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Rivers Influence Reef Pass Formation in the Society Islands

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Key Points:

- Reef pass location is significantly correlated with island drainage basin size in the Society Islands Archipelago
- Relationships between large rivers and reef passes weaken as islands age, implying that ocean processes maintain passes at older islands
- We propose two mechanisms through which rivers may form and maintain reef passes through sea-level cycles

Supporting Information:

Supporting Information may be found in the online version of this article.

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Abstract Reef passes are deep, navigable channels dissecting coral reefs around volcanic islands. Many reef passes are located offshore of large island river basins, suggesting a potential causal relationship. To clarify the mechanisms that form and maintain reef passes, we quantify the relationships between reef pass location and drainage basin size in the Society Islands. River basins draining toward reef passes are larger than those draining toward unbroken reef flats, suggesting that rivers help create and sustain reef passes. The correlation between reef passes and large rivers weakens for older islands, suggesting that oceanographic processes increasingly maintain passes as islands age and subside. We propose two river-driven reef pass formation mechanisms: reef incision, in which rivers erode into reefs during sea-level lowstands, and reef encroachment, in which corals growing in lower-elevation submerged river valleys preferentially drown during periods of rapid sea-level rise, leaving gaps in the accreting reef.

Plain Language Summary Coral reefs ring many volcanic ocean islands in the Pacific Ocean. It is well known that rivers discharging freshwater and sediment off islands affect reef structure and composition. Reef passes, or deep channels through reefs surrounding ocean islands, may result from long-term river erosion. Previous studies have proposed that reef passes correspond to the outlets of large island rivers, but this hypothesis has not been tested statistically. Here, we investigate if reef passes are close to big drainage basins through a geospatial analysis of the Society Islands Archipelago. We find that larger river basins on the islands drain to parts of the reef where passes are found, suggesting that river erosion plays a vital role in determining where deep channels are located within reefs, particularly for younger volcanic islands. We propose two ideas for how rivers could create passes in the Society Islands: reef incision, where rivers directly cut passes into reefs exposed when sea level is lower, and reef encroachment, where old river channels on land are preserved as passes when sea level rises. Our results show how rivers may support reef health over geologic timescales by enhancing water circulation between lagoons and oceans.

1. Introduction

Coral reefs encircling volcanic ocean islands often contain visually striking landforms, including reef passes (Guilcher, 1988; Purdy, 1974). Reef passes are deep channels (tens of meters) cutting through reef barriers and flats that facilitate wave- and tide-driven circulation. These passes regulate flow between the lagoon and ocean and, potentially, flush freshwater and sediment offshore during storms and other high-energy events (Hench et al., 2008; Leichter et al., 2013; Toomey, Woodruff, et al., 2016).

Previous studies have noted an apparent association of reef passes with large island drainage basins. Stark and Dapples (1941, p. 22) note that at Raiatea, in French Polynesia, reef passes are found "opposite prominent embayments in the shoreline which represent drowned mouths of valleys." However, there have been scarce quantitative observations to test this hypothesized spatial correlation. Such a relationship, if confirmed, would suggest that rivers are a driving mechanism for reef pass formation (Guilcher, 1988; Purdy & Winterer, 2006; Stark & Dapples, 1941; Toomey, Woodruff, et al., 2016).

Multiple factors affect reef development (Ramalho et al., 2013; Toomey et al., 2013), including sediment eroding off islands (Rogers, 1990), volcanic edifice subsidence (Darwin, 1842), and wave action (Ortiz & Ashton, 2019). Reefs are also sensitive to sea-level changes (Bosscher & Schlager, 1992; Thompson & Goldstein, 2005)—as sea level rises, subtle differences in water depth and underlying bedrock structure can influence whether accreting reefs build up to sea level ("keep up" or "catch up") or fail to keep pace with rising seas and drown ("give up") (Neumann & Macintyre, 1985; Toomey et al., 2013).

Island rivers can have detrimental short-term effects on reef health, but their longer-term effects may be beneficial. Terrestrial runoff or mass wasting events can destabilize reefs by increasing ocean turbidity and altering seawater chemistry (Bartley et al., 2014; Rogers, 1990). Although subaerial erosion occurs naturally on islands, anthropogenic modifications to island landscapes through agricultural practices may amplify the detrimental effects of surface runoff on reefs (Amato et al., 2016; Dadhich & Nadaoka, 2012; Richmond, 1993; Rodgers et al., 2012). Recent "ridge to reef" studies have examined how terrestrial sediment negatively impacts reef health, informing conservation and management planning (Carlson et al., 2019; Comeros-Raynal et al., 2019; Delevaux et al., 2018). However, over geologic timescales, island rivers may benefit reefs by creating passes that enhance hydrodynamic exchange between lagoons and oceans, enriching nutrient and biological particle circulation critical to reef health (Leichter et al., 2013).

The terrestrial influence on reef morphology likely declines over time (Ramalho et al., 2013), and lingering impacts of island rivers on reef become obscured as islands submerge (Ramalho et al., 2013). After uplift and construction, volcanic ocean islands lose land from subsidence (Darwin, 1842; Huppert et al., 2020; Jefferson et al., 2014) and erosion (Ferrier et al., 2013; Gayer et al., 2019; Hildenbrand et al., 2008) until they eventually vanish below sea level. Moreover, sea level oscillates on shorter timescales than islands subside (Dutton et al., 2015; Toomey, Ashton, et al., 2016), continuously affecting how much of the volcanic edifice is subaerially exposed and can impact the reef (Snyder et al., 2002).

Reef morphology may indicate signs of long-term island erosion as reefs build toward sea level while islands subside. Studies show rivers erode reefs through sediment and freshwater discharge, abrading and dissolving reef carbonate (Bartley et al., 2014). Over time and with sea level oscillations, these erosive processes may form and sustain reef passes. Here we investigate if reef pass locations correlate with large island river basins in the Society Islands. Based on our results, we propose two mechanisms for how rivers may create and maintain reef passes: reef incision, where rivers erode reefs during sea-level lowstands, and reef encroachment, where corals in paleochannel valleys drown during rapid sea-level rise, creating gaps in the reef. By examining how rivers may form passes, we aim to clarify the long-term benefits of island rivers on reef development.

2. Study Area

The Society Islands (Figure 1; Table S1 in Supporting Information S1) formed between approximately 1 and 6 Ma, with Bora Bora the oldest subaerially exposed island in the chain (6.08 ± 0.21 Ma), and Tahiti the youngest, with the southeastern Tahitian volcano having formed 0.95 (±0.18) Ma (Huppert et al., 2020). All islands have either fringing or barrier reefs dissected by reef passes. Older islands generally have fewer reef passes (Table S1 in Supporting Information S1). Portions of Tahiti's reefs are submerged on the northeastern shoreline (Guilcher, 1988) but are dissected by sunken channels similar to passes found on the fringing reefs (Figure 1a).

3. Island-Reef Spatial Analysis

We delineated river basins in the Society Islands by applying steepest-descent flow routing using the open-source MATLAB software topotoolbox (Schwanghart & Scherler, 2014) to 30-m resolution digital elevation models (Figure 2; Figure S1 in Supporting Information S1) (Farr et al., 2007; NASA Shuttle Radar Topography Mission, 2013) and then computing drainage area at basin outlets. We used basin area as a proxy for terrestrial effects on reefs because larger basins generally deliver higher water discharge and sediment flux (Ferrier et al., 2013). Larger basins may experience compounded effects due to higher average runoff per unit area, as they typically extend to higher elevations with enhanced precipitation, and because bedrock river incision rates typically increase with discharge, which scales positively with drainage area (Howard & Kerby, 1983; Whipple & Tucker, 1999).

Reef flat shorelines were hand-digitized from Sentinel 2 imagery collected from April to June 2021 and smoothed in ArcGIS Pro (Figure S1 in Supporting Information S1). Reef passes were mapped as visible interruptions in the reef crest. We then unwrapped reef crest shorelines by measuring the cumulative distance along the reef crest and recorded reef pass locations (Figure 2).

We assumed that each island drainage basin exerts its most substantial effect on the closest reef crest location. Basins were therefore associated with unwrapped reef locations by assigning each basin outlet to the nearest point on the reef crest within a 60-degree angle centered on the azimuth from the island centroid to the basin (Figure 2;

Figure 1. Satellite imagery of islands examined in this study: (a) Tahiti, (b) Mo'orea, (c) Taha'a, and Raiatea, (d) Huahine, (e) Bora Bora, and (f) Maupiti (source: Sentinel 2; April–June 2021). Island age increases clockwise from (a) to (f) (Table S1 in Supporting Information S1). Wave roses depicting the directional distribution of waves with heights greater than 1 m are included for all islands (source: WAVEWATCH III®). (g) Regional-scale map of the Society Islands with global inset map.

Figure S1 in Supporting Information S1). For irregular island coastlines like embayments, pathways were directed to follow waterways toward the reef crest. Although some paths intersect land, their orientation matches the expected drainage direction from each basin outlet to the reef crest. The total drainage area at each reef crest was calculated by summing the areas of all basins assigned to that point. To account for basins discharging over an area of the reef rather than an exact point on the reef edge, we applied a Gaussian-weighted moving average, which smooths the drainage basin area, using standard deviations of 1, 5, or 10 km. The resulting basin area curves were normalized by the island's maximum drainage area to facilitate inter-island comparison.

For each island, we separated all reef points and their associated basin areas into two groups—points in a reef pass, and points not in a reef pass—and tested for differences in the logarithmically transformed basin area between these groups to determine whether reef passes aligned with larger drainage basins. We applied the base-10 logarithmic transformation before the statistical analyses because drainage basin areas are typically log-normally distributed. Submerged and exposed passes at Tahiti were both considered in these statistical analyses. We used Mann-Whitney U and Kruskal-Wallis tests, which are compatible with non-normal distributions and unequal population sizes.

4. Results

Most reef passes coincide with peaks in drainage basin areas for all islands except Maupiti, the smallest and second-oldest island in our analysis, which has only one reef pass (Figure 3). Although this alignment is visually evident, we conducted a Monte Carlo analysis to quantify the likelihood of spatial correspondence by chance. We

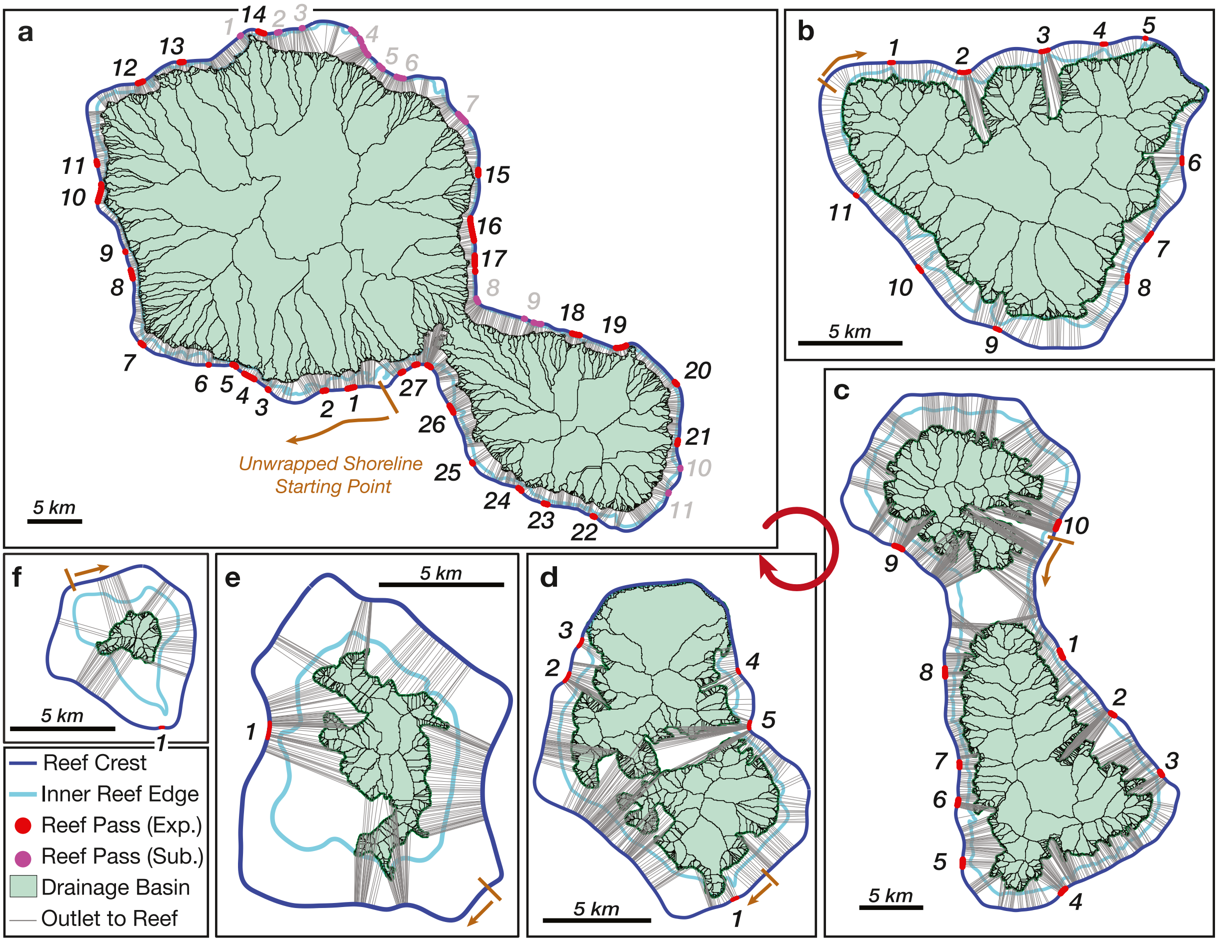

Figure 2. River basin and reef map with connecting drainage basin outlets to nearest reef crest locations for (a) Tahiti, (b) Mo'orea, (c) Taha'a and Raiatea, (d) Huahine, (e) Bora Bora, and (f) Maupiti. Reef passes are numbered and correspond to pass locations in Figure 3. The origin and direction of the unwrapped reef crest shoreline are marked with a brown line and an adjacent arrow. For (a) Tahiti, exposed reef passes are marked with black labels, and submerged reef passes are marked with gray labels.

randomly assigned reef pass locations along the drainage basin curves for each island, calculating total drainage areas for randomized pass locations and comparing them to the observed total basin area draining to passes. Fewer than 5% of the 10,000 random samples yielded total basin areas draining to reef passes that exceeded the observed values for all Gaussian-weighted averages across all islands, except for Maupiti, which we discuss below (Table S2 in Supporting Information S1).

Reef passes across most islands receive more island drainage per unit length than unbroken parts of the reef for both un-smoothed and smoothed drainage areas and for different smoothing filter widths (1–10 km) (Figure S2 in Supporting Information S1). Log-median drainage areas are higher for reef passes compared to unbroken portions of the reef flat, except at Maupiti (Table S3 in Supporting Information S1). All statistical analyses identified significant differences between pass-aligned and non-pass basin areas (p-values $< 10^{-3}$) at the 95% confidence level (Table S3 in Supporting Information S1).

Although reef passes predominantly align with large drainage basin outlets, there are exceptions, especially at older islands. Several large basins draining toward the reef shore between unwrapped reef locations 75–115 km in the northern reef flat at Taha'a lack modern passes and drain toward reef islands (*motu*) (Figures 1c and 3c). At the 18 km mark on Mo'orea (Figures 1b and 3b) and the 30 km mark on Huahine (Figures 1d and 3d), drainage area peaks with no reef passes correspond to areas of urban development on the north-northeastern reef flat (Table S1 in Supporting Information S1). At Maupiti, the lone reef pass falls between drainage basin outlets (Figures 2f and 3f), which may be due to the island's relatively old age (5.5 Ma) and small exposed subaerial landmass

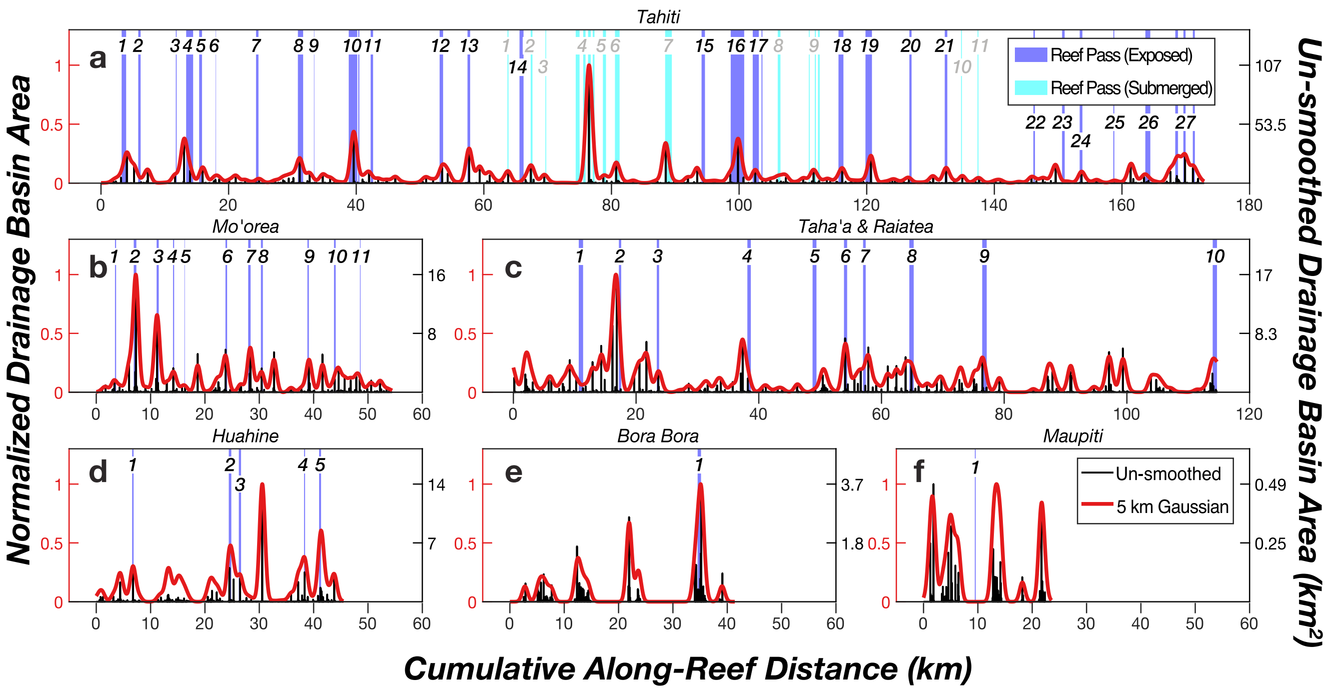

Figure 3. Normalized drainage area along the unwrapped reef crest shorelines for (a) Tahiti, (b) Mo'orea, (c) Taha'a and Raiatea, (d) Huahine, (e) Bora Bora, and (f) Maupiti. The black curve represents the un-smoothed drainage basin area (right axis). The red curve depicts the 5 km Gaussian smoothed normalized drainage basin area (left axis). Reef pass locations (numbers shown in Figure 2) are marked with numbered vertical bars (dark blue for passes bounded by subaerially exposed reef, light blue for passes bounded by submerged reef). The right axis shows the total drainage area for the un-smoothed data.

(~4.4 km^2). Consequently, in our Monte Carlo analysis, in 99% of samples across all smoothing windows, the simulated drainage area of this lone reef pass was greater than the observed (Table S2 in Supporting Information S1). Bora Bora, the oldest island, also has only one reef pass, such that some large basins have no associated reef pass, but unlike on Maupiti, the lone reef pass on Bora Bora is aligned with the largest peak in drainage area (Figure 3e).

5. Reef Pass Formation Mechanisms

Our results quantitatively demonstrate that reef passes in the Society Islands coincide with large island drainage basins, as suggested by previous observations (Purdy, 1974; Stark & Dapples, 1941; Toomey, Woodruff, et al., 2016). Based on this correlation, we propose two mechanisms by which rivers may form and maintain reef passes as an island experiences glacio-eustatic sea-level cycles superimposed on long-term subsidence (Figure 4). These multiple hypothesized reef pass formation mechanisms operate at different stages of a glacio-eustatic sea-level cycle and could therefore both occur throughout an island's drowning period.

5.1. Fluvial Mechanisms

The reef incision hypothesis (Figure 4) proposes that passes are formed during glacial lowstands when the reef platform is exposed to physical and chemical weathering from fluvial discharge (Purdy & Winterer, 2006). After volcanic construction and uplift cease, the island erodes and subsides (Ramalho et al., 2013). The accompanying reef grows to mean sea level during the first highstand (Toomey et al., 2013). As sea level falls toward a lowstand, reef platforms are exposed and susceptible to fluvial alteration (Guilcher, 1988; Toomey, Woodruff, et al., 2016). During lowstands, large rivers with high discharges would flow over or through the subaerial reef, carving reef passes by physical abrasion from terrigenous sediment (Purdy, 1974; Rogers, 1990) or freshwater chemical dissolution (Chauveau et al., 2021). These highly eroded reef segments would then be preserved as reef passes after post-glacial sea level rises to the second highstand. The reef incision hypothesis is consistent with geophysical imaging of Taha'a's lagoon sediments, which reveals what appear to be infilled channels incised during the Pleistocene lowstand by rivers that flowed to the reef (Toomey, Woodruff, et al., 2016).

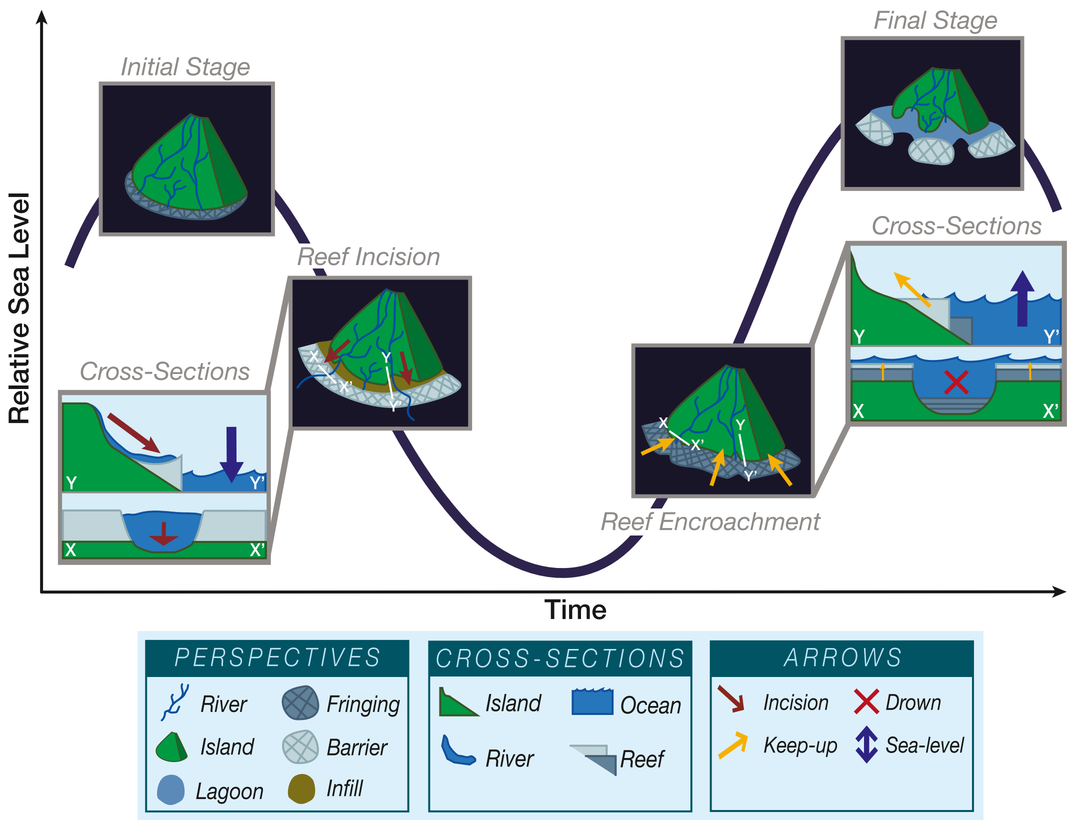

Figure 4. Proposed river-driven reef pass formation mechanisms: reef incision and reef encroachment. Each panel represents an evolutionary stage for the volcanic ocean island at the proposed sea-level stand. Reef incision would occur during periods of sea-level fall, whereas reef encroachment happens as sea levels rise. Cross-sectional diagrams for each formation mechanism illustrate processes occurring in the cross-shore (Y-Y′) and alongshore (X-X′) directions.

The reef encroachment hypothesis (Figure 4) proposes that reef passes preferentially form in relict fluvial channels, where deeper water prevents reefs from accreting fast enough to keep up with sea-level rise (Salles et al., 2018). In this model, large drainage basins carve substantial river valleys into the volcanic shield, creating topographic (bathymetric) lows. As sea level rises, fringing and barrier reefs encroach and grow on the newly flooded island topography (Blanchon et al., 2015). Reefs accreting on the interfluves between paleo-valleys start at a higher elevation and can keep pace (or catch up) with rising sea levels (Dutton et al., 2015; Neumann & Macintyre, 1985; Toomey et al., 2013). In contrast, reefs accreting in deeply incised paleo-valleys drown (or give up) due to deeper water and greater accommodation depth. Although there would be zones of shallower water further inland within flooded lowstand valleys, the combination of a poor substrate for coral growth, due to alluvial sediment infill, protection from ocean waves and nutrients, and the need for corals to keep pace with a rapidly migrating coastline due to concave-up valley profiles, would inhibit coral growth in flooded valleys. The difference between these fates can depend on slight elevation differences before sea-level rise, particularly on islands forming modern barrier reefs (Neumann & Macintyre, 1985; Toomey et al., 2013). The preferential growth response to sea-level rise makes it more likely that deeper paleochannels at the outlets of larger drainage basins become reef passes as sea level reaches subsequent highstands.

5.2. Oceanographic Mechanisms

Waves, currents, and tides likely influence reef pass location as islands age and rivers' influence on reef evolution wanes (Purdy, 1974; Toomey et al., 2013). Chronic abrasion from wave action could help form or maintain reef passes (Bramante et al., 2020). Although passes predominantly convey oceanward flow at the surface, reef pass beds are known to experience oscillatory currents (10 cm/s), which could keep reef passes open through time (Hench et al., 2008). As islands erode and submerge, lagoons enlarge, increasing tidal prisms. Tidal flows could help maintain reef passes aligned with more embayed portions of the coast, which have larger tidal prisms.

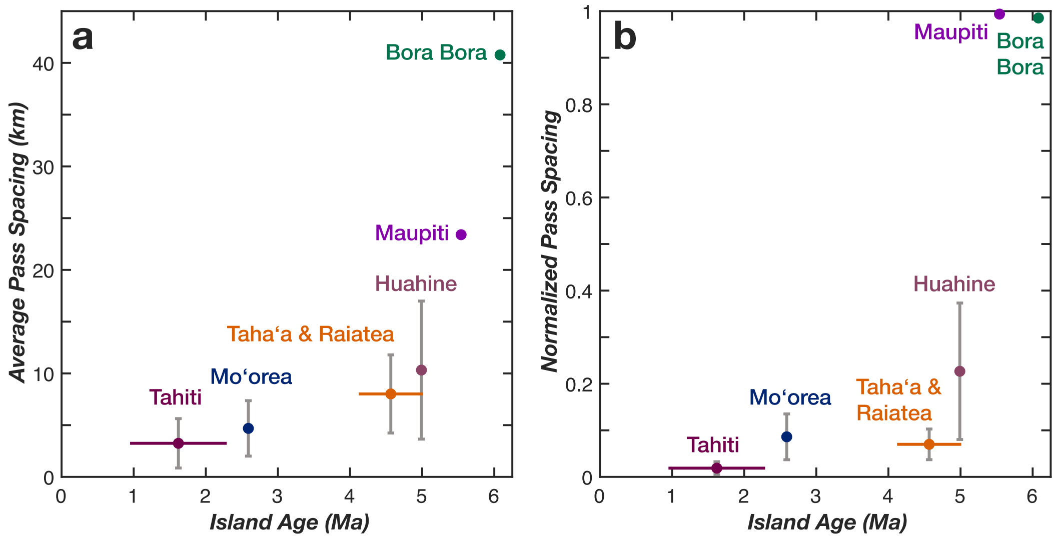

Figure 5. Comparison of reef pass spacing and island age. (a) Average distance between passes along the reef crest for each island. Gray vertical error bars represent the standard deviation of the distance between passes. (b) Average distance between passes normalized by the total length of the reef crest for each island. Gray vertical error bars represent the standard deviation of normalized pass spacing. The colored horizontal bars represent the range of ages for the Tahitian volcanoes (Nui and Iti) and Taha'a and Raiatea. The island color scheme is the same as in Figure 1.

Alternatively, increasing oceanographic control could eliminate reef passes, as wave-driven alongshore sediment transport infills these channels. Effectively, wave action and sea-level oscillations may be in the process of closing passes at Mo'orea and Taha'a, where several lagoon-ward notches in the reef crest do not extend to the ocean (Figures 1b and 1c). Evaluating these scenarios will require modeling the coupled influence of rivers and waves on reef morphodynamics as islands sink.

5.3. Island Age Progression

Our results suggest that as islands age, a transition occurs from islands and rivers governing reef pass formation and maintenance to oceanographic processes dominating modern reef morphology (Ramalho et al., 2013). Comparing the average distance between passes among the Society Islands, we find that reef pass spacing increases with island age, supporting the idea that rivers on older islands are less capable of maintaining passes (Figure 5). Younger islands generally have more exposed land due to recent volcanic construction and should, therefore, discharge more freshwater and sediment to the reef flat during sea-level lowstands. As the volcanic edifice becomes more submerged and land area decreases, with lagoons widening and reef type transitioning from fringing to barrier (Figure 1), reef passes may be maintained more by waves, currents, and tides. This transition from terrestrial to oceanographic control over reef morphology likely reflects ongoing base-level changes and the progressive reduction in drainage basin size associated with island subsidence. This transition may explain the misalignment of some reef passes and river basins at older islands like Bora Bora and Maupiti (Figure 3).

In the Society Islands, the transition from island to ocean processes driving reef morphology likely occurs midway through an island's subaerial lifespan. At Taha'a, the discovery of what appear to be infilled, Pleistocene-aged channels in the lagoon suggests that there may have been more reef passes before the Holocene (Toomey, Woodruff, et al., 2016). These possible relict channels, now closed, and the minimal riverine sediment found in sediment cores from the lagoon suggest a reduction in terrestrial influence on Taha'a's modern reef morphology over time. Moreover, depositional reef islands (motu), which form primarily through storm-induced wave action (Newell, 1961; Ortiz & Ashton, 2019; Woodroffe, 2008; Woodroffe et al., 1999), are also found on Taha'a's northern shoreline. The formation of subaerial islands on the reef flat represents another oceanographic process affecting reef evolution. Notably, reef island presence also increases at Maupiti and Bora Bora, where terrestrial processes no longer dominate reef morphology.

6. Conclusions

We present quantitative evidence that island rivers have influenced modern coral reef morphology. Reef passes, or deep channels dissecting reef flats that control hydrodynamic circulation between the ocean and lagoons, typically align with the outlets of large drainage basins, suggesting that fluvial processes can form reef passes in the Society Islands. We propose two mechanisms by which rivers could have created reef passes over sea-level cycles: reef incision and reef encroachment. These reef pass formation mechanisms are not exclusive of one another or of marine hydrodynamical influences on reef passes. We also find several instances where reef passes and river basins are not aligned, particularly at smaller, older islands with wide lagoons separating reefs from the volcanic edifice. This weaker spatial correlation suggests a transition from terrestrial to marine processes governing reef pass presence as islands age and subside. Island rivers likely promote long-term reef health by forming passes as reefs evolve, enhancing seawater circulation between lagoons and oceans.

Data Availability Statement

The elevation data is from the NASA Shuttle Radar Topography Mission (SRTM GL1) Global 30-m resolution dataset, provided by the OpenTopography Facility with support from the National Science Foundation (NASA Shuttle Radar Topography Mission, 2013).

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References

Amato, D. W., Bishop, J. M., Glenn, C. R., Dulai, H., & Smith, C. M. (2016). Impact of submarine groundwater discharge on marine water quality and reef biota of Maui. *PLoS One*, *11*(11), e0165825. https://doi.org/10.1371/journal.pone.0165825

Bartley, R., Bainbridge, Z. T., Lewis, S. E., Kroon, F. J., Wilkinson, S. N., Brodie, J. E., & Silburn, D. M. (2014). Relating sediment impacts on coral reefs to watershed sources, processes and management: A review. *Science of the Total Environment*, *468–469*, 1138–1153. https://doi.org/10.1016/j.scitotenv.2013.09.030

Blanchon, P., Granados-Corea, M., Abbey, E., Braga, J. C., Braithwaite, C., Kennedy, D. M., et al. (2015). Postglacial Fringing-Reef to Barrier-Reef conversion on Tahiti links Darwin's reef types. *Scientific Reports*, *4*(1), 4997. https://doi.org/10.1038/srep04997

Bosscher, H., & Schlager, W. (1992). Computer simulation of reef growth. *Sedimentology*, *39*(3), 503–512. https://doi.org/10.1111/j.1365-3091.1992.tb02130.x

Bramante, J. F., Perron, J. T., Ashton, A. D., & Donnelly, J. P. (2020). Experimental quantification of bedrock abrasion under oscillatory flow. *Geology*, *48*(6), 541–545. https://doi.org/10.1130/G47089.1

Carlson, R. R., Foo, S. A., & Asner, G. P. (2019). Land use impacts on coral reef health: A ridge-to-reef perspective. *Frontiers in Marine Science*, *6*, 562. https://doi.org/10.3389/fmars.2019.00562

Chauveau, D., Authemayou, C., Molliex, S., Godard, V., Benedetti, L., Pedoja, K., et al. (2021). Eustatic knickpoint dynamics in an uplifting sequence of coral reef terraces, Sumba Island, Indonesia. *Geomorphology*, *393*, 107936. https://doi.org/10.1016/j.geomorph.2021.107936

Comeros-Raynal, M. T., Lawrence, A., Sudek, M., Vaeoso, M., McGuire, K., Regis, J., & Houk, P. (2019). Applying a ridge-to-reef framework to support watershed, water quality, and community-based fisheries management in American Samoa. *Coral Reefs*, *38*(3), 505–520. https://doi.org/10.1007/s00338-019-01806-8

Dadhich, A. P., & Nadaoka, K. (2012). Analysis of terrestrial discharge from agricultural watersheds and its impact on nearshore and offshore reefs in Fiji. *Journal of Coastal Research*, *28*(5), 1225. https://doi.org/10.2112/JCOASTRES-D-11-00149.1

Darwin, C. R. (1842). The structure and distribution of coral reefs. In *Being the first part of the geology of the voyage of the Beagle, under the command of Capt. Fitzroy, R.N. during the years 1832 to 1836*. Smith Elder and Co.

Delevaux, J. M. S., Whittier, R., Stamoulis, K. A., Bremer, L. L., Jupiter, S., Friedlander, A. M., et al. (2018). A linked land-sea modeling framework to inform ridge-to-reef management in high oceanic islands. *PLoS One*, *13*(3), e0193230. https://doi.org/10.1371/journal.pone.0193230

Dutton, A., Webster, J. M., Zwartz, D., Lambeck, K., & Wohlfarth, B. (2015). Tropical tales of polar ice: Evidence of last interglacial polar ice sheet retreat recorded by fossil reefs of the granitic Seychelles islands. *Quaternary Science Reviews*, *107*, 182–196. https://doi.org/10.1016/j.quascirev.2014.10.025

Farr, T. G., Rosen, P. A., Caro, E., Crippen, R., Duren, R., Hensley, S., et al. (2007). The shuttle radar topography mission. *Reviews of Geophysics*, *45*(2), RG2004. https://doi.org/10.1029/2005RG000183

Ferrier, K. L., Huppert, K. L., & Perron, J. T. (2013). Climatic control of bedrock river incision. *Nature*, *496*(7444), 206–209. https://doi.org/10.1038/nature11982

Gayer, E., Michon, L., Louvat, P., & Gaillardet, J. (2019). Storm-induced precipitation variability control of long-term erosion. *Earth and Planetary Science Letters*, *517*, 61–70. https://doi.org/10.1016/j.epsl.2019.04.003

Guilcher, A. (1988). *Coral reef geomorphology*. Wiley.

Hench, J. L., Leichter, J. J., & Monismith, S. G. (2008). Episodic circulation and exchange in a wave-driven coral reef and lagoon system. *Limnology & Oceanography*, *53*(6), 2681–2694. https://doi.org/10.4319/lo.2008.53.6.2681

Hildenbrand, A., Gillot, P.-Y., & Marlin, C. (2008). Geomorphological study of long-term erosion on a tropical volcanic ocean island: Tahiti-Nui (French Polynesia). *Geomorphology*, *93*(3), 460–481. https://doi.org/10.1016/j.geomorph.2007.03.012

Howard, A. D., & Kerby, G. (1983). Channel changes in badlands. *Geological Society of America Bulletin*, *94*(6), 739. https://doi.org/10.1130/0016-7606(1983)94<739:CCIB>2.0.CO;2

Huppert, K. L., Perron, J. T., & Royden, L. H. (2020). Hotspot swells and the lifespan of volcanic ocean islands. *Science Advances*, *6*(1), eaaw6906. https://doi.org/10.1126/sciadv.aaw6906

Jefferson, A. J., Ferrier, K. L., Perron, J. T., & Ramalho, R. (2014). Controls on the hydrological and topographic evolution of shield volcanoes and volcanic ocean islands. In *The Galápagos* (pp. 185–213). American Geophysical Union (AGU). https://doi.org/10.1002/9781118852538.ch10

Leichter, J., Alldredge, A., Bernardi, G., Brooks, A., Carlson, C., Carpenter, R., et al. (2013). Biological and physical interactions on a tropical island coral reef: Transport and retention processes on Moorea, French Polynesia. *Oceanography*, *26*(3), 52–63. https://doi.org/10.5670/oceanog.2013.45

NASA Shuttle Radar Topography Mission (SRTM). (2013). Shuttle Radar topography Mission (SRTM) global [Dataset]. *OpenTopography*. https://doi.org/10.5069/G9445JDF

Neumann, A. C., & Macintyre, I. G. (1985). Reef response of sea level rise: Keep-up, catch-up, or give-up. In C. Gabrie, J. L. Toffart, & B. Salvat (Eds.), *Proceedings of the fifth international coral reef congress, Tahiti, 27 May–1 June 1985 (Volume 3, Symposia and seminars (A))* (pp. 105–110). Moorea, French Polynesia: Antenne Museum-EPHE.

Newell, N. (1961). Recent terraces of tropical limestone shores. *Zeitschrift für Geomorphologie*, *3*, 87–106.

Ortiz, A. C., & Ashton, A. D. (2019). Exploring carbonate reef flat hydrodynamics and potential formation and growth mechanisms for motu. *Marine Geology*, *412*, 173–186. https://doi.org/10.1016/j.margeo.2019.03.005

Purdy, E. G. (1974). Reef configurations: Cause and effect. In *Reefs in time and space* (pp. 9–76). https://doi.org/10.2110/pec.74.18.0009

Purdy, E. G., & Winterer, E. L. (2006). Contradicting barrier reef relationships for Darwin's evolution of reef types. *International Journal of Earth Sciences*, *95*(1), 143–167. https://doi.org/10.1007/s00531-005-0511-2

Ramalho, R. S., Quartau, R., Trenhaile, A. S., Mitchell, N. C., Woodroffe, C. D., & Ávila, S. P. (2013). Coastal evolution on volcanic oceanic islands: A complex interplay between volcanism, erosion, sedimentation, sea-level change and biogenic production. *Earth-Science Reviews*, *127*, 140–170. https://doi.org/10.1016/j.earscirev.2013.10.007

Richmond, R. H. (1993). Coral reefs: Present problems and future concerns resulting from anthropogenic disturbance. *American Zoologist*, *33*(6), 524–536. https://doi.org/10.1093/icb/33.6.524

Rodgers, K. S., Kido, M. H., Jokiel, P. L., Edmonds, T., & Brown, E. K. (2012). Use of integrated landscape indicators to evaluate the health of linked watersheds and coral reef environments in the Hawaiian islands. *Environmental Management*, *50*(1), 21–30. https://doi.org/10.1007/s00267-012-9867-9

Rogers, C. S. (1990). Responses of coral reefs and reef organisms to sedimentation. *Marine Ecology Progress Series*, *62*, 185–202. https://doi.org/10.3354/meps062185

Salles, T., Ding, X., Webster, J. M., Vila-Concejo, A., Brocard, G., & Pall, J. (2018). A unified framework for modelling sediment fate from source to sink and its interactions with reef systems over geological times. *Scientific Reports*, *8*(1), 5252. https://doi.org/10.1038/s41598-018-23519-8

Schwanghart, W., & Scherler, D. (2014). Short communication: TopoToolbox 2—MATLAB-based software for topographic analysis and modeling in Earth surface sciences. *Earth Surface Dynamics*, *2*(1), 1–7. https://doi.org/10.5194/esurf-2-1-2014

Snyder, N. P., Whipple, K. X., Tucker, G. E., & Merritts, D. J. (2002). Interactions between onshore bedrock-channel incision and nearshore wave-base erosion forced by Eustasy and tectonics. *Basin Research*, *14*(2), 105–127. https://doi.org/10.1046/j.1365-2117.2002.00169.x

Stark, J. T., & Dapples, E. C. (1941). Near shore coral lagoon sediments from Raiatea, society islands. *SEPM Journal of Sedimentary Research*, *11*. https://doi.org/10.1306/D42690D0-2B26-11D7-8648000102C1865D

Thompson, W. G., & Goldstein, S. L. (2005). Open-system coral ages reveal persistent suborbital sea-level cycles. *Science*, *308*(5720), 401–404. https://doi.org/10.1126/science.1104035

Toomey, M. R., Ashton, A. D., & Perron, J. T. (2013). Profiles of ocean island coral reefs controlled by sea-level history and carbonate accumulation rates. *Geology*, *41*(7), 731–734. https://doi.org/10.1130/G34109.1

Toomey, M. R., Ashton, A. D., Raymo, M. E., & Perron, J. T. (2016). Late Cenozoic sea level and the rise of modern rimmed atolls. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *451*, 73–83. https://doi.org/10.1016/j.palaeo.2016.03.018

Toomey, M. R., Woodruff, J. D., Donnelly, J. P., Ashton, A. D., & Perron, J. T. (2016). Seismic evidence of glacial-age river incision into the Tahaa barrier reef, French Polynesia. *Marine Geology*, *380*, 284–289. https://doi.org/10.1016/j.margeo.2016.04.008

Whipple, K. X., & Tucker, G. E. (1999). Dynamics of the stream-power river incision model: Implications for height limits of mountain ranges, landscape response timescales, and research needs. *Journal of Geophysical Research*, *104*(B8), 17661–17674. https://doi.org/10.1029/1999JB900120

Woodroffe, C. D. (2008). Reef-island topography and the vulnerability of atolls to sea-level rise. *Global and Planetary Change*, *62*(1–2), 77–96. https://doi.org/10.1016/j.gloplacha.2007.11.001

Woodroffe, C. D., McLean, R. F., Smithers, S. G., & Lawson, E. M. (1999). Atoll reef-island formation and response to sea-level change: West island, Cocos (Keeling) islands. *Marine Geology*, *160*(1–2), 85–104. https://doi.org/10.1016/s0025-3227(99)00009-2

References From the Supporting Information

Bodansky, E., Gribov, A., & Pilouk, M. (2002). Smoothing and compression of lines obtained by raster-to-vector conversion. In D. Blostein & Y.-B. Kwon (Eds.), *Graphics recognition algorithms and applications* (pp. 256–265). Springer. https://doi.org/10.1007/3-540-45868-9_22

OpenTopography. (2013). Shuttle radar topography mission (SRTM) global. https://doi.org/10.5069/G9445JDF