

APPLICATION OF BED THICKNESS DISTRIBUTIONS IN TURBIDITE DEPOSITS OF LEMNOS ISLAND, NE GREECE

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Abstract

The submarine fan deposits in Lemnos Island, of the NE Greece provide a perfect opportunity to investigate the influence of processes such as erosion and bed amalgamation in the alternation of the shape of a power-law cumulative frequency distribution. The bed thickness distribution in two outcrops of late Eocene to early Oligocene turbidite deposits that correspond to different sub-environment, has been assessed statistically. Sediments of the outcrop 1 at the SE parts of the Lemnos Island interpreted as outer fan deposits and sediments of the outcrop 2 located at the NE parts of the island as inner fan deposits show both a good fit to the power-law, amplifying the hypothesis that departures from power-law statistics might be used as evidence of erosion and bed amalgamation. The main difference between these two outcrops is that the power law exponent decreases abruptly from outcrop 1 to outcrop 2, confirming with the aspect that the power law exponent can be considered as a good indicator for the available sedimentary space.

Key words: submarine fan, turbidites, bed thickness, power-law.

Περίληψη

Οι αποθέσεις υποθαλασσιών ριπιδίων στο νησί της Λήμνου, στην ΒΑ Ελλάδα, παρέχουν μια πρώτης τάξεως ευκαιρία για την διερεύνηση της επίδρασης διαδικασιών όπως, η διάβρωση και η συμπαγοποίηση στην αλλαγή του σχήματος μιας κατανομής τύπου power-law. Η κατανομή των παχών σε δύο φυσικές τομές τουρβιδιτικών αποθέσεων ηλικίας Av. Ηωκαίνου-Κ. Ολιγοκαίνου προσδιορίστηκαν στατιστικά. Τα ιζήματα της τομής 1 στα ΝΑ τμήματα του νησιού έχουν ερμηνευθεί σαν αποθέσεις εξωτερικού ριπιδίου ενώ τα ιζήματα της τομής 2 σαν αποθέσεις εσωτερικού ριπιδίου. Οι δύο τομές έχουν καλή συσχέτιση με την κατανομή power-law ενισχύοντας την υπόθεση ότι αποκλίσεις από την power-law κατανομή μπορούν να θεωρηθούν σαν ενδείξεις για διάβρωση και συμπαγοποίηση. Η βασική διαφορά των δύο μελετηθέντων φυσικών τομών είναι ότι ο εκθέτης της κατανομής power-law μειώνεται απότομα από την τομή 1 στην τομή 2 επιβεβαιώνοντας την άποψη ότι είναι ανάλογος με τον διαθέσιμο χώρο ιζηματογένεσης.

Λέξεις κλειδιά: Υποθαλάσσιο ριπίδιο, τουρβιδίτες, πάχος στρωμάτων, power-law κατανομές.

1. Introduction-Geological setting

Distinctions between depositional environments are an essential component in basin analysis. The thickness of a turbidite bed in a particular point within a sedimentary basin is determined by the shape of the bed and the distance of the source. The shape of the bed depends upon factors such as initial sediment volume, grain size(s) and flow concentration (Middleton and Neale 1989, Rothman and Grotzinger 1995, Malinverno 1997, Carlson and Grotzinger 2001).

The frequency distribution of turbidite bed thickness provides informations on flow hydrodynamics and is a useful tool for petroleum reservoir modeling, particularly if thicknesses can be related to sediment volumes (Middleton and Neale 1989, Flint and Bryant 1993, Rothman and Grotzinger 1996, Malinverno 1997, Carlson and Grotzinger 2001). The bed thickness values, measured along a vertical succession, follow a power-law trend in their spatial distribution (Hiscott *et al.* 1992, Rothman *et al.* 1994, Rothman and Grotzinger 1996, Malinverno 1997, Carlson and Grotzinger 2001). Departures from power-law statistics between several sub-environments owe to sedimentary processes such as erosion and bed amalgamation (Rothman *et al.* 1994).

The study area is located in the NE Aegean (Fig. 1A). The sedimentological evolution of the Lemnos area is based on the geological mapping that was carried out by Roussos (1993) (Fig. 1B). From upper Eocene to lower Oligocene in Lemnos Island, Greece, submarine fan deposits and shelf deposits were accumulated with shelf deposits overlying the submarine fans (unit 1-4, figs. 1B, 1C) (Maravelis *et al.* 2006). The depositional processes were grain flows, debris flows and low, medium and high-density turbidity currents whereas the recognized sedimentary facies were classified as inner-fan, mid-fan and outer-fan deposits (Maravelis *et al.* 2006).

The aims of this paper are: (i) to highlight on how power-law cumulative frequency distributions can applied both on proximal and distal turbidite deposits and (ii) to use these results in order to establish the basin geometry evolution of Lemnos Island.

2. Methodology

The two data sets consist of measured vertical sequences of continuously exposed turbidites (Fig. 2). On account of the inability of distinction between the turbiditic and hemipelagic mud, the measurements were restricted to the arenaceous component. Each discernible sandstone bed was measured although a minimum cut-off of 1 cm was established. In cases where the determination of bed thickness was intractable on account of erosion, a number of measurements of the same bed were realized in order to evaluate the average bed thickness. Moreover, the thickness of each sandstone bed was measured irrespective of whether or not the beds are inferred to represent a single flow or multiple flows that have been amalgamated to form a single bed.

3. Sedimentological analysis

3.1. Outcrop 1:

This outcrop is located at the SE part of the Lemnos Island near the Skandali village (Fig 1). The deep water sediment deposits consist of monotonous alternations of sandstone and claystone beds (Fig. 2A). The majority of the sandstone beds are thin-bedded (< 10 cm) although a few beds with thickness from 20 cm to 33 cm have been found (Fig. 2B). Regular Tb- and Tc- type turbidites (less than 10 % of the measured sandstones beds contained the Ta subdivision of Bouma sequence) are parallel sided and laterally extensive with a few scours and no channels (Figs. 2C, 2D). Beds are almost always flat based, and tops grade into fine sediment (Fig. 2E). Tool marks can easily be found at the bottom of the thicker deposits although scour marks are very rare. The characteristic features of this outcrop demonstrate deposition from both low and high density turbidity currents. The above sediments, deposited in this particular outcrop, were interpreted as outer fan deposits (Maravelis *et al.* 2006).

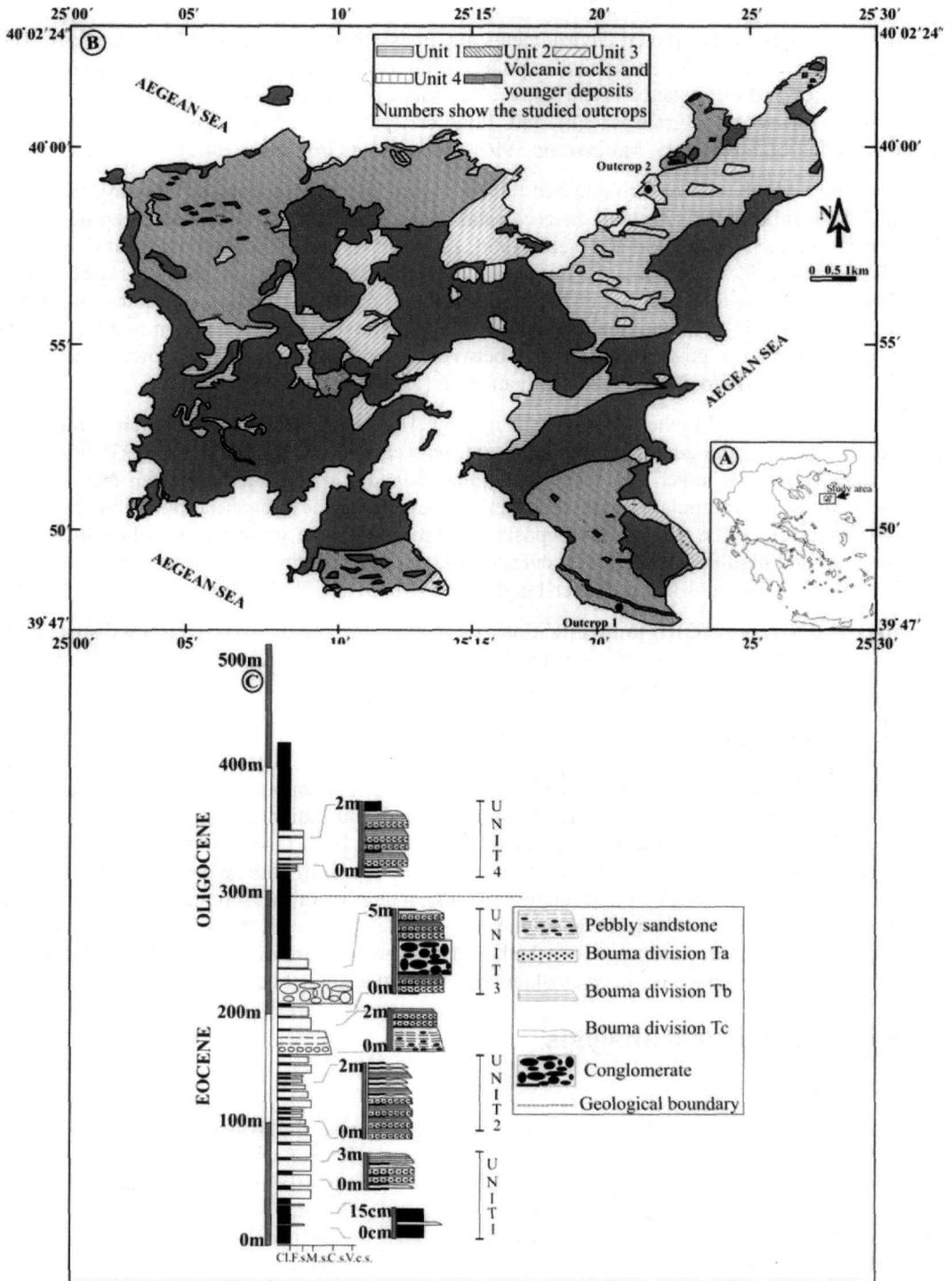


Figure 1 - (A) General location of the study area at the NE Aegean, Greece. (B) Geological map of Lemnos Island. (C) General stratigraphy of the study succession and indication of the main Bouma divisions

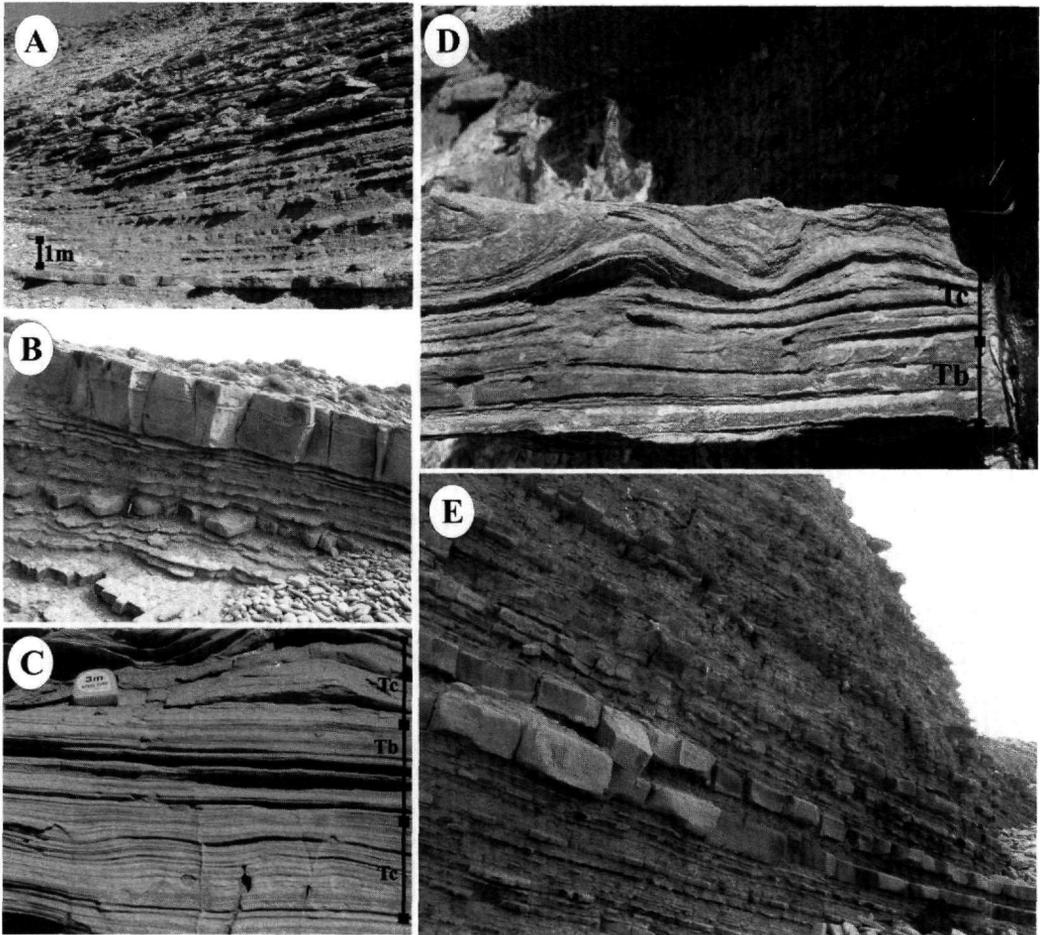


Figure2 - Detailed photographs of the outer fan deposits: (A) Monotonous alternations of sandstone and claystone beds. (B) Medium bedded sandstones in an overall thin bedded succession. (C and D) Regular Tb- and Tc-type turbidites. (E) Sandstones with flat bases in contact with claystones.

3.2. Outcrop 2:

This outcrop is located at the NE part of the Lemnos Island close to the Panagia village (Fig 1). Most of the sandstone beds are thin to medium bedded although a few beds with thickness up to 4 m have been found). Regular Ta- and Tb-type turbidites (less than 10 % of the measured sandstones beds contained the Tc subdivision of Bouma sequence) are parallel sided with bad lateral continuity (Figs 3B, 3C). Beds are almost sharp based although some of the thicker deposits presents erosive bases and tops grade into fine sediment (Fig. 3C). Scour marks can easily be found at the bottom of the thicker deposits. The characteristic features of this outcrop demonstrate deposition from high density turbidity currents. The above sediments deposited in this particular outcrop were interpreted as inner fan deposits and especially channel-fill deposits (Maravelis *et al.* 2006).

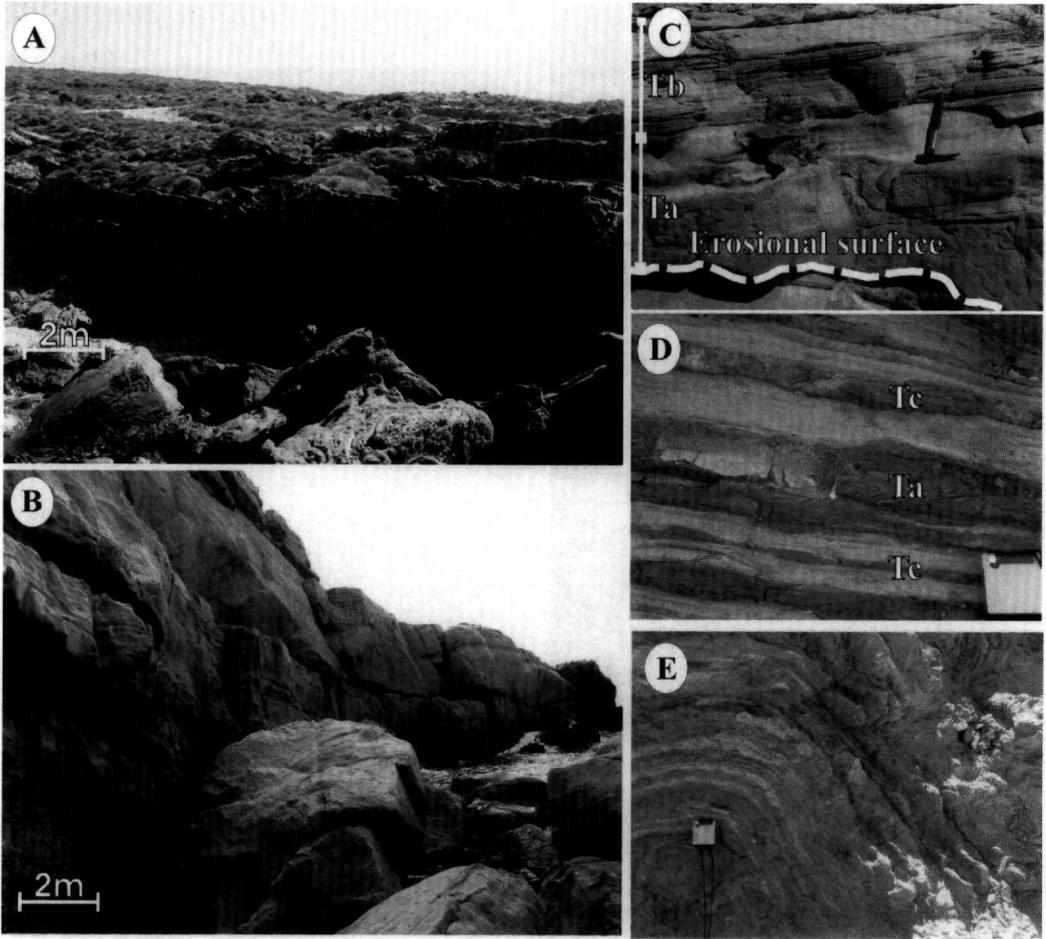


Figure 3 - (A and B) General photographs of the channel-fill. (C) Regular Ta- and Tb-type turbidites and erosional surface at the base of the thicker deposits. (D) Regular Ta- and Tc-type turbidites. (E) Levee deposits

4. Statistical analysis

4.1. Outcrop 1:

In this outcrop, 189 sandstone beds were measured and their log-log values cumulative distribution showed a good fit to the power-law ($R^2 > 0.9$) (Fig. 4) suggesting that erosion and bed amalgamation were not the dominant processes during deposition. Moreover, a high value of power-law exponent (1.33) indicates a broad basin geometry.

4.2. Outcrop 2:

In this outcrop, 58 sandstone beds were measured and the log-log cumulative distribution showed a good fit to the power-law ($R^2 > 0.9$) (Fig. 5) suggesting that erosion and bed amalgamation were not the dominant processes during deposition. Moreover, a low value of power-law exponent (0.73) indicates less broad basin geometry than the outcrop 1. In figure 5 it can be observed that the thickness of two beds is much greater than the rest. This indication could lead to the assumption that excluding these two thick beds, the distribution would be similar to that in outcrop

1. The previous assumption is invalid because if we exclude these two beds the power-law exponent remains low and below unity.

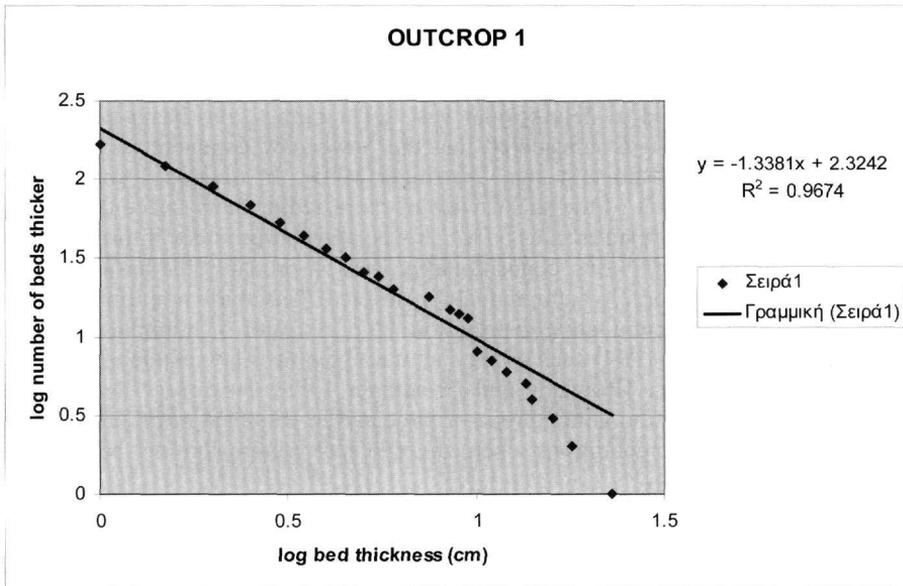


Figure 4 - Log-log bed thickness cumulative distribution of outcrop 1

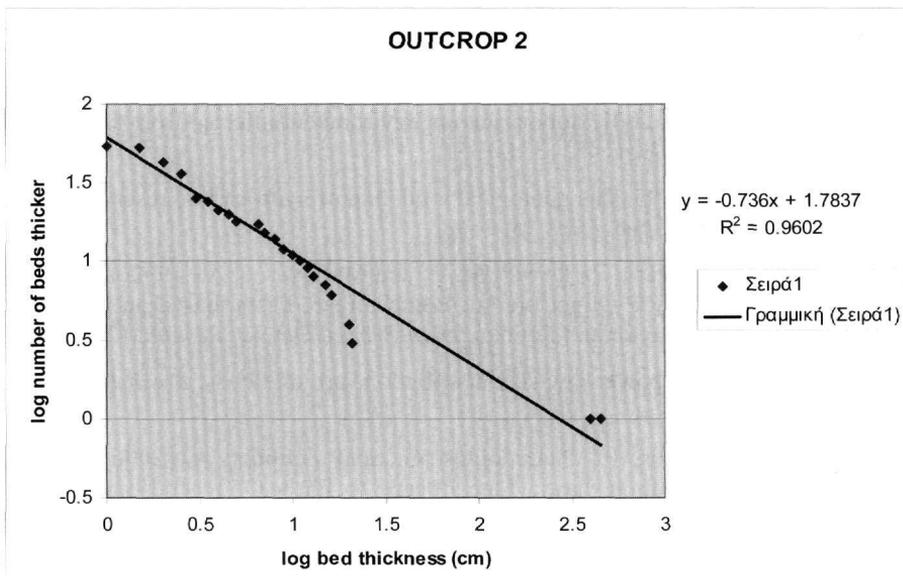


Figure 5 - Log-log bed thickness cumulative distribution of outcrop 2

4. Discussion- Conclusions

The sedimentological analysis in these two outcrops showed that erosion and bed amalgamation were not the dominant factors which controlled the deposition of sediments. Even in the outcrop 2, which has been interpreted as channel-fill deposit, the majority of the sandstone beds presented with flat or sharp bases while the erosion restricted in some of the thicker beds. The statistical analysis showed that the linear fit of the two measured outcrops in the log-log plots show a high

least squares value ($R^2= 0.96$) thus have a good fit to the power-law (Carlson and Grotzinger 2001) corresponding to minimal erosion (Rothman *et al.* 1994). The main difference between these two outcrops is that the power-law exponent decreases abruptly from 1.33 at outcrop 1 to 0.71 at outcrop 2. This difference at the power-law exponent can provide useful information about the variation of turbidite deposition from region to region. It has been hypothesized that changes in the power-law exponent are related to depositional variation ranging from basin geometry to flow types (Rothman *et al.* 1994). It is considered that the power-law exponent is analogous to the available sedimentary space (Rothman and Grotzinger 1995). In outcrop 1 the high value in power-law exponent is the result of the subsistence of more sedimentary space than in outcrop 2 where the turbidity currents formed thicker beds. This conclusion provides information about the basin geometry suggesting that, during depositional processes, probably the basin was broader at the outcrop 1 than at the outcrop 2 which gradually restricted. This study amplifies the theory that the existence of a power-law cumulative distribution is an indicator of minimal erosion and bed amalgamation (Rothman *et al.* 1994) such as the fact that the power-law exponent is analogous to the available sedimentary space (Rothman and Grotzinger 1995). However, the presence of the power-law cumulative distribution although is not indicated in Rothman *et al.* (1994), this model could be applicable in specific conditions where the effect of the erosion and bed amalgamation was not of great importance.

5. Acknowledgments

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