The observation that shallow-marine carbonate strata often have exponential lithofacies thickness distributions is one of the most fundamental results in carbonate stratigraphy in recent years. This is both because it is an observation that can be tested for its repeatability in outcrop and subsurface examples, and also because it raises the question of what sedimentary processes lead to the formation of particular lithofacies thickness distributions. This in turn links to the significant issue of how carbonate strata record climatic and oceanographic change through geological time.

This study applies a simple 1D numerical stratigraphic forward model of carbonate platform strata (Dougal) to investigate how relative sea-level oscillations could control lithofacies distribution. Dougal records platform-top carbonate accumulation influenced by water-depth dependent sediment production in euphotic, oligophotic and aphotic production profiles with a lag-depth controlling onset of production.

Results from single model runs highlight the issue of non-stationary behavior where statistical properties of the strata change with elevation up the section, and show that exponential lithofacies thickness distributions can be generated from an entirely deterministic model. Results of multiple model runs (more than 27,000 in total) spanning a range of production and accommodation creation rates, demonstrate that the accommodation and sediment supply do act as major, though non-linear, controls on carbonate lithofacies distribution, but significantly that lithofacies distributions also have an autocyclic control through oscillations in deposition during certain high-frequency rising limbs on the glacio-eustatic curve. In these multiple model runs only about 13% of the total runs created exponential distributions, compared to 28% in the documented outcrop examples, also suggesting that other processes, including three-dimensional process not included in this model, play an important role.
In addition to providing some understanding of the nature of lithofacies thickness distributions under varying oceanographic and climatic regimes, the findings presented here have broader implications. This is particularly true where lithofacies thickness has an impact on the performance and productivity of hydrocarbon reservoirs, such as economically-important platform and ramp interiors in both icehouse and greenhouse settings.
The Origins of Shallow-Water Carbonate Lithofacies Thickness Distributions: 1D Forward Modelling of Factory Type and Relative Sea-Level Control

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1 The Data

- Based on careful observations from many Neoproterozoic and Palaeozoic platform carbonate outcrops Wilkinson et al. (1997 & 1999) asserted that a fundamental property of carbonate strata is an approximately exponential lithofacies thickness distribution
- An exponential distributions simply means many thin beds, and proportionately fewer thick beds, with a particular rate of decrease in frequency from thin to thick
- Further testing in Burgess (2008) based on KS testing of outcrop data against theoretical exponentials showed that the situation is slightly more complex
- Results from this analysis show that 16 of 56 outcrop examples can be confidently shown to be exponential, while 28 are very probably not exponential, though still with a many-thin and few-thick lithofacies unit pattern
- All of which raises several questions that this poster will frame and make some tentative initial steps to answer...

2 Why are lithofacies thickness distributions important?

- What kind of lithofacies areal extent distributions exist in ancient carbonate strata?
- Do lithofacies thickness distributions contain any information on lithofacies areal extents?

Modern carbonate deposystems contain abundant information on lithofacies areal extents, BUT are these area distribution “snap shots” representative for the ancient record?

What happens to the lithofacies areas when they go through the preservation filter?

And what kind of lithofacies thickness distributions would result from the above modern deposystems?

3 Questions arising...

- Why so many thin lithofacies units and relatively few thick units?
- What depositional processes are responsible for this pattern?
- What are the implications of this pattern for lateral extent of carbonate lithofacies and their areal size distributions??
4. A model called Dougal

- A 1D SFM for platform-top deposition (Pollitt, 2008; Burgess and Pollitt in review)
- Three production profiles accumulating five lithofacies
- Variable production rate of each profile
- Also subsidence and erosion by dissolution
- But also an important control from lag-depth autocycles
  - Multiple cycles per eustatic rising limb
- Eustatic oscillations drive accommodation variations that control facies thicknesses

5. Single Dougal Runs: Production, RSL and autocycle control on lithofacies thickness distributions

- Exponential lithofacies thickness distributions are possible with deterministic models.
- Production rate, relative sea-level history and operation of autocyclicity related to lag depth are all important controls on occurrence of exponential distributions.

6. Multiple Dougal runs: Mapping the parameter space to understand the controls

To really begin to understand the controls on lithofacies thickness distributions it is necessary to run thousands of model cases to map the model parameter space.
Control by production profile in Dougal

Multiple eustatic curves spanning the range of likely variation, from greenhouse to icehouse

Each eustatic curve is then run with multiple production curves and production rates

- Multiple production profiles representing various interactions of: euphotic, oligophotic and aphotic
- Requires in the order of 70000 model runs but should be a robust mapping of the parameter space and should shed light on control by factory type
- Work currently in progress...

3D facies body modelling with CarboCAT

CarboCAT is a cellular automata model that calculates spatial evolution of lithofacies according to simple rules

Initial trials suggest exponential distributions are difficult to produce...

Conclusions

- Information contained in lithofacies thickness distributions could prove useful for subsurface prediction – use SFMs to begin to understand the processes
- Three main factors appear to favour formation of exponential lithofacies thickness distributions in the 27,205 model runs performed for this study.
  - Complex variations in the rate of creation of accommodation
  - Rate of sediment production
  - Lag-depth oscillations
- Exponential lithofacies thickness distributions can be generated from a purely deterministic model.
- Other processes not included in Dougal probably play an important role...

Comparison with outcrop examples

- Is it possible to invert Dougal against lithofacies thickness distributions measured from outcrop?
- If best-fit inversions are possible, what would this tell us about the responsible depositional processes?

References