The Science of Surfing Waves and Surfing Breaks - A Review

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ABSTRACT

Surfing breaks have great social and economic value for coastal communities. In order to preserve and enhance these resources, a common language is needed that will bridge the gap between the colloquial slang of surfers and the technical language of scientists and policy makers. This language is the science of surfing waves and surfing breaks, and the more it is developed and used, the easier relations will be between the interested parties. This paper will create the basis for such a language to be used in future studies of surfing waves and surfing breaks.

Surfing waves and surfing breaks are currently understood well enough to predict the effects of coastal modifications on surfing locations and to design artificial surfing reefs. However, the use of this knowledge for more practical applications has been limited. This paper consolidates the literature on the science of surfing waves and surfing breaks in an effort to communicate the basics of this science to coastal planners, engineers and policy makers. First, the types of surfing waves that are preferred by surfers are discussed, including a description of the main surfing wave parameters. Second, it is shown that the wave type determines the surfing skill level required and types of maneuvers that can be performed. Third, the seabed features that cause waves to transform well for surfing are presented.

ADDITIONAL KEY WORDS: *Surfing break components, surfing reef components, peel angle, breaking intensity, wave sections, section length, surfing maneuvers, surfer's skill level.*

INTRODUCTION

Every year more and more people decide to take up surfing as a leisure activity. The enormous social and economic benefits of having a quality surfing break in a coastal community are only now being fully realized by planners and policy makers. Increasingly, the preservation and enhancement of surfing breaks is being practiced because of its value to the community (e.g., BLACK, 2001a and 2001b; BLACK and MEAD, 2001; BLACK et al., 1998, 1999, 2000 and 2001; BORRERO, 2002; COURIEL, 1996; MEAD, 2001; MEAD and BLACK, 1999a and 2002; MEAD et al., 1998 and 2001; MOFFATT & NICHOL ENGINEERS, 1989; PATTIARATCHI, 1999a and 2000).

Surfers are traditionally defensive about any activity in the vicinity of their favorite surfing breaks. This behavior may be justified because history shows that their rights have at times been ignored and many surfing breaks have been destroyed by coastal modification. When enhancements have been made, they have been unintentional rather than an original objective. Now, with the emergence of more progressive attitudes by councils and coastal engineers toward surfers, there is a need for a common language between the parties. This language needs to bridge the gap between the colloquial slang of surfers and the technical language of scientists and policy makers.

Development of such a common language will help in the preservation of surfing breaks and construction of artificial surfing reefs. This language is the science of surfing waves and surfing breaks. The more it is developed and used, the easier relations will be between the interested parties. This paper creates the basis for such a language to be used in future studies of surfing waves and surfing breaks. It compiles and summarizes the literature on the science of surfing waves and surfing breaks from numerous journal and conference papers, theses, dissertations and technical reports. A concise background is provided on surfing waves and surfing breaks with references to more detailed information. First, the types of waves that surfers prefer are discussed, including a description of the main surfing wave parameters. Second, it is shown that wave type determines required surfing skill level and maneuver types that can be performed. Third, the seabed features that cause waves to transform well for surfing are presented. Finally, the way the configuration of these features creates good surfing waves is discussed.

THE HISTORY OF SURFING WAVE AND SURFING BREAK RESEARCH

The study of the physical processes behind surfing waves and surfing breaks has come a long way since the initial investigations of Hawaiian surf breaks in the early 1970s (WALKER and PALMER, 1971; WALKER *et al.*, 1972; WALKER, 1974a and 1974b). Significant advances began in the 1990s with the development of the Artificial Reefs Program at Waikato University in New Zealand (ANDREWS, 1997; HUTT, 1997; MEAD, 2001; MOORES, 2001; SAYCE, 1997; SCARFE, 2002) and the Cable Stations Artificial Reef

Project at the University of Western Australia (PATTIARATCHI, 1997, 1999 and 2000; PATTIARATCHI *et al.*, 1999; BANCROFT, 1999). The First Artificial Surfing Reefs Symposium in Sydney, Australia (1997), and the Second in San Diego, California (1998) further spurred interest. They brought together surfing enthusiasts from a wide range of disciplines and localities. More recently, the Second Surfing Art, Science, and Issues Conference (SASIC2) put on by the Groundswell Society in Ventura, California (2002) encouraged discussion.

A summary of surfing science and artificial surfing reef construction knowledge was presented in *Journal of Coastal Research,* Special Issue No. 29. Subsequently various areas of surfing research have defined themselves. They are as follows:

- The effects of submerged reefs on sediment transport and salient formation (ANDREWS, 1997; BLACK and ANDREWS, 2001a and 2001b; BLACK and MEAD, 2001);
- The relationship of surfers to surfing waves (DALLY, 1990, 2001a and 2001b; HUTT, 1997; HUTT *et al.*, 2001; MOORES, 2001; SCARFE, 1999, 2002; SCARFE *et al.,* 2002);
- The bathymetric shape of surfing breaks (ACHENBACH, 1998; MEAD, 2001; MEAD and BLACK, 1999b, 2001a and 2001b; RAICHLE, 1998; SCARFE, 1999 and 2002; SCARFE *et al.* 2003a, 2003b and *in press*; WEST *et al.,* 2002);
- The prediction of wave-driven currents (SYMONDS and BLACK, 2001);
- The prediction of breaker intensity of surfing waves (SAYCE, 1997; SAYCE *et al.,* 1999; MEAD and BLACK, 2001c); and
- The prediction of beach surfability (DALLY, 1989; PATTIARATCHI *et al.*, 1999; SCARFE, 2002).

The study of surfing waves and surfing breaks can be thought of as two separate but related subjects. The study of surfing waves investigates the different characteristics of waves and how they relate to surfing rides and surfers. The study of surfing breaks examines how seafloor bathymetry transforms ordinary waves into surfing waves. Figure 1 diagrammatically shows how surfing break bathymetry transforms ordinary waves into surfable waves.

CHARACTERISTICS OF SURFING WAVES

Surfers desire waves where the break point "peels" along the wave crest. They surf just ahead of the advancing wave crest within the "wave pocket" where most of the wave's power is located. Unless they are beginners, surfers are not satisfied with riding waves that do not peel. If the wave peels to the right from the surfer's perspective (to the left when looking from the beach), the wave is said to be a "righthand" wave, or a "righthander." If the wave peels to the left from the surfer's perspective (to the right when looking from the beach), the wave is said to be a "lefthand" wave, or a "lefthander."

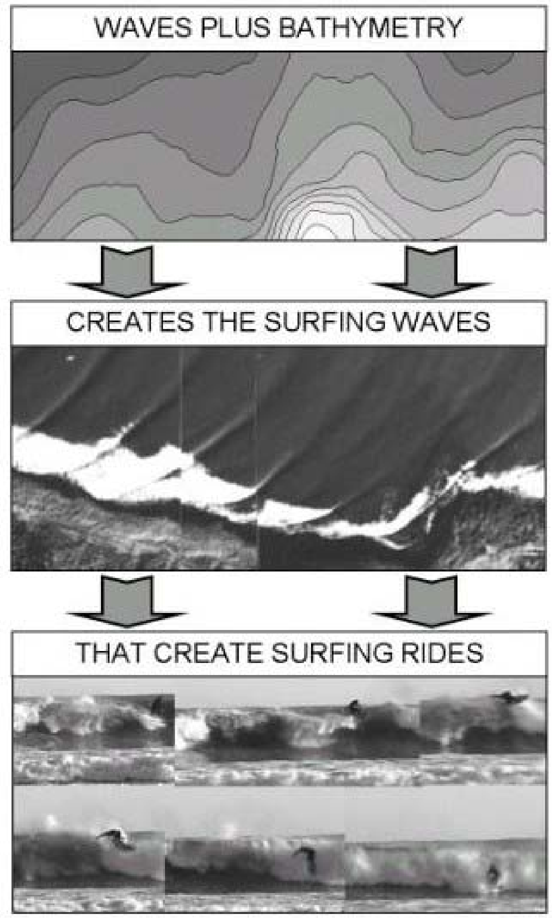

Figure 1. *Ordinary waves are transformed by surfing break bathymetry into surfing waves, which create surfing rides.*

Together, the speed at which the wave peels and the breaker type determine the skill level required to surf a wave (HUTT, 1997; HUTT *et al.,* 2001, MOORES, 2001) as well as the types of maneuvers that can be performed (SCARFE, 2002; SCARFE *et al.,* 2002). Not all waves are suitable for surfing, and among those that are, not all can be surfed by surfers at all levels. The character of surfing waves varies not only from location to location, but also from day to day with tide level and swell. In fact, even successive waves can break with considerably different characteristics.

There are various different types of surfing (Figure 2), which include short boarding, long boarding, body boarding, and body surfing. Surfboards for short boarding are generally between six and seven feet long, and the surfing style is aggressive. Surfers who ride short boards, or short boarders, perform fast and powerful surfing maneuvers. Surfboards for long boarding range from seven to eleven feet long. Long boards are also called Malibu's (or Mal's), because they suit the slow and gentle waves found at places like Malibu, California. Riding long boards, or long boarding, is a much slower and more relaxed style of surfing, because waves suitable for long boarding break more slowly and softly than those for short boarding. Shorter Mal's are called mini-Mal's and cross over between the two styles of standup surfing.

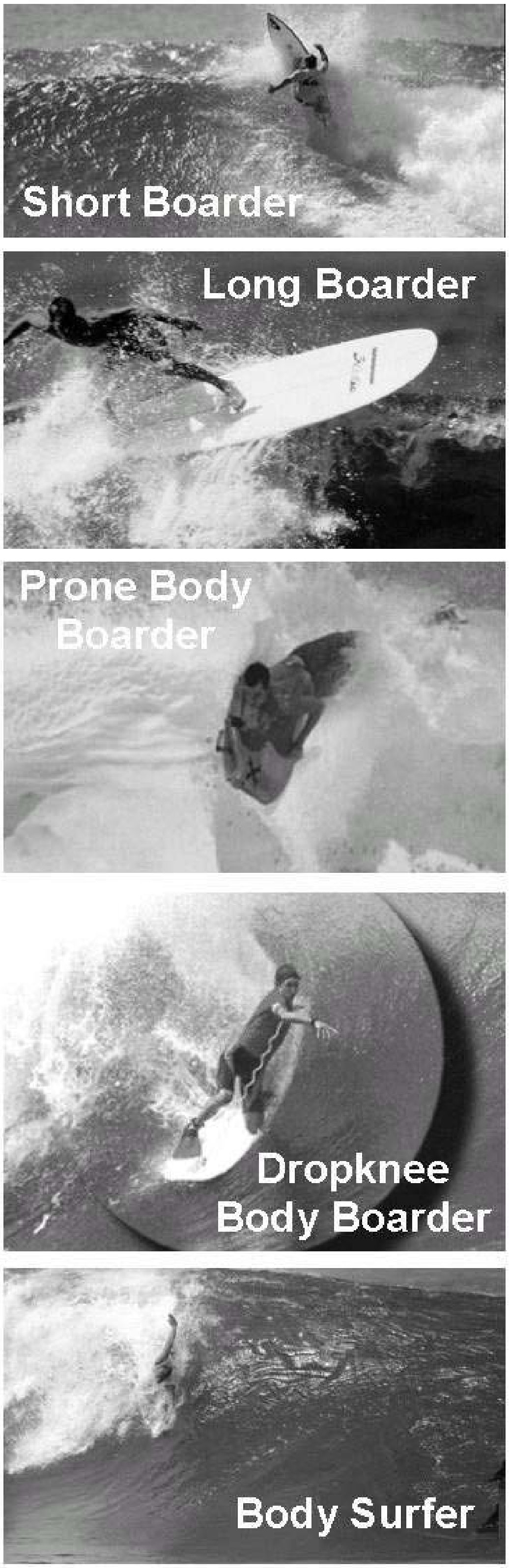

Figure 2. *Types of surfing from top to bottom – Short board surfer (www.aspworldtour.com), long board surfer (www.kahunavideo.com), prone body boarder (www.bodyboarderweb.com), body surfer (www.worldbodysurfing.com) and drop knee body boarder (www.bodyboarderweb.com).*

Body boarding, also called boogie boarding, uses a small foam board rather than a fiberglass board. The board is about three feet long, and the surfer generally does not stand up on it. When riding a body board lying down, the style is called "prone." There is a style of body boarding where the body boarder almost stands that is called "drop knee." Fins or flippers are used to catch waves rather than paddling as in standup surfing. The combination of fins and a small board makes it difficult to stand up. When riding "drop knee," the surfer kneels on one knee and stands on the other. Body surfers do not use a board at all; they surf the wave using their body as a board. Fins are often used to help the swimmer catch the wave.

Although there are four main types of surfing, most of the scientific surfing research has focused on short boarding. Therefore, this review also focuses on short boarding waves, but the concepts are applicable to all types of surfing waves and can be extrapolated to other surfing styles. For example, long boarders desire waves with higher peel angles and lower breaking intensities than short boarders. Body boarders desire waves with more extreme breaker intensities.

Surfing Wave Parameters

The four most important wave parameters for analysis of surfing waves are breaking wave height (H_B), wave peel angle (α), wave breaking intensity (B_I), and wave section length (S_L) (SCARFE *et al.* 2002 and 2003a). Other surfing wave parameters exist (see DALLY, 1990, 2001a and 2001b; MEAD, 2001; MOORES, 2001; SAYCE, 1997; SAYCE *et al.,* 1999; SCARFE, 2002; WALKER, 1974), but they are only derivatives of these four main variables. Any surfing wave can be described using only these four variables. SCARFE *et al.* (2002 and 2003a) recommend the sole use of these four to maintain consistency within the scientific surfing literature.

Wave Height (Hb)

Surfing wave height is often considered the most important variable at a surfing break (RAICHLE, 1998). Oceanographers measure wave height from the crest to the trough of the wave. Groups of surfers develop their own definitions of wave heights, which can be slightly larger or smaller than the distance from crest to trough. In the scientific study of surfing waves, the oceanographic method of measuring from crest to trough is used. Waves come in sets, and surfers ride the largest waves in a set. HUTT (1997) recommends the use of an average of the top 10 % of waves ($H_{1/10}$) when measuring wave statistics for surfing rather than significant wave height ($H_{1/3}$).

Wave Peel Angle (α)

Peel angle is defined as the angle between the trail of the broken whitewater and the crest of the unbroken wave as it propagates shoreward (Figure 3; WALKER, 1974; HUTT, 1997; HUTT, *et al.*, 2001; MEAD, 2001b; SCARFE, 2002). Peel angles range between 0° and 90°, with low angles creating fast surfing waves and high angles creating slow waves. An angle of 0° is described as a closeout (MEAD and BLACK, 2001b).

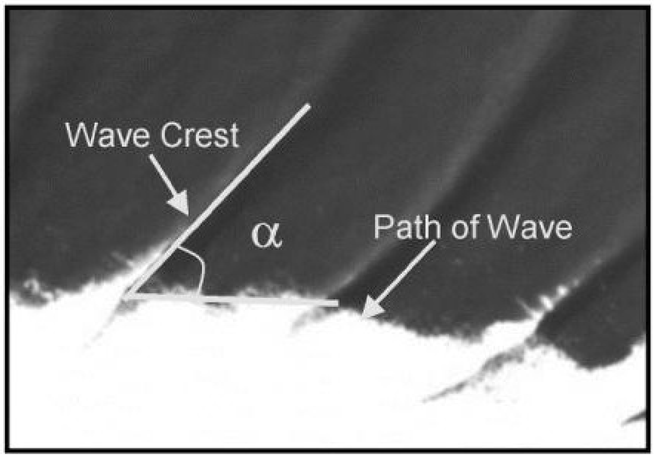

Figure 3. *The peel angle, α, is defined as the angle between the trail of the broken white water and the crest of the unbroken part of the wave as it propagates shoreward (from Mead, 2001).*

The wave peel rate describes how fast the wave breakpoint advances laterally along the wave crest. Surfers must surf at least as fast as the wave peel rate in order to stay in front of the wave break point. Peel angle is closely related to wave peel rate because they both relate to how fast a wave is breaking. Although theoretical models designed to relate peel angle with peel rate have been developed (DALLY, 1990 and 2001a), SCARFE (2002) and SCARFE *et al.* (2002) recommend using peel angle because it can be more accurately numerically modeled and is more sensitive to maneuver type. Using complex field experiments, SCARFE (2002) measured peel angles and peel rates for different maneuver types. Peel angle was found to control maneuver type, while no relationship could be found with peel rate. DALLY (2001b) and MOORES (2001) have both looked at maximum surfer speeds that give approximations of the maximum surfable peel rate.

Wave Breaking Intensity (B_I)

Orthogonal seabed gradient is the dominant variable controlling wave breaker intensity (MEAD and BLACK, 2001c). Waves will break either as spilling, plunging, surging, or collapsing breakers, depending on the orthogonal seabed gradient. Waves break on a continuum between these main types of breakers (KOMAR, 1998). Surfers generally prefer waves with steep or plunging faces (MEAD and BLACK, 2001c). These waves provide greater power to propel surfers and the opportunity for more advanced surfers to experience barrel rides. Traditional methods of describing wave type, such as the Irribarren number, the surf scaling parameter, or the surf similarity parameter have not been found to be appropriate for surfing rides (MEAD and BLACK, 2001c; SAYCE, 1997; SAYCE *et al.*, 1999). These methods are used to describe all forms of wave breaking from spilling to collapsing and are too general for surfing waves (MEAD and BLACK, 2001c).

The types of plunging waves that surfers ride vary greatly. MEAD and BLACK (2001c) investigated the shapes of plunging waves at 28 “world-class” surfing breaks. The term “world-class” has been used in literature to describe surfing breaks that are representative of the best surfing locations in the world. A cubic curve was fitted to the barrel shape, also termed the wave vortex. The ratio between the height and width of the vortex is called the vortex ratio and is a good indicator of breaker intensity (MEAD and BLACK, 2001c). A linear relationship was seen when the vortex ratio was plotted against the orthogonal seabed gradient for each surfing site. Regression analysis by MEAD and BLACK (2001c) showed that Equation 1 can be used to quantify the wave breaker intensity (R^2 = 0.71), where X is the orthogonal seabed gradient and Y is the breaker intensity.

$$Y = 0.065\,X + 0.821 \qquad (1)$$

MEAD and BLACK (2001c) note that Equation 1 is the first attempt at quantifying the breaker intensity of plunging surfing waves and is simplistic. They suggest that the method might be improved by incorporating wave height and period. In reality orthogonal seabed profiles are made up of varying gradients, with the deeper water gradient generally lower than the shallow water gradient. The shallower water gradient has more of an effect than the deepwater gradient. The effect of steps in the profile, or multiple gradient profiles, on breaker intensity is still relatively unknown. However, MEAD and BLACK’s (2001c) simple relationship can still be used to quantify the design characteristics of artificial surfing reefs and to differentiate between breaker intensity at surfing breaks. Breaker intensity has been classified by MEAD and BLACK (2001c) as medium, medium/high, high, very high, and extreme. Each classification was defined by the breaking intensity range based on Equation 1.

Wind strength and direction affect breaking intensity. Offshore winds increase breaking intensity, and onshore or cross-shore winds lower it. The perfect wind conditions for surfing are light offshore. These wind conditions delay wave breaking, causing the wave to break in shallower water and increasing the breaker intensity. Strong offshore winds make waves hard to catch.

Wave Section Length (S_L)

It is rare to find surfing waves peeling with a regular and consistent character. Peaks in wave crests from unorganized swells and wave focusing as well as from undulating bathymetry cause waves to break in sections. Waves breaking in sections create interesting and challenging surfing rides because surfers can perform different maneuvers on the various sections. However, the section must not be so long or fast that the surfer is trapped behind the wave pocket. A new section begins when there is a change in wave height (H_b), peel angle (α), or breaking intensity (B_I), and is said to have a section length of S_L. Wave sections have been investigated by MOORES (2001), SCARFE, 2002 and SCARFE *et al.* (2002).

Relating Surfing Waves To Surfers

Studies have related surfers to surfing waves in order to determine design criteria for artificial surfing reefs. This research falls into two categories. The first relates a surfer's skill level to surfing wave parameters. The second relates surfing maneuvers to surfing wave parameters.

Surfer Skill Level

Different surfing waves suit different types of surfers, and surfers prefer to ride waves that match or challenge their abilities. The range of wave heights, peel angles, breaking intensities, and section lengths that a surfer can successfully negotiate depends on skill level. WALKER (1974) developed a classification scheme to describe the surfable limits of beginner, intermediate, and expert surfers based on peel angles and wave height. Subsequently, the scheme was revalidated for modern surfing standards by HUTT *et al.* (2001). The delineations between the surfer skill level categories were made with a more quantitative 1-to-10 ranking system by HUTT *et al.* (2001).

The higher the surfing skill level, the greater the ability to negotiate difficult sections and link sections together for long surfing rides. MOORES (2001) looked at how skill level related to a surfer's ability to surf through wave sections with decreases in peel angles. His general findings were:

- The higher the skill level, the longer the sections that can be made.
- Surfers with high skill levels do not require as much speed coming into a section because they have more ability to generate speed.
- Surfers with a skill level of 3 or less (beginner) cannot make sections.

MOORES (2001) used his findings to develop maximum section length, duration, and speed values for artificial surfing reef design. The relationship between surfer skill and breaking intensity has not yet been quantified.

Surfing Maneuvers

Surfing is a recreational activity and performing maneuvers is the goal of most surfers. The types of maneuvers a surfer performs are dependent on ability, style of surfing, and wave type. For any given wave type, most surfers will perform similar types of maneuvers (SCARFE, 2002; SCARFE *et al.*, 2002). The first investigations into surfing maneuvers were undertaken by SCARFE (2002) and SCARFE *et al.* (2002). Definitions of each maneuver can be found in SCARFE (2002) and SCARFE *et al.* (2002 and 2003b).

SCARFE (2002) found three types of maneuvers: functional, expressive, and transitional (Figure 4). Functional maneuvers are required for anyone to surf. A functional maneuver such as speed weaving is required simply to keep up with a breaking wave. It performs the function of staying in the powerful section of the wave. A more expressive maneuver such as an aerial is performed solely to fulfill the surfer's need to perform a difficult feat. Maneuvers such as top turns and bottom turns can be considered as transitional moves that are used to link together functional maneuvers with expressive maneuvers. Each maneuver can be categorized as functional, transitional, or expressive, depending on when it is being done. A bottom turn may be functional when dropping into a wave, transitional when preparing for an aerial, or expressive when executed under certain conditions.

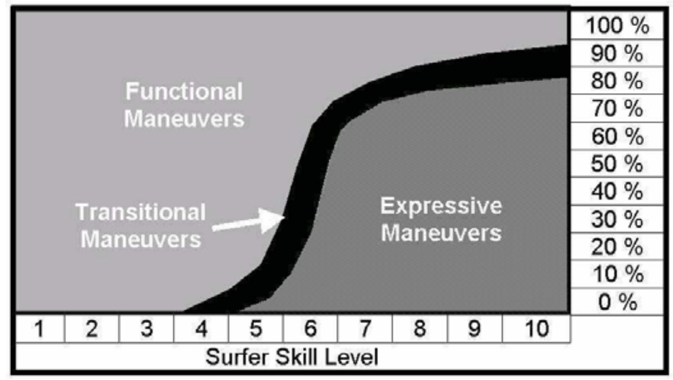

Figure 4. *Relationship between the percentage of each surfing maneuver type and skill level (from Scarfe, 2002).*

The category of a maneuver also changes depending on the surfer's skill level. Surfers with low skill levels perform more functional maneuvers, while those at higher skill levels perform more expressive maneuvers. A basic, functional maneuver to an expert surfer will be an expressive maneuver to a beginner. The ability of surfers of different abilities to perform each maneuver type is tabulated in SCARFE (2002).

Analysis of peel angles during certain maneuvers by SCARFE (2002) and presented in SCARFE *et al.* (2002) yielded design criteria to incorporate maneuver type into wave sections of artificial surfing reefs (Figure 5). These maneuvers represent the division in peel angles where a maneuver can be performed. For example, although the word cutback is used here, in the analysis it is just as likely that a surfer will perform a roundhouse for the given wave scenario. When surfing through a speed section, a surfer can speed weave, perform a floater or foam bounce, or experience a barrel ride if the breaker intensity is high enough.

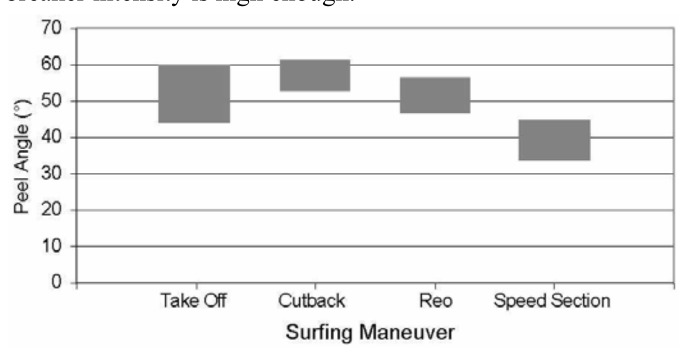

Figure 5. *Range of peel angles that are suitable for different surfing maneuvers (from Scarfe, 2002; Scarfe* et al.*, 2002).*

Maneuver type is also related to breaking intensity. For a given peel angle, a surfer may perform a top turn on a wave with a medium breaking intensity, a reo or vertical re-entry if the breaking is higher, or a barrel if the breaking intensity is extreme. SCARFE (2002) investigated how breaking intensity from orthogonal seabed gradients relates to maneuvers; however, findings were inconclusive. The measurement of breaking intensity on a section-by-section scale is difficult, and it would have been preferable to use more descriptive terminology.

Configuration of Wave Sections

Variation in any of the four surfing wave parameters creates a new section. Different maneuvers can be performed depending on the configuration of wave sections. Figure 6 illustrates how section length, peel angle, and breaker intensity can affect maneuver type. Surfers are likely to perform the maneuvers shown in Figure 6 for the corresponding wave sections. Incorporating interesting and varying sections into artificial surfing reefs will challenge surfers and keep rides interesting. Maneuver type for a section is also dependent on the previous section (SCARFE *et al.*, 2002). For example, a surfer riding a section with a low peel angle will be traveling fast to keep up with the wave break point. If the next section dramatically increases in peel angle, then the surfer will perform a move such as a cutback to lose speed and stay in the powerful pocket of the wave.

CHARACTERISTICS OF SURFING BREAKS

Planar beaches with parallel contours do not produce good surfing breaks (SCARFE *et al.*, 2003b). The peel angle is too low for surfing. Waves simply "closeout" as the wave crest breaks all at once rather than peeling. More interesting bathymetric features are needed to cause waves to break along the wave crest rather than all at once. All good surfing breaks have preconditioning components and/or shallow water features that cause waves to peel. This is why most surfing spots are near prominent morphological features, such as river mouths with ebb deltas, coral/rock reefs, points, rock ledges, piers, jetties, or beaches where large scale bar/rip features are created by edge waves.

The majority of waves that break on shorelines are not suitable for surfing. In order for waves to break well for surfing, wave height, peel angle and breaking intensity must be within the surfable range (HUTT *et al.*, 2001; MOORES, 2001; SCARFE 2001; SCARFE *et al.*, 2002). Top surfers can ride waves ranging from a very low to an extremely high, dangerous breaker intensity within a range of wave heights from 1-50 feet. In fact, it is becoming apparent that top surfers are now able to surf waves of almost any size and any breaking intensity. The major surfing wave parameter that differentiates a surfable from a non-surfable wave is peel angle. Therefore, the role of a surfing break is to increase peel angle to within surfable limits. Although peel angles can be too high to challenge more advanced surfers, high peel angles do not necessarily prevent surfers from riding waves, whereas low peel angles do.

Surfing Reef/Break Components

MEAD and BLACK (2001a) identified the major bathymetric features that cause surfing breaks to form good surfing waves. Surfing reef or surfing break components were classified based on surveys and numerical modeling of world-class surfing breaks in New Zealand, Australia, Indonesia, Hawaii, California and Brazil. Each component was distinguished by its shape and function. MEAD and BLACK (2001a) refer to these features as surfing reef components, but this term also includes surfing break features made of material other than reef. The identified components are ramp, platform, wedge, focus, ledge, ridge and pinnacle. Schematic diagrams of each component are shown in Figure 7.

Depending on the configuration, orientation and size of these components, MEAD and BLACK (1999b and 2001b) found that different wave types are produced. Any alteration of these components by natural processes or human actions will change the surfing wave parameters at the surfing break.

The "favored orthogonal direction" is the wave alignment that produces the best quality surfing waves over a reef component (MEAD and BLACK, 2001a). Any deviation from the optimum alignment will cause an increase or decrease in ideal peel angle. This leads to waves breaking more quickly or slowly than desired for high-performance surfing.

Definition of Components

MEAD and BLACK's (2001a) definitions of functional reef components are as follows:

Ramp

A ramp causes waves to refract and organize themselves. The directional spread of offshore waves is aligned orthogonally to ramp contours prior to breaking on another morphological component. Good quality surfing waves do not break on a ramp.

Focus

A focus is a seabed ridge that causes a peak in wave height and lowers the effective seabed gradient, making it easier for a surfer to take off. Focuses can also occur at any section of a surfing ride. Depending on water depth relative to swell and extent of focusing, peaks will cause wave breaking or increase the wave height of an advancing wave prior to its breaking over another reef component.

Platform

A platform is a flat, horizontal plane, and therefore has little effect on advancing waves. Platforms join different components without altering wave orientation or causing excessive shoaling. A platform's two main functions are to maintain wave orthogonals established by a ramp or focus and to allow sufficient depth of water for waves to break above a ledge. In the first situation, an optimal platform is just deeper than the depth where waves will break at a particular site.

Wedge

A wedge is a planar component, tilted downward in the offshore direction, similar to a ramp. It differs because it is at an angle to the favored orthogonal direction and in shallow enough water to cause wave breaking. This is the main wave-breaking component of most surf breaks. The orientation of the wedge determines the amount of refraction and therefore the wave peel angle.

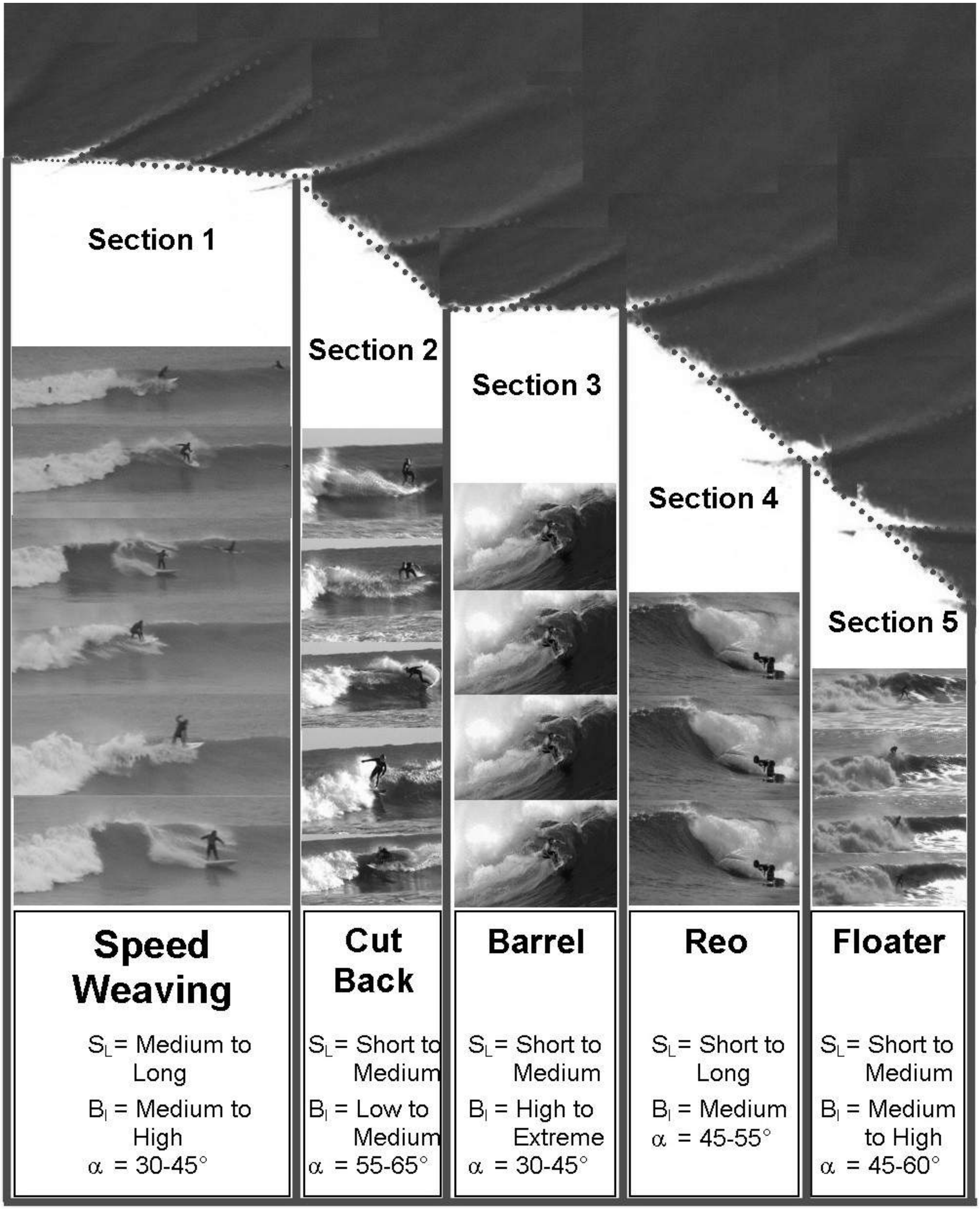

Figure 6. *Configuration of wave sections suitable for different types of maneuvers. Adapted from Scarfe* et al. *(2002).*

Ledge

A ledge is a very steep wedge with a platform extending shoreward from its top edge. Little or no refraction can occur, and therefore the orientation of the ledge is critical. A ledge must have a gradient >1:4, or waves are likely to surge and collapse. Plunging waves are common on ledges.

Ridge

A ridge is similar in shape to a focus, but oriented so that it does not cause wave convergence. The ridge provides a section of steeper seabed gradient, causing a decrease in peel angle and increase in breaker intensity. Ridges do not refract waves significantly compared with wedges. A focus can become a ridge when the wave angle changes significantly and water depth is low enough to cause wave breaking.

Pinnacle

A pinnacle increases breaker intensity in a way similar to a ridge, except it is more abrupt and affects a smaller area. Pinnacles as well as focuses often define the takeoff zone and help surfers to catch waves.

MEAD and BLACK (2001a) subcategorized components by their functions. Ramps, focuses, and platforms precondition the wave prior to breaking by aligning and shoaling. Wedges, ledges, ridges and pinnacles cause the wave to break. The breaking components are often small-scale features that are nestled on larger, preconditioning components.

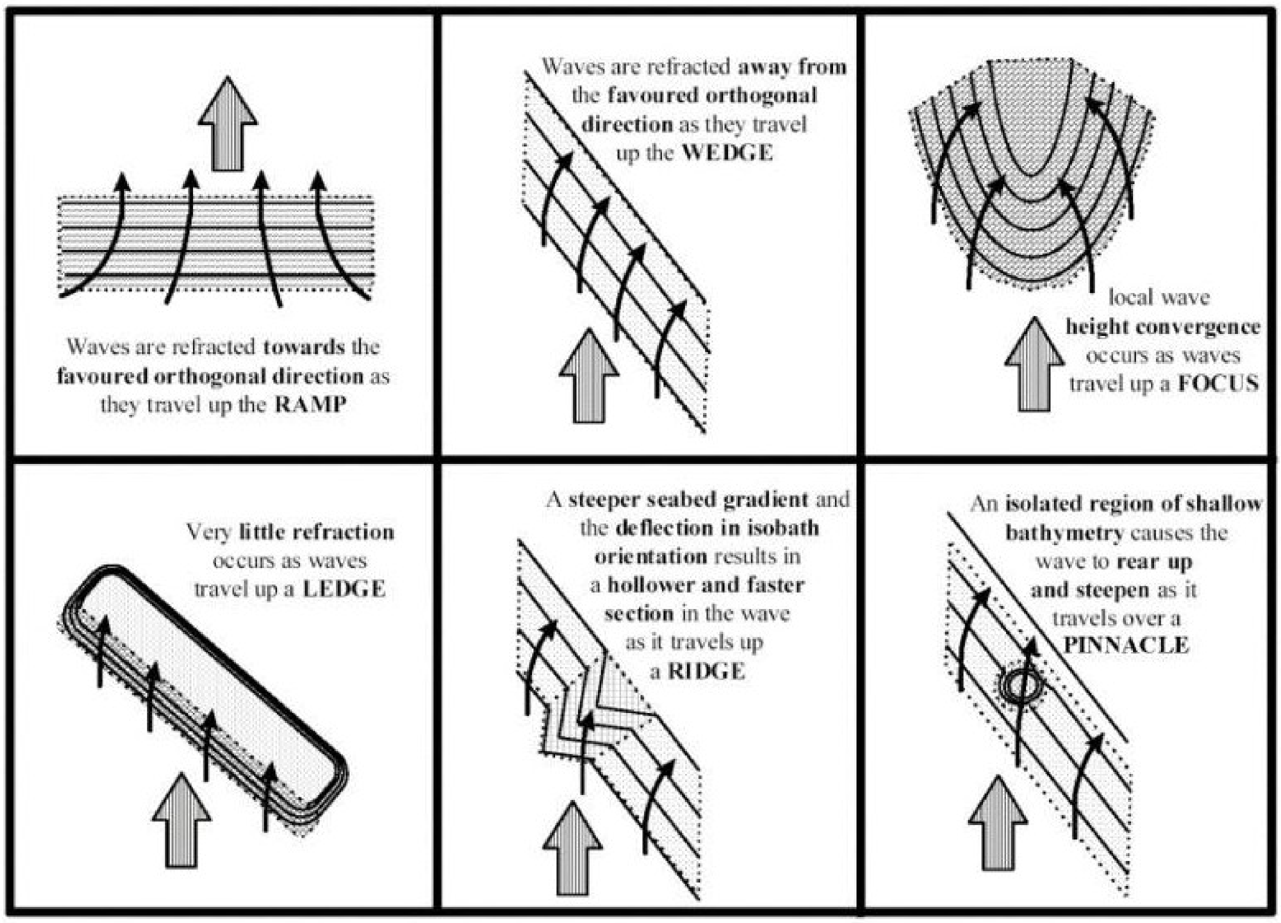

Figure 7. *Reef components that make up the bathymetry of world-class surfing breaks (from Mead and Black, 2001a). The large arrows represent the "favored orthogonal direction," and the small arrows represent transformations to the wave orthogonals. Note that the platform has not been included here because it is essentially a flat component that does not refract waves that pass over it.*

Configuration of Components

Different types of waves can be produced depending on the configuration of reef components. The components combine holistically to produce quality surfing waves, and depending on size, orientation, and configuration, produce different wave types (MEAD and BLACK, 1999b). Analysis of the reef component configuration by MEAD and BLACK (2001b) showed four common setups of surfing breaks. They are:

- Ramp/Wedge
- Ramp/Platform/Wedge
- Ramp/Focus/Wedge
- Ramp/Ledge/Platform

In a case study of Bingin Reef, Bali, Indonesia by MEAD and BLACK (1999b), the role of different reef components was investigated using numerical modeling. Bingin was found to produce consistent and surfable peel angles over a range of wave heights because of the configuration of five main components (Figure 8). Bingin is a Ramp/Focus/Wedge configuration with a ridge superimposed on the wedge and a platform abutting the wedge.

Most surfing breaks do not produce perfect surfing waves throughout the entire tide cycle, especially when tidal ranges are large. As the water depth changes, the components that comprise the break also change, either in function or in impact on wave propagation. SCARFE (2002) showed that the 3.5-4.0 m tide range at Manu Bay, Raglan, New Zealand can behave as two different surfing breaks depending on the tide because the component configuration changes.

Scale of Components

The seven components identified by MEAD and BLACK (2001a) occur at macro, meso and micro-scales (SCARFE, 2002). At the largest scale, offshore components refract and organize waves before they break. For example, a ramp can align waves along the whole coast or be a smaller component of a surfing break, aligning a section of the wave prior to its breaking on another component (MEAD and BLACK, 2001a). Macro-scale components influence wave direction and shoaling but do not cause waves to break. Meso-scale components focus and orient waves prior to breaking and can cause wave breaking. Micro-scale components are superimposed on meso-scale features and create wave sections between 5 and 40 m (SCARFE, 2002).

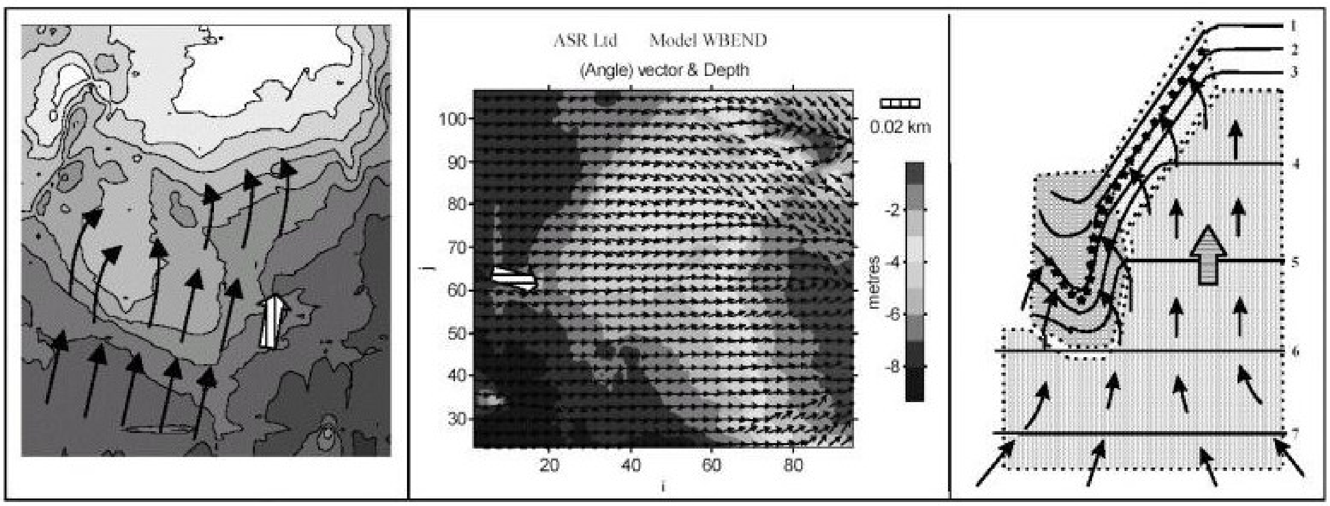

Figure 8. *Ramp/Focus/Wedge configuration of reef components at Bingin Reef, Bali, Indonesia (from Mead and Black, 2001b). From left to right – measured bathymetry, numerical model output of refraction over the surfing reef, idealized schematic of the component configuration. The configuration of the components was manipulated by Mead and Black (1999b) to see the role each component played in the creation of the world-class surfing waves at Bingin Reef.*

Example of Scale - Manu Bay Surfing Reef, Raglan, New Zealand

The surfing reefs at Raglan are part of a large boulder headland with a gently sloping sandy continental shelf starting about 6 m below mean low water (see HUTT, 1997; HUTT *et al.,* 2001; MEAD, 2001; MOORES, 2001; SAYCE, 1997; SCARFE, 2002). At a macro-scale, the continental shelf acts as a wedge, organizing and refracting swell toward the favored orthogonal direction for each surfing spot. Often even very messy swells produce clean surfing waves at Raglan because of the headland effect (MEAD and BLACK, 2001b). This effect occurs where shorter period local swells are filtered out as waves refract on the wedge of the headland, resulting in clean, organized, long-period waves at surfing breaks relative to the offshore wave spectrum.

The reef meso-scale components of Manu Bay and The Ledge are defined by MEAD and BLACK (2001b) as a wedge/ridge configuration. The Ledge is a section of Manu Bay that only breaks under certain conditions. It is the heaviest and most spectacular of all the Raglan surfing breaks because of the hollow barrels that can be surfed. A ridge feature creates The Ledge by increasing breaker intensity and lowering peel angle for the section.

Micro-scale reef components (Figure 9) were identified by SCARFE (2002) at Manu Bay in addition to the meso-scale features identified by MEAD and BLACK (2001b). Refraction modeling and measurements of wave breaking location from video (SCARFE *et al.*, 2003a) by SCARFE (2002) showed how these features refract and focus waves to create the surfing break. It is these micro-scale features that create sections with different peel angles and breaker intensities. In fact, SCARFE *et al.* (2003b) showed that meso-scale features are actually made up of many micro-scale components. For example, SCARFE *et al.* (2003b) used “The Poles” at Atlantic Beach, Florida to show that, at a meso-scale, an ebb tidal delta acts as a focus. The delta is comprised of many smaller features that act together holistically under different conditions to determine the location and degree of wave focusing.

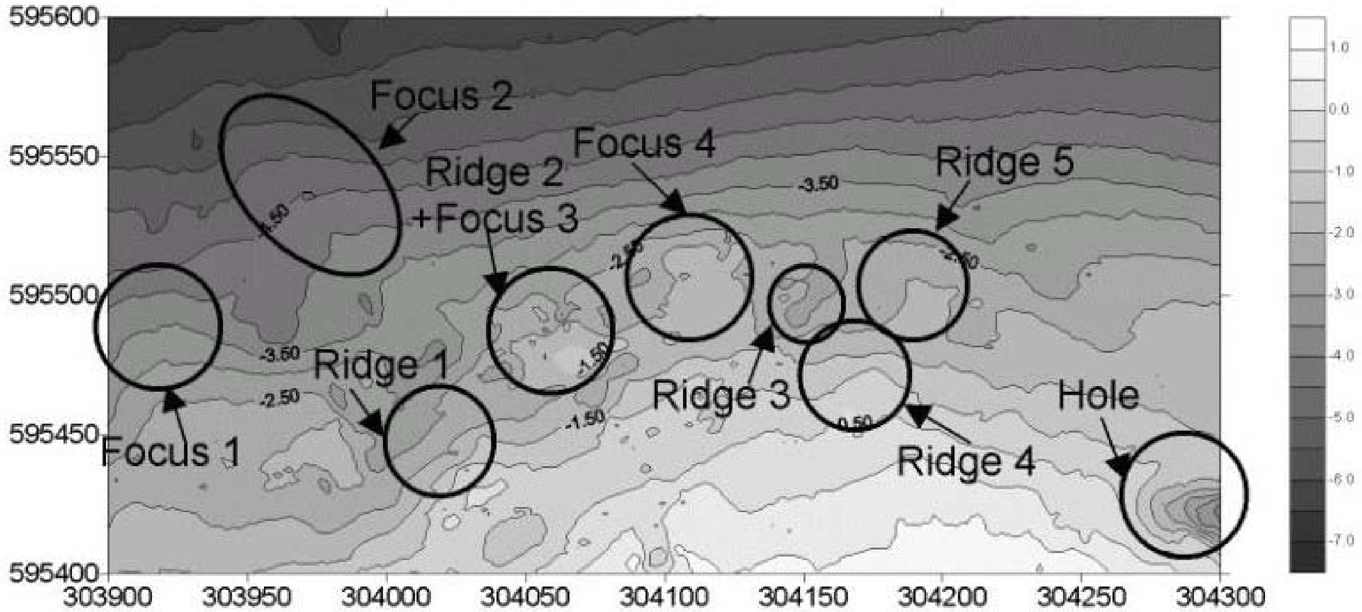

Figure 9. *Micro-scale reef components at Manu Bay and The Ledge. Under different wave conditions and tide heights these components have different effects on wave breaking (from Scarfe, 2002; Scarfe* et al.*, 2002 and 2003a).*

DISCUSSION

The body of knowledge about the ways surfing breaks create surfing waves is large enough to be used to predict the possible effects of coastal activities on surfing breaks and to design artificial surfing reefs (ASRs) (for information on ASRs, see BLACK, 2001a and 2001b; BLACK and MEAD, 2001; BORRERO, 2002; EVANS and RANASIGNHE, 2001; MEAD, 2001; MEAD and BLACK, 2002; PATTIARATCHI, 1999 and 2000; RANASIGNHE *et al.*, 2001). However, at this time practical applications of this information are limited. Coastal engineering projects are still undertaken without considering their effects on the surfing environment. This is not simply caused by coastal engineers who ignore the impacts of their activities on surfing. Rather, a lack of education exists among those who manage our coasts about the mechanics of surfing breaks and the ways coastal modifications affect surfing conditions. The rise in profile and political power of environmental surfing organizations, such as the Surfrider Foundation and Groundswell Society, as well as the volume of scientific surfing information, can help to preserve and enhance surfing breaks.

This paper hopes to communicate to surfing and non-surfing coastal planners, scientists and engineers the basics of surfing science. Although there are still gaps in the knowledge about the ways in which surfing waves are created, this paper shows that there is sufficient understanding to incorporate surfing amenity into coastal projects.

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