DEM: Normal faulting 1. The effect of syn-kinematic sedimentation on faulting in pre- and syn-kinematic layers

An understanding of the interaction between sedimentation and fault displacement and resulting stratigraphy is key to improve interpretation of seismic data. A modification of one parameter such as sedimentation impacts fault propagation in the syn-tectonic stratigraphy and, as a result, local accommodation space and subsequent deposition locations creating variation in overburden thickness which then affects faulting in the pre- and syn-tectonic layers. A complicated feedback loop (chicken and egg situation) that is sometimes hard to unravel. Here, the relationship between changes in sedimentation and the resulting stratigraphy and faults in both pre- and syn-tectonic sedimentation during basement fault propagation is shown. This is investigated in relation to a pair of domino faults with constant displacement.

The intention of this data is not to provide full interpretation and discussion of the results but to provide an indication of the complexity within observed stratigraphy when only sedimentation changes. When presented with only a static representation of stratigraphy it is sometimes tricky to understand what is observed, hopefully these movies and images will help.

A discrete element modelling method is used where the media has dimensions of 400x40 units containing 35,475 circular elements with radii varying between 0.25-0.50 unit. Elements interact as though connected by breakable elastic springs, where each link is assigned unique properties to introduce heterogeneity into the system (**Figure 1**). The initial breaking strain of the link between a pair of elements is defined as a percentage of the length (Re) that separates them (bst).

These experiments investigate the effect of deposition of sediment on faulting in both pre- and syn-tectonic layers. There is no variation in the strength of these layers. Sediment is added at intervals by placing elements to fill all empty space below a defined sea level. Elements that represent sediment are taken from a set of five files (dimensions: 750 x 4 units) with radii varying between 0.25-0.35 unit. Each file is selected at random and all elements that do not overlap existing ones by >15% of their summed radii are deposited. This ensures that elements deposited in each sediment layer do not have aligned weaknesses. A sixth file is then used with radii of 0.15-0.40 units to fill remaining void space.

There are a host of parameters that can be modified in these experiments for example; the material properties and number of pre-kinematic layers, fault number, spacing and dip, displacement rates and timing, sedimentation fill rate and properties, sea level changes and deposition of deltas (with varying foreslope dip and prograding, aggrading and retrogradational fills).

Results of experiments with varying amounts of sediment deposited per interval are presented, all other parameters are constant. Sedimentation starts at an initial height of 35 units (after pre-tectonic layers have settled to gravity) and is modified according to parameters in **Table 1.** Experiments run to 3,000,000 timesteps and sediment is input 25 times (every 120,000 timesteps), divided into 5 intervals. Initially the fault planes dip at 50^{o} which rotate to 33^{o} at the end of an experiment. **Figure 2** shows the height of the sediment layers graphically against deposit number where the deposition is:

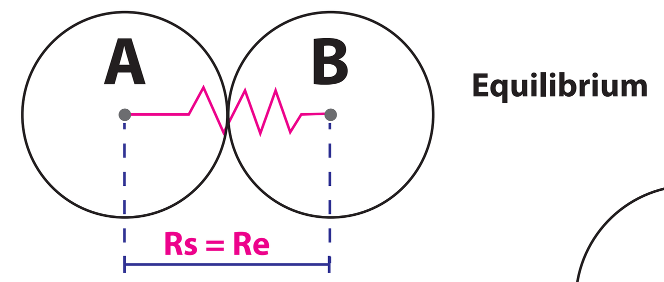
(a) constant,

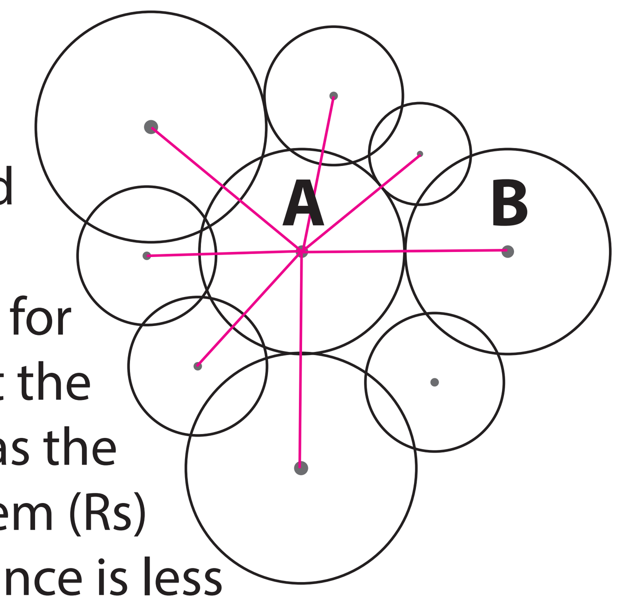
(b) rising or falling

(c) rising to interval 3 and then falling or vice versa, and

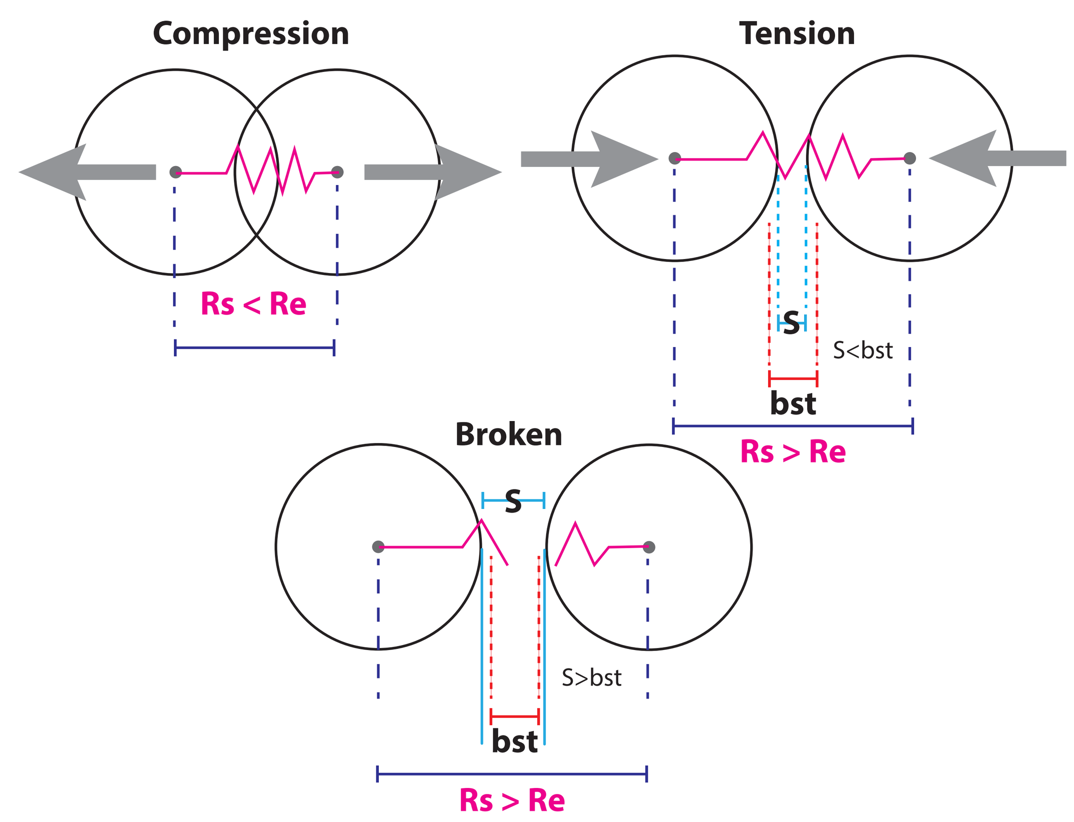
(d) in alternating intervals starting of 0.0 and 1.0 unit.

Data is output every 40,000 timesteps to generate movies (Time: 1 to Time: 75). **Table 2** shows the correlation between the number of timesteps, output time and deposit number.





Elements are connected by a breakable elastic spring. Equilibrium (Re) for an element pair is set at the start of an experiment as the separation between them (Rs) providing that the distance is less than their radii summed. In a media with elements of varying size this is set as the initial separation regardless of radii. This puts the inital media in a stable equilibrium.



Once an experiment starts the bonds around an element act to try and bring the links back to their equilibrium position through compressional (push the elements apart, Rs<Re) and tensional (pull the elements back together, Rs>Re) forces. If the separation (S) between an element pair in tension is less than a defined breaking strain/distance (bst) then the force acts to bring them back to the equilibrium separation. This is unique for each bond pair. If this distance is exceeded (S>bst), the bond is broken and no tensional force is experienced on the bond but a compressional one is permitted when the Rs<Re. The force exerted on an element is the sum of the forces on each bond multipled by the strength of the spring.

The constitutive equations of the modelling can be found in the following publication:

Discrete-element modelling of extensional fault-propagation folding above rigid basement fault blocks
E Finch, S Hardy, R Gawthorpe
Basin research 16 (4), 467-488
DOI:
https://doi.org/10.1111/j.1365-2117.2004.00241.x

Figure 1

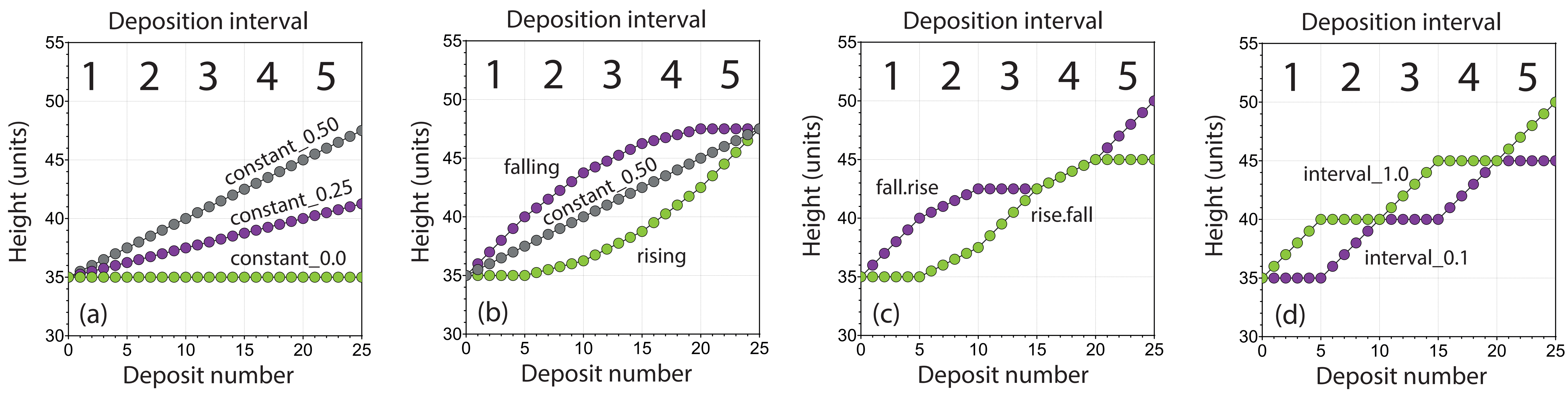


Figure 2

Examples of output from experiments are shown in **Figure 3**, where in **(a)** it is presented coloured to the 25 depositional layers with pre-kinematic layers coloured green and grey and syn-kinematic sediment coloured in shades of blue and yellow alternating by interval, and **(b)** the pre-kinematic layers are coloured in shades of grey and syn-kinematic sediment is coloured by interval.

Comparison between fault geometries of experiments (a) and (b) are shown in **Figures 4** (individual layers) **and 5** (intervals)**.** Similarly experiment sets (c) and (d) are shown in **Figures 6** (individual layers) **and 7** (intervals)**.**

Files **NF.layers.pdf and NF.intervals.pdf** comprise of individual pages of figures showing the relationship between faults in the pre-kinematic layers and sediment at the end of each interval both for individual layers and the five intervals.

The movies are named according to Table 1.

Table 1

		height change per deposit (unit)				
	Interval	**1**	**2**	**3**	**4**	**5**
(a)	constant_0.0	0.00	0.00	0.00	0.00	0.00
	constant_0.25	0.25	0.25	0.25	0.25	0.25
	constant_0.50	0.50	0.50	0.50	0.50	0.50
(b)	rising	0.00	0.25	0.50	0.75	1.00
	falling	1.00	0.75	0.50	0.25	0.00
(c)	rise.fall	0.00	0.50	1.00	0.50	0.00
	fall.rise	1.00	0.50	0.00	0.50	1.00
(d)	interval_1.0	1.00	0.00	1.00	0.00	1.00
	interval_0.1	0.00	1.00	0.00	1.00	0.00

Table 2

End of Interval	1	2	3	4	5
Timesteps (million)	0.6	1.2	1.8	2.4	3.0
Output time	15	30	45	60	75
Deposit number	5	10	15	20	25

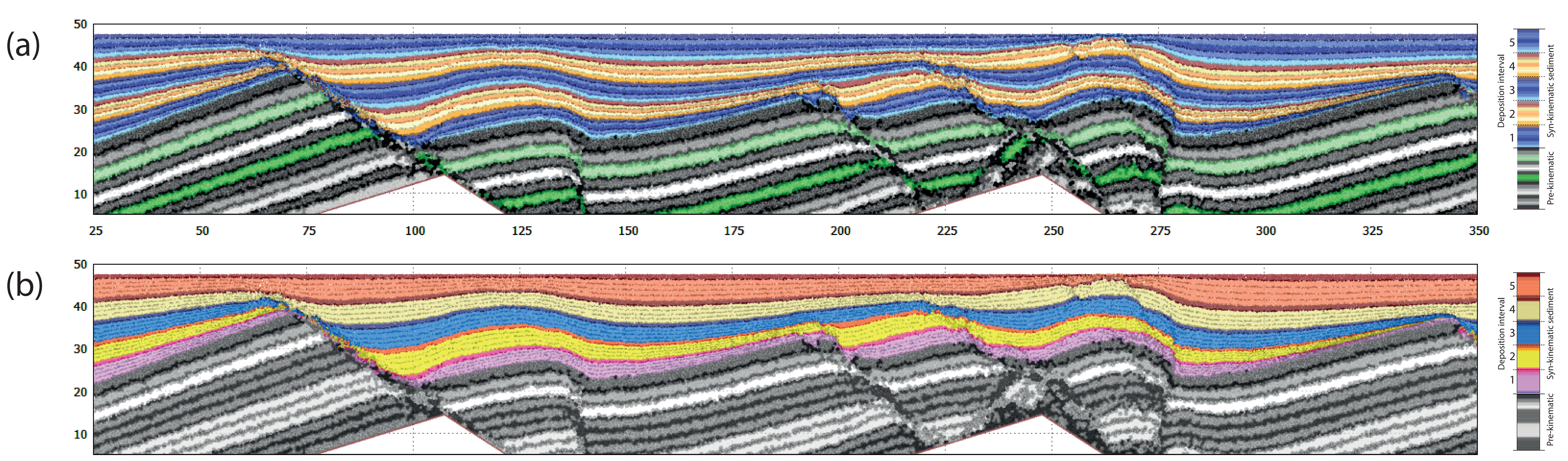


Figure 3

Figure 4 Comparison between the final geometry of experiments with interpreted faults showing 25 individual layers of fill with (a) a static deposition level, rising deposition levels of (b) 0.25 unit and (c) 0.5 unit, (d) rising, and (e) falling levels. Pre-kinematic layers and coloured green/grey and syn-kinematic sediments are in alternating intervals shaded blue and yellow. The total fill level is the same for the constant_0.5 (c), rising (d) and falling (e) experiments but the amount of fill per interval changes resulting in different faults in the pre- and syn-kinematic sediments. N: is the final number of elements in the experiment.

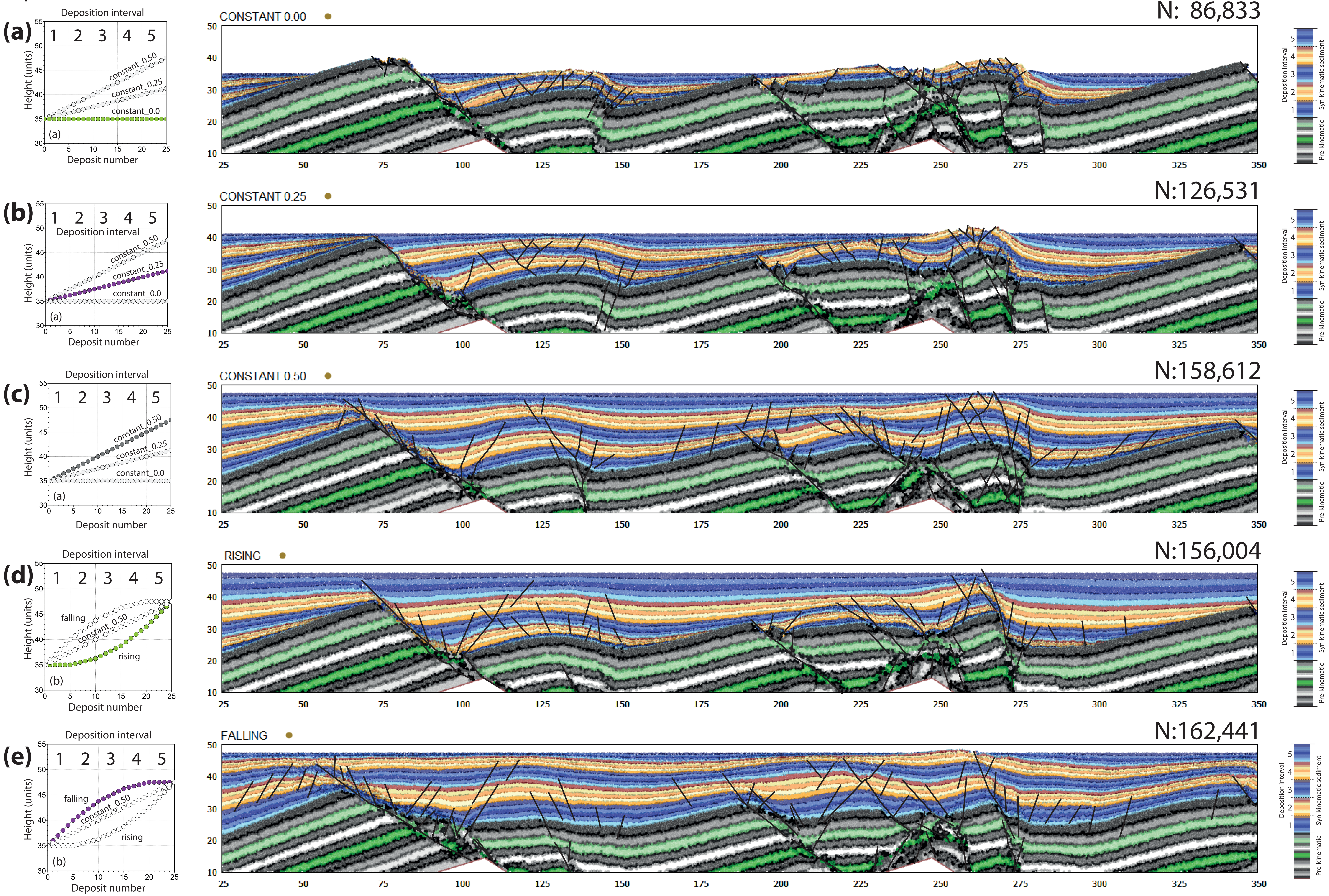


Figure 5 Comparison between the final geometry of experiments with interpreted faults showing five intervals of fill with (a) a static deposition level, rising deposition levels of (b) 0.25 unit and (c) 0.5 unit, (d) rising, and (e) falling levels. Pre-kinematic layers and coloured grey and syn-kinematic sediments are in coloured by interval. The total fill level is the same for the constant_0.5 (c), rising (d) and falling (e) experiments but the amount of fill per interval changes resulting in different faults in the pre- and syn-kinematic sediments. N: is the final number of elements in the experiment.

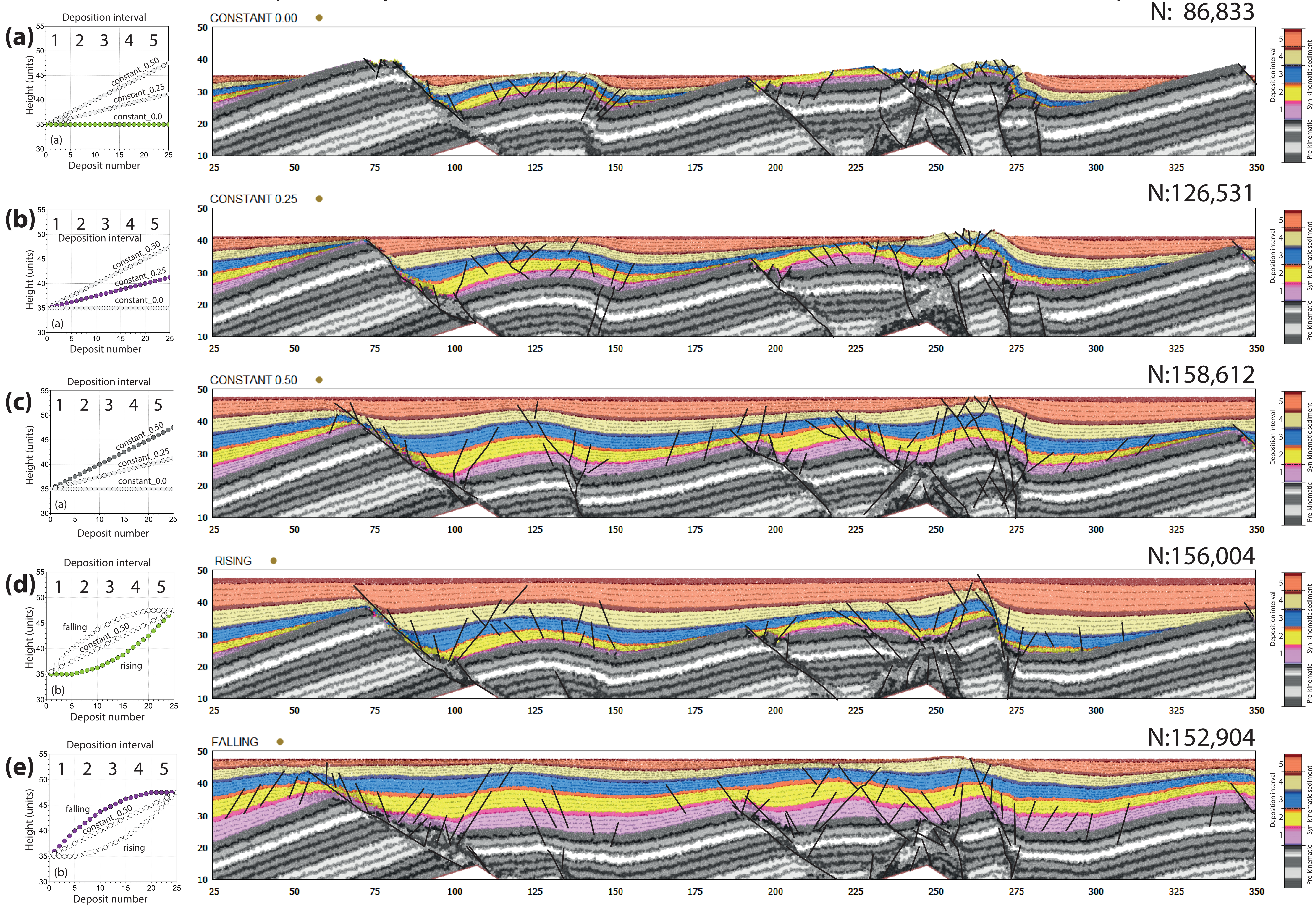


Figure 6 Comparison between the final geometry of experiments with interpreted faults showing 25 individual layers of sediment fill where it (a) rises and falls, (b) falls and rises, (c) has alternating intervals of 1.0 and 0.0 and, (d) has alternating intervals of 0.0 and 1.0. Pre-kinematic layers and coloured green/grey and syn-kinematic sediments are in alternating intervals shaded blue and yellow. The total fill level is the same for the fall.rise (b) and interval_1.0 (c) experiments and similarly for the rise.fall (a) and interval_0.1 (d) experiments. N: is the final number of elements in the experiment.

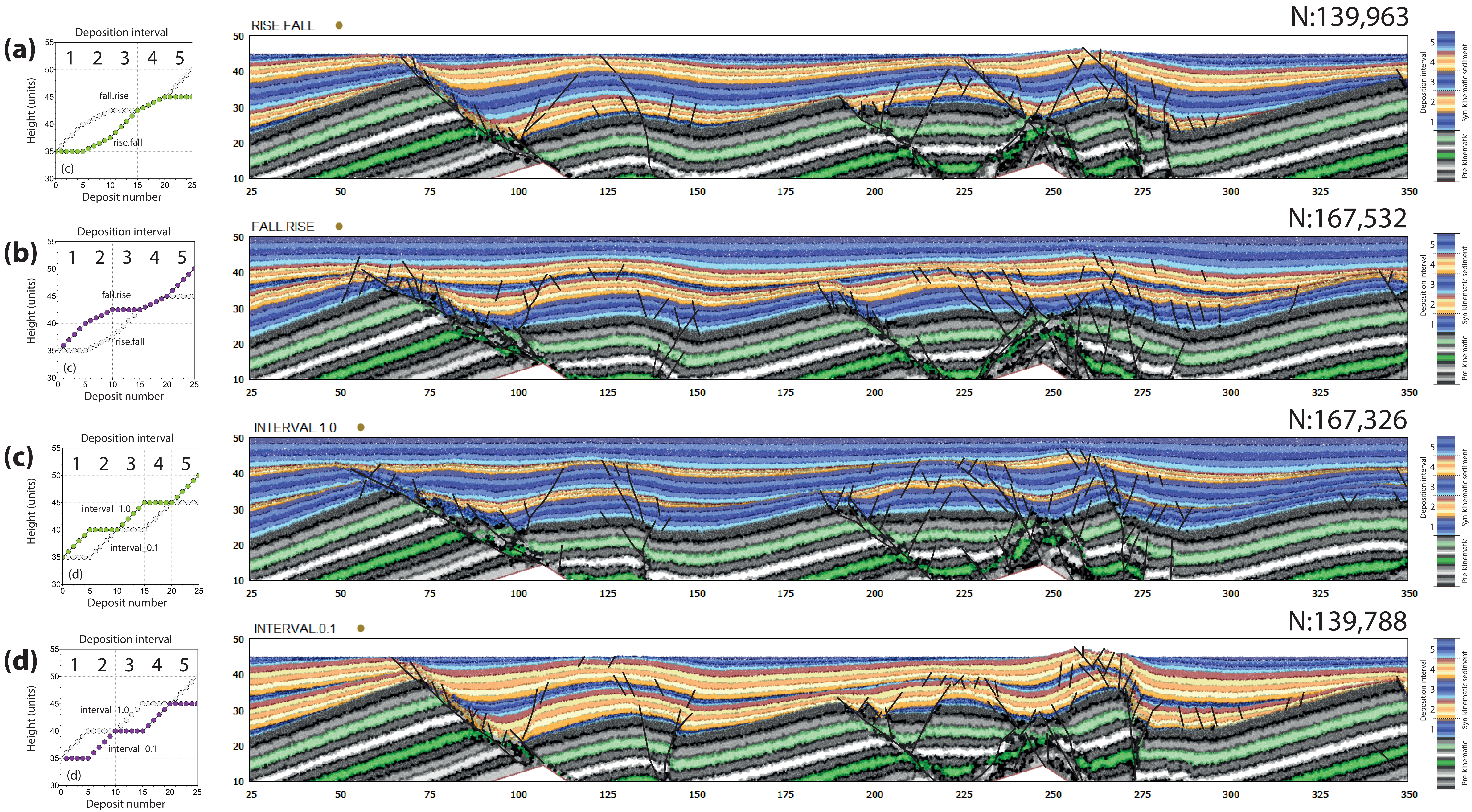


Figure 7 Comparison between the final geometry of experiments with interpreted faults showing five intervals of sediment fill where it (a) rises and falls, (b) falls and rises, (c) has alternating intervals of 1.0 and 0.0 and, (d) has alternating intervals of 0.0 and 1.0. Pre-kinematic layers and coloured green/grey and syn-kinematic sediments are in alternating intervals shaded blue and yellow. The total fill level is the same for the fall.rise (b) and interval_1.0 (c) experiments and similarly for the rise.fall (a) and interval_0.1 (d) experiments. N: is the final number of elements in the experiment.