RHYTHMIC PATTERN OF LONGSHORE BARS RELATED TO SEDIMENT CHARACTERISTICS

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INTRODUCTION

Despite a number of valuable contributions by many predecessors, namely F. P. Shepard (Ref. 1) and G. H. Keulegan (Ref. 2), our knowledge regarding the effect of a longshore bar on the sedimentary process of a coast has long remained a plausible, qualitative understanding that a longshore bar constitutes a zone of active migration of bottom deposit due to agitation of breakers and currents. This was probably due mainly to the difficulty of performing an accurate hydrographic survey near the breaker zone. On the other hand, the geometrical characteristics along a single bar profile, which was sounded off either from a stable pier (Ref. 1) or a suspended cable (Ref. 3) resulted in a hopeless scatter.

An aerial photograph, if taken under favorable conditions, may show an interesting picture of submerged topographies in a distinct contrast made by the bright tone of a shallow bar crest or a shoal, against the dark background of a deep trough or a rock bottom. By comparing such photographic records with convenient soundings derived from some of the Japanese coasts, an interesting topographical feature of a longshore bar has been disclosed. A longshore bar may attain a rhythmic pattern consisting of echelons of arcuate (or lunate) bar unit, which in entire appearance strongly resembles that of a honeycomb.

It has also been discovered that a rhythmic bar pattern is correlated with other important factors either dynamic or static, which participate in the general processes of a coast, namely the shoreline configuration, the shoreface slope and deposit, the topographies on the offshore bottom, transformation of incident waves, the longshore currents and the littoral drifts. The authors have further attempted to develop a hypothetical concept on the origin of littoral rhythms as well as the behaviors of alongshore movement of sediment, and to consider their engineering impli-

cations on the basis of such findings.

Although our success which has been achieved so
far is yet incomplete due to lack of available data,
it is believed that the approach and concept as pro-
posed in the present paper may suggest an encouraging
line of research toward formulating a unified macro-
scopic view on the mechanics of the littoral process.

LONGSHORE BAR PATTERNS

RHYTHMIC BAR PATTERNS

Figs. 1 - 5 show reproduction from aerial photo-
graphs which were taken over the Japanese coasts. An
outstanding feature which is common to these pictures
is that the crests constitute an assembly of arcuate
units which are arranged in successive echelons of
different spacings depending upon the distance from
the shoreline. These places, equally located very
close to a river mouth, are known for predominant action
of littoral drift along the shoreline. It is recog-
nized that the farther offshore, the longer the spacing
of an arcuate unit tends to become. The bar echelons
are not completely separated from each other. The feet
of the outer units join those of the inner ones produc-
ing a wide shoal there due to broadening out of the
bar crests. This shoal extends toward inshore, frequen-
tly at oblique angles, as far as the shoreline, where
again the feet of the innermost bars join the interior
topography, the shoreline. We notice a remarkable fea-
ture that where the bar group of the innermost echelon
is merged with the shoreline there exists a slight out-
ward projection of the beach.

Thus, a beach which is confronted with a rhythmic
bar system is usually marked by a series of an orderly
indentation having the inter-apex spacing essentially
similar to that of the offshore bars and apparently
greater than that ordinarily found with a beach cusp.

Such a striking combination between longshore bars
and shoreline configuration will be seen, in the chap-
ters to follow, to represent the basic rhythms which
govern in effect the overall characteristics of other
factors either conspicuous or so minute that they may
otherwise evade our attention as mere irregularities.

OCCURRENCE OF BAR RHYTHMS

A scrutiny of extensive phtographic evidences
derived from nearly entire stretch of the Japanese
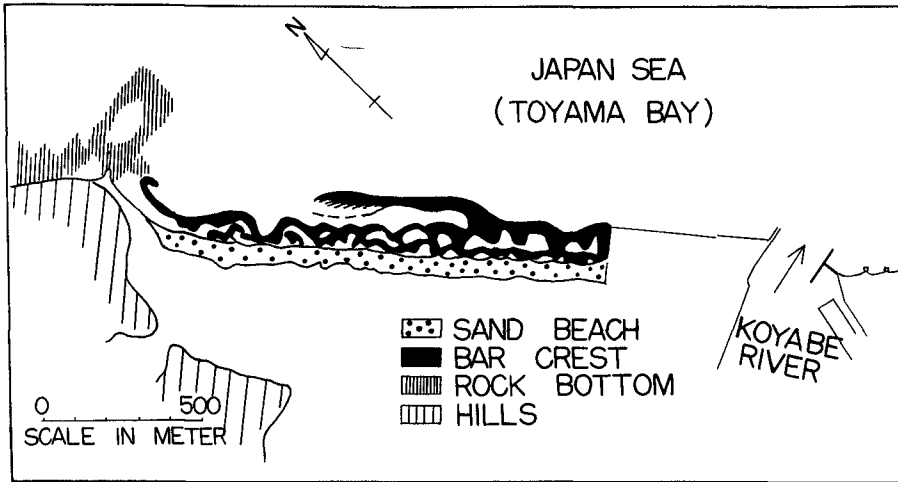
Figure 1. Rhythmic bar pattern, near Fushiki, 1961.
(by courtesy of Japan Geogr. Inst.)
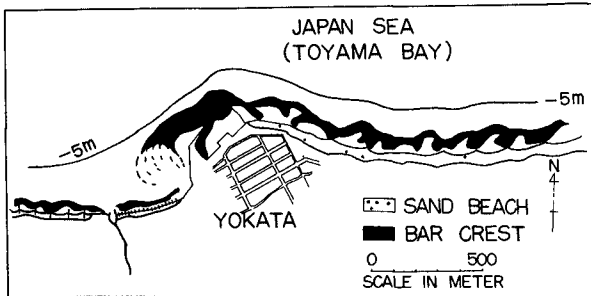
Figure 2. Rhythmic bar pattern, Yokata, 1961.
(by courtesy of Japan Geogr. Inst.)
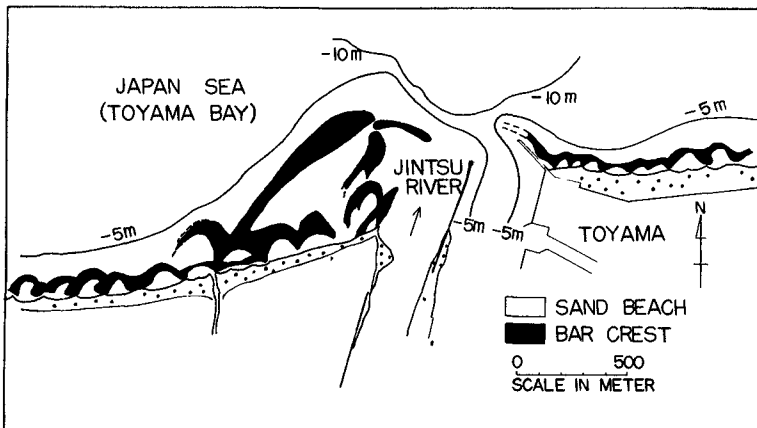
Figure 3. Rhythmic bar pattern, Jintsu, 1961.
(by courtesy of Jap. Geogr. Inst.)
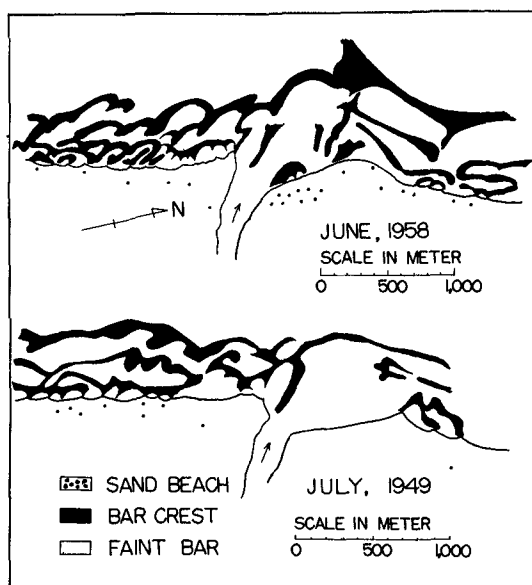
Figure 4. Rhythmic bar patterns of 1958 vs. 1949,
           Shin-shinano. (by courtesy of Jap. Geogr.
           Inst. and Niigata Prefecture)
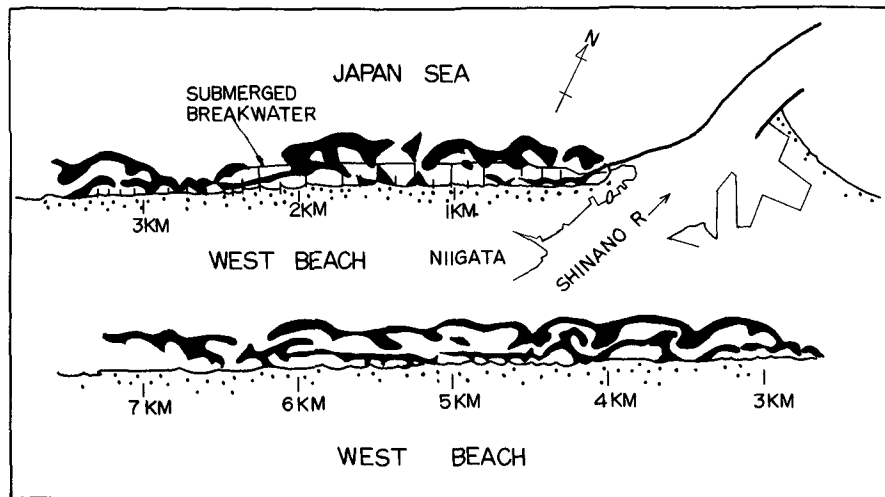
Figure 5. Rhythmic bar pattern, Niigata west beach,
           1958. (by courtesy of Niigata Prefecture)

coasts shows that a rhythmic bar system may occur at
localities where some fundamental requirements are satis-
fied. Primarily, a beach must be close to a rich source
of supply. Secondly, the bottom must be sufficiently
gentle in the shallow water zone. The local wave con-
ditions merely affect the magnitude of predominant rhy-
thms. The nature of bottom deposit is likewise ruled
out as insignificant; the rhythmic bar pattern has been
discovered not only on a sandy beach but also on a gra-
vel beach. Therefore, the beaches lying close to a
river mouth are frequently marked with bar rhythms. On
the other hand, a beach skirting a sharply descending
alluvial fan is often devoid of either a rhythmic bar
or, on some occations, even a sign of a straight bar,
although a shoreline indentation may still exist. Con-
sequently, a delta beach adjacent to an estuary is the
most likely place for occurrence of bar rhythms.

Fig. 6 demonstrates such an example. Along the
eastern half of the Toyama Bay coast which is found at
the rim of a group of alluvial fans of the Kurobe and
other rivers, the bottom slope is as great as 4 % down
to the depth of -10 m and 20 - 15 % down to -100 m,
while along the delta beach westward from the mouth of
the Joganji river the bottom slope becomes gentler,
falling to 2 - 0.8 % down to -10 m and 3 - 2 % down to
-100 m. The photographic evidences show that it is
only at the western half of the Toyama Bay coast that a
rhythmic bar pattern is found to exist, while the east-
ern half of the same coast totally lacks in a bar of
any noticeable size. The experiences of the authors on
the Japanese coasts show that a bottom slope of about
2 % down to -10 m is approximately the limit for occur-
rence of a rhythmic bar pattern.

In fact, the two requirements mentioned above may
be summed up in one definitive condition that occurrence
of a rhythmic bar pattern depends essentially on the ex-
tent to which the unconsolidated sediment on the near-
shore bottom is subjected to significant agitation by
waves. It is probably due to this reason that a rhyth-
mic bar pattern is also found at a place which is loca-
ted relatively far from a source of supply yet provided
with a gentle bottom slope. Therefore, a source of
supply must not always be a river. It may be an erod-
ing beach where the sand supply is derived immediately
from the regressing beach, or a tidal inlet where the
alongshore component of sediment drift is intercepted
over a shallow bottom near the shoreline by a transver-
sal flush of tidal currents in and out of the inlet.

RHYTHMIC BAR VERSUS STRAIGHT BAR
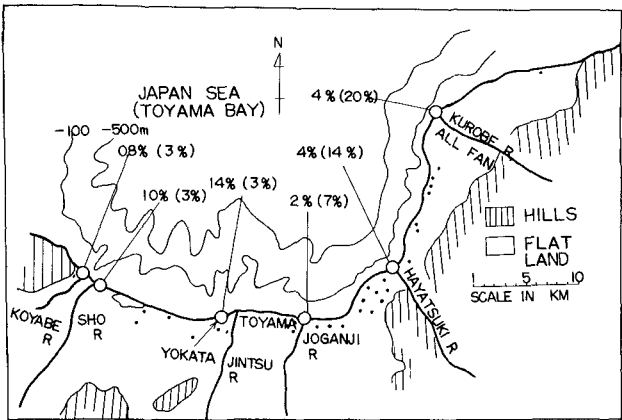
Figure 6. Bottom slopes along Toyama Bay coast.
Attached figures out of and in parentheses
indicate slopes down to -10m & -100m each.
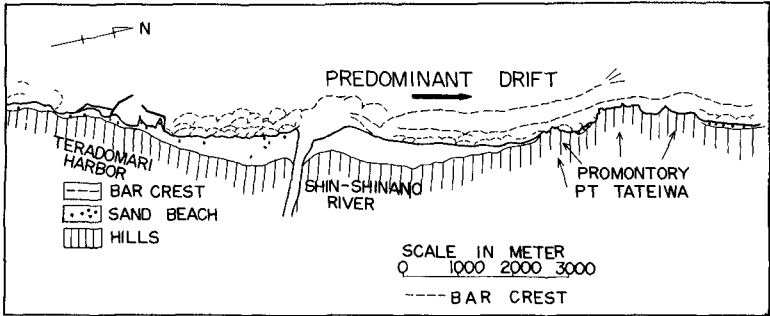
Figure 7. Comparison of rhythmic and straight bars
at outlet of Shin-shinano, 1958.
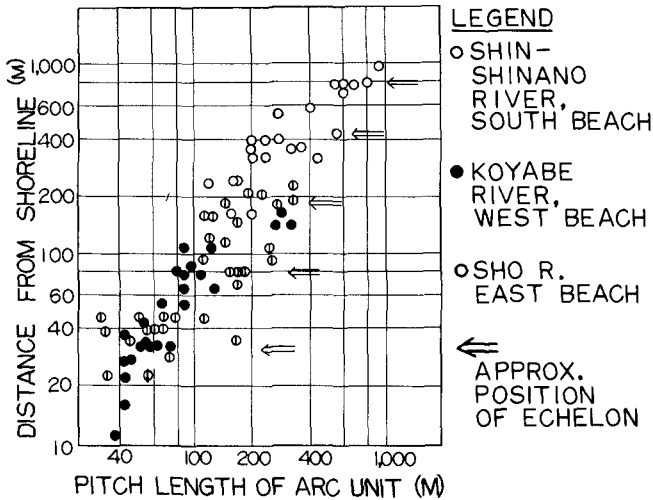
Figure 8. Size of arcuate bar with distance from shore.

A straight bar is encountered almost on any type
of sandy beach, unless the bottom slope is too steep,
say below about 2 % down to the depth of -10 m.

What are the physical properties which distinguish
these two types of bars? On the beaches cited in Figs.
1 - 5, we find the rhythmic bars more pronounced on the
updrift side of the source of supply than on the down-
drift side. According to Fig. 7, along the beach of
the Shin-shinano river the bars are largely straight
on the downdrift side. It is interesting to recognize
here that the middle echelon, a straight bar, continues
to extend on the rocky bottom around the promontories
and into a sandy bottom lying further north, while the
innermost echelon which consists of rhythmic bars is
absorbed into the sandy beach just short of Pt. Tateiwa,
the first of the three promontories in this area. On
the updrift side the rhythmic bars also fail to detour
the rock bottom in front of the Teradomari harbor.

Summing up these evidences, we are inclined to pre-
sume that a straight bar may indicate the presence of
a strong uni-directional drift of bottom deposit, which
is so active that it may transport sediment even beyond
promontories through a well-defined zone on the rock
bottom without undergoing appreciable diffusion midway;
while the rhythmic bar may rather imply a stagnating
pattern of alongshore drift in which the bottom deposit
is preserved more or less in a self-contained system of
equilibrium. In fact, such an assumption seems largely
allowable, for, as we will see later in the discussions
on the movement of littoral rhythms, the rhythmic pat-
tern of coastal topographies would not move an appre-
ciable distance along the shoreline. However, in view
of its heavy implications on the fundamental problems
of coastal sediment, this point must not be emphasized
without further evidences.

TOPOGRAPHICAL PROPERTIES OF RHYTHMIC BAR

TYPES OF BAR RHYTHMS

Fig. 8 gives a general relationship between the
unit size of bar rhythms and the position of echelons,
each expressed in terms of spacing between both feet of
each arcuate unit and the distance of the arc center
from the shoreline, respectively. Data have been read
off from the aerial photographs on the west coast along
the Toyama Bay and the south beach at the Shin-shinano
river, where the bottom slope down to a depth of -10 m
is approximately 1 %.

The unit size of a bar rhythm is almost uniform

within the same echelon, but varies to an appreciable
degree by echelon and also by locality. The average
unit size for each echelon, shown in the ordinate of
Fig. 8, seems to increase by the doubling process, say
$S \times 2^0$, $S \times 2^1$, $S \times 2^2$, ..., and $S \times 2^6$ in the order
toward offshore, in which the most appropriate value
for the basic multiplicand S will be 40 - 50 m on the
beaches treated here. The value of S may vary by loca-
lity, mainly in accordance with the regional predomi-
nance of wave conditions.

The shape of an arcuate unit is not necessarily
symmetrical. It is skewed toward the predominant drift
direction on all the beaches cited here. The skew may
be attributed to the predominant wave incidence or
direction of longshore currents. According to Shepard
(Ref. 1), rip channels will be formed on the bottom of
the surf zone. However, this is obviously unable to
affect the overall bar system for a durable period of
time, because it is a passing topography with a life
span of merely a few weeks. On the other hand, coastal
structures may affect the shape of an arcuate rhythm of
a bar to an appreciable extent, depending upon the mag-
nitude of a structure as well as the nature of a bar.
For instance, on the Niigata west beach (Fig. 5) where
part of the shoreline is protected with a submerged
breakwater and a series of groins in order to prevent
erosion, the bar rhythms are disfigured considerably,
particularly near the protected shoreline.

PROFILES ACROSS A RHYTHMIC BAR

Fig. 9 shows a bottom topography of the Niigata
west beach which was obtained by a sounding, together
with a rhythmic bar pattern traced from an aerial pho-
tograph. There is a lag of one month between these
data; however, it may not impair the usefulness of this
comparison since no significant wave action took place
in the mean time.

According to Figs. 9 and 10, a correlation between
the rhythmic patterns of a bar and the perpendicular
bottom profiles is well defined, and our previous ob-
servation is confirmed that the foot of an arcuate
unit corresponds to a shoal, while the center of the
arc to a deep trough and a steep bottom slope in the
surf zone. This fundamental relationship has also been
recognized on the beach of Tokai, Japan, which is expo-
sed to the sea and swell of the Pacific Ocean and fre-
quently subjected to extremely violent waves due to a
typhoon. The shoal may become so shallow that on some
occasions it is wadable. The authors have encountered
such an example at the gravel beach of the Ishikawa

Prefecture, where the bathing children walked over this shoal to play on the crest of an offshore bar. Here the crest of the bar rose to a depth of about 1.5 m, while the trough was about 3 m deep.

BAR RHYTHMS VERSUS NEARSHORE TOPOGRPHIES

TYPES OF SHORELINE RHYTHMS

Bibliographies are replete on the subject of beach cusp since the days of D. W. Johnson (Ref. 4). However, it has been only in recent years that the rhythmic undulation having a greater inter-apex spacing than that of an ordinary beach cusp has been given a serious attention.

Per Bruun (Ref. 5) recognized from investigation of the nearshore topographies along the Danish North Sea coast that these "shoreline waves" migrated alongshore as if they were a mass of land at a variable rate between 0 and 1,000 m per year. According to his measurement the spacing ranged between 300 and 2,000 m, while the amplitude between 60 and 80 m. Discussing on the origin of such a shoreline rhythm, he describes: "there may be some connection between the migrating undulations and breaches in the longshore bar, possibly due to erosion by rip currents because the wave trough is often formed behind a breach and the crest just ahead." He further pointed out that the rhythms ("humps") were also present on the offshore bottom along the same coast.

On the other hand, O. F. Evans (Ref. 6) made studies on the beach cusps, including a large undulation, on the southern beaches of the Lake Michigan. According to him, the beach cusp may be classified into five different categories, of which the significant types of natural origin are:
(1) "very large capelike cusps (or undulations) formed during storms along the beaches that are susceptible to considerable erosion and deposition."
(2) "large cusps (undulations) which have their apexes continuing out into the lake as a ridge of sand on the lake bottom."
(3) "ideal cusps which usually occur in series and come nearest of all to being evenly spaced."

According to his measurement, the "very large capelike cusps", which apparently are equivalent to Bruun's shoreline wave of the order of 10^3 m, are spaced within the range from 96 to 1,050 feet, the average being 296 feet allowing for an appreciable scatter. The "large cusps", the second largest of his classification
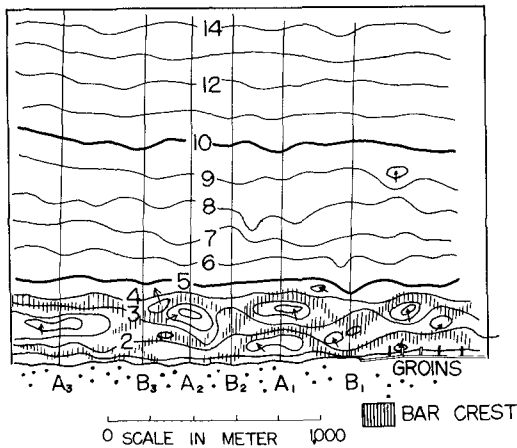
Figure 9. Nearshore topography shown with bar positions, Niigata west beach, 1958.
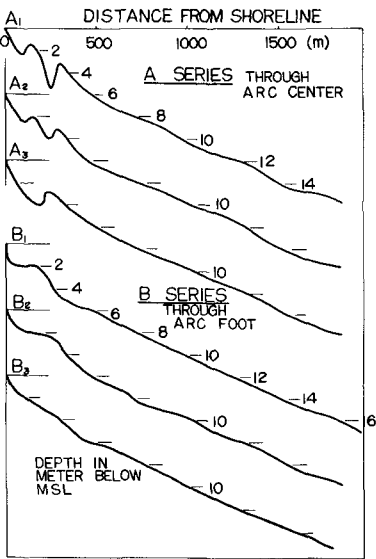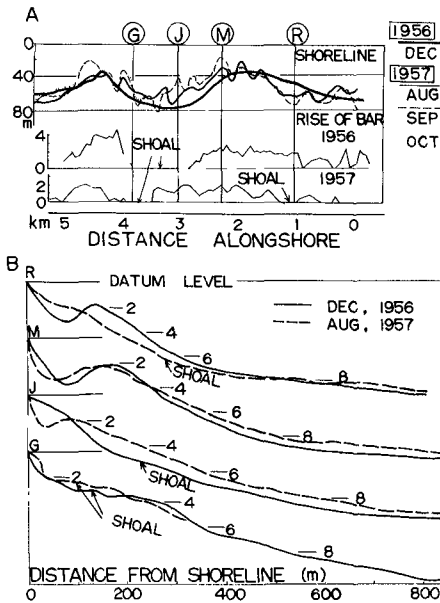
Figure 10. Perpendicular bottom profiles across bar crests and shoals, Niigata west beach. (Cf. Fig. 9)

Figure 12.
Bar rhythms reproduced from aerial photograph, 1961. (by courtesy of Jap. Atomic Gener. Co.)

Figure 11. Shoreline A. Shoreline rhythms compared with bars. (reproduced from Mogi, Ref. 8)

B. Perpendicular bottom profiles across bar crests and shoals, Tokai beach, Japan.

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equivalent to Bruun's wave of the order of 10^2 m, have also uneven spacings ranging from 33 to 102 feet with the average being 69 feet. However, the scatter of spacing is improved to a considerable degree with this cusp as compared with the capelike cusp. Finally, the "ideal cusps" are the best graded in the inter-apex spacing of the three categories, ranging from 0.9 to 34.5 feet.

He also described the nature of the foreshore bottom which was found to occur in particular connection with these different shoreline rhythms. As for the large capelike cusp, "the underwater terrace slopes gently and has on it an excess of sand down to a depth of several feet." The capelike cuspate projection results from alternate accretion and erosion of such an accidental deposition on the shallow bottom due to changing conditions of waves and currents. On the other hand, the large cusps are always accompanied by their ridges called "ball and low." He admitted further that "where the ends of the ridges join the shore, ... the increase in the supply of sand at the shoreline results in the formation of (this type of) cusp." Apparently, this transversal ridge is identical to the nearshore shoal which, as we have already recognized from the aerial photographs (Figs. 1 - 5), bridges the feet of a bar rhythm and the corresponding outward projection of a shoreline. As for the ideal cusps, however, he does not seem to have recognized any conspicuous topography on the corresponding foreshore bottom, except that their occurrence appeared to depend on the breaching of a (longshore) ridge. The relationship between the ideal cusp and the foreshore bottom has been somewhat better described by Ph. H. Kuenen (Ref. 7), who remarks that in front of the embayments the foreshore is sometimes built out under water in a delta shape.

In Japan, A. Mogi of the Japan Hydrographic Office was probably the first to demonstrate the presence of regular rhythms on the shoreline configuration. Fig. 11-A shows a partial reproduction from his result based on the shoreline investigation at the northern half of the Tokai beach, Japan. According to his measurement, the shoreline undulations found here consist of three different types of rhythms as tabulated below:

TABLE I.   Dimensions of Shoreline Rhythms, Tokai, Japan.

class	largest	medium	smallest
spacing	2,000	300	30 - 60 m
amplitude	40 - 50	20 - 30	10^0 order m

RHYTHMIC PATTERN OF LONGSHORE BARS
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In nature, these three types of rhythms are super-
posed on one another, each slightly skewed toward the
predominant direction of littoral drift. He also recog-
nized that the largest rhythms are associated with the
geometrical properties of the longshore bar, i.e. that
the apex and embayment are found behind the breaching
and the center of a longshore bar, respectively. This
finding seems just the contrary of what Dr. Bruun has
previously discovered on the Danish North Sea coast, if
we should interpret the term "breach" as used by him to
mean a shoal which lies in the gap of a continuous bar.

The present authors have also recognized regular
rhythms on the undulating configuration of a shoreline
from aerial photographs as well as sounding data in
Japan. Figs. 12 and 13 show such examples. Fig. 12
shows reproduction of an aerial photograph of the Tokai
beach, which was taken in July, 1961, roughly three years
after the beach investigation of Dr. Mogi, where the
perpendicular scale has been exaggerated to help visua-
lization. By comparing Fig. 12 with the preceding Fig.
11-A, we note a striking coincidence between the rhyth-
mic phases of 1957 and 1961, each measured three years
apart, although in 1961 a medium-sized rhythm of about
800 m in spacing occurred individually on the southern
end of the beach.

Fig. 13 has been derived from the Niigata west
beach. Here also, we recognize several types of shore-
line rhythms, as classified in the table below:

TABLE II. Dimensions of Shoreline Rhythms, Niigata.

Class	I	II	III	IV
Spacing	7,000 or greater	3,000	200 - 300	10^1 order
Amplitude	40	30	20	10^0 order

unit: meter

The rhythms of the order of 300 m, measured at one-year
interval, fit surprisingly well to each other, although
those of greater orders show some appreciable amount of
perpendicular displacements due possibly to active beach
erosion which has long been in progress here. (See Fig.
13-B) Since our range of survey is limited only to 7
km along the shoreline, there is no way of asserting
whether or not the greatest rhythm, Class I, having a
spacing as great as or greater than 7,000 m, could be
actually present in nature as a repeating phenomenon.
In fact, this might have been brought about by scour at
the foot of a long river jetty where the converging
waves produced a large embayment. (See also Fig. 5)

It is often very difficult to recognize a shoreline rhythm beyond the order of 10^3 m in spacing either from an aerial photograph or by inspection in the field, since it may merely represent the general trend of a group of lesser rhythms of the order of 10^2 m and less. Only by convenient exaggeration of an accurate sounding data becomes such a long-range undulation sufficiently noticeable. On the other hand, the best defined of these various rhythms on the Niigata west beach is that belonging to Class III, which has the average spacing of 325 m, apparently a counterpart to the medium rhythm found at the Tokai beach. This average was taken from 60 such rhythms which were observed by three successive surveys conducted approximately at one-year interval. The type of sample distribution is roughly Poissonian, having the mode value exactly at 300 m and a negligible scatter by year.

SHORELINE RHYTHMS ASSOCIATED WITH BAR RHYTHMS

The predecessors in the subject of a shoreline rhythm as cited so far have equally pointed out a possibility, though to a varying degree, that the shoreline rhythms may be connected with longshore bars. Dr. Mogi (Ref. 8) compared the phases of the shoreline rhythms with the alongshore distribution of the rise of a bar, i.e. the height of a bar crest above trough, on the Tokai beach, Japan. (Fig. 11-A) The apex of the greatest spacing of the order of 2,000 m was found to lie behind the breaching of a bar, while the embayment behind the center of each bar unit where the rise seemed most pronounced. It is surprising to note that this bar-shoreline relationship is very strict, hardly variable even if the entire system of rhythms are displaced along the shoreline. We see this feature by examining the bottom profiles across the bar and shoreline. (Fig. 11-B) The survey lines R and J were both once close to an apex and once to an embayment, and on the bottom profiles were found once a shoal and once a bar, correspondingly. Along the survey line M, which was always closer to an embayment, we find a bar at all times. On the other hand, the survey line G remained closer to an apex, and a shoal was always there.

The similar relationship between the shoreline and the bar holds with respect to smaller rhythms of the order of about 300 m. Figs. 14 and 15 give an example derived from the precision survey along a portion of the beach stretch of Fig. 11. We recognize that it is the inshore bar that corresponds to the shoreline rhythm of about 300 m in spacing, while the bar of the outer echelon corresponds to the shoreline rhythms of the order of about 2,000 m. Unfortunately, due to limitation of accuracy in the surf-zone sounding as well as smoothing
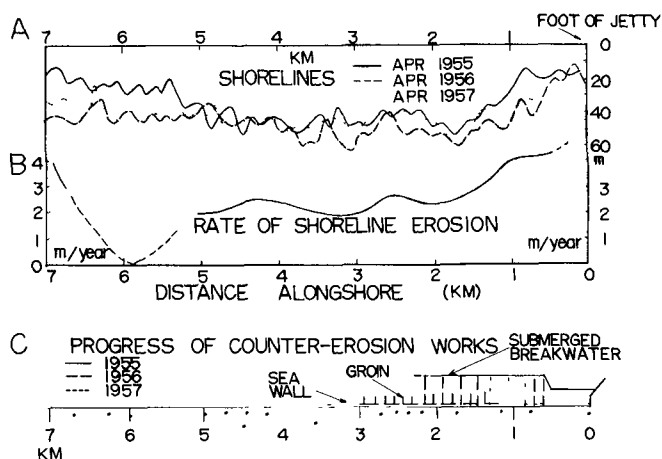
Figure 13. A. Shoreline rhythms, Niigata west beach.
            B. Rate of erosion averaged over past 10
               - 20 years shows a rhythmic trend.
            C. Progress of recent counter-erosion works.
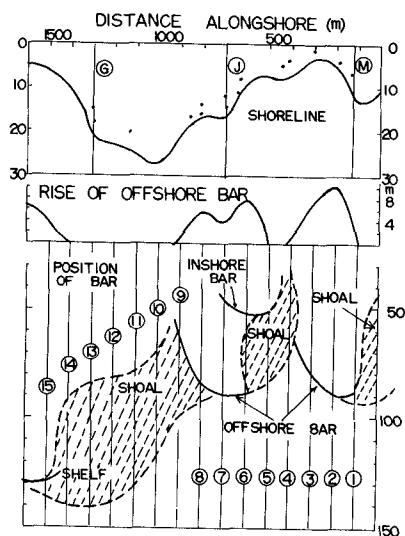
Figure 14. Shoreline and
bar rhythms reproduced
from sounding & air photo.
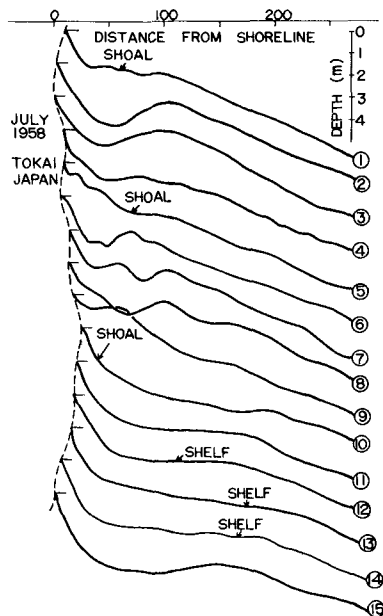
Figure 15. Bottom profiles along survey lines shown
            in Fig. 14, Tokai beach, Japan.

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of the bottom features by summer swells, it is impossible
to visualize the inshore bars from the sounding map exce-
pt as a broad shoal. Figs. 14 and 15 further confirm
the result of our previous observation that the feet of
an offshore shoal is continued toward inshore and in
effect join the apexes of the shoreline rhythms as well
as those of an inshore echelon. Where such a double
merging occurs, there is an apex of a large undulation,
while at an isolated foot of the inshore bar we find a
less conspicuous apex of a smaller rhythm. Likewise,
according to Fig. 16, which has been reproduced from the
result of Dr. Mogi (Ref. 8), the beach cusps, expressed
in terms of inter-apex spacing, seem to correspond to
their positions within the phase of a medium rhythm of
the order of about 300 m, although an appreciable scat-
ter is also recognized. The limitation of sounding ac-
curacy prevents us from tracing a minute feature on the
foreshore bottom in relation to a beach cusp.

The similar relationship has been checked by uti-
lizing the sounding data on the Niigata west beach. Fig.
17 compares the shoreline undulations, the positions of
bar crests, the rise of bar, and the refraction coeffi-
cients based on the wave period of 10 seconds and arri-
ving at right angles to the mean shoreline. From here
is also derived roughly the same conclusion as that al-
ready obtained on the Tokai beach, although the corres-
pondence between the rhythms on the shoreline and the
bar seems to have been largely obscured due probably to
gradual extension of counter-erosion structures in the
vicinity of the jetty. (See Fig. 13-C) Fig. 18 further
compares the same factors on the basis of recent sound-
ings. Agreement between the shoreline and bar rhythms
seems largely satisfactory except for the portion bet-
ween 1 - 2 km which is protected by counter-erosion
structures.

The evidences so far presented as well as our expe-
riences with aerial photographs emphasize that there
exists a significant relationship between the rhythms
of the longshore bars and of the shoreline configura-
tions. However, as we will see later, this is not a
cause-and-effect relationship; they are both a conti-
nuation of other rhythms which are found to lie on the
offshore bottom.

RHYTHMS ON THE OFFSHORE BOTTOM

Per Bruun has discovered an undulating rhythm on
the offshore bottom along the Danish North Sea coast
which is spaced by about 1.5 - 3 km and distinguished
in every respect from a mere irregularity. No other
published study is available for reference on this sub-
ject, except for extensive bibliographies regarding the
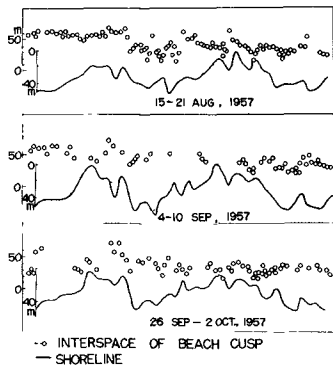
Figure 16. Along-
shore distribution
of inter-apex size
of beach cusp, re-
produced from Mogi,
Ref. 8.
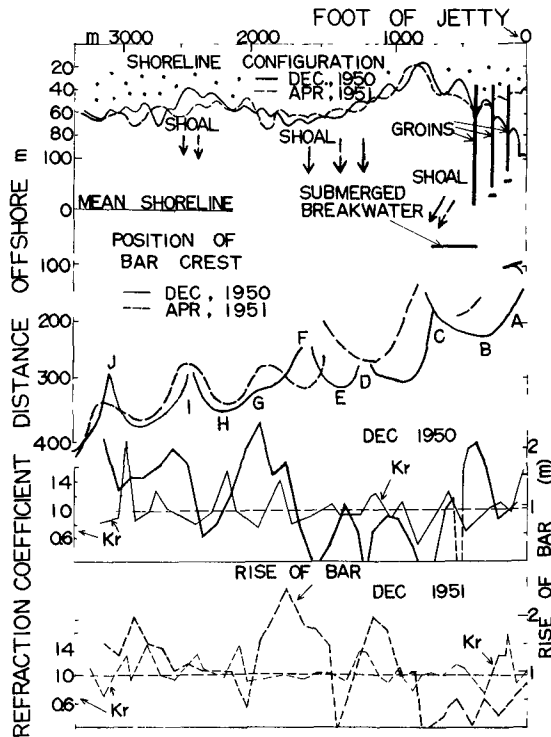
Figure 17. Shoreline rhythms, bar rhythms and refrac-
tion coefficients compared for two consecutive years,
Niigata west beach. (Cf. Fig. 19)
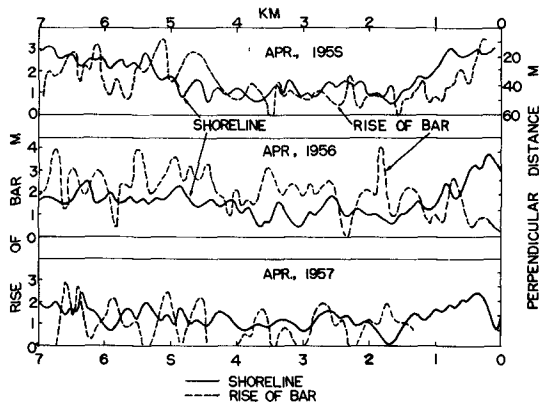
Figure 18. Shoreline and bar
rhythms compared for three con-
secutive years over longer stretch
of Niigata west beach, Japan.
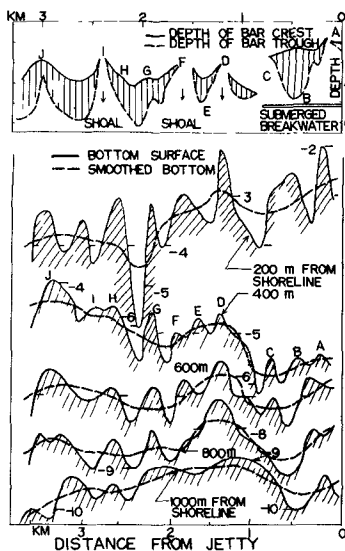
Figure 19. Rhythmic undulations on offshore bottom
compared with bar topographies, shown in
elevated view, Niigata. (Cf. Fig. 17)

submarine valleys which seem, however, to lie far beyond
the scope of a shore process. Encouraged by his study,
the present authors examined the nature of such a giant
rhythm found on the offshore bottom in relation to other
rhythms which have been already confirmed to exist on the
inshore bottom. The result has been as yet too incon-
clusive to publish in a generalized form. However, some
interesting features have been recognized.

Fig. 19 shows the elevated view of the bottom topo-
graphies of the Niigata west beach sounded in December,
1950. At about 1 km from the shoreline where the depth
is about 10 m we notice a gentle undulation on the bot-
tom spaced by about 1.5 - 2 km between adjacent ridges,
which is overlapped by a smaller inconspicuous rhythm
of the order of about 300 m. As these rhythms approach
the shore, there is a general increase of the rise of
the rhythms not only in the mean trend (shown by dotted
curves) but also in the minute pattern due to occurrence
of dendritic ridges and valleys. Thus, at the distance
of 400 m from the shoreline, i.e. immediately offshore
of the bar crest, the entire bottom is covered with
slender ridges spaced by about 300 m on average.

We recognize a remarkable feature by comparing the
positions of these ridges with the elevated view of the
longshore bars that each of the ridges is impressed on
the bar topography. The ridge corresponds to a shallow
crest and a shallow trough, and where this ridge or val-
ley is pronounced - as it is always so at the crest or
trough of the mean bottom (dotted curves), respectively
- there is a breaching of a bar, i.e. a shoal. We
further notice an important fact by comparing Fig. 19
with the shoreline configuration as shown in our pre-
vious Fig. 17, that these offshore undulations are
virtually impressed on the shoreline, i.e. that there
is an embayment behind a trough or valley and an apex
behind a crest or ridge. (Compare alphabetical symbols
attached in Figs. 17 and 19.) This pattern has been
illustrated by an ideal sketch in Fig. 20.

Now, we realize that the role of a longshore bar
is limited merely to smoothing the undulating curve
on the shoreline and unable to extinguish completely
the original rhythms which start at the offshore bot-
tom. This also explains why a shoreline rhythm occurs
where there is no bar at all. In fact, the present
authors have observed a number of such examples from
studies of aerial photographs on the Japanese coasts;
a beach having a very steep bottom slope, exceeding 3 -
4 % sometimes, is marked with shoreline rhythms where
no bar is visible.

Questions remain, however, as to the origin of
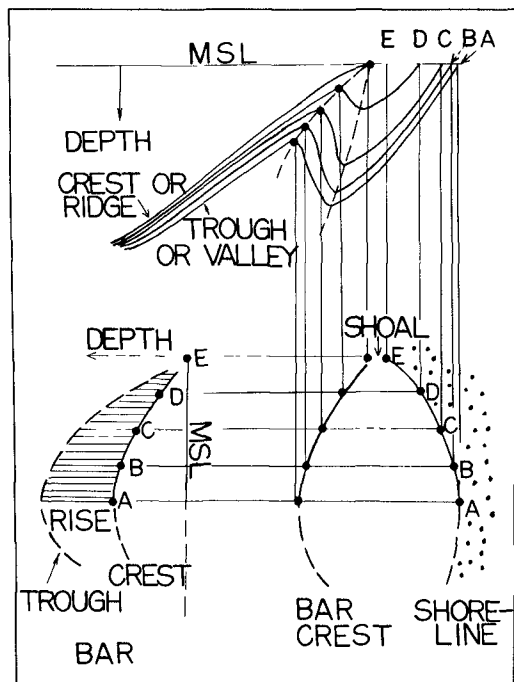
Figure 20. Ideal corre-
lation between undula-
ting rhythms on offshore
bottom, size and posi-
tion of longshore bars,
and shoreline rhythms.

REDRAWN FROM TAYAMA (1951)
SOUNDING IN 1947
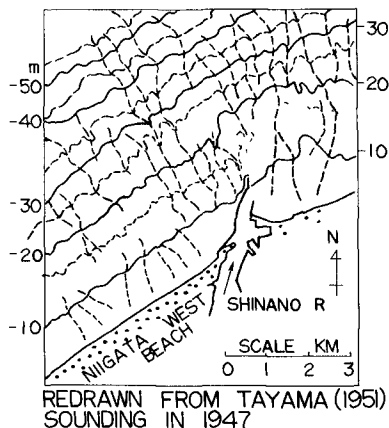
Figure 21. Submarine
topography near Shinano
river outlet, reproduced
from T. Tayama et al
(1951). Dotted curves
indicate courses of
submarine valleys.
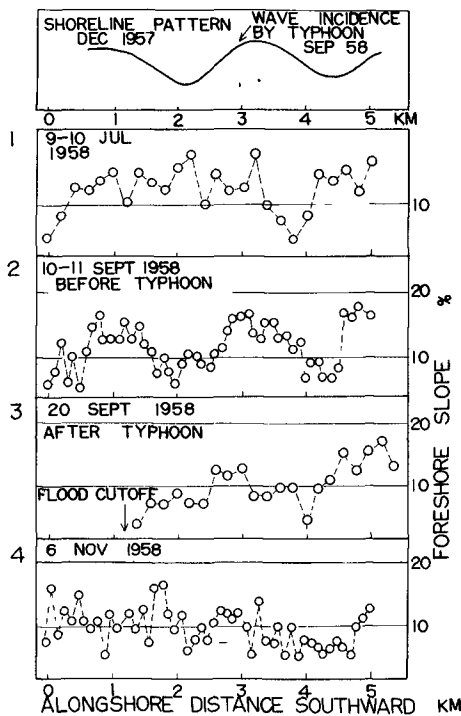
Figure 22. Shoreface
slopes of Tokai beach, shown to retain basic rhythms.

such an offshore undulation and also of its dendritic
breaking pattern on the nearshore bottom. The present
authors have not been successful in providing any recom-
mendable answer to these questions. However, a tenta-
tive explanation has been attempted as follows. It is
recalled that in an early section of this paper we have
noticed a frequent occurrence of rhythmic bar patterns
in the vicinity of a large river mouth. Usually, sub-
marine valleys are found to occur in an appreciable
number on the foreset slope of the submerged delta of
a large river. According to our Fig. 21, these valleys
are spaced by about 1 km or so on the foreset bed off
the mouth of the Shinano river, Niigata. Some of them
are traced a long way to the nearshore bottom, attain-
ing a depth of about 10 m. If all the large undulati-
ons which have been found on the offshore bottom could
be a topography originating from the valleys of the
foreset slope, it will follow that they are more or
less a stationary feature. However, the accuracy of
the available data prevents us from tracing every un-
dulation found at a depth of 10 m as far away as the
foreset bed where the depth is approximately 25 - 30 m.
We must not go too far with an array of hypothesis
which touches upon a field of the submarine geologists.

MOVEMENT OF RHYTHMS

Both Dr. Bruun (Ref. 5) and Dr. Mogi (Ref. 8) seem
to believe that the shoreline rhythms migrate along the
general direction of littoral drift. Interestingly
enough, the rate of migration estimated by both authors
are roughly congruous; 700 m/year in one instance and
0 - 1,000 m/year in general by Bruun, and 500 - 1,000
m/year by Mogi.

However, if we compare the shoreline configura-
tions of the Tokai beach, Japan, measured by Mogi in
1956 and 57 (Fig. 11-A), with that read off by the
present authors from an aerial photograph of 1961
(Fig. 12), it is realized that no substantial change
has taken place on the shoreline rhythms over a period
of 3 - 4 years, for the fundamental phase patterns of
these two data agree with each other surprisingly well,
even though the latter involves errors due to wave
swashes and tide levels which might have obscured the
shoreline position appreciably. In fact, as Dr. Mogi
points out, the shoreline rhythms migrated slightly
between winter, 1956 and summer, 1957, but they resumed
their original positions in summer, 1961, roughly three
years later. This leads us to assume that the shoreline
rhythms may undergo a slight shifting and/or skewing
movement under changing conditions of waves and currents,
but not keep on migrating indefinitely at the rate sug-
gested by these authors.

RHYTHMIC PATTERN OF LONGSHORE BARS
RELATED TO SEDIMENT CHARACTERISTICS

The present authors have once interviewed an aggregate manufacturer in the Ishikawa Prefecture, Japan, who was engaged in exploiting beach gravels at an apex of a long shoreline rhythm which was spaced by about 1,000 m. He claimed that the site had been there with the same stationary apex since he started this business several years ago. According to him, the apex had not moved to any marked degree in either direction alongshore, although an appreciable change was noticed in the perpendicular direction due to erosion or deposition by seasonal conditions of waves and currents. There is another evidence which seems to support the view of the present authors. In our previous Fig. 13-B a long-term trend of shoreline regression is compared with the rhythmic undulation of the shoreline on the Niigata west beach. The former has been averaged from the results of continuous surveys conducted for the past 10 - 20 years during which the trend of regression has been almost consistent in time though variable in position. We notice an excellent fit between the rate of regression and the general rhythms of shoreline, i.e. that the regression has always been intensive at the embayment but relatively slow at the apex of each rhythm which has a spacing of about 2,000 m on average. This seems to enable us to assume that the general trend of the large shoreline rhythms will remain virtually unchanged for at least a period of a decade or two.

On the other hand, we have not made any particular attempt to check the validity of the concept of "migrating sand humps" on the offshore bottom as proposed by Dr. Bruun, owing partly to limitation of the accuracy of data on a deep bottom, and partly to the general interruption of bottom topographies caused by the subsidence of the Niigata area in recent years.

OTHER MINUTE RHYTHMS

Shoreface slope
We are familiar with the general topography of a small beach cusp where the shoreface is steep at the apex and gentle at the embayment. However, it is very hard to recognize this feature consistently with a medium rhythm of the order of 10^2 m. Frequently, the shoreface slope on both opposite sides of an appex may show a different trend. This scatter will be partly accounted for by the presence of a series of small beach cusps and partly by the behavior of the beach at the time of measurement, i.e. whether it is progressing or retreating.

With the large rhythm of the order of 10^3 m, however, it seems that the analogy of a beach cusp holds in general. According to our measurements at the Tokai

beach (Figs. 22-1 - 22-4), the shoreface slope was
steep near the apex and gentle near the embayment, al-
though there is a scatter due probably to a skewing
pattern of the shoreline rhythms or to difference of ex-
posure of each shoreline stretch. The most striking
feature in Figs. 22 is that this basic trend does not
undergo a material change even if the beach is subjected
to formidable action of typhoon waves which attain a
height of 5 - 7 m at breaking. (Compare Fig. 22-2 and
22-3.)

Beach deposit

We have compared the measured shoreface slope with
the median size of deposit sampled at various foreshore
levels between the step and the upper berm on the Tokai
beach. The results show a hopeless scatter except for
one case in which the grain size of the step deposit
has been used from the samples of September, 1958 (be-
fore typhoon). (Fig. 23) Our data have been smoothed
(shown in dotted curves in Fig. 23) and replotted again-
st the result of Bascom (Ref. 9) in Fig. 24. It is
recognized that the slope - grain size relationship is
best defined where both factors best fit the shoreline
rhythms of the order of 2,000 m. Also considering the
fact that of all the levels on the foreshore the shore-
line step is the place where the wave impact is most
strongly displayed, we are inclined to presume that the
shoreface slope is as subtly dependent on the wave im-
pact as on the nature of deposit.

DYNAMICAL FACTORS ASSOCIATED WITH BAR RHYTHMS

WAVES

Over the nearshore bottom which undulates at regu-
lar rhythms, there will be a zonal convergence and di-
vergence of incident waves due to refraction. In a
three dimensional laboratory flume we often observe
that a train of uniform waves are refracted and regrou-
ped into separate fluxes having a finite crest length
near the shallow water. This phenomenon seems to occur
also in nature. We often encounter aerial photographs
which show separate groups of wave trains progressing
in the nearshore water almost at right angles to the
shoreline. Judging from the crest patterns as observed
on such photographs, this phenomenon is not always attri-
buted to interference between two different trains of
waves arriving from different generation areas.

We have constructed a refraction diagram by utili-
zing a wave of 10 seconds arriving at right angles to
the shoreline, and compared the refraction coefficients
Kr at the depth of 5 m with the shoreline configuration

and the longshore bars. (Fig. 17) The result is not fully convincing, mainly because the depth contours beyond -10 m was not available in our data. However, if we take into consideration a relatively slight change of the value of K_r at the positions F, G, H and I, it is recognized that there is a good correlation between wave transformation and undulating bottom topographies. The waves converge at the undulating ridge or shoal where the crest of a bar sways toward inshore and becomes shallower, while it diverges at the undulating valley or the position of the pronounced rise of a bar where the bar crest sways toward offshore and becomes deeper. We may neglect the portion A - E, since it is affected by artificial structures.

This relationship leads us to another interesting conclusion that a deep bar trough may not always be a result of high waves, for where such a deep trough, and hence a conspicuous bar having a large amount of rise, is found, the bar crest is also deep and the wave is diverged. A small wave breaking over a deep barrier may not be able to create a plunging action of sufficient violence which could account for such a deep trough as found in the center of a bar rhythm. It must be rather attributed to the influence of the offshore bottom topographies which are impressed continuously through the bar zone and into the shoreline. Then, a question arises as to why we find only a small rise near the shoal area where a greater effect of wave impact is expected to occur by our conclusion. One of the most likely causes will be that the converging waves advancing along this profile lose much of its energy by partial breaking over the undulating ridge on the offshore bottom, to such an extent that by the time they reach the final breaking position near the bar zone the height is reduced much lower than predicted by the theoretical refraction value. Another possible cause is ascribed to a surging action near the shoal which will result in smoothing of the bottom topography there. Whichever case it may be, it seems that a discrepancy of the local intensities of incident wave energies is obscured by the presence of an arcuate bar before they reach the shoreline.

Now a question arises as to how the littoral rhythms can remain stationary against rapidly changing conditions of waves. Is it possible that a particular type of littoral rhythms may represent a state of equilibrium where the wax and wane of the nearshore topography is delicately balanced against a particular type of waves? The present authors find it impossible to provide any promising clue to answer this extremely difficult yet vitally important question for the time being. However, as a helpful suggestion, an analogi-

cal example is drawn from our observation of the formation of a beach cusp which seems to correlate the stability conditions with the spectral properties of incident waves. The actual process of cusp formation is illustrated in Fig. 25; the wave was a gentle swell of 0.5 m in height and 8 seconds in period, arriving perpendicularly to the shoreline.

Stage 1. Backwash due to the preceding wave retards breaking of the following wave at the embayment, and breaking occurs prematuredly at the apexes.

Stage 2. Uprush at the apexes makes a two-thronged advance and a moment later a delayed breaking occurs at the embayment.

Stage 3. All the uprush begins to meet at the embayment. Impeded by flanking uprush from the apexes, that of the embayment is halted midway. Thus, a scarce amount of material is pushed upward from this part, while a relatively great amount of coarse material is carried up toward the summit of the apex.

Stage 4. All the uprushes clash at the center of the embayment causing a strong turbulence. Backwash starts toward offshore immediately thereafter, eroding the embayment and carrying fine material with them. Backwash gains in strength attaining a maximum momentum at the shoreline just where the following wave is about to break. And the same process is resumed.

It is doubted whether a group of waves each possessing a distinguished wave period could produce the same effect, for the backwash may be either too early or too late to create the breaking pattern of Stage 1, and consequently the succeeding stages will be largely interrupted. It seems necessary that the waves must have a relatively narrow optimum band of spectral frequencies in order to form a beach cusp. The shoreface slope will also count, since the time needed for the uprush and backwash to conclude a cycle should coincide with the wave period.

It is questionable if this observation with a small beach cusp could be extended to a greater rhythm of the order of 10^2 or 10^3 m. However, on the other hand, we realize that there exists a large-scale and long-period return of energy from the surf zone toward offshore in a manner of surf beat (having a time scale of 10^2 seconds) and rip currents, which represent a sporadic recompensation of the potential energies of the surf zone fed by the mass transport of the incident waves. Accordingly, our hypothesis is that there may

Figure 23. Shoreface slope and grain size at shore-
line step shown to follow simi-
lar trend.(Cf. Fig. 22, upper
insert, -2 and -3)

DISTANCE SOUTHWARD FROM
KUJI RIVER IN km
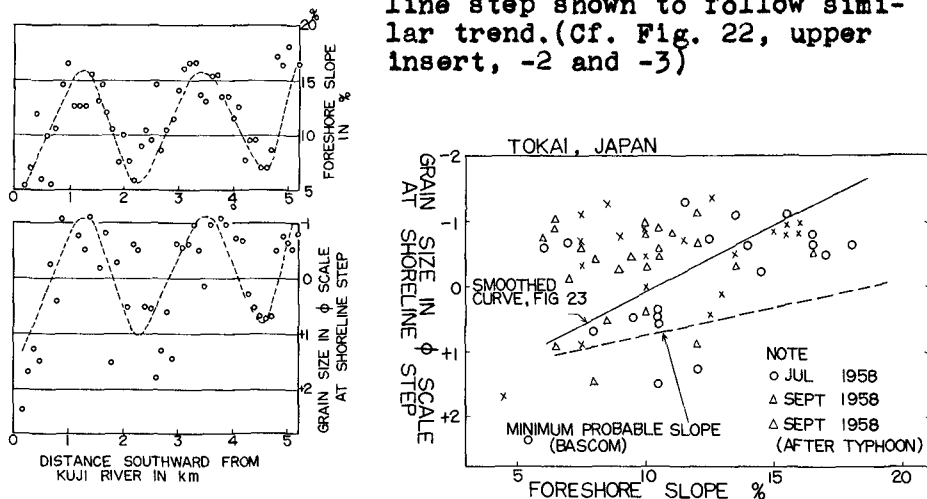
Figure 24. Grain size-shoreface slope relationship
compared with result of Bascom. (Cf. Fig. 23)

EXPOSED SHOREFACE ×××× BREAKER
WAVE OR SWASH ⟶ SWASH DIRECTION
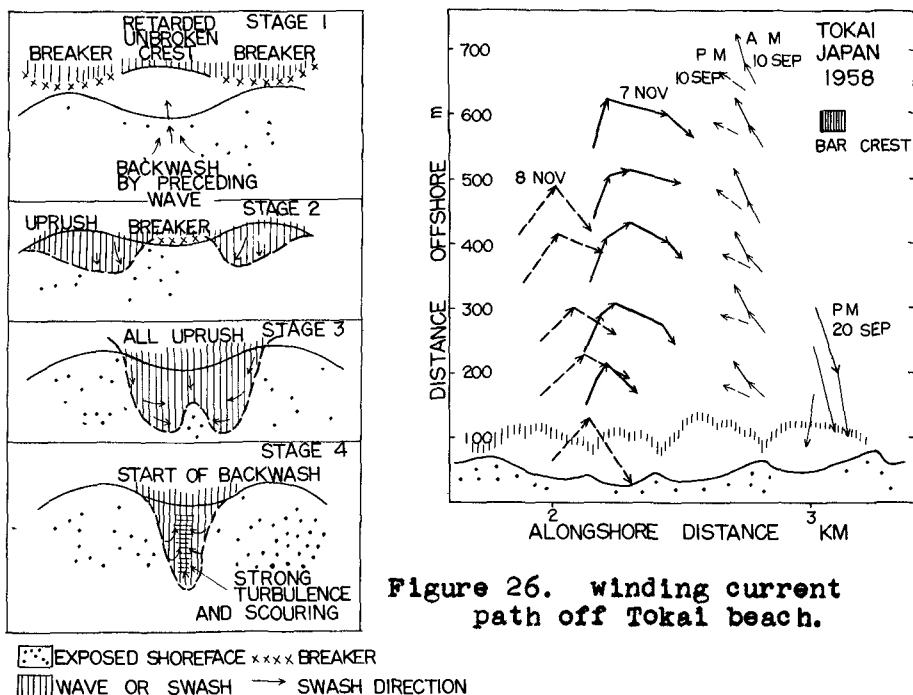
Figure 26. Winding current
path off Tokai beach.

Figure 25. Process of swash action at beach cusp,
sketched on the basis of field observation.

be a particular long-term set of wave spells having a
well graded ensemble property of spectra which is com-
patible with the particular stability equilibrium of a
coast. However, there remain yet a number of other
important questions which must be tackled before procee-
ding to answer ours.

LONGSHORE CURRENTS

According to our field investigation of longshore
currents at the Tokai beach, the path of floats assumed
a winding motion in space and time as they drifted along
the shoreline. Fig. 26 shows some of such measurements,
which were obtained by using a current vane placed at
1 m below the sea surface. An interesting feature of
these simultaneous paths of the floats is that they
follow roughly a similar curve over the entire zone of
measurement ranging from the shoreline to an offshore
distance of about 600 m (about 8 - 9 m deep). The cur-
rent velocities were very low at all times, mostly ar-
ound 30 cm/sec.

On the other hand, we measured the alongshore com-
ponents of current velocities by using the same type of
float. (Fig. 27 A-F) Despite that each run was carried
out at different time and under different wave condit-
ions, we recognize a feature which is largely common to
all the measurements, that at an alongshore position of
about 2.5 km, the approximate position of a large shore-
line embayment (See Fig. 11-A.), there is always a sharp
change of current velocities and occasionally a complete
reversal of direction, while near the positions of about
1 km and 3 km, approximately the shoreline apex, the
reverse currents seem to predominate.

An immediate conclusion which could be derived
from the results of these measurements is that there
seems to exist a rhythmic unit of current system which
coincides with each position of embayment of the order
of 10^2 and 10^3 m. This assumption has been illustrated
in an ideal picture in Fig. 28. According to this as-
sumption, there exists an independent whirling current
in the embayment of the shoreline, while there is a
continuous current in the offshore water which winds
gently in accordance with the intervals of the whirl-
ing eddies. Therefore, in front of the embayment where
the alongshore components of the whirling current come
in phase with those of the offshore current, the mea-
sured values are higher than those in front of the apex
where two currents are often opposed. It seems as if
the longshore currents consisted of a nearshore circu-
lating system of winding currents and eddies which is
more or less independent from the neighbors and con-

(A)
(B)
(C)
(D)
(E)
(F)

ALONGSHORE VELOCITY COMPONENT CM/SEC

DISTANCE ALONGSHORE KM

ALONGSHORE DISTANCE KM
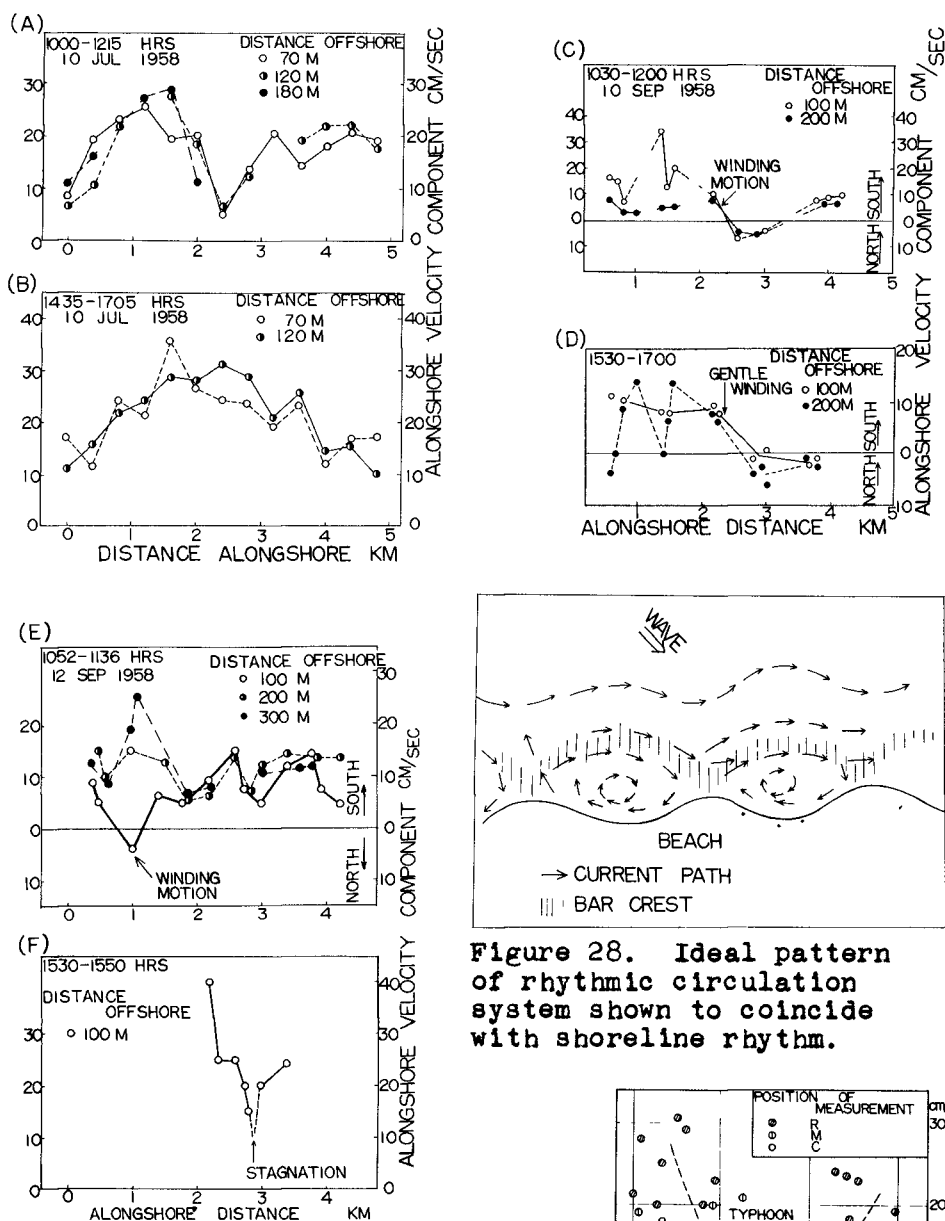
**Figure 27. Distribution of
alongshore velocity components,
Tokai beach, Japan.**

**Figure 28. Ideal pattern
of rhythmic circulation
system shown to coincide
with shoreline rhythm.**

BEACH
→ CURRENT PATH
||| BAR CREST

**Figure 29. Alongshore compo-
nents of swash currents by
typhoon waves measured at dif-
ferent positions of shoreline
rhythm, Sept. 1958, Tokai beach.**

POSITION OF MEASUREMENT cm/sec
R
M
C

TYPHOON
EYE
OVERHEAD

TIME IN HRS

ALONGSHORE DISTANCE KM

273

fined in an embayment of the rhythmic undulation of the shoreline.

This ideal pattern of currents will undergo a change if the current velocities are intensified. Fig. 29 shows an extreme case in which the alongshore components of swash currents were observed at the shoreline during the peak of typhoon waves. We still recognize the effect of the rhythmic configuration of shoreline on the current pattern, i.e. the currents are speedier at the place which is exposed to wave incidence (R), while they are relatively low at the sheltered side of the shoreline apex (M and C).

LONGSHORE DRIFT

Significant drift of longshore sediment occurs mainly along the shoreline and the bar crest where the bottom deposit are easily set in suspension by agitating action of breakers. According to the observation of the authors, these two types of longshore drift seem to occur in a step-and-rest manner following the rhythms on the shoreline and the bar.

In order to study the behavior of beach drift, the authors dumped brick fragments of about 16 mm in median diameter in front of a beach cusp on the Tokai beach. The breaker height was about 1 - 2 m, and the current velocities ranged from 5 to 30 cm/sec. The drifting fragments were washed away to the shoreline step and none was found to return to the shoreface, whereas it is usually believed that beach drift along the shoreline occurs in a continual zig-zagging action on the shoreface slope. Interestingly enough, they were discovered at the updrift step of the downstream apex in an appreciable quantity. Our explanation of this field experiment is that where there exists a conspicuous indentation of a beach cusp the beach drift will move in a stepping flight from one apex to another in the direction of the longshore current rather than dragged on the shoreface where exchange of swash between the neighboring embayments is hindered by a steep rise of the intermediate apex. In connection with this, it is recalled that the famous Einstein hypothesis on the movement of bottom deposit in a two-dimensional flow emphasizes on the rest time between flights of an individual grain. In the same analogy, it may be said in our case that the rate of beach drift along the shoreline will to some extent depend on the rest time of the bottom sediment on the updrift side of a beach cusp. However, we must think of a possibility that this ideal pattern will undergo a change, as has been the case with longshore currents, if wave conditions become more rigorous. Under such conditions,

a relatively stronger erosion will take place on the up-
drift side, producing a skew of the shoreline rhythm to-
ward the downdrift direction.

In considering the littoral drift along the bar
crest, it must be recalled that the longshore current
takes a winding path roughly conforming the curvature
of a longshore bar. There is no reason why the bottom
sediment on the bar crest should not be affected by
this winding behavior of current and carried along the
same curvature from shoal to shoal. This path is a
lengthy detour involving an appreciable process of dif-
fusion midway, but it may still be relatively short as
compared to the rest time during which the drifting
sediment remain deposited at the shoal. Here again we
are faced with the possibility of a rhythmic flight of
littoral drift.

According to our hypothesis which has been discus-
sed so far, we realize that it will be very difficult
for the bottom sediment to travel perpendicularly across
the surf zone between the shoreline and the longshore
bar. In fact, as we have already seen, the embayment is
a position which is most susceptible to erosion, or, in
other words, a position where the drifting sediment will
find it most difficult to arrive and settle. According
to the observation of Dr. Mogi on the Tokai beach, when
the beach was advancing the beach cusp occurred, but
when it was retreating the beach cusp disappeared. It
seems that only with appearance of a beach cusp the
embayment can arrest a sufficient amount of beach drift.

Our hypothesis regarding the rhythmic behavior of
littoral sediment will further lead us to propose a
detailed process on the perpendicular movement of the
surf-zone sediment. The conventional notion is that
a steep wave erodes the beach by carrying an appreciable
amount of beach material toward the offshore bottom,
which is, however, carried back to the beach by a sub-
sequent swell of a low steepness. Our explanation is
that if a swell predominates there will be a strong on-
shore drag of bottom deposit at the shoal due to vio-
lent surging of refracted waves, thus giving rise to
an increase in the portion of the beach drift as compa-
red to the portion on the bar crest. On the other hand,
if a strong wind wave predominates, there will be a re-
inforced component of offshoreward recompensation of
incident energies in the form of a rip current or under-
tow, thus resulting in the increased portion of litto-
ral drift along the bar crest and in the relative dec-
rease in the beach drift. In the latter case, the result
will often be an erosion at the shoreline.

SOME ENGINEERING IMPLICATIONS OF LITTORAL RHYTHMS

Dr. Bruun states in effect that a sudden silting may occur at a coastal inlet due probably to migration of a shoreline hump or wave. This statement seems an adequate warning, and in the light of our theory it must be afforded more emphasis since such an accident might recur due to the same wave which would not migrate away at a noticeable rate. The authors are aware of a case where a sudden advance of a shoreline at a portion of the eroding beach was attributed to some mysterious action of a newly built sea wall. Although the authors have not had an opportunity to investigate the sounding data on the beach in question, it is highly probable from our theory that it is due to the shifting action of a shoreline rhythm. No positive action of a sea wall could have been involved in this case.

The authors have been impressed, in reviewing a number of instances from aerial photographs, by an inadequately short length of coastal groins as compared to the distance of a longshore bar from the shoreline. However, in order to provide a workable design criterion on the functional specifications of groins or jetties, we will have to proceed further with a continuing effort to verify the hypothetical processes as tentatively proposed in the present paper with quantitative evidences.

The rhythmic distribution of wave impacts along the shoreline is also something to take into consideration in designing a coastal structure. This point commands a particular weight when a structure, such as a submerged breakwater, is to be placed on the offshore bottom where waves will act without undergoing a smoothing action by a bar. Further, by considering the stationary nature of the littoral rhythms and hence of the alongshore distribution of wave impacts, we may specify the local strength of a sea wall or a unit weight of armor elements for each position within the rhythm phase. In fact, on the Niigata west beach, the submerged breakwater was scoured by violent breakers and slumped from position to position. There is a sign that this failure pattern follows the undulation rhythms on the offshore bottom, although we have not yet completed numerical checking on the details of this process.

However, the most immediate and valuable gain from recognizing the presence of stationary littoral rhythms is a possibility that we can shed light on the seemingly intractible process of a coast by introducing an orderly procedure of approach. We are in a position to treat the undulating topographies on the coastal feature as

important "factors", which in the past have been understood as mere irregularities.

Finally, the present theory will provide helpful suggestions in planning a coastal investigation project, namely in determining the factors and areal extent to cover and emphasize as well as the reasonable procedures of measurement and the adequate period of investigation.

CONCLUDING REMARKS

1. A careful investigation of nearshore topographies by aerial photographs as well as sounding data has shown that a rhythmic bar system is tied in closely with various rhythms found along the littoral zone.

2. These rhythms are classified roughly into three different types of the order ranging from 10^C to 10^3 m.

3. These rhythms, represented in various factors such as longshore bars, shoreline configurations, deposit and slope of shoreface, waves and currents, have been found to originate at the undulations inherent to the offshore bottom.

4. The origin of such a large-scale rhythm on the offshore bottom as well as dendritic ridges or valleys on the inshore bottom, has been left for a future problem.

5. Several hypotheses have been presented as to the rhythmic transformation of incident waves, rhythmic behaviors of littoral currents and drifts.

6. Recognition of the presence of stationary rhythms on a coast yields useful suggestions regarding the engineering purposes.

due to these people.

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