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Geological characteristics of the Cua Dai beach zone by geophysical data and the relation to the regional accretion - erosion phenomenon

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ABSTRACT

This study presents some research results on the relationship between the geological environment of the surface layer and the level of modern tectonic activity in the sea waters of the Hoi An - Cua Dai area based on the interpretation of high-resolution shallow seismic data combined with the surface sediments' grain-size analysis and other available data sources. The results show that the surface geological environment in the coastal waters North of the Thu Bon river fault is influenced by modern tectonic activities, believed to be a part of causing geological catastrophic events.

Keywords: Accretion, erosion, Hoi An - Cua Dai.

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INTRODUCTION

Erosion - accretion in the coastal zone are normal geological processes, taking place regularly under the combined influence of internal, exogenous, and anthropogenic factors according to specific rules. However, when these phenomena occur abnormally, beyond the control of humans, they can be considered a form of geological hazard, which needs to be studied in detail and comprehensively to determine the cause, origin, evolution, and influence on human life.

In the past 10 years, the coast of Hoi An has been strongly eroded, causing severe landslides. On average, each year, the sea penetrates the mainland from 10–15 m on a length of about 2 km. Besides, a dune with an area of about 15 hectares floating up to 2 m high right at a distance of 1.5 km outside Cua Dai just a few years ago has become an unusual phenomenon, attracting the attention of managers as well as scientists at home and abroad [1–5]. Many projects and projects have clarified the origin and mechanism of formation of this type of geological hazard, mainly focusing on exogenous causes, including river and sea dynamics, marine and marine dynamics, meteorology, hydrogeology, etc., [6, 7] as well as human impacts such as the construction of hydroelectric dams and over-exploitation of sand upstream. Studies on endogenous origin, including geology, geomorphology, and tectonics, have also been interested in research [8, 9] but mainly on the mainland and are still limited in number, the extent of detail, and quantification.

STUDY AREA AND MATERIALS

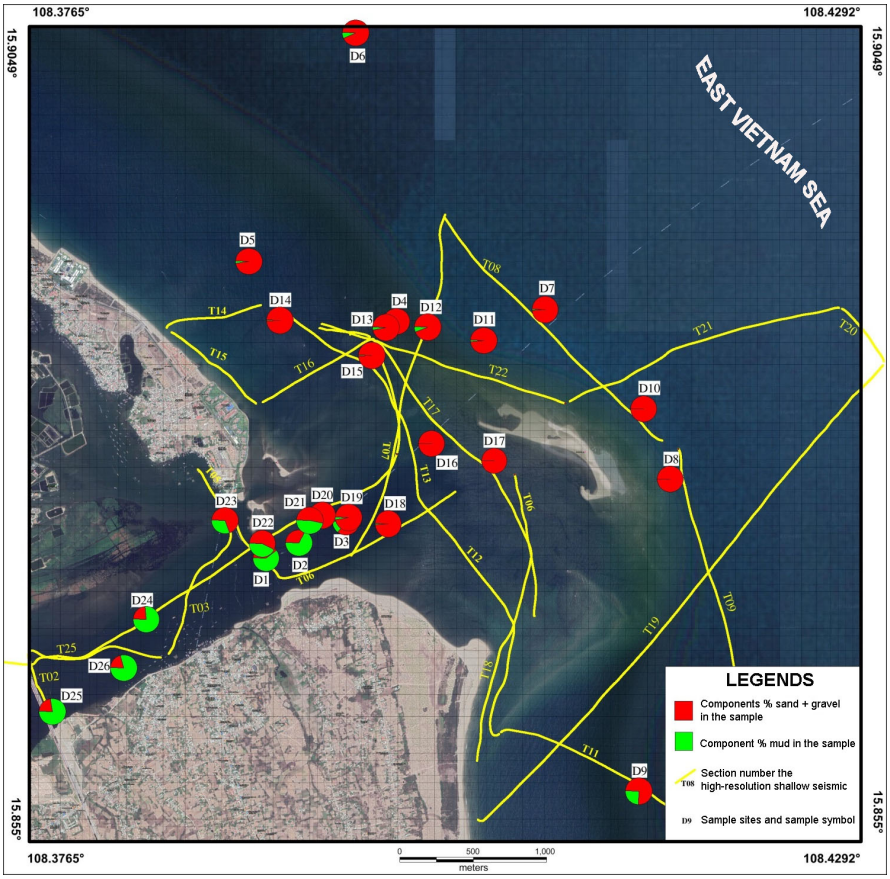

Figure 1. The HRSS profile, sampling sites, and surface sediments' grain-sized compositions of the study area

The study area ranges from 15.855°N, 108.370°E to 15.895°N, 108.435°E (Fig. 1), including the entire most severely eroded coastal area and the estuary area of Thu Bon (Cua Dai) with unusually fast floating sand islands. The data source is mainly based on high-resolution shallow seismic survey data (HRSS), a widely used method in research studies. marine geology [10–12]. A Boomer system with 500 J capacity, pulse period 0.5 s, sampling step 0.1 ms according to designed survey routes in a network designed to survey the overall modern geological - tectonic context in the area (Fig. 1). Simultaneously, 26 surface sediment samples were collected for grain-size analysis using the laser method on the Horiba LA-960 particle analyzer to assess the trend of transporting mud and sand from the estuary to the sea (Table 1). In addition, other available geophysical data sources are used for comparison and contrast to improve the reliability of the HRSS data analysis.

Table 1. Results of grain size analysis of sediments in the study area

Sample ID	Sediment	Gravel (%)	Sand (%)	Mud (%)	Average size (mm)
D1	Sandy mud	0	40.3	59.7	24.33702
D2	Sandy mud	0	33.2	66.8	16.9551
D3	Muddy sang with minor gravel	0.3	84.5	15.1	538.02686
D4	Sand	0	98	2	361.01889
D5	Sand	0	97.3	2.7	333.82587
D6	Sand	0	92.8	7.2	320.95065
D7	Sand	0	98.8	1.2	261.11209
D8	Sand	0	100	0	245.99234
D9	Muddy sand	0	75.2	24.8	96.71584
D10	Sand	0	100	0	430.98071
D11	Sand	0	98.1	1.9	231.22581
D12	Sand	0	93.5	6.5	213.76706
D13	Sand	0	96.3	3.7	297.14267
D14	Sand	0	99.2	0.8	301.94662
D15	Sand	0	99.3	0.7	265.24438
D16	Sand	0	100	0	454.46133
D17	Sand	0	100	0	433.34512
D18	Sand	0	98.5	1.5	365.55722
D19	Sand	0	96.7	3.3	518.46313
D20	Sand	0	96.9	3.1	189.60609
D21	Muddy sand	0	53.6	46.4	65.52124
D22	Muddy sand	0	57.8	42.2	78.32758
D23	Muddy sand	0	69	31	102.90396
D24	Sandy mud	0	24	76	15.62735
D25	Sandy mud	0	22.9	77.1	13.74646
D26	Sandy mud	0	20.9	79.1	14.41396

ANALYTICAL RESULTS

The HRSS data include 26 cross-sections with a total volume of over 40 km of the route, processed by the specialized software REFLEXW ver. 6.5, then calibrated and linked in 3D space to improve the accuracy of interpretation results (Fig. 2) [13, 14].

In the framework of this paper, some essential characteristics of modern sedimentary formations on the seabed surface to a depth of 30 m are determined according to the features of the acoustic wave field reflected on the typical seismic sections as follows:

Section T08-T09 (Fig. 3) is located on the Northeast slope of the floating sand island,

showing two different sedimentation environments. The shallowest part of the cross-section (5–6 m of water) represents a depression filled with chaotic, unclassified sedimentary materials, meaning the coarse-grained sediment deposited at the foot of the sand island. The Northern part of the sand island has a robust and bumpy seafloor surface, representing a frequently fluctuating energy-dynamic environment, covering and filling on a continuously discontinuous surface with an oscillation amplitude vertical movement up to several m. In contrast, in the Southern part of the sand island, the seabed surface is relatively flat with thin layered surface sediments with strong reflectance amplitude, which is typical for well-selected sedimentary components deposited in a stable dynamic environment.

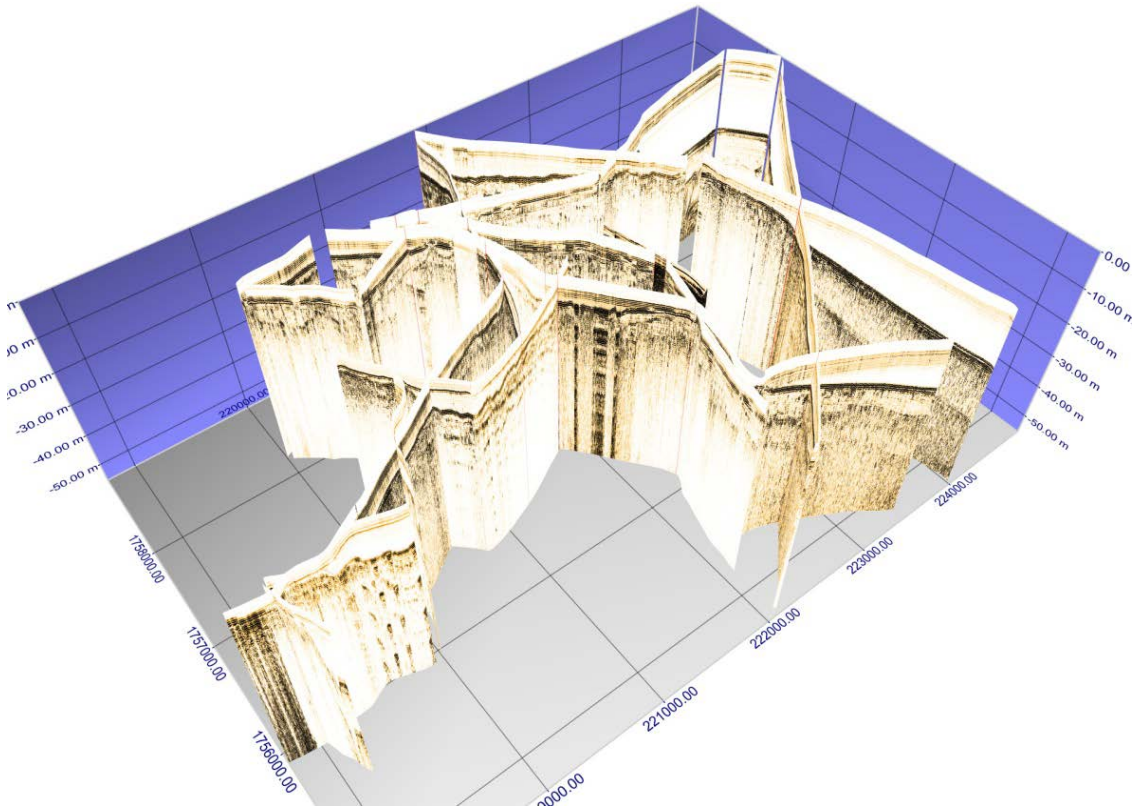

Figure 2. Post-interpretation 3D combination of HRSS profiles of the study area

The seismic section T19 (Fig. 4) has the Southwest-Northeast direction and is located close to the Southeast edge of the estuary dune arc with the position of the floating sand island near the center of the section. On the observed cross-section from the river mouth to the sand island is a low-lying terrain with an elevation difference of 2 m to 3 m. Lying at the foot of the outer sand island exists a high floating underground structure, which acts as a barrier to retain most sedimentary material transported from the Thu Bon river and from the North bank stream. Surface sediments have a relatively flat and thinly layered deposition surface with strongly reflective boundaries, showing a relatively large proportion of clay components. There were almost no signs of shifting stratigraphic boundaries observed below these sediments.

The seismic section T25-T21 (Fig. 5) is located at the northwest edge of the floating sand island; although it is almost parallel to the T19 seismic profile, it has distinctly different manifestations. In the sediment layers close to the surface, it is possible to observe discontinuity and sudden

displacement of sediment boundaries with large vertical amplitude. Outside the sand island, a high-floating underground structure also occurred on the seabed. The top part of the section is sedimentary material (sand) which is retained on a low-lying bottom and raised to form a sand island floating on the sea surface. This amount of sand is almost not transported far, so the outer seabed only exists mainly sediments with high clay content, which are deposited for a long time in the deep-water environment.

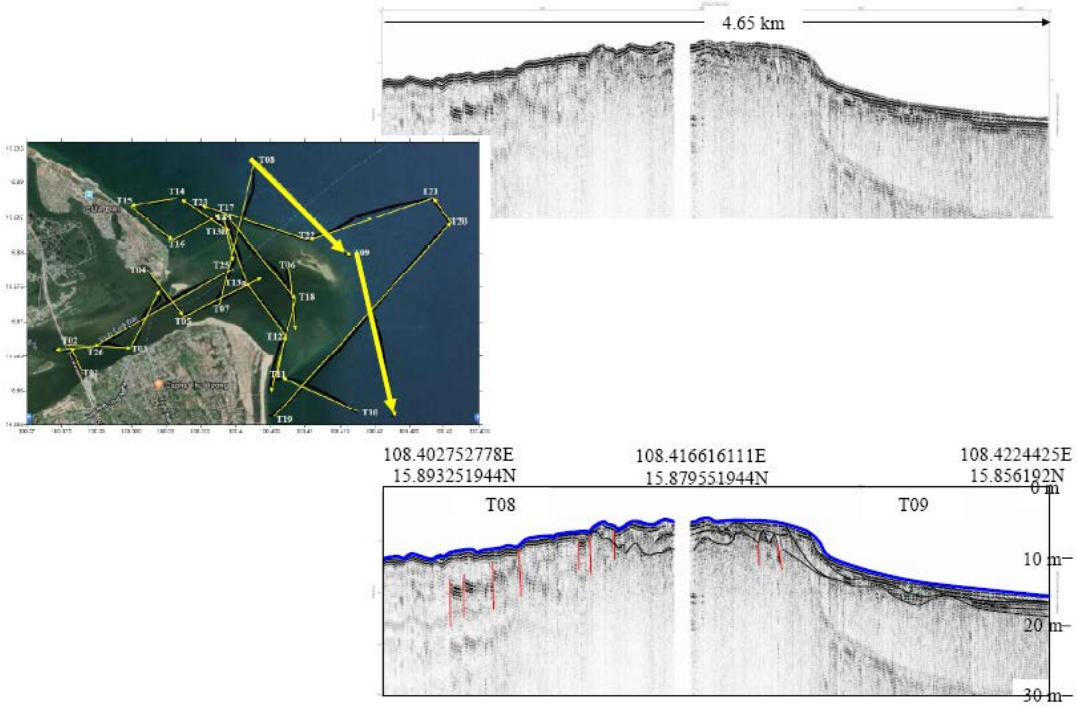

Figure 3. The T08-T09 seismic profile and seismic interpretation

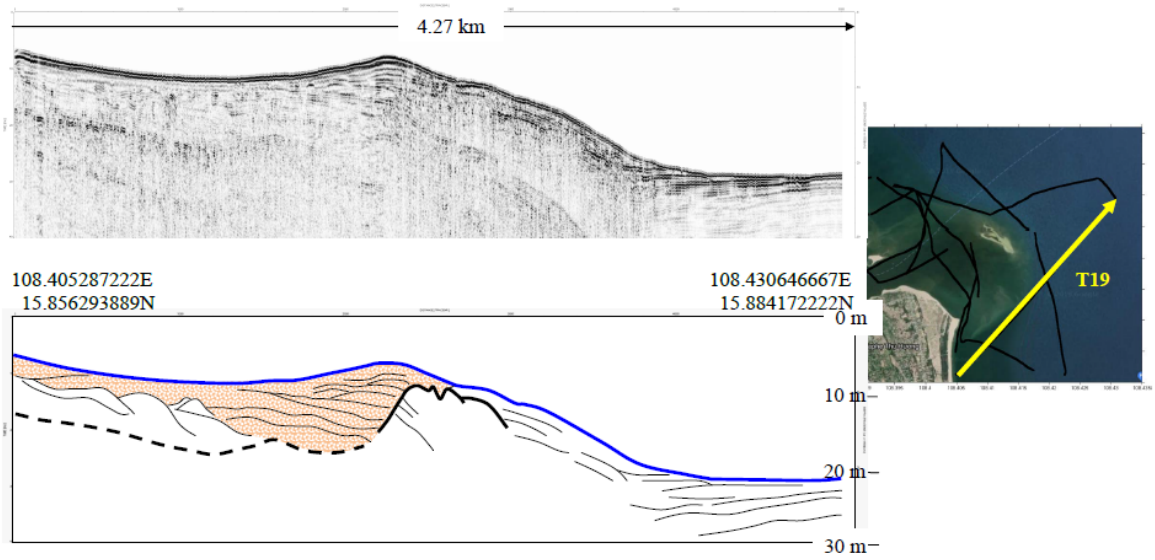

Figure 4. Seismic profile T19 and interpretation

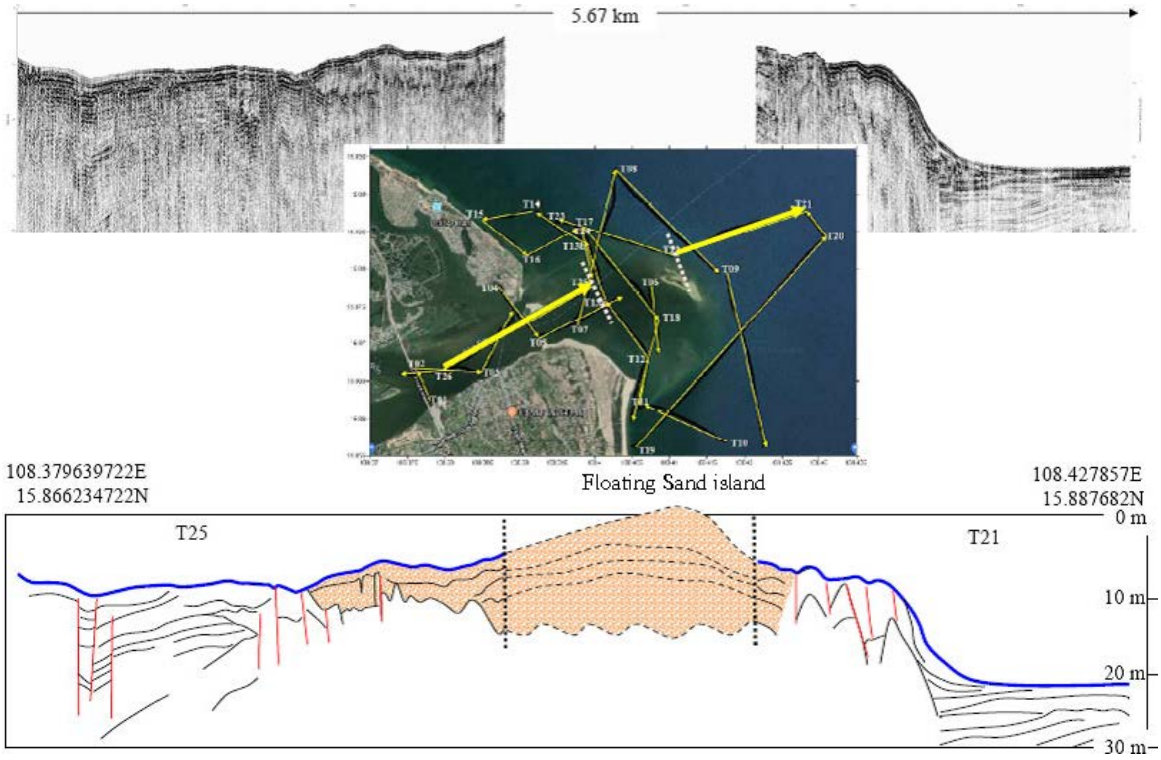

Figure 5. Seismic profile T25-T21 and seismic interpretation

Manifestations of modern tectonic activities are also commonly observed in the sea near the North shore of Cua Dai, in the coastal area of Hoi An, where severe erosion is taking place. Figure 6 shows two parallel sections of the Hoi An shoreline at a depth of only 3–5 m, showing the sediment boundaries below the modern mud and sand formations with a thickness of 5–7 m. The sediments are intermittent, strong vertical displacement, accompanied by the phenomenon of gas columns (determined by the characteristics of not transmitting sound waves and appearing at stratigraphic discontinuities) being released through the fracture zones to penetrate the upper sand layer (Fig. 6C). Although the thickness of the sand layer is small and the composition is relatively uniform; but gas columns still exist, proving that the gas source is quite abundant and continuously replenished.

According to the calculation results of the Bouguer gravity anomaly field (Fig. 7), the study area is divided into two parts with distinctly different density structures. The boundary is a zone of strong gravity gradient fluctuations that lie almost coincident with the fault location of the Thu Bon river. Hoi An coast is located at the edge of a nearly isometric negative anomaly zone with anomalous values reaching over -40 mG, while the position of the floating sand island is right at the boundary between two distinct anomalous zones.

The results of airplane anomaly field calculation (Fig. 8) show a similar picture of the anomaly with the boundary also almost coinciding with the location of the Thu Bon river fault, in which the values The anomaly fluctuates the most with an amplitude of about 200 nT, forming an oval anomaly located right next to the southern coast of the Thu Bon river.

The above analysis results reveal that the study area consists of two geological structural units that differ in physical properties, divided by the Thu Bon river fault. The left bank (Hoi An) shows a high magnetic anomaly field and a low Bouger gravity anomaly field, typical for a sedimentary environment with weak cohesion, low density, and containing magnetic mineral

components. In contrast, the right bank (south of Cua Dai) is characterized by a low-magnetic, high-density structural mass associated with uplifted granite formations near the surface.

The results of the analysis of the grain size of 26 surface sediment samples in the study area show that the surface sediments in the study area consist of three main groups: i) group 1 (sand) consisting of 16 samples; ii) group 2 (mud and sand) includes five samples and iii) group 3 (mud sand) includes four samples of silty sand and 1 sample of low grit sand (Table 1).

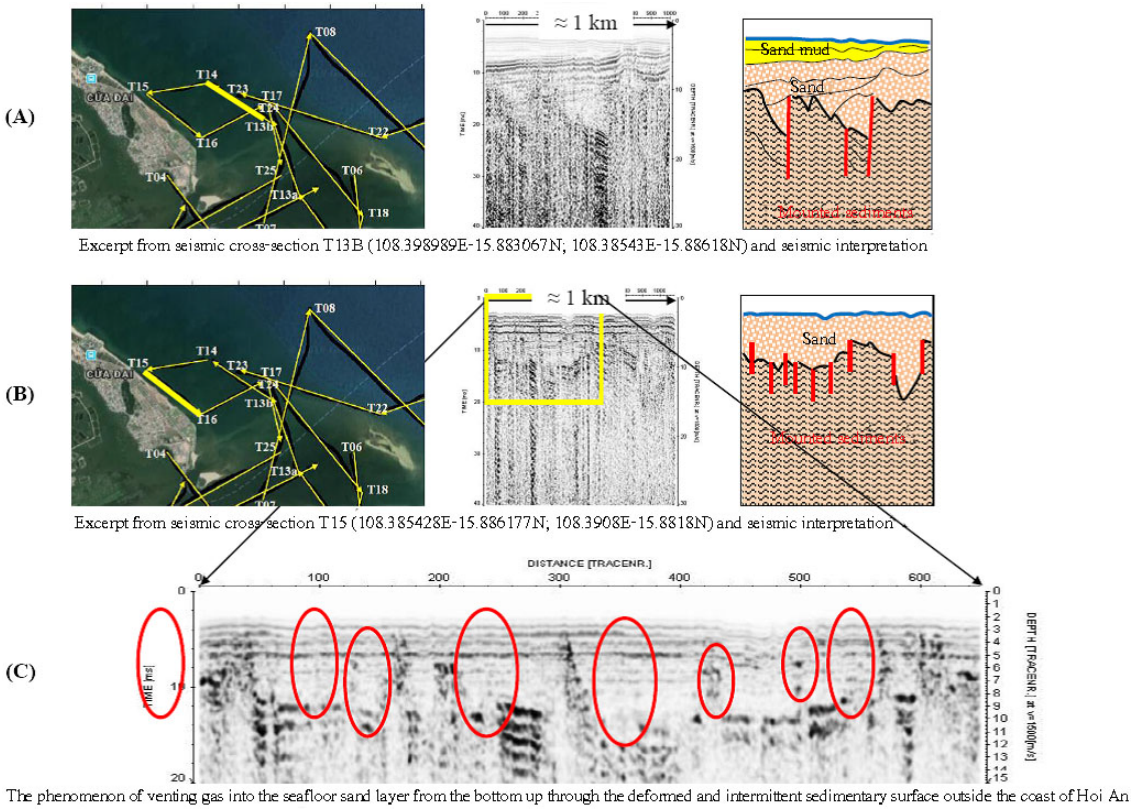

Figure 6. Images of sedimentary boundaries disrupted or shifted are seen in cross-sections T13B (A) and T15 (B) in the Hoi An coastal zone, from where cumulated gases are released from deep layers (C)

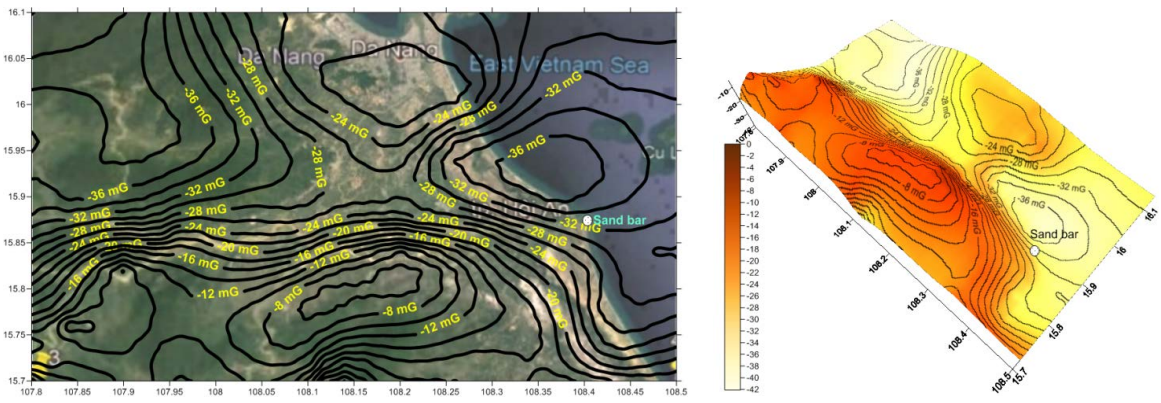

Figure 7. Map of Bouguer gravity anomaly field (mG) of the study area [15]

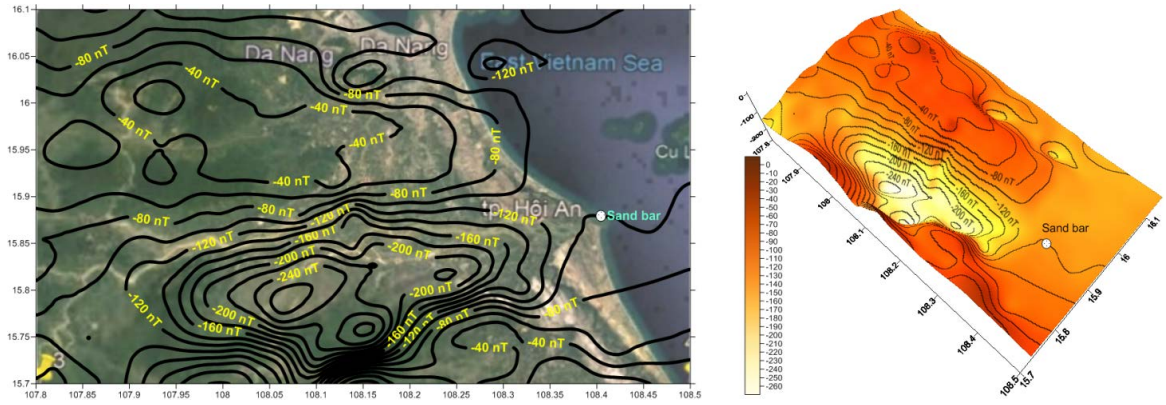

Figure 8. Map of airplane anomaly field (ΔTa) of the study area [16]

Spatially, there is a clear division in composition as follows. Group 1 (sand and muddy sand) is distributed mainly on the left side of the river mouth and around the sand island. Group 2 (sandy mud) is distributed primarily in the river and at the estuary, showing the state of continuous erosion on the left bank of the river (the mud is still in the form of clumps that have not been destroyed and mixed with the sand in sample D3). The sediment is pushed out under the strong influence of the estuary dynamics, the location of the sand island is where the estuary dynamics no longer prevail, and the accreted right bank will be where the slurry-like material is introduced on sample point D9.

DISCUSSIONS AND CONCLUSIONS

Cua Dai - Hoi An estuary is one of the critical locations for Quang Nam province in terms of socio-economic aspects (tourism, navigation, fishing, etc.). The phenomenon of unusual geological environment fluctuations in a recent short time in this area is a concern of local management levels and domestic and international scientists. Many research works have been carried out to determine the causes and mechanisms of sand island formation, thereby serving as a scientific basis for solutions to prevent and mitigate natural disasters and orient the overall planning and recovery for sustainable and stable development for the locality.

As mentioned above, exogenous factors play a crucial role in forming and developing estuary dunes. However, it is also impossible not to consider the impact of endogenous factors on these subjects.

According to the analysis of high-resolution shallow seismic survey data and the distribution of surface sediment fields in the Cua Dai - Hoi An area, it is possible to identify the marine geological environment of Thu Bon river mouth (Cua Dai). These include floating sand islands formed and developed in an area with a specific recent tectonic mode of activity and still have complicated developments. The level of recent tectonic activity in the area is generally divided into two regions, corresponding to the Bouger gravity anomaly and airplane anomaly: (i) the stabilization zone on the right bank of the Thu Bon river and (ii) the area of modern tectonic activity on the left bank of Thu Bon River, including the coastal zone of Hoi An with the fact that the manifestations of faults, stratigraphic discontinuities with different degrees in the strata sediments close to the seabed, overshadowed by the modern seabed sediment cover with weak cohesion, frequently re-deposited and leveled on the surface. These modern tectonic activities are believed to be the cause of localized processes of spreading, subsidence, and deterioration in the surface sediments, which are considered one of the causes of the geological hazards in the area. However, to conclude with a scientific and objective basis, it is necessary to continue to

analyze and interpret the collected documents in detail, and at the same time, more studies are needed to be more comprehensive and in-depth.

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