Earth-Science Reviews 127 (2013) 140–170

Contents lists available at ScienceDirect

Earth-Science Reviews

journal homepage: www.elsevier.com/locate/earscirev

Coastal evolution on volcanic oceanic islands: A complex interplay between volcanism, erosion, sedimentation, sea-level change and biogenic production

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A R T I C L E I N F O

Article history:
Received 1 June 2013
Accepted 9 October 2013
Available online 19 October 2013

Keywords:
Coastal evolution
Oceanic island volcanoes
Volcanism
Erosion
Sedimentation
Sea-level change

A B S T R A C T

The growth and decay of oceanic hotspot volcanoes are intrinsically related to a competition between volcanic construction and erosive destruction, and coastlines are at the forefront of such confrontation. In this paper, we review the several mechanisms that interact and contribute to the development of coastlines on oceanic island volcanoes, and how these processes evolve throughout the islands' lifetime. Volcanic constructional processes dominate during the emergent island and subaerial shield-building stages. During the emergent island stage, surtseyan activity prevails and hydroclastic and pyroclastic structures form; these structures are generally ephemeral because they can be rapidly obliterated by marine erosion. With the onset of the subaerial shield-building stage, coastal evolution is essentially characterized by rapid but intermittent lateral growth through the formation of lava deltas, largely expanding the coastlines until they, typically, reach their maximum extension. With the post-shield quiescence in volcanic activity, destructive processes gradually take over and coastlines retreat, adopting a more prominent profile; mass wasting and marine and fluvial erosion reshape the landscape and, if conditions are favorable, biogenic processes assume a prominent role. Post-erosional volcanic activity may temporarily reverse the balance by renewing coastline expansion, but islands inexorably enter in a long battle for survival above sea level. Reef growth and/or uplift may also prolong the island's lifetime above the waves. The ultimate fate of most islands, however, is to be drowned through subsidence and/or truncation by marine erosion.

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http://dx.doi.org/10.1016/j.earscirev.2013.10.007

1. Introduction

Coastlines are the ever-changing boundary between the land and the sea. They are complex threshold-driven, non-linear dynamical systems (Naylor and Stephenson, 2010) whose evolution is the product of mutual adjustments in topography and fluid dynamics in response to changes in external conditions (Wright and Thom, 1977; Trenhaile, 1997; Woodroffe, 2002). Few places on our planet experience more dramatic and rapid changes in topography and external conditions than the coasts of hotspot islands, which experience the effects of volcanism, flank collapses, and exposure to open ocean. Additionally, coastlines on oceanic island volcanoes have a clear beginning (through volcanic emergence) and a predictable end (through island subsidence/erosion), and evolve as the edifices themselves evolve. Oceanic island volcanoes are, thus, prime natural laboratories to study the different processes that interplay in a complex manner to shape coastlines.

Oceanic hotspot islands are prominent, dynamic geological features that rise from the deep seafloor by a combination of volcanic, intrusive and tectonic processes. Coastlines are established as soon as oceanic island edifices breach sea level, and they become the forefront of a raging battle that, in the long term, is lost. This confrontation is, essentially, a competition between volcanic (and biogenic) construction on one side, and erosive destruction on the other. This balance, or more appropriately this imbalance, of powers varies in space and time as island edifices evolve. In this paper we offer an overview on the main mechanisms that shape oceanic island coastlines, and how these mechanisms act differentially throughout the successive stages of island evolution. An analysis of the various factors that control coastal evolution on oceanic island volcanoes is also presented here and discussed, albeit in a qualitative manner.

2. Oceanic hotspot island evolution and development of coastlines

Oceanic island volcanoes frequently follow an evolutionary trend that exhibits some basic similarities across different hotspot systems (Schmincke, 2004; Ramalho, 2011). This evolutionary trend is essentially caused by variations in the rate of magma-supply through geological time. This, in turn, is a function of plate motion relative to the hotspot melting source, plate age/thickness, proximity to a plate boundary, and melt source characteristics (Ramalho, 2011). Internal factors such as those described above directly influence the distribution, style and intensity of magmatism over space and time, and the relative position of the edifices with respect to sea level. External factors also contribute to edifice evolution: environmental conditions not only control the nature and intensity of the erosive agents that act upon the edifices but also control the relative importance of biological processes in the system. The evolution of oceanic island systems is, thus, somewhat different