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Diversity in the geomorphology of shallow-water carbonate depositional systems in the Saudi Arabian Red Sea

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ABSTRACT

Coral reefs and their associated accumulations of carbonate sediment adopt particularly complex planform geometries atop the coastal shelf of the Saudi Arabian Red Sea. By assembling 95,000 km^2 of remote sensing data into a GIS, this study aims to relate the morphology of these shallow-water depositional environments to processes that sculpt the coastal zone. A typology that sorts carbonate systems into end-members on the basis of their morphology and relationship to the coastline is developed. The resulting GIS was interrogated for spatial patterns in the distribution and abundance of the end-members. While several depositional morphologies are present throughout the length of the Saudi Arabian Red Sea, the occurrence of others is restricted to narrow regions of latitude. Such differences in distribution can be explained in process-terms by the rift tectonics of the Red Sea basin, spatial variability in the presence of sub-seafloor evaporites, and the input of siliciclastic detritus onto the coastal shelf via wadis. This paper provides a foundation for understanding the morphological diversity of shallow-water carbonate systems in both the modern ocean and rock records.

1. Introduction

The classification of coral reef morphology has a long history, starting with Darwin (1842) who defined the three broad classes 'fringing reef', 'barrier reef', and 'atoll', terms still used to this day. Later works have strived to capture more subtle morphological variations. For example, the typology of Hopley et al. (1989) splits the Great Barrier Reef (GBR) into nine classes while more than a thousand reef types have been defined by Andréfouët et al. (2006) at the global scale. The span in number of classes presented by these studies is indicative of the morphological complexity of coral reef systems. Coral reefs are not by any means made of corals alone. Many other calcareous organisms, both animal and plant, contribute to the volume of a reef (Hart and Kench, 2007). A "carbonate system", as defined in this paper, therefore considers the shallow-water (<30 m) accumulation of both reefs and associated carbonate sediments. Carbonate systems can be partitioned on the basis of planform morphology of reefs and sediments into distinct 'morphological end-members'.

The classification of carbonate systems is relevant to a number of disciplines. Coral reef managers often lack knowledge on the diversity of carbonate systems over which they preside, their size, and how carbonate systems are connected with one another (Andréfouët et al., 2006). A knowledge deficit is problematic because the morphology of carbonate systems influences the biogeographic patterns of reef associated species (Bellwood and Hughes, 2001), and is an important consideration in the design of marine protected areas (McLeod et al., 2009). Modern carbonate systems also serve as analogs for understanding ancient carbonate systems (Montaggioni et al., 1986; Rankey, 2002; Purkis et al., 2007; Harris et al., 2011; Purkis et al., 2012a, 2012b; Harris et al., 2013). The definition of carbonate systems can also be used to structure comparative analyses. For example, carbonate systems that are similar in their appearance may be expected to exhibit similar carbonate production values (Perry et al., 2008; Leon and Woodroffe, 2013). Finally, carbonate system morphology provides much needed context for more detailed mapping of seabed habitats at fine spatial resolution (Andréfouët et al., 2006; Rowlands et al., 2012).

Diversity in the morphology of carbonate systems can sometimes be explained in terms of underlying tectonics, the action of wind, waves and currents, changes in the position of sea-level, antecedent topography, and climate (Darwin, 1842; Fairbridge, 1967; Maxwell, 1970; Purdy, 1974; Hopley, 1982; Bosence, 2005; Purkis et al., 2010; Harris et al., 2011; Purkis et al., 2012a; Leon and Woodroffe, 2013). The morphology of a carbonate system is not static through time. For instance, considering the carbonate systems of the Australian GBR, Hopley (1982) recognizes an evolutionary progression through different morphological end-members from juvenile (unmodified antecedent platforms, submerged reefs, irregular patch reefs), to mature (crescentic reefs, lagoonal reefs) and finally to senile (planar reefs). Morphology is therefore a temporally dynamic property of a carbonate system.

This study considers the morphological diversity of carbonate depositional systems in the Saudi Arabian Red Sea (Fig. 1), which Bosence

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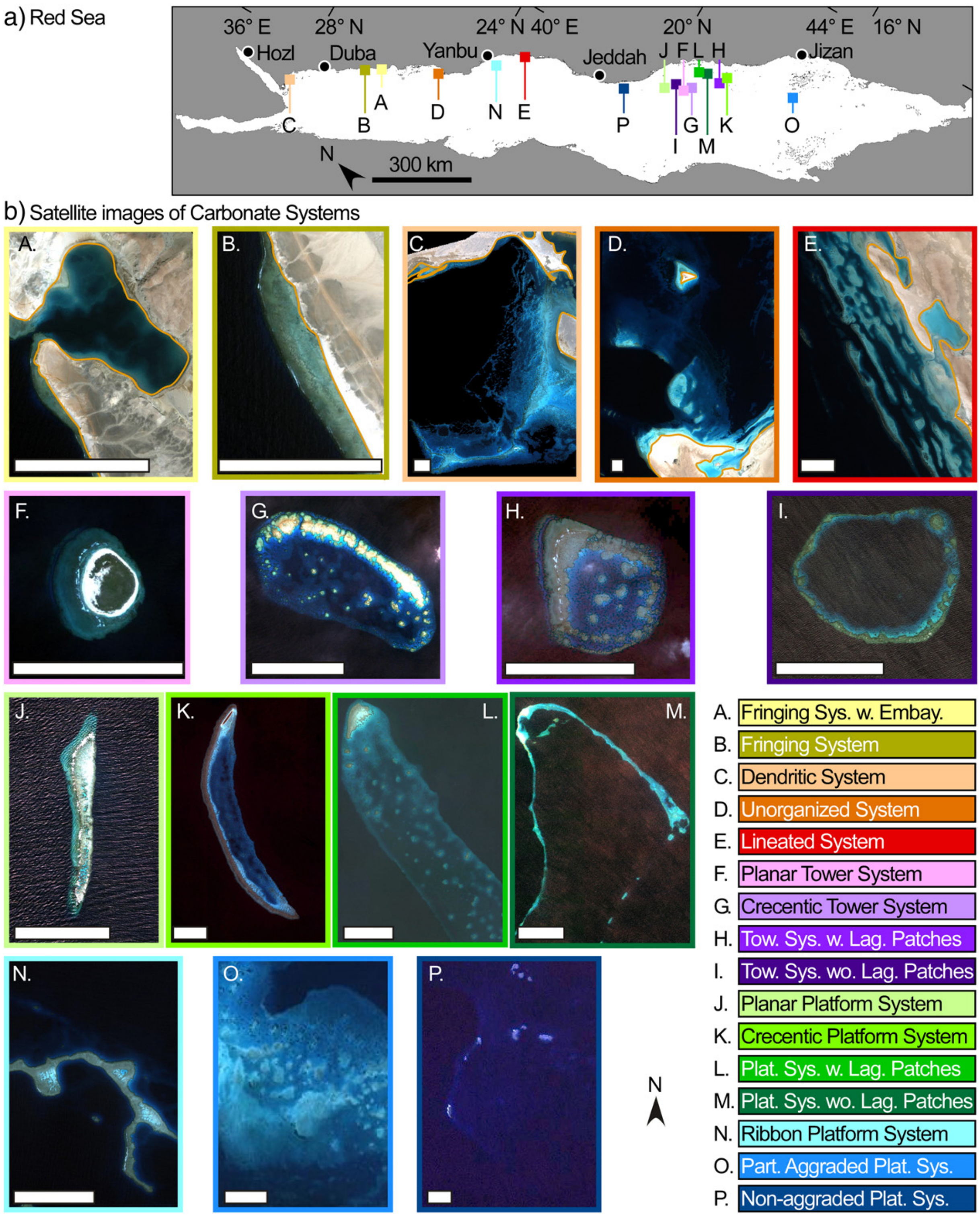

Fig. 1. a) The Red Sea basin. Note rotated north axis. Letters and boxes indicate position of image subsets shown below; b) subsets of QuickBird satellite imagery that illustrates the sixteen morphological end-members of the Saudi Arabian Red Sea typology (Fig. 2). In each image, the horizontal scale bar represents 1 km. First row (A–E) are carbonate systems with an 'Attached Form', second row (F–I) are carbonate systems in the 'Tower Group', third row (J–M) are carbonate systems in the 'Platform Group with an Aggraded Edge' and forth row (N–P) are carbonate systems in the 'Platform Group with a Non-aggraded Edge'. Names of Carbonate Systems in key are abbreviated; see Fig. 2 for details.

(2005) broadly explains in terms of the input of siliciclastics as controlled by the hyper-arid Arabian climate, combined with the action of rift-related tectonics. Despite the relatively small size of the Red Sea, a wide variety of carbonate systems have been documented (Sheppard et al., 1992; Dullo and Montaggioni, 1998; Bosence, 2005). Nonetheless, there has not been an effort to collate this morphological diversity into a logical scheme of classification, nor to analyze the spatial distribution of this morphological diversity, as, for example, has been undertaken in the GBR (Hopley et al., 1989) and Torres Strait (Leon and Woodroffe, 2013), Australia.

This study will firstly propose a robust typology for identifying morphological end-members of the carbonate systems of the Saudi