Investigating Carbonate Platform Types: Multiple Controls and a Continuum of Geometries*

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Abstract

Current classifications of carbonate platforms use depositional gradient to separate systems into two end member types, ramps and flat-topped platforms. Facies and sequence stratigraphic predictions vary significantly between these two end-members. However, many examples exist that do not conform to this simple classification. We have used a series of 2D numerical forward model runs to investigate how sediment production, transport and other controls such as tectonic subsidence, antecedent topography, and relative sea-level oscillation interact to determine platform geometry.

Modelling results suggest that rates of offshore sediment transport relative to rates of autochthonous production are a critical factor in maintaining a ramp profile in stable cratonic settings under a constant rate of relative sea-level rise. Type of carbonate production profile, for example euphotic versus oligophotic, is not a significant control in our model cases. Both euphotic and oligophotic production profiles produce FTPs when sediment transport rates are low relative to production rates, and ramps when sediment transport rates are relatively high. These results suggest a continuum of platform types, ranging from transport-dominated, low-gradient systems, to in-situ accumulation dominated systems. A system may be transported dominated because of high-energy processes able to break down and transport even bound sediment, or because carbonate factories produce only sediment easily transportable even under low energy conditions. Breaks of slope in underlying topography and differential fault subsidence are a stronger control on platform geometry in in-situ accumulation dominated systems. Relative sea-level oscillations tend to move the locus of sediment production laterally along any slope present on the platform, distributing sediment accumulation across the whole width of the platform, suppressing progradation and steepening, and so favouring development of low-gradient systems.

Based on all these results, we suggest that simple cut-off classification into ramp and flat-topped platform types can be useful, but a more meaningful approach is to describe and predict platform strata in terms of a multiple dimension platform parameter space containing a continuum of geometries controlled by sediment production, sediment transport, antecedent topography, differential subsidence effects, relative sea-level oscillations and perhaps other as yet unappreciated controls.

References

Allen, P.A., P.M. Burgess, J. Galewsky, and H.D. Sinclair, 2001, Flexural-eustatic numerical model for drowning of the Eocene perialpine carbonate ramp and implications for Alpine geodynamics: GSA Bulletin, v. 113/8, p. 1052-1066.

Aurell, M., B. Badenas, D.W.J. Bosence, and D.A. Waltham, 1998, Carbonate production and offshore transport on a Late Jurassic carbonate ramp (Kimmeridgian, Iberian Basin, NE Spain); evidence from outcrops and computer modeling, *in* V.P. Wright, and T.P. Burchette, (eds.), Carbonate ramps: Geological Society Special Publications, v. 149, p. 137-161.

Dorobek, S.L., 1995, Synorogenic carbonate platforms and reefs in foreland basins; controls on stratigraphic evolution and platform/reef morphology, *in* S.L. Dorobek, and G.M. Ross, (eds.), Stratigraphic evolution of foreland basins: Society for Sedimentary Geology Special Publication, v. 52, p. 127-147.

Dorobek, S.L., 1995, Tectonic controls on carbonate platform evolution; selected examples from the South China Sea region, *in* G.M. Ross (ed.), Lithoprobe; Alberta basement transects: Lithoprobe Report #47, p. 165-180.

Grotsch, J., and C. Mercadier, 1999, Integrated 3-D reservoir modeling based on 3-D seismic; the Tertiary Malampaya and Camago buildups, offshore Palawan, Philippines: AAPG Bulletin v. 83/11, p. 1703-1728.

Pomar, L., 2001, Types of Carbonate Platforms: A Genetic Approach: Basin Research, v. 13, p. 313-334.

Purser, B.H., 1973, (ed.) The Persian Gulf: Holocene Carbonate Sedimentation in a Shallow, Epicontinental Sea: New York, Springer-Verlag, 471 p.

Schlager, W., 2005, Carbonate sedimentology and sequence stratigraphy: SEPM Concepts in Sedimentology and Paleontology Series No. 8, 200 p.

Simpson, J., 1987, Mud-dominated storm deposits from a Lower Carboniferous ramp: Geological Journal, v. 22/3, p. 191-205.

Williams, H.D., P.M. Burgess, V.P. Wright, G. Della Porta, and D. Granjeon, 2011, Investigating carbonate platform types; multiple controls and a continuum of geometries: Journal of Sedimentary Research, v. 81/1, p. 18-37.

Investigating Carbonate Platform Types: Multiple Controls and a Continuum of Geometries

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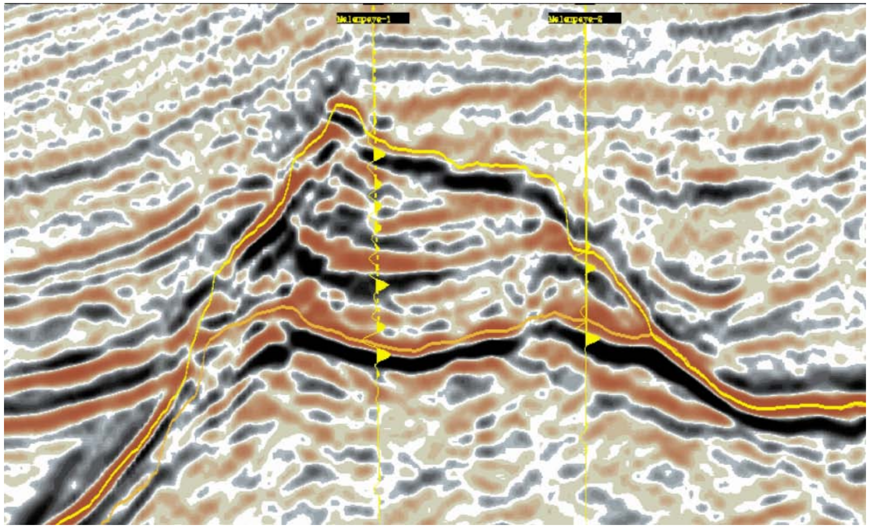
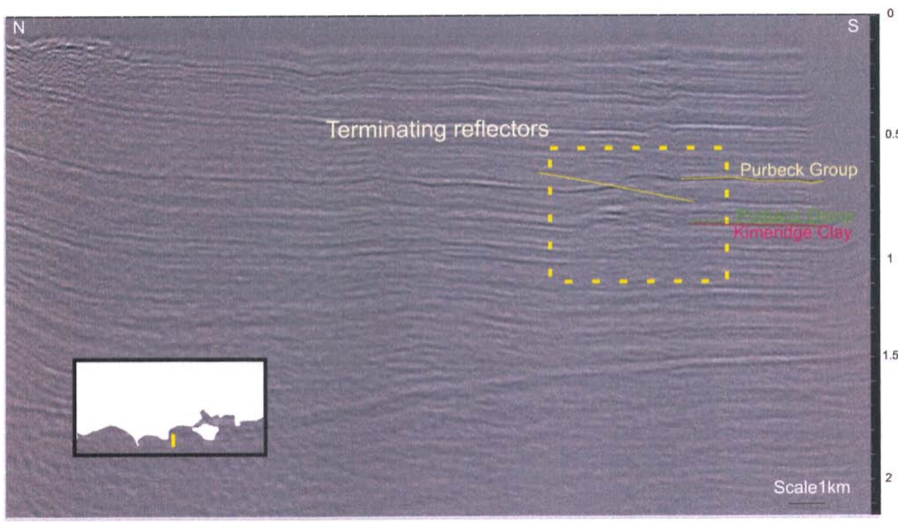
Subsurface facies prediction in carbonate platform strata



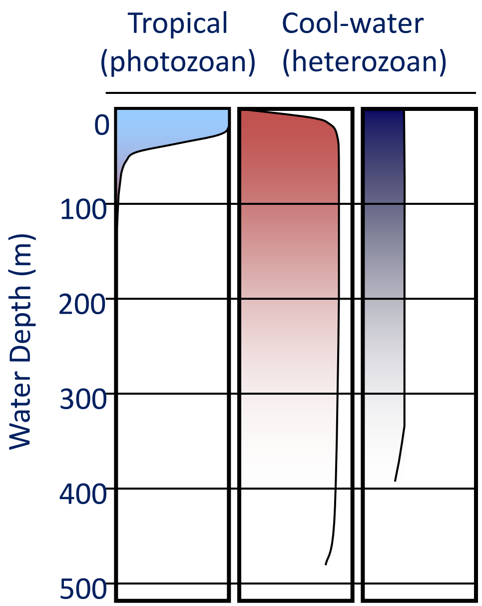
Miocene buildup, offshore Philippines, Grötsch2 and Mercadier, 1999



2d line west of the Isle Of Wight, UK, showing Mesozoic strata including Portland Group and Purbeck Group ramp carbonates

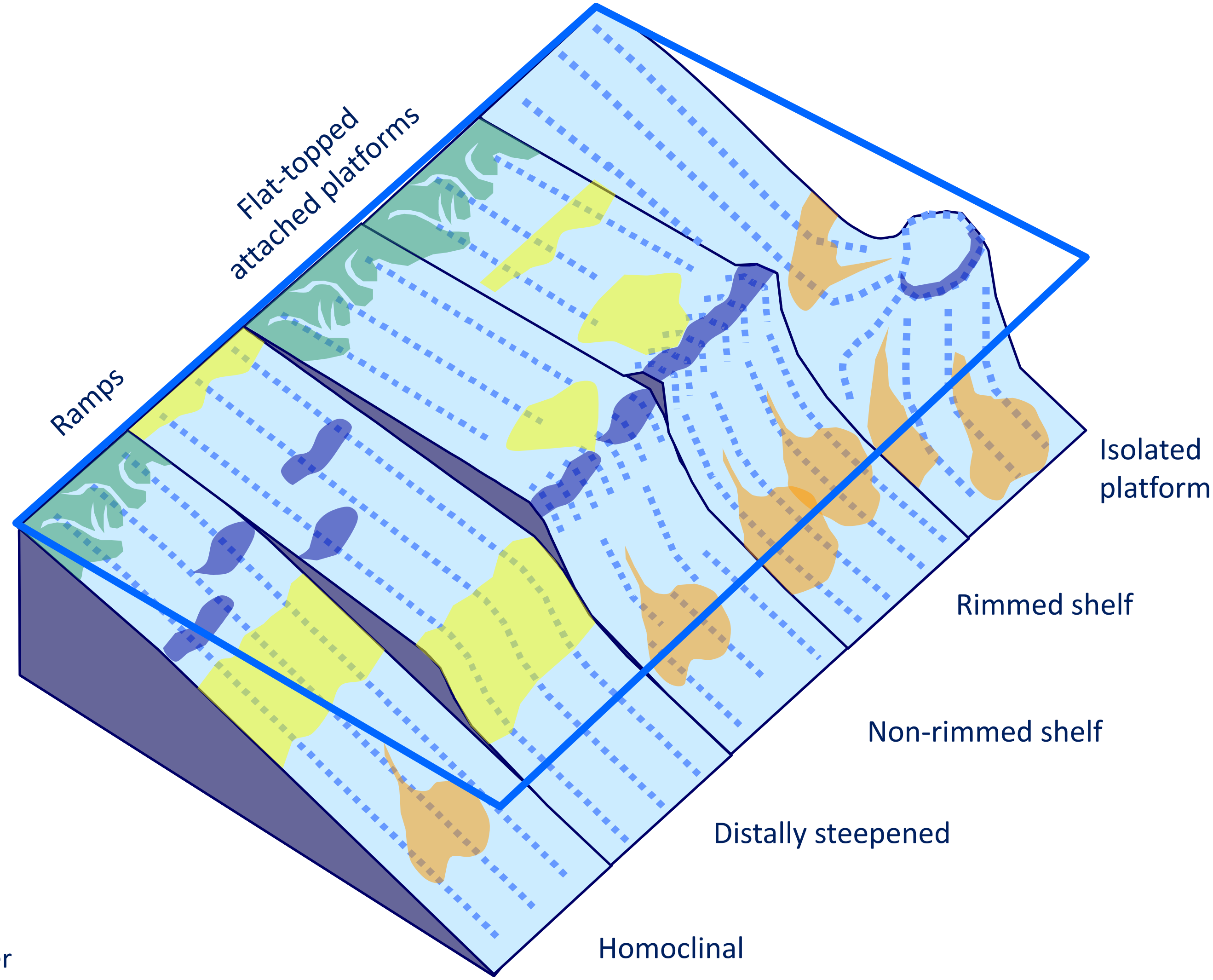
- Predictions usually require some knowledge of location on the platform and the likely distribution of facies from known tie points
- Relatively easy to do on a steep-margined flat-top platform because platform margin is often clear and can be used as a tie point for predictive models
- Still issues though e.g. fine grained versus coarse grained platform interiors, platform margin reservoir quality etc
- Knowledge of location on the platform is more difficult in ramp systems
- Tram-line reflection geometries gives little or no clue about location on the ramp
- Also, the fundamental controls on ramp formation are obscure
- Need improved predictive models to deal with tram-line ramp platforms

Platform Types & Classifications



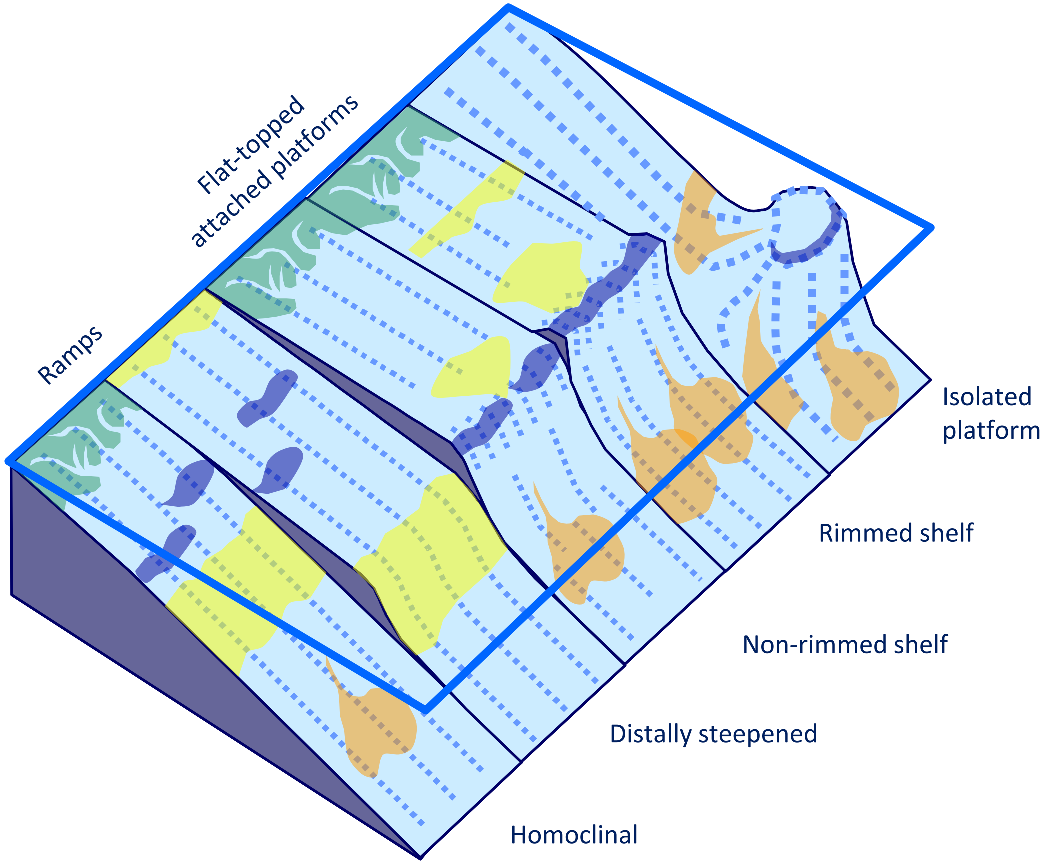
Modified from Schlager 2005

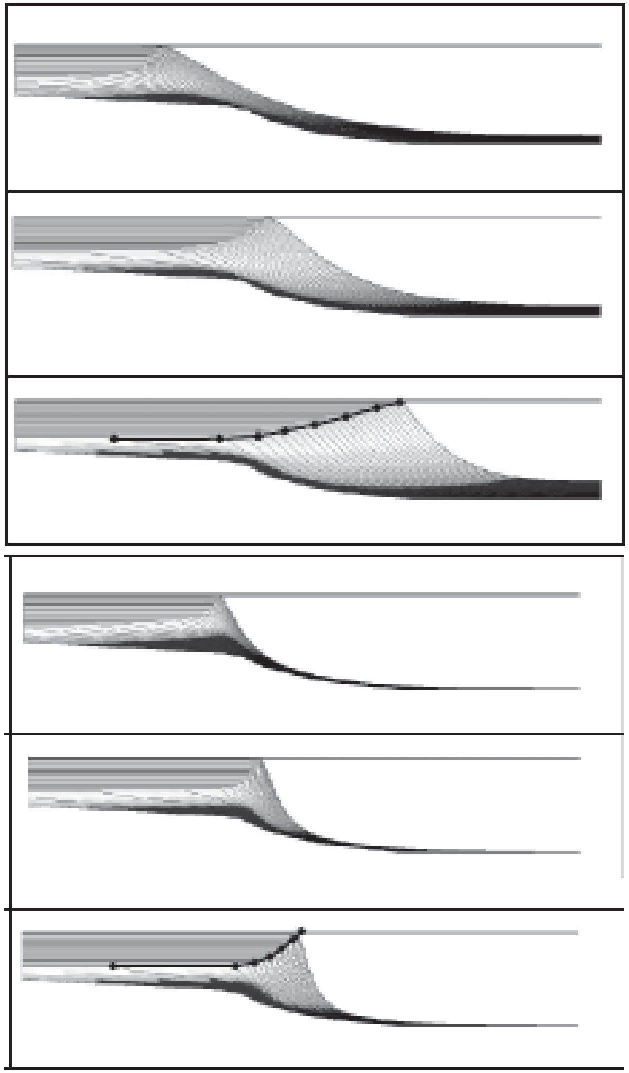
What are the fundamental controls that determine basic platform type?



Modified from Pomar 2001

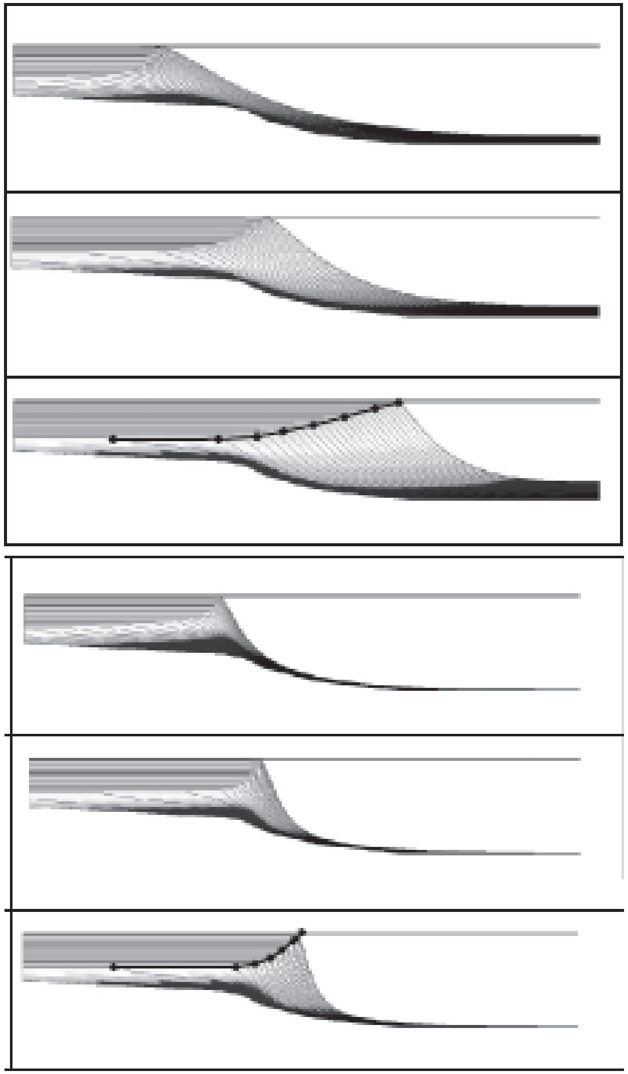
- Try to recreate the various attached platform geometries in a stratigraphic forward model and systematically vary the controlling parameters to understand what geometries result
- Use Dionisos which combines in-situ carbonate growth with diffusional sediment transport





Stratigraphic Forward Modelling Assumptions

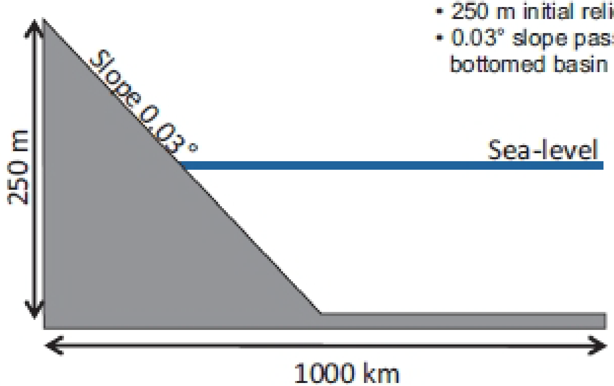
- Rate of sediment transport is proportional to topographic gradient
  - ❑ Steep gradient leads to high rates of transport
- Rate of sediment transport varies with sediment type
  - ❑ Coarse grains transported at lower rates than fine grains
  - ❑ Cohesive sediment transported at lower rates than non-cohesive sediment
- Rate of sediment production varies as a non-linear function of water depth
  - ❑ Note that production rate is different from accumulation rate



Stratigraphic Forward Modelling Parameters

M1 Input Parameters

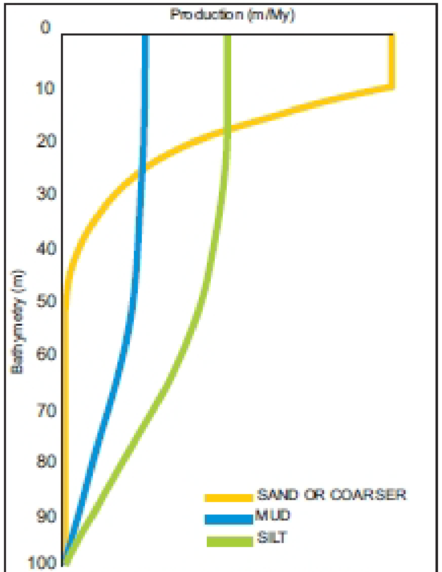
- Bathymetry at 5 Ma
- 1000 Km long 2D grid with 10 Km grid cells
- 250 m initial relief
- 0.03° slope passing into 125 m flat bottomed basin



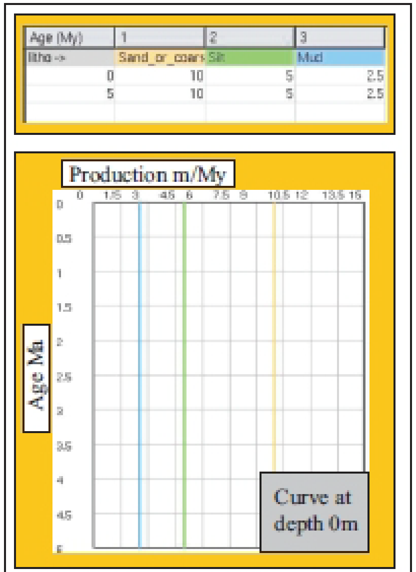
Initial basement bathymetry

Modelled Lithologies

- Carbonate sand or coarser
- Silt
- Mud

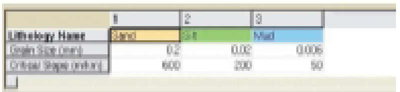


Carbonate Production Vs Water Depth

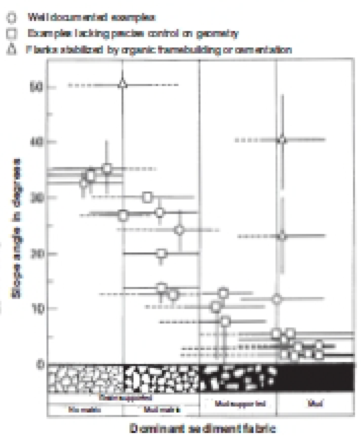


Carbonate Production Vs Time

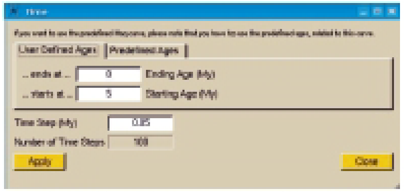
Angle of repose



GRAIN	GRAIN SIZE	CRITICAL SLOPE
Sand or coarser	0.2 mm	3°
Silt	0.02 mm	12°
Mud	0.006 mm	30°



Model Duration

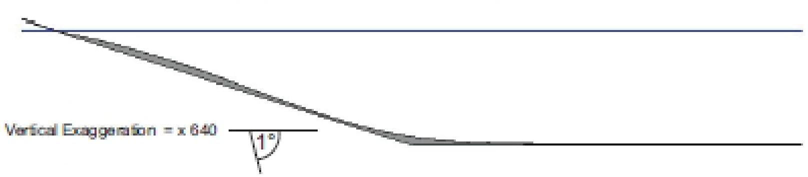


- 5 to 0 My = 5 My model duration
- 0.05 My time step

Initial model rates

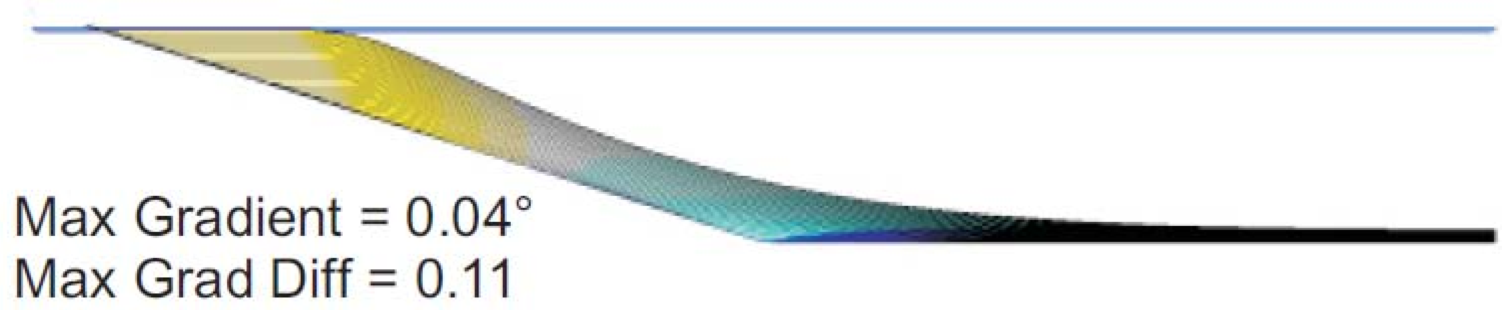
GRAIN	Initial Sediment Production Rate m/My	Initial Diffusion Coefficient Km²/ky
Sand or coarser	10	0
Silt	5	0
Mud	2.5	0

Resultant M1 Dionisos geometry



Carbonate Platform Geometry: Ramps = Transport

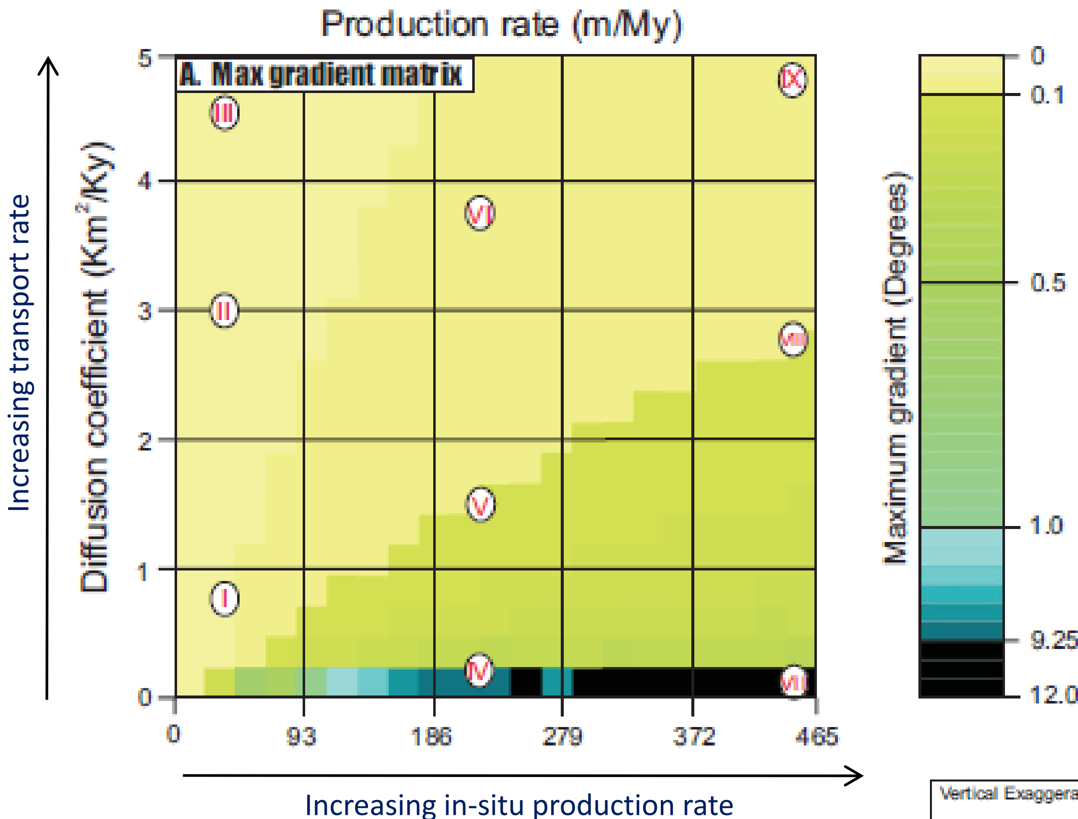
Relatively High Transport Rate



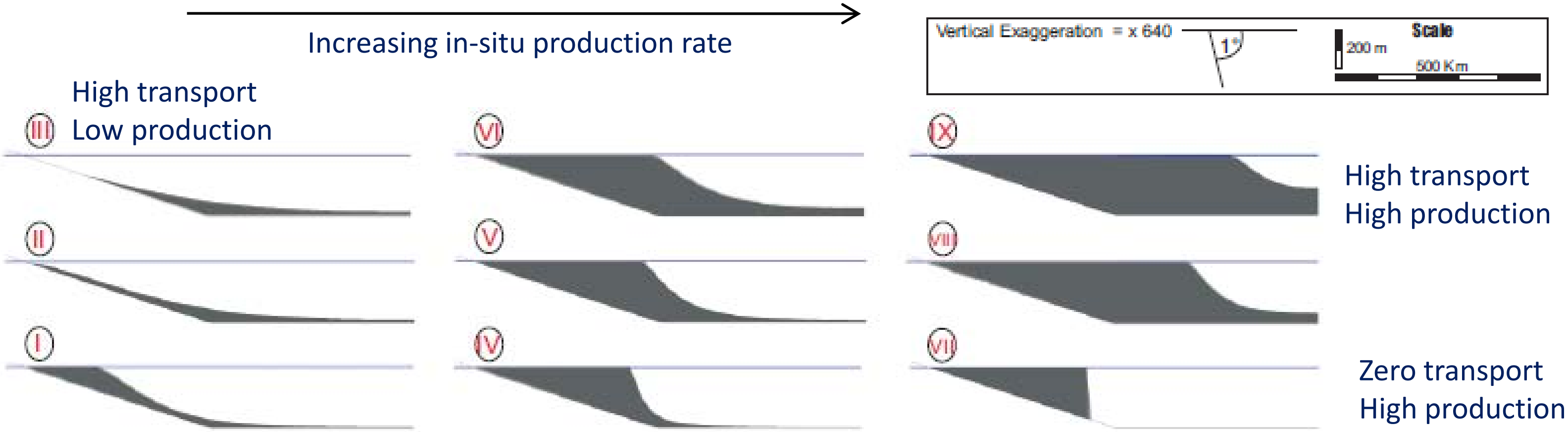
Relatively Low Transport Rate

Williams et al., 2011, JSR

Carbonate Platform Geometry : Ramps = Transport



- Forward modelling study suggests that classification as ramp versus flat-top steep-margined platform may be misleading
- Reality is probably a process continuum, from in-situ production dominated to transport dominated

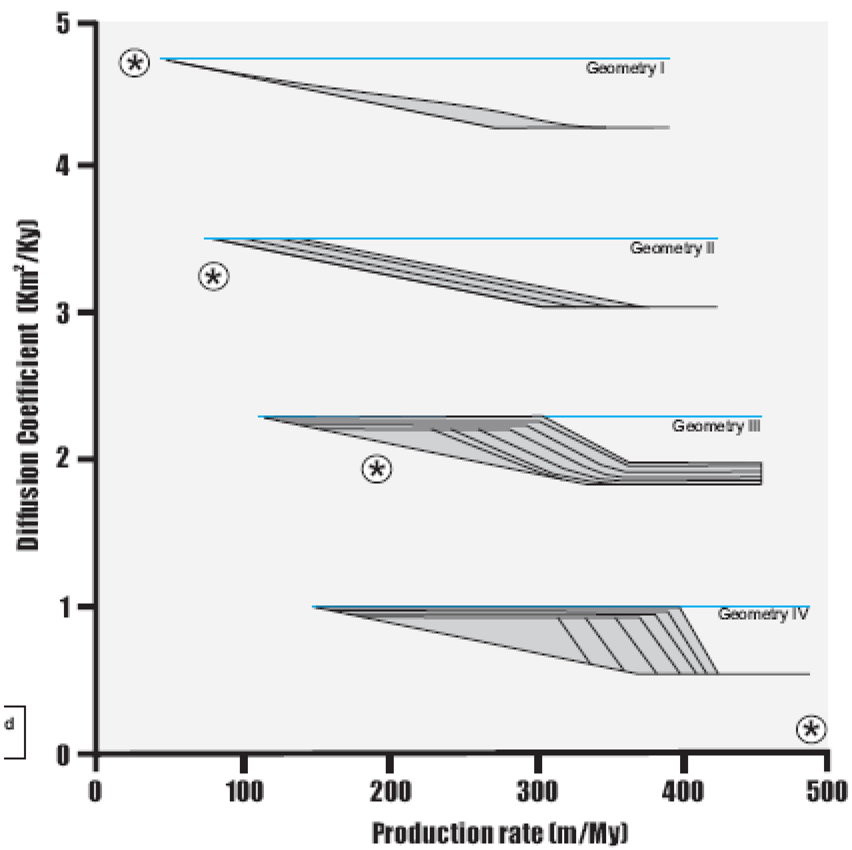


Williams et al., in press

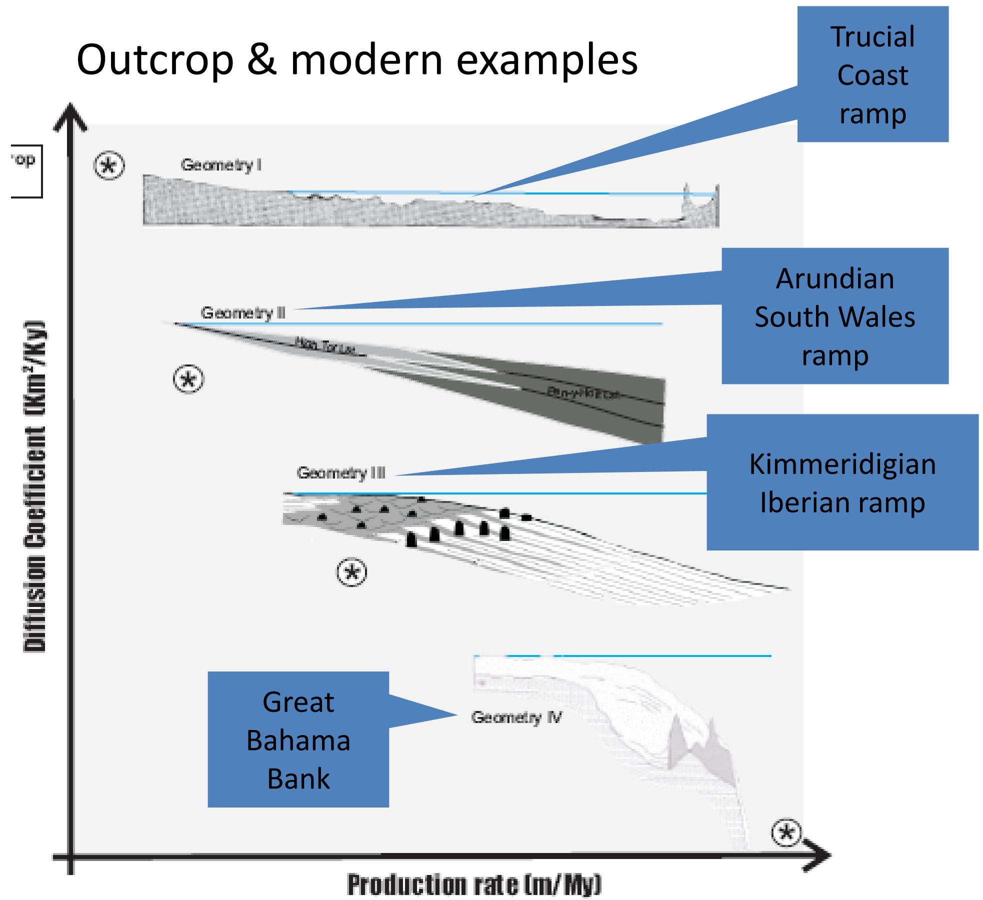
Williams et al., 2011, JSR

Carbonate Platform Geometry : Ramps = Transport

Modelled continuum



Outcrop & modern examples

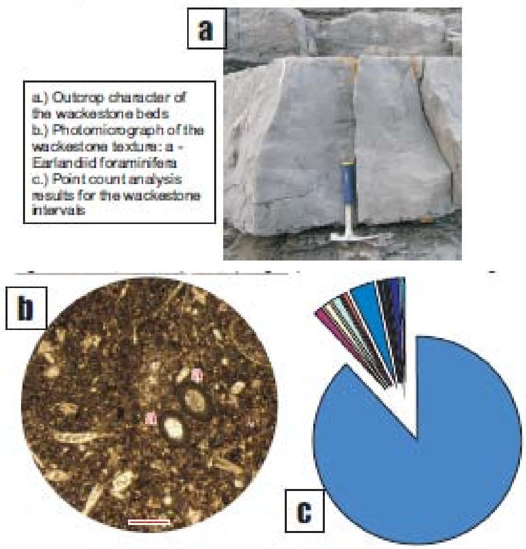


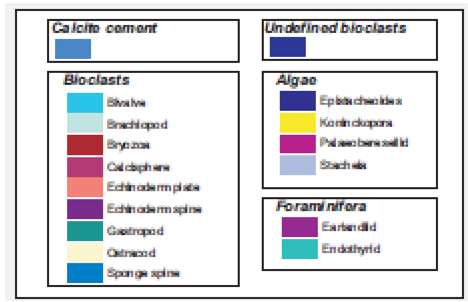
Geometry I: The low angle homoclinal ramp is comparable with the Trucial Coast ramp (image modified from Purser, 1973).
Geometry II: Low angle ramp geometry akin to the Arundian aged South Wales ramp (image modified from Simpson, 1987).
Geometry III: An intermediate geometry (flat-topped ramp) akin to the Kimmeridgian aged ramp of the Iberian basin (image modified from Aurell et al., 1998).
Geometry IV: FTP geometry comparable with the Great Bahama Bank (image modified from Schlager, 2005).

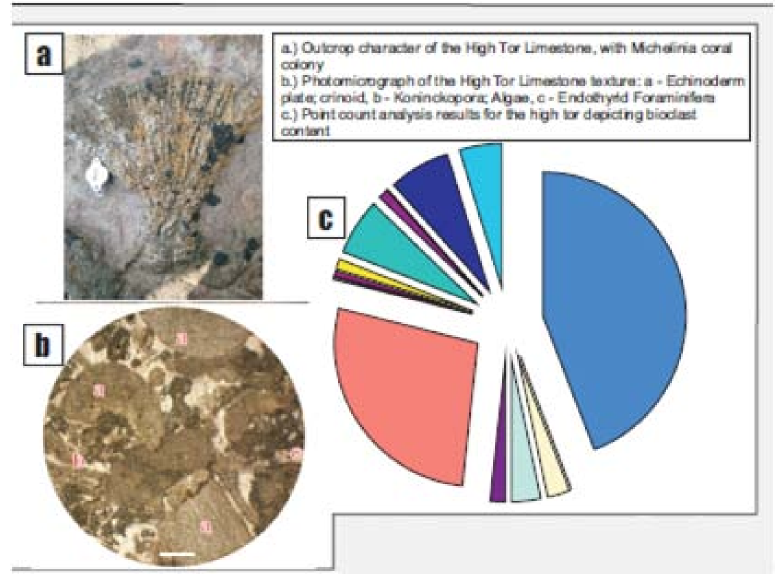
Carbonate Platform Geometry : Ramps = Transport

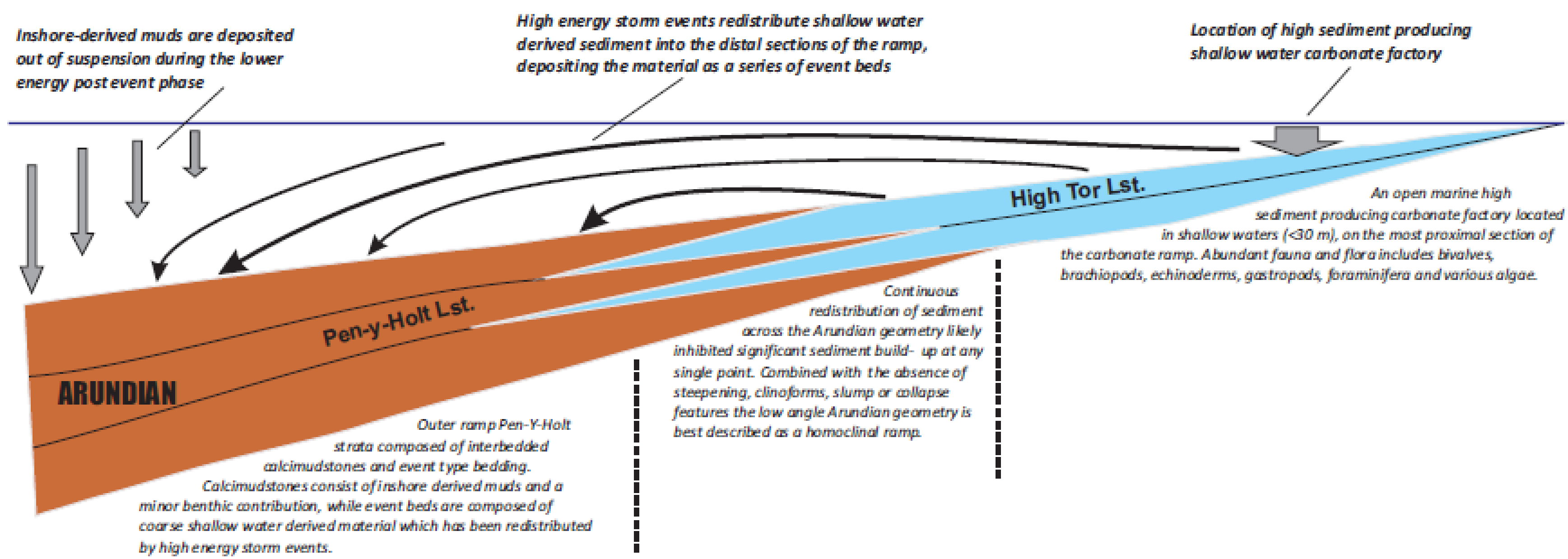
The Transport Sink: the Pen Y Holt Fm.

The Factory: The High Tor Limestone

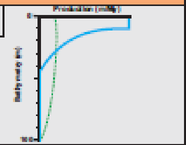
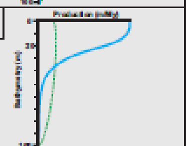
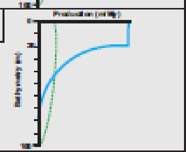
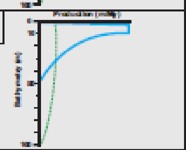
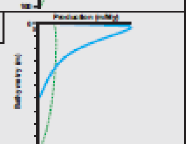
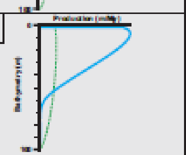
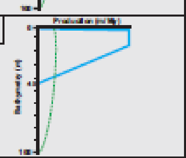
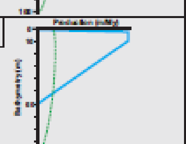


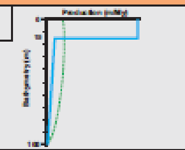
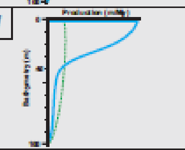
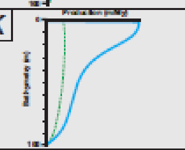
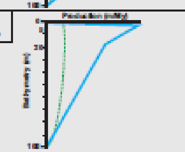
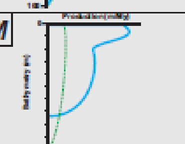
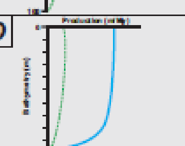






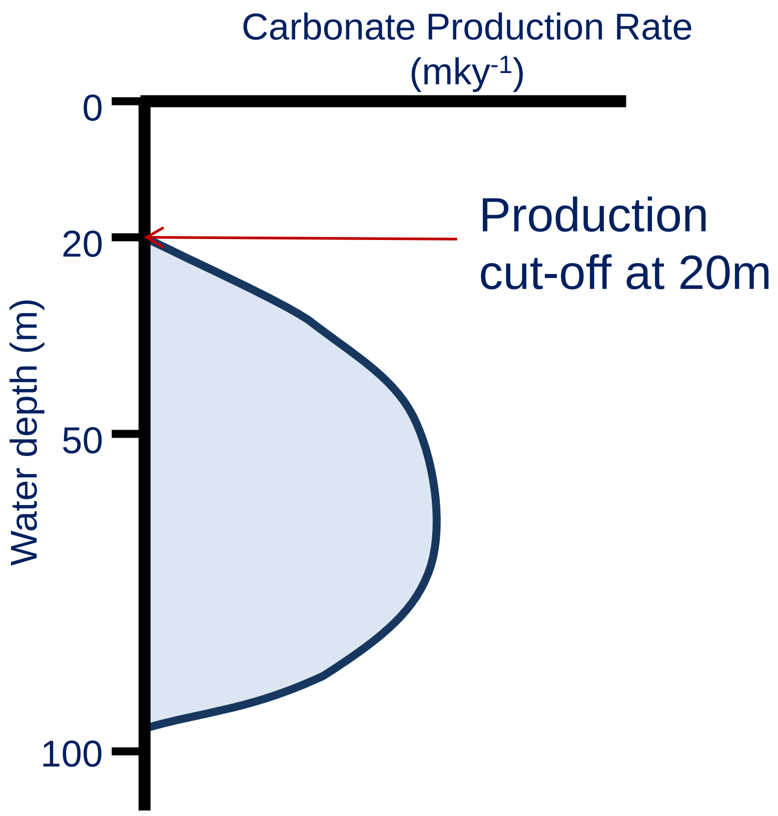
Carbonate Platform Geometry : Factory matters little

Production Profile	High Diffusion, Moderate Production Example	Low Diffusion, Moderate Production Example
A 	Max Gradient = 0.027° Max Grad Diff = 0.01	Max Gradient = 3.157° Max Grad Diff = 55.156
B 	Max Gradient = 0.022° Max Grad Diff = 0.011	Max Gradient = 3.157° Max Grad Diff = 55.16
C 	Max Gradient = 0.028° Max Grad Diff = 0.011	Max Gradient = 3.766° Max Grad Diff = 41.946
D 	Max Gradient = 0.025° Max Grad Diff = 0.011	Max Gradient = 3.181° Max Grad Diff = 55.58
E 	Max Gradient =0.023° Max Grad Diff = 0.011	Max Gradient = 3.172° Max Grad Diff = 55.415
F 	Max Gradient = 0.029° Max Grad Diff = 0.011	Max Gradient = 7.353° Max Grad Diff = 129.046
G 	Max Gradient = 0.028° Max Grad Diff = 0.023	Max Gradient = 6.150° Max Grad Diff = 107.759
H 	Max Gradient = 0.028° Max Grad Diff = 0.021	Max Gradient = 6.150° Max Grad Diff = 107.759

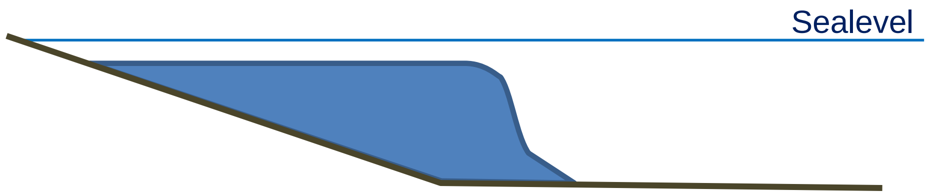
Production Profile	High Diffusion, Moderate Production Example	Low Diffusion, Moderate Production Example
I 	Max Gradient = 0.027° Max Grad Diff = 0.01	Max Gradient = 5.077° Max Grad Diff = 77.15
J 	Max Gradient = 0.027° Max Grad Diff = 0.014	Max Gradient = 8.238° Max Grad Diff = 144.781
K 	Max Gradient =0.031° Max Grad Diff = 0.024	Max Gradient =8.894° Max Grad Diff = 156.494
L 	Max Gradient = 0.027° Max Grad Diff = 0.012	Max Gradient = 8.238° Max Grad Diff = 144.78
M 	Max Gradient = 0.031° Max Grad Diff = 0.027	Max Gradient = 10.545° Max Grad Diff = 186.151
N 	Max Gradient = 0.038° Max Grad Diff = 0.048	Max Gradient = 10.873° Max Grad Diff = 192.072
O 	Max Gradient = 0.039° Max Grad Diff = 0.037	Max Gradient = 9.689° Max Grad Diff = 170.734

Williams et al., 2011, JSR

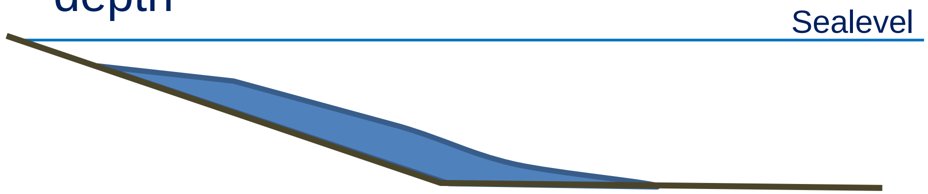
Carbonate Platform Geometry : Factory matters little



- No transport = flat top platform
- Platform top at 20m water depth

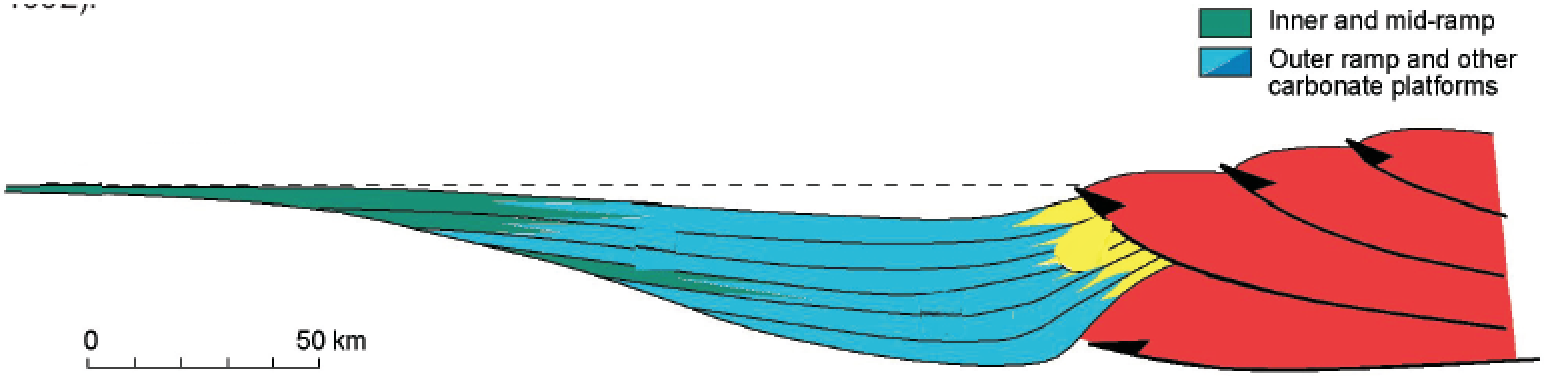


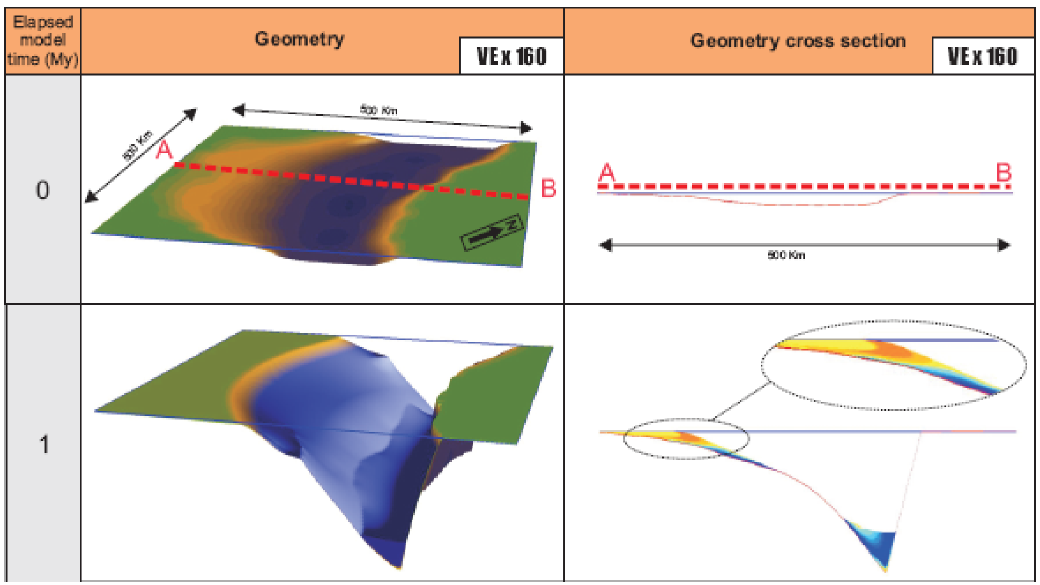
- High transport = ramp
- No accumulation in less than 20m water depth



NB If the factory makes sediment that is more prone to transport, then it can be an important control on overall platform type

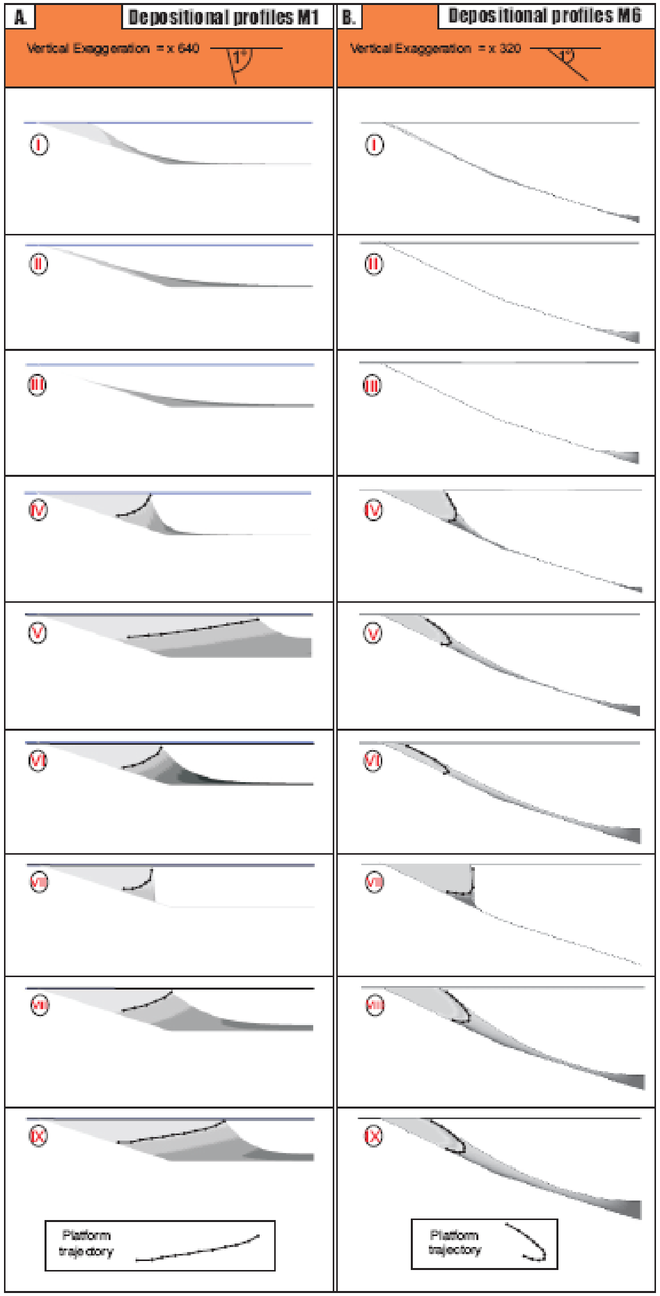
Carbonate Platform Geometry : Tectonic Controls





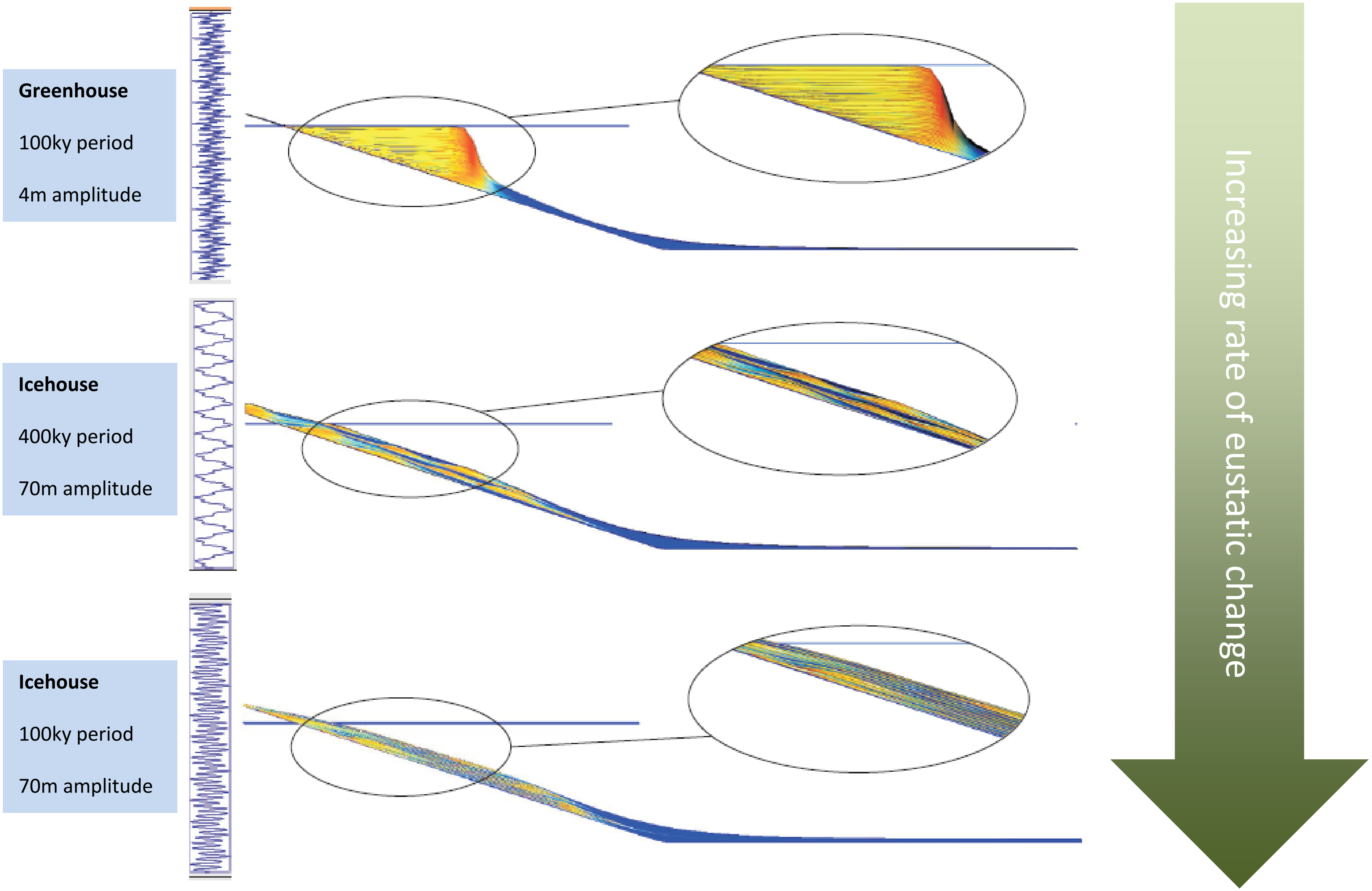
- Rotational subsidence, where rates of subsidence increase laterally, occurs in tectonic settings like foreland basins
- Simple models suggest that this has a significant impact on platform geometry and stacking patterns (e.g. Dorobek, 1995; Allen et al., 2001) but systematic analysis is required to properly understand what this impact will be…

Carbonate Platform Geometry : Tectonic Controls



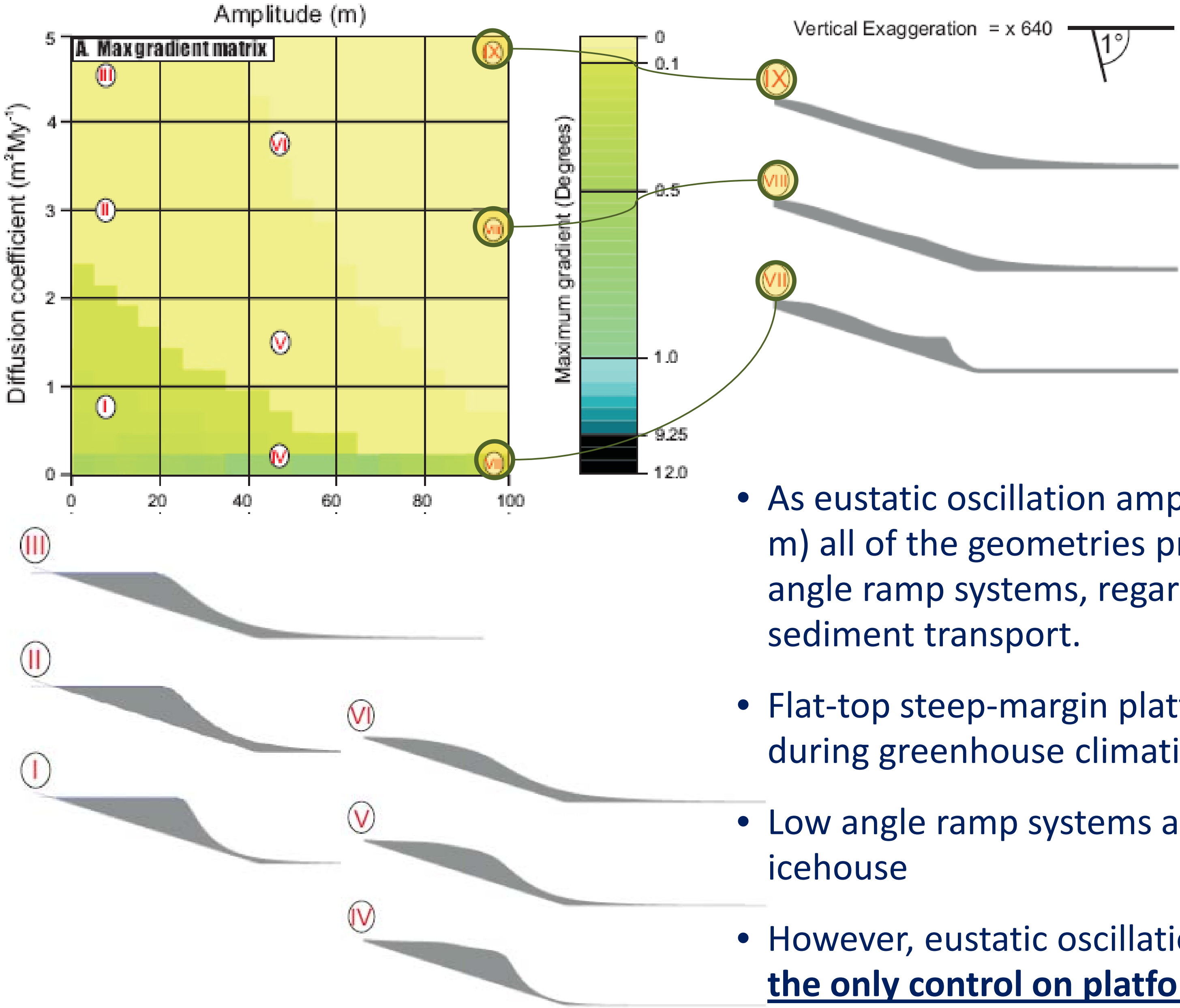
- Rotational subsidence acts to suppress progradation and steepening by increasing gradients, hence increasing the rate of sediment transport, and leading to formation of ramp-like geometries
- On the left, standard reference model, on the right, the same models but with the addition of rotational subsidence with a maximum of $100mMy^{-1}$ at the distal end of the profile
- At relatively high rates of rotational subsidence (Geometry III and IV) a low-angle ramp with retrogradational stacking is produced
- The low angle ramp geometries are a consequence of increased topographic gradients leading to higher rates of sediment transport.

Carbonate Platform Geometry : Eustatic Controls



- Eustatic oscillations are a key control on incidence of flat-top steep-margined platform versus ramp geometries
- Most basically, greenhouse flat-top platforms versus icehouse ramps

Carbonate Platform Geometry : Eustatic Controls

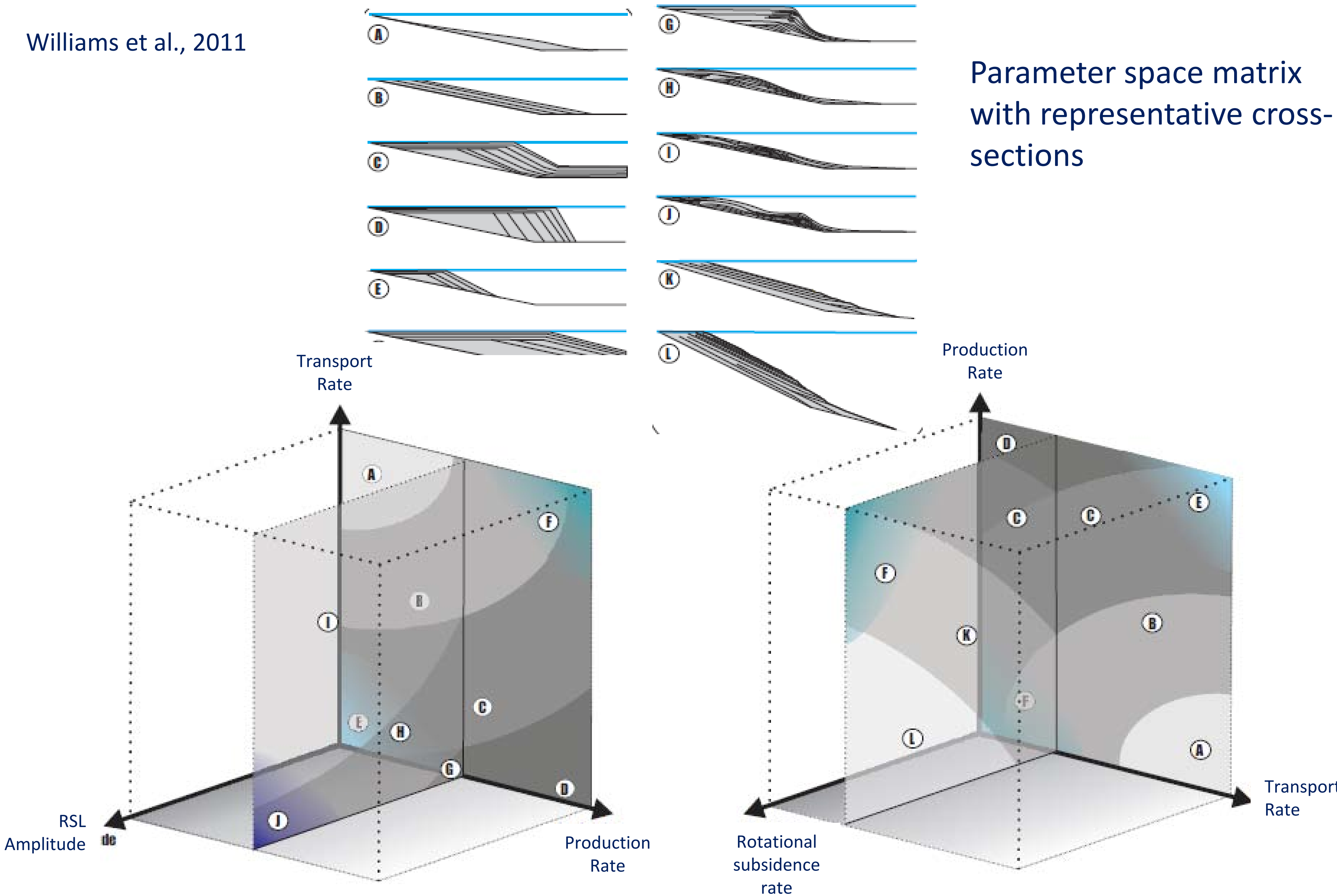


- As eustatic oscillation amplitude increases (>50 m) all of the geometries produced are very low angle ramp systems, regardless of the rate of sediment transport.
- Flat-top steep-margin platforms are more likely during greenhouse climatic conditions
- Low angle ramp systems are more likely during icehouse
- However, eustatic oscillations **are clearly not the only control on platform geometry**

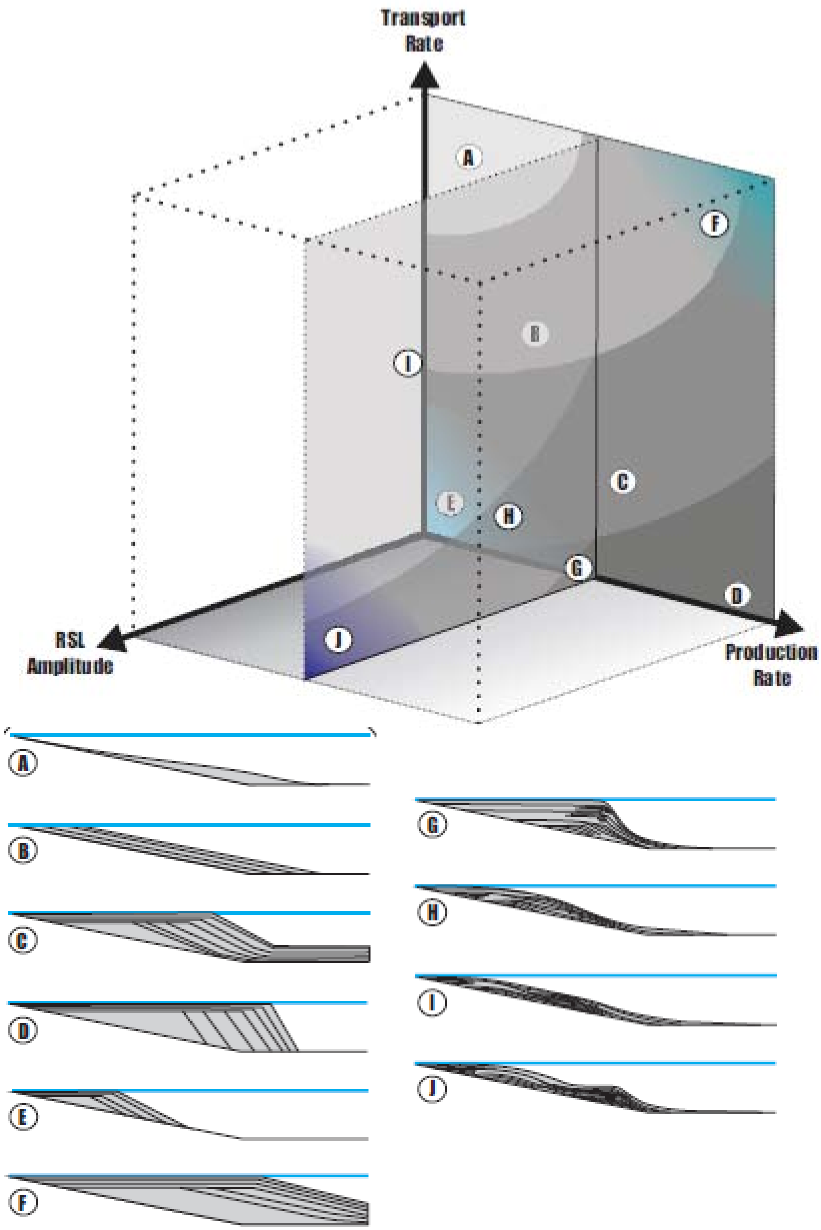
Carbonate Platform Geometry : Multiple Controls

Williams et al., 2011

Parameter space matrix with representative cross-sections



Carbonate Platform Geometry : A Process Continuum



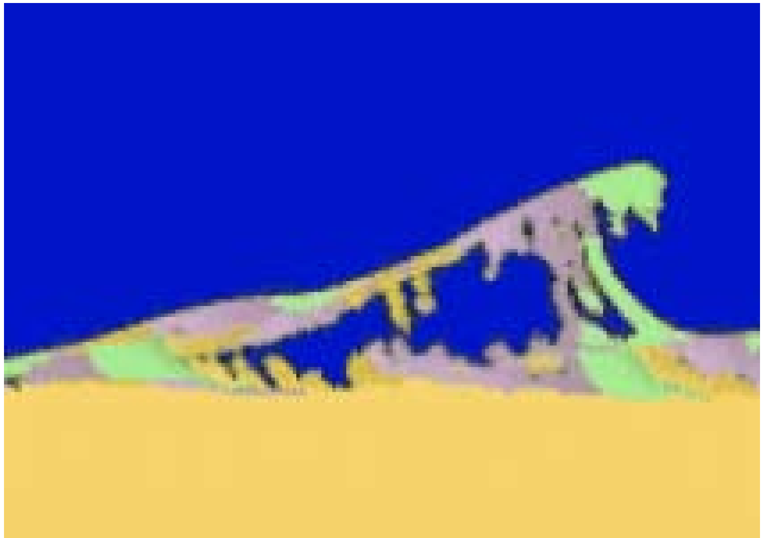
Preliminary conclusion:

- Carbonate platforms should not be classified into discrete classes e.g. ramps, flat-top platforms
- Better approach is to consider a process continuum, and a continuum of form, multiple controls and a multi dimensional parameter space

BUT …

- This raises the question of how to predict facies distributions
- Map the parameter space with realistic process-based SFMs
- CSDMS model development…

Carbonate Platform Geometry : Next Steps



- Use the next generation of stratigraphic forward models e.g. CSDMS models that include more realistic biology and detailed representations of sediment transport processes to map facies distributions in the model parameter space
- Tie this modelling back to outcrop and subsurface examples by trying to classify the outcrop and subsurface examples according to this parameter space and make testable away from data point facies predictions

Summary

- Basic platform geometry e.g. flat top steep-margin platform versus ramp, is a consequence of multiple controls leading to a continuum of form
- Sediment transport is a key control
- High frequency eustatic oscillations and rotational tectonic subsidence are also key controls, along with other factors not discussed here e.g. basin bathymetry
- Platform type is best treated as a continuum rather than applying arbitrary classification cutoffs
- The best predictions of facies distribution will likely come from methods based on multiple controls modelled as a multiple parameter space