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# Distribution and potential of the titanium, zircon and rare earth minerals in the coastal placer, South Suoi Nhum, Binh Thuan province

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ABSTRACT

Coastal placer ore is one of the minerals, which demonstrates highly economic values and is used in many industrial applications. The demand for ilmenite, zircon and monazite, etc. has increased during the recent years. The coastal placer along the Ninh Thuan Province elongates over ~120 km, from Phong Dien to Ham Tan, in which the South Suoi Nhum Placer shows a high potential of the heavy minerals. Therefore, studying the spatial distribution, and mineral resources of the mineral placers for quality evaluation, mining feasibility and mineral processing is an essential task. In this paper, the authors describe the distribution pattern and potential of heavy mineral in the South Suoi Nhum Placer in order for orientation of mining and processing of placers in Vietnam and coastal area of Binh Thuan particularly.

## 1. Introduction

Spatial distribution and correlation of the coastal placers are important roles in evaluation of placer potential. Meanwhile, these parameters also control general recovery values, mining and processing technology of the placers.

Based on re-reviewing the pre-existing document on morphology, size of the placer ore bodies together with data derived from trenches, exploration drilling, sample analysis, etc. we present some results of distribution pattern relationship between ilmenite, rutile, zircon and monazite as well as their potential in the South Suoi Nhum coastal placer. These results are the basis for placer mining and processing orientation for Vietnam in general and for Binh Thuan in particular.

## 2. Geological setting of South Suoi Nhum placer ore bodies

### *2.1. Stratigraphy*

Stratigraphy of South Suoi Nhum area consists of the Quaternary unconsolidated sediments, which were defined as the Pleistocene and the Holocene ages as follow:

*Quaternary System – Holocene Stage – Phan Thiet Formation – Marine sediments ($mQ_1$ pt):* The red and unconsolidated sediments of the Phan Thiet Formation are widely observed over the most study area, in which ~50% area is overlain by the grey sediments. This formation is mainly observed in the west of the study area. Mineral composition is quite simple, which is mainly composed of fine – medium grained sand, ~1.3–14.7% clay. The sediments show red color in the upper part and become lighter downwards before they turn to the yellowish grey or light grey color. The rocks have been firmly compacted, medium-weakly consolidated. The upper part is yellow to red, partly friable and weathered sand. Weathering crust varies from 1-2m. Heavy mineral concentration in the red sand,

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which varies from 0.25-1.576%, some samples show heavy mineral content up to 7.106%; Zr of 0.005-0.509%, up to 1.769% in some places. The heavy mineral-containing formation is overlain by the Holocene gray sand formation, whose thickness is up to 52m. Total thickness of the formation ranges from 2 to 62 m.

*Quaternary System – Holocene Stage – Marine-Aeolian sediment ($mvQ_2$)*: This formation has been formed as sand dunes, whose height is various from 10 – 80 m above surrounding terrain and are exposed over 150 – 900 m long. Sediment compositions consist of gray, whitish gray, medium – fine grained quartz sand containing ilmenite, zircon, rutile; low shale content (0.1-1.2%, 0.4% on average). Heavy mineral content varies from 0.25-1.482%, 12.306% in some places; Zr content changes from 0.01 – 0.463%, 3.251% in some places. Total thickness of this formation ranges from 2 – 52m.

Although the red sand formation is different from the gray sequence in term of physical fashion they all contain heavy minerals such as titanium, zircon and monazite.

*Quaternary System – Holocene Stage – fluvial sediment ($aQ_2$)*: This formation is observed along the stream valley in the Northeast of the region. Sediment composition is composed of sand, silty sand, shale, light gray, and light brown gravelly sand. Total thickness is of 1-3m.

*Quaternary System – Holocene Stage – Marine sediment ($mQ_2$)*: The Holocene marine sediment deposit is widely observed along the modern coast and is affected by wave, tide and nearshore currents and its thickness varies from 1-4m.

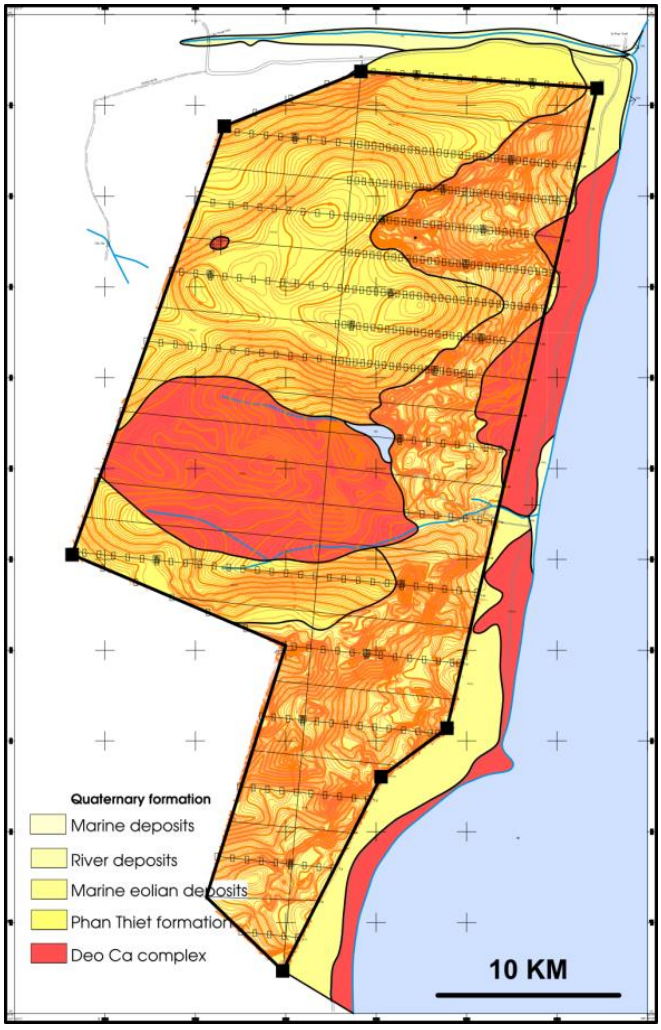


*Figure 1. Large-scale geological map of the South Suoi Nhum area, Binh Thuan Province*

### *2.2. Magma*

Two phases of intrusive magmatism of the Deo Ca Complex have been identified and observed on an area of ~2km$^2$ in the central and eastern area of the region. Lithology of the complex mainly consists of whitish gray medium grained granosyenite, biotite granite, biotite-hornblende granite. This complex has been observed at the bottom of most of the drill holes and is overlain by the heavy mineral-containing sand formation. The basement surface is gently inclined and simple. The placer bottom is situated at higher elevation in central area.

### *2.3. Geomorphology*

The geomorphology of the region can be subdivided into the following types:

*Marine deposition terrain:* This type of terrain occupies a significant area of the region, which are composed of the Pleistocene – Present marine terraces, sand bar and coastal plain.

*Alluvial terrain:* The alluvial terrain is observed in western area of the region that is dominated by flat lying and/or gently tilted plains. This terrain is limited within the study area and elongate along the fluvial valleys in the region.

*Marine – Lagoonal terrain:* This terrain elongates over ~several km along the major valleys or in low-lying areas at an elevation of several to tens of meter and 500 – 600m wide.

*Aeolian – Marine Terrain:* The age of this terrain has been defined as the Holocene and it is characterized by dominance of sand dunes. These dunes are situated near the present coast and are parallel to the shoreline, which extend tens of meters from the shoreline to several km landwards.

*Aeolian Terrain:* This terrain was subdivided into two subtypes as follow:

Aeolian deposition terrain: This subterrain is characterized by wind process. It is exposed on a small area near the coast, which extends from tens of meter near the coast to several km landwards. The stoss side of sand dunes dips to the sea while the lee side tilts landwards. Two types of sand dunes were identified in this subterrain: stable dune and mobile dune. The stable dunes demonstrate a development of natural or artificial plantation in or to stabilize the sand dune while the mobile dunes are very limited and regularly change in morphology due to the wind effect.

Wind-eroded terrain: some low-lying areas are situated by the sand dunes. This terrain was resulted from wind erosion process. The size of these low-lying areas varies from tens of meters to hundreds of meters and is localized distribution.

*Incised – eroded terrain:* This terrain consists of low hills and hinterland. The hills are characterized by cone shaped, steep side and their height is varies from 50 to >200m. These hills are distributed erratically in the region and have recently experienced strong erosion. The bed rocks are exposed in the hinterland and have been eroded into marine terraces. This terrain is developed on the volcanic rock of the Nha Trang Formation and on the granite rock of the Deo Ca Complex.

### *2.4. Characteristics of placer ore bodies*

Our results showed that heavy mineral are observed in the Holocene gray sand and the Pleistocene red sand formations. They all contain titanium, zircon, monazite and therefore the ore body boundary are unclear. The ore content can be directly estimated by hand lens in the field or under microscope in the lab. The red sand formation can be distinguished from the gray formation by its color and shale content (gray sand demonstrate higher shale content) and the ore bodies have been delineated by heavy mineral content derived from boreholes.

The heavy minerals are disseminated regularly from the gray to the red sand formation along the cross-sections. The ore bodies in both gray and red sand formations are characterized by large scale and flat-lying.

Within the study area, two ore bodies have been defined: one is in the red sand formation while the second body is situated in the gray sand formation.

**Ore body in the red sand unit (Ore body 1):** The ore body one is situated in the red sand of the Phan Thiet Formation ($mQ_1pt$), and is

observed in almost of the area. On crossection, the ore bodies are flat-lying. the thickness varies from 2-62m, 31.24m on average and tends to be thinner eastwards of the region, where it is overlain by the gray sand. The ore body show a large scale in both area and depth and mainly contain titanium and zircon, which are regularly disseminated. The heavy mineral show black colour, medium - fine grained, relatively rounded and contain iron stains. The ore mineral are mainly composed of titanium group (ilmenite + rutile anatase + leucoxene) and zircon with minor monazitet and non-ore minerals such aretourmaline, garnet, stavrolite, biotite, epidote, limonite, hematite, chlorite, quartz, feldspar. Heavy mineral content derived from heavy mineral samples ranges from 0.250% to 1.576%, 0.696% on average; coefficient of variation is 36.06%, zircon content varies from 0.005% to 0.596%; 0.130% on average. The whole content of the ore minerals based on drill hole data ranges from 0.255% to 3.394%, 0.777% on average; zircon content ranges from 0.0375% to 0.756%; 0.145% on average (accounting for 18.7% of total ore minerals).

**Ore body in the gray sand unit (Ore body 2):** The ore body has been deposited in the Holocene marine-Aeolian sedimentary formation. The ore body is flat lying, and is exposed to the ground surface, which is composed of wavy sand bar, dune and ridge situated at 10 - 80 meters of elevaltion above surrounding areas. The thickness of the ore body varies from 2 - 52 meters, 16.93 meters on average. The ore body 1 is thinner at the hill side and becomes thicker at the higher elevation. Mineral composition of the ore body 1 consists of fine – medium grained quartz sands mixed with gray, whitish gray to yellow silts containing titanium mineral group (ilmenite + rutile + anatase + leucoxene) and zircon. In addition, monazite with low content and other non-ore minerals such as quartz, feldspar, amphibole, etc were also obseved. Ore minerals distributed relatively evenly, forming thin black bands, black gray lens, intermittently stringing from a few millimeters to 1 - 2 centimeters thick, they have ripple shape. Whole content of the ore minerals based on heavy mineral samples ranges from 0.250% to 1.482%, 0.677% on average; coefficient of variation is 38.85%, zircon content range from 0.001% to 0.463%; 0.108% on average. Whole content of the ore minerals based on drill holes ranges from 0.252% to 1.362%, 0.721% on average; zircon content range from 0.021% to 0.282%; 0.125% on average (accounting for 17.3% of total ore minerals).

Research results shows that placer ore bodies in south Suoi Nhum area characterized by simple morphology, horizontal lying, widely spread on most of the explored area. The ore bodies demonstrate large scale, whole content of usable ore minerals in the red sand and gray sand strata are distributed evenly. The two ore bodies in the red and gray sand formations show similar mineral distribution pattern and to some extent they can be considered to be merged into one larger ore body.

## 3. Spatial distribution and correlation between ore minerals in the coastal placers, South Suoi Nhum

### *3.1. Characteristics of statistical distribution of ore minerals*

Titanium coastal placer in general and placer ores in South Suoi Nhum area in particular have been formed in marine and marine-Aeolian environment and hence mineral composition is relatively simple and well sorted. The deposition conditions and mineral sources demonstrate particular features. Therefore, mineral composition as well as their characteristics are also different. Results of the heavy mineral analysis show that heavy mineral composition are described as follow:

- Magnetic induction group: mainly magnetite mixed minor martite and were observed in all heavy mineral samples.
- Electromagnetic group: mainly ilmenite, tourmaline, epidote, monazite, less limonite with minor very few garnet, hematite, amphibole, stavrolite, cromite, etc.
- Heavy non-electromagnetic group: mainly zircon, leucoxene, less rutile, anatase, kyanite, silimanite and very few pyrite, amphybole, etc.

- Light non-electromagnetic group: mainly quartz, very few feldspar.

Among minerals mention above the usable minerals in placer are ilmenite, zircon, rutile, anatase, leucoxene and monazite.

Mineral composition in the red sand and gray sand formation are summarised in Table 1.

Table 1 shows that sand composition mainly consist of 83.42% to 98.69% quartz the remainings are ilmenite, rutile, anatase, leucoxene, zircon and monazite.

Relations of the ore minerals in placer ores have been studied based on pair correlation coeficients between ore minerals. Correlation coeficients between ore minerals and whole usable minerals (WUM) in the gray and red sand ore bodies are summarized in Table 2 and Table 3.

*Table 1. Composition of synthetic heavy mineral samples in the gray and red sand formations*

| N$^o$ | Minerals | Mineral contents (%) | |
|---|---|---|---|
| | | Gray sand strata | Red sand strata |
| 1 | Quartz | 84.86 to 98.45 | 83.424 to 98.688 |
| 2 | Ilmenite | 0.015 to 5.329 | 0.020 to 3.288 |
| 3 | Rutile | 0.03 to 0.180 | 0.00 to 0.063 |
| 4 | Anatase | 0.02 to 0.034 | 0.00 to 0.030 |
| 5 | Leucoxene | 0.001to 0.285 | 0.00 to 0.285 |
| 6 | Zircon | 0.002 to 1.260 | 0.002 to 1.260 |
| 7 | Monazite | 0.00 to 0.034 | 0.00 to 0.034 |
| 8 | Magnetite | 0.002 to 0.008 | 0.005 to 0.942 |
| 9 | Tourmaline | 0.020 to 0.297 | 0.016 to 0.258 |
| 10 | Silimanite | *very few* | *very few* |
| 11 | Stavrolite | few grains | few grains |
| 12 | Garnet | few grains | few grains |
| 13 | Amphibole | few grains | few grains |
| 14 | Hematite | few grains | few grains |
| 15 | Epidote | *very few* | *very few* |
| 16 | Limonite | *very few* | *very few* |
| 17 | Tourmaline | *very few* | *very few* |
| 18 | Pyrite | *very few* | *very few* |
| 19 | Chromite | few grains | few grains |
| 20 | Kyanite | *very few* | *very few* |
| 21 | Xyrtolite | few grains | few grains |
| 22 | Feldspate | few grains | few grains |
| 23 | Clay mineral group | | 2 - 6 |

*Table 2. Content correlation coefficients between the ore minerals in the gray sand ore body*

| | WUM | Ilmenite | Rutile | Anatase | Leucoxene | Zircon | Monazite |
|---|---|---|---|---|---|---|---|
| WUM | 1 | | | | | | |
| Ilmenite | 0.991 | 1 | | | | | |
| Rutile | 0.720 | 0.660 | 1 | | | | |
| Anatase | 0.860 | 0.800 | 0.780 | 1 | | | |
| Leucoxene | 0.570 | 0.510 | 0.680 | 0.700 | 1 | | |
| Zircon | 0.910 | 0.850 | 0.790 | 0.940 | 0.630 | 1 | |
| Monazite | 0.241 | 0.232 | 0.142 | 0.121 | 0.083 | 0.163 | 1 |

Results of the Tables 2, 3 and 4 show that mineral compositions of coastal placers in south Suoi Nhum area are relatively simple and similar to other placers in Vietnam. The biggest difference in here is that the zircon content is much higher while monazite content is lower than other regions. The whole content of ore minerals is distributed evently with correlation coeficient ranging from 36.06% (for red sands) to 38.85% (for gray sands). The relationship between the pair correlation of ore minerals in placers in South Suoi Nhum is quite close.

### *3.2. Grain-size distribution*

Grain-size analysis on ore containing fraction and ore concentrate are summarised in Tables 4 and 5. Table 4 shows that ore-containing sand are mainly fine grained and quite well sorted. Size fraction mostly concentrates on a range of 0.1 to <0.5mm, in which 0.5 - 0.25mm fraction accounts for 32.5% in red sand and 36.3% in gray sands. particles belonging to 0.25 ÷ 0.10mm size fraction account for 44.4% in red sands and 47.5% in gray sands. <0.1mm fraction varies from 18.4% in red sands to 14.2% in gray sands. Size fraction >0.5mm presents 3.2% and 5.3% the red and gray sand respectively. The ore concentrate shows fined grained texture, which ranges from 0. to 0.25mm.

In terms of grain size, the gray sand differs from the red sand by higher shale content in the gray sand formation while sand fraction shows similars grain-size fashion and mainly center on 0.1- 0.5mm size range.

*Table 3. Content correlation coefficients between the ore minerals in the red sand ore body*

| | WUM | Ilmenite | Rutile | Anatase | Leucoxene | Zircon | Monazite |
|---|---|---|---|---|---|---|---|
| WUM | 1 | | | | | | |
| Ilmenite | 0.995 | 1 | | | | | |
| Rutile | 0.700 | 0.669 | 1 | | | | |
| Anatase | 0.873 | 0.840 | 0.692 | 1 | | | |
| Leucoxene | 0.621 | 0.587 | 0.565 | 0.638 | 1 | | |
| Zircon | 0.946 | 0.913 | 0.720 | 0.914 | 0.580 | 1 | |
| Monazite | 0.226 | 0.227 | 0.113 | 0.150 | 0.090 | 0.171 | 1 |

*Table 4. Grain-size distribution of the ore-containing sand*

| N$^o$ | Grain size levels (mm) | Gray sand strata | | | Red sand strata | | |
|---|---|---|---|---|---|---|---|
| | | Max (%) | Min (%) | Average (%) | Max (%) | Min (%) | Average (%) |
| 1 | > 1.0 | 0 | 1.5 | 0.1 | 0 | 1.7 | 0.2 |
| 2 | 1.0 - 0.5 | 0 | 43.4 | 3.1 | 0 | 41.0 | 5.1 |
| 3 | 0.5 - 0.25 | 0 | 86.3 | 36.3 | 0 | 78.1 | 32.5 |
| 4 | 0.25 - 0.10 | 10.5 | 86.2 | 47.5 | 7.2 | 78.1 | 44.4 |
| 5 | 0.1 - 0.05 | 0.1 | 46.7 | 13.2 | 0.3 | 38.6 | 15.4 |
| 6 | < 0.05 | 0.1 | 4.9 | 1.0 | 0.1 | 7.2 | 3.0 |

*Table 5. Grain-size distribution of ore minerals*

| N$^o$ | Concentrate ore types | Average granule composition (%) | | | |
|---|---|---|---|---|---|
| | | > 0.5mm | 0.5 - 0.25mm | 0.25 - 0.1mm | < 0.1mm |
| **Gray sand strata** | | | | | |
| 1 | W.Ilmenite | 0.19 | 7.91 | 60.76 | 31.14 |
| 2 | W.Zircon | 0.04 | 5.31 | 74.02 | 20.63 |
| **Red sand strata** | | | | | |
| 1 | W.Ilmenite | 0.17 | 8.05 | 61.72 | 30.07 |
| 2 | W.Zircon | 0.01 | 4.11 | 76.11 | 19.77 |

### *3.3. Spatial distribution of ore minerals*

*a. Thickness of the ore bodies*

Variation in thickness of placer ore bodies in the red and gray sand formations are described in Figures 2 and 3.

Thickness of the ore body in the red sand unit varies from 1 - 61 meters, 29.79 meters on average and it is unevenly variable. The ore body is thinner from the center to the sides in the direction normal to the shoreline while it tends change more dramatically and becomes thinner southwards along the shoreline.

In the gray sand unit, the thickness of the ore body ranges from 2 - 30 meters, 16.62 meters on average. The ore body thickness varies erratically. In general, thickness of the ore body tends to decrease gradually from the center to the two-sides in the normal direction to the shoreline. Whereas the ore body is strongly variable and tends to decrease gradually southwards along the coast.

*b. Whole content of ore minerals*

The variation of the whole content of ore minerals in the red and gray sand formations is shown on Figures 4 and 5.

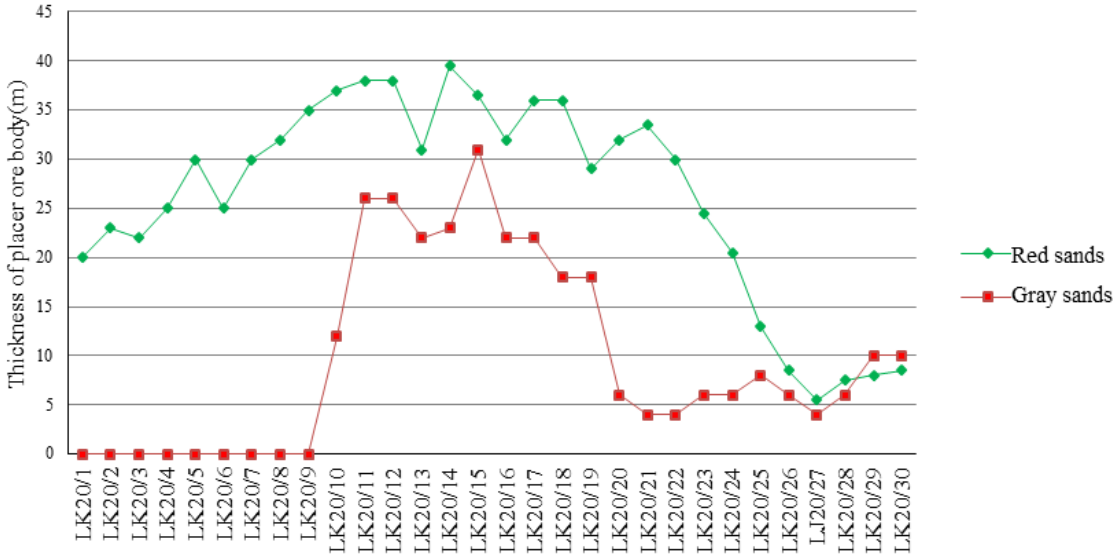


*Figure 2. Variation in thickness of the placer ore bodies in the gray and red sand formations along the Section 20*

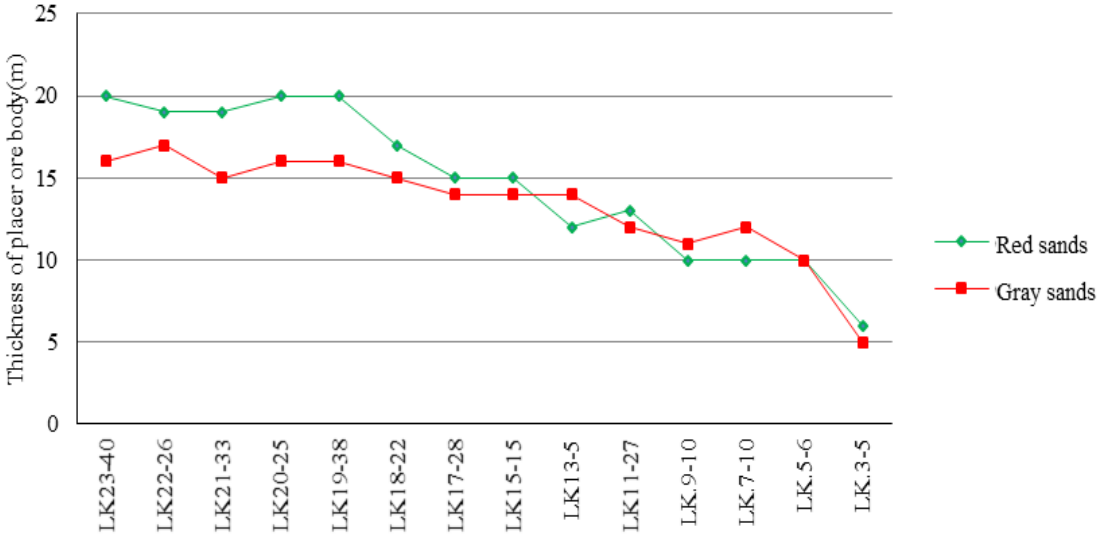


*Figure 3. Variation in thickness of the placer ore bodies in the gray and red sand formations along the Center Section*

Our results showed that the concentration of ore minerals in the red sand formation is evenly varied from 0.250% to 12.317%, 7.10% on average. The whole mineral content is less variable and tends to decrease from the center to the two-sided edges in the normal direction to the shoreline. On the other along the directional parallel to shoreline, the content of ore minerals tends to decrease gradually from north to south. Content of ore minerals in placers of the gray sand strata ranges from 0.250% to 12.306%, 6.02% on average. The study results also showed that the ore minerals are strongly variable in contents. In general, content of the ore minerals demonstrates a strong variation along the normal direction to the coastlines while the content of ore minerals tends to decrease gradually from north to south along the coastline.

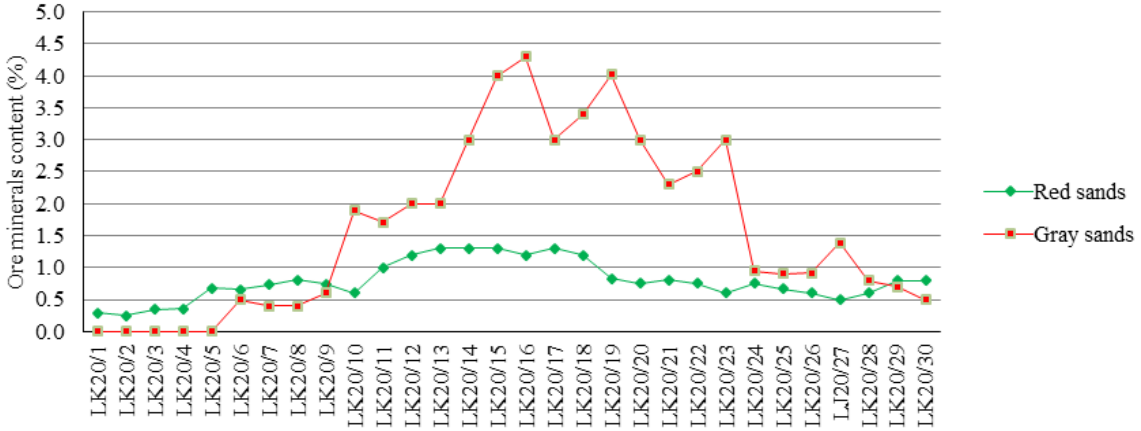


*Figure 4. Variation in average contents of ore minerals along the section 20*

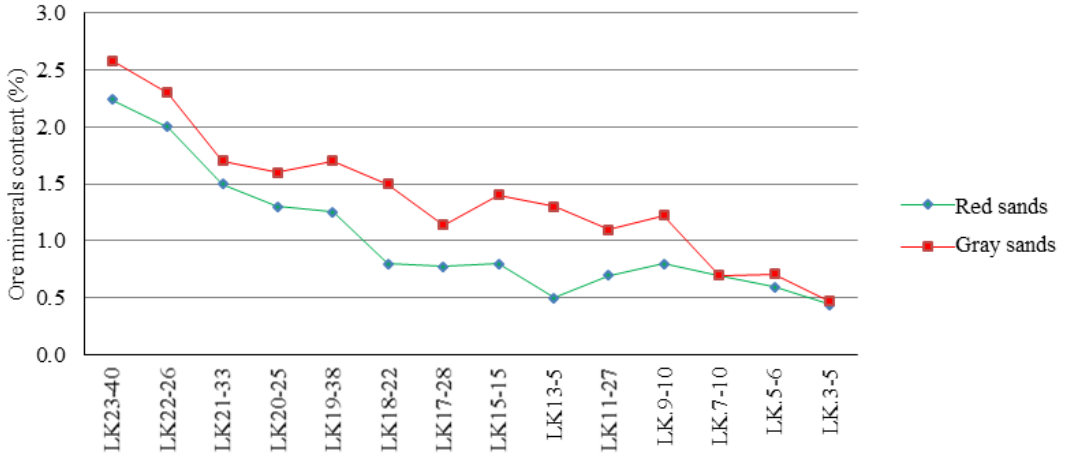


*Figure 5. Variation in average contents of ore minerals along the Center section*

*Table 6. Mineral resources and mineral reserves of the placer ores of South Suoi Nhum*

| Name of ore body | Mineral resources and mineral reserves of the placer ore minerals (thousand tons) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Whole ore minerals | | | Titanium mineral groups | | | Zircon | | | Monazite | | |
| | 121 level | 122 level | 333 level | 121 level | 122 level | 333 level | 121 level | 122 level | 333 level | 121 level | 122 level | 333 level |
| TQ.1 | 522.86 | 1108.12 | 216.16 | 423.02 | 903.56 | 215.69 | 98.69 | 201.39 | 43.55 | 1.15 | 3.17 | 0.47 |
| TQ.2 | 143.42 | 1050.82 | - | 114.46 | 844.93 | - | 28.65 | 203.18 | - | 0.31 | 2.71 | - |
| Sum | 666.27 | 2158.93 | 216.16 | 537.48 | 1748.49 | 215.69 | 127.34 | 404.56 | 43.55 | 1.46 | 5.88 | 0.47 |

**4. Potential of Placer minerals in South Suoi Nhum area**

Mineral resources and mineral reserves of the placer minerals in South Suoi Nhum area are summarized in Table 6.

Data from Table 6 show that total of mineral reserves of the placer minerals in both gray and red sand formations in South Suoi Nhum estimated at 121 + 122 categories are 2,825.21 thousand tons (titanium group: 285.97 thousand tons; zircon: 531.9 thousand tons and monazite: 7.34 thousand tons), in which mineral reserves at 121 category is 666.27 thousand tons (titanium group: 537.48 thousand tons; zircon: 127.34 thousand tons and monazite: 1.46 thousand tons) and mineral reserves at 122 category is 2,158.93 thousand tons (titanium group: 1,748.49 thousand tons; zircon: 404.56 thousand tons and monazite: 5.88 thousand tons). Total mineral resources of placer minerals in South Suoi Nhum area computed at 333 category is 216.16 thousand tons (titanium group: 215.69 thousand tons; zircon: 43.55 thousand tons and monazite: 0.47 thousand tons).

**5. Conclusion**

From the above study results, some conclusions are made as follows:

- Geological structure of the South Suoi Nhum area is quite simple, mainly composed of the Holocene gray, gray-yellow deposits of the marine-aeolian sediments and the Pleistocene marine brown-red deposits of the Phan Thiet Formation. Lithological compositions are mainly fine sand containing placer minerals.

- Placer ore are observed in both gray and red sand formations, which consist of titanium – zircon placer ores. The ore body thickness is relatively steady and they are exposed to the surface. The thickness of the ore body in the gray sand ranges from 2 - 52m, 16.62m on average while the thickness of the ore body in the red sand formation changes from 1 - 61m, 29.79m on average. Whole content of ore minerals in the gray sand formation ranges from 0.250% - 12.371%, 7.1% on average while the whole content of ore minerals in the red sand stratum varies from 0.250% - 12.306%, 6.02% on average but zircon content is higher accounting for 17-18% of the whole usable minerals.

- Usable mineral composition of the gray and red sand strata are entirely similar, including essential minerals such as ilmenite, zircon, rutile, anatase, leucoxene, and monazite. Non-ore minerals such as quartz, feldspar, tourmaline, garnet. The placer ore minerals are evenly disseminated and show quite a close positive correlation to each other. The grain-size fractions of the gray and red sands are also quite similar and mainly concentrated in a range <0.5mm, the most common grain size spectrum varies from 0.5 - 0.25mm. The ore minerals such as ilmenite, zircon, rutile, anatase, leucocene, monazite primarily concentrate on 0.25 - to 0.1mm fraction. The ore concentration is evenly distributed.

- The thickness of the ore body in both gray and red sand formations is strongly variable. The thickness of the ore body is strong changed from the center to the sides along the directional perpendicular to the coastline. Parallel to the coastline, the thickness of the ore body tends to decrease gradually from north to south.

- Content of the ore minerals in gray and red sand formation varies evenly. Along the directional perpendicular to coastline, the content of ore minerals is strongly variable from the center to the margins. Whereas, the content of ore minerals tends to decrease gradually from north to south along the parallel direction to coastline. However, content of ore minerals in the gray sands are more variable than in the red sands.

- Total mineral reserves of the placer ore minerals in both gray and red sand formations in South Suoi Nhum area estimated at 121 + 122 categories are 2,825.21 thousand tons (titanium group: 285.97 thousand tons; zircon: 531.9 thousand tons and monazite: 7.34 thousand tons), in which mineral reserves at 121 category is 666.27 thousand tons (titanium group: 537.48 thousand tons; zircon: 127.34 thousand tons and monazite: 1.46 thousand tons) and mineral reserves at 122 category is 2,158.93 thousand tons (titanium group:

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