

The flattened seabed characters at the nearshore islands of Vietnam

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Abstract

Flattened seabed characters at the nearshore islands, namely Bach Long Vi, Con Co, Ly Son, Phu Quy, Hon Khoai and Tho Chu, were analysed based on depth contour map with 1 m vertical resolution and the application of ArcMap 10.4 software. Consequently, a series of seabed cross sections was automatically created by using the software, which provides the time-saving benefit and improves the scientific relevance. The result shows that flattened seabed characters of those islands were comparable in terms of general pattern, but still remained some distinctions depending on particular location. The depth of flattened seabed levels does not reach 30–50 m depth at northern and southern Vietnam's sea (seabed surrounding Bach Long Vi, Hon Khoai, Tho Chu islands), while the value reaches over 100 m depth at southern central Vietnam's sea (seabed surrounding Ly Son, Phu Quy islands). The classification of flattened seabed reveals the following depth levels: 0–2 m, 5–8 m, 12–14 m, 20–25 m, 25–27 m, 27–30 m, 32–35 m, 40–45 m, 45–50 m, 53–55 m, 60–65 m, 65–70 m, 75–85 m and 90–115 m.

Keywords: Flattened seabed, Vietnamese islands.

INTRODUCTION

One of the topographic characters of earth surface in general and seabed in particular is flattened surface feature. The analyses of flattened landscaped character were necessary objects of geomorphological research, and it can be said to be a component of fundamental geomorphology study. The land surface topology in general and their flattened characters in particular were the result of cumulative impacts caused by endogenous and exogenous processes formed the landscape, which include the sea level oscillation and tectonic movement factors.

The previous literature on flattened seabed at Vietnam's sea was rare and poorly detailed. The main reason is due to the low resolution of depth data, while a flattened seabed seems to be small in size, which causes more difficulties in observation and measurement, especially in comparison with mainland research. Another limitation is due to the lack of confidence researches on flattened surface forming dynamics. There are some results of previous literature dealing with flattened surface, which are involved in some geomorphology and sedimentology researches, however their depth range of a flattened surface was so wide. Such as, Vo Thinh [1] carried out flattened surface classification, including: 10–15 m, 25–30 m, 50–60 m at seabed area surrounding Con Co island; and 10–20 m, 20–30 m, 30–50 m, 50–60 m, 60–80 m and >80 m at seabed area surrounding Ly Son island; and < 5 m, 5–20 m, 20–30 m, 30–50 m, 50–60 m, 80 m, 95–100 m at seabed area surrounding Phu Quy island; 4–5 m, 25–30 m at seabed area surrounding Hon Khoai island; and 5–15 m, 15–20 m, 30–40 m at seabed area surrounding Tho Chu island. The other authors, such as Tran Duc Thanh [2] conducted a classification at surrounding Bach Long Vi island, including: 0–7 m, 7–10 m and > 10 m. Nguyen The Tiep [3] also pointed out a classification of flattened seabed at Vietnam's continental shield, in which the depth range of a flattened surface was about dozen meters.

In general, seabed character at surrounding nearshore islands is predominantly steeply

sloping, but there is also the appearance of some flat/gentle slope surfaces, which are only determinable in the case of using high resolution depth data obtained in recent time. The flat surfaces appear at different depth levels, which possibly correspond to geomorphologic development cycles. In response to the certain situation, the paper deals with flattened seabed characters at some island regions, which are representative of the nearshore island system in the continental shelf of Vietnam, including: Bach Long Vi, Con Co, Ly Son, Phu Quy, Hon Khoai and Tho Chu (fig. 1).



Figure 1. Scheme of research areas

Based on ArcMap application and high resolution bathymetry data, the research generated a series of seabed cross sections, which were used for determination of flattened seabed steps for each section, each region, and further for comparison among them.

METHODOLOGY

The flattened seabed steps were defined by the relative flat surfaces on the seabed cross sections. In certain circumstance, the result

may show several flattened seabed steps at different depth levels, and steep slope is usually located between those surfaces. The flattened seabed character is one of the morphological characters of an area, and the methodology of studies dealing with that subject belongs to fundamental geomorphological research field. In previous literature, the flattened seabed analysis was done by visual interpretation of bathymetry maps or cross sections.

This paper also deals with the above principle, however with the help of ArcMap 10.4 application. By that way, the study saved time of section creation, which resulted in the increase in volume of work (the number of cross sections), and also improved the certainty level of data analysis.

In general, the analysis of landform was based on topology map, and the study's data was obtained by bathymetry map with 1 m depth resolution, created by Centre of Sea Observation and Mapping, Vietnamese National Marine and Island Services. That is the most detailed observation data of Vietnam's seabed so far.

The procedure for analysis includes 2 steps: a) 1st step (generating cross-sections): digitizing detailed bathymetry data at seabed regions surrounding islands for bathymetry mapping and creating DBM (digital bathymetry map) in an ArcMap database; determining the number of cross sections and their orientation based on expert methodology, taking into consideration the area's size and their complexity in order to represent the flattened seabed characters (e.g. for the small islands such as Bach Long Vi, Con Co with circle shape, simpler seabed morphology, so five cross sections are needed; but for larger and more complex area such as Tho Chu, seven cross sections are needed); using the module cross section in ArcMap software, version 10.4 for generating cross sections for visual interpretation of flattened seabed characters. The number of flattened seabed steps and their depths for each island were scientific basis for analyses and comparison among them. b) 2nd step (determining flattened seabed steps):

determining flattened seabed step (almost flat surface) was typically based on expert method, in which the longer the flattened surface presented on cross section, the more stable the forming dynamic regime as well as the higher the conservative level, statistic number of flattened seabed steps and their corresponding depths according to each cross section and each seabed location. The conservative degree of a steepened surface had inverse relationship with the strength of deforming processes and the duration time since it formed. For that reason, the comparison among those locations must be done in the sense of remaining objects with some unclarified elements.

RESULTS

Bach Long Vi island's seabed

General morphologic characters of the local seabed: the island is located at central region of Tonkin Gulf (figs. 1–2). It is an offshore island with small land area, dominated by hilly landform with an average altitude of 60 m, and those hills follow northeast - southwest direction. The seabed surface is steeper at eastern and western parts in comparison with southern and northern parts. As consequence, seabed's depths increase more rapidly at eastern and western parts in comparison with northern and southern parts of the island; in addition, the seabed is also characterized by relatively flattened surface character (fig. 2).

The flattened seabed steps: the analysis of cross sections as shown in figure 2 represented the flattened levels, including 0–3 m, 9–15 m (BLV1 section); 40–42 m and 46–48 m (BLV2 section); 0–2 m, 40–47 m (BLV3 section); 7–8 m, 13–14 m and 31–32 m (BLV4 section); 8–9 m, 15–16 m and 20–23 m (BLV5 section); 8 m, 14 m and main part of 32–33 m (BLV6 section).

In summary, the clearly visible flattened seabed steps surrounding Bach Long Vi island include 20–23 m (BLV5 section), 32–33 m (BLV6 section), 40–47 (BLV3 section) and 46–48 m (BLV2 section). The synthesis levels for the whole seabed area include 0–3 m, 6–15 m, 20–25 m, 32–33 m and 40–48 m.

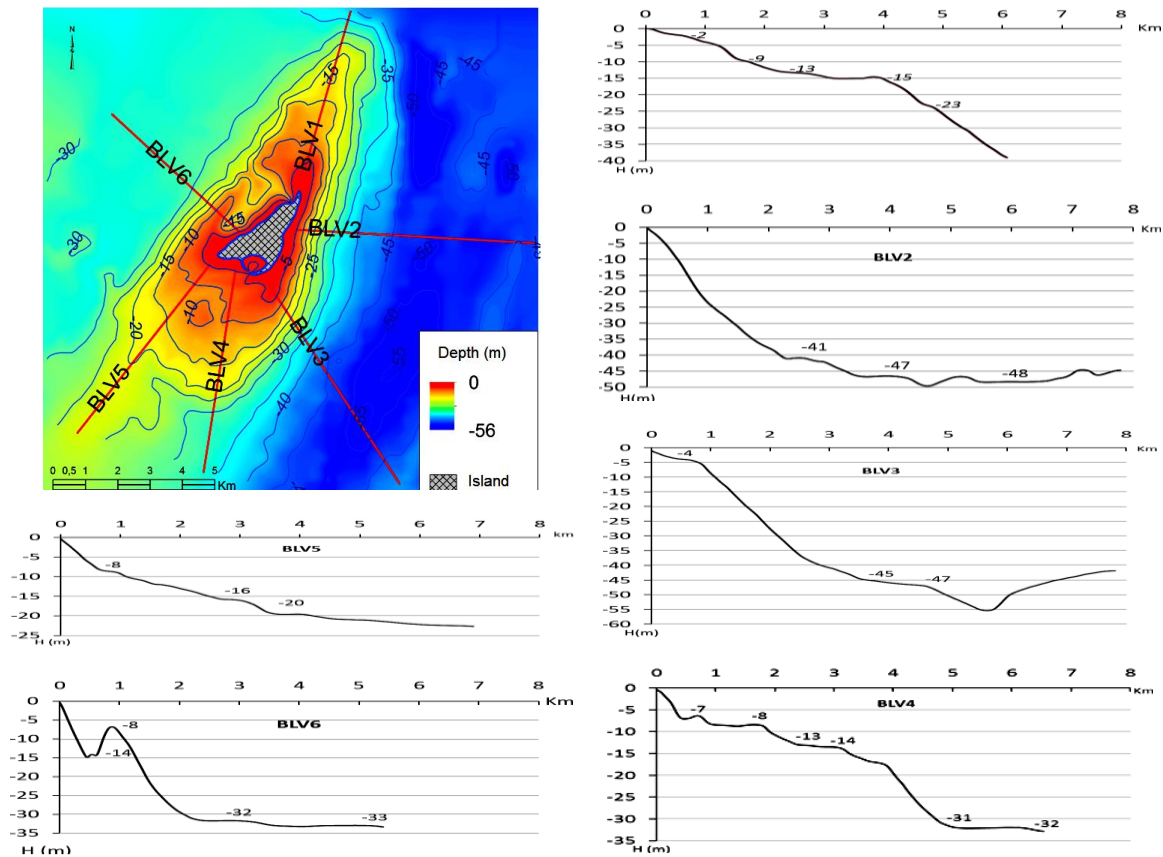


Figure 2. Section situation and seabed cross sections surrounding Bach Long Vi island

Con Co island's seabed

General morphologic characters of the local seabed: The island is a nearshore island belonging to Quang Tri province, 27 km eastward from Lay foreland and 28 km far from Cua Tung harbor. The island's landform is simpler, including some remained volcanic craters, flat basaltic eruption surface, sea-wind accumulation bodies. The seabed is dominated by steep slope, but also clearly shows the flattened step character, particularly in the east of the island.

The flattened seabed steps: Fig. 3 represented the results of analysis of several cross sections, which pointed out some flattened seabed steps, including 32–35 m and 37–40 m (CC1 section); 12–14 m, 32–35 m and 48–52 m (CC2 section); 0–2 m, 29–30 m and 44–48 m (CC3 section); 0–3 m, 26–27 m, 34–35 m and 49–52 m (CC4 section); 32–34 m and 50–52 m (CC5 section).

In summary, the clearly visible flattened seabed steps surrounding Con Co island include 32–35 m (CC1 and CC5 sections), 44–48 m (CC3 section), 48–52 m (CC2 and CC5 sections). The synthesis levels for the whole seabed area include 0–2 m, 12–14 m, 27–30 m, 32–35 m, 38–40 m, 44–48 m, 48–52 m.

Ly Son island's seabed

General morphologic characters of the local seabed: Ly Son island is an onshore island, 25 km eastward from Sa Ky river's mouth and 350 km southwestward from Hoang Sa archipelago. If taking into consideration both the island and its surrounding region, the local morpho-structure shows a highland feature with average altitude of 100 m, that rises up over the present sea level, and the highland slope was submerged under the present sea level. The flattened seabed steps were clearly visible, particularly at seabed surrounding Cu Lao Re island.

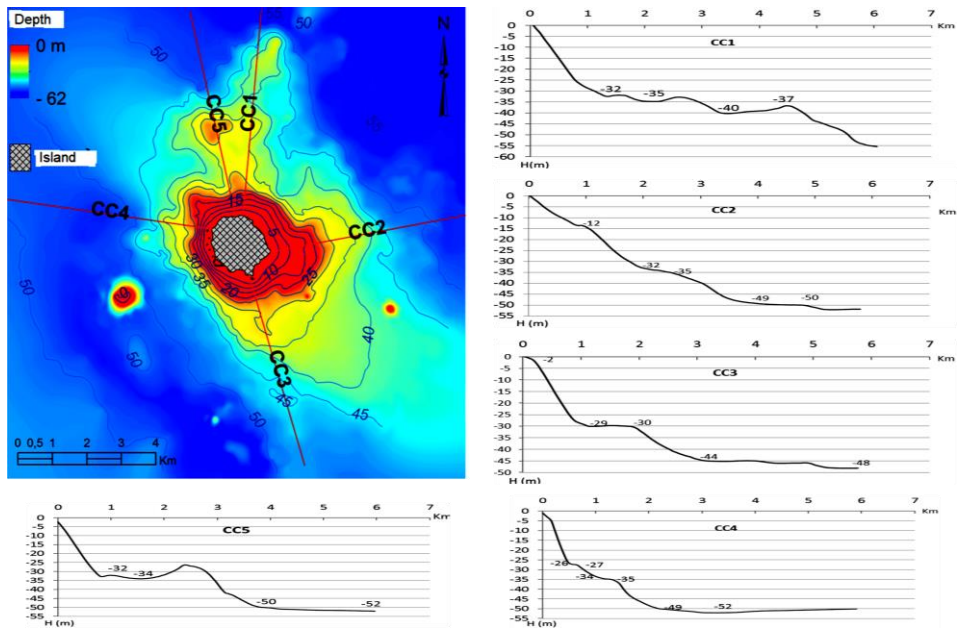


Figure 3. Section situation and seabed cross sections surrounding Con Co island

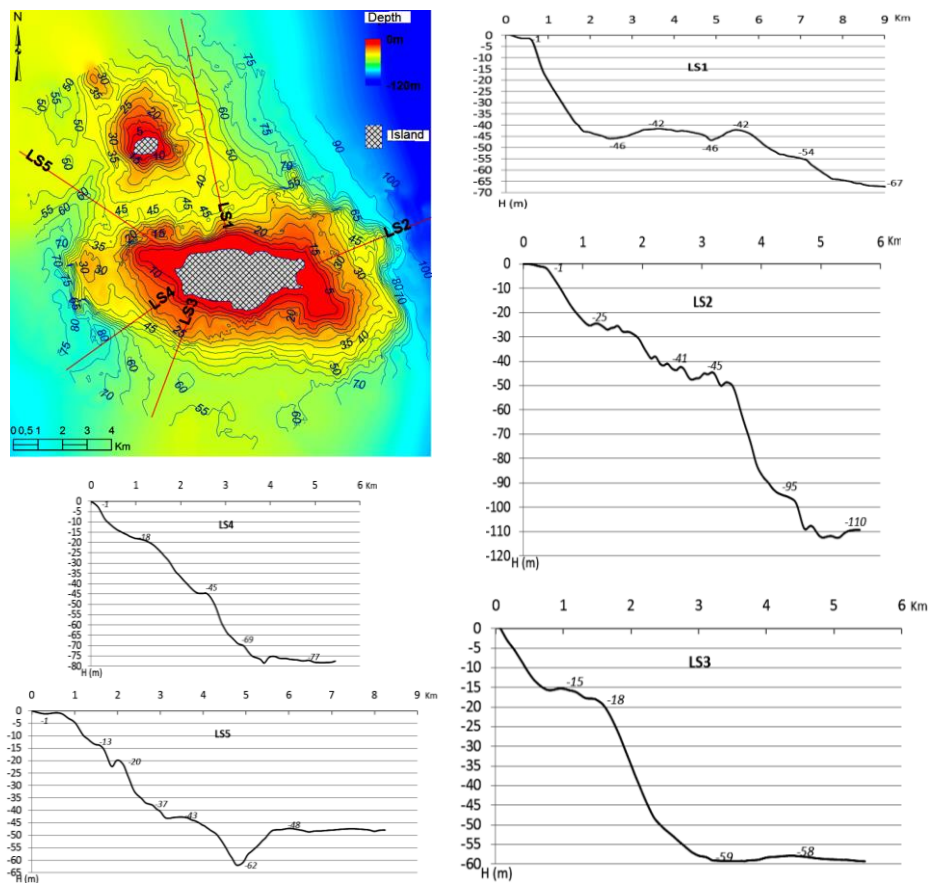


Figure 4. Section situation and seabed cross sections surrounding Ly Son island

The flattened seabed steps: Fig. 4 represented the results of analysis of several cross sections, which pointed out some flattened seabed steps, including 0–1 m, 42–46 m, 53–55 m and 65–67 m (LS1 section); 0–2 m, 25–28 m, 40–50 m, 90–95 m and 95–115 m (LS2 section); 15–20 m and 50–60 m (LS3 section); 15–20 m, 45–50 m, 65–70 m and 75–80 m (LS4 section); 0–2 m, 12–14 m, 20–23 m, 36–37 m and 43–48 m (LS5 section).

In summary, the clearly visible flattened seabed steps surrounding Ly Son island include 43–48 m (LS1, LS5 sections), 40–50 m (LS3 section), 50–60 m (LS3 section), 43–48 m (LS5 section). The synthesis levels for the whole seabed area include 0–2 m, 12–14 m, 15–20 m, 20–23 m, 25–28 m, 36–38 m, 44–45 m, 47–49 m, 53–55 m, 65–70 m, 75–80 m and 95–115 m.

Phu Quy island’s seabed

General morphologic characters of the local seabed: Phu Quy island (belonging to Phu Quy district, Binh Thuan province) is a nearshore island, 100 km southeastward from Phan Thiet city. The district consists of a number of islands

and Phu Quy island is the biggest one with the area of approximately 16 sq.km. Landform of the island is characterized by mountainous, hilly features and some coastal terraces. The island’s altitude gradually decreases from northern to southern parts. The seabed surrounding the island may reach the depths of 200–500 m, it was mainly formed by basaltic rocks, and the remaining part was formed by coral reefs, coral arcs. The local seabed was highly distinguishing in accordance with its seaward directions, steep in the eastward and southeastward directions from the island and relatively gentle in other directions (fig. 5).

The flattened seabed steps: Fig. 5 represented the results of analysis of several cross sections, which pointed out some flattened seabed steps, including 0–2 m and 21–25 m (PQ1 section); 10–15 m, 49–50 m, 59–61 m, 67–68 m, 75–76 m and 80–83 m (PQ2 section); 6–8 m, 25–27 m, 30–32 m, 41–45 m, 47–48 m and 63–65 m (PQ3 section); 0–5 m, 19–20 m, 28–32 m and 40–45 m (PQ4 section); 2–4 m, 7–9 m, 17–20 m, 23–25 m and 28–29 m (PQ5 section).

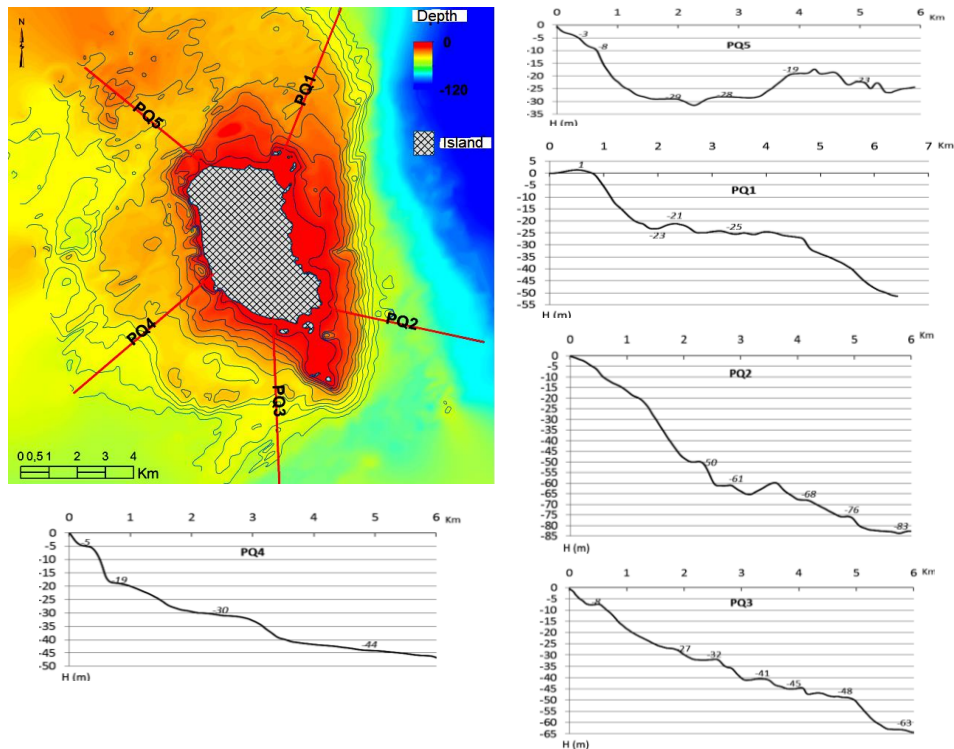


Figure 5. Section situation and seabed cross sections surrounding Ly Son island

In summary, the clearly visible flattened seabed steps surrounding Phu Quy island include 23–25 m (PQ5 section), 21–25 m (PQ1 section), 28–32 m (PQ4, PQ5 sections), 40–45 m (PQ4 section) and 80–83 m (PQ2 section). The synthesis levels for the whole seabed area include 0–2 m, 5–10 m, 10–15 m, 19–20 m, 23–25 m, 28–32 m, 40–45 m, 47–50 m, 59–61 m and 75–85 m.

Hon Khoai island’s seabed

General morphologic characters of the local seabed: Hon Khoai district is the name of a group of islands belonging to Ca Mau province. Among those islands, the biggest one is Hon Khoai island, located 14.6 km southwestward from Nam Can town (Ngoc Hien district). Hon Khoai island is characterized by low hilly, mountainous features and coastal cliff slope, which were typical topological structures of

nearshore island system. The local seabed was almost flat, however it has a narrow and steep creek in the north, and conjunction with deep sea in the south of the island (fig. 6).

The flattened seabed steps: Fig. 6 represented the results of analysis of several cross sections, which pointed out some flattened seabed steps, including 4–6 m and 8–9 m (KH1 section); 4–7 m (HK2 section); 5–7 m, 24–28 m and 30–31 m (HK3 section); 4–6 m and 25–28 m (HK4 section); 3–4 m, 5–7 m and 11–12 m (KH5 section).

In summary, the clearly visible flattened seabed steps surrounding Hon Khoai island include 3–4 m (HK5 section), 4–6 m (HK4 section), 5–7 m (HK1, HK2, HK3, HK4 sections), 11–12 m (HK5 section). The synthesis levels for the whole seabed area include 3–7 m, 11–12 m, 24–28 m, 30–31 m.

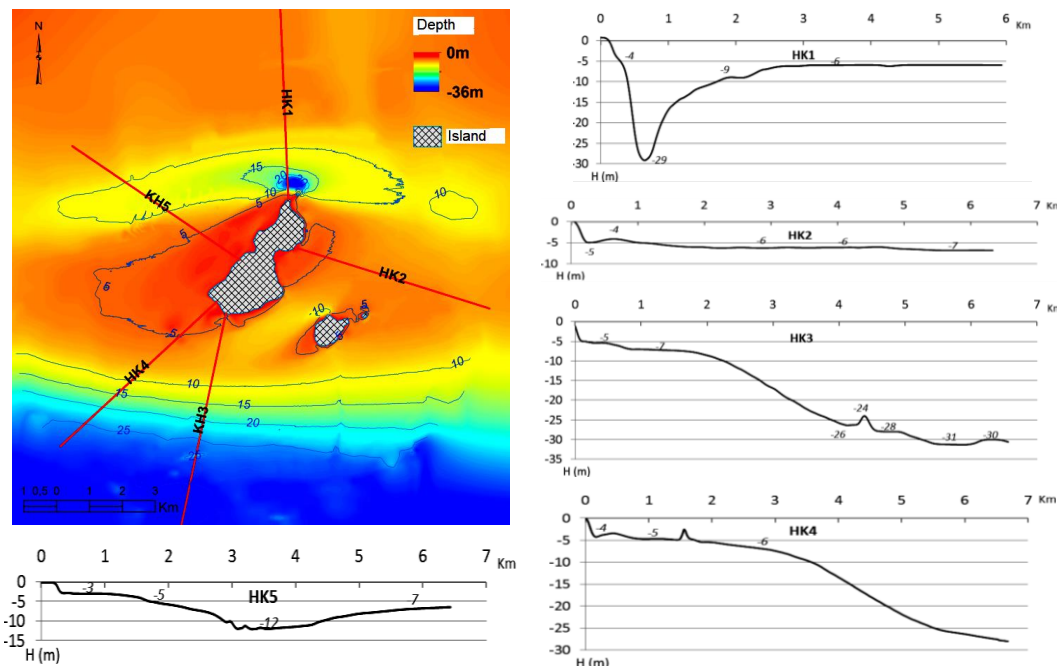


Figure 6. Section situation and seabed cross sections surrounding Hon Khoai island

Tho Chu island’s seabed

General morphologic characters of the local seabed: Tho Chu island belongs to Tho Chu archipelago in Thai Lan Gulf, in the southwest of Phu Quoc island and it is considered as the extreme southwest island of Vietnam. Tho Chu archipelago belongs to Tho Chau commune,

Phu Quoc district, Kien Giang province. Tho Chu is the biggest island in the archipelago, located about 198 km far from coast of Rach Gia Gulf. The morphologic characters of those islands are hilly landform, with average altitude of about 100–150 m, dominated by flat top hill and coastal cliff slope. The seabed surrounding

island is complex a large number of deep holes, which can reach the depth of hundred meters (fig. 7).

The flattened seabed steps: Similar to above-mentioned islands, results of analysis of several cross sections pointed out some flattened seabed steps, including 32–35 m (TC1 section); 22–23 m, 30–32 m and 34–36 m (TC2 section); 26–32 m (TC3 section); 4–5 m and 35–39 m (TC4 section); 22–24 m, 31–33 m,

35–37 m, 44–45 m and 50–51 m (TC5 section); 26–27 m and 44–47 m (TC6 section); and 41–44 m (TC7 section).

In summary, the clearly visible flattened seabed steps surrounding Tho Chu island include 26–32 m (TC1, TC3, TC4 sections), 34–39 m (TC2, TC4 sections), 44–47 m (TC6). The synthesis levels for the whole seabed area include 26–32 m, 34–39 m and 44–47 m.

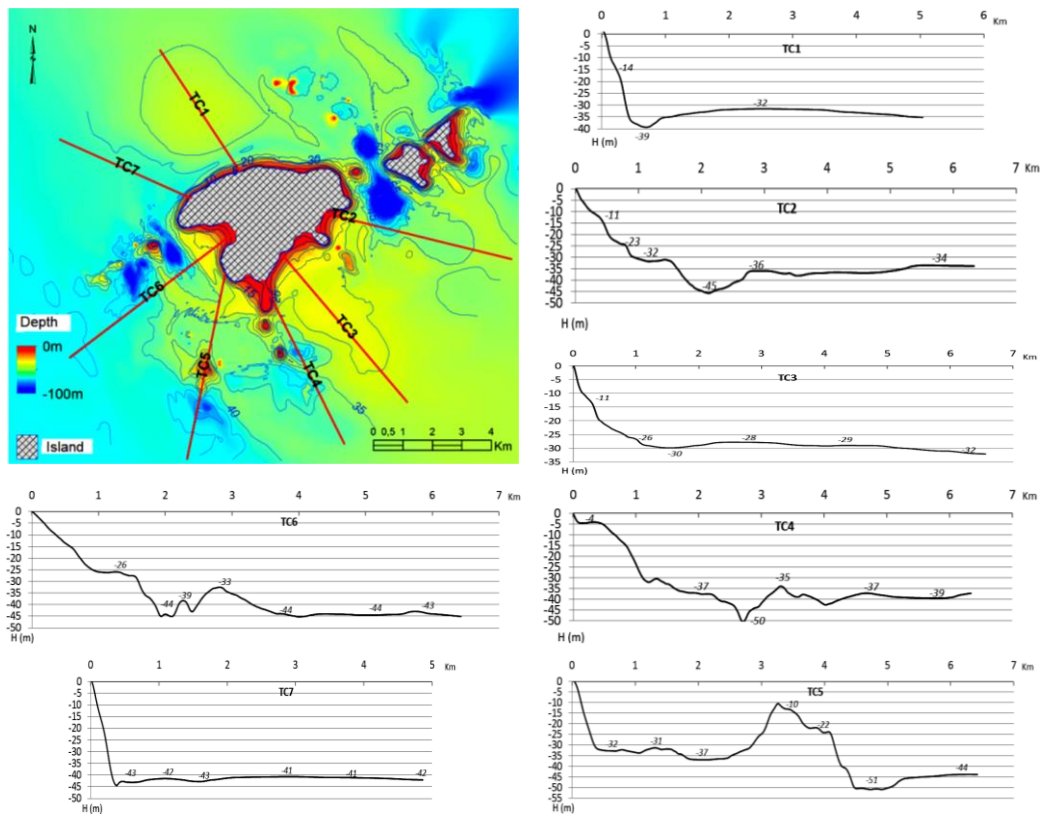


Figure 7. Section situation and seabed cross sections surrounding Tho Chu island

Synthesis of research results

The seabed topology of the areas surrounding nearshore islands of Vietnam was clearly represented by flattened seabed characters with several flat surfaces at different depth levels depicted on series of seabed cross sections.

There is a light difference in flattened characters between the above-mentioned seabeds surrounding the islands, therefore their flattened levels could be classified with almost the same pattern for entire nearshore

island system. However, the comparison of flattened seabed steps among regions surrounding the mentioned islands or island groups shows the distinction in terms of quantity of flattened seabed steps and their depths. Table 1 shows the analysis results, focusing on the quantity of flattened seabed steps and their depths, in 6 seabed regions surrounding the mentioned islands, which are representative of seabed characters in Tonkin Gulf, central part, southern central part and southern part of Vietnam.

Table 1. The comparison of flattened seabed steps in the surrounding regions of 6 islands

Bach Long Vi	Con Co	Ly Son	Phu Quy	Hon Khoai	Tho Chu
0–3 m	0–2 m	0–2 m	0–2 m		
			5–10 m	3–7 m	
6–15 m	12–14 m	12–14 m	10–15 m	11–12 m	
		15–20 m	19–20 m		
20–25 m		20–23 m	23–25 m		
		25–28 m		24–28 m	
	27–30 m		28–32 m		26–32 m
32–33 m	32–35 m			30–31 m	
		36–38 m			34–39 m
	38–40 m				
40–48 m	44–48 m	44–45 m	40–45 m		
					44–47 m
	48–52 m	47–49 m	47–50 m		
		53–55 m			
			59–61 m		
		65–70 m			
		75–80 m	75–85 m		
		90–115 m			

Table 1 shows the popular flattened levels (occurring at least in 3 islands’ seabed regions) including 0–2 m, 10–15 m, 20–25 m, 30–35 m, 40–48 m, 47–52 m. The deeper flattened levels (53–55 m, 59–61 m, 65–70 m, 75–85 m and 90–115 m) are only discovered at seabed belonging to southern central Vietnam. These observations do not appear in the remaining regions (seabed regions surrounding Bach Long Vi, Con Co, Hon Khoai and Tho Chu islands) because the observation data do not yet reach those depths. At seabed surrounding Tho Chu island, the popular flattened levels only appear at 20–50 m depth, while at seabed surrounding islands belonging to northern and northern central regions, the popular flattened levels occur at 0–50 m.

DISCUSSION AND CONCLUSION

The main research results are possibly the basis for discovering the popular flattened seabed steps among research regions and also point out the particular levels for each region.

In our point of view, a flattened seabed level was formed by one or more factors: Exogenous processes (erosion/sedimentation process for formation of terraces, or the remaining features of ancient coast); the sea level fluctuation; tectonic movement phases; or response to geologic structure (flat stratigraphy of sedimentation or volcanic eruption rocks,...

(?); or vertical tectonics (wide flat seabed). Therefore, it can be said that flattened seabed pattern at a region primarily respond to their own formation factor at each island’s location belonging to Vietnam’s island system, and the difference among them was reflected for their structures and forming dynamics.

The addition of depth observation and the help of ArcMap software contributed to improvement of accuracy and speed of seabed analysis in general and flattened seabed analysis in particular. The comparison of this study with previous literature shows that the flattened seabed characters were mentioned in terms of sea terrace. In the natural point of view, a sea terrace belongs to flattened seabed category, but on the other hand, a flattened seabed level does not always belong to sea terrace category. In the previous documents, the sea terrace was determined by not only topo-bathymetry analysis but also sedimentation analysis; in particular a series of projects deals with determination of submerged sea terraces at southern central sea [1, 4–6]. In spite of reaching a deeper level (-233 m), these mentioned projects had some limitations such as the wide depth range of a sea terrace (e.g. from 0 m to 25 m, or from 60 m to 80 m,...), which was not convincing; or determination of sea terrace only based on its depth without considering its steepened character. Therefore,

the more detailed depth observation data and research field on flattened seabed character was the sufficient complement for previous studies.

The paper comes to some conclusions as follows:

The study methodology is based on cross section establishment and statistical analyses of the morphologic elements of established sections, with the assistance of ArcMap software, which relatively improved the accuracy and completeness of flattened seabed characters. However, similar to other study methodologies, this kind of research always depends on resolution of bathymetry data and also the experiences of researchers.

Seabed topology at the surrounding regions of several nearshore islands of Vietnam clearly shows the steepened characters; the flattened levels include 0–2 m, 10–15 m, 20–25 m, 30–35 m, 40–48 m, 47–52 m, 53–55 m, 59–61 m, 65–70 m, 75–85 m and 90–115 m. Each island or island region had its own particular flattened seabed characters, which reflected not only the formation processes but also the conservative conditions.

The research's results were obtained by the depth observation data with the resolution of 1 m depth. However, due to the limitation of observation area (usually no more than 7 km seaward from coast of islands), the research's results only belong to those boundaries.

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