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MINERAL RESOURCES EXPLOITATION

Research paper

The engineering and geological substantiation of the resource potential of the bed of the South China Sea

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Abstract

The program for the development of the national economy based on own mineral raw materials as adopted in the Socialist Republic of Vietnam requires an increase the volumes of minerals. This includes both liquid hydrocarbons, and non-traditional solid minerals. This paper examines the resource base of mineral deposits in the South China Sea. The objective was to determine and scientifically establish classification criteria for zoning (regionalization), as well as to identify prospective areas with deposits of ferromanganese formations and other solid minerals. An analysis was undertaken of placers on the shelf and deposits of ferromanganese formations in the deep areas of the Vietnam Sea. A multiparameter analysis of the hydrological, geophysical, engineering and geological, environmental conditions of the deposit positions was conducted. In addition, criteria for the prospects of the formation and development of deposits of ferromanganese formations were established. These criteria enabled areas with different prospectivity ratings to be identified. Within the South China Sea, zones (areas) with a high, medium, and low potential for the presence of nodules were identified. Similar zoning for the crusts was also identified. The areas of these zones were determined. The results of the research established that the total potential area of ferromanganese nodules is 91,480 km². The area with the potential of ferromanganese crusts is 2,421.6 km², while the area of coexistence of nodules and crusts is 18,777 km². Furthermore, priority regions for future exploration are those with high nodule potential covering an area of 18,110 km² and the regions of high crust potential with an area of 882.6 km². Based on the materials obtained, the bed of the Vietnamese Exclusive Zone of the South China Sea was zoned. Maps of the resource and predictive prospects of the seabed were drawn, and the prospecting and exploration operations can be established within this framework.

Key words

resource potential, shelf, deep water areas, multiple factor analysis, placers, ferromanganese formations, deposit, nodules, crusts, predictive prospects, zoning, South China Sea, Vietnam

РАЗРАБОТКА МЕСТОРОЖДЕНИЙ ПОЛЕЗНЫХ ИСКОПАЕМЫХ

Научная статья

Инженерно-геологическое обоснование ресурсного потенциала дна Южно-Китайского моря

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Аннотация

Принятая в Социалистической Республике Вьетнам программа развития народного хозяйства, базирующегося на собственной минерально-сырьевой базе, требует повышения объемов добычи полезных ископаемых, в том числе жидких углеводородов, вовлечения нетрадиционных видов твердых полезных ископаемых. Исследована ресурсная база месторождений полезных ископаемых Южно-Китайского моря. Идея исследований заключалась в определении и научном обосновании классификационных критериев зонирования (районирования) и выделении перспективных участков с залежами

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железомарганцевых образований и других твердых полезных ископаемых. Проведен анализ россыпных месторождений на шельфе и залежей железомарганцевых образований в глубинных районах Вьетнамского моря. Проведен многосторонний анализ гидрологических, геофизических, инженерно-геологических, экологических условий залегания месторождений, определены критерии перспективности образования и развития залежей железомарганцевых образований. Эти критерии позволили произвести выделение участков с различным рейтингом перспективности. В пределах Южно-Китайского моря выделены зоны (участки) с высоким, средним и низким потенциалом нахождения конкреций, а также выявлена аналогичная зональность для корок. Определены площади указанных зон. Результаты исследований показали, что общая потенциальная площадь железомарганцевых конкреций составляет 91 480 км², площадь с потенциалом железомарганцевых корок – 2421,6 км² и площадь сосуществования конкреций и корок – 18 777 км². При этом приоритетными районами для будущих разведок являются районы с высоким потенциалом конкреций площадью 18 110 км² и районы с высоким потенциалом корок площадью 882,6 км². На основании полученных материалов произведено районирование дна Вьетнамской эксклюзивной зоны Южно-Китайского моря и составлены карты ресурсно-прогнозной перспективности морского дна, в пределах которых необходимо организовывать поисково-разведочные работы.

Ключевые слова
ресурсный потенциал, шельф, глубоководные районы, многофакторный анализ, россыпи, железомарганцевые образования, месторождение, конкреции, корки, прогнозная перспективность, районирование, Южно-Китайское море, Вьетнам

The program for the development of the national economy based on own mineral raw material, as adopted in the Socialist Republic of Vietnam requires an increase in the volumes of mineral extraction. This includes both liquid hydrocarbons, and solid minerals (SM), deposits of which are virtually not extant on land[1] [1–3].

The country is characterized by the long coastline of the western margin of the Pacific Ocean, the proximity of the northwestern border of the megabelt and the northern subequatorial belt of ferromanganese nodules. The results of the geological studies of the seabed, the positive experience in the development of placers on the coast and shelf, as well as the intensification and claims of China for the development of the South Chinese Sea (SCS) predetermine the relevance of the extension of geological exploration and development of offshore deposits by Vietnam [1–3, 4, 5].

Marine solid minerals (SM) contain the components of strategic importance for the economic and industrial development of Vietnam. They are especially important in the field of high-tech engineering, and include placers of ilmenite, rutile, zircon, monazite, cassiterite, inter alia, ferromanganese concretions and crusts, polymetallic sulfides and, potentially, enriched polymetallic mud [6, 7].

Thus, the exploration and prospecting of marine minerals in Vietnam are of great importance. They will contribute to a focused and rational use of mineral resources for the process of industrialization process, the consolidation of the country's sovereignty in the Exclusive Economic Zone, and the development of Vietnam towards becoming a maritime power. Vietnam adopted the Strategy for Sustainable Maritime Economic Development of the country up to 2020 (starting from 2007), 2030 and further up to 2045[2].

In order to address the issue of the development of the resource base, engineering and geological substantiation of the prospects for the development of offshore deposits of solid minerals of Vietnam was undertaken. This was based on the use of maps of predictive resource zoning of the seabed. The purpose of the research was to identify and scientifically establish the classification criteria for zoning (regionalization), as well as to identify prospective areas with deposits of ferromanganese formations (FMF) and other solid minerals (SM). Classification attributes were used with regard to the development of zoning maps. This was in accordance with the priority of prospecting for offshore deposits and the development of tools and methods for engineering and geological studies of seabed deposits in the shelf zone and deep areas of the Vietnam Sea (the Exclusive Economic Zone) [2, 3].

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[1] Resolution No. 36-NQ/TW (October 22, 2018) "Vietnam's marine economy to 2030 and vision to 2045"

[2] Resolution No. 36-NQ/TW (October 22, 2018) "Vietnam's marine economy to 2030 and vision to 2045"

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For this purpose, we conducted the following studies:

– analysis and assessment of the current level and state of offshore exploration, as well as the extent to which Vietnam has developed shelf zone and deep areas in the South China Sea;

– assessment of the conditions for the formation and accumulation of building materials and placers in the coastal areas as well as the shelf zone, as prerequisites for identifying zones and regions with potential and prospective conditions for the formation and development of ferromanganese deposits in the seas of Vietnam;

– survey and analysis of the potential of solid minerals of the seabed of Vietnam, including the results of studies of deposits of building materials, placers in the Vietnam waters and ferromanganese deposits in the deep areas of the South China Sea;

– a bathymetric map of the bed of the SCS was drawn; other factors influencing the formation and development of ferromanganese deposits in the World Ocean were also summarized and analyzed for the purpose of identifying these features in the Vietnam Sea (Fig. 1);
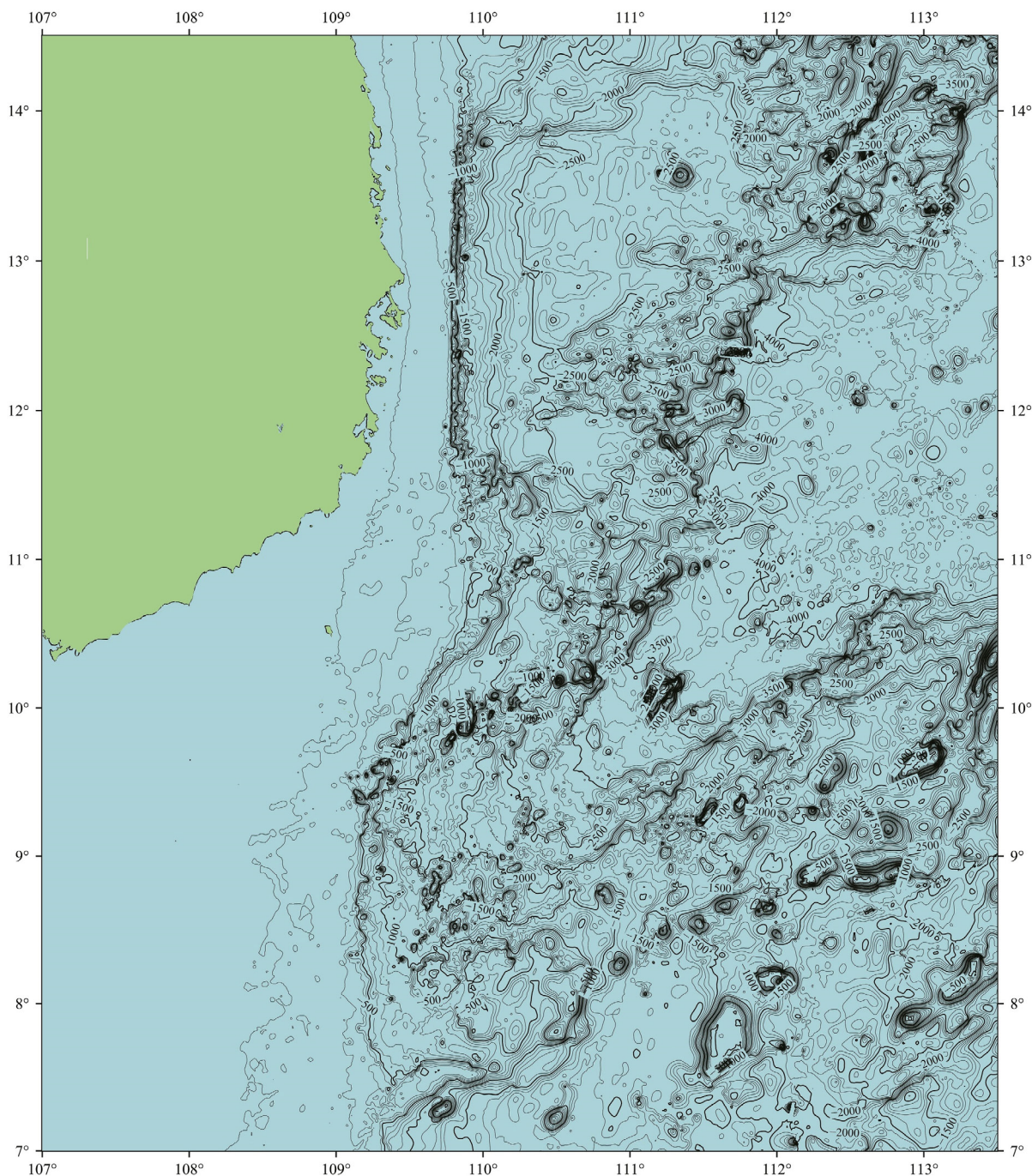

Fig. 1. Bathymetric map of the bed of the South China Sea

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– favorable criteria impacting the formation of ferromanganese ores were identified for the purpose of zoning the bed of the SCS. This took into account the potential for their formation in the form of nodules and crusts for future prospecting and exploration.

These studies used a range of results from previous studies in various fields, i.e. geology [4, 5, 8, 9], geophysics [5], petrography [5, 10], geochemistry [6, 7], hydrology [7, 11–13], oceanography [7, 11, 12, 14], geomorphology [6, 7, 9, 13, 15], engineering geology [7, 16–18], mineralogy [19], seabed topography [20], inter alia [21, 22].

Criteria were developed on the basis of multiple factor analysis. They are represented in Tables 1–3.

The zoning criteria are arranged in descending order of prospectivity from 1 to 6. Criteria 1, 2, 3 are essential in the conditions of the SCS and they shall be given priority consideration.

In certain cases, in addition to these criteria, geomorphological criteria are used, in order to assess continental shelves, valleys between seamounts and the topography of seamount tops.

The criteria used to identify the areas unfavorable for the formation and growth of ferromanganese nodules and crusts are presented in Table 4.

Table 1

Criteria for zoning of deposits of ferromanganese nodules

No.	Criterion	Value of the criterion for the rating assigned		
		high	medium	low
1	Sea depth, m	3,000–4,000	> 4,000	2,000–3,000 abyssal plains near continental slope and uplift
2	Seabed slope angles, deg	0–3	0–3	0–3
3	Age of formation of seabed configuration (seamounts/plains), myr	Multiple millions of years (Very favorable conditions – an old seabed: 15.5–24 myr)	Seabed formed 15.5–24 myr ago	Multiple millions of years
4	Presence of nuclei for the formation and development of nodules	Present. The areas being away from submarine volcanoes, seamounts being rich in silica bioclast	Present. Areas away from submarine volcanoes, seamounts rich in silica bioclast	Present
5	Current velocity, cm/s	< 4 for the diagenetic genesis	< 3	No effect
6	Sediments on the seabed surface	Virtually none	Virtually none	Virtually none

Table 2

Criteria for zoning of deposits of ferromanganese crusts

No.	Criterion	Value of the criterion for the rating assigned		
		high	medium	low
1	Sea depth, m	800–1,800	500–800; and > 1,800	500 m to the seabed
2	Seabed slope angles, deg	15–40	15–40	15–40
3	Age of formation of seabed configuration (seamounts/plains), myr	Multiple millions of years (>3). Older age favors to the formation of ores	Multiple millions of years (>3). Older age favors to the formation of ores	Relatively young surface
4	Bedrock surface	No sediment on the basalt surface (very high), on the limestone surface, granite, rhyolite (high)	No sediment	Sediment in some places
5	Current velocity, cm/s	4–5	4–15 (500–800 m); and < 3 (at the depths > 1,800 m)	No need to consider
6	Sediments on the seabed surface	None	None	None

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These criteria enable the bed of the Vietnam Sea to be zoned, and a number of areas identified, where it is advisable to undertake prospecting and exploration for the presence of ferromanganese formations (Fig. 2).

The results of studies of the Exclusive Maritime Economic Zone of Vietnam, the potential classification and the corresponding areas of ferromanganese deposits are as follows:

Group of nodules

– The area with a high potential for nodules is 18,110 km², the largest area of which is 13,460 km², located in the central valley in the southwest of the South China Sea.

– The area with a medium potential for nodules is 28,400 km².

– The area with a low potential for nodules is 44,970 km², including 4 regions, the largest of which with an area of 34,110 km² is located in the north of the territory under investigation.

Group of crusts

The total area is 2,421.6 km², including:

– the area with a high potential of 882.6 km²,

– the areas with medium and low potential of 1,539 km².

Group of simultaneous (coexisting) nodules and crusts with an area of 18,777 km².

These maps constitute a basis for the planning of exploration works within the Vietnam Sea, enabling a high extent of detection of the deposits of ferromanganese formations and further planning of mining operations.

Table 3

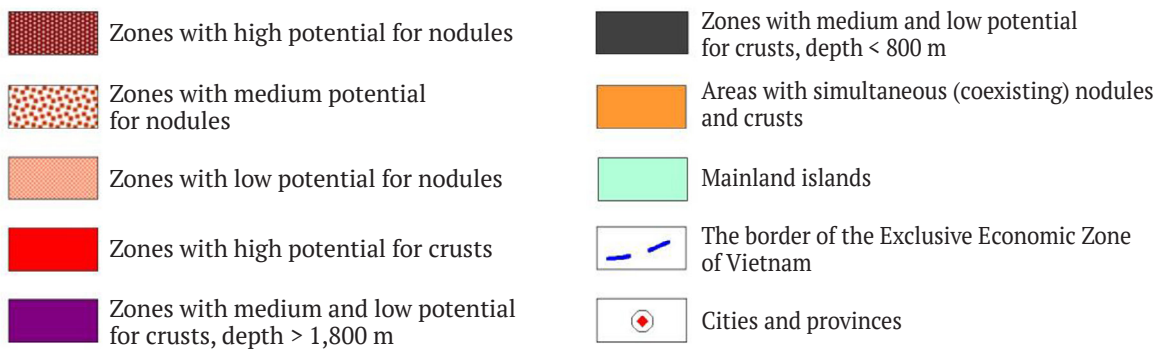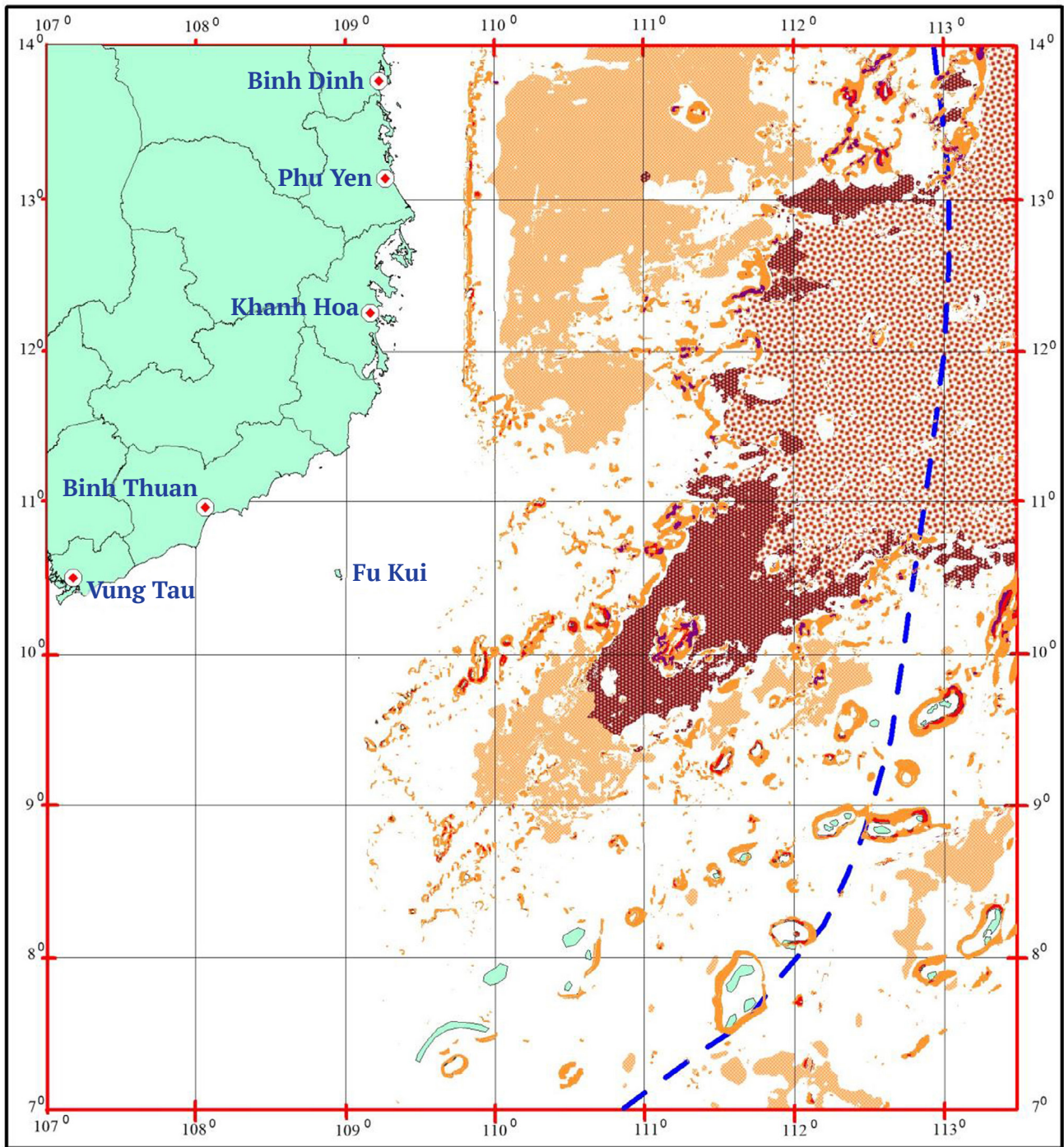**Criteria for zoning of deposits of ferromanganese nodules and crusts**

No.	Criterion	Value of the criterion for the rating assigned	
		medium	low – no
1	Sea depth, m	500–4,000	500–4,000
2	Seabed slope angles, deg	7–15	7–15
3	Age of formation of seabed configuration (seamounts/plains), myr	> 3	< 3
4	Bedrock surface	Nuclei present. Sediment accumulation on the surface is heterogeneous	Nuclei present. Sediment accumulation on the surface is heterogeneous
5	Nucleus for the development of nodules		
6	Current velocity, cm/s	4–15	4–15

Table 4

Areas without potentially perspective conditions for the formation of nodules and crusts

No.	Criterion	Crusts	Nodules
1	Sea depth, m	< 500 m	Continental shelf, depth up to 500 m. Plains exhibit a gentle slope angle (0° – 3°) on continental slopes, seamounts exhibit gentle tops
2	Seabed slope angles, deg	Flat top of seamounts (0–3)	3–7 and > 40
3	Age of formation of seabed configuration (seamounts/plains), myr	Relatively young surface, very young volcanics	No affect
4	Bedrock surface	No need to consider	Does not affect
5	Presence of nuclei for the formation and development of nodules	No affect	Present
6	Current velocity, cm/s	No need to consider	No affect

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Fig. 2. Map of the zoning of the bed of the SCS according to the potential
for finding promising ferromanganese deposits (the area/map of exploration zones)

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Conclusions

The Vietnamese Sea represents a typical geological structure of marginal seas. It includes a shelf with placers, abyssal plains with seamounts bearing deposits of ferromanganese formations of various types, all of which considerably enhance the mineral resource and raw material potential of Vietnam.

The predictive zoning of the SCS bed for areas for prospecting and exploration works shall be based on the following factors: classification criteria identified in the results of the multiple factor analysis of known underwater solid minerals (SM) deposits; existing data from geological, hydrological, geophysical, engineering and geological, and other studies.

The zoning areas with different potential for nodules and crusts to be identified in the following categories: high, medium and low; on the South China Sea bed (as well as within the Exclusive Economic Zone of Vietnam), and for these areas to be defined.

The results of the research revealed that the total potential area of ferromanganese nodules is 91,480 km^2; the area with the potential of ferromanganese crusts is 2,421.6 km^2; and the area of coexistence of nodules and crusts is 18,777 km^2. Based on the above, the priority regions for future exploration are the regions of high nodules potential with an area of 18,110 km^2, and the regions of high crust potential with an area of 882.6 km^2.

It is recommended that offshore exploration works in the SCS be planned and conducted on the basis of the perspective areas and classification attributes established herein.

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