Fluvial Landscapes and Stratigraphy in a Flume

Nikki Strong and Chris Paola
National Center for Earth-surface Dynamics (NCED)
Department of Geology and Geophysics
University of Minnesota
St. Anthony Falls Laboratory
23rd Ave SE
Minneapolis MN 55414 USA

ABSTRACT

We use data from an experiment conducted in the Experimental EarthScape (XES) facility, National Center for Earth-surface Dynamics (NCED), St. Anthony Falls Laboratory (SAFL), University of Minnesota, to demonstrate why incised valleys preserved in the stratigraphic record probably bear little resemblance to the actual valleys as they appeared in the paleolandscape. In an experiment designed to study fluvial response to changes in sea level, we find that preserved incised-valley structures are typically broader and have more gentle side slopes, than the topographic features from which they develop. Also, because of widening driven by valley wall erosion during both relative sea-level rise and fall, there is virtually no remnant of terraces formed during falling relative sea level preserved in the stratigraphic record. The process of filling an incised valley due to rising relative sea level is not a passive depositional process that simply buries and preserves the original shape of the valley; rather, it includes an energetic erosional component that substantially reshapes the original valley form.

INCISED VALLEY EVOLUTION AND PRESERVATION

The geological community has long recognized the significance of identifying incised valleys in the stratigraphic record as well as understanding the relationships between the filling of incised-valleys and their geomorphologic evolution. Incised valley geometries and fill are often used to infer the record and effects of sea level change on coastal environments, both as a tool in petroleum exploration (e.g. Van Wagoner et al. 1988, 1990; Posamentier and Allen 1999) and to better understand the environmental consequences of sea level change (Warrick et al. 1993; Nicholls and Leatherman 1994). Furthermore, incised valleys typically comprise basin scale erosional unconformities that can be identified in seismic sections, well logs, and outcrops, and thus are used to correlate stratigraphic facies and time (e.g., Van Wagoner et al. 1990).

Previous work on both modern and preserved incised valleys has illustrated the complexity of incised valley fill. A common interpretation of the stratigraphic record in such fills is that detailed layering reflects discrete external (allogenic) forcing mechanisms, including high frequency climate change, (low amplitude) high frequency tectonic movement, eustatic sea level and lake level fluctuations, and local faulting (Kraus and Middleton 1987; Bromely 1991; Lopez-Gomez and Arche 1993; Blum and Tornqvist 2000). The question of whether there are other mechanisms that could potentially produce the same geomorphic and stratigraphic signatures as these external factors is difficult to address from field data alone. Here we use experimental data to illustrate the role of autogenic (internal) processes in producing this complexity.

EXPERIMENTAL FACILITIES

The experimental data presented in this paper come from an experiment conducted in the Experimental EarthScape (XES) facility, National Center for Earth-surface Dynamics, St. Anthony Falls Laboratory, University of Minnesota, Twin Cities. The XES facility is a large (6 m x 3 m x 1.3 m) experimental basin with a programmable subsiding floor. Water discharge and sediment discharge into the basin as well as the experimental equivalent of eustatic sea level (ESL) are also fully controllable. XES Run 02 modeled basin filling by a braided river system prograding into a standing body of water. Since the objective of XES Run 02 was to isolate and identify the effects of changes in sea level on basin geomorphology and stratigraphy, sediment and water supply were held constant during the run as well as rates and geometry of subsidence A schematic diagram of the experimental basin in dip section (parallel to the mean flow direction) and of the experiment in plan view is shown in Figure 1. The experiment was divided into two stages: Stage I (isolated slow and rapid cycles), which was intended as a study of basic geomorphic response as a function of cycle period, and Stage II: (superimposed slow and rapid cycles), which was intended to investigate the nonlinear interaction between two (ESL) cycle periods. Here we use data only from the isolated rapid cycle of Stage I. For a more detailed description of the XES facility and further discussion on this experiment as well as others conducted in the facility, see Paola et al. (2001), Heller et al. (2001), Sheet et al. (2002), Cazanacli, et al. (2002), Violet et al. (2005), Strong et al. (2005), and Kim et al. (2006) as well as the NCED, SAFL, University of Minnesota's Sedimentology Research Group web sites at www.nced.umn.edu, www.safl.umn.edu, and http://www.geo.umn.edu/orgs/seds/, respectively.

EXPERIMENTAL OBSERVATIONS

The advantage of using experimental work to answer the question posed above is that an experiment allows observation of the complete process of valley incision, filling, and preservation as layers of sedi-

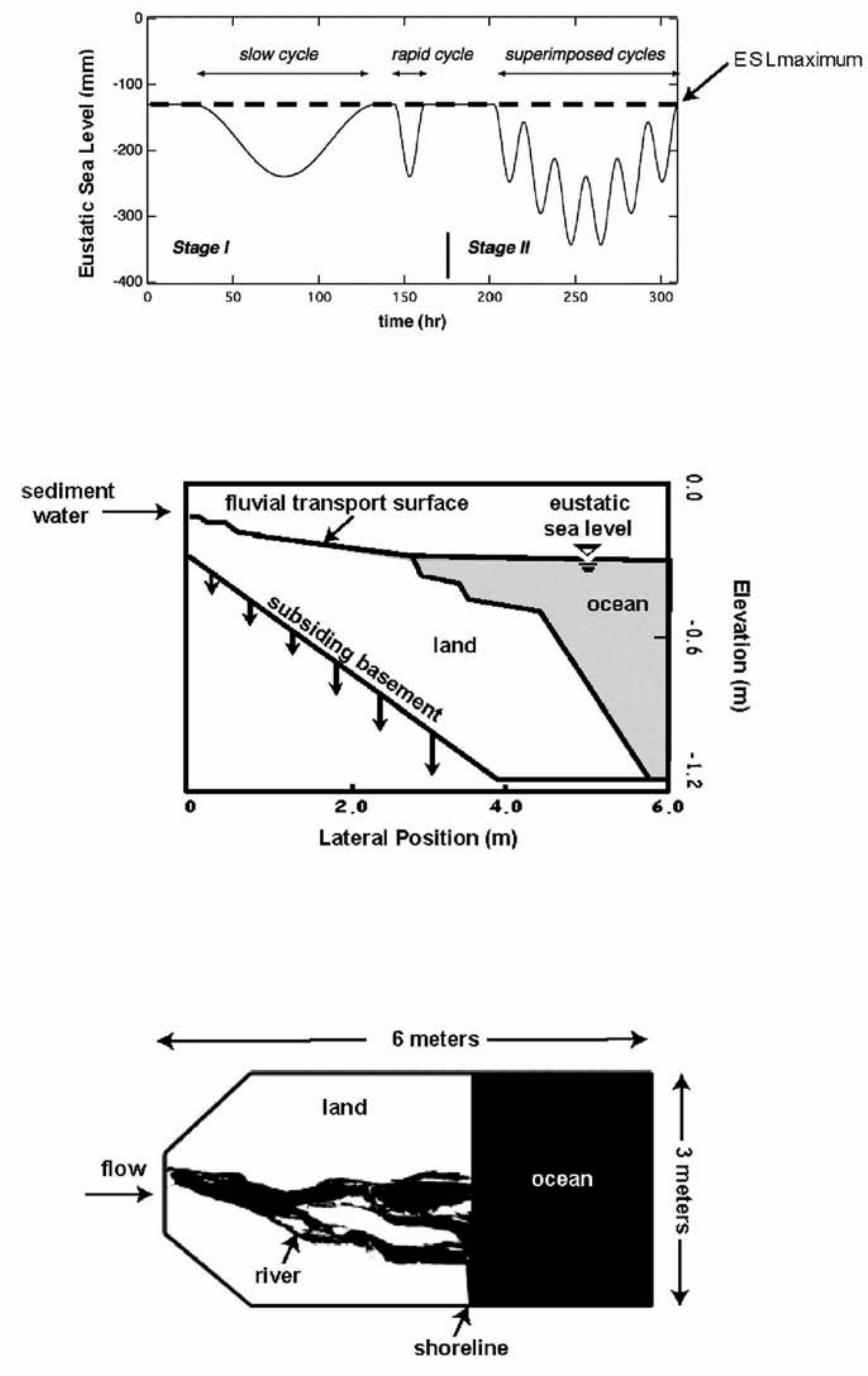

Figure 1. a) XES Run 02 eustatic sea level (ESL) curve. b) Schematic diagram of the experimental basin in dip section (parallel to the mean flow direction). Flow is from left to right. c) Schematic diagram of the experiment in plan view. White is exposed sediment and black is water.

ment. What the experiment demonstrates is that autogenic effects, such as fluvial avulsion, superimposed on a single continuous allogenic forcing, in this case relative sea level change, can produce a geomorphologically complex and time-transgressive valley form that easily could be misinterpreted as representing multiple high frequency, smaller scale allogenic forcing events.

Complexity in the experiment resulted from the fact that the width of the incised valley was influenced by two competing processes: narrowing during incisional events, a phenomenon also documented by Cantelli et al. (2004) during a series of dam-removal experiments, and widening associated with erosion of the valley walls (Fig. 2). By enhancing lateral channel mobility, deposition tends to accelerate valley widening. In addition, autogenic processes of channel incision, deposition, and migration act to localize and randomize the incision and widening process. The general trend is of valley incisional narrowing during accelerating rates of relative sea level fall and deposition and widening during decelerating rates of relative sea level fall and during relative sea level rise. Therefore during falling relative sea level, episodes of valley incision and narrowing produced a complex step-like morphology of unpaired autogenic terraces (Fig. 3) despite the fact that sea level fall was continuous, albeit with varying rates, a phenomenon also observed in experiments conducted by Muto and Steel (2004).

These terraces are, however, not well preserved in the stratigraphic record due to valley widening during valley filling. The incised valley that formed during the isolated rapid eustatic sea level cycle fall is not visible in the final deposit. What is visible is a composite, valley-shaped unconformity surface that formed due to a series of erosion-narrowing and widening-filling events during the entire relative sea level cycle. The apparent "valley walls" visible in strike section comprise a highly diachronous erosional surface that bears little resemblance to any paleogeomorphic surface that existed during the experiment.

CHANGE IN RIVER VALLEY MORPHOLOGY WITH CHANGE IN RELATIVE SEA LEVEL (RSL)

The major consistent trend in the evolution of the experimental valleys is that rivers, and thus river valleys, tend to deepen and narrow with a positive acceleration in falling RSL and to widen when the rate of RSL fall decelerates and during RSL rise (Cantelli et. al.,2004; Wong et al. 2004). These observations can be summarized by considering a hypothetical river valley evolving in response to a simple RSL curve symmetrical and sinusoidal in shape like the one in Figure 4.

Because of the sinusoidal shape of the RSL curve, the rate of fall in RSL accelerates, from the beginning of RSL fall until it reaches its maximum rate of fall midway down the curve. During this period of increasingly rapid RSL fall, the river valley tends to narrow as it incises (Fig. 4a-c.) As RSL continues to fall, but at a progressively slower rate, the valley tends to widen and continues to incise until the end of the fall at the local minimum in the RSL curve (Fig. 4d). With rising RSL the valley floor aggrades and the valley continues to widen (Fig. 4e-f) due to both trapping of

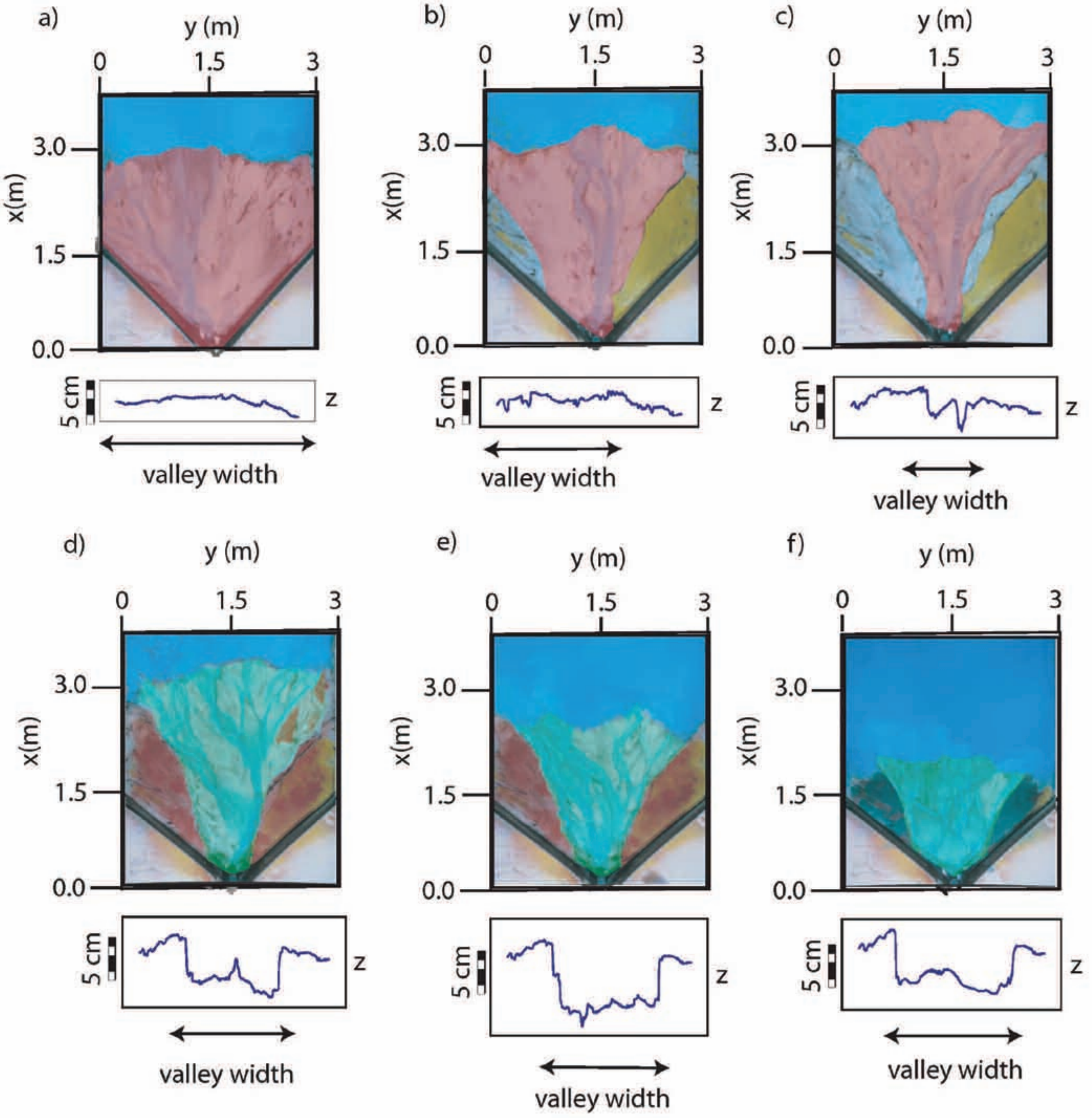

Figure 2. Maps of incised valleys in plan view and topographic profiles of the experimental deposit surface (at a downstream distance of x = 2000 mm) for the falling and rising stages of the isolated rapid eustatic sea level cycle a) before the eustatic sea level cycle began, b) 3 hours into the eustatic sea level cycle fall, c) 4.5 hours into the isolated eustatic sea level cycle fall, when the rate of relative sea level fall was greatest, d) 9 hours into the eustatic sea level cycle fall at the end of the fall, e) 3 hours into the eustatic sea level cycle rise, f) the end of the eustatic sea level cycle rise. The valley is mapped in red for the falling and in green for the rising stages of the sea level cycle.

upstream-supplied sediment and sediment supplied by valley wall erosion. At the end of the RSL cycle rise an unconformable surface in the shape of a valley is visible in the subsurface (Fig. 4g). This widened erosional surface, preserved in stratigraphic strike section as an erosionally bounded fill, forms due to a series of widening and filling events during the decelerating-fall and rising phases of RSL. These apparent "valley walls" visible in strike section comprise a highly diachronous erosional surface that does not represent any paleogeomorphic surface that existed during the evolution of the valley; in particular, it is wider and has lower sidewall gradients than any synoptic valley.

CONCLUSIONS

What is preserved in the sedimentary record after the incised valley fills is the outline of a valley that never existed in the landscape. The

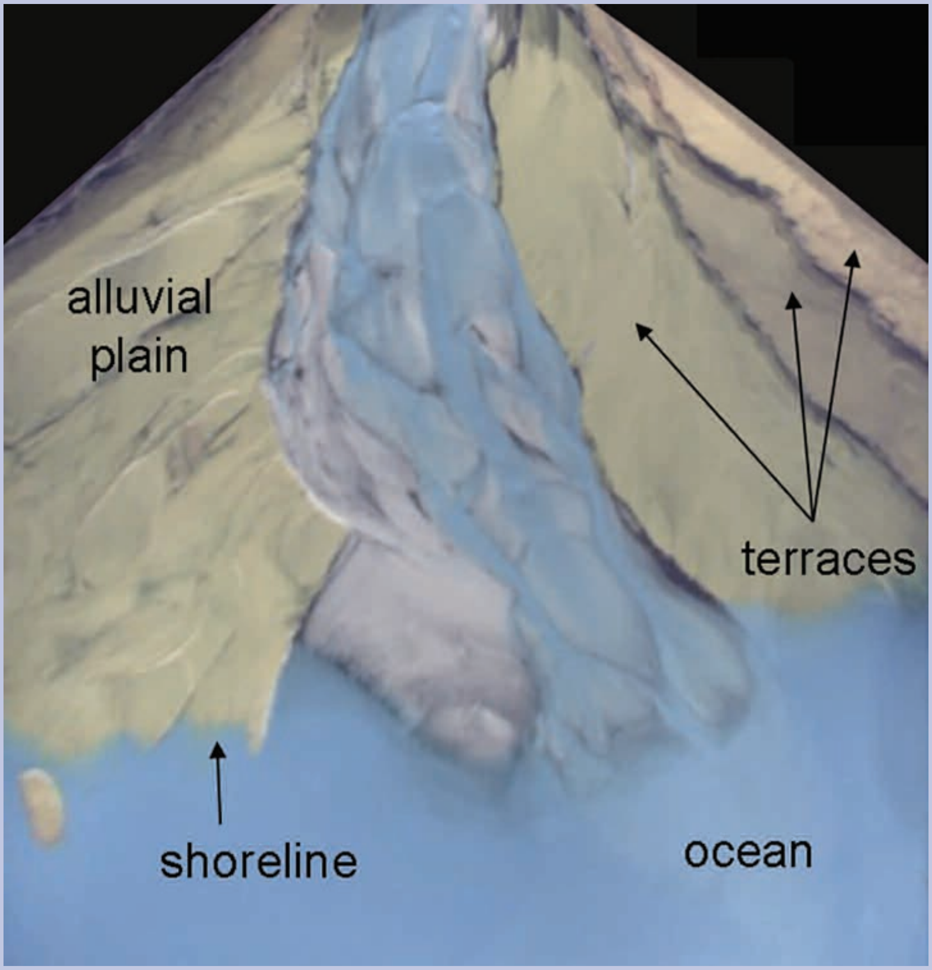

Figure 3. Incised valley in the experimental landscape.

evolution of the incised valley during the sea level cycle is represented in the stratigraphic record by a composite surface formed during numerous widening and filling events, representing the superposition of autogenic deposition and incision on overall allogenic valley cutting and filling.

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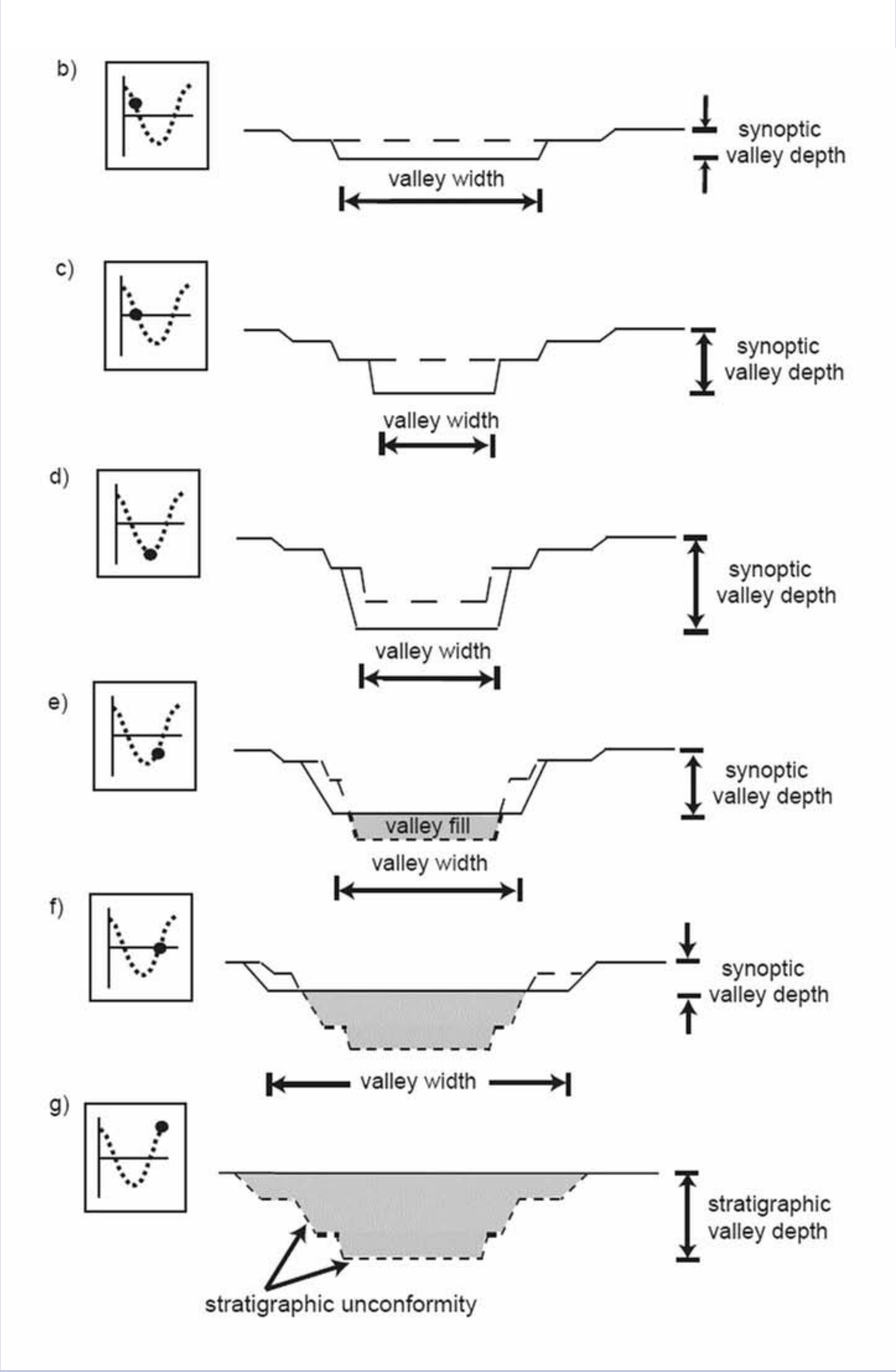

Figure 4. Hypothetical incised valley evolution in response to falling and rising RSL.

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The awards listed below were earned from presentations at the SEPM Annual Meeting in Houston, Texas, April 2006. The awardees will be recognized at the SEPM Annual Meeting in 2007.

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Honorable Mention:
Mark Rowan and K. Inman, *Shallow and Deep Structural Provinces of the Northern Gulf of Mexico*

Poster Presentation: (3 way tie)
Lisa Ashabranner, R. C. Shipp, and N. B. Stillman, *A Mass Transport Fairway in Block BS-4, Santos Basin, Deepwater Brazil: Implications for Field Development*

William Dawson and W. R. Almon, *Shale Facies and Seal Variability in Deepwater Depositional Systems*

Linda Hinnov, *CHRONOS Cyclostratigraphy Tools: Astronomical Calibration of Geologic Time at 0.02 to 0.40 Myr Resolution*

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