The Intrinsic Effect of Shape on Retrogradation Motif and Timing of Drowning: An Example from a Frasnian Carbonate Pinnacle Reef System, Bugle Gap, Canning Basin, Western Australia*

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Abstract

Attic oil accumulations associated with small buildups developing under the influence of a progressive increase in accommodation space on top of larger flat-topped carbonate platforms have been previously discovered. While high-resolution seismic data are necessary to detect the presence of these small buildups or pinnacle reefs, quantitative data from an analog outcrop setting can provide input to numerically assess the geometric and volumetric evolution of these drowned carbonate platforms and pinnacle reefs.

Outcrops of the Devonian reef complexes of the Canning Basin of Western Australia reveal textbook examples of carbonate platform margins developing during high rates of subsidence. Several Frasnian outcrops in the Bugle Gap area of the Canning Basin are well exposed, show minor postdepositional tectonic deformation, have an exhumed topography, and are recognized by a set of retrograding and backstepping pinnacle reefs forming the southern tip of a carbonate platform. The evolution and stratigraphic architecture of these pinnacle reefs was evaluated, spatially recorded using digital surveying tools, and the quantified data assembled and visualized in a digital outcrop model. Subsequently, 2D surface models and 3D volumetric models were built reconstructing pinnacle reef development, allowing quantification of volumetric and geometric parameters.

An intrinsic cause of the demise of isolated carbonate systems is related to the shift - as a consequence of increasing slope height - of the depositional regime from accretion to erosion, and hence from aggradation to retrogradation. This is because retrogradation reduces the production area at the platform top eventually becoming nil, and as a result, the time of drowning depends on the size of the production area. Nevertheless, those Bugle Gap pinnacle reefs that do have similar sizes seem to have different times for their termination. It could be demonstrated and quantified timing of drowning is not only depending on the size of the production area. Also shape and shape parameters of the production area are important constraints determining the timing of the demise of platform systems. More generally, wider implications can be evoked to highstand systems tracts and prograding carbonate systems.

The intrinsic effect of shape on retrogradation motif and timing of drowning:

An example from a Frasnian carbonate pinnacle reef system, Bugle Gap, Canning Basin, Western Australia

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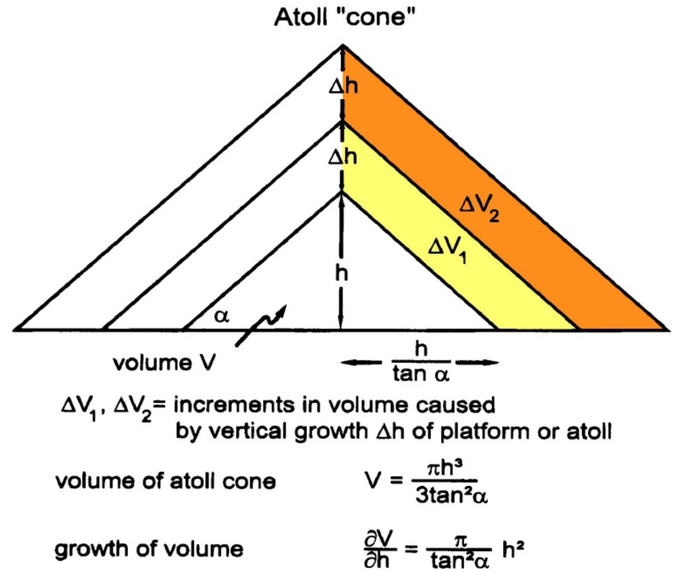
Take away message

- Many processes control and influence the geometry and architecture of evolving carbonate platforms (tectonism, eustacy, climate, oceanography).

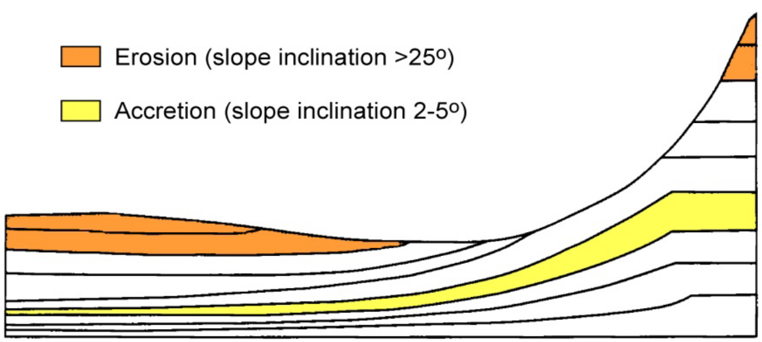
- **We want to show that shape and geometry by themselves intrinsically influence the style and motif of developing carbonate systems.**

Theoretical background

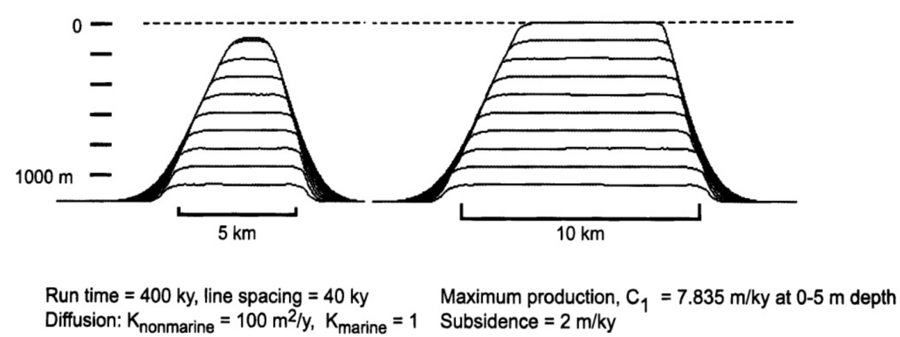
- If a carbonate system is aggrading and A/S=1, the inclination of the slope increases automatically.
- The steepening−with−height rule results in a shift of the depositional regime from accretion to erosion.
- Given these self−erosional circumstances the sediment budget on the slope becomes negative.
- The ensuing reduction of the production area at the platform top results in A/S>1 and may lead to drowning.



Schlager, 1981



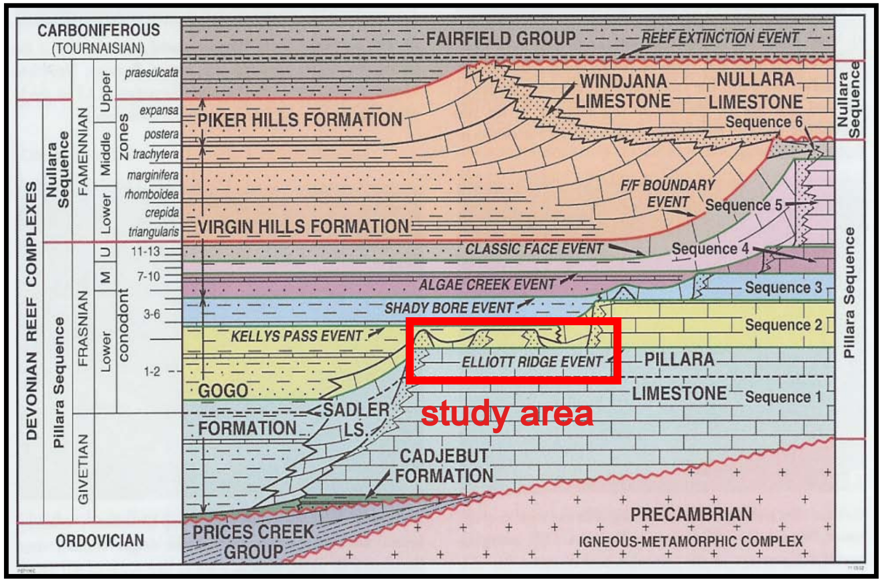
Schlager and Camber, 1986



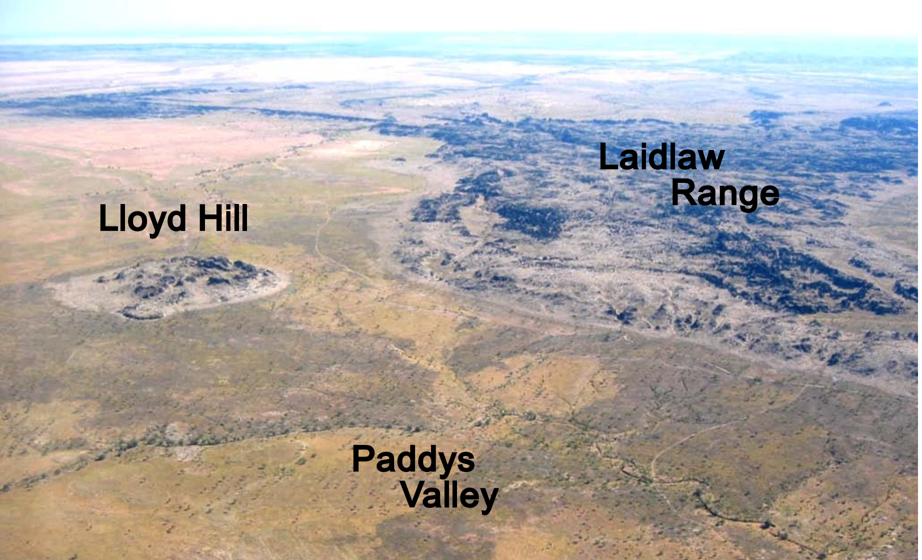
Schlager, 2005

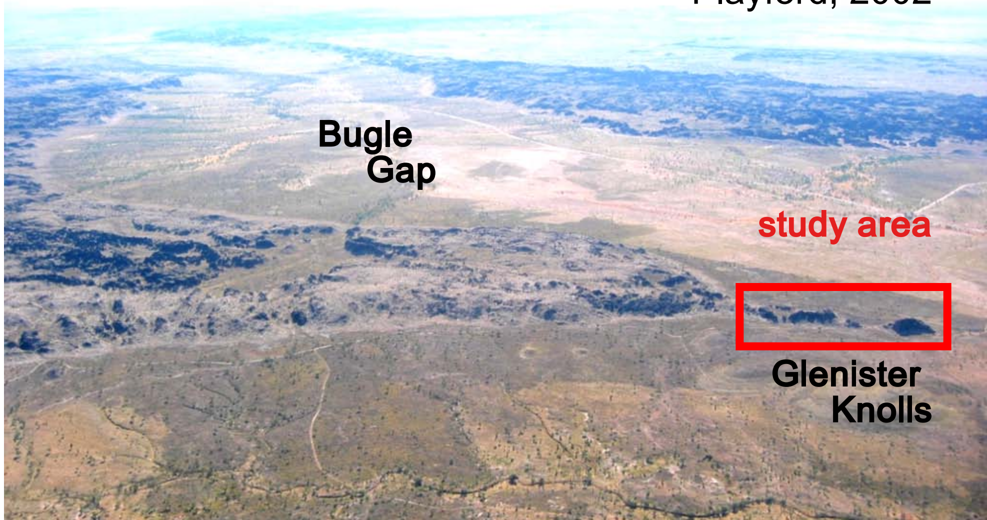
A classic retreating carbonate system

- Devonian reef complexes of the Canning Basin of Western Australia allow quantification of retreating and drowning patterns during a key period in geologic history
- Second-order aggradation and retrogradation for most of the Frasnian.
- We studied the Lower Frasnian second Pillara Sequence observed in the Bugle Gap area.
- Platform types include isolated platforms, reef-rimmed platforms, and pinnacles.

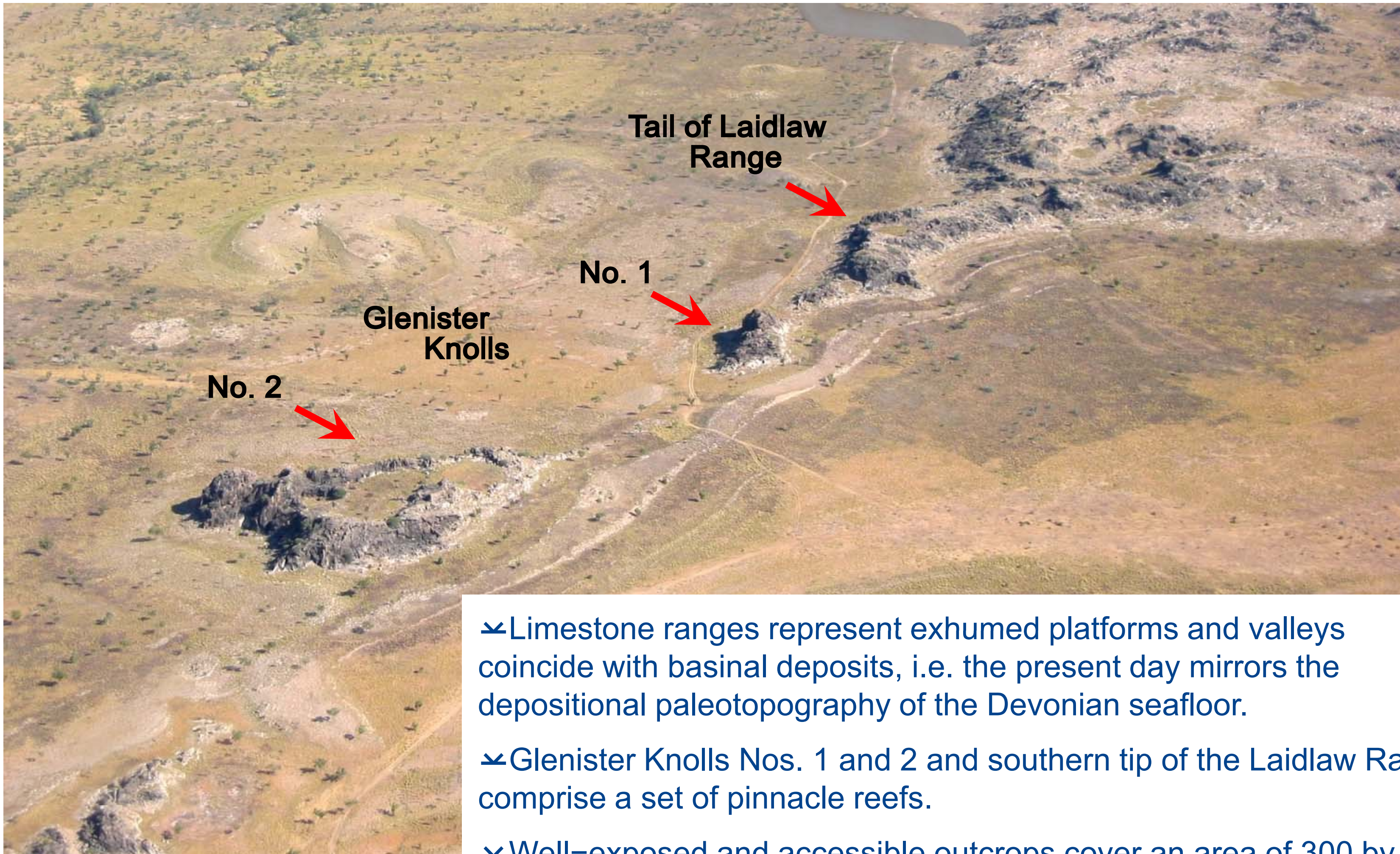


Playford, 2002





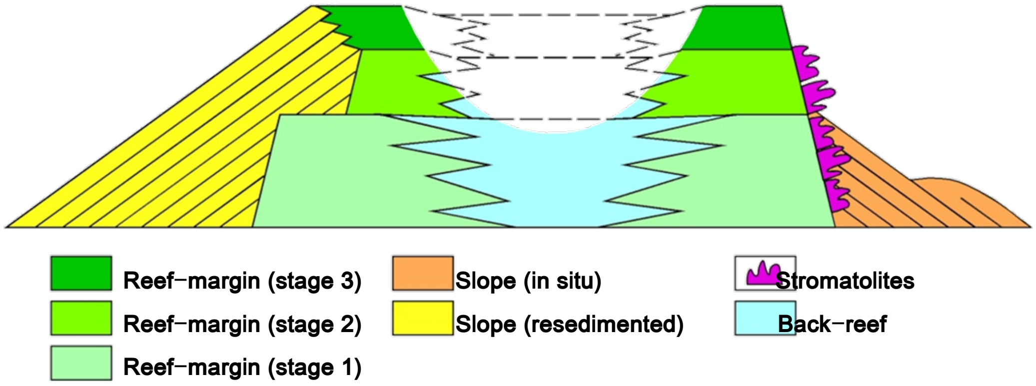
Glenister Knolls and Laidlaw Range outcrops



- Limestone ranges represent exhumed platforms and valleys coincide with basinal deposits, i.e. the present day mirrors the depositional paleotopography of the Devonian seafloor.
- Glenister Knolls Nos. 1 and 2 and southern tip of the Laidlaw Range comprise a set of pinnacle reefs.
- Well−exposed and accessible outcrops cover an area of 300 by 1500 m with a maximum outcrop height of 20−30 m.

Evolution of Bugle Gap pinnacle reef system

- The development of the pinnacle reefs comprises three stages with aggrading to retrograding patterns.



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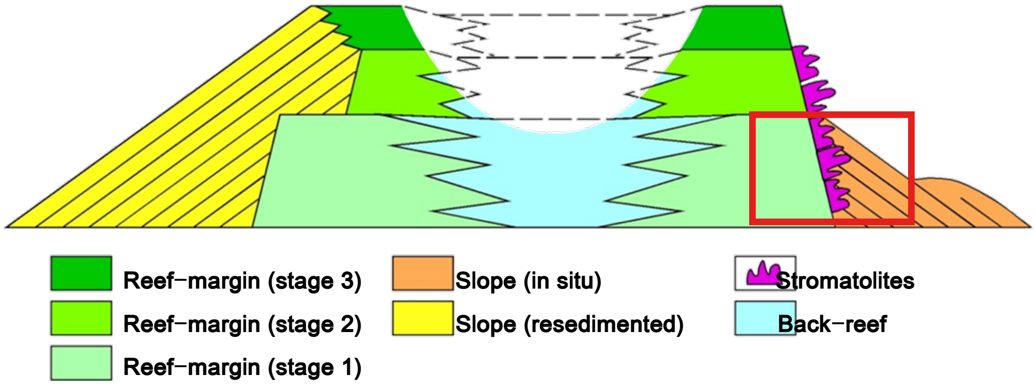
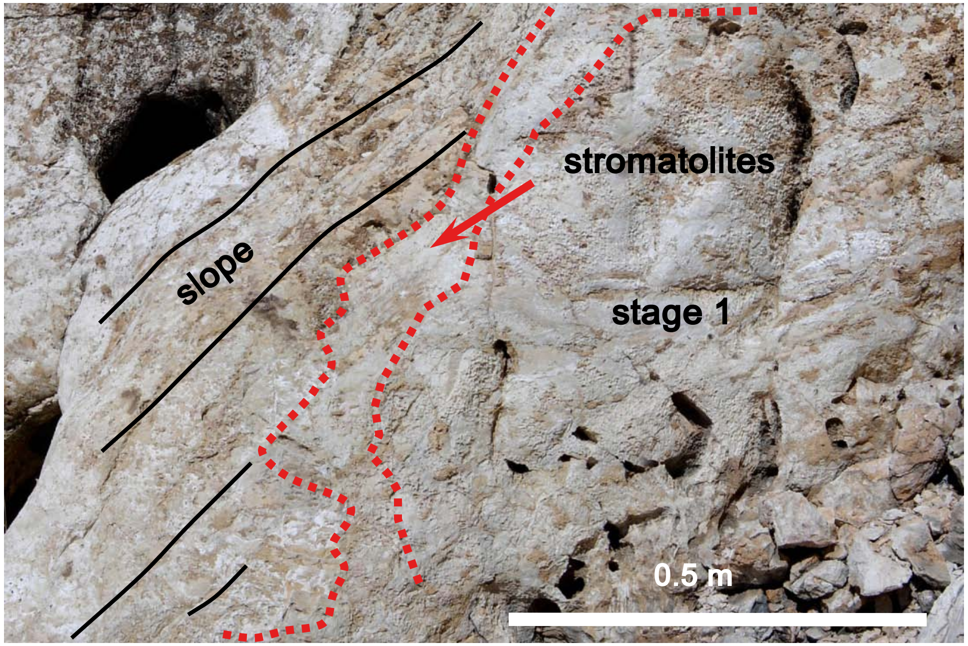
- The development of the pinnacle reefs comprises three stages with aggrading to retrograding patterns.
- Steep reef−margin walls (~60−80º):
  - Fringing stromatolites
  - Onlap of slope and basin sediments





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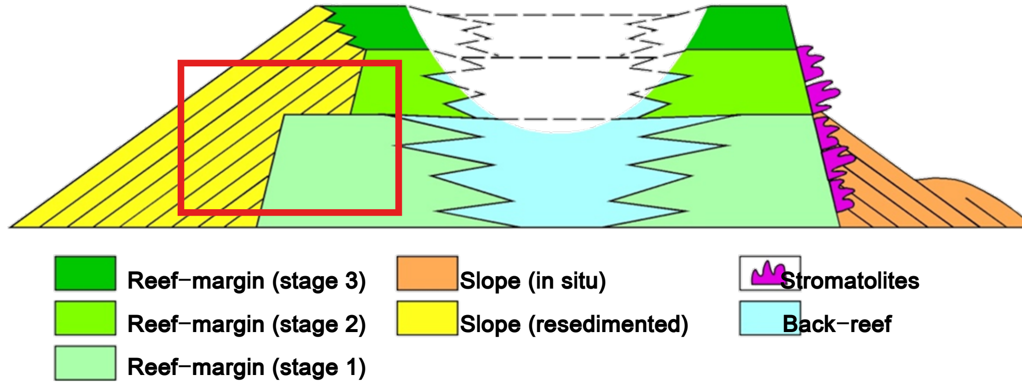

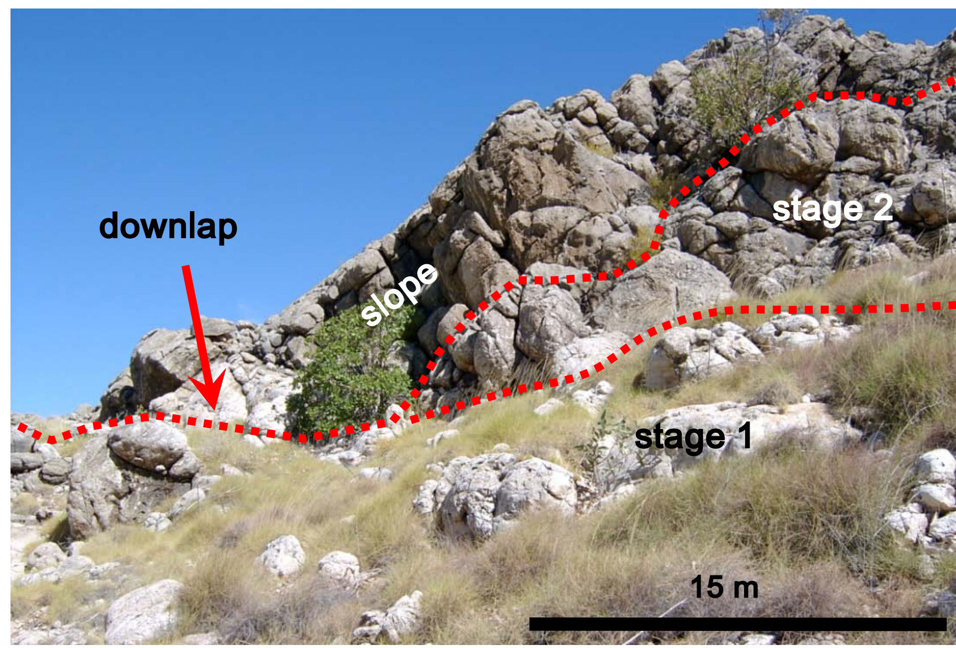

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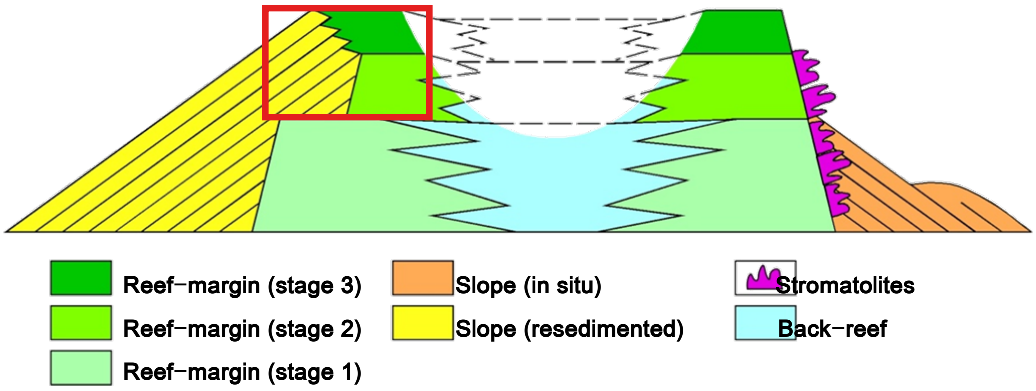

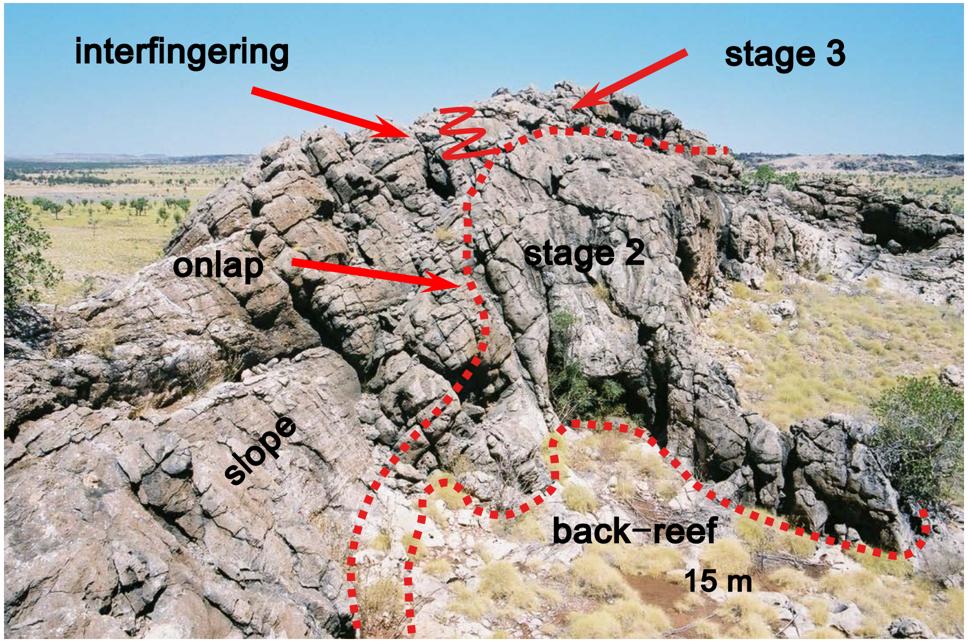

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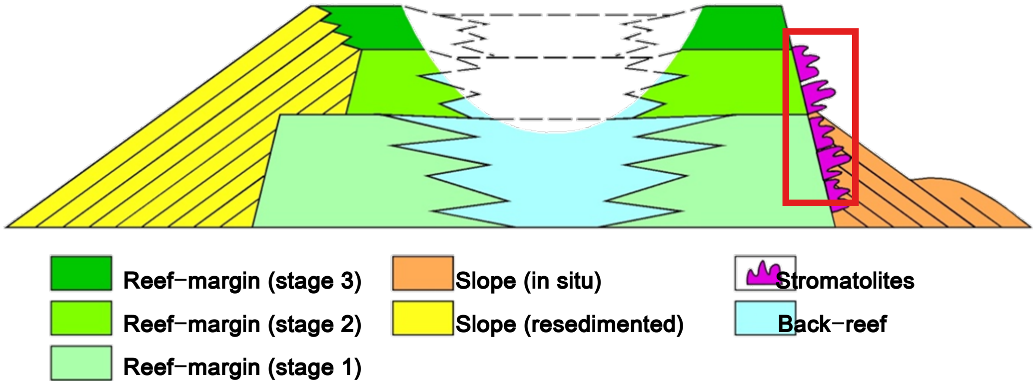

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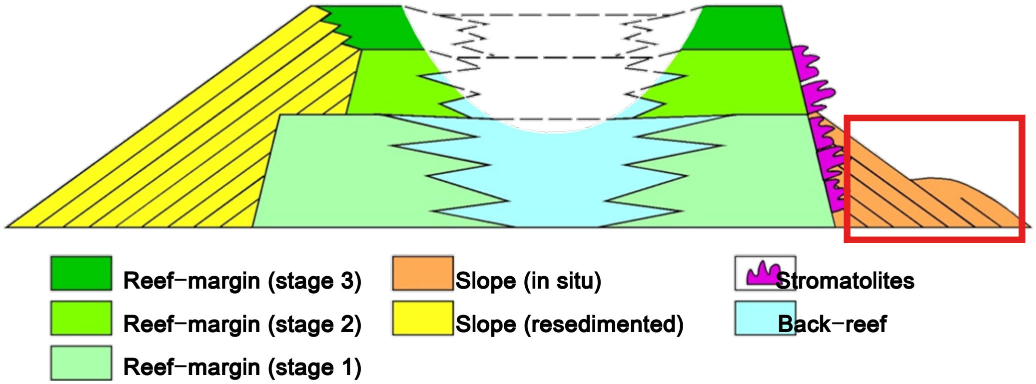
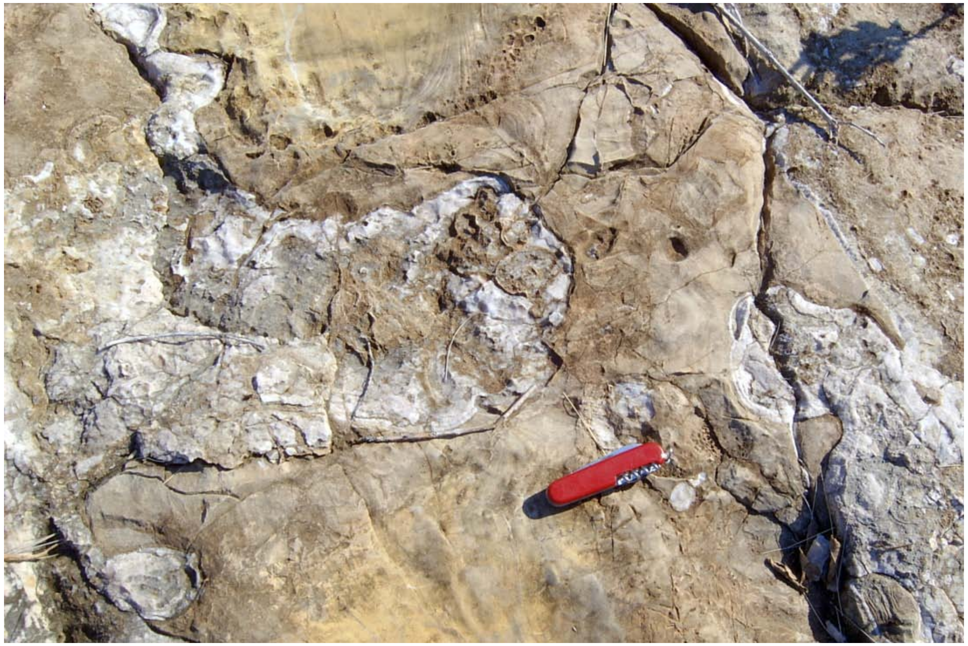
- Stage 3 comprises two types of slope deposition with 1) in situ slope deposition, and 2) resedimented slope deposits.





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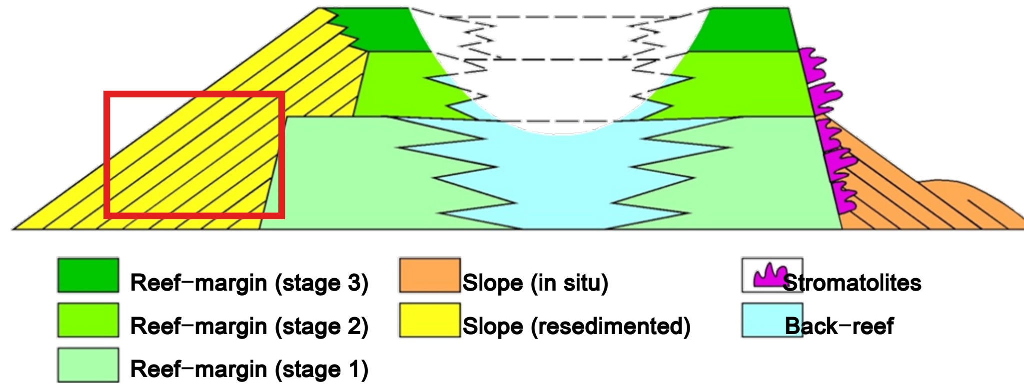
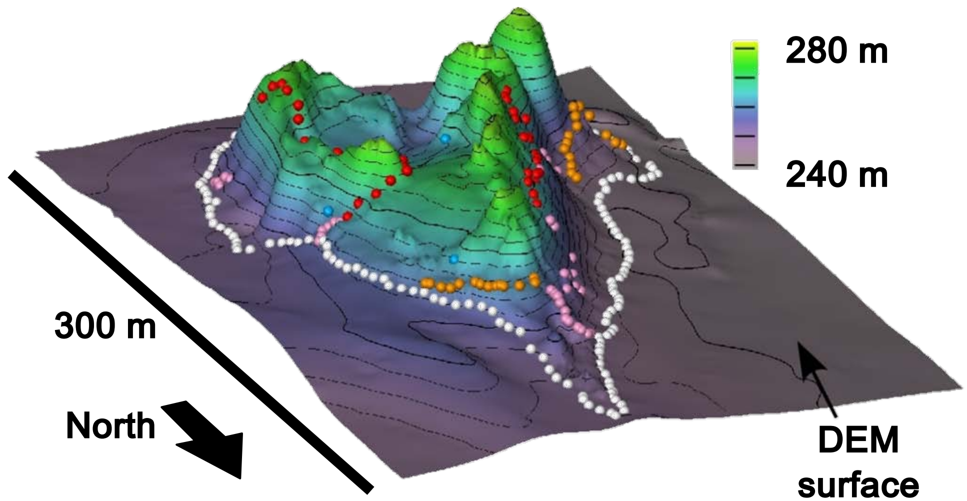
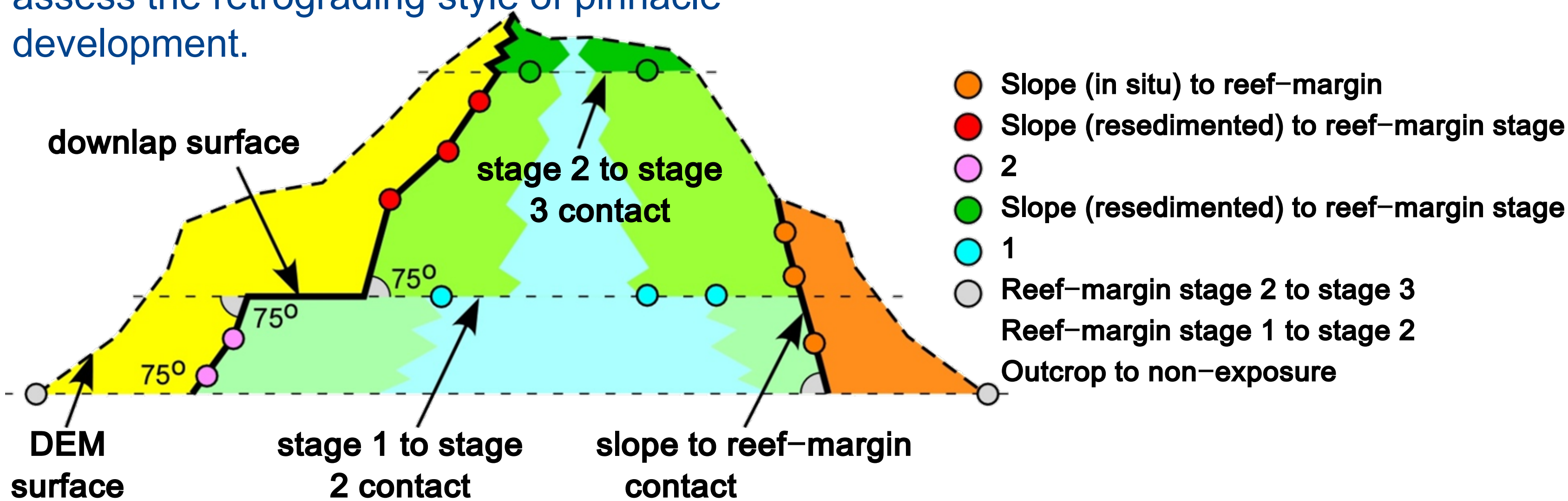


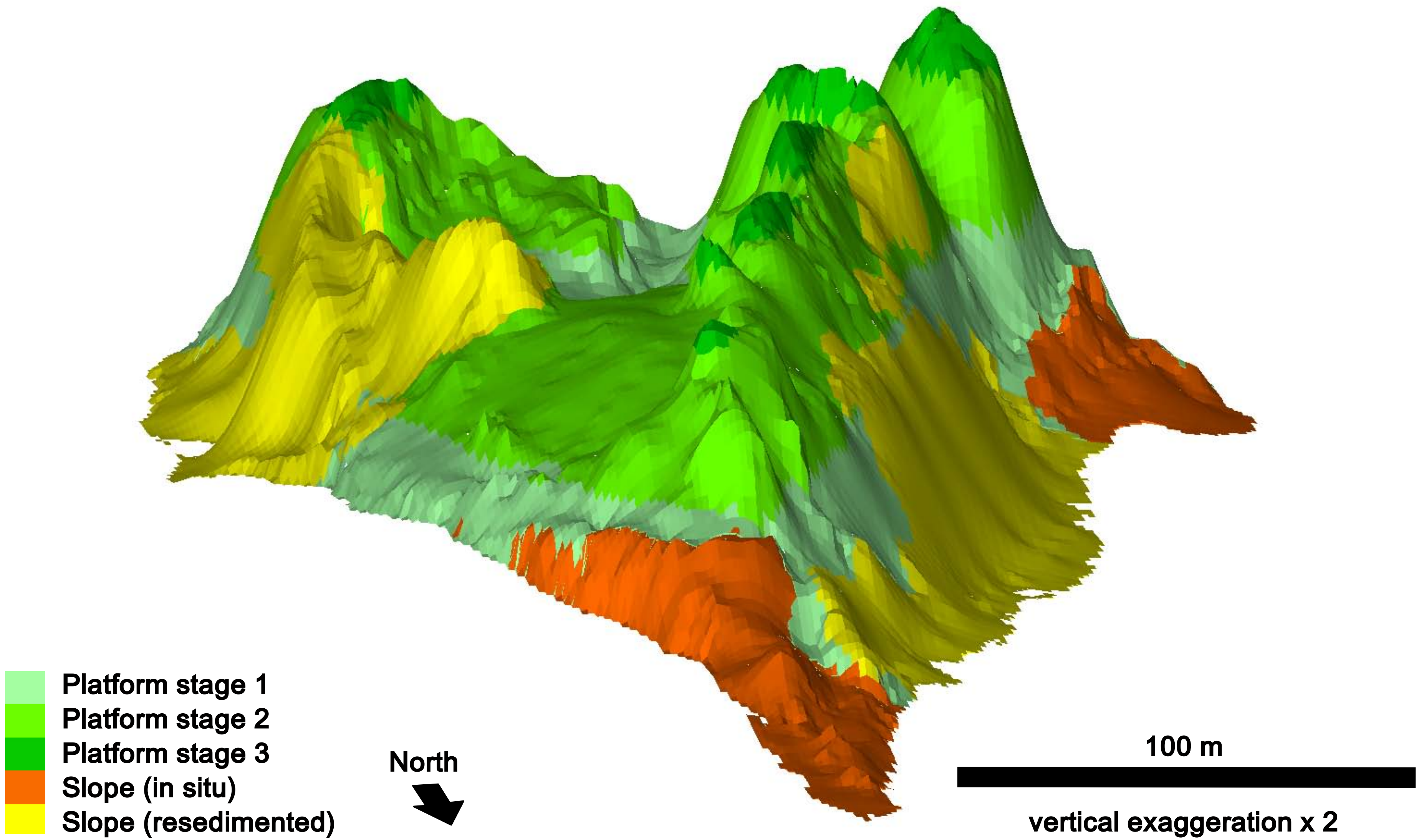
Digital outcrop modeling

- RTK GPS was used to spatially assemble and model the outcrops in 2D and as 3D volumes.
- Both the present−day configuration of the pinnacle reefs as well as the maximum paleoreef extent were modeled.
- Numerical data on geometry and shape can be extracted to quantitatively assess the retrograding style of pinnacle development.

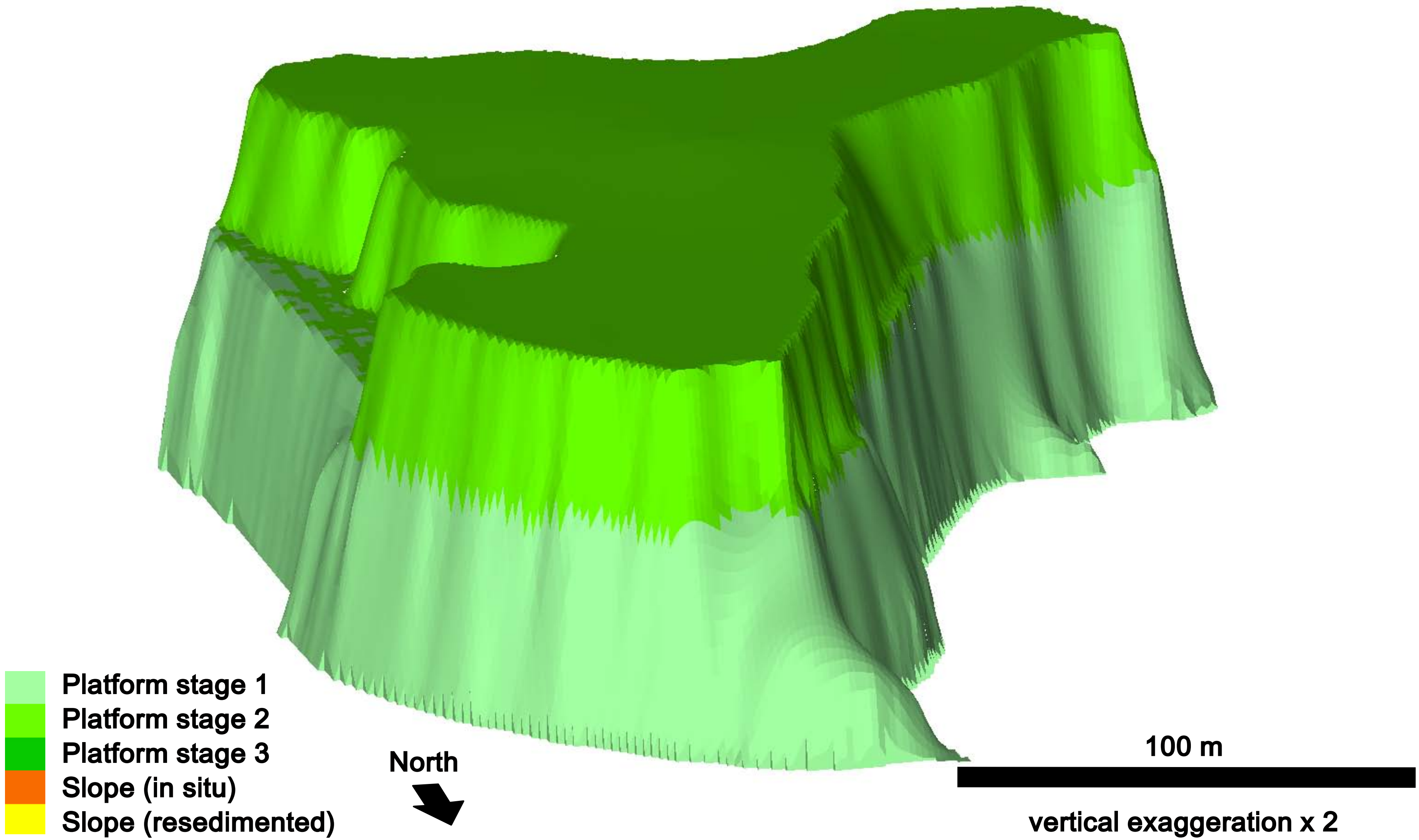




Digital outcrop modeling – present day

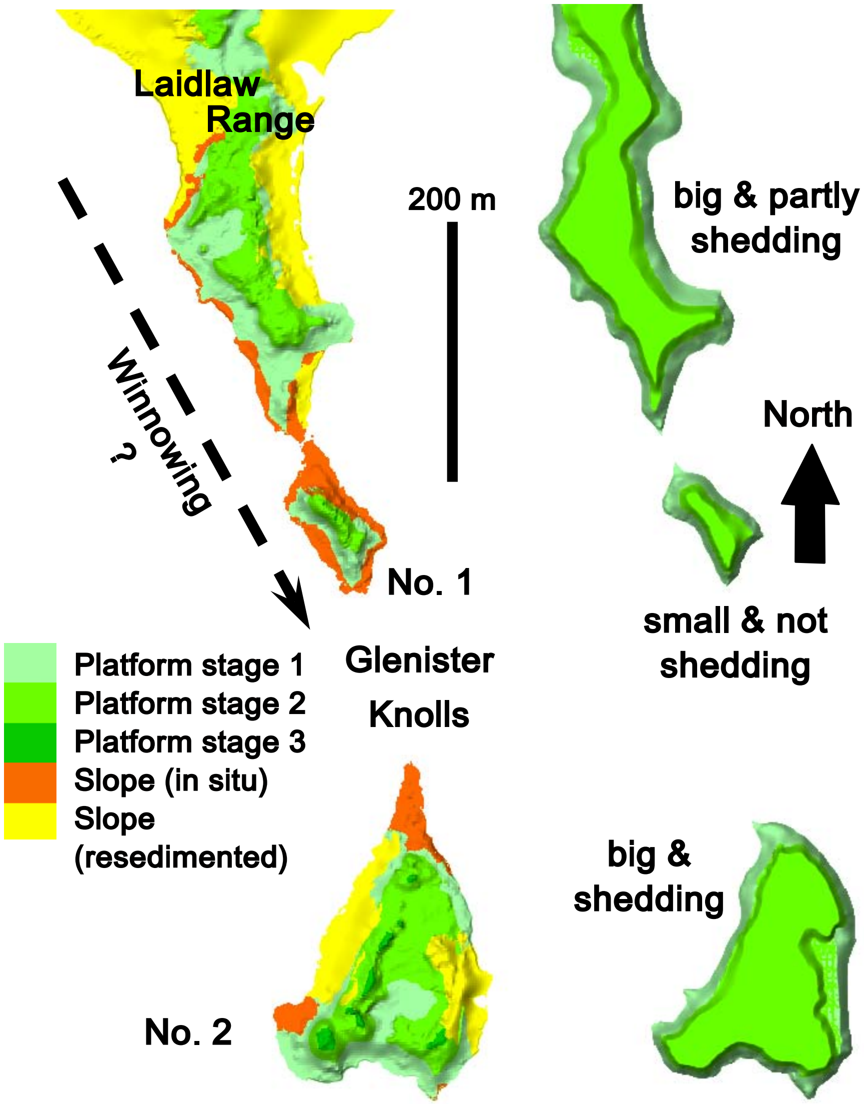


Digital outcrop modeling – paleoreefs



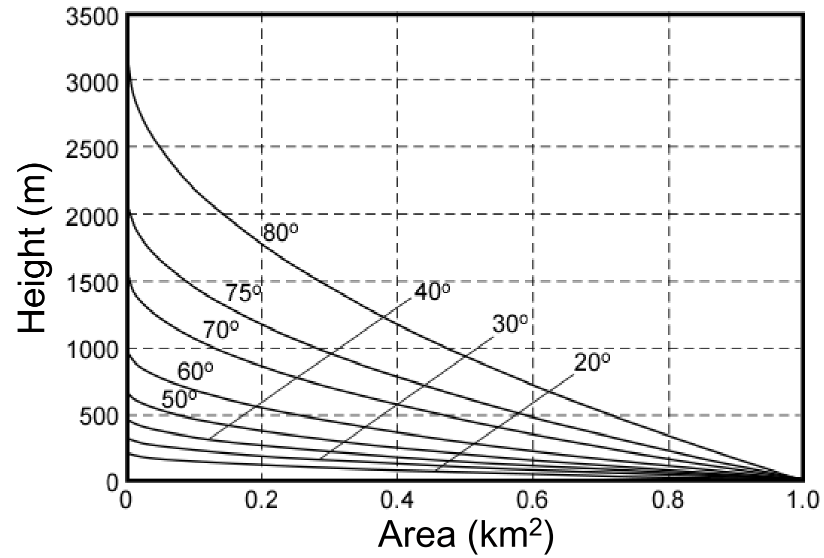
Interpretation of development motifs

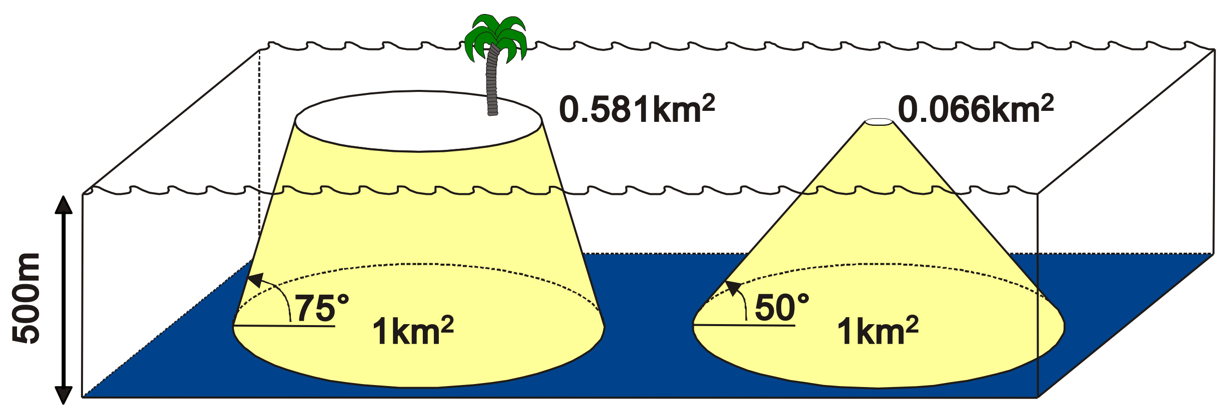
- Patch reefs encounter reduction in platform−top surface area by retrogradation.
  - Self−erosional margins (syndepositional fissures, breccia talus, stromatoporoids are cut, stromatolite and slope onlapping contacts at ~ 60−80º).
  - Backstepping.
- The variation in type and distribution of slope sediments can be explained by:
  - Winnowing currents.
  - Timing of drowning and termination of platform−top shedding of slope sediments.
  - **Pinnacle with more elongate shape naturally has a relatively smaller volume of sediment per margin length being transported to the flanks because of the longer perimeter.**



Theoretical considerations – margin angle

- Theoretical curves have been computed illustrating progressive decline of platform-top area against height development for retrograding isolated carbonate platform systems.
- Decline curves for cone-shaped hypothetical systems with a fixed plane base area of 1 km^2 but variable margin inclinations.

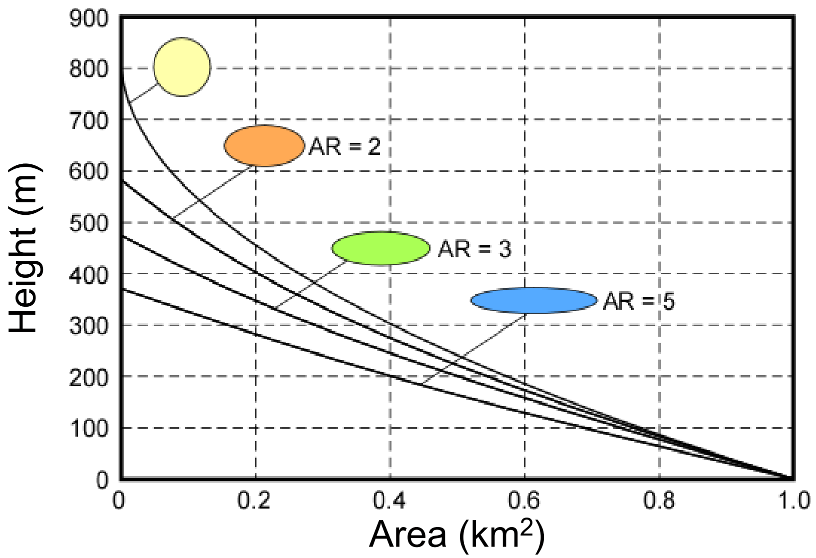


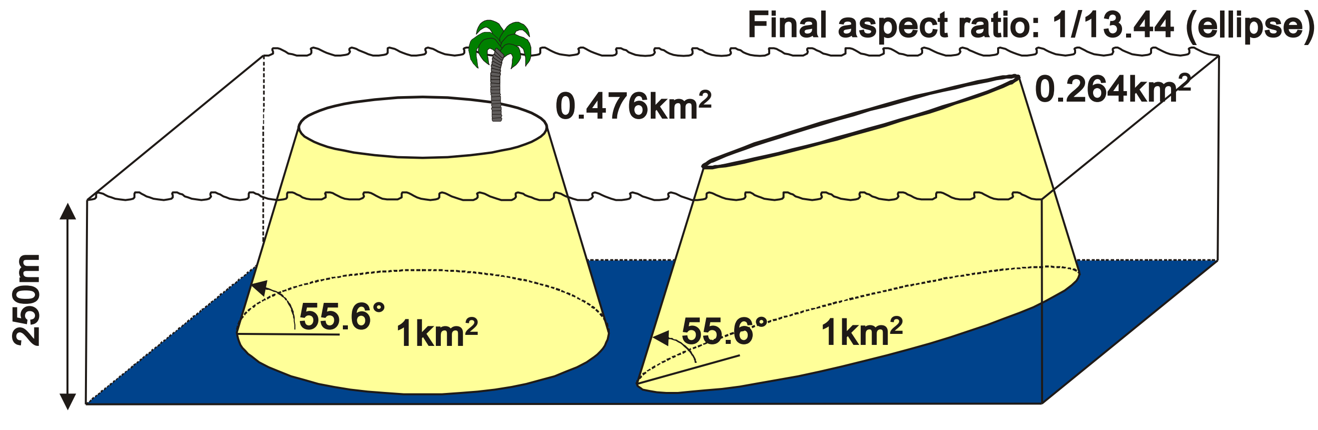


Aspect ratio: 1/1 (circle)

Theoretical considerations – aspect ratio

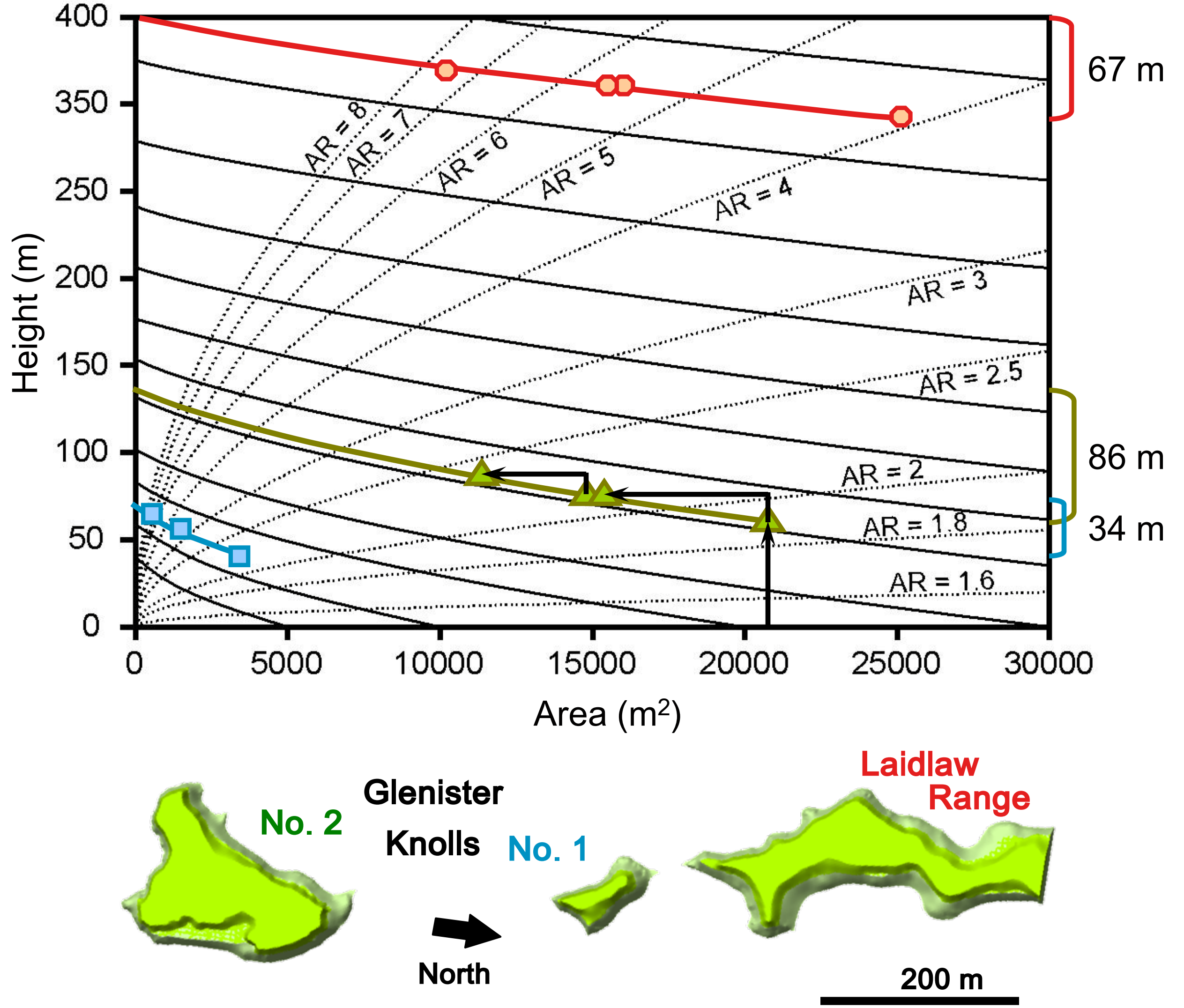
- Decline curves for different circle and ellipse shapes with varying aspect ratio (AR of 1, 2, 3, and 5).
- All systems commence with a production area of 1 km² and have a retrogradational margin inclination of 55.6°.
- Aspect ratio increases with increasing height development.





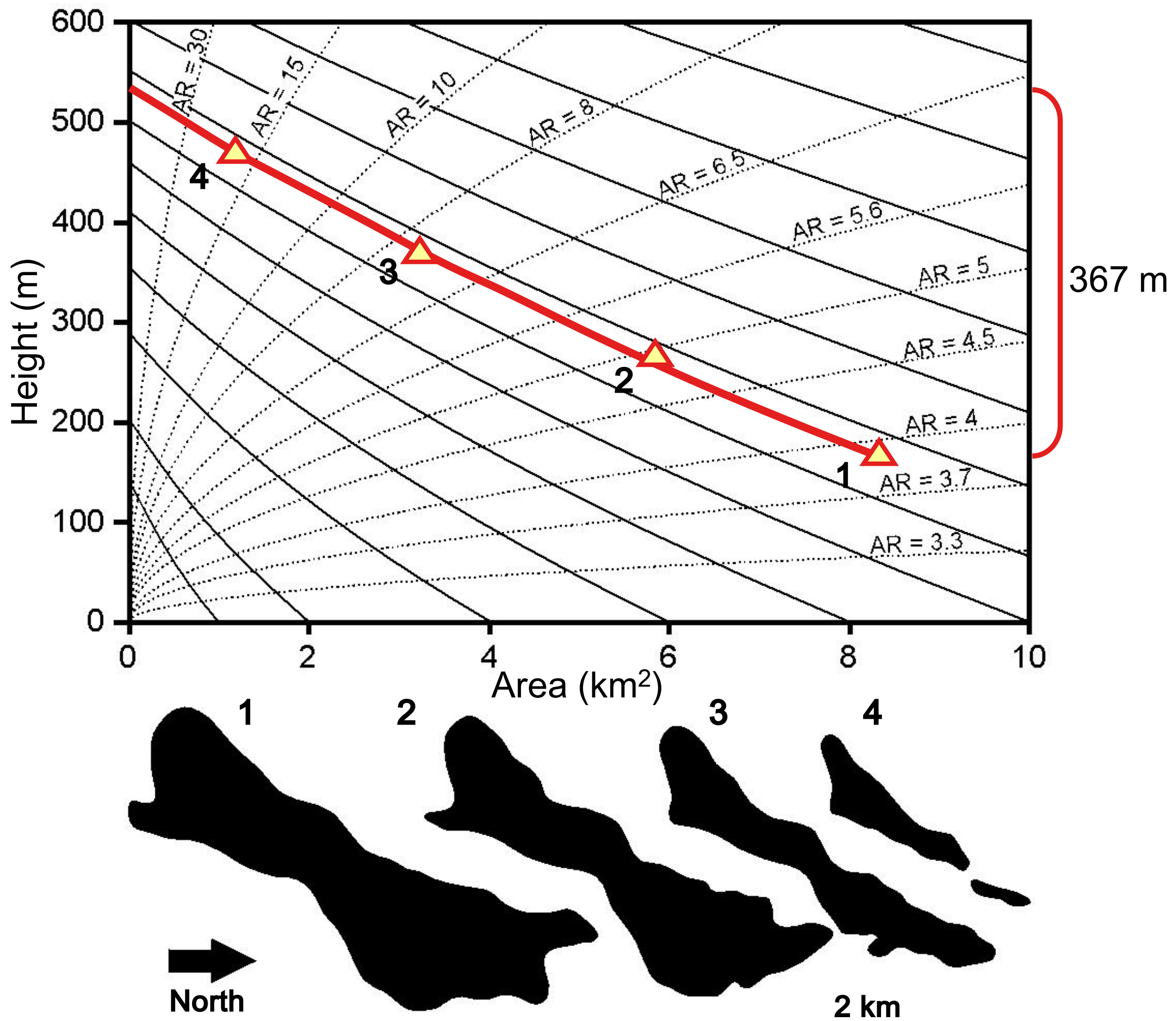
Empirical quantitative evaluation

- Area against initial aspect ratio is plotted for base stage 1.
- Next, area versus correlative height for top 1, base 2, and top 2.
- Datapoints follow hypothetical decline curve.
- All 3 pinnacles fit model
- GK No. 1 could only have developed 5 m after stage 2 (1 and 2 = 29 m).
- Laidlaw Range started with larger area as GK No. 2 but declines more rapid and has less potential to grow upward (~ 20 m less).



Decline curve of Tertiary Malampaya buildup

- Tertiary Malampaya buildup.
- Retrogradational margin inclination of 24°.
- Area against initial aspect ratio is plotted for phase 1 followed by area versus correlative height for the other 3 phases.
- The decline in area plotted against height development closely tracks the theoretical curve.
- The progressive increase in aspect ratio (3.9, 4.7, 7.0, and 8.0) is as predicted except for the last time step.



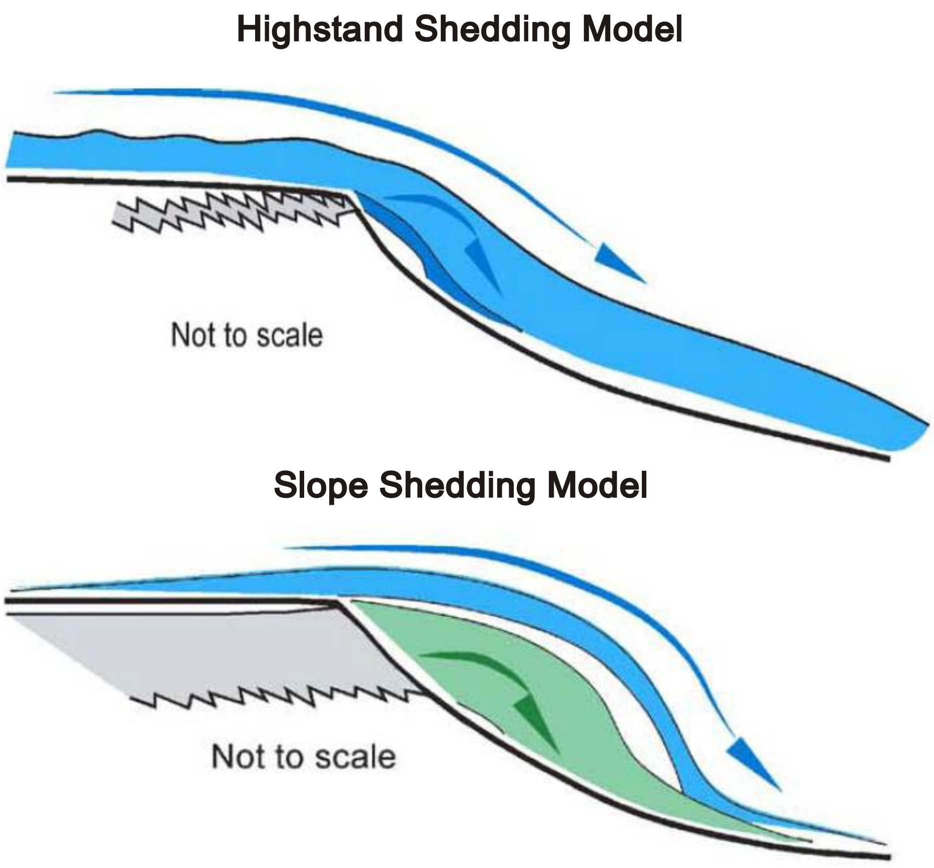
Gr□tsch and Mercadier, 1999

Implications for prograding systems

- There should also be an intrinsic effect linked to shape between the progradational potential of platforms.

- For high stand shedding, the progradation potential is larger for circular platforms, i.e. for platform with small aspect ratios and shorter perimeters.

- For the slope shedding model the volume of sediment that is produced on the slope is larger for platforms with high aspect ratios.



Kenter et al, 2005

Conclusions

- The evolution and stratigraphic architecture of a set of retrograding Lower Frasnian **pinnacle reef outcrops** in the Canning Basin of Western Australia were evaluated, **spatially assembled and modeled** in 2D and as 3D volumes.
- The differences in type and **distribution of slope sediments** could be explained by **variation in pinnacle size and shape**.
- Longer perimeters (a **more elongate shape**) naturally have relatively **less sediment** being deposited along the flanks given **equal platform−top factories**.
- The variation in progressive decline of platform−top areas and its associated height development can be predicted with **theoretical decline curves** for ellipse shaped carbonate systems for which aspect ratios vary.
- There is an **intrinsic impact of shape on timing of drowning**.
- **Shape also has an intrinsic effect** on platform development during periods of **highstand and platform progradation**.

Implications

- While understanding the processes that affect the geometric evolution of carbonate platforms is vital for developing improved sequence stratigraphic models, it is equally critical to comprehend the **intrinsic consequences of shape and geometry** on their development.

- When you plan to buy a tropical island during our period of global warming and progressively increasing sea level we recommend to **buy a circular atoll**.

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