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Role of Basin-Margin Physiography and Sediment Supply History in Sequence Architecture: Insights from Field Studies and Computer Modelling

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There is a general agreement that stratal geometries in depositional sequences are controlled by tectonic subsidence, eustasy, and sediment inpzut, as the main three variables which act together in creating and filling accommodation. However, also variables commonly assumed to be of marginal importance, e.g. compaction or marine current regime, can have surprisingly pronounced effects in depositional geometry. A potentially important and so far under-researched variable is the basin-margin physiography, which becomes important especially in fault-bounded basins. Topographic breaks, formed by faulting at the margins of extensional and strike-slip basins, are known to be essential in providing the gradient between the depth of the fluvial channel and the water depth seaward of the river mouth, which is the most important pre-requisite for the development of steep „Gilbert-type" foresets in coarse-grained delta systems (Postma 1995). If such physiographic break is absent, the deltas tend to develop a flat, „shelf-type" morphology at the basin margin. The delta morphology is an important control on the response of the depositional system to relative sea/lake-level changes, and its expression in stratigraphy. The critical "initial depth" is defined here as the pre-depositional bathymetry at the basin margin, resulting most commonly from the delay between the onset of subsidence and the onset of sediment input.

In this study we explore the influence of the initial bathymetry on the stratigraphic architectures of high-frequency sequences, using a series of computer-model runs based on outcrop and subsurface data from two basins with prominent coarse-grained delta systems: the Bohemian Cretaceous Basin (Czech Republic) and the Gulf of Corinth (Greece). The two cases represent end-members in terms of rates of base-level change: a relatively slowly subsiding (c. 80 m/Ma), strike-slip margin of the intracontinental Bohemian Cretaceous Basin during a time interval characterized by low-magnitude eustatic changes of the Mid-Cretaceous greenhouse period, vs. an order of magnitude faster subsidence along extensional faults in the Gulf of Corinth (c. 1 km/Ma), with a possible influence of high-frequency, large-magnitude, sea- or lake-level changes induced by the Quaternary climate.

The Bohemian Cretaceous coarse-grained deltas show a variety of internal geometries, ranging from stacks of very thin (3–15 m) deltaic packages with low-angle foresets (or they show no foresets distinuishable on outcrop scale) to thick (55–75 m) packages of high-angle foresets in Gilbert-type deltas (Uličný 1998). Significant differences exist between architectures of deltas deposited along margins of a pull-apart sub-basin or in neighbouring sub-basins, under very similar subsidence rates, same eustatic sea-level fluctuations, and probably also similar sediment supply rates. All these deltaic packages show a degree of influence of high-frequency sea-level fluctuations. The modelling in this case focused on understanding the role of initial depth in governing the geometry and stacking of high-frequency sequences of the Gilbert-type vs. shelf-type deltas.

Along the margins of the Gulf of Corinth, huge Gilbert deltas of probably Early Pleistocene age, of inferred lacustrine origin with marine incursions, with up to 700 m thick foresets, show distinct variations in internal architecture (e.g., Dart et al. 1994). Whereas some deltas show a complex stacking of sequences in both the topset and foreset areas, other examples from the same depositional setting show a uniform pattern of foreset progradation and topset aggradation, suggesting no major changes in base level.

Hardy et al. (1994), in a numerical modelling study of these deltas, attempted to simulate the effects of high-frequency, glacio-eustatic sea-level changes on their internal architecture. Because the stacking patterns predicted by the modelling showed a number of thin, vertically stacked, shelf-type deltas, very different from the real architectures, Hardy et al. (1994) rejected the possibility of high-frequency sea- or lake-level fluctuations in this depositional setting. In this case, our modelling runs were focused on the testing of the role of initial depth of c.

100–500 m, combined with a range of realistic subsidence rates and a high-frequency eustatic curve similar to the Quaternary glacio-eustasy, in creating depositional architectures close to the real examples.

For the forward modelling runs, we used the CONG program developed by D. Waltham and G. Nichols. The principal aim was to discriminate between the influence of the accommodation added by the pre-depositional bathymetry and the accommodation created by eustasy, syndepositional subsidence, and compaction. In both cases modelled, the main variable was the initial bathymetry, and other variables (eustasy, subsidence, supply) were held constant between the runs. Several series of runs were tested for different sea-level curves in the Cretaceous case, and for different subsidence rates in the Quaternary case.

Our experiments demonstrate that the dimensions of the depositional system, strongly dependent on the initial depth of the basin prior to the onset of sedimentation, significantly influence the internal geometries and stacking patterns of sequences formed in response to high-frequency sea-level changes. The initial depth sets the ratio between the accommodation available at the basin margin versus the magnitude of relative sea-level (RSL) change. (1) In case of large initial depth, the short-term accommodation is dominated by vertical dimension: deltas are characterized by steep foreset slopes and short progradation distances. Because the magnitude of the RSL fluctuations equals only a fraction of the total foreset height, high-frequency sequences in such settings can be contained largely within the foresets and part of the topsets, unless the long-term relative sea level results in flooding of the whole depositional system. (2) In case of small initial depth, the accommodation is dominated by horizontal dimension, i.e. flat slopes of shelf-type deltas and long progradation distances. The RSL magnitude is then close to the vertical dimension of the whole depositional system, and short-term, small-scale RSL changes result in rapid shifts of the shoreline across tens of kilometres and in vertical stacking of thin deltaic sequences. A dramatic illustration of this relationship is the Gulf of Corinth case, where adding a reasonable initial depth to the model setup led to a good fit with the observed data, because it allowed the evolution of thick foresets, affected by the base-level changes (of c. 80–100 m magnitude) only in their uppermost parts.

This further strengthens the point that a specific stacking pattern of clastic strata in one location does not have a predictive potential for deriving cyclo- or sequence-stratigraphic „templates“ usable in a location of different physiography. Basin modelling efforts which fail to recognize the importance of initial depth for setting the geometry and dimensions of the depositional systems will result in false predictions of geometric relationships between stratigraphic units and incorrect interpretations of basin history.

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Comparative Rheology Map – a New Approach Connecting Experimental and Natural Observations

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Strength (differential stress) for naturally deformed rocks at different crustal levels is usually extrapolated using experimental flow laws or paleopiezometric equations where incoming variables are temperature and steady recrystallised grain size, respectively. Experimental flow law equations are favoured by geologist dealing with large-scale processes while paleopiezometric equations are commonly used to estimate flow stress in narrow shear zones. Shortcoming of the present approaches is that temperature and recrystallised grain size are not assessed together in estimating flow stress in natural tectonites.

Derby and Ashby (1987) suggested that nucleation and grain growth are competing processes that determine recrystallised grain size. De Bresser et al. (1998) and Shimizu (1998) proposed temperature-dependent linear type of paleopiezometric equation based on the above suggestion. In their model, flow stress decreases more rapidly with increasing grain size and increasing temperature. Principal goal of this contribution is to use this approach in assessing flow stress in naturally deformed marbles and quartzites.

De Bresser et al. (1998) noted, that temperature-independent paleopiezometers lie at the boundary between grain-size insensitive (GSI) creep and grain-size sensitive (GSS) creep suggesting equal contribution of both regimes on bulk strain rate:

$$\dot{\varepsilon}_{(GSI)} = \dot{\varepsilon}_{(GSS)} \quad (1)$$

$$A_{(GSI)} \cdot \Delta\sigma^{n} \cdot \exp(-H_{(GSI)}/RT) = A_{(GSS)} \cdot \Delta\sigma^{m} \cdot d^{-p} \cdot \exp(-H_{(GSS)}/RT) \quad (2)$$

in which $\dot{\varepsilon}$ is strain rate, $\Delta\sigma$ is flow stress, d is grain size, H is the apparent activation enthalpy for flow, T is absolute tem-