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Provenance, routing and weathering history of heavy minerals from coastal placer deposits of southern Vietnam

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ABSTRACT

Heavy mineral rich sands along the coastal margin of southern Vietnam often contain commercial deposits of ilmenite and zircon but their origin is unknown. A multi-method approach based on petrology, geochemistry and detrital zircon geochronology was used to define the provenance and transport history of these mainly Quaternary sands. A trend of progressive enrichment of ilmenite TiO_2 content, from north to south, was observed. This reflects increased levels of weathering attributed to a wider coastal margin and shelf in the south combined with a succession of erosion and reburial events associated with interstadial and interglacial sea-level changes. Weathering took place during lowstands. Detrital zircon U—Pb age signatures collected from 25 major river outlets along the coast of Vietnam helped to locate potential sand sources. Prominent age groups spanning 90–120 Ma and 220–250 Ma with a minor group at 400–500 Ma are present in all of the detrital zircon U—Pb age distributions of contemporary beach sands and Quaternary coastal dune placer deposits. Proterozoic grains are also present but constitute <10% of dated grains. The main source terrain for the placer sands is southern Vietnam where there are widespread outcrops of Mesozoic magmatic rocks. Detrital zircon U—Pb age signatures from river sands that drain this area are identical to zircon age distributions in placer sands. River sands from northern Vietnam, the Mekong and its delta contain abundant Paleozoic and Proterozoic zircons, which are largely absent from the placer sands, and so are ruled out as primary sources.

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1. Introduction

Beach and dune placer deposits occur along the 3260 km coastline of Vietnam, as well as offshore in water depths up to 30 m or more, are economically important sources of ilmenite, rutile and zircon (Fig. 1). The heavy mineral rich sands are mainly found in beach dunes, beach ridge, washover and backshore deposits associated with Holocene to Pleistocene sealevel changes. Onshore deposits occur as bands, typically 1–4 m thick, that extend 1–3 km inland from the coast, and are up to 10 km in length. Most of the high-value deposits are found south of latitude 16°N particularly in the central SE Vietnam provinces Ninh Thuan and Binh Thuan (Fig. 1), to the northeast of Ho Chi Minh City. Surveys made in 2011 by the Department of Geology and Mineral Resources of Vietnam estimated that there are at least 650 million tons of ore reserves along the coastal margins between northeastern Vietnam and Vung Tau in the south. Sand ilmenite content typically varies from 10 to 100 kg/m^3 although some locations have concentrations well above this. Rutile contents are usually <1 kg/m^3, although in some places it can reach up to 3–4 kg/m^3 (e.g., coastal areas north of Da Nang). Zircon abundances also vary; the highest average content (up to 12 kg/m^3) can be found in the coastal sections of Ham Tan in Binh Thuan Province (Fig. 1). Mineral grain sizes are typically in the range of 0.16–0.25 mm. Understanding the origin of these minerals and the processes by which they became concentrated is the primary motivation of this study.

Ilmenite is an important source of titanium oxide. Fresh unaltered ilmenite has TiO_2 wt% values up to the stoichmetric value of 52.6 wt%. Chemical weathering and alteration, especially in oxidising and/or acidic environments, can change ilmenite chemistry by reducing Fe and Mn, increasing Ti and adding Al, Si, Th, P, V and Cr (Pownceby, 2010). The distribution and proportions of the different types of altered grains in the heavy mineral sands influences their commercial value as a source of Ti, and therefore it is important to understand the distribution and proportions of the different types of altered grains in the deposits which requires identifying where the alteration occurred and defining grain transport history.

Coastal sands along the southeast-central coastline of Vietnam typically comprise an outer and inner sand barrier. The former consists of

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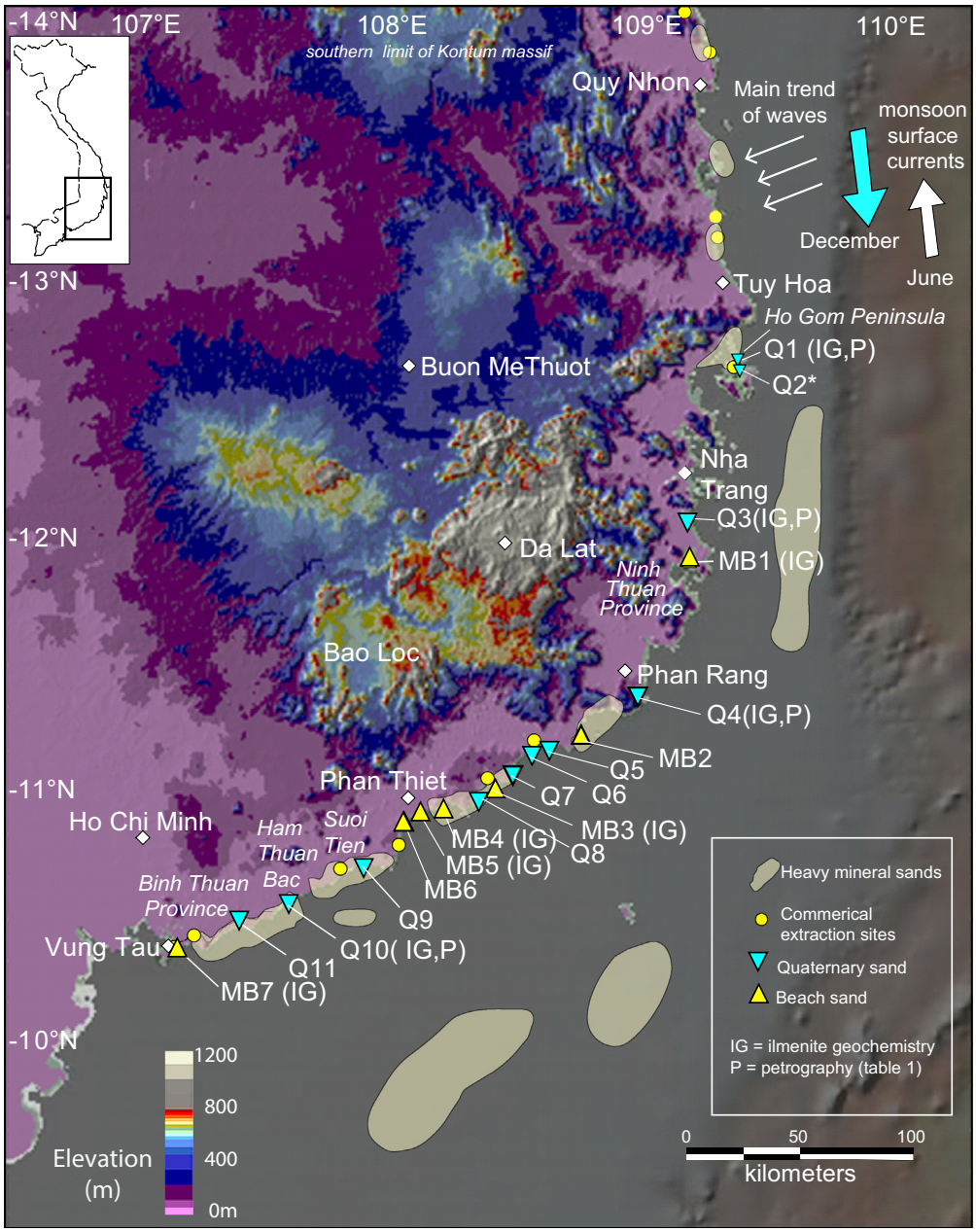

Fig. 1. Locations of placer and beach sands samples and main commercial extraction sites in southern Vietnam. Samples with illmenite composition data, and mineralogical data reported in Table 1, are also indicated.

loose white sand that sometimes form tombolos (e.g., Ho Gom Peninsula). The inner sand barrier located up to 20 km inland consists of light yellow to reddish yellow sands that include dunes found at elevations over 100 m above sea level, such as in the area north of Vung Tau or Ham Thuan Bac district (Fig. 1). Whether these sands are locally derived is unclear. The aim of this study is to better understand the environmental processes that led to the alteration and concentration of the heavy minerals and to define where the sand came from. It is known that the sands are closely linked to sea-level oscillations during the Quaternary, especially Holocene glacioeustatic changes between 8 and 5 ka (Stattegger et al., 2013). Falling sea level causes remobilisation of coastal sands deposited during highstands and increases bedrock erosion inland. Larger volumes of sediment would have been more intensely weathered during glacial periods (Wan et al., 2017) and the subaerial exposure of unconsolidated shelf sediments during associated lowstands would have affected ilmenite chemistry by causing enrichment in TiO_2. Wave action and longshore drift would also have contributed to the winnowing process, sorting grains according to size and density, hence it is entirely possible that sand grains are far removed from their original source areas.

2. Regional geology and geomorphology

The source and volume of beach sands depend on wind, wave and tide regimes as well as local erosion and fluvial transport rates. Detailed study of a river catchment in northern coastal Vietnam has indicated that greatest erosion reflected by river bedload and chemistry occurs within the mountainous regions where precipitation rates are highest, and that both weathering and erosion rates are linked to monsoon intensity (Jonell et al., 2017). Transport of sediment to the coast is dominated by discharge from the Mekong River in the south and by the Song Ma and Song Hong (Red River) in the north. Between these large rivers, that have their headwaters in Tibet and southwest China, the central areas of Vietnam are more locally drained by relatively small

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