Berms and other cross-shore bedforms

A berm is one of the first things you generally notice about a beach. The berm can consist of sediment, but also of organic matter (such as logs, trash and shell hash).

It is generally a result of the piling up of sediment from swash. Swash is strongly asymmetric, both due to significant frictional losses and due to infiltration within the beach.
Berms are generally found in conjunction with an offshore bar.

Roughly speaking, berms scale linearly with the breaker wave height $H_b$ (Bagnold, 1940). This agrees with the simplistic view that the swash consists of bores (or gravity currents) that are generally some fraction of the breaker wave height.

However, rigorous analysis requires and exhaustive account of the beach substrate (i.e., the permeability of the grain-size distribution and its variation along and cross-shore).

**Longshore bars**

Spit with accompanying longshore bars on the Florida panhandle

There are several hypotheses related to the formation of longshore bars:
1. The origin of longshore bars is related to the convergence of the undertow and the landward flux of material associated with Stokes drift. Komar calls this the **break-point hypothesis**.

2. Progressive edge waves push sediment out of their path and form a ‘wall’ at the location of their maximum excursion.

3. Longshore bars are a result of reflected wave energy, forming standing waves and causing the formation of newer, offshore bars.

Regardless of the mechanism, several facts remain about most natural longshore bars:

- The crest of the bar is usually collocated with the breaker line. Plunging (efficient) breakers are most often related with longshore bars. This is used as support for the break point hypothesis.
- Longshore bars are generally found on supply-rich, sandy beaches.
- Longshore bars ‘protect’ the beach. Laboratory studies have shown that erosion is stronger on beaches without bars than with them.
- Longshore bars often turn into crescentic bars nearer shore.
Multiple longshore bars evolving into crescentic bars (Komar)

- Sometimes longshore bars create multiples of themselves.

**Formation of multiple bars**

The formation of multiple bars suggests a feedback between bar formation and the flows that produce it.

Though analysis is beyond the scope of this course, Mei (1985) showed that if the bar wavelength is one-half the surface-wave wavelength, there will be a resonant interaction between the bed and the surface waves. Interaction of this kind is called **Bragg reflection**. The result is that wave energy is retained within the region of the bars – ultimately resulting in the formation of new bars offshore.
Despite the appeal of the theory, some have suggested that multiples are simply a result of differing wave fields at differing times.

**Beach cusps**

Left Photo: Coarse-sand/pea-gravel beach in New Zealand. Right photo: Fine sand beach in Ixtapa, Mexico.

Beach cusps have been discussed in the literature since the beginning of modern geology (Jefferson, 1899; Johnson, 1910). The accepted/traditional explanation for beach cusps has been that they are a manifestation of coastal edge waves or ‘surf beats’ (Longuet-Higgins and Stewart, 1962).

However, Werner and Fink (1993) used the ‘new’ concept of self-organization to describe the phenomenon.

They used a cellular-automaton model the paths of particles responding to randomly imposed swash.
Cellular-automaton models simulate kinematics only – i.e., they are essentially a set of geometric rules that generate topography over ‘time’.

Despite the simplicity of the model, Werner and Fink (1997) were able to consistently (regardless of the kinematic complexity) produce cuspate geometries accounting only for the interaction between geometry and flow kinematics.

The work is extremely similar to work Werner and others investigating the formation of unidirectional ripples.

**Ripples**

Ripples are the dominant bedform inshore of the continental slope break and outside of the surf-zone. Dunes (and antidunes), as they have been traditionally defined, only exist in shallow (~O(1) m) depths and in the presence of an appreciable current (i.e, tidal channels).

There are many different varieties of wave-influenced ripples.

Wiberg and Harris (1994), using Clifton (1976) as a reference, characterize ripples into three categories:
1. **Orbital ripples** scale linearly with wave orbital diameter. Sometimes orbital ripples are called **vortex ripples**.
2. **Anorbital ripples** have a roughly constant dimensionless wavelength.
3. **Suborbital ripples** are a transitional form in between anorbital and orbital ripples.

Wiberg and Harris (1994) suggest that most ripples made in the laboratory are orbital ripples and that most ripples in the geological record are anorbital.

If ripples are anorbital, you cannot extract information about the wave environment from the preserved stratigraphy.

**Ripples influence on form drag**

Most of the emphasis on ripples arises from the need to characterize form drag.
Grant and Madsen (1982) and Madsen (1991) propose several relationships to describe ripple height $\eta_r$ and wavelength $\lambda$. They are:

$$\frac{\eta_r}{A_{bm}} = 0.27 - 0.33\sqrt{\tau^*}$$

(1a)

and

$$\frac{\eta_r}{\lambda} = 0.16 - 0.36(\tau^*)^{2.3}$$

(1b)

where $\tau^*$ is the Shields stress based upon skin friction only.

Madsen suggests that you should then form a new roughness length scale $k_r = 4\eta$.

Their data and analysis is drawn strongly from laboratory experiments. Though they have consistently checked their results with field observations, oftentimes the scatter from their analysis is large.

Wiberg and Harris (1994) suggest that the Grant and Madsen (1982) formulation is only good for orbital ripples.

In its place, they suggest the Wiberg and Nelson (1992) formula
\[ \frac{\tau_{\text{total}}}{\tau_{sf}} = 1 + \frac{C_D \eta_r}{2\kappa^2 \lambda} \left[ \ln \left( \frac{\eta_r}{z_{0, sf}} \right) - 1 \right]^2 \] (2)

where \( \tau_{sf} \) is the shear stress calculated from skin friction only. \( C_D \) is bedform drag coefficient (~ 1), \( \kappa \) is the von Karman constant and \( \eta_r \) is the amplitude of the ripples.

To calculate the height of the ripples \( \eta_r \),

\[ \frac{\eta_r}{\lambda} = \exp \left[ -0.095 \left( \ln \frac{d_0}{\eta_r} \right)^2 + 0.442 \ln \left( \frac{d_0}{\eta_r} \right) - 2.28 \right] \] (3)

where \( \lambda = 535D \) for anorbital ripples. \( d_0 \) is the wave orbital diameter at the bed.

**Combined-flow bedforms**

All of the bedforms described by Wiberg and Harris and previous work by Grant-Madsen dealt with pure oscillatory bedforms. Several new studies have attempted to characterize combined-flow structures. These make up **hummocky cross-stratification (HCS)**. In the coming years, we will see considerable work on combined-flow bedforms. Several new laboratory flumes are under construction that will be able to generate high Reynolds number combined-flow boundary layers.
From early experiments by John Southard et al., it appears that very little wave orbital velocity can generate apparently unidirectional bedforms.