LETTERS TO THE EDITOR

DISCUSSION: Gravel Beach Profile Characterization and Discrimination

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ABSTRACT

The problem of representing beach profile configuration by means of one point estimate related to the sediment volume stored under the profile is examined for several gravel beaches in Wales. The recent index prepared by CALDWELL and WILLIAMS (1985) is shown both to be similar to that prepared by SONU and VAN BEEK (1971), and to be a poor discriminator of profile differences when concerned with discriminating between aspects of the profile which reflect process differentiation. Reasons for this poor specification are suggested.

INTRODUCTION

The nature and morpho-sedimentary response of gravel dominated beaches tend to be neglected areas of modern coastal studies judged by the relatively small number of papers concerned with these features compared to the number of papers devoted to their fine clastic counterpart. On that basis alone CALDWELL and WILLIAMS's (1985) contribution on a potential method for discriminating between cross-beach profiles expressed on gravel beaches, is of value.

CALDWELL and WILLIAMS (1985) report on an approach to gravel profile analysis, as well as commenting on results taken from an unpublished source (ORFORD, 1978). This short paper aims (a) to add some background to that original study, (b) to comment on the proposed method of gravel beach profile characterization introduced by Caldwell and Williams, (c) to enlarge on some of their points concerning their interpretation of the earlier approach (ORFORD, 1978) to beach profile characterization, and finally (d) to try to draw some general conclusions concerning the validity of beach gravel profile discriminations advocated in these two studies of Welsh gravel beaches.

BEACH CONTEXT OF PROFILE ANALYSES

Before discussing the proposed method of profile characterization, it is important to set the context of gravel beach morphology and sedimentation for the type of beach where the two cited studies were undertaken. In both cases the gravel beaches are dominated by material whose axis size are $> -2\phi$. Morphologically the beach ridges are single, asymmetric in cross-beach shape and freestanding, as in the case of Gileston, S. Wales (CALDWELL and WILLIAMS, 1985) and Llanrhystyd, W. Wales (ORFORD, 1975, 1978, 1979). Caldwell and Williams's second beach at Nash, S. Wales is unusual in that it is lodged against the junction of a limestone wave cut platform and cliff feature and hence the beach has no discernable free back slope as does the freestanding beach ridge. Llanrhystyd and Gileston beaches are characteristic of numerous single gravel ridges found along the storm-dominated western and southern coasts of the U.K. Along the Welsh coast such features are often located within distinct littoral (wave energy plus sediment) cells controlled by a crenellate coastline.

Sea-level for those areas has been effectively stationary over the last 2000 years, so that new sediment supplies tend to come from longshore sources. As most of these gravel beaches cling (=fixed) to the coastline, new longshore sediment sources (related to cliff erosion) are restricted to supplying only short stretches of beaches before being halted by natural headlands. As most of these gravel beaches owe their existence to being swept onshore with a rising sea level and the reduced longshore supply by headland control means that most of these beaches are characterized by an economy of sediment scarcity. This is important in that few gravel beaches show convex cross-beach profiles that are normally associated with major beach aggradation.

The diversity of storm wave approach on the western UK coast (southwest through to northwest) is reflected in continual longshore reworking of the limited gravel reservoir found in these beaches. This is shown by the spatial and temporal sediment size/shape gradients found longshore, which also means that profile position can never be strictly independent of position within the crenellate wave/sediment cell. As a consequence of the reduced gravel sediment supply to the beachface, the upper beach has often been extended vertically by major storm wave activity building up the beach ridge crest height. Thus 'fingerprints' of severe storms may dominate the upper beach for months, if not years (ORFORD, 1977). Amplification of swash run-up on the steep upper beach slopes (<15°) is commonly experienced with run-up two to four times the breaking wave height. Longshore gradients of run-up height (due to wave refraction variation in exposed and lee elements of crenellate bays) leads to variable longshore beach ridge heights (ORFORD, 1979) which in turn can practically affect the macro-shape of the beach profile. Gravel beach width is also affected by the exposure of the profile. Gravel beach width is also affected by the exposure of the profile to wave attack, as the smallest gravel beach widths are often related to the extent to which foreshore sand builds up in front of the gravel beach as a function of fine weather conditions.

Most of these gravel beaches have meso to macro spring tidal ranges (>3 m). As a consequence of limited gravel supply and large tidal ranges, the gravel tends to be emplaced at the high water mark leaving seaward of the gravel a foreshore zone formed from a low water wave cut platform which in some cases (Llanrhystyd) is covered by a thin veneer of sand. The varying rate of wave deformation over the variable cross-beach geometry exposed through the tidal cycle, means that a variety of breaker types can be found across the inter-tidal zone from multiple spilling breakers at low water to surging forms against the steep upper gravel beach at high water. This change from dissipative to reflective wave regimes is shown when even in storms, constructive berms can be found at the foot of the gravel beach due to the generation of constructive spilling waves over the foreshore sand zone (ORFORD, 1977).

BEACH PROFILE CHARACTERIZATION

In a study of 68 beach profiles ORFORD (1978) characterized the profile type in terms first proposed by SONU and VAN BEEK (1971). Contextual differences between these two studies necessitated modification of Sonu and van Beek's categories (Figure 1), and a subsequent assessment of the profile in terms of whether it showed a step or bar profile (Figure 2). A quantitative index of profile type was obtained by calculating the volume under the active profile (Q) bounded by the active beach width (W) and active beach height (H) measured between the gravel seaward edge and swash limit of high water. Modification of Sonu and van Beek's method of calculating the sediment storage of the profile was required, as the variable tidal range at Llanrhystyd meant that on some occasions only one third of the total gravel beach volume, Q was divided by H to derive Qa, where Qs was the average sediment volume per active unit meter of beach height. Profiles were also subdivided into two sets depending on whether the active profile height exceeded the median high water tidal limit of +3 m O.D. This crudely separated spring and neap related profiles.

Due to difference in beach structure, the convex profiles found by Sonu and van Beek are only very rarely found at Llanrhystyd. Those occasions were during neap tides associated with highly constructive waves which built up a sizable berm that effectively filled the available wetted profile. In the absence of full beach width convex profiles category C is deleted from the profile set (see Figure 1). This absence means that the degree of overall profile variability, when measured by Sonu and van Beek's method, was substantially reduced.

Mid-beach berms do not appear on these gravel profiles. The position of berms are related to the maximum swash limit of the tide associated with the profile formation and not to the maximum beach width. This removes categories A3 and B3 from the profile set (see Figure 1).

CALDWELL and WILLIAMS (1985) attempt to standardize profiles by means of a geometrical transformation that expands the observed profile so that it fits an arbitrary but constant beach height (Hc) and beach width (Wc). The area under the profile bounded by Hc and Wc is expressed as the pro-

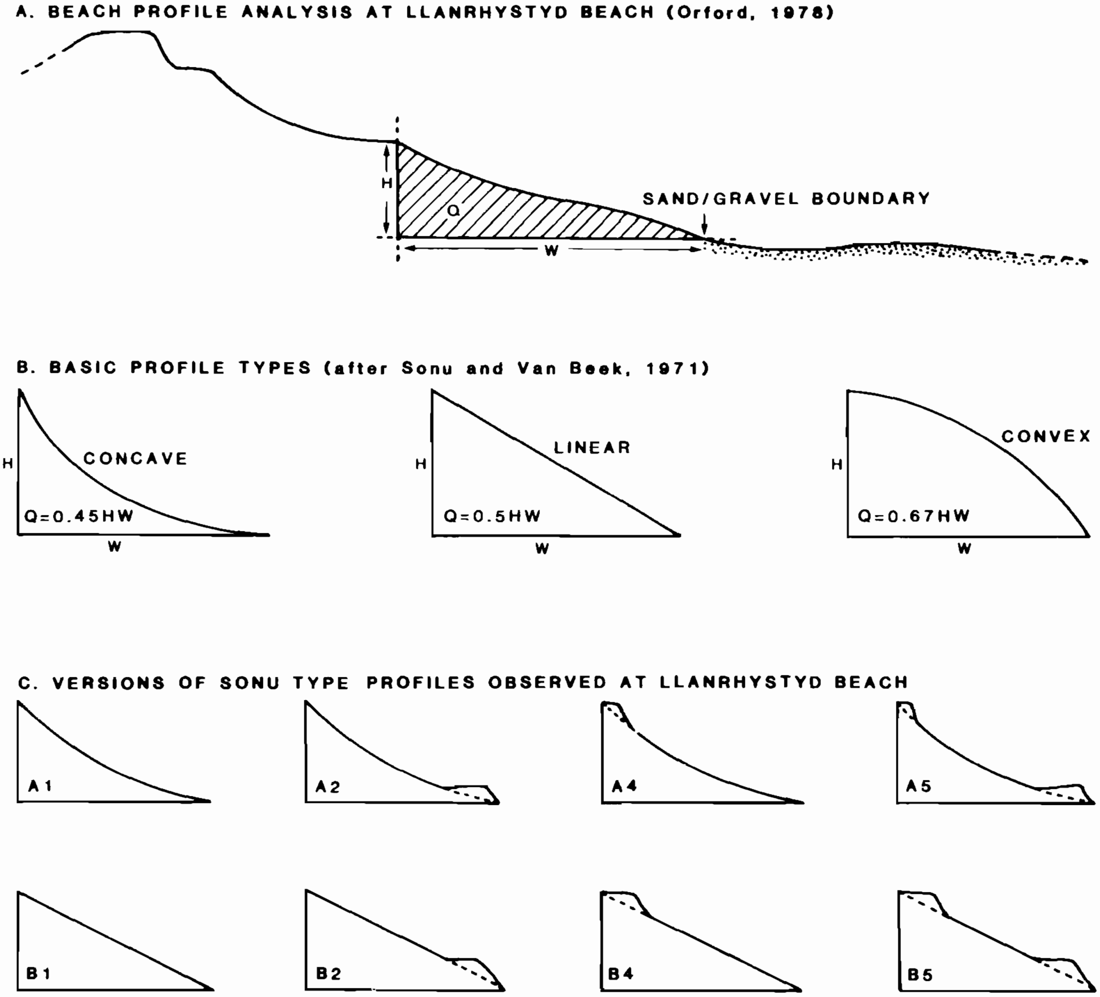

Figure 1. A. Beach profile dimensions as defined for the study of gravel based profiles at Llanrhystyd (ORFORD, 1978). B. Basic beach profiles identified by SONU and VAN BEEK (1971) on sand beaches on the Outer Banks, North Carolina. C. The eight profile types as a function of berm presence/position used in the Llanrhystyd study.

portion of the total area of a rectangle defined by Hc x Wc. This value they denote as the hypsometric integral. By using the areal proportion to define the integral, the use of the transformation becomes redundant. If the transformation alters the relative structure of the profile then the proposed transformation runs into difficulties of data distortion. If the transform doesn't alter the relative structure of the profile then the area under the profile relative to the area of the Hc x Wc rectangle should not alter regardless of profile stretching — hence the transformation is redundant.

The derived hypsometric integral is directly comparable to the constant term used by SONU and VAN BEEK (1971) in that the integral CALDWELL and WILLIAMS (1985, Figure 3) associate with pooled linear profiles (0.485) is approximately the same as Sonu and van Beek's value (*cf* 0.5) while their pooled concave profile integral of 0.42 is similar to Sonu and van Beek's value of 0.45.

BEACH PROFILE DISCRIMINATION

The power of any profile characterization is

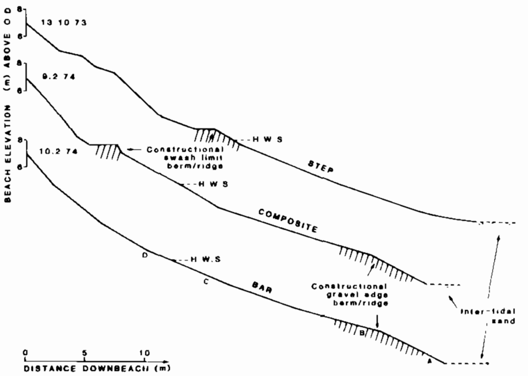

Figure 2. Examples of step, composite and bar beach profiles identified at Llanrhystyd. Each profile starts from the gravel ridge crest. HWS marks the predicted position of spring tide high water.

measured by the ability it has in discriminating between profile types. In an attempt to distinguish between the eight Sonu profile types of the Llanrhystyd data Qs was regressed against W. Analysis of covariance was used to test for any significant differences between the resulting eight regression slope estimates. None of the slope estimates (ranging from 0.378-0.484) were significantly different ($F_{obs} = 0.403$), while the pooled slope estimate of 0.444 was highly significant ($F_{obs} = 634.5$; $p>0.001$) indicating that the visual subdivision of the Llanrhystyd data into Sono profile types was not a valid proposition. This result gives rise to CALDWELL and WILLIAMS's (1985, p. 133) comment that "ORFORD, (1978) failed to produce significant statistical evidence of the heterogeneity of profile populations."

CALDWELL and WILLIAMS (1985) claim that their integral index allows profile discrimination when using Sonu and van Beek's profile types. The test of this hypothesis is made using the Mann-Whitney U-test which considers the relative inter-digitation of two sets of integral values (for two profile types) when placed in rank order. Discrimination is not clear cut: linear versus concave profiles are clearly differentiated, but berm position within these two profile types is not readily discriminated as only very marginal significances ($p = 0.05$) are achieved for some of the profile comparisons. Such differences should be treated with some suspicion given that a X^2 test of integral frequency histograms (CALDWELL and WILLIAMS, 1985, Figure 4) shows no significant difference between integral values for concave plus berm profiles.

Figure 3A shows the results of applying the integral method to Llanrhystyd profile data subdivided by Sonu and van Beek's typology. The clarity of concave-linear discrimination is not expressed by these data — for example the median integral value for A1 to B5 are not progressively incremental as Caldwell and Williams's data suggest.

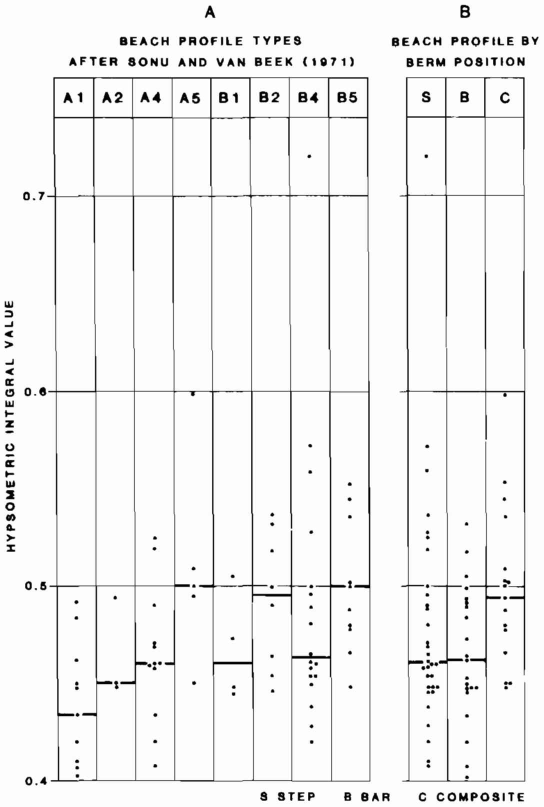

Figure 3. Discrimination of Llanrhystyd profiles using CALDWELL and WILLIAMS's (1985) hypsometric integral value. A. Discrimination using SONU and VAN BEEK's (1971) profile types. B. Discrimination using step/bar/composite profile types. The thick line represents the position of the median integral value for each profile type.

Given this variable discrimination, it seems appropriate to test for profile differences based on the presence and position of berms either at the swash limit (see Figure 2, step) or at the gravel edge (Figure 2, bar). A third profile type with constructural features at the top and bottom of the profile was also identified (Figure 2, composite). Step, bar and composite profiles have been related to fair-weather, storm and severe storm conditions respectively (ORFORD, 1977) and therefore have an added power of being process-related and hence beneficial to subsequent morpho-sedimentary analysis. Figure 4 shows nominal subdivision of the Llanrhystyd data based on the step, bar and composite grouping, plus the division of profiles based on whether the active profile height was above or below the +3 m O.D. position. However even with these subdivisions tests of analysis of covariance shows that none of these groups could be considered significantly different in terms of the response of Qs with W (profile storage with beach width). Although some difference in regression slope estimates exist (Table 1) they are not sufficient to suggest that storage variations imposed by upper and lower berms appears to make any impact on overall profile storage.

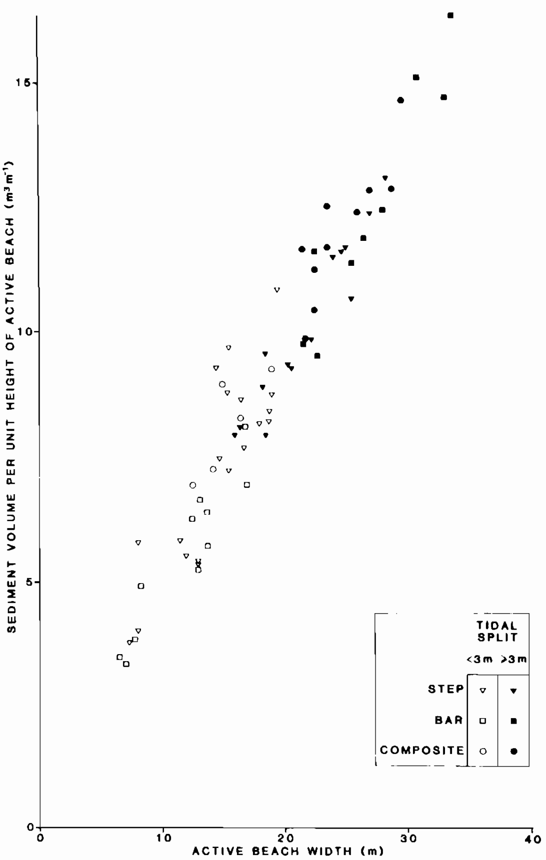

Figure 4. Discrimination between step/bar/composite profile type on the basis of sediment volume per unit height of active beach and active beach width. Tidal split refers to the profile elevation above the medium HW line of +3 m O.D., or below it.

Finally the Llanrhystyd step, bar and composite profiles are assessed in terms of integral values (Figure 3B). Ignoring the tidal split, only composite profiles show evidence of differences in storage values from other profile types — through the range of integral values for all three profile types is clearly overlapping to a major degree.

Table 1. Regression slope estimates for beach profile storage Qs as a function of active beach profile width, in terms of profile type and tidal elevation.

	Step	Bar	Composite
>+3 m O.D.	0.441	0.38	0.355
<+3 m O.D.	0.413	0.50	0.418
Pooled	0.411	0.457	0.401

DISCUSSION

Why does the Llanrhystyd data show no distinctive numerical profile differentiation as opposed to CALDWELL and WILLIAMS's (1984) Gileston and Nash data? Lack of discrimination may be related to one or all of the following points:

(1) There are problems in assigning profiles to *a priori* groups by visual inspection. It may be that the procedure should be reversed and profile groupings selected only after numerical characterization. However, at best, only differences between linear and concave profiles are likely to be specified by that approach.

(2) The Qs and integral indices are not sensitive to the small changes in beach volume which are important in morphological terms. Analysis of Llanrhystyd data suggests that berms have an importance in a dynamic interpretive sense that is out of proportion to the volume of the feature.

(3) The gross characterization of a profile by a single point value using only profile volume is probably too crude a technique. For example, the position of the berm is crucial to all profile typologies, yet no indication of position is obtained in any of these indices. SWART (1974), VAN HIJUM (1974), and AUBREY *et al.* (1978) offer more detailed and exacting methods of profile characterization which may be better suited to this respect.

(4) Profile variability in these two studies have been extended by two factors. (A) Caldwell and Williams's data came from two beaches. This may introduce sediment size and shape composition differences which may be translated into profile dif-

ferences. (B) The Llanrhystyd data were collected over spring-neap-spring tidal cycles, such that at neap high water only the lowest third of the profile was wave affected. Features built at that position would have been built from particle populations radically different from those found at the beach crest (ORFORD, 1975). The overall angle of beach slope is very different in these two positions and berm development although constructional in both places, would show a considerable difference in volume and morphology. In short a swash step built at the overall mid-beach position will be substantially different in structure from a winnowed berm derived from the outer cobble frame (BLUCK, 1967) of a gravel beach's seaward edge.

Finally the use of detailed tidal cycle histories underlines the point that any numerically based profile classification of Llanrhystyd data would have generated the wrong dynamic interpretation of most profiles. The designation of step/bar/composite status was undertaken in the light of net changes between time adjacent profiles. Choice of profiles characterization solely on either Qs or integral value would have led to erroneous profile process characterization.

CONCLUSION

We are still some way from obtaining a numerically sound method of gravel beach profile characterization that will generate low or negligible misclassification of profile type. Until that characterization is available it appears that profile characterization based on the step/bar/composite typology may be the best we can manage given that its interpretation appears viable in both process and facies terms.

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