MODELING SHOREFACE AND BARRIER RESPONSE TO SUBSIDENCE EVENTS

Peter Cowell, Coastal Studies Unit, Institute of Marine Science, University of Sydney

ABSTRACT

Simulated evolution of the Long Beach barrier-strand-plain was undertaken using the Shoreface Translation Model (Cowell *et al.*, 1995) to assess the effects and likelihood of shoreface rotation (steepening and deepening of the shoreface), including sequestering by the prograding barrier of sand from the inner shelf (in supplementing sand supplied from the Columbia River via littoral transport); the effects of episodic earthquake-induced subsidence on barrier evolution; and recession estimates for the present coast due to a future seismic event, calibrated against past responses to such events.

Preliminary results suggest that shoreface rotation is a necessary behaviour to obtain observed inner-shelf morphology, and that this makes the time interval between subsidence events more important than event magnitude in governing coastal recession in response to events. Initial, predictive implications are that a) a future subsidence event may cause almost twice as much recession as predicted on the basis of classic Bruun concepts and b) inner-shelf sand source contributed much less that 50 percent toward the strand-plain progradational volume.

A tendency toward deepening of the shoreface over time can be expected where the general depth of the inner-continental shelf is less than a long-term equilibrium (Roy and Cowell, 1998). Although little is known theoretically about shelf equilibrium, new interpretations of shoreface sediment patterns in the context of shoreface evolution, together with evidence from radiometric dating and computer modeling, suggests that the presence of a shoreface ravinement is the result of long-term lowering of the shoreface (Cowell *et al.*, in press). Time-dependent geometric parameters in the Shoreface Translation Model (STM) can simulate rotational deepening and steepening of the shoreface. Such simulation involves increasing the parameter that specifies the seaward depth of the upper shoreface in the STM.

Estimates of progradation rates were used to derive inputs concerning sediment supply based on the work of Woxell (1998). The prehistoric rate of sediment supply was assumed constant (statistically stationary). Based on the geometry of the progradational wedge, the volume rate of deposition in the strand plain before 1200 BP is 13.57 $m^3\ a^{-1}$ per meter of shoreline, decreasing to about 7 $m^3\ a^{-1}\ m^{-1}$ after 1200 BP. Simulated sand supply was assumed to derive from two sources: a) the Columbia River via littoral transport; and b) the inner-continental shelf through the effects of shoreface rotation. Under conditions of invariant shoreface dimensions (classic Bruun assumption), all the sand must be sourced from littoral transport. With shoreface rotation, sand comes from both sources.

Without additional information, we cannot know in advance the proportions supplied from each source since shoreface rotation is controlled in part by the evolution of the strand plain itself (a non-linear problem). Thus, the appropriate littoral sand input can be estimated only through successive iterations of the simulated evolution. The criteria for convergence toward a correct solution for littoral sand supply include replication of a) the progradation width of the strand plain and b) the topographic and stratigraphic geometry measured in the field.

STM simulations of sea-level fluctuations involved sudden subsidence events, followed by full rebound during the next time step (with these successive steps assumed to entail $\Delta t = 0$ and $\Delta t = 100$ years, respectively). Quake magnitude-frequency was based on Atwater and Hemphill-Haley (1997): subsidence magnitudes were assumed proportional to the period of time since the previous event, with a maximum subsidence of 2 m. Stable sea levels were applied in subsequent time steps until the next event. Figure 1 compares simulated strand plains for a) an invariant shoreface with constant shoreface parameters ($h_* = 15$, $L_* = 3000$, $L_o = 2000$, being upper-shoreface depth and width and active width of the lower shoreface, respectively), and b) shoreface rotation with a shoreface deepening during inter-quake periods at a rate of $\Delta h_* = 1$ m per 100 years until the occurrence of the next quake. The invariant-shoreface simulation follows classic Bruun assumptions whereas the rotational-shoreface simulation assumes that the general elevation of the inner-continental shelf surface is shallower than the long-term (order many millennia) equilibrium surface. During each quake for the rotational case, the depth of the upper shoreface was reduced to $h_* = 15$ m to simulate the effects of longer response time, and the infinitesimal time available, for shoreface adjustment in deeper water during a subsidence event.

For the invariant-shoreface simulation, sediment supply was set at 1358 m^3 per 100-year time step (per meter of shoreline) from 4500 BP to 1200 BP, then reducing to 700 m^3 per 100 years from 1200 to 0 BP. These sediment inputs were based on volumetric analysis of the present-day strand plain, and assume that the only source is from the Columbia River (via littoral transport). The imposed sediment input was reduced by 50 percent (as a first guess) for the rotational-shoreface simulation on the assumption that the inner-continental shelf provided an additional sediment source.

The results show that the simulated sediment input was reduced too much for the rotational-shoreface since the strand plain prograded to only 78 percent of its present width (Figure 1b). Thus, further iterations are required with increased sediment input (but these are yet to be undertaken). Animation of the full evolution however shows that the inner-shelf becomes a net source of sediments only well into an inter-event period since, during and immediately after a seismic event, displacement of sand seaward from sub-aerial strangulating goes toward backfilling the sea-floor depression created by earlier shoreface deepening.

The invariant-shoreface simulation produced inner-shelf topography that is inconsistent with the present-day morphology: an unrealistic bulge (clinoform) formed in the prograding shoreface (Figure 1a). Alternative trials with invariant shoreface dimensions of different magnitudes failed to reduce the morphological discrepancy to any significant degree. Nevertheless, since this simulation prograded 8 percent too far, markedly larger shoreface dimensions than any tested may reduce the clinoform and redistribute some of the depositional volume further offshore, thus reducing the sub-aerial volume and extent of the barrier.

Dramatic differences between responses of invariant and rotational shorefaces emerge from the simulations of subsidence events. Subsidence-induced shoreline recession with invariant shorefaces (classic Bruun response) is proportional to the magnitude of the subsidence (*i.e.*, sea-level rise); this response parameter is insensitive to earthquake timing (Figure 2). The opposite is the case with rotational shoreface behaviour, indicating the strongly non-linear effect of event sequencing and sensitivity to antecedent morphology (Figure 3).

The comparative severity of a future seismic-event (2-m subsidence within the next 100 years) for invariant and rotational shorefaces differ significantly (Figure 4). The conventional analysis (classic Bruun) predicts a much smaller recession than if shoreface rotation is a reality. Unfortunately for the local community, model calibration against the long-term coastal evolution suggests that shoreface rotation is more likely to be the governing behaviour. Thus the larger impact prediction should be anticipated.

REFERENCES

Atwater, B. F., and Hemphill-Haley, E. 1997. *Recurrence intervals for great earthquakes of the past 3,500 years at northeastern Willipa Bay, Washington*, U.S. Geological Survey Professional Paper 1576, 108 p.

Cowell, P.J., Roy, P.S., and Jones, R.A. 1995. Simulation of large-scale coastal change using a morphological behaviour model, *Marine Geology*, 126, pp. 45-61.

Cowell, P.J., Roy, P.S., Cleveringa, J. and de Boer, P.L. 1999. Simulating coastal systems tracts using the Shoreface-Translation Model, *International Association of Sedimentologists Special Publication*, Oxford, Blackwell Scientific Pub. (in press).

Woxell, L. K. 1998. *Prehistoric beach accretion rates and long-term response to sediment depletion in the Columbia River littoral system*, USA, M.S. Thesis, Portland State University, Portland, Oregon, 206 p.

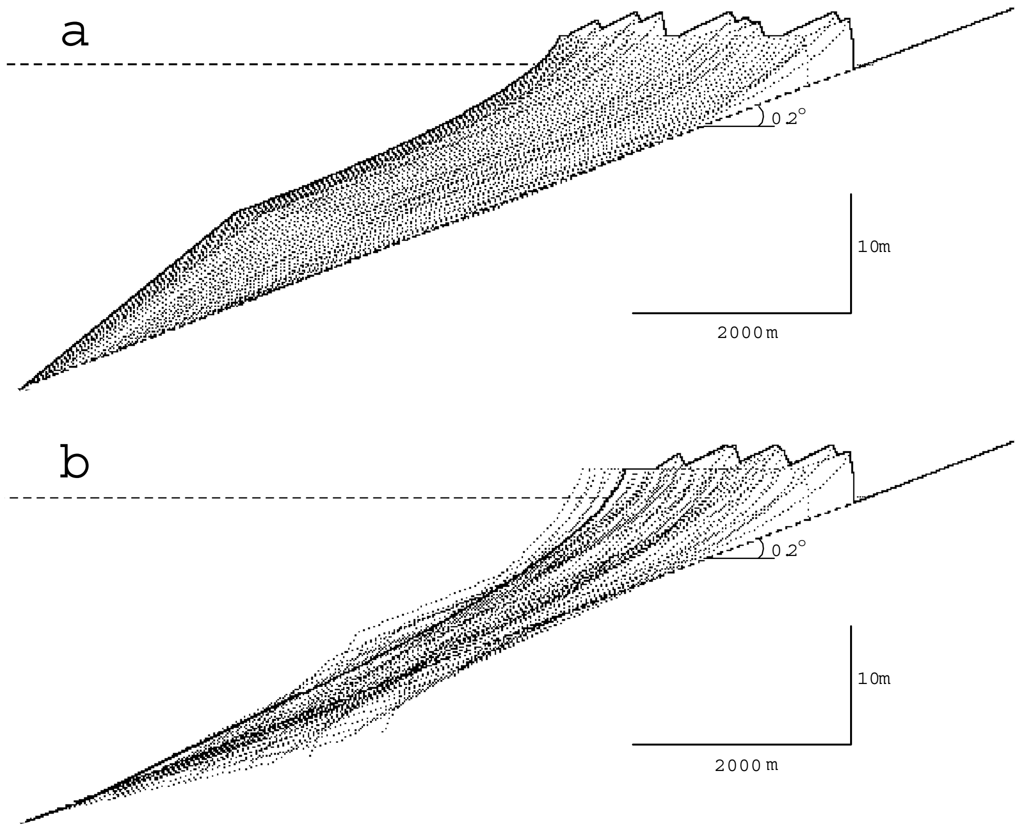

Figure 1. STM simulation of the Long Beach strand plain with a) constant shoreface dimensions (h_* = 15, L_* = 3000, L_o = 2000) and littoral sediment input of 1358 m^3 m^{-1} per 100-year time step (reducing to 700 m^3 m^{-1} after 1200 BP); and b) time-varying shoreface dimensions, causing shoreface rotation, and a littoral sediment input of 676 m^3 m^{-1} per 100-year time step (reducing to 300 m^3 m^{-1} after 1200 BP).

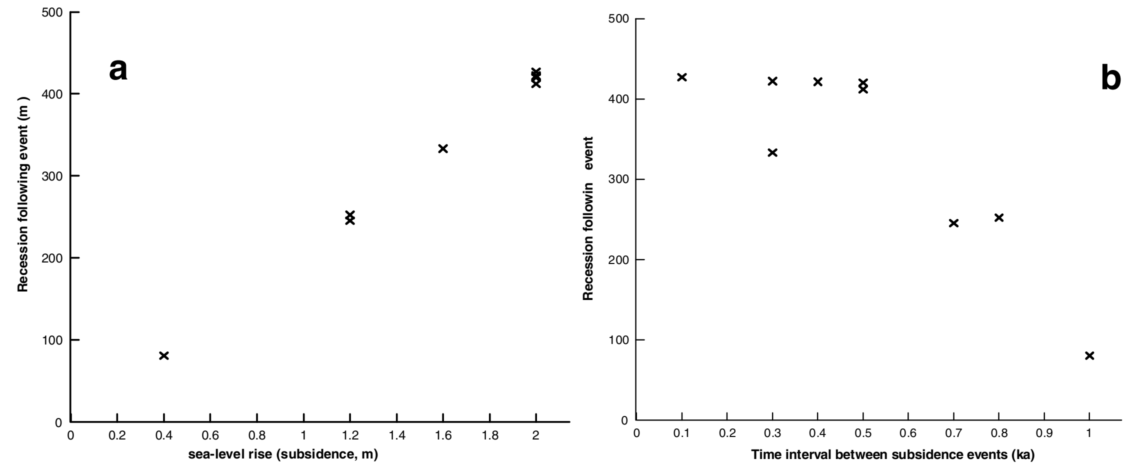

Figure 2. Recession as a function of a) subsidence, and b) the length of time between successive subsidence events, from simulation with invariant shoreface.

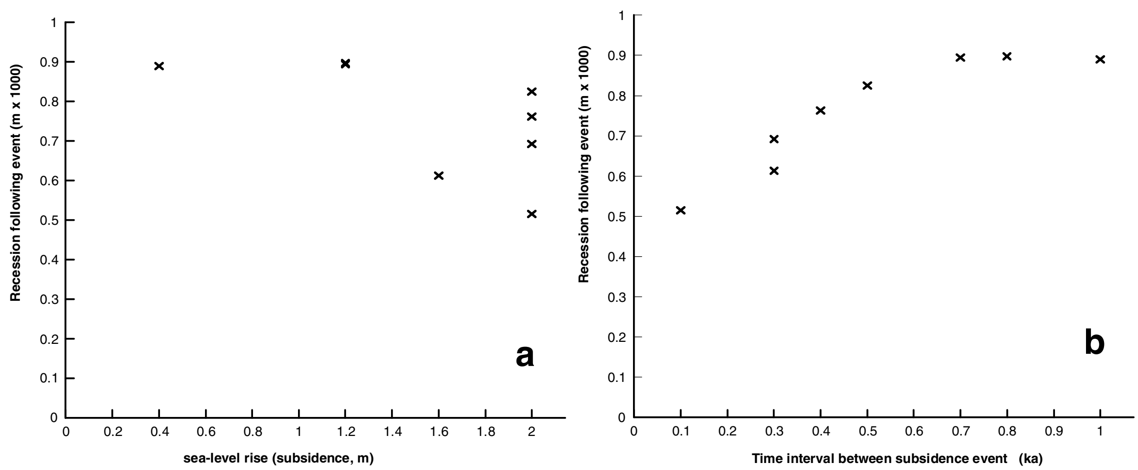

Figure 3. Recession as a function of a) subsidence, and b) the length of time between successive subsidence events, from simulation with shoreface rotation.

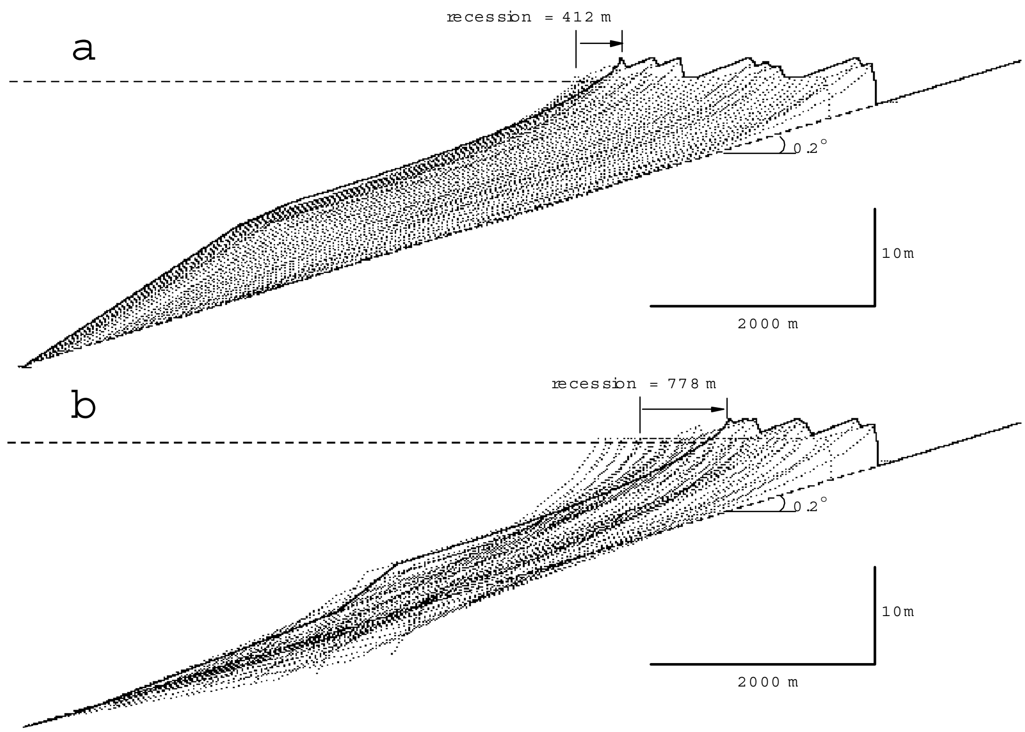

Figure 4. Simulated recession due to a future earthquake event for a) an invariant shoreface, and b) a rotational shoreface. Subsidence = 2 m for both cases.