic groups. It is possible that "two oceans" identified for Pleistocene (Levitan, 2016) also have existed in the Late Pliocene: "ice-bearing" (i.e., Indian Ocean part of the South Ocean, in the given case, siliceous–lithogenic group) and "ice-free" (ascribed to the low and moderate latitudes, carbonate–lithogenic group).

Results of analysis of variance. The analysis of variance is aimed at determining the significant influence of definite qualitative or quantitative factor on the change of the studied resultative feature. For this purpose, factor supposedly having or not having significant influence is divided into gradation classes (or groups) and significance between the average values in data sets corresponding to the factor gradations is analyzed to determine the factor influence.

In this paper, we applied one-way analysis of variance, i.e., method testing the effect of a single independent variable on a dependent variable.

The distribution of biogenic and abiogenic matter was studied in more detail using a one-way analysis of variance data on the abiogenic matter, calcium carbonate, biogenic silica, and organic carbon (Fig. 3a). It was established that the distribution of abiogenic and biogenic matter depends on its facies affiliation: with confidence level of 95% for abiogenic matter (Fig. 3b), with confidence level of 99% for calcium carbonate (Fig. 3c), and with confidence level of 95% for organic carbon (Fig. 3d).

The distribution of abiogenic matter was controlled by the laws of mechanical differentiation, i.e., according to size of detrital particles, as well as was determined by the morphometric features of the considered structures of the Indian Ocean floor (Figs. 1, 3a, 3b). Our studies showed that the maximum concentrations of abiogenic matter in sediments are observed on the continental slope and in basins, which is related to the maximum sedimentation rates on the continental slopes overlain by terrigenous sediments and in the deep-water basin areas subjected to the influence of mud flows and submarine landslides from adjacent continental slopes. In addition, the high AM concentrations in the deep floor area accumulating red clays

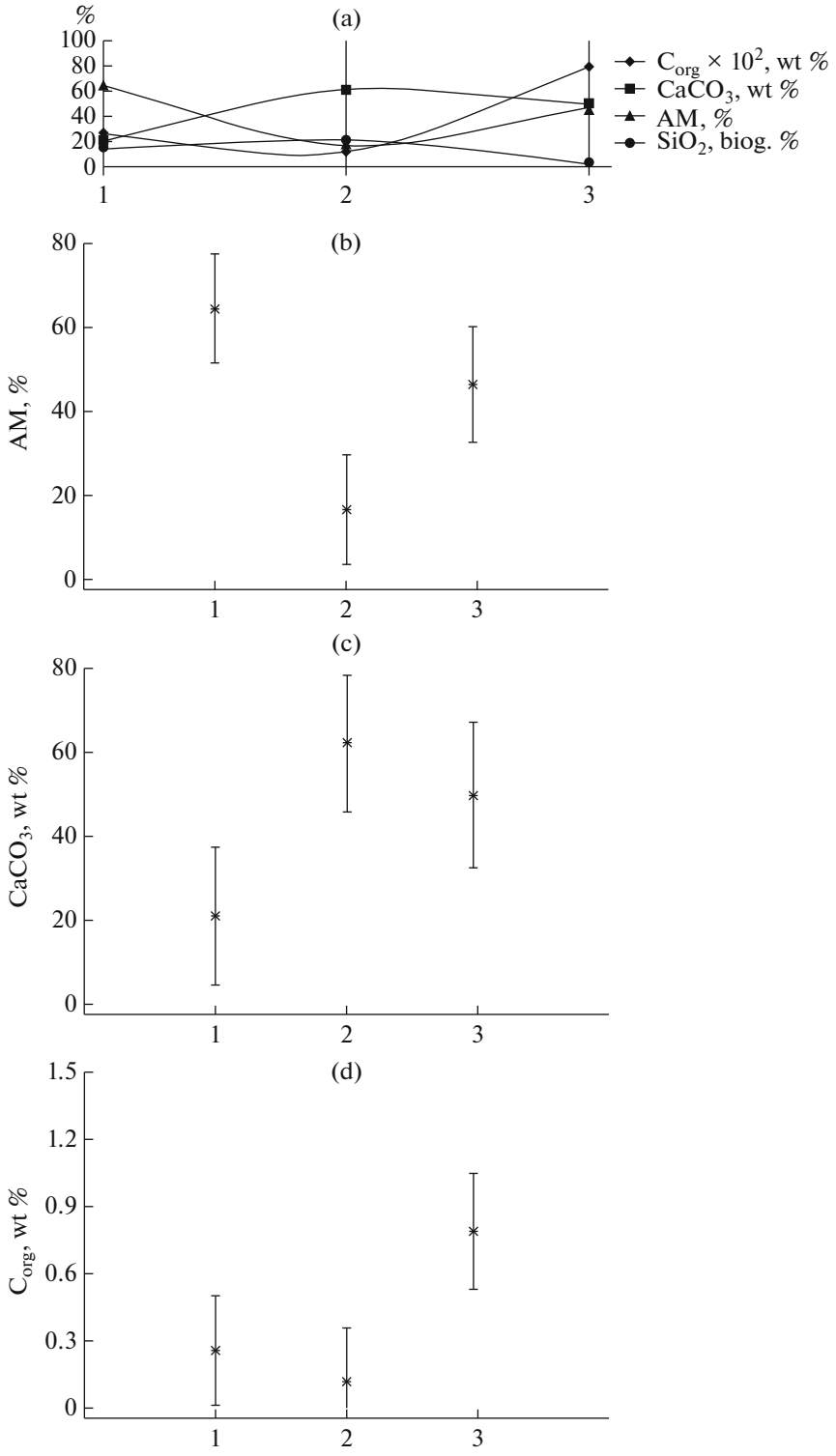

Fig. 3. Distribution of the average contents of major components of sediments (in percents) in main facies regions according to the analysis of variance: (a) summary profile; (b) average values and 95% confidence intervals of AM distribution; (c) average values and 99% confidence intervals of $CaCO_3$ distribution; (d) average values and 95% confidence intervals of C_{org} distribution. (1) deep-water basins; (2) submarine ridges and rises; (3) continental margins.

Table 2. Summary data on polynomial regression relationship between C_{org} and AM

Independent variables	Coefficients of the regression equation	Precision error of regression equation	Student t-test	*P*-value
CONSTANT	–0.0102	1.0101	–0.014	0.321
AM	0.026	0.00594	4.31	0.0003
AM	–0.00086	0.000239	–3.60419	0.0015

Dispersion	Sum of squares	Number of freedom degree	Estimated dispersion	Fisher's criterion	*P*-value
Regression dispersion	0.0334667	2	0.0167	11.55	0.0003
Discrepancy	0.0333153	23	0.00145		
Total dispersion	0.066782	25			

Determination coefficient	50.11%
Corrected determination coefficient	45.78%
Standard error	0.038
Average absolute error	0.02
Durbin–Watson statistics	2.12

are caused by the absence of carbonates due to their dissolution. The lowest contents of abiogenic matters are noted on rises where AM is diluted by carbonates.

Analysis of calcium carbonate distribution in sediments (Figs. 3a, 3c) showed that its high contents are restricted to submarine ridges and continental slopes, while the lowest contents, to basins. The maximum concentrations of carbonates on the submarine ridges and rises are mainly determined by a weak influence of diluting AM, as well as by the elevated production of $CaCO_3$ and its minimum dissolution at shallow depths. Signficant role is played by sediments predominating on continental margin. Therefore, the continental margins of the Arabian Peninsula and Australia (the latters are beyond the scope of our analysis) are occupied by carbonates of different composition and show high $CaCO_3$ contents. Owing to the circum-continental zoning in the distribution of primary production, these areas show the highest carbonate productivity. In the abyssal basins below the carbonate compensation depth (CCD), carbonates are dissolved.

The distribution of C_{org} in the Upper Pliocene sediments (Figs. 3a, 3d) indicates its highest values on the continental margins owing to the mentioned circum-continental zoning of primary production. In addition, the abundant fine sedimentary material accumulating in this facies setting serves as sorbent for organic matter. At the same time, a mechanism of "biological pump" provides transportation of AM through planktonic organisms on the floor (Lisitsyn, 1978). The C_{org} concentrations in abyssal sediments are much lower than on the continentnal margins due to the decrease of primary production and a relative increase of sediment grain size on submarine ridges, which is related to the extraction of C_{org}-bearing fine sedimentary material by bottom currents.

Results of the regression analysis. The regression analysis is successfully applied in oceanology for studying the distribution of diverse components of sediments in different facies settings. For instance, it was applied to map the C_{org} content in sediments of different facies (Costa et al., 2018) or to analyze the distribution of organic carbon in the surface sediments in Ubatuba Bay (Burone et al., 2003).

The relationships between calcium carbonate, organic carbon abiogenic matter, biogenic silica, and their accumulation depths were analyzed using one-way regression analysis. The relationships were estimated for the following pairs: (1) C_{org} and abiogenic matter (AM) (in mass accumulation rates (g/cm^2) ka; (2) C_{org} and $CaCO_3$ (in percents) (3) $CaCO_3$ (in percents) vs. accumulation depth; (4) $CaCO_3$ and AM (in percents); (5) SiO_2 biog. and $CaCO_3$ (in percents).

The study of the first pair, C_{org} and AM (Table 2), by a polynomial regression allowed us to found a statistically significant relationship between two variables at 99% level, which is confirmed by P-value less than 0.01 (Table 2). In the given case, the determination coefficient (R^2) is 50.11% and represents the proportion of the variance in the dependent variable C_{org} that is predictable from the independent variable AM, which is explained by the constructed regression model. Standard regression error (mean squared deviation of regression residual) is 0.038. This value represents a standard deviation of observed C_{org} from predictable C_{org}. The polynomial regression equation has the following form:

$$C_{org} = -0.0102 + 0.026AB - 0.00086AB^2.$$

The relationship between mass accumulation rates of C_{org} and AM (Fig. 4a) indicates that at relatively low (up to 5–7 (g/cm^2) ka) mass accumulation rates of AM, the

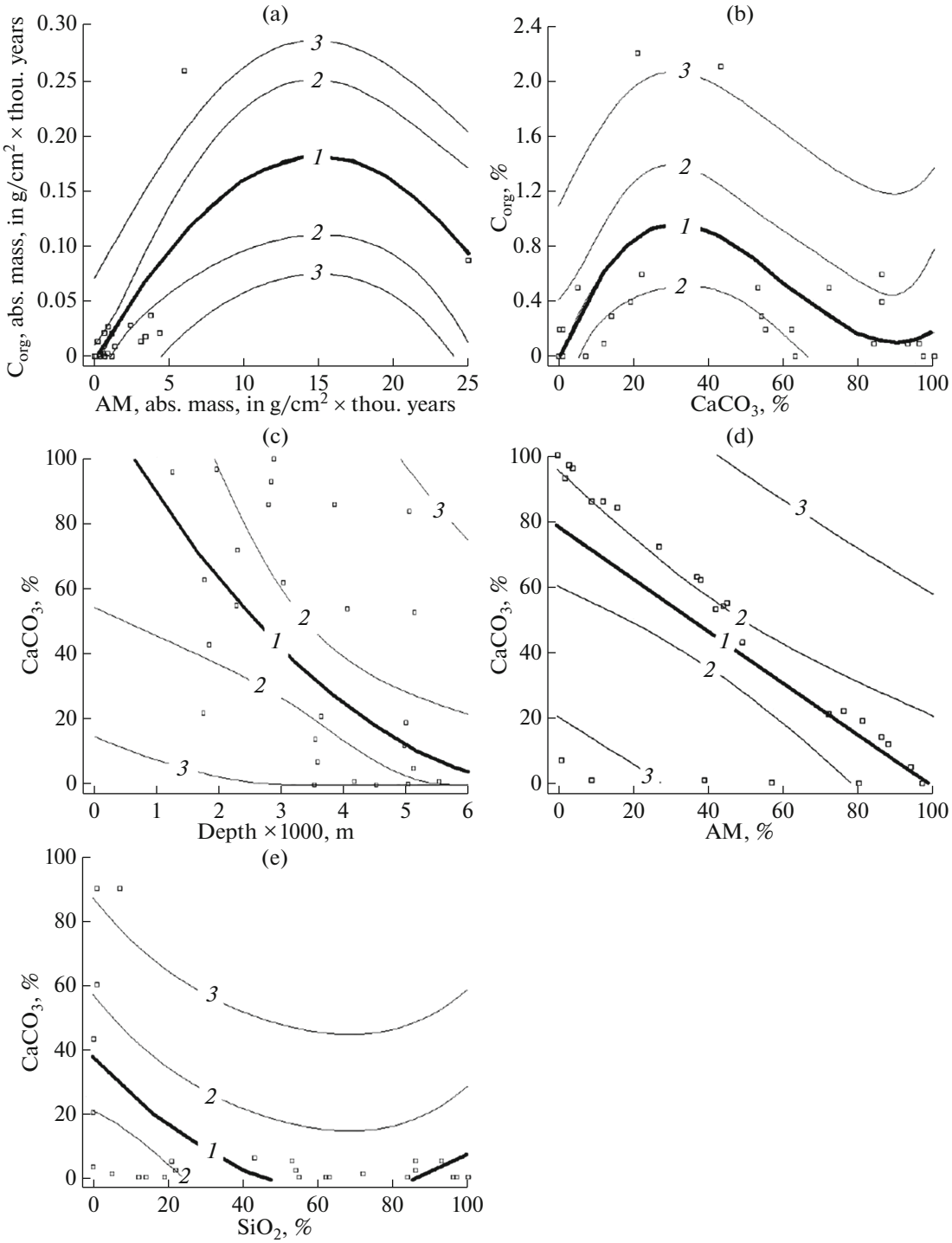

Fig. 4. Results of regression analysis: (a) plot of polynomial regression plot for relationships between mass accumulation rates of C_{org} and AM (in g/cm^2 thou years); (b) plot of polynomial regression for relationship between C_{org} and $CaCO_3$ (in wt %); (c) plot of non-linear inverse relationship between $CaCO_3$ (in wt %) and hole depth (in m); (d) plot of non-linear inverse relationship between $CaCO_3$ (in wt %) and AM (in %); (e) plot of non-linear opposite relationship between $CaCO_3$ (in wt %) and SiO_2 biog. (in %). (*1*) regression line; (*2*) confidence interval for the average values of predicted regression values; (*3*) confidence interval corresponding to the predicted regression value.

components show a positive correlation, which is likely caused by absorption of dissolved organics by essentially pelitic material of AM. At the same time, the right-hand part of the figure suggests that at ultrahigh mass accumulation rates of AM (>15 (g/cm^2) ka), the predominant part of this material does not absorb dissolved OM, since it has been already precipitated on AM and therefore dilutes the lesser part of AM, which absorb C_{org}.

Table 3. Summary data on polynomial regression of C_{org} and $CaCO_3$ regression

Independent variables	Beta coefficient	Precision error of regression equation	Student's t-test	*P*-value
CONSTANT	0.015	0.21	−0.07	0.94
$CaCO_3$	0.0702	0.027	2.65	0.015
$CaCO_3^2$	−0.002	0.0007	−2.225	0.035
$CaCO_3^3$	−0.0000084	0.000005	1.85	0.08

Dispersion	Sum of squares	Number of freedom degree	Dispersion	Fisher's criterion	*P*-value
Regression dispersion	2.48	3	0.83	3.4	0.035
Discrepancy	5.35	22	0.24		
Total dispersion	7.82	25			

Determination coefficient	32%
Corrected determination coefficient	22.3%
Standard error	0.5
Average absolute error	0.3
Durbin–Watson statistics	2.2

The regression polynomial study revealed a statistically significant relationship between variables C_{org} and $CaCO_3$ in wt % (Fig. 4b, Table 3) with a 95% confidence level, which confirms *P*-value < 0.05. The determination coefficient of 32% suggests that the dependent variable C_{org} has changed by this value under the influence of the independent variable $CaCO_3$. The standard error is 0.5 (Table 3). The polynomial regression best fits the equation:

$$C_{org} = -0.015 + 0.0702CaCO_3 - 0.0015CaCO_3^2 + 0.0000084CaCO_3^3.$$

The relationship between C_{org} and $CaCO_3$ in the Upper Pliocene sediments (Fig. 4b) shows a complex dependence. It shows a tight positive correlation at low values (up to 30% $CaCO_3$), which can be interpreted by simultaneous accumulation of both components on continental margins (Fig. 3a). At calcium carbonate contents from 30 to 80%, correlation is negative, which likely indicates a dilution of organic matter in a setting of submarine ridges and rises. A trend of positive correlation at high (>80% $CaCO_3$) contents could be explained by the presence of specific organic matter in calcitic shells at extremely low contents of other organic varieties (partially, owing to the removal of this organics with fine sediment fractions in the crest zones of the ridges and rises, Table 1). According to last data, the C_{org} contents in sediments of submarine ridge could be lowered also owing to its intense consumption by bacteria inhabiting mud waters (Sunita et al., 2018). At the same time, the same relations are also observed in other facies conditions: on the continental margins of the Arabian Peninsula (Table 1). They are controlled by different mechanisms: accumulation of carbonate deposits in the absence of terrigenous flux (except for aeolian material) and the elevated C_{org} in sediments owing to upwelling (Levitan, 1992).

The $CaCO_3$ (%) shows a moderately negative correlation with accumulation depth (m) (Fig. 4c), at correlation coefficient of −0.6 (Table 4). The *P*-value < 0.01 and equal 0.004 (Table 4) confirms a relationship between $CaCO_3$ and depth at a statistic significance of 99%. The determination coefficient in this regression model is 30.3%. Thereby, a standard error is 2.97. The calcium carbonate in sediments shows a significant decrease at depths from 4500 to 5000 meters (Fig. 4c). The correlation of $CaCO_3$ versus depth is determined by non-linear equation:

$$CaCO_3 = (10.9406 - 0.0015D)^2,$$

where D is the depth × 1000, m.

Obtained data should be interpreted as a result of $CaCO_3$ dissolution with depth, and the mentioned change in its content within 4500–5000 m is clearly related to the known acceleration of carbonate dissolution with approaching the carbonate compensation depth (Lisitsyn, 1978).

The study of regression for $CaCO_3$ and AM (values are given in relative percents) indicates their mutual dilution, which is proved with a significance level of 99% (Fig. 4d, Table 5). Thereby, *P*-value is less than 0.01 (Table 5). The determination coefficient of 50.3% shows a proportion of variance of the dependent variable $CaCO_3$ under the influence of the independent variable AM. Thereby, the standard regression error is 2.91. The dependence of $CaCO_3$ variable versus abio-

Table 4. Summary data on regression analysis of $CaCO_3$ and depth relations. Equation of non-linear regression: $Y = (a + bX)^2$

Parameters	Coefficients of the polynomial regression equation	Standard errors in estimated coefficients	Student's *t*-test	*P*-value
a	10.9406	1.73	6.32	0.00
b	–0.0015	0.0005	–3.23	0.004

Dispersion	Sum of squares	Number of freedom degree	Dispersion	Fisher's criterion	*P*-value
Regression dispersion	92.08	1	92.08	10.4	0.004
Discrepancy	212.27	24	8.84		
Total dispersion	304.35	25			

Correlation coefficient	–0. 6
Determination coefficient	30.3
Corrected determination coefficient	27.4%
Standard error	2.97
Average absolute error	2.39
Durbin–Watson statistics	1.26

Table 5. Summary data on regression analysis of relationships between $CaCO_3$ and abiogenic matter (AM). Equation of linear regression: $Y = a + bX$

Parameters	Regression coefficient	Standard errors in estimated coefficients	Student's *t*-test	*P*-value
a	77.8702	8.6	9.05	0.000
b	–0.793	0.16	–4.93	0.000

Dispersion	Sum of squares	Number of freedom degree	Dispersion	Fisher's criterion	*P*-value
Regression dispersion	17048.6	1	17048.6	24.28	0.000
Discrepancy	16850.4	24	702.1		
Total dispersion	33899	25			

Correlation coefficient	–0.71
Determination coefficient	50.3
Corrected determination coefficient	48.2%
Standard error	26.5
Average absolute error	17.98
Durbin–Watson statistics	1.28

genic matter (AM) can be described by the linear regression equation:

$$CaCO_3 = 77.8702 - 0.793AM.$$

The polynomial regression study of the relations between biogenic silica (%) and $CaCO_3$ (%) revealed their statistical relationships at a significance level of 99%, which is confirmed by *P*-value of 0.007 (Table 6). The relations between two variables is shown in Fig. 4e. The determination coefficient is 35.3% (Table 6), which explains the proportion of variance in the dependent variable SiO_2 biog. owing to variance of the independent variable $CaCO_3$. The relationships of SiO_2 biog. dependence with $CaCO_3$ can be described by the polynomial regression equation:

$$SiO_2biog. = 37.6361 - 1.261CaCO_3 + 0.0096CaCO_3^2.$$

Analysis of Fig. 4e shows that these variables have a negative correlation at SiO_2 biog. from 0 to 60–70% and a positive correlation at higher SiO_2 biog. Thus, the components dilute each other in the first case (in most facies settings), while accelerated dissolution of

Table 6. Summary data on polynomial regression of SiO_2 biog. (%) and $CaCO_3$ (wt %) relationships

Independent variables	Beta coefficient	Precision error of regression equation	Student's *t*-test	*P*-value
CONSTANT	37.6361	8.26	4.56	0.0001
$CaCO_3$	−1.261	0.49	−2.59	0.016
$CaCO_3^2$	0.0096	0.005	1.91	0.07

Dispersion	Sum of squares	Number of freedom degree	Dispersion	Fisher's criterion	*P*-value
Regression dispersion	6263.7	3	3131.9	6.3	0.007
Discrepancy	11494.2	22	499.75		
Total dispersion	17757.9	25			

Determination coefficient	35.3%
Corrected determination coefficient	29.6%
Standard error	22.4
Average absolute error	14.3
Durbin–Watson statistics	1.3

carbonates in the second case (at maximum depths of abyssal basins in the South Ocean) eliminates their diluting role for biogenic SiO_2.

CONCLUSIONS

Mutual correlation methods were used to analyze the contents of major components (C_{org}, $CaCO_3$, abiogenic matter, and SiO_2 biog.) in the Upper Pliocene sediments of the Indian Ocean recovered in 26 DSDP holes.

It is established that major components (AM, $CaCO_3$, and SiO_2 biog.) can be divided into three groups based on their relationships: (1) three-component association confined to continental margins and forming a compact cluster; (2) two-component mixture of abiogenic matter and $CaCO_3$, and (3) two-component mixture of abiogenic matter and biogenic silica. The second and third groups are restricted to the abyssal floor: the second group is restricted to the moderate and low latitudes, while the third group, to the Indian Ocean sector of the South Ocean.

Obtained data agree well with classical concepts on the distribution of abiogenic and biogenic material in oceanic settings. Thereby, one-way analysis of variance revealed that the distribution of abiogenic and biogenic materials clearly depends on their facies affiliation.

The application of one-way regression analysis (with presentation of linear and non-linear regression equations, which consider the relationships of components with 95–99% statistical significance) allowed us to estimate reliably the component analysis data and to unravel previously unknown features, for instance, in the distribution of C_{org} depending on the mass accumulation rates of AM and percentage of $CaCO_3$, as well as relations between the percentages of $CaCO_3$ and SiO_2 biog.

Obtained tendencies can be used in developing the numerical models of the Late Pliocene sedimentation in the Indian Ocean.

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REFERENCES

L. Burone, P. Muniz, A. M. S. Pires-Vanin, and M. Rodrigues, "Spatial distribution of organic matter in the surface sediments of Ubatuba Bay," J. An. Acad. Bras. Sci. **75** (1), 75–90 (2003).

E. M. Costa, W. S. Tassinari, H. S. K. Pinheiro, S. J. Beutler, and L. H. C. Dos Anjos Mapping soil organic carbon and organic matter fractions by geographically weighted regression, J. Environ. Qual. **47** (4), 718–725 (2018).

T. A. Davies, B. P. Luyendyk, et al., DSDP Init. Repts. **26**, (1974)

J. W. Farrell, I. Raffi, T. R. Janecek, D. W. Murray, M. A. Levitan, K. A. Dadley, K.-C. Emeis, M. Lyle, J.-A. Flores, and S. Hovan, "Late Neogene sedimentation patterns in the eastern equatorial Pacific," In: Proc. ODP, Sci. Results **138,** 717–756 (1995).

R. L. Fisher, E. T. Bunce, et al., DSDP Init. Repts. **24**, (1974).

P. T. Harris, M. Macmillan-Lawler, J. Rupp, and E. K. Baker, "Geomorphology of the oceans," Mar. Geol. **352**, 4–24 (2014).

M. A. Levitan, *Paleooceanology of the Indian Ocean* (Nauka, Moscow, 1992) [in Russian].

M. A. Levitan, "Comparative analysis of pelagic pleistocene silica accumulation in the Pacific and Indian oceans," Geochem. Int. **54** (3), 257–265 (2016).

M. A. Levitan, L. G. Domoratskaya, and A. V. Koltsova, "History of organic carbon accumulation," *Quantitative Parameters of the Mesozoic–Cenozoic Sedimentation: Essays,* Ed. by M. A. Levitan (Pero, Moscow, 2018a), pp. 15–40 [in Russian].

M. A. Levitan, L. G. Domoratskaya, and A. V. Koltsova, "History of carbonate accumulation," *Quantitative Parameters of the Mesozoic–Cenozoic Sedimentation: Essays,* Ed. by M. A. Levitan (Pero, Moscow, 2018b), pp. 62–97 [in Russian].

M. A. Levitan, L. G. Domoratskaya, and A. V. Koltsova, "History of terrigenous sedimentation," *Quantitative Parameters of the Mesozoic–Cenozoic Sedimentation: Essays,* Ed. by M. A. Levitan (Pero, Moscow, 2018c), pp. 98–124 [in Russian].

A. P. Lisitsyn, *Sedimentation in Oceans. Quantitative Distribution of Sedimentary Material* (Nauka, Moscow, 1974) [in Russian].

A. P. Lisitsyn, *Oceanic Sedimentation. Lithology and Geochemistry* (Nauka, Moscow, 1978) [in Russian]

E. S. Simpson, W. R. Schlich, et al., DSDP Init. Repts. **25**, (1974).

R. Sunita, S. Walter, U. Jaekel, H. Osterholz, A. T. Fisher, J. A. Huber, A. Pearson, Th. Dittmar, and P. R. Girguis, "Microbial decomposition of marine dissolved organic matter in cool oceanic crust," Nature Geosci. **11**, 334–339 (2018).

E. Uliana, C. B. Lange, B. Donner, and G. Wefer, "Siliceous phytoplankton productivity fluctuations in the Congo Basin over the past 460000 years: marine vs. riverine influence, ODP Site 1077," Proc. ODP, Sci. Results **175**, 1–32 (2001).

T. H. van Andel, C. R. Heath, and T. C. Moore, "Cenozoic tectonics, sedimentation and paleoceanography of the central equatorial Pacific," Geol. Soc. Amer. Mem. **143**, 1–65 (1975).

J. J. Veevers, J. R. Heirtzler, et al., DSDP Init. Repts. **27,** (1974).

Ch. C. von der Borch, J. G. Sclater, et al., DSDP Init. Repts. **22**, (1974).

R. B. Whitmarsh, O. E. Weser, D. A. Ross, et al., DSDP Init. Repts. **23**, (1974).

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