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A PETALINE SAND PATTERN ALONG THE SHORELINE

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A petaline sand pattern, which is rhythmic along the shoreline, forms due to the action of surging waves on the beach. A similar small-scale sand pattern forms in a circular wave basin, and the rhythmic spacing of the petaline sand pattern increases linearly with the swash length.

Key words: Sand pattern, Sand petals, Circular waves, Wave basin

1. Introduction

It is well-known that, in the nearshore region, diverse types of sedimentary sand patterns form under the action of beach waves. Of these, sand ripples and beach cusps are perhaps most familiar and until recently numerous investigations have been concerned with these as reviewed by Komar[1], for example. Sand ripples have a pattern which is rhythmic in the direction of wave propagation, and are formed easily in most wave tanks as well as in nature. Beach cusps have a pattern rhythmic in the direction transverse to that of wave propagation. So far no clear visual demonstration of transversely rhythmic patterns seems to have been performed in wave tanks (Escher[2], Bowen and Inman[3]).

Recently, we happened to find at a low tide a sand pattern which consisted of an alongshore array of gentle sand mounds each in the form of a flower petal (Fig. 1). This pattern seems to have been formed owing to the heap of whitish and light sand on the beach. It should be noted that the large ridge and runnel feature shown by Davis[4] seems to have a similar appearance, though the petaline sand pattern is much smaller in scale. The above sand pattern seems different from that of a beach cusp when viewed in detail. The purpose of this paper is to demonstrate a plausible process for the formation of the petaline sand

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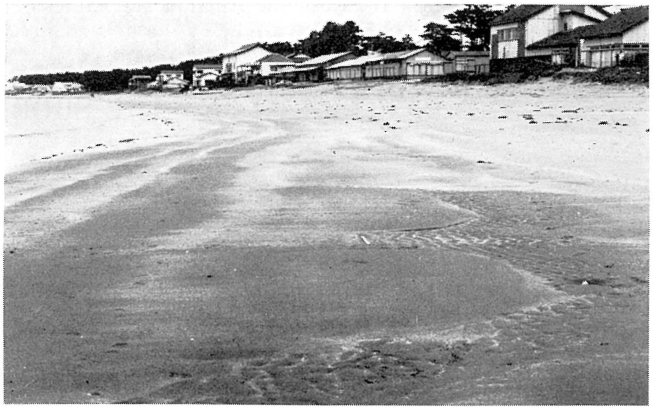


Fig. 1. A petaline sand pattern left on the beach at a low tide at Tsuyazaki, Fukuoka. The length of a scale bar is 50 cm. The coast is to the right.

pattern in a wave basin, and to discuss a few of its characteristics.

2. Experimental methods

Figure 2 shows the experimental apparatus. We used two circular basins; one was 53 cm in diameter and 20 cm in depth, and the other 100 cm in diameter and 20 cm in depth. Figure 2 shows the latter basin. Circular water waves were generated concentrically by moving a plunger up and down at the center of the water-filled basin. We used several plungers of different shapes, and the mostly used one is illustrated in Fig. 2. Strokes d of plunger oscillation were 2.0, 4.0 and 6.0 cm, and the oscillation frequency f was varied between 1.2 and 2.6 Hz.

We used beach sand with a median diameter of 0.019 cm and a density of 2.54 g/cm^3 as a bed material. When using the 100 cm diameter basin, we placed a layer of the sand with the thickness of about 3 cm on a sloping floor set around the inside circumference of the basin (Fig. 2). The slope of the floor from the horizontal was 8°. When using the 53 cm diameter basin, the sand was heaped up in a similar form on the bottom of the basin without a sloping floor. The slope θ of the surface of sand beds from the horizontal was varied between 5 and 12°.

3. Results and discussion

When a circumferential swash zone was exposed to surging circular waves, we observed that a marked, rhythmic sand pattern along the swash zone forms (Figs. 3(a)–(e)). We set up a sloping sand floor with $\theta=10°$ before the start of of plunger oscillation (Fig. 3(a)). Immediately

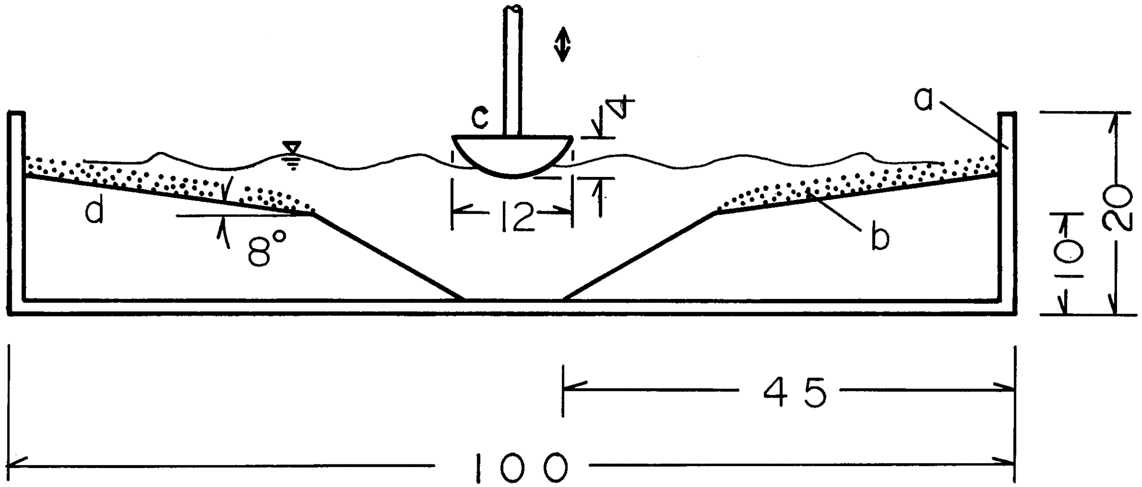
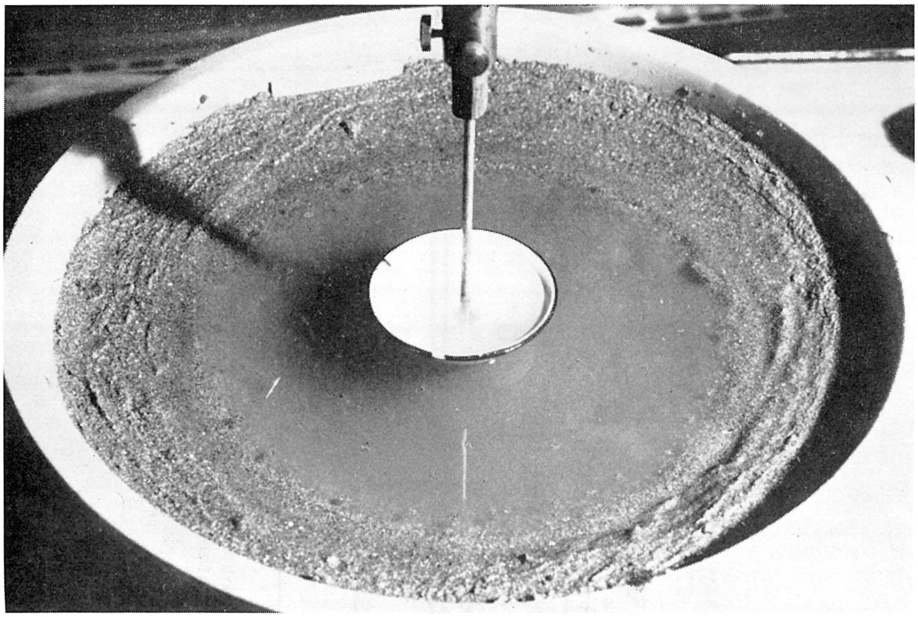
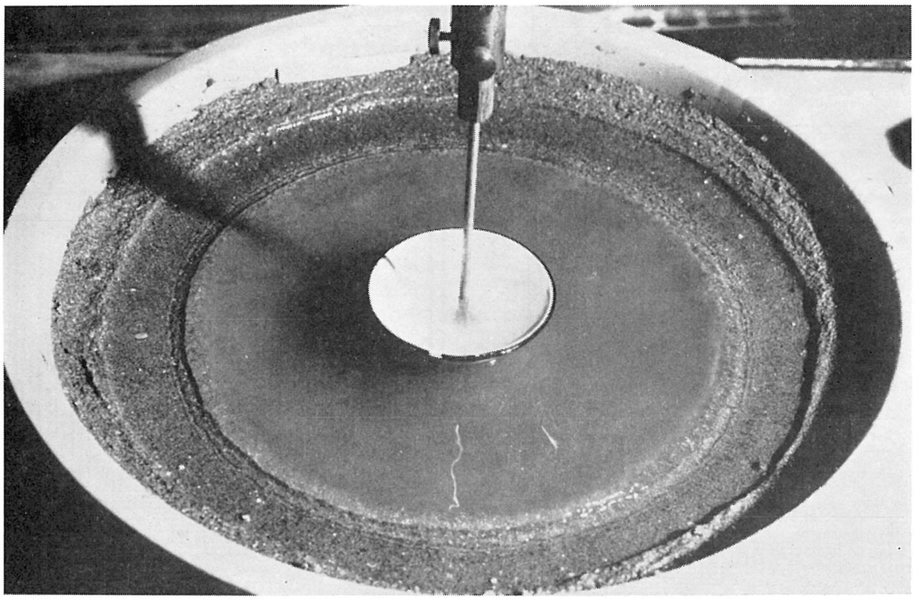


Fig. 2. Schematic diagram of experimental set-up (dimension in cm). Double arrow indicates the direction of plunger oscillation.

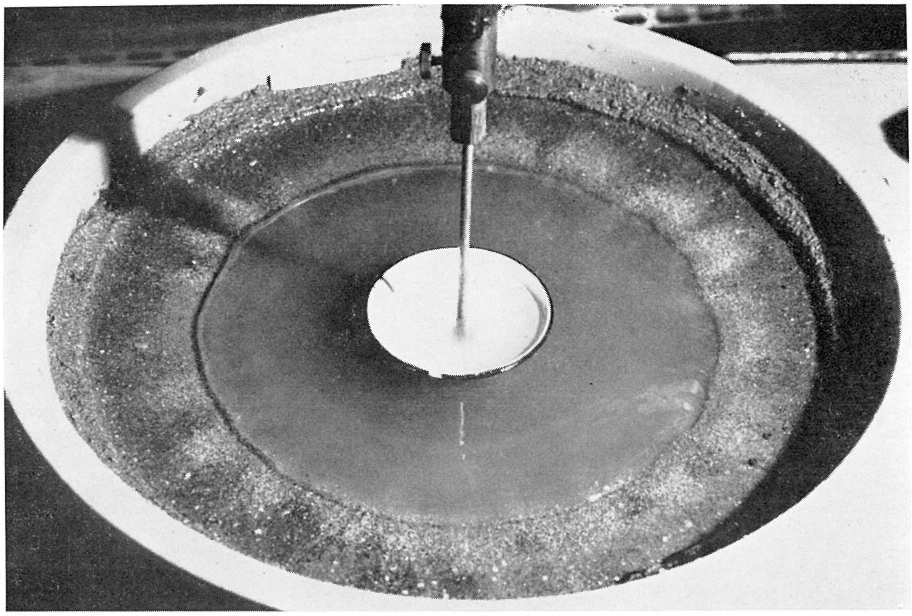
a : Circular basin, b : sand bed, c : plunger, d : sloping floor.



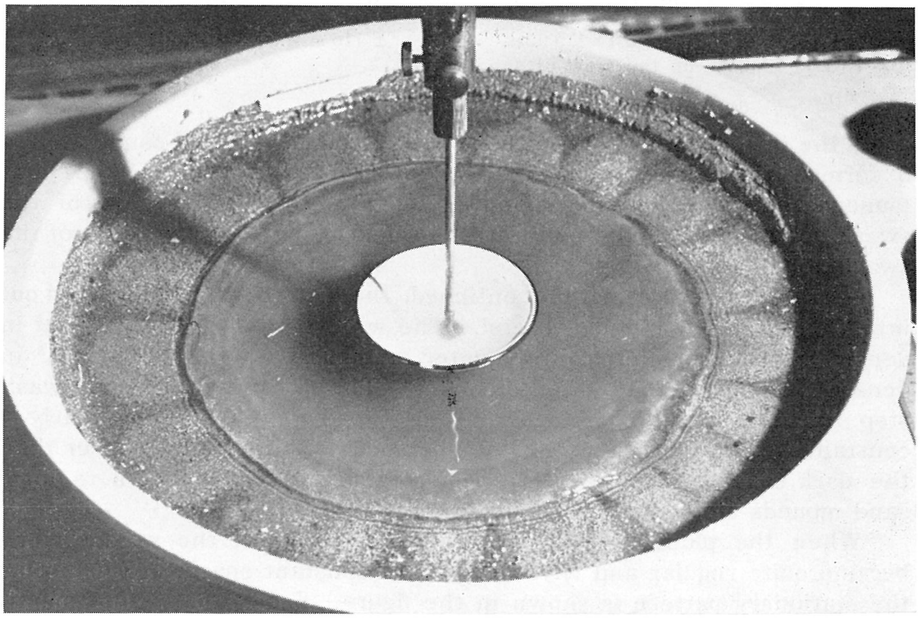
(a)



(b)



(c)



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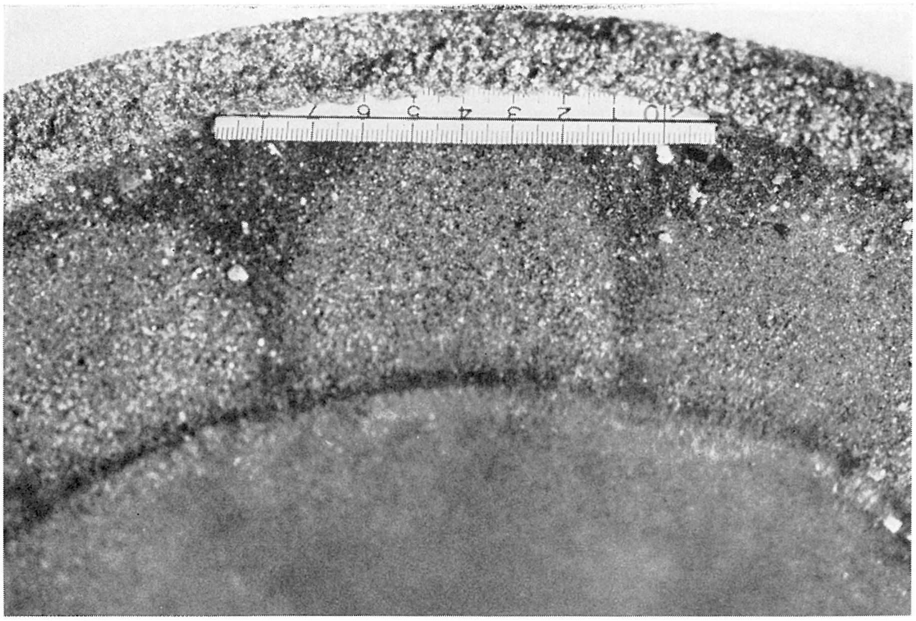


(e)

Fig. 3. Process of sand petal formation; t is the time passed from the start of plunger oscillation. d=2.0 cm, f=2.57 Hz, scale length=10 cm.
(a) t=0 s. (b) t=1.5 min. (c) t=16 min. (d) t=50 min.
(e) A close-up top view of sand petals.

after the onset of the oscillation, a smooth swash zone of sand with $\theta = 5°$ formed circumferentially (Fig. 3(b)). Then, the backwash step (Matsunaga and Honji[5]) formed along a circumferential lower edge of the swash zone, and also the berm crest formed along the upper edge of the swash zone.

As the plunger oscillation continued, the sand began to be sorted out into whitish sand and dark sand. The whitish sand was 2.46 g/cm^3 in density and about 0.025 cm in diameter, and the dark sand 2.88 g/cm^3 in density and about 0.013 cm in diameter. The circumferential backwash step line began to be distorted into a cusped wavy one with nearly a constant wave length (Fig. 3(c)). The sorted whitish sand lighter than the dark sand heaped on a layer of the dark sand and began to form sand mounds along the swash zone.

When the plunger oscillation continued further, the sand pattern became quite regular and rhythmic with a constant spacing (Fig. 3(d)); the stationary pattern is shown in the figure. Each sand mound constituting the rhythmic pattern may properly be called 'sand petal'. Figure 3(e) shows a close-up top view of sand petals. Figure 4 shows a bird's-

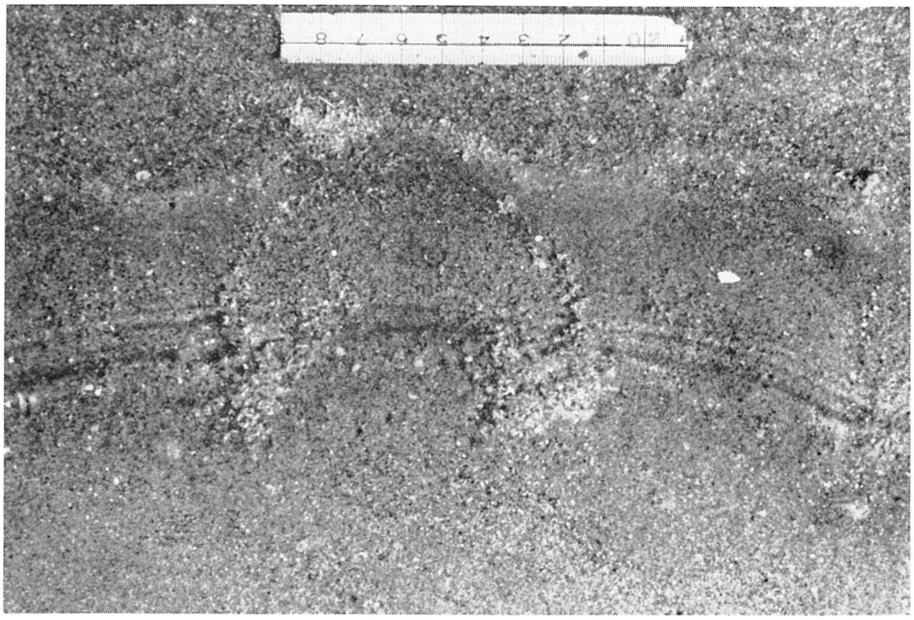
Fig. 4. Bird's-eye view of sand petals.
$d=4.0$ cm, $f=2.57$ Hz, $\theta=9°$, $t=17$ min., scale length $=10$ cm.

eye view of other sand petals. The sand pattern shown in Fig. 1 is very similar to the pattern of these sand petals.

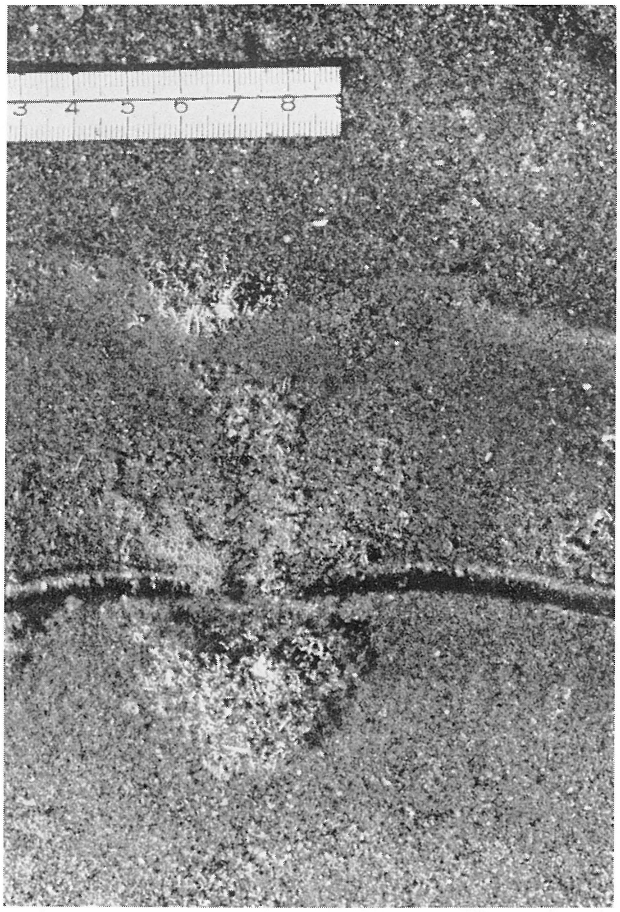
We visualized flows on and around the petals with floating sawdust (Figs. 5(a), (b)). A pair of circulatory flow was induced on the petals by wave swash (Fig. 5(a)), and a small-scale offshore (downward in the picture) current flew out along the boundary between the neighboring petals (Fig. 5(b)); the backwash step line ran transversely to the direction of the current. Based on these pictures, we illustrate the sand petals and the flows around them schematically (Fig. 6), where we also show the cross-sectional porfiles of the sand petals. The circulatory flow on a petal is counter-rotating.

We measured the rhythmic spacings L and swash lengths S (defined in Fig. 6) of a number of sand petals. The data of L are plotted against S (Fig. 7), where L increases with S approximately linearly. This is a very simple relationship though S may depend on various parameters related to waves and bed materials. According to the results of field observation of beach cusps by Longuet-Higgins and Parkin[6], there is also a linear relationship between swash lengths and beach cusp spacings.

We would like to stress that the sand petal is different from a beach cusp. At a glance, the pattern of dark sand illustrated as the dotted region in Fig. 6 has the appearance of a pattern of beach cusps. However, the dotted region is a trough and the region of sand petals is a gentle mound. This form of relief is clearly different from that of common beach cusps. The direction of the circulatory flow induced in beach cusps, as pointed out long ago by Bagnold[7], is opposite to that of the flow on the sand petals, and the position of the rip current on beach cusps described by him is also different from that of small-scale offshore current shown in Fig. 6. Furthermore, the profile of a step line of underwater deltas often followed by beach cusps as reported in Timmermans[8] and Kuenen[9] is different from the profile of the present back-



(a)



(b)

Fig. 5. Flow patterns on and around petals visualized by means of saw-dust method.

(a) Pair of circulatory flow on petals; scale length = 10 cm.
(b) Close-up view of offshore current; scale length = 6.2 cm.

wash step line.

In conclusion, the sand petal is a new type of sand patterns rhythmic along a shoreline, although it has the same type of a relationship between L and S as beach cusps.

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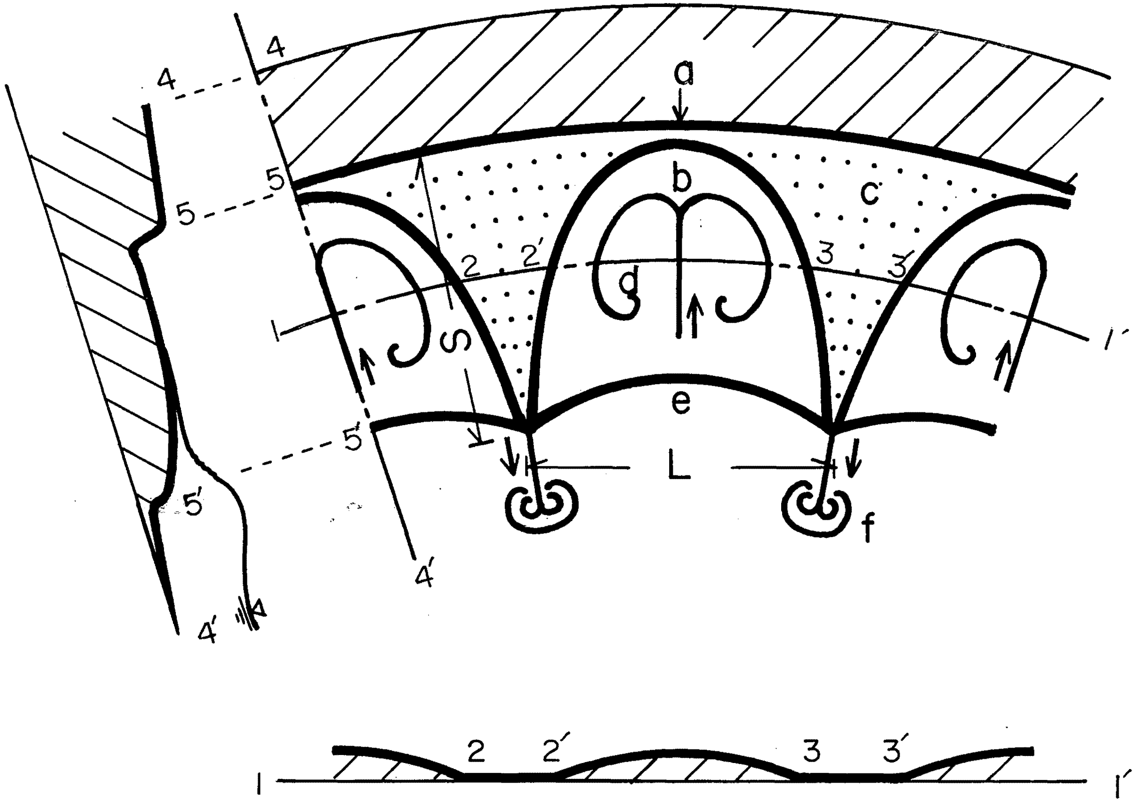

Fig. 6. Schematic diagrams of flows on the petals and their cross-sectional profiles. Arrows indicate the direction of the flows.

a : Berm crest, b : sand petal, c : dark sand,
d : pair of circulatory flow, e : distorted backwash step,
f : small scale rip current,
L : rhythmic spacing of sand petal, S : swash length.

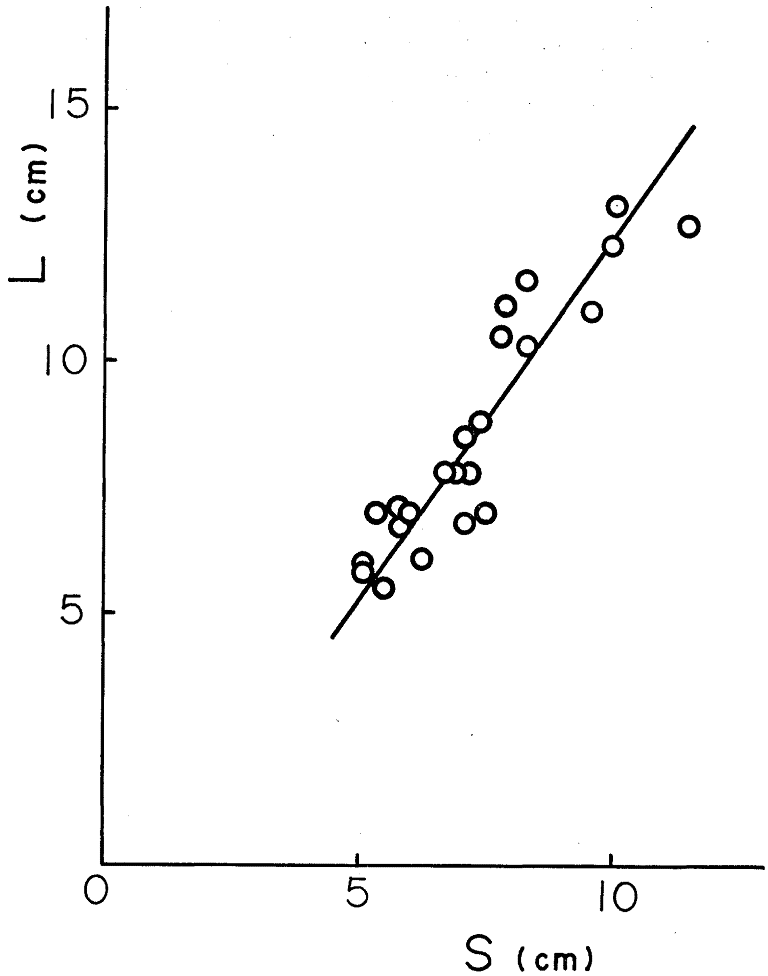

Fig. 7. Swash-length dependence of the rhythmic spacing for sand petals.

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