Modeling the Future of Sand Beaches

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***Abstract*–Sand beaches are associated with sea level stillstands and may occur when waves have cut sufficiently wide shore platforms for them to repose upon. During the present near-stillstand lasting over the past 5000 years, waves have cut wide platforms, and wherever sufficient sand is available, beaches have formed along the world's coastlines. Global warming causes sea level to rise and there is good evidence that the present near-stillstand is being terminated and replaced by much higher rates of sea level rise. Models show that during rapid sea level rise the future of sand beaches largely depends upon the rate of development of new wave-cut platforms, a process that proceeds at much faster rates on gently sloping coasts than on steep coasts backed by sea cliffs. Sand beaches on gently sloping coasts such as the U.S. east coast will survive by washover and inland migration. Along steep coasts backed by sea cliffs, such as the U.S. west coast, sea level rise will more likely result in drowned platforms with cliffs plunging to the sea and a loss of sand beaches.**

I. INTRODUCTION

Today's coastal zone is the cumulative result of processes acting upon it now as well as those that have been acting over geologic time. When these processes are considered in terms of the time scales in which they are measured, they may be grouped as seasonal to multi-decadal and millennial. Seasonal forcing includes atmosphere and ocean dynamics that drive the rainfall and floods bringing sediment to the coast as well as generating the waves and currents that transport sediment and shape the coast. Multi-decadal processes are enhancements and protractions of seasonal cycles on decadal scales. In addition to shaping the coast, the patterns of multi-decadal variability form the basis for our interpretation of past climates from their signature in proxy records [1, 2]. Millennial scale forcing includes the tectonics that determine the basic types of coast, insolation cycles that cause glacial and interglacial epochs, and the sea level changes that determine the position of previous coastlines [3]. Collectively, these processes and their temporal and spatial scales have been addressed in the preceding two sessions while their application to modeling coastal evolution is the subject of this session.

II. MODELING COASTAL PROCESSES

Models are simplifications of the real world. They treat the first order processes, and to facilitate computation, they neglect the higher order. A good process model of coastal evolution will incorporate all of the necessary first order processes and neglect those that are of lesser importance [4]. Further, model validation requires accurate data sets that cover the temporal and spatial ranges of the model domain. This means that modeling coastal evolution must move forward in time from past known conditions and be evaluated by the present before proceeding to the future. Individual processes, usually in the form of modules, must each be validated individually as well as interactively with other process modules within the model. Much of the scientific findings from modeling are made during detailed analysis of the interacting process modules. From this it follows that modeling must proceed as a multidisciplinary team effort.

III. IMPLICATIONS FOR BEACHES

The processes and concepts underlying the evolution of coastlines and their modeling have been presented in these three sessions. In the remaining time we discuss some important findings for the future of our beaches that have emerged from our modeling efforts [5]. These findings are from the interaction of modules for beach profiles and shoreline change with those for platform cutting when time stepped for sea level change (Fig. 1).

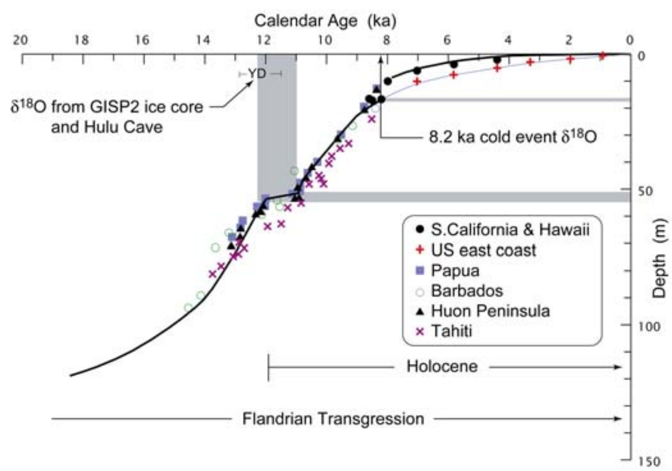

Fig. 1. Sea level during the Flandrian transgression with stillstands associated with the Younger Dryas (YD), the 8.2 ka cold event, and the last 5 ka (modified from [6]).

Along the west coasts of the Americas, the coastal area typically consists of a wave-cut terrace backed by high sea

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cliffs. The module interactions show that sand beaches are associated with sea level stillstands and may occur when waves have cut sufficiently wide shore platforms for them to repose upon [6, 7]. During the present near-stillstand lasting over the past 5000 years, waves have cut wide platforms, and wherever sufficient sand is available, beaches have formed along the world's coastlines. Given a sufficient mass of sand over a gently sloping platform, waves will form beaches that are in equilibrium with the wave intensity [8]. However, the model shows that the reservoir of sand over the platform must equal or exceed the critical mass before an equilibrium beach can exist. When the quantity of beach sand equals or exceeds the critical mass, beaches undergo equilibrium adjustments during storms. When the quantity is less than the critical mass, large waves cause disequilibrium and offshore loss of sand. The critical beach mass depends on platform size and slope, wave climate, and sand size. Most California beaches consist of shallow wave-cut platforms covered with thin veneers of sand that are now at or below critical mass. Rapid sea level rise will submerge platforms and decrease sand reservoirs and sandy beaches will disappear.

These findings can be summarized as nature's requirements for a seasonal beach:

- The formation of a wave-cut platform requires a stillstand in sea level. And the stillstand must be of sufficient duration to cut a gently sloping platform of sufficient width for beaches to form.
- Stable beaches cannot form over platforms that slope more than about 2%.
- Given a sufficient mass of sand over a gently sloping platform, waves will form beaches that are in equilibrium with the wave intensity.
- The reservoir of sand over the platform must equal or exceed the critical mass before an equilibrium beach can exist.
- The critical beach mass depends on:
  - platform size and slope
  - wave climate
  - sand size
- When the quantity of beach sand equals or exceeds the critical mass, beaches undergo equilibrium adjustments during storms. When the quantity is less than the critical mass, large waves cause disequilibrium and offshore loss of sand.
- Most California beaches consist of shallow wave-cut platforms covered with thin veneers of sand that are now at or below critical mass.
- Therefore, sea level rise will submerge platforms and decease sand reservoirs, and sandy beaches will disappear.

IV. CONCLUSIONS

Global warming will cause sea level to rise, and there is good evidence that the present near-stillstand is being terminated and replaced by much higher rates of sea level rise. Our model shows that during rapid sea level rise, the future of sand beaches largely depends upon the rate of development of new wave-cut platforms, a process that proceeds at much faster rates on gently sloping coasts than on steep coasts backed by sea cliffs. Sand beaches on gently sloping coasts such as the U.S. east coast will survive by washover and inland migration. Along steep coasts backed by sea cliffs, such as the U.S. west coast, sea level rise will more likely result in drowned platforms with cliffs plunging to the sea and a loss of sand beaches.

Acknowledgments

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