Why have the old Cape Verde Islands remained above sea-level?

Insights from field data and wave erosion modelling

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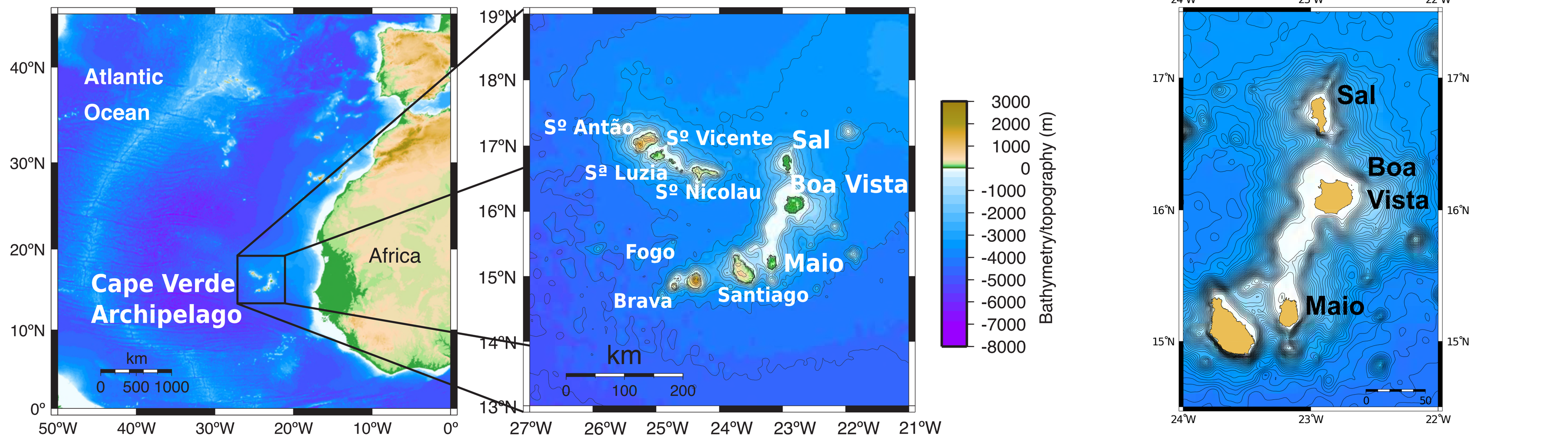
1. Introduction

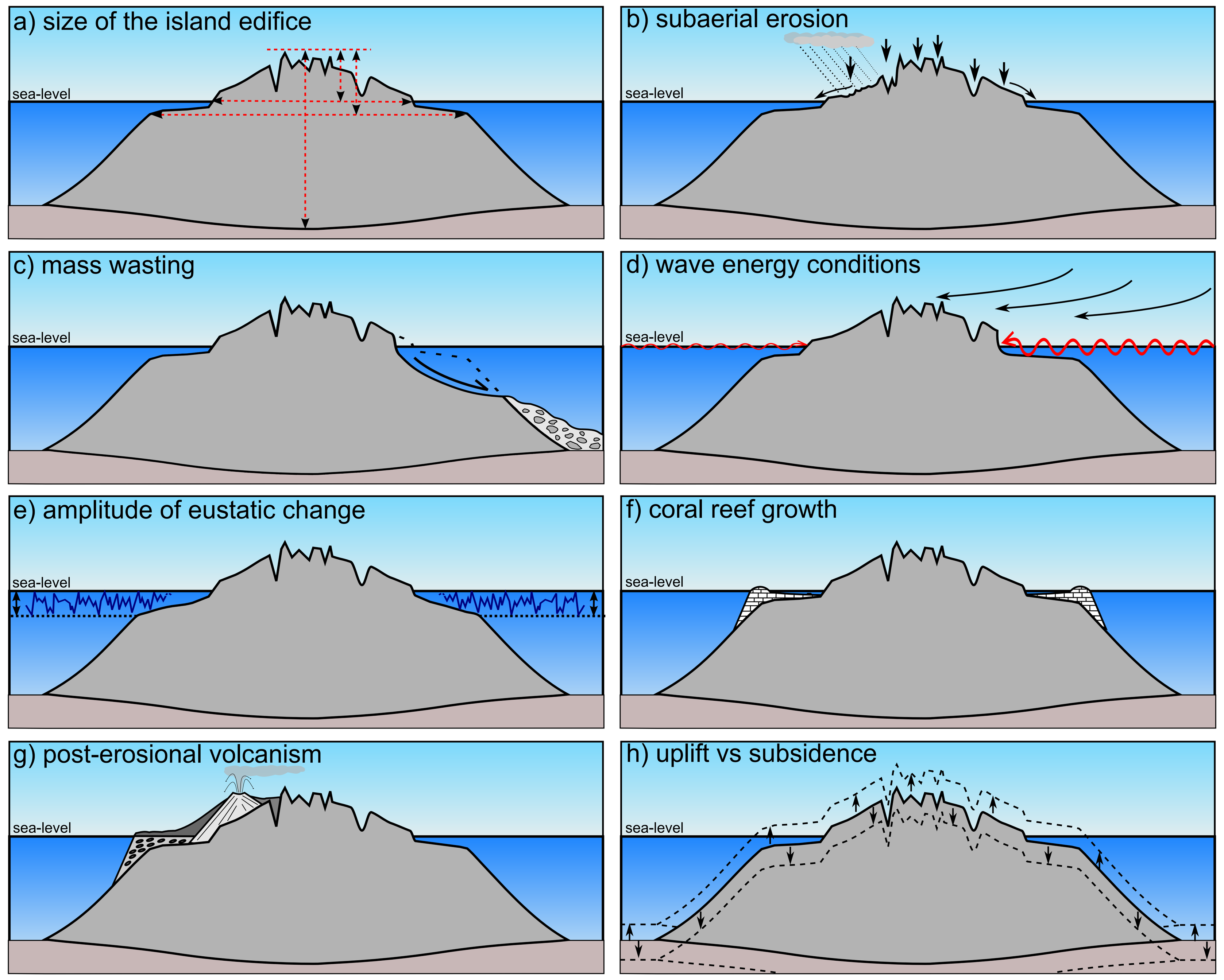
The ultimate fate of late stage ocean islands is to be drowned beneath the sea surface and become a guyot. This process is essentially dictated by subsidence in edifices in young lithosphere and/or in fast-moving plates, or by marine erosion that truncates edifices located in old lithosphere and in mid-plate stationary swells like in Cape Verde. Several factors control the transition from island to guyot but only a few play a crucial role in maintaining ocean island edifices above sea-level. This study reports on how three of the oldest of the Cape Verde islands - Sal, Boa Vista and Maio - have been maintained above sea-level just through an uplift process.

Location of the Cape Verde Archipelago, and bathymetry/topography around Sal, Boa Vista and Maio.



2. Factors controlling ocean island survival

Several factors complexly interplay to control the transition from island to guyot. These are, chiefly:

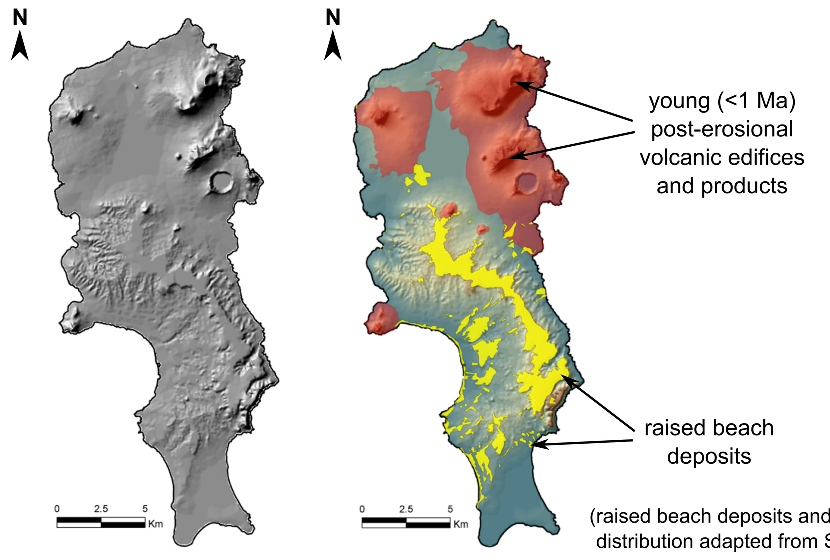


From these, only (f) coral reef growth, (g) post-erosional volcanism and (h) uplift may extend considerably the survival of an island. In this study we focus on three islands that are pratically devoid of coral reef and products of post-erosional (rejuvenated) volcanism. Additionally, these islands experienced an uplift trend during the Quaternary (Ramalho *et al.* 2010a,b,c). Thus, only uplift can be accounted for prolonging the islands' life above sea-level.

3. Anatomy of the Old Cape Verde Islands

3.1 Sal

Sal is flat-lying except for a few recent (<1 Ma) cones from the last post-erosional stage (Torres *et al.* 2002, Holm *et al.* 2008). The remaining area consists of marine terraces up to 100 m a.s.l., somewhat degraded by fluvial erosion.



Sal Island was completely truncated by marine erosion, sometime between ~9 and ~5.5 Ma (when Serra Negra volcano erupted), and later again until it resurged by an uplift process sometime after ~3 Ma b.p. (Ramalho *et al.* 2010a).

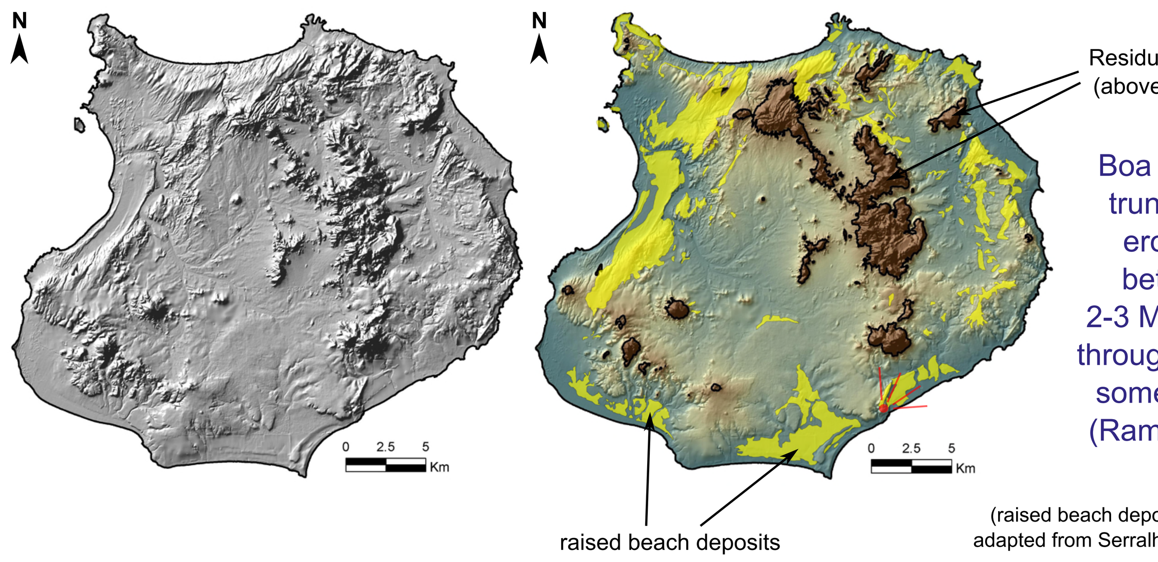
Late Pliocene/Quaternary marine terraces/ shore platforms at:

1 m	23 m
2.5 m	24 m
4 m	38 m
6 m	44 m
9 m	47 m
12 m	52 m
13 m	55-60 m
18 m	100 m (!)

(Zazo *et al.* 2007, Silva *et al.* 1990 Ramalho *et al.* 2010a)

3.2 Boa Vista

Boa Vista is flat and devoid of young volcanic forms - the last eruptive stage occurred ~4.5 Ma (Dhyr & Holm 2010). Its relief was razed by marine erosion up to 110-120 m a.s.l., with the exception of a few erosive-resistant, mostly phonolitic, residual reliefs whose tallest barely reaches 380 m a.s.l.



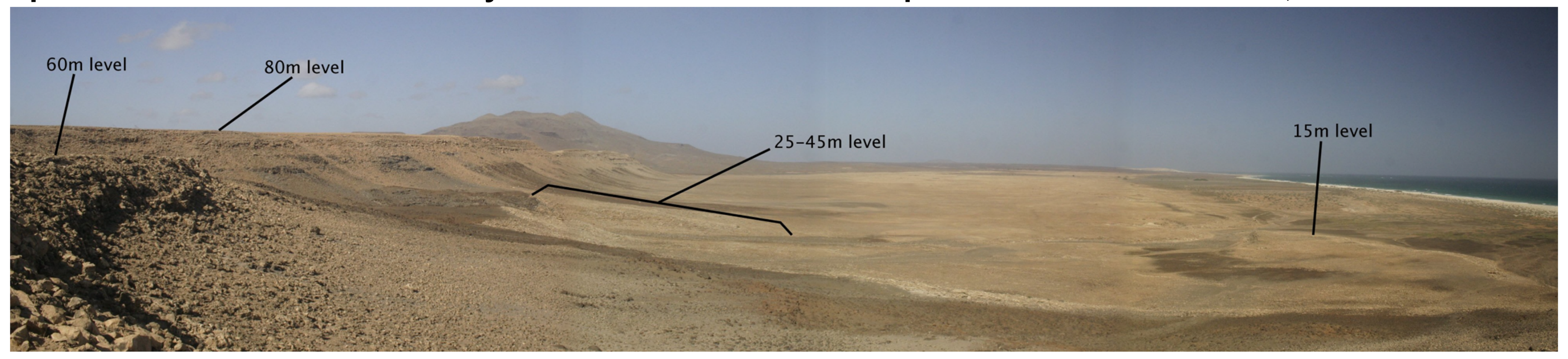
Boa Vista was almost truncated by marine erosion sometime between ~4.5 and 2-3 Ma b.p.; it resurged through an uplift process sometime after ~3 Ma (Ramalho *et al.* 2010a)

Late Pliocene/Quaternary marine terraces/ shore platforms at:

2-3 m
4-8 m
10-15 m
18-28 m
25-45 m
50-60 m
67-70 m
70-80 m
90-105 m
110-120 m (?)

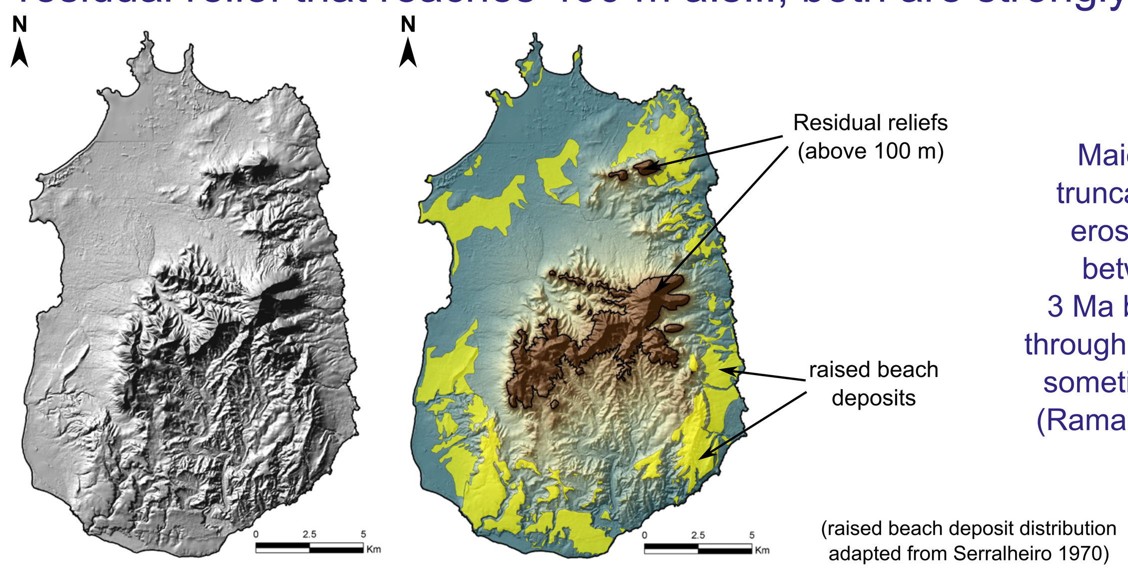
(Serralheiro *et al.* 1974, Ramalho *et al.* 2010a)

Uplifted Late Pliocene/Quaternary marine terraces and shore platforms in João Barrosa, SE Boa Vista



3.3 Maio

Maio is a small, low-lying island completely devoid of young volcanic morphologies since its last eruptive period finished ~7 Ma (Mitchell et al. 1983). The island exhibits a peripheral "staircase" of marine terraces up to 100 m a.s.l., arround a central residual relief that reaches 430 m a.s.l.; both are strongly incised by fluvial erosion.



Maio was almost truncated by marine erosion sometime between ~7 and 3 Ma b.p.; it resurged through an uplift process sometime after ~3 Ma (Ramalho *et al.* 2010a)

Late Pliocene/Quaternary marine terraces/ shore platforms at:

2-6 m
8-12 m
15-20 m
30-40 m
55-65 m
65-75 m
80-100 m

(Serralheiro 1970, 1976, Ramalho *et al.* 2010a)

4. Wave erosion modelling

A numerical model (Trenhaile 2000, 2001) was used to investigate whether wave erosion during the last 3 Ma would have been capable of completely truncate these islands in the absence of uplift, and/or what uplift rates/trends would be compatible with the islands' geomorphology.

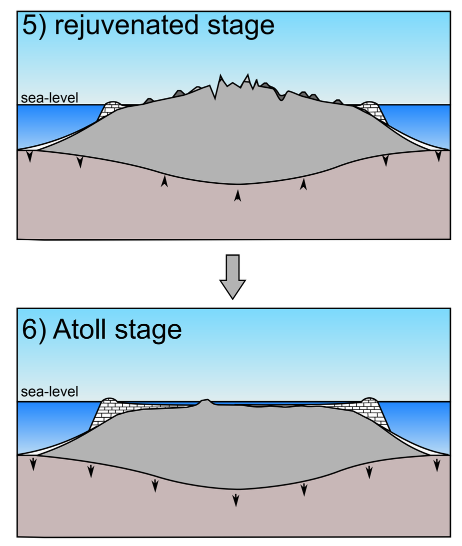
$$E_y = IM\sum_{W_t=1}^{W_t=n}\left(T_d W\left(512.61(H_b/0.78)e^{-kWs} - S_{f\,min}\right)\right)$$

- Eustatic curve used is from Bitanja *et al.* 2008
- Wave data from NOAA regional ocean wave models

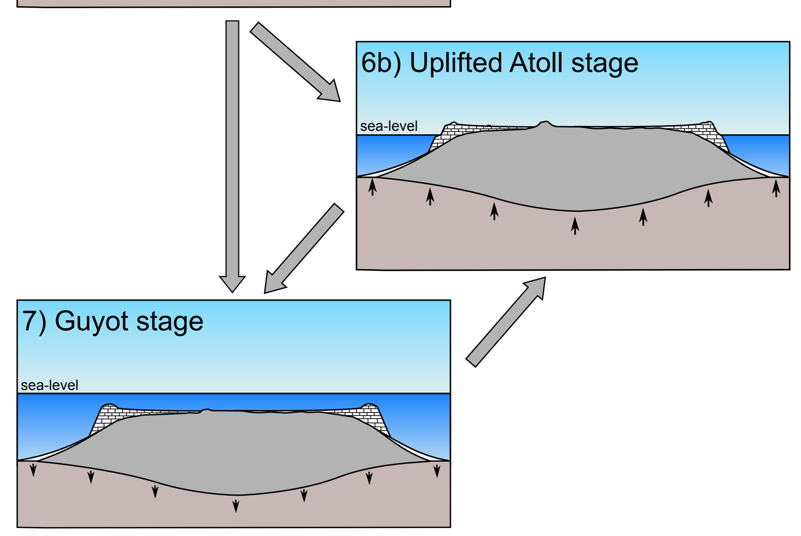
Ey - Amount of backwearing (m) over a given period at a specific intertidal level; ***I*** - iteration interval (5 years);
M - Coefficient used to convert the force exerted at the surf-rock interface into the amount of cliff and platform erosion that occurs at each model iteration;
T_d - Number of hours per year in which the water level is at a given intertidal elevation. ***W*** - Hourly number of waves of each of the n deeper-water height categories;
k - Rate at which surf energy is attenuated from the breaker zone to the waterline, according to bottom roughness;
$db = Hb/0.78$ - Breaking wave depth; $Ws = db/\tan\beta$ - width of the surf zone; $Fb = 0.5\rho_W db$ - Wave force at the breakers;
$S_f = 0.5\rho_W(Hb/0.78)e^{-kws}$ - Surf force reaching the waterline; $S_{f\,min}$ - Threshold wave force able to iniate rock erosion;

5. Atoll *vs* Razed Island

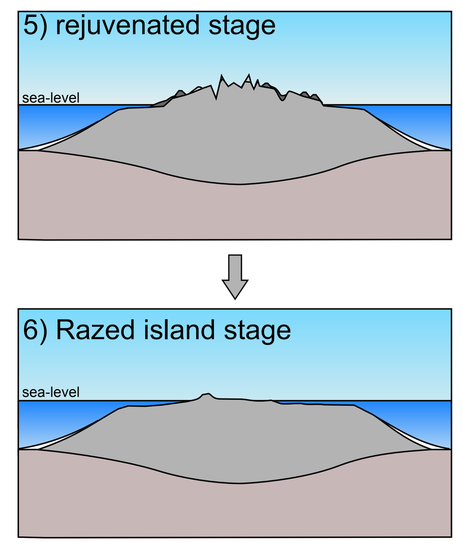
Fast moving plate environment
subsidence trend



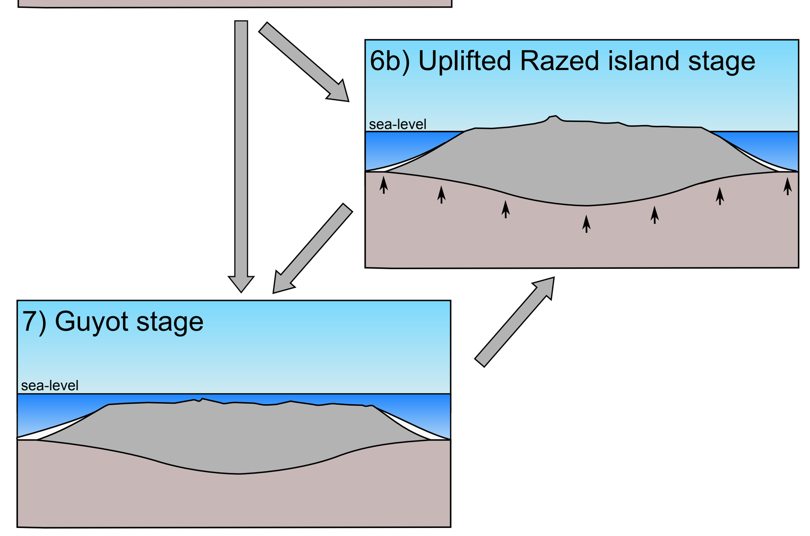
Atolls are mainly generated by a combination of subsidence and coral growth



Stationary or slow moving plate
uplift trend or vertical stability



Razed islands are mainly generated through wave truncation processes



6. Conclusions

- **The old Cape Verde Islands have been increasing in area since the Late Pliocene or early Quaternary, when they were nearly or completely truncated by marine erosion.**
- **Field data and wave erosion modeling further support the idea that this increase in area has been almost entirely sustained by a consistent uplift trend during the Quaternary.**
- **In the absence of such uplift trend the islands would probably have been completely eroded by now and turned into guyots.**
- **The term razed islands is proposed to describe residual islands that are surrounded by extensive wavecut platforms, without coral reefs, in opposition to the term atolls; razed islands are mainly generated through wave truncation processes whilst atolls are mainly generated by a combination of subsidence and coral growth.**

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