Progradation Rates of Marine Deltas Influenced by Longshore Currents - Numerical Modeling*

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Abstract

Stable to falling sea-level or increasing sediment supply shift shorelines basinwards and tend to force deltaic depocentres to the shelf-edge where they become an important source for deep-water sands. As a result, shelf-edge deltas may develop not only during periods of forced regression and lowstand, but also during a time of slow relative sea level rise and highstand when sediment supply to deltas is sufficiently high to exceed rising accommodation.

Recent numerical modeling for stable sediment supply and the present-day relative sea level rise of 2.1 m/kyr rate has indeed shown that many modern deltas appear to be able to cross their entire shelf width within a time range as short as 2.5 - 70 kyr. Factors involved in these simulations include rate of sediment supply, rate of relative sea level rise, shelf and delta gradients and sediment compaction; whilst the role of marine erosion and sediment redistribution have remained unaccounted for. In particular, nearshore circulation may result in the temporary removal of part of the delta sediment, thus significantly slowing delta cross-shelf progradation on a 4th-order cycle scale. The non-cohesive sediment loss for a delta budget due to a longshore flow activity and the impact of this on shelf transit times were modeled for eight modern river deltas (Ebro, Kizil Irmak, Nile, Rio Grande, Brazos, Colorado, Krishna and Orange) based on CERC formula. Results have shown that sediment redistribution by longshore drift alone may lengthen the time of delta progradation to the shelf edge by 4-51 % for 2.1 m/kyr relative sea level rise. The strongest increase of a potential cross-shelf transit time was found for the wave dominated Orange Delta, which enters the open ocean. For deltas facing basins of smaller fetches, storm-intensified coastal erosion can also be a critical factor. For example, inclusion of storm data into simulations for the Ebro Delta resulted in an increase of its initial cross-shelf transit time by 9%.

These preliminary results suggest that 4th-order highstands may be too short in duration for the development of deltas at the shelf edge of broad, passive margin shelves, especially during Icehouse times.

Selected References

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Galloway, W.E., 1975, Process framework for describing the morphologic and stratigraphic evolution of deltaic depositional systems, *in* M.L. Broussard (ed.), Deltas, models for exploration, p. 87-98.

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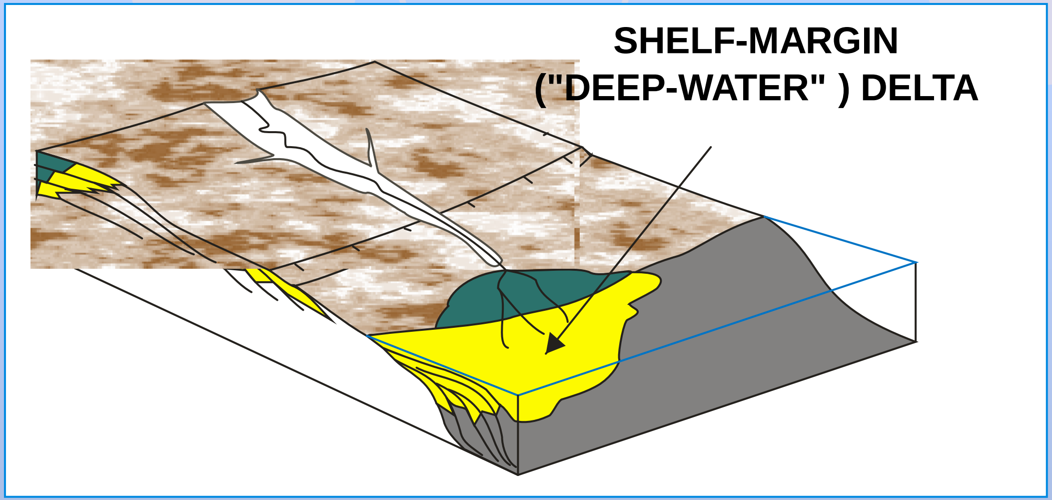
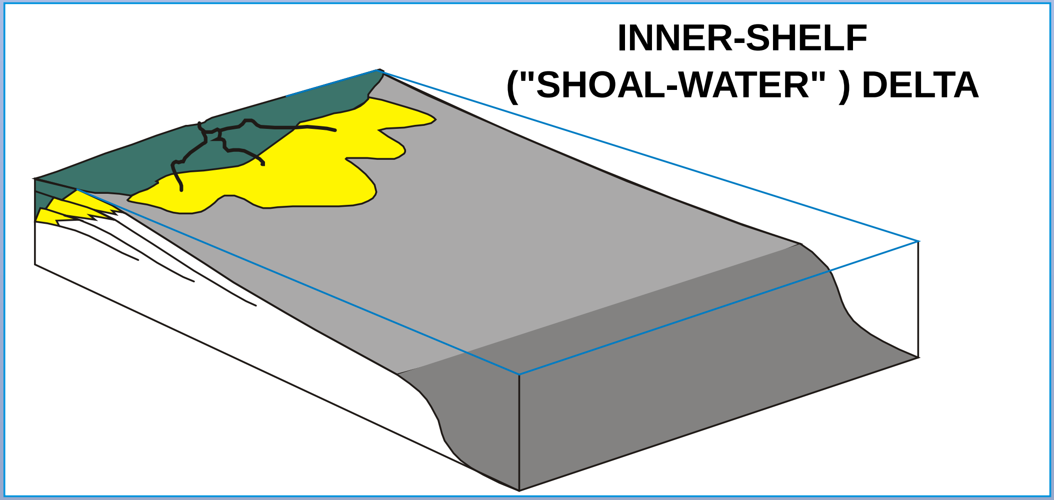
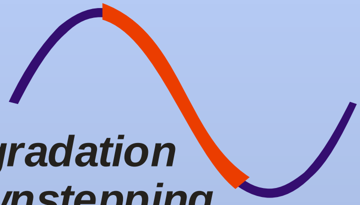
4th order Cycle of Relative Sea-Level





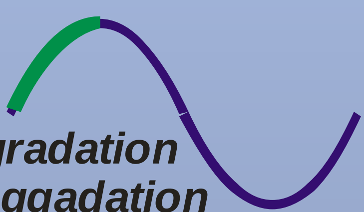
(Porebski & Steel, 2003)

Falling stage



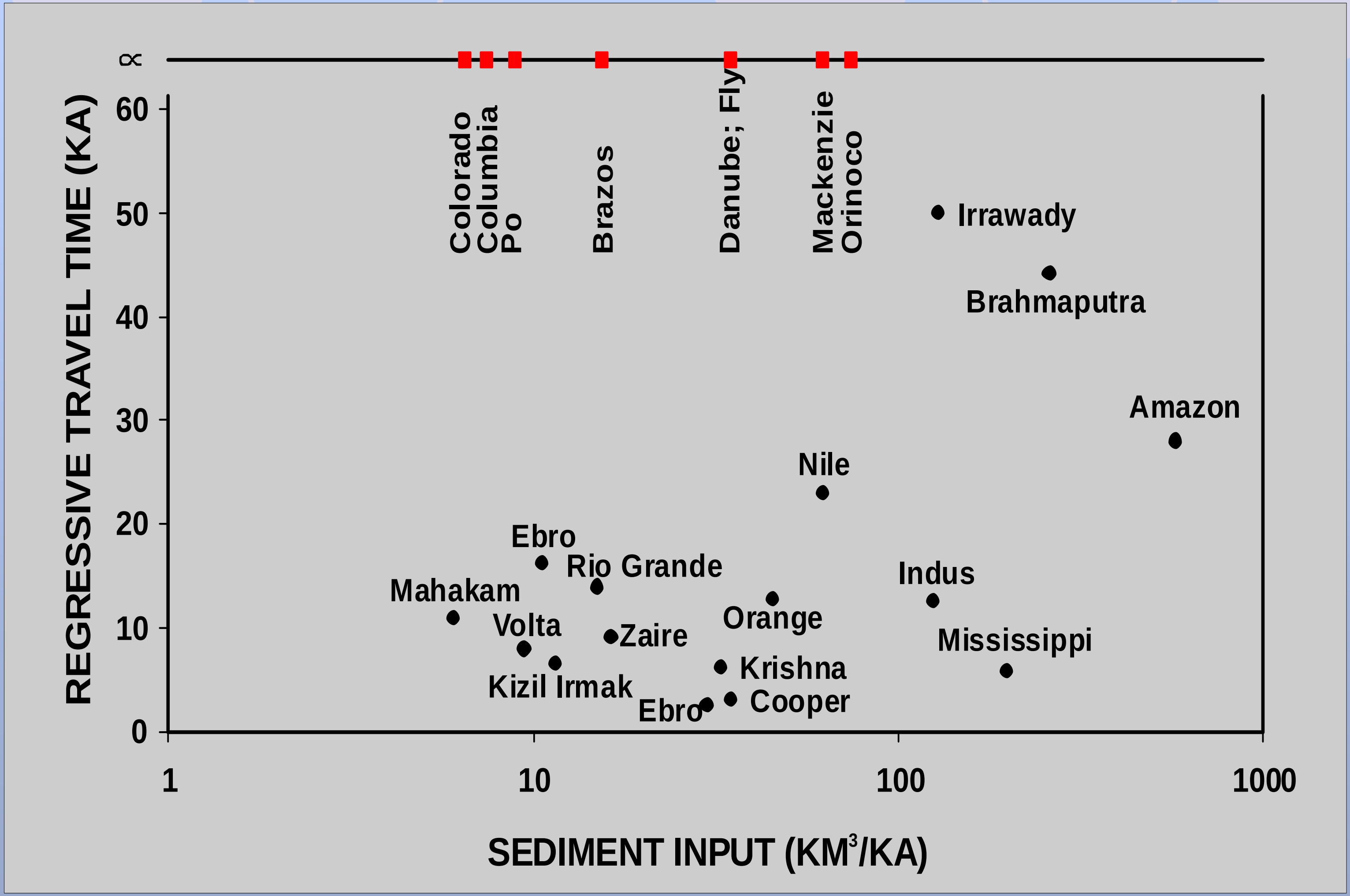
Progradation to downstepping

Highstand



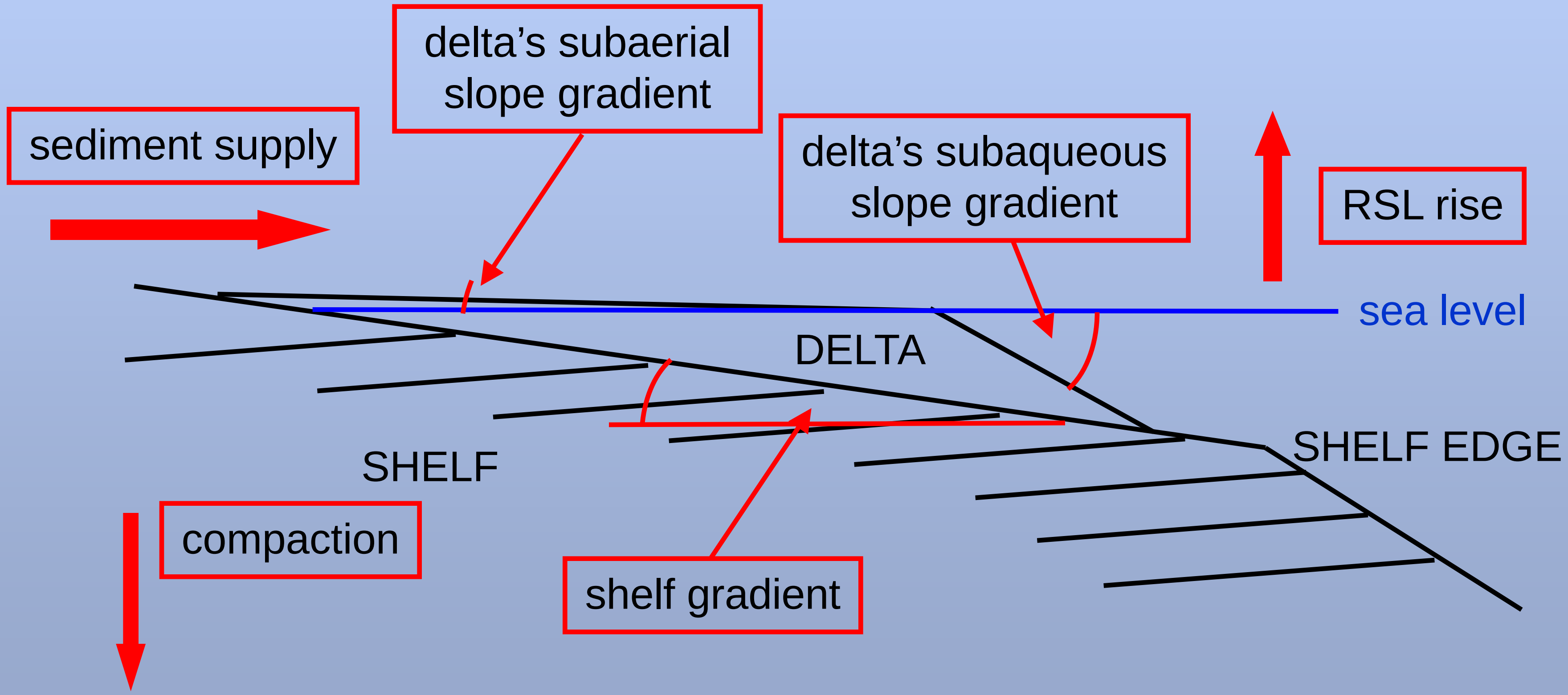
Progradation with aggadation

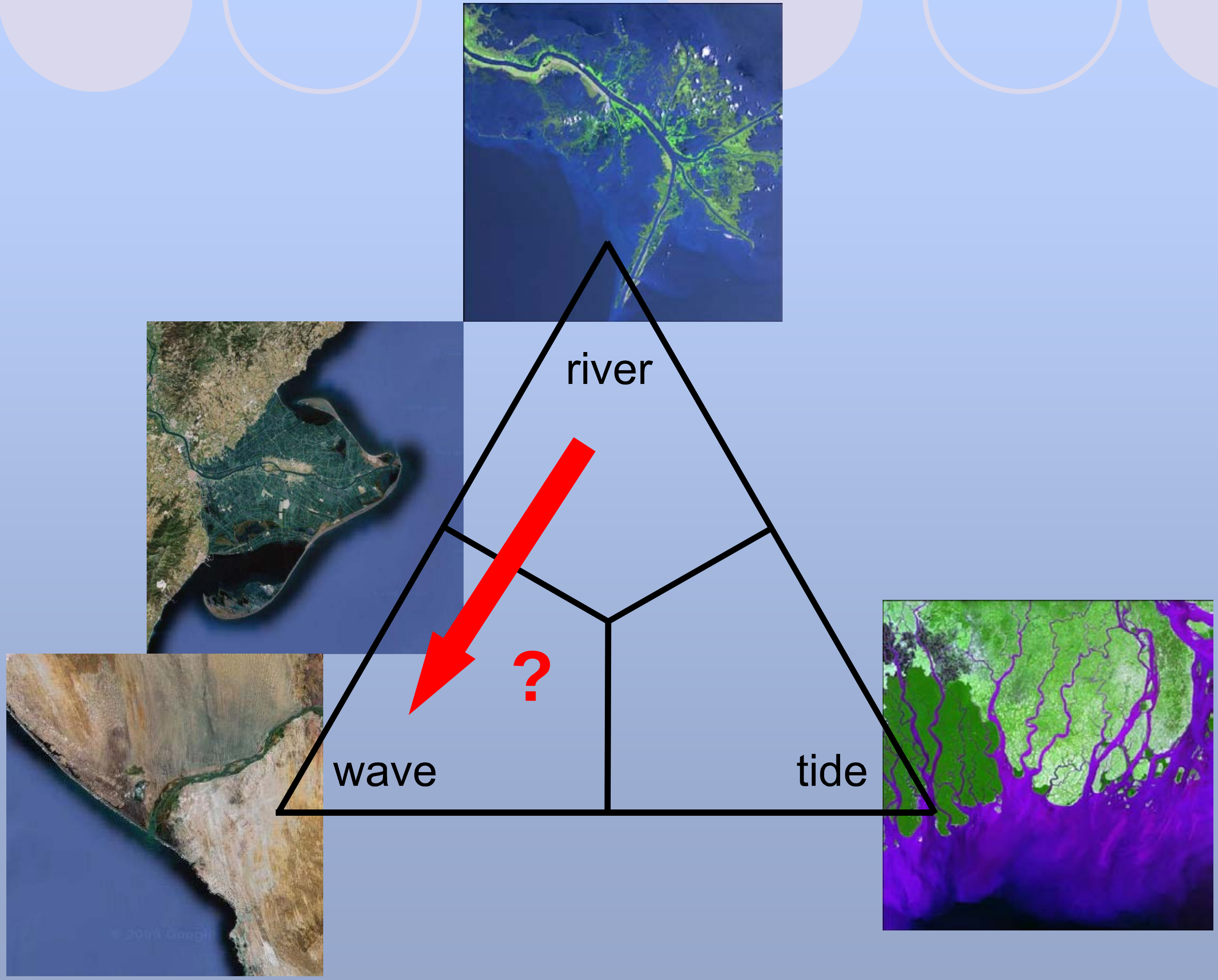
Shelf Transit Times For RSL Rise 2.1 m/ka)



Database: Burgess & Hovius (1998); Calculations: Muto & Steel (2002)

Muto and Steel (2002): Input Parameters





Galloway (1975), www.maps.google.com, NASA/JPL after www.fgmorph.com

Calculations

- longshore transport
  - wave data (H, T, θ), time span of 30 - 40 years
  - potential longshore sediment transport, CERC formula (US Army Corps of Engineers, 2002), N/time

$$I = K\,(EC_g)_b \sin\theta \cos\theta$$

  - volumetric sediment transport, m^3/time

$$Q_L = \frac{I}{(\rho_s - \rho)g(1-n)}$$

  - transformation

$$H_b = H_0\,(\cos\theta_0 / \cos\theta_b)^{1/2}\,(C_{g0} / C_{gb})^{1/2}$$

Calculations

- delta transit time through shelf, t_w
  - Muto & Steel (2002)

$$-At_w \tan\phi + \left(cSt_w\right)^{0,5} \tan\beta\left(\tan\phi\right)^{-1}\left(\tan\beta - \tan\phi\right)^{-1} - W = 0$$

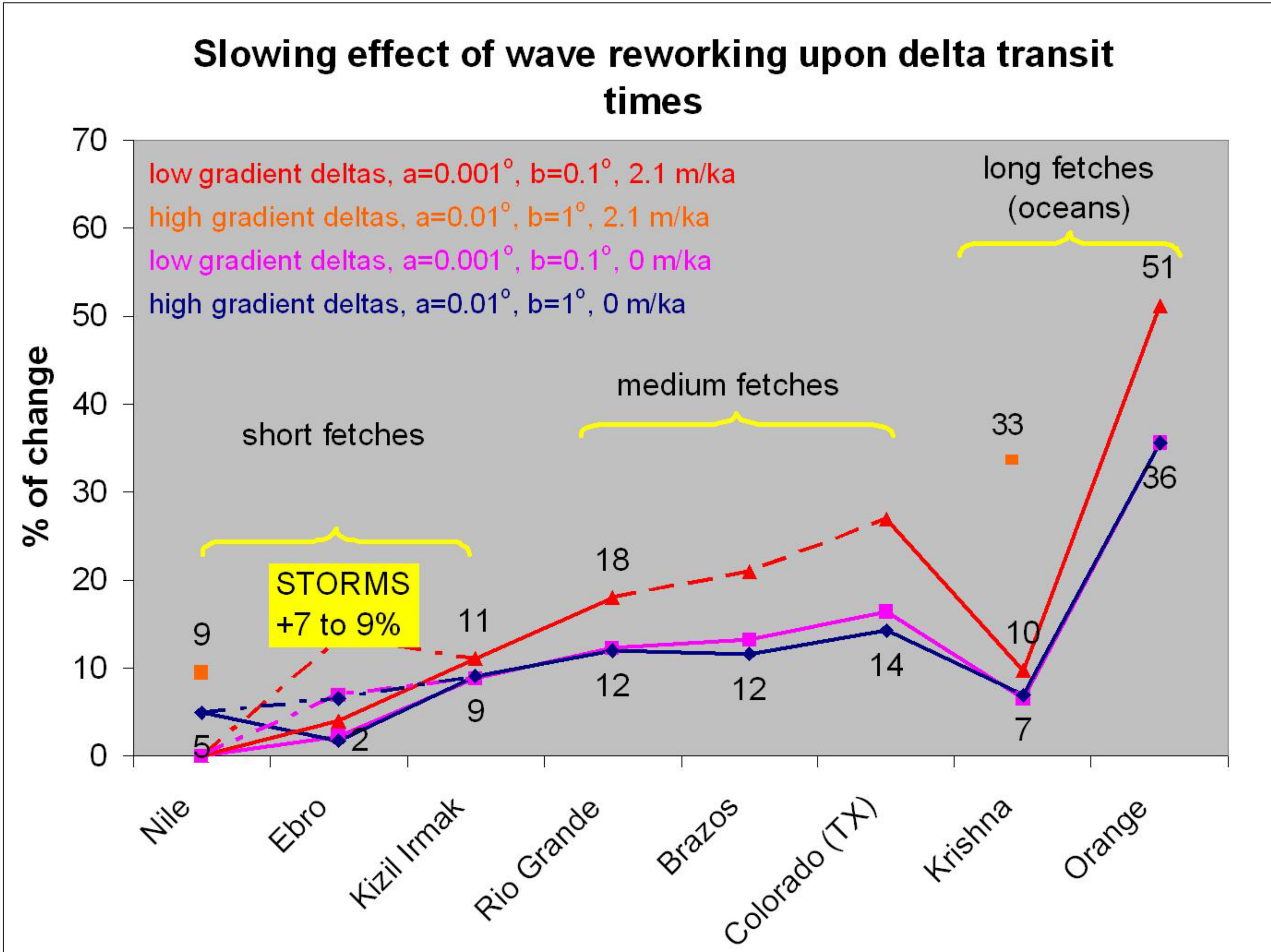
$$c = 2\left(\tan\beta - \tan\phi\right)\left[\left(\frac{\tan\phi}{\tan\beta}\right) - \left(\frac{\tan\alpha}{\tan\beta}\right)\right]\left[1 - \left(\frac{\tan\alpha}{\tan\beta}\right)\right]^{-1}$$

  - Burgess & Hovius (1998)

$$t_W = 1.4\left(\frac{V_s}{Q - Q_T}\right)$$

Results

Delta	Regime	W [km]	ϕ (°)	β min	S (km^2 ka^{-1})	**S_P** (km^2 ka^{-1})	t_W/**t_{WP}**(ka)			
							A=2.1 (mka^{-1})		A=0 (mka^{-1})	
							α=0.001° β=min	α=0.01° β=1°	α=0.001° β=min	α=0.01° β=1°
Nile	wave	50	0.286	0.1	0.223	**0.213**	-	33.8/**37.0**	-	20.5/**21.5**
Ebro	fluvial-wave	70	0.102	0.2	0.214	**0.201**	16.2/**18.35**	∞/∞	10/**10.7**	20.1/**21.4**
Kizil Irmak	wave	35	0.164	0.2	0.063	**0.058**	**6.5/7.22**	∞/∞	5/**5.44**	24.4/**26.6**
Rio Grande	wave	80	0.143	0.2	0.214	**0.191**	13.9/**16.4**	∞/∞	10.6/**11.9**	34/**38.1**
Brazos	wave	140	0.041	0.1	0.221	**0.199**	∞/∞	∞/∞	18.9/**21.4**	39.7/**44.3**
Colorado	wave	105	0.109	0.2	0.093	**0.081**	∞/∞	∞/∞	50.6/**58.9**	109.6/**125.2**
Krishna	fluvial	48	0.096	0.2	0.221	**0.207**	6.2/**6.8**	20.7/**27.5**	4.6/**4.9**	8.7/**9.3**
Orange	wave	180	0.07	0.1	0.591	**0.435**	12.7/**19.2**	∞/∞	10.1/**13.7**	36/**48.8**



Slowing effect of wave reworking upon delta transit times
% of change
0
10
20
30
40
50
60
70
low gradient deltas, a=0.001°, b=0.1°, 2.1 m/ka
high gradient deltas, a=0.01°, b=1°, 2.1 m/ka
low gradient deltas, a=0.001°, b=0.1°, 0 m/ka
high gradient deltas, a=0.01°, b=1°, 0 m/ka
short fetches
medium fetches
long fetches (oceans)
STORMS +7 to 9%
9
5
2
11
9
18
12
12
14
33
10
7
51
36
Nile
Ebro
Kizil Irmak
Rio Grande
Brazos
Colorado (TX)
Krishna
Orange

Highest rate of RSL change allowing delta to reach shelf edge

River	Low gradient deltas			High gradient deltas			
	Shelf transit time (ka)		**RSL**	Shelf transit time (ka)		**RSL**	
	0	2.1	**(m ka^{-1})**	0	2.1	**(m ka^{-1})**	**(%)**
Ebro	11	18	2,9	21	∞	1,5	7
Kizil Irmak	5	7	4,6	27	∞	0,9	8
Rio Grande	12	16	4,2	38	∞	1,3	11
Brazos	21	∞	1,2	44	∞	0,6	11
Colorado	59	∞	0,9	125	∞	0,4	13
Krishna	5	7	4,1	9	28	2,2	6
Orange	14	19	4,0	49	∞	1,1	27

Decrease from 6 – 27 %

Conclusions

- For deltas entering shelves of relatively small or partly protected basins, longshore reworking plays minor role in slowing delta progradation, so that deltas should be able to get to the shelf edge during 4th-order highstands and feed sand reservoirs on the slope. This process could be particularly effective during Greenhouse times.

- For deltas growing onto oceanic shelves subjected to large fetches and shelves affected by frequent storms, longshore reworking may effectively slow down or even halt progradation, thus preventing the delta from reaching the shelf edge during 4th-order highstands. Significant deep-water sand reservoirs may develop only during Icehouse lowstands.