Some Ancient Shore Features

著者	Mii Hideo
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Hideo Mii

(With 9 text-figures)

INTRODUCTION AND ACKNOWLEDGEMENTS

This study is undertaken to clarify the characteristics of the erosive features of the recent sea shore and as related with the geological significance of some erosive features which are found on the surface of unconformity and considered as those formed on the ancient shore. In this article are described and illustrated the possible shore features in the geological column and some buried by the deposits of marine terraces of Quaternary Period on some coasts in Japan.

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REMARKS ON RECENT ROCKY SHORE

The characteristic features of some recent rocky shores will be briefly stated for comparison with those of ancient shores. Among the features some are now being produced by marine and subaerial agencies associated with the present sea level, others are emerged or submerged ancient ones. The shore features to be described were observed on, enumerated from the north, 1) the southwestern coast of Aomori Prefecture, 2) Natsudomari Peninsula, Aomori, 3) Oga Peninsula, Akita, 4) Miyako and its vicinity, Iwate, 5) Iwaizaki, Kesennuma City, Miyagi, 6) Kinkazan and Enoshima Islands, Miyagi, 7) Matsushima, Miyagi, 8) the southern coast of Boso Peninsula, Chiba, 9) Misaki and its vicinity, Kanagawa, 10) the southern coast of Izu Peninsula, Shizuoka, 11) the eastern coast of Kii Peninsula, Mie, and 12) the southwestern coast of Kii Peninsula, Wakayama.

1. Major Features

In general, rocky coasts are characterized with four kinds of major erosive features, namely, offshore, shore and coast platforms, and sea cliff. Their characteristics are summarized as follow.

i) *Offshore platform* :- This occurs in the offshore zone permanently covered with water, and is remarkable for the seaward sloped surface commonly of about five degrees. The depth varies according to places of whether facing the open or sheltered sea. At the seaward margin the depth measures about ten meters in the open sea, but gradually decreases toward the sheltered sea and is usually less than five meters along the extremely sheltered coast. The landward and seaward margins are bordered with steep slope of cliffs.

The major part of the offshore platform is considered a wave-cut surface produced by present wave erosion, and therefore, it may be called wave-cut platform.

ii) *Shore platform* :- This occurs within the intertidal zone, characterized with nearly horizontal surface bordered with a steep slope or low cliff at the seaward and landward margins respectively. It is more or less higher on the open coast than on the sheltered one, but the difference in height is generally slight.

The majority of the shore platforms may be due to peculiar planation of waves, by which the lower limit of active subaerial weathering becomes exposed, and therefore, may be called sea-level platform.

iii) *Coast platform* :- This occurs at various levels above highest high water level and are usually sloped seawards. Some are developed at relatively constant levels of about two and six meters above mean sea level, and others are inconstant. The former type is believed to be associated with the ancient raised sea levels indicated by raised beaches. The latter is possibly produced by storm wave or subaerial erosion.

iv) *Sea cliff* : This is commonly remarkable for the steep slope of about 60 degrees to vertical or overhanging in part, while the cliff is of a gentle slope of about 10 to 20 degrees in some cases where the bedding or joint planes are gently inclined seawards and the coasts face the open sea. There are two types of sea cliffs, active cliff with exposed solid rocks, and dead one covered with debris and vegetation. The active cliff is well developed on the open coast, and decreases in height towards the sheltered coast. Generally there is no active cliff on the extremely sheltered coast such as the head of deep inlet where the dead cliff is developed. Essential factors for their development are wave erosion at the base and subaerial weathering in the higher part of the cliff.

2. Minor Features

The mentioned major features are generally sculptured by various kinds of excavations such as may be found on the surface of unconformity. These are not uniformly incised in the major features, but are developed locally according to the height above or below sea level, the kind of rocks, and the place whether facing the open or sheltered sea.

i) *Wave-cut notch, cave, and tunnel* :- These occur commonly at the foot of sea cliffs and the edges of the coast, sea-level and wave-cut platforms, but are sometimes found at the base of low scarps developed on the platforms. The majority of these excavations are incised into the weak planes or layers, and therefore, they are often increased in their height towards the up-dip side according to the inclination of weak planes or layers. These are mainly due to wave abrasion aided by sand rasp, and partly to current erosion and solution.

ii) *Wind-blasting notch and cave* :- When compared with the wave-cut notch and cave above mentioned, some excavations show similar features, but differ in their inconstant levels and the irregular outline. Such type of excavation is the result of cavernous weathering, which wind blasting aided by sand rasp may play an important part. The wave-cut excavations occur in cliffs of all kinds of rocks, but the wind-blasting ones are generally lacking in the cliffs of homogeneous fine-grained rocks such as fine-grained sandstone, siltstone, slate, limestone, granite and others. They are common in cliffs of conglomerate, coarse-grained sandstone, coarse-grained tuff, tuff breccia, andesite and liparite. In addition, the wind-blasting excavations are relatively large and abundant on the coast facing the direction of prevailing wind.

iii) *Pothole* :- Potholes excavated by wave abrasion are classified into three main types according to process, viz., a) eddy hole produced by the eddy action of water, b) gouge hole caused by the oblique impact of water, and c) plunge-pool hole produced by falling water. Although potholes are of various shapes and dimension, they are generally nearly circular or elliptical in outline, ranging from 0.1 to 2.5 meters in diameter and depth.

The potholes occur on sea-level and wave-cut platforms, but are more common on the lower part of sea-level platform and in the higher part of wave-cut platform than elsewhere. Generally, they are best developed at the head of miniature inlets and along the weak planes such as joint or bedding. With regard to the local difference, it is noteworthy that they are relatively large and abundant on the open coast rather than on the sheltered one.

iv) *Solution pool* :– Solution pools are broad and shallow depressions ranging from ten to 100 centimeters in diameter and one to ten centimeters in depth. The majority of them measure about 30 centimeters in diameter and five centimeters in depth. Such pools occur only on the nearly horizontal parts of sea-level platforms of conglomerate, sandstone, limestone, coarse-grained tuff and tuff breccia.

v) *Solution hole* :– Solution holes, being narrow and relatively deep depressions produced by solution, are nearly circular in outline, ranging from three to 20 centimeters in diameter and depth. The walls are vertical or slightly concave and irregularly etched in general. These are often closely incised at the seaward margin of sea-level platforms of sandstone and rare on the horizontal part or in the rocks other than sandstone.

Such a type of depression may originate from the holes due to boring organisms and possibly enlarged by the solvent action of fresh and sea waters.

vi) *Hole by boring organisms* :– Some echinoderms, chitons, gastropods, pelecypods and algae have boring activities especially chemically, and incise various shaped holes into the rocks below high water level. Such holes are usually small ranging from one to several centimeters in diameter, and are developed on the surface of sea-level and wave-cut platforms and also the face of a scarp or into the wall of potholes. Some have narrow mouths but more or less broaden out within, others are bowl-shaped or irregular pits which may indicate an initial stage of the excavation. These are best developed on wave-cut platform and in the lower part of sea-level platform of fine-grained sandstone and siltstone.

vii) *Honeycomb structure* :– This structure consists of closely spaced holes which are nearly circular or elliptical in outline, ranging from a few millimeters to about one meter in diameter and depth. When compared with the wind-blasting caves already mentioned, the present holes have certain similar characteristics, such as in the occurrence with inconstant levels and in the lacking in homogeneous fine-grained rocks. However, in honeycomb structure the individual holes are not as large and more closely spaced compared with the wind-blasting caves. In addition, an important difference between the two is that the honeycomb structures are not only found on the face of cliffs but also on the surface of platforms and the wall or roof of other excavations.

viii) *Miniature valley and channel* :– These are commonly developed along the weak planes or layers such as closely spaced joints, beddings, faults, other fractures and silty rocks less resistant than the surrounding rocks, whereas the minority of them have no relation with the weak planes. Such excavations vary in their width and depth, but are generally larger on the sloped surface than on the horizontal part of sea-level platform.

At the seaward margin of sea-level platform, there are often found small remnants separated by deep valleys or channels from the platforms. Such a residual feature is well developed at the tip of promontories or capes in general.

3. Relation of Shore Features to Sea Level

It is to be noticed that the erosive shore features associated with the present sea level occur locally according to height as mentioned already. This is illustrated in Fig. 1. From this relation the places where ancient shore features occur whether offshore, shore or coast zone may be determined.

4. Distinction Between Marine and Fluviatile Features

The distinction between marine and fluviatile erosive features is not simple. The

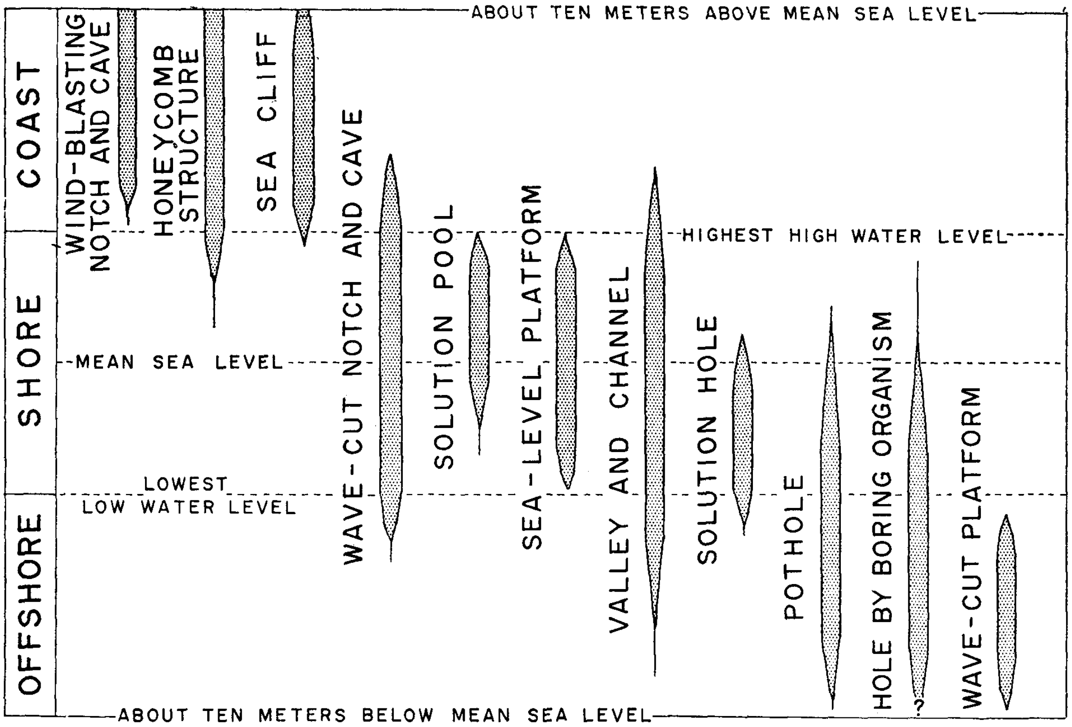

Fig. 1. Relation of erosive features to sea level.

features of the latter are produced in some valleys or lake shores remote from the sea and at a level considerably higher than sea level. However, compared with marine features they show several similar characteristics, such as in the development of cliff, rock platforms, notch, pothole and solution pool, and there is no essential difference between the two, in spite of the different process in their development.

Consequently, it is difficult to distinguish between the marine and fluviatile products only by the erosive features but the holes of marine boring organisms afford good evidence for the former. To determine whether the erosive features are of marine or fluviatile origin, it may be necessary to refer to the characteristics of the deposits, and the organic remains and the erosive features directly superposed upon an unconformity surface.

REMARKS ON ANCIENT ROCKY SHORE

During field observations along several coasts of Japan, the writer was fortunate in finding ancient shore features on the surface of unconformity between marine terrace deposits and basement rocks.

1. Maido, Aomori Prefecture

Along the northern coast of Kawajiri, Maido situated on the southwestern coast of the Tsugaru Peninsula, Aomori Prefecture, there can be observed the surface of an unconformity between the Pliocene Narusawa and Pleistocene Yamadano formations. The former comprises fine-grained sandstone with intercalated calcareous sandstone and siltstone layers. The latter consists of laminated medium-grained sandstone and forms a remarkably flat terrace of 20–30 meters high.

In the northern sea cliff of Kawajiri, the surface of unconformity is observed at a level of five to seven meters above mean sea level and is characterized with a nearly horizontal and smooth surface for a distance of about 500 meters. As one proceeds northwards and southwards, the surface gradually lowers to merge underground. That is to say, the Yamadano formation fills in the relief of the Narusawa formation, and thus forms a flat

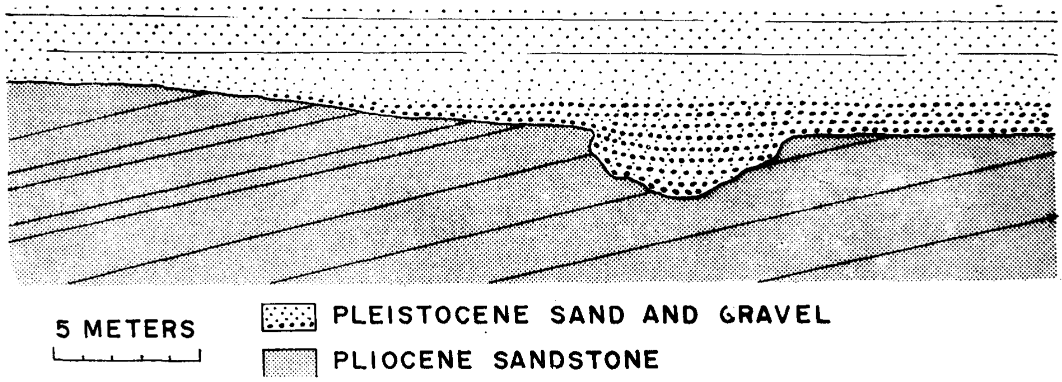

Fig. 2. Boundary between the Pleistocene Yamadano and Pliocene Narusawa formations in the northern sea cliff of Kawajiri, Maido, Aomori Prefecture. Notice gravel filled excavation in the Pliocene siltstone.

terrace. At an outcrop the terrace deposits are found filling an excavation in the foundation rocks, appearing as if pothole or channel (Fig. 2).

Though there is found no marine fossil from the Yamadano formation, it is inferred to be of marine origin because of the well-sorted sand or pebble and extensive distribution. This terrace is extensively developed along the western coast of the Tsugaru Peninsula for a distance of about 30 kilometers. Therefore, it is possible that the surface of unconformity was more or less attacked by wave erosion before the deposition of the Yamadano formation. The origin of the nearly horizontal surface can be readily explained by marine erosion associated with an ancient sea level.

For the reasons stated it may be concluded that an outcrop shown in Fig. 2 exhibits an ancient sea-level or wave-cut platform with a pothole or channel incised into it.

2. Hachiro-Gata, Akita Prefecture

Surrounding the Hachiro-gata (lagoon) in Akita Prefecture, there is an extensive 40-meter marine terrace of the Pleistocene Katanishi formation comprising fine-grained sandstone. The Katanishi formation is superposed with unconformity on the Pliocene Wakimoto or Miocene Funakawa formation comprising siltstone. The unconformity between the Katanishi and subjacent formations is remarkable for the flat and nearly horizontal surface in general.

i) *Miyazawa* :- Along the sea cliff in the vicinity of Miyazawa situated on the western coast of Hachiro-gata, an interesting feature is observed on the surface of unconformity between the Katanishi and Wakimoto formations. The boundary is characterized with the

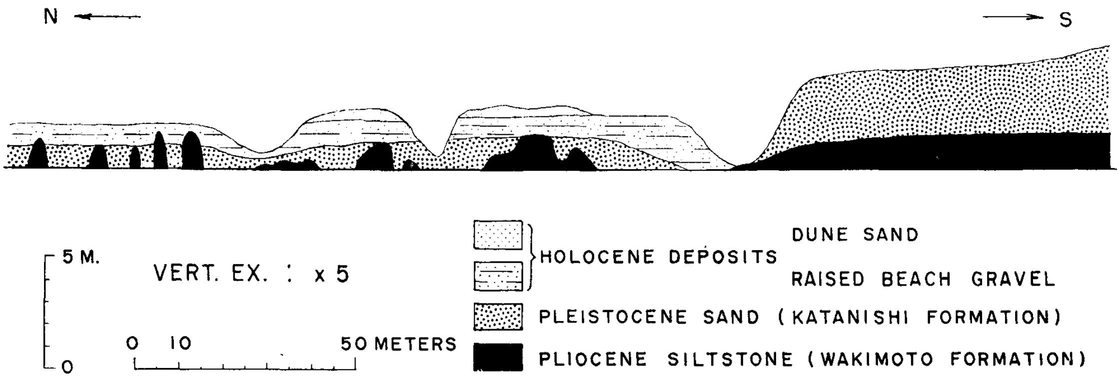

Fig. 3. Unconformity between the Pleistocene sand and Pliocene siltstone along the sea cliff of Miyazawa, Akita Prefecture. The boundary is nearly horizontal in the southern (right) side, but is very irregular in the northern side.

almost horizontal and smooth surface at a level of three to five meters above mean sea level in the southern part of the cliff; the surface of unconformity is very irregular for a distance of about 150 meters as shown in Fig. 3. On the irregular surface of unconformity, there are found various shaped and sized holes incised by boring organisms, and the overlying Pleistocene Katanishi formation yields abundant remains of marine organisms as molluscs, echinoids, bryozoans and algae, whereas a few of them are found on the horizontal unconformity surface in the southern part of the cliff.

These individual shells and other remains have generally random orientation, but some tabular fragments stand nearly vertically and are tightly packed together in part. These may indicate the vibration of oscillatory currents as swashing and backwashing waves or tidal currents during their deposition (Mii, 1957, p. 23).

Further northwards the boundary between the Katanishi and Wakimoto formations lowers and goes underground, and there is no indication of it in a nearly 40 meters deep drilling at a place 400 meters distant from the northern margin of the observed boundary. This suggests that a slope is developed in the north of the irregular surface of the unconformity.

The above stated features may be arranged into three zones of horizontal, irregular and sloped surface of unconformity, and these closely resemble the recent sea-level and wave-cut platforms in the order of development and characteristics. That is to say, the horizontal part is similar to the sea-level platform in its horizontal and smooth surface. The irregular part is considered as an ancient sea margin of the platform where there are often developed small remnants separated by numerous excavations as potholes, valleys and channels.

If such a view can be accepted, this may explain why the surface of the unconformity is partly horizontal and smooth, but in part very irregular or sloped. Drifted fragments of marine organisms may accumulate in the excavations sculptured along the sea margin of the platform, and therefore, should richly accumulate in the deposits overlying the irregular surface of unconformity by the oscillated waves and currents.

ii) *Moritake*:– At the outcrop along the road traversing the 40-meter marine terrace in the northern vicinity of Moritake, situated in the northeastern part of Hachiro-gata, the terrace deposits are found filling rather deep excavations in the Miocene Funakawa formation comprising massive siltstone, appearing as if filling potholes incised into the foundation rocks (Fig. 4). These excavations are interpreted to be of marine origin, because of the terrace deposits consisting of well-sorted and non-imbricated pebble and sand layers, and of the extensive development of the terrace along the coast.

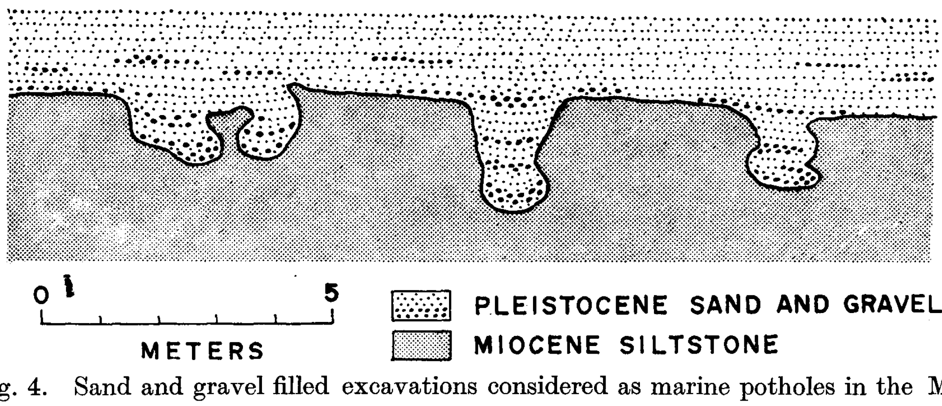

Fig. 4. Sand and gravel filled excavations considered as marine potholes in the Miocene siltstone in the vicinity of Moritake, Akita Prefecture.

3. Shirahama, Wakayama Prefecture

Along the southwestern coast of the Kii Peninsula in Wakayama Prefecture, a

Pleistocene marine terrace is well developed. The terrace gravels, consisting of well-sorted granule to cobble layers measuring about three meters or more in thickness, have in part yielded marine molluscan remains, and are superposed on the Miocene Tanabe, Kanayama and Mesozoic Hidaka groups with clino-unconformity.

i) *Akugawa* :- The eastern hill of Akugawa, Shirahama, is a broad marine terrace covered with pebbles measuring between two to five meters in thickness. The terrace deposits are overlain with unconformity by the Miocene Kanayama group comprising an alternation of sandstone and siltstone.

At the seaward part of the terrace, the surface of the unconformity was observed by digging out with a hand shovel, and is shown in the accompanying photograph (Fig. 5). The surface is almost horizontal and is remarkable for the many small holes filled with gravels. The holes have more or less vertical walls partly irregularly etched, bowl-shaped bottoms, and are nearly circular in outline, ranging from three to ten centimeters in diameter and a few to five centimeters in depth. It is thought that these holes originated from solution holes or pools during the formation of the marine terrace, and the surface incised with the holes is a part of an ancient sea-level platform.

Fig. 5. Plan view of solution holes on the surface of unconformity between the Pleistocene marine terrace gravels and Miocene sandstone. Akugawa in Shirahama, Wakayama Prefecture.

ii) *Seto Cape* :- At the cape of Seto situated in the southwestern part of Shirahama, the stratified sandstone of the Miocene Kanayama group is superposed with unconformity by the gravel beds of the 30-meter marine terrace. In the exposures along the road traversing the terrace, there is observed the surface of unconformity exhibiting several important features. Some of them were already described by Hatai, Funayama and Mii (1957, p. 40–41).

At some outcrops the surface of the unconformity exhibits a low scarp of about 50 centimeters in height, by which the surface is separated into two parts of different level (Figs. 6 and 7). From some outcrops it is inferred that the higher leveled surface buried by the terrace deposits may be shaped like a promontory projecting seawards, and that the lower one may be developed at the seaward margin of the terrace. Of the two leveled surfaces the lower one is remarkable for numerous excavations appearing as if filling potholes incised into the foundation rocks (Fig. 8). Generally, the higher surface is relatively smoother than the lower one.

By digging out the terrace gravels covering the lower surface of the unconformity, some of the excavations were found to be nearly circular in outline and to have vertical

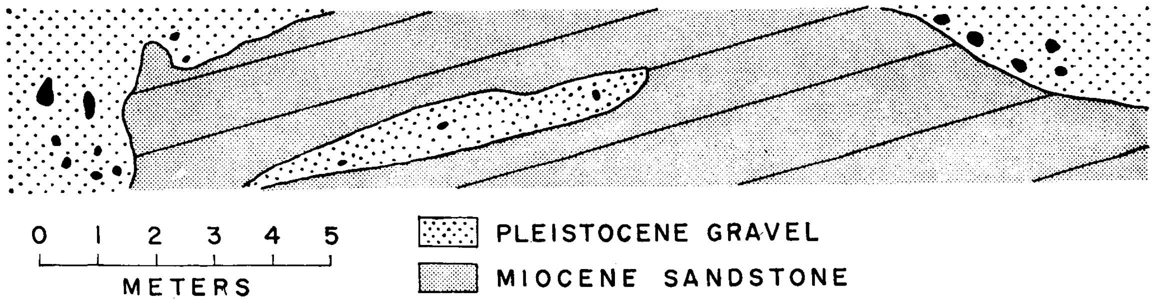

Fig. 6. Buried low cliff incised with notch or cave and lens-like structure which is possibly an ancient notch or cave in the Miocene sandstone. Outcrop of a road at the cape of Seto, Shirahama, Wakayama Prefecture.

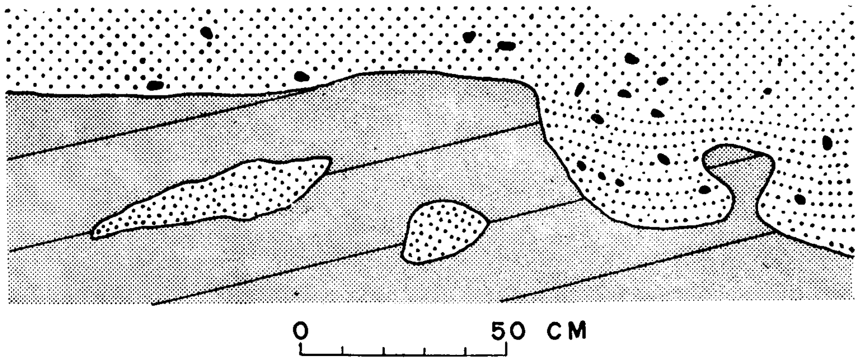

Fig. 7. Two lens-like structures and irregular surface of the Miocene sandstone at the cape of Seto, Shirahama, Wakayama Prefecture (After photograph).

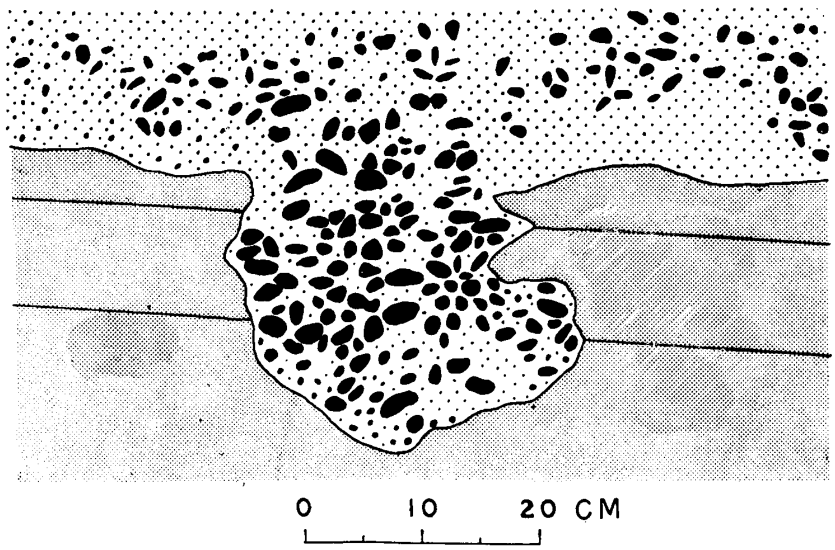

Fig. 8. An excavation appearing as if filling a pothole in the foundation rocks at an outcrop of a road cut, Seto Cape, Shirahama, Wakayama Prefecture (after photograph).

or slightly concave walls with well developed spiral grooves, others had elongated elliptical outline with U-shaped vertical section, as shown in Fig. 9. From these it is obvious that the former type may be considered as filling eddy holes and the latter as gouge holes incised into the Miocene sandstone during the stage of terrace development. However, as shown in the right hand part of Fig. 7, some excavations are uncertain as to their origin whether originally potholes or eroded and enlarged crevice because of having similar cross

Fig. 9. Plan view of buried potholes on the surface of the foundation rocks. At the cape of Seto, Shirahama, Wakayama Prefecture.

sections.

As shown in the left hand part of Fig. 6, a low scarp between the two leveled surfaces has a concave face presenting a feature analogous to a profile section of notch. It is to be noticed that the same outcrop presents a lens-like structure composing pebbles and granule in the Miocene sandstone. At another outcrop shown in Fig. 7 near the one just mentioned, there are similar lens-like structures surrounded with the foundation rocks, giving the impression of their syngenetic origin. However, the materials composing the lens-like structures coincide with the terrace deposits, and form sharp contacts with the Miocene sandstone. Thus, it is interpreted that there is an unconformity separating the two of lens-like gravels and Miocene sandstone.

It is to be added that the general contour of the lens-like structures is more or less parallel with the bedding plane of the Miocene sandstone. This orientation is the most favorable condition for the excavation of wave-cut notches and caves as already stated. Therefore, the origin of the excavations in which the lens-like arranged gravels were deposited is considered to have been a wave-cut notch or cave deeply incised into a low cliff between the two leveled rock platforms, of which only a portion is now observed. If a wave-cut cave or notch is filled by gravels and is observed in an outcrop nearly parallel with the face of the cliff incised with it, it may be able to expect a feature similar to the lens-like structure just mentioned.

A problem still remains concerning the origin of the two different leveled surfaces of unconformity. That the higher one is developed in a shape of promontory projecting seawards with the lower one along the foot of its seaward margin ; this closely resemble the occurrence of recent sea-level and wave-cut platforms. This view is born out by that the lower surface is incised by more numerous excavations, the majority of which are of mechanical origin, than the higher one. This indicates that the lower surface was produced in the offshore zone or the seaward part of a shore zone where wave abrasion is active. A low scarp between the two also presents characteristics similar to a recent cliff between sea-level and wave-cut platforms, such as in the height of about 0.5 meters and in the development of wave-cut notches and caves. For these reasons it is considered that the higher leveled surface may correspond to an ancient sea-level platform during the formation of the terrace, and the lower one to a wave-cut platform.

PRESERVATION OF ANCIENT SHORE FEATURES

It is of importance to note that the ancient shore features described above are all filled or covered with marine deposits which must have protected them from subsequent wave and subaerial erosions. The evidence suggests that the land was submerged after development of the erosive features, and that the marine deposits were being developed on them by submergence continued intermittently and possibly assisted with longshore drifting.

If the land had been emerged subsequently to the development of shore erosive features, the original features would be more or less modified and partly destroyed by subaerial weathering and erosion. For this reason it may be concluded that subsequent deposition due to submergence is an important condition for the preservation of shore features.

If such a view is accepted, this may readily explain why the surface of unconformity is much more extensive than the present wave-cut and sea-level platforms. In general, the present sea-level and wave-cut platforms are less than 500 meters in width because platform cutting takes place only within the surf zone. On the basis of bottom sediments off Santa Cruz in California, Bradley (1958, p. 972) described that the modern wave-cut platform is 480 meters in maximum width. However, the marine terraces already described are generally 1,000 to 2,000 meters in width even within the marine erosive part. Such extensive width is best explained by erosion during slow submergence.

Concerning the preservation of some shore features formed above low water level, several remarks are here added. If the land had submerged continuously without any particular condition, those above low water level such as sea-level platform, solution pool and hole, would be strongly eroded by breakers in spite of deposition, because the submerged features may be exposed to effective wave erosion within the surf zone. The preservation of the features can be partly explained by longshore or offshore drifting, and in part attributed to intermittent submergence.

In the case of the cape of Seto at Shirahama in Wakayama Prefecture, it may be notcied that a cobble to boulder zone is developed in front of the buried cliff between the inferred ancient wave-cut and sea-level platforms, whereas further inland the boulder zone gradually changes to pebble size rounded gravels admixed with coarse-grained sand. The boulders are usually about one meter in diameter, three meters in maximum, and consist of sandstone similar to the foundation rocks. Although the top surface of the boulders are more or less rounded, their degree of roundness seems to have been due to both wave attack and subaerial weathering for their most part, because their basal parts often preserve the original angular surface. These facts may suggest that the boulder zone in front of the buried cliff had probably been deposited during the sea cliff retreat, that is to say, during the development of the ancient erosive features. Therefore, it can be postulated that this boulder zone might play an important role in the preservation of the ancient cliff because the zone is considered to protect a submerged cliff from wave attack. In the preservation of the ancient sea-level platform, however, the boulder zone alone is not the cause. The horizontal surface incised with solution pools of a submerged sea-level platform might be strongly eroded by breakers and change into a sloped one even if there was developed a boulder zone in front of the platform.

For the preservation of the original erosive features formed above low water level, it may be most favorable that the land is intermittently submerged. If an intermittent submergence makes progress rather more rapid than wave erosion, the original features may receive little effect of the subsequent wave attack within the surf zone.

CONCLUSIONS

Based upon the observations and analyses of the characteristic erosive features on rocky shores, two types can be recognized as, those which are now being produced by marine and subaerial agencies associated with the present sea level, and those which are of emerged or submerged origin. The former is composed of three major features of sea cliff, sea-level and wave-cut platforms which are incised with various kinds of minor excavations. These erosive features occur locally according to the height above or depth below mean sea level. This is summarized as shown in Fig. 1.

During field observations, it was fortunately verified that some ancient shore features are preserved on the surface of unconformity between marine terrace deposits and the basement rocks. As the result of comparison between ancient and modern shore features, it is concluded that some of the buried erosive features were developed as a level above low water line, that is to say, at a place landward from the shoreline. This indicates that the land was intermittently submerged during the planation of the unconformity surface. Such a view readily explains why the surface of unconformity is much more extensive than the present day wave-cut and sea-level platforms.

A review and consideration of the field evidence lends support to the conclusion that the ancient features on the surface of unconformity are not only evidence for determining the position of the ancient shoreline, but also suggest the process of transgression because they are closely related to sea level and its standing time. Finally, it may be emphasized that the surface of unconformity should be given more consideration because some might partially or ultimately at least be affected by marine erosion.

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