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Table of Contents

The Ngoc Linh Complex in Central Kon Tum Massif: an exposed remnant of the Early Paleozoic collisional tectonism in East Central Indochina mainland

Hai Thanh Tran, Truong Tai Nguyen, Hau Vinh Bui, Thanh Xuan Ngo, Monsup Cho, Chi Kim Ngo, Dao Anh Vu, Hiep Huu Nguyen, Binh Van Phan, Hung Quoc Nguyen..... 1

Late Cretaceous Magmatism in the Nui Sam Area (An Giang Province, Southwestern Vietnam): Implications for the Tectono-Magmatic Evolution of the Ankroet Complex

Bui Vinh Hau, Tran Thanh Hai, Nguyen Truong Tai, Ngo Thi Kim Chi, Phan Van Binh, Vu Anh Dao, Nguyen Huu Hiep, Nguyen Quoc Hung, Ngo Xuan Thanh 10

U–Pb zircon geochronology of meta-diorite in the Vit Thu Lu area, northern Quang Tri, central Vietnam

Dinh Trong Tuong, Nguyen Quoc Hung, Tran My Dung, Ha Tri Dung, Dang My Cung, Ngo Xuan Thanh 16

Post-collisional extension during the Early Paleozoic in Northeast Vietnam: Evidence from syenitic complex

Chu Van Dung, Tran My Dung, Ngo Xuan Thanh 23

Zircon U–Pb constraints on episodic magmatism of the Hai Van granitoid complex and implications for the Indosinian orogeny in central Vietnam

Dinh Trong Tuong, Ngo Xuan Thanh, Tran My Dung Ha Tri Dung 34

Controlling factors on mineralization in the Tram Tau felsic volcanic formation (Tu Le Basin, North Vietnam)

Tran Thi Huong, Nguyen Hoang, Tran Thanh Hai 42

Distribution and Metamorphic Evolution of REE-bearing Minerals in Metapelitic Rocks of the Nam Co Formation, Song Ma Suture Zone, NW Vietnam

Bui Vinh Hau 56

Technology for rare earth ore beneficiation in Vietnam

Thanh Hai Pham..... 63

Structural and tectonic controls on gold mineralization in the northern Kon Tum massif, Vietnam

Vu Tien Thanh, Nguyen Van Vuong, Luong Thi Thu Hoai 73

Potential for Marine Ion-Adsorption Rare Earth Deposits: Sedimentary Facies Controls in Southwestern Vietnam

Nguyen Huu Hiep, Phan Van Binh, Tran Thanh Hai, Bui Hoang Bac 85

Fluvial geomorphology and weathering crust controls on ion-adsorption rare earth element mineralization in Northwestern Vietnam

Dinh Thi Hue, Vu Anh Dao 93

Tectonic – Geomorphology and its relation to geo-hazards in the Southwest region of Vietnam

Nguyen Xuan Nam, Tran Thanh Hai, Ngo Thi Kim Chi, Hoang Ngo Tu Do, Vu Anh Dao, Nguyen Xuan Quang..... 100

Grain-size and mineralogical characteristics of surface sediments in the Con Co Island area and their environmental significance

<i>Phan Van Binh, Hoang Van Long, Le Anh Thang, Vu Anh Dao, Nguyen Huu Hiep, Nguyen Quoc Hung, Bui Vinh Hau, Vo Thi Cong Chinh, Nguyen Thi My Hanh</i>	108
Shoreline change assessment on Phu Quoc Island using Satellite Remote Sensing and the Digital Shoreline Analysis System (DSAS)	
<i>Ngo Thi Kim Chi, Tran Thanh Hai, Bui Minh Quan, Bui Vinh Hau, Phan Van Binh, Vu Anh Da¹, Nguyen Xuan Quang</i>	117
Geological characteristics of karst and their relationship to underground karst collapse in Quang Ninh province	
<i>Nguyen Xuan Nam, Nguyen Dinh Tuan, Doan Thi Ngoc Huyen</i>	124
Geotourism Development Potential of Co To Island, Quang Ninh Province, Vietnam	
<i>Phan Van Binh, Vu Anh Dao, Bui Vinh Hau, Nguyen Xuan Nam, Vo Thi Cong Chinh, Nguyen Thi Minh Thu</i>	138
Geological hazards at the main dam of Dap Troi reservoir, Ninh Binh Province, Vietnam	
<i>Ban To Xuan</i>	150
The erosion and accretion at Day River mouth, Vietnam	
<i>Ban To Xuan</i>	161
Spatio-temporal variation of agricultural drought based on SMAPI evaluation toward supporting water resources management in the Red River Basin	
<i>Nguyen Hoang Hiep, Nguyen Lan Huong, Tran Thi Phuong Linh,</i>	179
Landslide hotspot identification by instance-based learning: A comparison of k-nearest neighbour and the entropy-based distance algorithm (Kstar)	
<i>Minh Nhut Dao, Quoc Phi Nguyen, Duong Van Hoa</i>	188
Performance of stochastic inversion approaches of groundwater flow and heat transport modeling in parameter estimation	
<i>Doan Thi Thanh Thuy, Nguyen Hoang Hiep, Nguyen Bach Thao, Vu Thu Hien</i>	203
Environmental Issues of Rare Earth and Critical Mineral Mining in Vietnam	
<i>Quoc Phi Nguyen, Thi Mai Hoa Phan, Thi Cuc Nguyen, Quang Minh Nguyen, Van Binh Nguyen, Trung Thanh Dao, Minh Nhut Dao, Ha Tuan Anh, Khanh Phuong Mai</i>	210
Application of the remote sensing ecological index (RSEI) to assess ecological quality in Coal mining areas of Quang Ninh province, Viet Nam	
<i>Nguyen Thi Cuc, Phan Thi Mai Hoa, Nguyen Anh Hoa, Nguyen Van Bin</i>	219
Environmental vulnerability assessment for sustainable mining using GIS based AHP - VIKOR approach: A Case Study of Ha Quang, Cao Bang District, Vietnam	
<i>Phan Thi Mai Hoa, Nguyen Quoc Phi, Nguyen Thi Cuc</i>	230
Assessment of Hydrodynamic Changes Induced by Dredging and Sand Mining in Tra Ly Estuary for Sustainable Resource Management	
<i>Vu Thi Lan Anh, Nguyen Thi Hoa, Nguyen Thi Hong, Tran Thi Ngoc, Vu Van Ngoc, Nguyen Cham Anh, Nguyen Thi Thuy Hien, Phan Thi Mai Hoa</i>	246

Grain-size and mineralogical characteristics of surface sediments in the Con Co Island area and their environmental significance

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Abstract

The Con Co Island marine area, located in the nearshore zone of central Vietnam, is strongly influenced by marine hydrodynamics and seabed topography. This study aims to characterize the grain-size and mineral composition of surface sediments and to analyze the relationship between sedimentary features and the modern depositional environment. Analysis of 256 surface sediment samples identified 12 distinct sedimentary facies with clear spatial distribution patterns. Fine-grained sediments (mud and muddy sand) are mainly distributed in the west–southwest of the island, corresponding to gentle seabed slopes and low-energy hydrodynamic conditions. In contrast, coarse-grained sediments (gravel and sandy gravel) are concentrated in the east–southeast, where steep slopes and erosional seabed features such as channels and scours indicate high-energy conditions. Variations in grain-size and mineral composition reflect a close linkage with wind, wave regimes, and seabed morphology. The results reveal a multi-source origin of sediments, providing insights into the characteristics of the modern depositional environment and offering a scientific basis for marine resource management and environmental protection in the region.

Keywords: Sediments, Con Co Island, grain size analysis, mineralogy, depositional environment

1. Introduction

Con Co Island, located within the Con Co Special District, Quảng Trị Province, Vietnam, is an administrative unit of strategic importance for national defense, security, and maritime sovereignty. The study area covers approximately 144 km², delineated by 17 geographic coordinate points (Figure 1, Table 1). The island is nearly circular in shape, with an average elevation of 7–10 m above sea level, featuring two prominent high points: 37 m in the eastern sector and 63.4 m in the central–western part of the island.

The seabed topography in the study area trends northwest–southeast, with water depths ranging from 0 to 60 m. The seabed slope gradually decreases from the nearshore zone toward the southwest and southeast, creating a pronounced spatial differentiation in sediment accumulation conditions. The region experiences a tropical monsoon climate, strongly influenced by the northeast monsoon and the hot, dry western wind, while marine factors also play a significant role. The wave regime exhibits strong seasonal variability: in winter, waves predominantly come from the northeast, whereas in summer, waves are mainly oriented from the southeast–south and southwest, with wave heights and energy flux exhibiting pronounced spatial and temporal variability.

In recent years, numerous studies have been conducted on the geology and nearshore marine environment of Vietnam. Notable examples include large-scale marine geological and mineral surveys at 1:500,000 scale, studies on natural conditions and coastal marine resources in Quảng Trị Province, and detailed geological, geomorphological, and mineral investigations of Con Co Island at 1:50,000 scale. These studies have provided essential datasets on regional geological characteristics and natural conditions.

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However, research focusing specifically on surface sediment characteristics—particularly the relationships between grain-size distribution, mineral composition, and the modern depositional environment under local hydrodynamic conditions—remains limited. Clarifying these features is critical for identifying sediment sources, understanding transport–deposition mechanisms, and reconstructing modern sedimentary environments. Therefore, this study aims to analyze the grain-size and mineral composition of surface sediments in the Con Co marine area, elucidating the relationships between sedimentary characteristics and hydrodynamic–topographic factors, and providing a scientific foundation for coastal geological research, resource management, and environmental protection in the region.

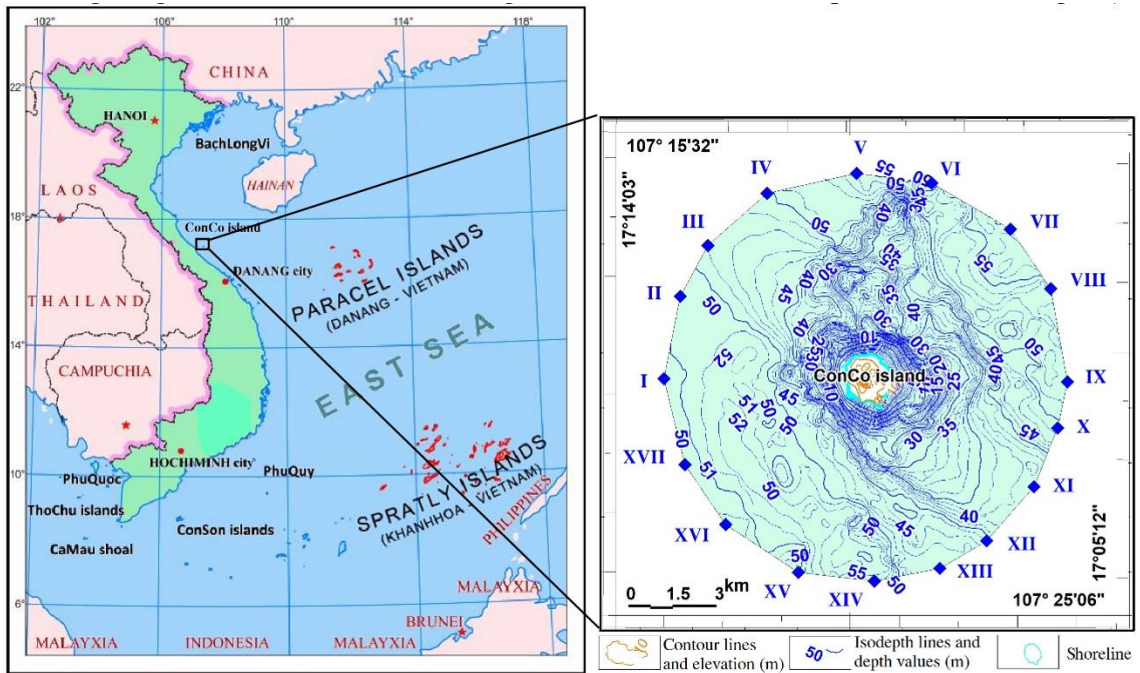


Figure 1. Location map of the study area.

Table 1. Geographic coordinates defining the boundaries of the study area.

No.	Point ID	Latitude (°N)	Longitude (°E)	No.	Point ID	Latitude (°N)	Longitude (°E)
1	I	17° 09' 35.81"	107° 16' 20.39"	10	X	17° 08' 41.55"	107° 23' 51.47"
2	II	17° 11' 06.30"	107° 16' 39.02"	11	XI	17° 07' 36.83"	107° 23' 24.35"
3	III	17° 12' 01.82"	107° 17' 10.55"	12	XII	17° 06' 37.70"	107° 22' 30.34"
4	IV	17° 12' 59.41"	107° 18' 18.64"	13	XIII	17° 06' 07.52"	107° 21' 36.55"
5	V	17° 13' 21.35"	107° 20' 01.33"	14	XIV	17° 05' 53.34"	107° 20' 21.52"
6	VI	17° 13' 10.40"	107° 21' 27.34"	15	XV	17° 06' 03.19"	107° 18' 54.52"
7	VII	17° 12' 20.00"	107° 22' 57.24"	16	XVI	17° 06' 55.48"	107° 17' 31.28"
8	VIII	17° 11' 14.40"	107° 23' 43.55"	17	XVII	17° 08' 01.21"	107° 16' 44.61"
9	IX	17° 09' 32.20"	107° 24' 02.96"				

2. Data Sources and Research Methods

2.1. Data Sources

The dataset utilized in this study was inherited from the project “Basic Survey of Resources and Environment of Selected Islands and Major Archipelagos for Marine Economic Development Planning and Maritime Sovereignty Protection”, conducted under the leadership of the Center for Marine Resource and Environmental Planning and Investigation – Northern Vietnam.

The dataset comprises 256 surface sediment samples analyzed for grain-size distribution and 44 samples subjected to quantitative mineralogical analysis, collected from the coastal waters surrounding Con Co Island. This dataset provides a reliable and comprehensive representation of sedimentary characteristics in the study area.

2.2. Research Methods

a. Field Survey

Field surveys were conducted to collect surface sediment samples and record environmental characteristics at each sampling station. Sampling points were distributed according to a pre-established network. For each station, detailed information on location, water depth, seabed morphology, and relevant environmental parameters was systematically recorded in field logs and sample sheets, ensuring the accuracy and consistency of the dataset.

b. Laboratory Analysis

Grain-size analysis: Collected sediment samples were processed and analyzed using a combination of sieving and pipette techniques to determine the grain-size composition. Grain-size classification followed the Wentworth scale (1922). Based on these data, sedimentary parameters including mean grain diameter (Md), sorting coefficient (So), and skewness (Sk) were calculated according to Rukhin (1969). Cumulative and frequency grain-size curves were generated to support sediment characterization.

Sediment classification: The proportion of each grain-size fraction (gravel, sand, silt, and clay) was computed and used to classify sediments following the Folk (1974) system. This approach allowed accurate identification of sediment types and delineation of characteristic sedimentary facies within the study area.

Quantitative mineralogical analysis: The detrital mineral composition was determined using a binocular microscope, focusing on major components including quartz, feldspar, lithic fragments, and biogenic particles. Morphological features and roundness of grains were also documented to infer sediment provenance and transport-deposition processes.

c. Principles of Surface Sediment Mapping

The surface sediment map was developed by integrating laboratory analysis results with bathymetric data and geophysical survey information. Sedimentary facies were delineated according to Folk (1974), with boundaries defined based on spatial continuity and sediment similarity.

The delineation of sedimentary facies considered seabed morphology, geomorphological features, and geophysical interpretations such as shallow seismic profiles and side-scan sonar imagery. Acoustic reflectivity data were employed to differentiate grain-size variations, with coarser sediments typically producing stronger reflections compared to finer sediments (Figures 2 and 3).

Additionally, sonar and seismic data allowed the identification of characteristic seabed features such as sand waves, erosion gullies, depressions, and exposed bedrock, improving the accuracy of sediment facies boundaries. However, in areas with abrupt changes in sediment type or complex seabed morphology, boundary delineation may be approximate and requires refinement in subsequent detailed studies.

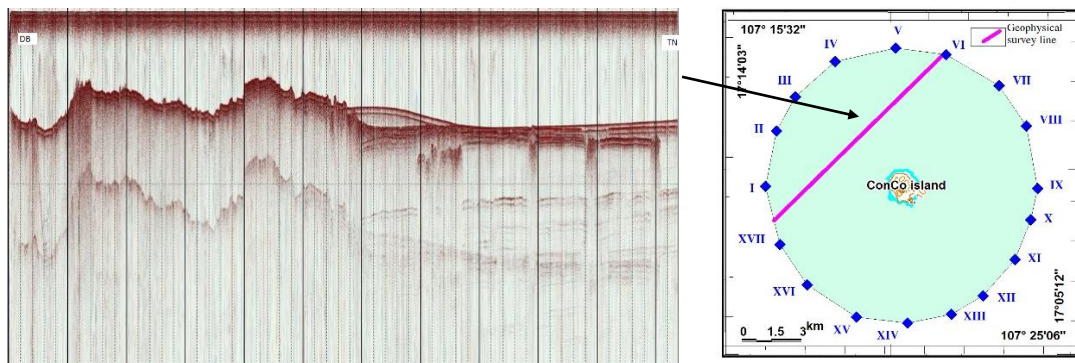


Figure 2. Seismic line CC16–TU06 crossing the seabed topography from bedrock in the northern sector of Con Co Island to mud deposits in the western sector of Con Co Island.

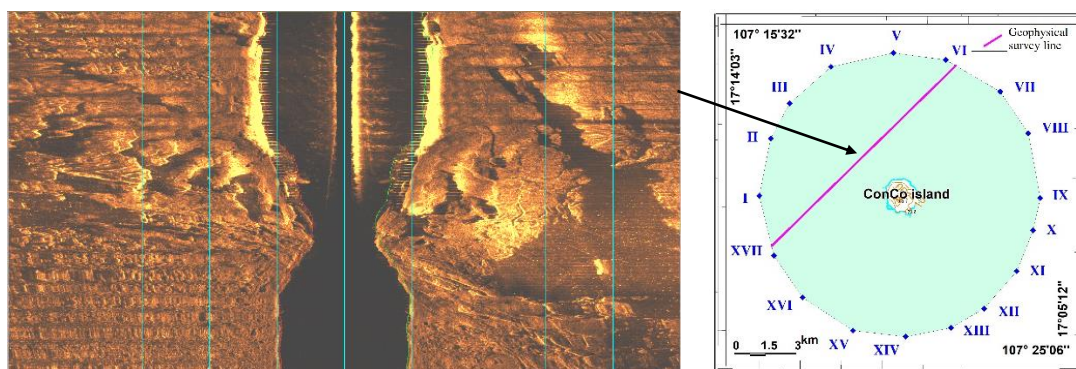


Figure 3. Sonar swath illustrating exposed bedrock and coarse-grained sediments along seismic line CC16-TU07.

3. Results and Discussion

3.1. Research Results

Based on the analysis of 256 grain-size samples and 44 mineralogical samples, the study area was classified into 12 sedimentary facies following the Folk (1974) classification system. These facies include: sandy gravel (sG), muddy gravel (mG), sandy-muddy gravel (msG), gravelly sand (gS), sand with gravel ((g)S), sandy-muddy gravelly sand (gmS), muddy sand with gravel ((g)mS), silty sand (siS), muddy sand (mS), muddy gravel (gM), sandy mud (sM), and mud (M) (Figure 4, Table 2).

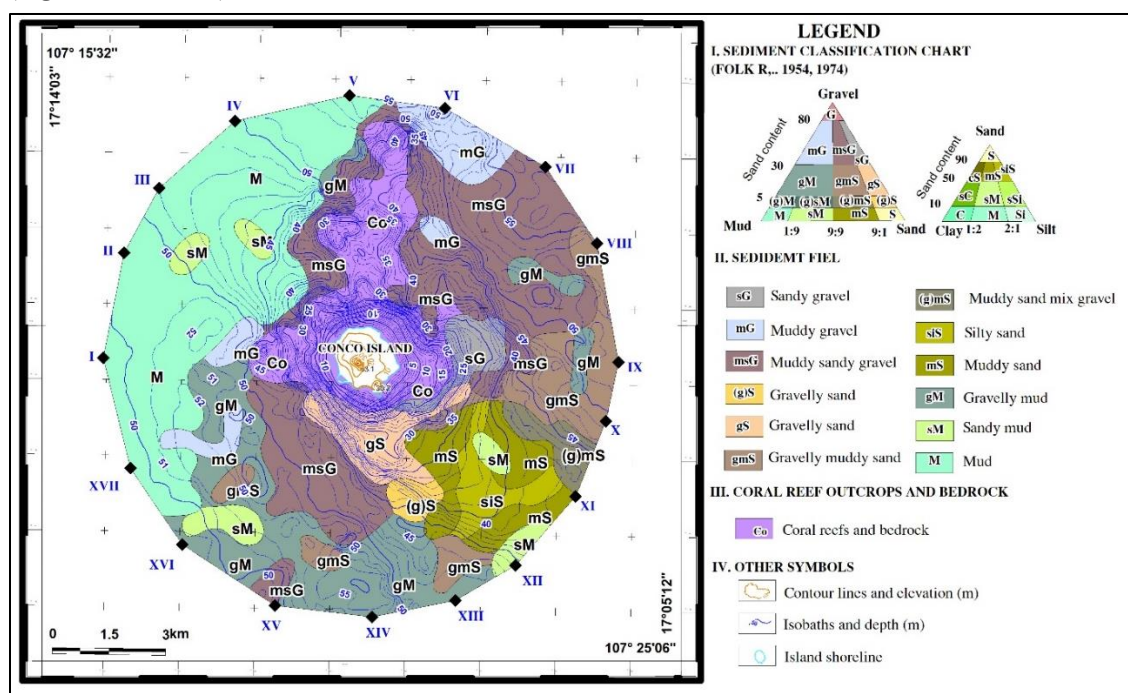


Figure 4. Surface sediment facies map of the Con Co Island marine area (reduced from the 1:50,000 scale map; Hoàng Văn Long, Phan Văn Bình et al., 2016).

Table 2. Statistical summary of surface sediment composition parameters in the Con Co Island marine area.

No.	Sediment type	Statistics	C	Si	M	S	G	Md	So	Sk	Q	Fel	R
1	Sandy gravel – sG (n=10)	Min	0.00	0.00	0.00	40.80	33.80	0.781	1.616	0.446	0.68		2.66
		Max	0.00	5.80	5.80	65.00	58.20	2.555	2.397	2.261	1.90		7.38
		Mean	0.00	1.38	1.38	53.78	44.84	1.665	1.974	1.034	1.29		5.02
2	Muddy gravel – mG (n=21)	Min	2.00	17.80	23.50	8.00	31.20	0.059	5.467	0.010	0.16		9.18
		Max	19.40	38.70	50.30	33.20	68.50	2.697	17.889	7.348	11.39		11.28
		Mean	8.22	26.59	34.80	23.58	41.62	0.906	12.244	0.521	4.02		9.96
3	Sandy-	Min	0.00	4.00	4.00	15.70	30.30	0.479	0.177	0.076	0.05	4	6.40

No.	Sediment type	Statistics	C	Si	M	S	G	Md	So	Sk	Q	Fel	R
	muddy gravel – msG (n=48)	Max	8.30	27.60	34.60	48.20	76.40	2.733	12.584	2.859	35.00	6	36.38
		Mean	2.75	16.17	18.92	33.96	47.13	1.717	4.502	0.393	9.08	5	17.43
4	Sand with gravel – (g)S (n=3)	Min	0.00	0.10	0.10	92.60	2.50	0.418	1.250	0.823			
		Max	0.00	2.80	2.80	97.40	4.60	0.622	1.517	1.149			
		Mean	0.00	1.13	1.13	95.20	3.67	0.549	1.342	0.991	0.10		0.02
5	Gravelly sand – gS (n=8)	Min	0.00	0.00	0.00	66.80	5.70	0.435	1.298	0.731			
		Max	0.00	4.70	4.70	93.20	28.50	1.070	2.345	1.926			
		Mean	0.00	1.29	1.29	83.90	14.81	0.726	1.635	1.226	0.79		3.30
6	Sandy-muddy gravel – gmS (n=24)	Min	2.50	15.80	21.00	35.40	8.20	0.147	2.331	0.069	0.05	5.00	4.47
		Max	12.30	33.50	42.00	64.80	29.80	0.793	13.862	1.486	6.18	6.00	9.83
		Mean	6.59	26.31	32.90	45.44	21.66	0.464	8.099	0.276	1.53	5.50	7.56
7	Sandy-muddy with gravel – (g)mS (n=9)	Min	0.00	8.80	12.80	52.30	1.90	0.126	1.379	0.140	27.00		
		Max	16.00	33.50	45.20	85.30	4.50	0.560	6.714	0.813	36.73		
		Mean	5.48	21.22	26.70	70.60	2.70	0.259	3.030	0.521	31.86	3	4.43
8	Silty sand – siS (n=9)	Min	2.70	15.30	18.70	62.80	0.00	0.130	1.341	0.131	0.04		
		Max	11.30	28.30	37.20	81.30	0.00	0.343	4.587	0.721	15.00		
		Mean	6.57	23.63	30.20	69.80	0.00	0.187	2.958	0.320	7.52	2	4.34
9	Muddy sand – mS (n=14)	Min	2.30	9.40	11.70	50.10	0.00	0.065	1.442	0.069	0.17		0.85
		Max	24.30	39.90	49.80	87.70	0.90	0.383	8.072	1.229	23.00		13.72
		Mean	11.76	27.41	39.16	60.49	0.34	0.143	4.477	0.310	4.53	5	8.59
10	Muddy gravel – gM (n=26)	Min	7.90	24.50	39.10	6.40	5.30	0.009	4.177	0.107	0.06	3	0.32
		Max	38.70	47.80	83.60	39.30	29.10	0.435	17.962	13.697	37.00	4	77.10
		Mean	20.50	34.83	55.33	27.10	17.57	0.136	11.418	2.650	9.00	3.5	24.66
11	Muddy sand – sM (n=17)	Min	16.90	26.30	50.80	10.20	0.00	0.003	4.033	0.311	0.18	4	2.03
		Max	54.00	48.10	89.80	49.20	0.80	0.056	7.352	2.079	35.00	5	6.26
		Mean	37.11	37.42	74.52	25.43	0.05	0.019	5.582	0.952	15.55	4.5	4.15
12	Mud – M (n=67)	Min	32.70	33.90	73.80	1.30	0.00	0.003	2.978	0.415	0.14	4	1.51
		Max	58.60	55.80	98.70	22.40	4.10	0.013	6.496	2.692	41.00	7	62.47
		Mean	45.29	48.47	93.75	6.00	0.25	0.006	3.938	0.926	24.98	4.82	15.28

(Min = Minimum; Max = Maximum; Mean (TB) = Average; C = Clay (%); Si = Silt (%); M = Mud (%); S = Sand (%); G = Gravel (%); Md = Mean grain size (ϕ); So = Sorting; Sk = Skewness; Q = Quartz (%); Fel = Feldspar (%); R = Rock fragments (%); Bio = Biogenic fragments; n = grain-size samples)

The sedimentary facies exhibit a distinct spatial distribution, reflecting different hydrodynamic and bathymetric conditions:

- Coarse-grained sediments (gravel, gravelly sand, sandy-muddy gravel) are predominantly distributed in the eastern to southeastern areas of the island, at water depths of 10–45 m, corresponding to steep bathymetric zones, exposed bedrock areas, and coral reef regions.

The main sedimentary material consists of biogenic fragments (mollusk shells and coral), with a low content of lithogenic material.

- Transitional sediments (sandy mud, silty sand, sandy silty gravel) are distributed on gently sloping seabed areas at average depths of 30–50 m, showing a mixture of biogenic and lithogenic materials.

- Fine-grained sediments (mud, muddy sand, muddy gravel) are widely distributed in the West–Northwest area of the island at depths >40 m, where the seabed is relatively flat and hydrodynamic conditions are weak, favoring the deposition of fine material.

Overall, sediment parameters indicate sorting ranging from moderate to poor, with skewness predominantly toward fine grains, reflecting deposition under conditions strongly influenced by marine hydrodynamics. Mineralogical composition shows that the sediments are primarily of biogenic origin, with shell fragments dominating, while quartz, rock fragments, and feldspar occur at lower proportions.

3.2. Discussion

a. Sediment distribution patterns and the role of seabed topography

The distribution of surface sediments in the Con Co island waters exhibits pronounced spatial differentiation, strongly controlled by seabed morphology and geomorphology. Seabed topography is the primary factor governing the spatial distribution of surface sediments in the study area.

- The West–Northwest region features a relatively flat seabed at greater depths (>40 m), favoring the deposition of fine material. Sediments in this area are characterized by small grain sizes ($Md \approx 0.006\text{--}0.019\text{ mm}$) and poor sorting, reflecting a low-energy environment dominated by depositional processes.

- The East–Southeast region of Con Co has complex seabed geomorphology, including steep slopes, depressions, and erosional features. This morphological differentiation favors coarse-grained and mixed sediments while limiting the accumulation of fine material.

The widespread occurrence of basalt bedrock and surrounding coral reefs provides a local source of sediment, particularly contributing to biogenic fragments.

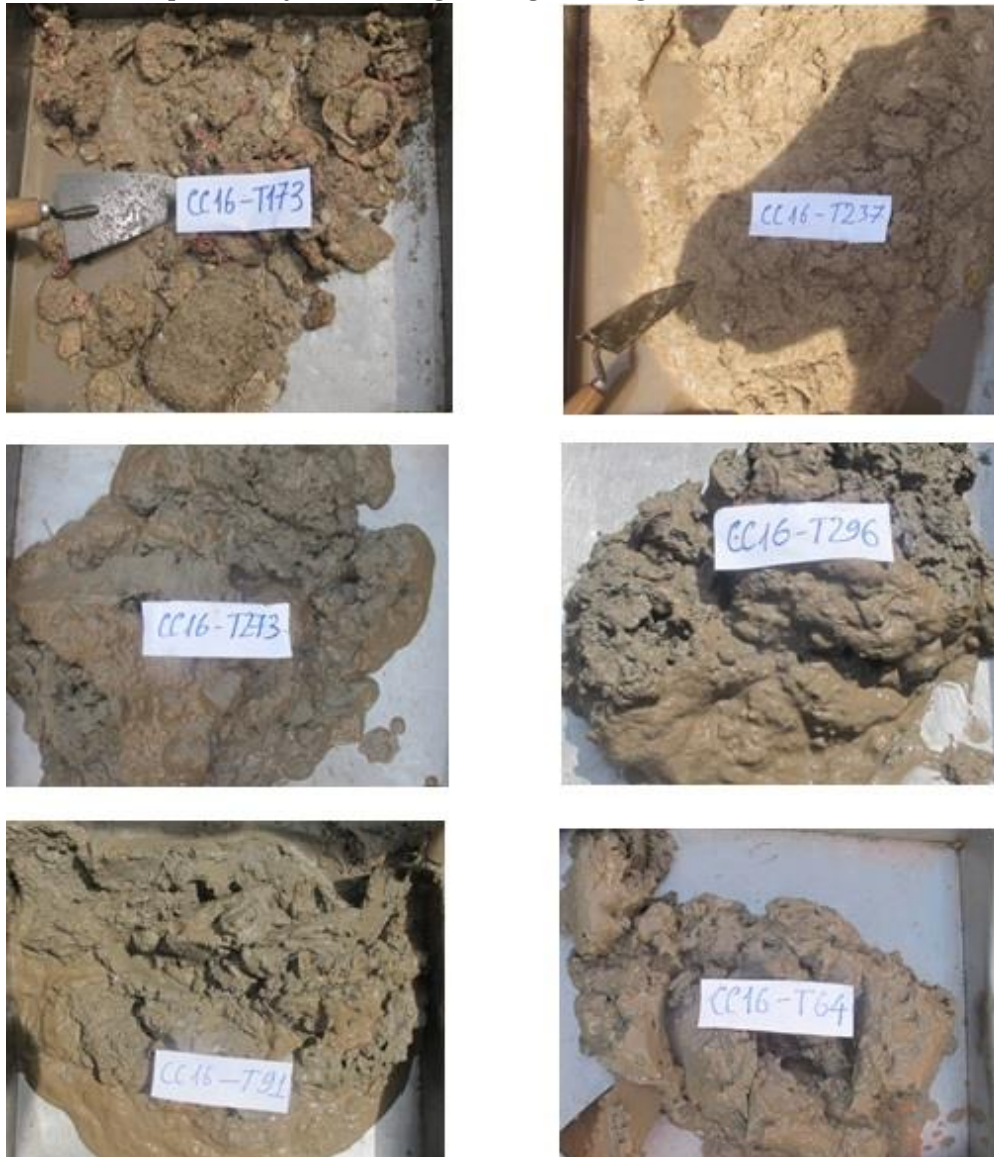


Figure 5. Sediment types from the Con Co Island sea area: (a) gray to light gray sandy gravel with abundant shell fragments at station CC16-T173; (b) gray to yellowish-gray sand at station CC16-T269; (c) gray to grayish-green silty sand at station CC16-T273; (d) gray to gray-green-brown sandy silty gravel at station CC16-T296; (e) gray to gray-green cohesive clay at station CC16-T91; (f) gray to gray-green cohesive clay at station CC16-T64 (Photo: Phan Van Binh).

b. Influence of marine hydrodynamics

Hydrodynamic factors such as waves, wind, and seasonal currents play a decisive role in sediment transport and sorting.

- The East–Southeast area is strongly influenced by waves and currents, especially during the northeast monsoon, which enhances the winnowing of fine particles and the accumulation of coarse grains.
- In contrast, the West–Northwest area experiences lower-energy conditions, conducive to fine sediment deposition.

This contrast highlights the general distribution pattern: This pattern is consistent with the fundamental principle of sediment hydrodynamic sorting: high-energy environments favor the selective removal of fine particles and the residual accumulation of coarse-grained sediments, while low-energy environments promote the deposition of fine-grained material. The study area, and the central Vietnamese coast in general, experiences pronounced seasonal variability in wind, waves, and currents, with north-to-south flow in winter and the reverse in summer. These hydrodynamic factors strongly control sediment sorting and deposition.

c. Sediment provenance and depositional environment

Mineralogical analysis indicates that sediments in the study area have a mixed origin:

- Biogenic source (dominant): coral fragments, mollusk shells, marine organisms (20–70%).
 - Lithogenic source (secondary): quartz (4–32%), rock fragments (3–9%), feldspar (very minor).
- These characteristics reflect a mixed-source nearshore depositional environment. The dominant biogenic fraction, derived from in situ carbonate production by coral reefs and mollusks, indicates that local biological productivity is the primary sediment contributor. The subordinate lithogenic fraction, comprising quartz, rock fragments, and trace feldspar, suggests a secondary terrigenous input likely transported by coastal currents from mainland river systems and reworked from relict sediments deposited during lower sea-level stands.

Modern sediment formation has also been influenced by past sea-level changes, particularly the Last Glacial Maximum (LGM) and the Holocene transgression, which shaped the seabed morphology and current depositional conditions.

d. Scientific and practical significance

Scientific significance:

- Clarifies the distribution patterns and provenance of surface sediments, providing a basis for reconstructing modern and paleo-depositional environments in the region.

Practical significance:

- Supports marine resource exploration, including construction materials and reclamation projects.
- Aids in marine environmental assessment, especially regarding pollutant accumulation in fine-grained sediments.
- Contributes to predicting marine geological hazards and informs sustainable coastal and island management.

4. Conclusions

The Con Co island waters are characterized by 12 surface sediment facies with complex spatial distributions, reflecting the interaction between seabed morphology and marine hydrodynamic conditions.

Coarse-grained sediments are primarily distributed in the East–Southeast sector, associated with high-energy environments and locally derived biogenic material. In contrast, fine-grained sediments are concentrated in the West–Northwest sector, where low-energy conditions and relatively flat seabed topography favor the deposition of fine material.

Mineralogical composition indicates that the sediments are predominantly of biogenic origin, supplemented by a minor contribution from lithogenic sources. The distribution and characteristics of these sediments are strongly influenced by seasonal variations in waves, wind, and currents, as well as past sea-level fluctuations.

These findings provide a critical scientific basis for marine geological research, resource management, and environmental protection in the Con Co island waters.

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