

## HOLOCENE MARINE BENCHES IN SOUTH AMERICA AND ELSEWHERE\*\*

by

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**RESUMEN.**—*Terrazas marinas holocenas en Suramérica y otros lugares.*— Las terrazas marinas bajas, o “plataformas costeras, tales como las que se presentan en algunas costas de rocas duras en Nueva Zelanda septentrional y en otros lugares, pueden atribuirse en su mayor parte a la erosión del oleaje de tormenta con el nivel del mar en su posición actual, aun cuando algunas en lugares protegidos (las del tipo del “Old Hat”) pueden explicarse como desarrolladas por la remoción de la regolita mediante la acción débil del oleaje, hasta dejar expuesta una superficie plana, horizontal, de roca no meteorizada, a un nivel de saturación acuática a la altura media de la pleamar (Fig. 2).

Se ha observado erosión de oleaje de tormenta que esculpe plataformas de rocas duras al nivel de las pleamares, y aún muy por encima de ellas; pero donde este proceso opera, produciendo un “corte de sierra” en el litoral, la erosión marina también está practicando otro corte a un nivel inferior, cuyo resultado, combinado con la abrasión marina y la acumulación mar adentro, produce un perfil submarino que se inclina hacia el mar desde un borde litoral situado entre la pleamar y la bajamar, o aún por debajo de ésta. Donde se presenta una plataforma de oleaje de tormenta, ésta termina hacia el mar, por consiguiente, en una escarpa, y el perfil de la costa es escalonado (Figs. 3, 4); pero cuando no hay diferencia apreciable de nivel entre los dos cortes, o cuando predomina el del inferior, no se produce ni la “plataforma costera” ni el perfil escalonado. Por consiguiente, éste no es, en manera alguna, universal.

Los procesos secundarios, activos entre las tormentas, generalmente rebajan un poco las superficies de las plataformas costeras de oleaje de tormenta, manteniendo, y aún acentuando, su regularidad y horizontalidad. En la costa tropical del Brasil, en donde la abrasión marina está actualmente (bajo las condiciones de clima húmedo-cálido prevaecientes) inhibida por la meteorización tropical del litoral, el cual priva a las olas de los fragmentos de rocas duras y partículas necesarias como herramientas de corrosión, se han descrito plataformas costeras que han sido atribuidas a la meteorización de lloviznas salinas, un proceso análogo a los procesos secundarios que rebajan y pulen las superficies de algunas terrazas esculpidas por las olas (Fig. 5). Puede advertirse que la meteorización por llovizna salina, esencialmente un proceso de pulimiento, quizás haya modificado únicamente plataformas costeras que fueron esculpidas por la acción de las olas durante una fase del óptimo climático del Holoceno en la cual la meteo-

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rización del terreno, bajo condiciones de aridez, produjo fragmentos gruesos, que sirvieron como herramientas de abrasión para el oleaje.

No todos los geomorfológicos admiten que algunas plataformas de oleaje que hoy se encuentran como terrazas marinas, se desarrollaron por encima del nivel del mar, o aún al nivel de la pleamar. En realidad FAIRBRIDGE ha afirmado que todas ellas atestiguan antiguos niveles de bajamar. En parte debido a esto, pero también porque se ha observado que la generación de plataformas de oleaje de tormenta tiene lugar en varios niveles aún en zonas adyacentes de la misma costa, no hay acuerdo general respecto de la magnitud de la emergencia de las costas, si es que esta ha tenido lugar, en cuanto evidenciada por las terrazas de oleaje.

Algunas terrazas de oleaje de tormenta, que pueden existir hoy como formas remanentes, fueron probablemente esculpidas durante el óptimo climático del Holoceno y deben estar hoy, si sobreviven, a una mayor altitud (con respecto al nivel del mar) que aquella en la cual se desarrollaron. Este puede ser el caso de las plataformas costeras de las islas de Santa Helena y Tutuila, descritas por R. A. DALY, pero solo es posible conjeturar acerca de la magnitud de la emergencia que ellas indican. Es posible que tengan unos 2.300 años de edad en relación con la "inmersión de Abolhos" de FAIRBRIDGE — +5 o +6 pies.

En el caso de muchas terrazas prominentes, tales como las de los ejemplos bien conocidos en Nueva Zelandia septentrional, en donde el proceso de corte todavía progresa activamente, la teoría de que ellas representan formas remanentes es inadmisibles. Aun cuando FAIRBRIDGE ha aseverado con fiabilidad que todas ellas (incluyendo las plataformas del Old Hat) deben haber sido desarrolladas al nivel de la bajamar durante el óptimo climático del holoceno, esta es una extrapolación de sus propias observaciones, hechas en costas de calizas bañadas por aguas templadas y erosionadas por solución, muy difícil de admitir.

SUMMARY.—Low marine benches, or "shore platforms" such as are present on some hard-rock coasts in northern New Zealand and elsewhere, are for the most part attributable to erosion by storm waves with sea level at its present stance, though some in sheltered places—those of the "Old Hat" type— can be explained as developed by removal of regolith by weak wave action so as to expose a plane, horizontal surface of unweathered rock at a level of water-saturation at mean high-water level (Fig. 2).

Storm-wave erosion has been observed cutting platforms in hard rocks at and even well above the level of high water spring tides; but where this process operates, making a horizontal "saw-cut" into the land, marine erosion is also making another cut at a lower level, the result of which, combined with marine abrasion offshore and accumulation farther seaward, is to produce an under-water profile that slopes seaward from a landward edge situated between tides or even below low-water mark. Where a storm-wave platform is present it ends seaward, therefore, at a scarp and the coastal profile is stepped (Figs. 3, 4); but where there is no appreciable difference of level between the two cuts or where cutting at the lower level is dominant neither a "shore platform" nor a stepped profile is produced. Thus the stepped profile is by no means universal.

Secondary processes, active between storms, commonly lower the surfaces of storm-wave shore platforms somewhat, maintaining and even intensifying their planeness and horizontality. On the tropical coast of Brazil, where marine abrasion is at present (under the hot-humid condition of climate prevailing) inhibited by tropical weathering of the coastal terrain, which deprives waves of the coarse hard-rock fragments and particles needed as tools of corrasion, shore platforms have been described which are attributed to sal-spray weathering, a process analogous to the secondary processes that are lowering and smoothing

the surfaces of some wave-cut benches (Fig. 5). It may be suggested that salt-spray weathering, essentially a smoothing process, has perhaps merely modified shore platforms that were cut by wave action during an arid phase of the Holocene climatic optimum, when weathering of the land under arid conditions produced coarse debris, which became available as tools of abrasion for wave action.

Not all geomorphologists admit that some wave-cut platforms that are now found as marine benches were developed above or even at high-water levels. It has indeed been claimed by FAIRBRIDGE that they all register former low-water levels. Partly because of this, but also because the cutting of storm-wave platforms has been observed to take place at various levels even on adjacent parts of the same coast, there is no general agreement as to the amount of coastal emergence, if any, that is evidenced by the occurrence of wave-cut benches.

Some storm-wave benches, which may exist now as relict forms, were presumably cut during the Holocene climatic optimum and must, if they survive, be now at a greater altitude (with respect to sea level) than that at which they were developed. This may be true of the shore platforms of Saint Helena and Tutuila islands (Fig. 6) that were described by R. A. DALY, but it is possible only to guess how much emergence they indicate. They may perhaps be 2300 years old and date from the "Abrolhos submergence" of FAIRBRIDGE — +5 or +6 ft.

In the case of many conspicuous benches, such as the well-known examples in northern New Zealand, where cutting is still actively in progress, the theory that they are relict forms is inadmissible. Though FAIRBRIDGE has confidently claimed that all of them—even the Old Hat platforms—must have been developed at the level of low water during the Holocene climatic optimum, this is a very doubtfully admissible extrapolation from his own observations on limestone coasts bathed by warm waters and eroded by solution.

In 1924 BARTRUM claimed with a considerable show of reason that wave abrasion can and does produce benches at and above high-water level on hard-rock coast. Acceptance and even discussion of this has been retarded by the flat refusal of some critics to accept the theoretical possibility of quasi-simultaneous erosion at two levels so as to develop a step in the shore profile. This negative attitude was assumed by GUILCHER in his treatise on "littoral morphology" (1954).

Another authority, FAIRBRIDGE however, while rejecting the evidence for development of a high-level bench, accepts a stepped shore profile as "normal". His claim of normality for a stepped profile depends, however, on an assumption that the step down at the outer edge of a shore platform is in all cases the initial profile of the coast uneroded (FAIRBRIDGE, 1952). In some cases it practically is, but as a generalization this is inadmissible. So also is the claim of GILL (1950) that the step down is a nip (low cliff) made by marine erosion during a recent temporary lowering of sea level.

It seems obvious that erosion at a lower level below the edge of the shore platform (if, of course, there is a shore platform) can always be in progress but may be very weak, whereas shore-platform erosion, at times extremely vigorous, takes place only intermittently—when storm waves break on the shore.

BARTRUM's attention was first attracted to stepped shore profiles (1916) when he studied the "Old Hat" type of shore platform, as he afterwards (1924) called it, naming it from the "brim" of Old Hat Island, Bay of Islands, New Zealand (Fig. 1), which had been figured by J. D. DANA and F. von HOCHSTETTER. It is produced by rapid subaerial weathering down to the surface of water saturation, which moves landward during cliff-cutting, followed by removal of the regolith by gentle wave action in sheltered places (Fig. 2). Such shore platforms border the numerous drowned —valley inlets of northern New Zealand (Fig. 1).

It was to the problematic shore platforms of what he called the "storm-wave" type, however, that BARTRUM afterwards (1924 and later papers) gave his serious attention. He studied these only on the surf-beaten west coast of the Auckland Peninsula (Fig. 1); but they are by no means uncommon and have been described, for example, in south-eastern Australia by various authors. They were, indeed, observed in the vicinity of Sydney by the American geologist DANA in 1840. DANA then remarked, and repeated the remark in 1894 (p. 220): "The level of greatest wear is that of the breaker at or above high tide."

The most striking thing about all true storm-wave platforms that are still developing—it is, indeed, a proof that they are still developing—is absence of fallen rock debris from the foot of the cliff at the rear of the platform (Fig. 3). It is this that differentiates them from benches that were cut when sea level stood higher, the remnants of which are now beyond the reach of waves and wave abrasion. Commonly, though not in all cases, the cliff at the rear is vertical or even overhangs. From such cliffs much rock debris must fall; and the absence of such an accumulation shows that rock slides and fallen blocks are rapidly broken up and removed by some agency. This can only be attack by the storm waves that are seen occasionally to oversweep the high shore platforms. (Compare JOHNSON, 1933).

It seems obvious that breaking storm waves that sweep over the shore platforms armed with the debris supplied by recent rock falls and slides can attack the base of the cliff at the rear, and also that they must abrade the platform itself. It is still an unsolved problem, however, why the extension of the platform landward into fresh rock should take place so rapidly as compared to the rate of down-wearing that platforms commonly develop almost strictly horizontally. Being nearly horizontal, a storm-wave shore platform ends seaward in a quite high, near-vertical scarp; and it is scarp, separating the storm-wave cut platform from the margin of a sea-bed that may be several metres lower, that makes such platforms conspicuous features.

The common process of shore cliffing by undercutting involves the making of a complementary horizontal saw-cut into the land by breaking waves generally between tide levels. The stepped profile of a shore bordered by a storm-wave shore platform (Fig. 3) can scar-

cely be explained, however, except by the hypothesis that there are potentially two such cuts being made one above the other and that in some places these are separated by a difference of level of several metres. Whether a shore platform develops or not depends on (1) whether there is this appreciable difference in level between the saw-cuts, and (2), if there is this gap, whether the upper saw-cut keeps ahead of the lower one. Thus on many coasts there is no shore platform. Even on the exposed west coast of Auckland near Muriwai, where in some places shore platforms are wide (Fig. 3), BARTRUM has figured places where the platform at the level of the upper saw-cut remains narrow, even embryonic. Where shore platforms are conspicuously wide, apart from the presence of rocks that are rather easily eroded the reason seems to be an unexplained weakness of the continuous low-level wave attack. That the low-level attack is quite commonly weak is evidenced by luxuriant growth of sea-weeds on the scarp at the outer edge of the shore platform.

Varying exposure to storm waves determines the level, it may be the varying height above high water, at which shore platforms develop. On the Auckland west coast at Muriwai, which, although exposed to fierce westerly gales, is in places protected from the full onslaught of the waves by irregularity of outline, BARTRUM observed that the level of platform-cutting varied in height by as much as 1.2 metre in a very short distance. He found the platforms always "from a foot or two to as much as 8ft (2.5 m) above high-water level" (BARTRUM, 1952).

In the more sheltered waters of Hauraki Gulf, on the eastern (leeward) coast of northern New Zealand (Fig. 1), there are also conspicuously developed, and still developing, shore platforms, but these are exactly at the level of high water spring tides—measured and figured (in 1955) in a paper on marine algal ecology by Miss V. DELLOW (Mrs. CASSIE)—see Fig. 4. To quote her diagnosis: "Where the coast is completely unprotected"—she means where the exposure is maximum for this leeward coast—"the littoral topography has been moulded into a high-spring-tide wave-cut platform". There is a very steep drop into deep water at its margin; the 20-metre line is close inshore. Such benches, fringing islands in Hauraki Gulf, are admirably shown in photographs accompanying Miss DELLOW's paper. The steep descent from the outer edge appears to be, as in the Old Hat type, the infantile profile of a steep drowned coast, i. e. the initial profile almost unmodified by low-level marine erosion. In other words, this is a case where the upper saw-cut is well developed but the lower one scarcely at all. There is quite a strong resemblance of the whole shore profile to that of the Old Hat type, but the platform cannot be explained by removal of regolith only. It is wave-cut in rock, along with the complementary cliff.

Some authors have been impressed by the importance of processes—chemical and physical—which are at work on shore platforms, gradually lowering and also smoothing them. These could operate whether the platforms have been formed originally by storm-wave ac-

tion or whether they are features that have emerged owing to a lowering of sea level. As early as 1935 BARTRUM observed some platforms thus smoothed, but regarded the effects as secondary, i. e. not capable themselves of producing benches. He attached much importance to "superficial disintegration which may with confidence be ascribed to alternate wetting and drying", but suggested also "some effect from crystallization of salts from penetrating sea water." Observed later in Hawaii (WENTWORTH, 1938) the wetting-and-drying levelling effect has been called "water-level weathering" (though some prefer "water-layer weathering"). Essentially it levels the rock surface, especially that of unjointed rocks, by crumbling away the dividing ridges exposed between water-filled hollows. (BARTRUM regarded the smoothness of the wide platform at Muriwai, Fig. 3, as due to this process).

Recently TRICART (1959) has drawn attention to such platform levelling, which he attributes entirely to crystallization of salt from sea spray; he has described it in an account of features on the tropical coast of Brazil. He thus explains cutting of niches on seaward-facing slopes and the expansion of some of the niches into level benches on unjointed homogeneous rocks such as mica schist. Though the process may be slow in action, on that coast it is certainly not likely to be overtaken by coastal retreat due to marine abrasion. Such abrasion is very weak, not because of absence of breakers but because in the hot —humid climate intense chemical weathering reduces all regolith to fine-grained debris with no residue of coarse fragments that would be available as tools of abrasion. The total amount of coastal erosion recently achieved is negligible; headlands are not trimmed back.

TRICART has found salt-spray weathering restricted to certain parts of the coast where insolation is above average. There only the sun's rays are strong enough frequently to dry up sea spray that accumulates from time to time.

The theory of deepening and inosulation of hollows in the rock by the process of salt-spray weathering is plausible enough —though very probably water-layer wathering also plays its part. General lowering of already levelled benches by such processes is conceivable; but a theory of levelling of uneven and sloping surfaces to form benches is not so easily acceptable. The benches (Fig. 5) are there, however, and it is possible to suggest an alternative explanation of the primary levelling. This is abrasion by storm waves at a time when, temporarily, the climate was insufficiently humid to promote the thorough chemical weathering of rocks that now inhibits mechanical corrosion by waves or any other agency. TRICART has suggested that the climate at the Holocene climatic optimum was relatively arid; and perhaps it was sufficiently arid to produce the result. Thus the benches of the coast of Brazil may be relict examples of storm-wave platforms.

Some of the benches of the Brazil coast are at such a height above sea level that they are now no longer subject to spray weathering.

They were perhaps smoothed by that process when sea level stood higher —i. e. at the climatic optimum. These were benches developed originally above sea level which are now at a still greater altitude. This suggests a compromise on the question whether, as some maintain, all high-level benches in stable regions have been exposed by eustatic withdrawal of the sea from them. It would appear that the solution of this problem lies between the position taken up by extreme eustatists and that of those who believe in the development of some of the high-level platforms with sea level at its present stance. As spokesman of the extreme eustatists FAIRBRIDGE (1952) maintained in a paper presented at the New Zealand meeting of the Pacific Science Congress in 1949 that: "all the varied types of platform attributed to contemporary marine erosion are nothing but 'normal' platforms of various former sea levels." He declared his belief, however, that the platforms he described as "normal" were developed "at the level of low water spring tides", though this he has changed slightly in a later publication (1961) to development at "mean low-tide level".

The level of low water is assumed by FAIRBRIDGE to be the downward limit of subaerial weathering, and he further assumes that the boundary between weathered regolith and unweathered bedrock sets and absolute downward limit to marine abrasion (and planation) on all coasts. This is an extension (disputed by BARTRUM, 1952) of the current explanation of Old Hat platforms; but its author accepts the fact that there may be a step in the shore profile as it is normally developed —that the profile includes at its landward margin a bench that ends seaward in a scarp. In fact, he attempts to establish this as a general rule. He regards the marginal scarp as unaffected by marine erosion. The theory is actually based on scarcely warrantable extrapolation from FAIRBRIDGE's own investigations of the special case of platforms on the calcareous shores of Western Australia, where erosion down to, and controlled by, low-water level takes place almost wholly by solution and where there is, moreover, only a very small tidal range (0.3 m). FAIRBRIDGE's generalized theory of planation at low-water level was opposed by BARTRUM (1952) on the ground that it denies the possibility of any abrasion of fresh rock by marine action. BARTRUM pointed out that in regions where breaking waves are armed with coarse debris they are known to abrade fresh rock, and so it is impossible that the base of the weathered zone should set a limit to downward corrasion.

The theory announced by FAIRBRIDGE amounts to an assertion that all observed coastal benches cut on rock must have originated at low-water level during one or another of the episodes of high sea level he believes he recognizes as occurring within the last 5000 years. According to curves of sea-level fluctuation published by FAIRBRIDGE (1958, 1961) the highest among several high sea-levels reached were about +3m. If we tentatively accept this (despite the failure of SHEPARD (1960) and his associates in the Gulf Coast region to find any evidence that sea level has been above its present stance in the Holocene) how are we to explain away DALY's much publicized



claim for submergence twice as great? (In his last well-considered review of the evidence he relied on DALY, in 1927, reduced his former estimate of a +6m stance to +5m.)

The answer appears to be that at least some of the platforms considered by DALY to establish the +6m or +5m stance were developed at times when sea level was higher, though not very much higher, than it is now and that these platforms were cut as storm-wave benches somewhat above the level of high water, but probably not so high above it as JOHNSON (1931) believed.

Amongst the most remarkable of the rock benches described by DALY are those on Tutuila Island, Samoa (1920a; 1920b), and Saint Helena Island (1927). The Tutuila bench is continuous for many miles and is of interest in that it has been alternatively described (by JOHNSON) as a storm-wave platform. That at Saint Helena is continuous along the whole lee (north-west) side of the island, to which side it is confined. Like the Tutuila example the bench at Saint Helena is cut on basalt. They are at the same altitude (about 2.5m) and this is uniform for long distances. At both places the tidal range is very small. Except for these difference the benches resemble those described by BARTRUM at Muriwai (where the altitude varies from place to place and there is a considerable tidal range). The benches end seaward in scarps (Fig. 6) that descend into water in places 4 metres deep. DALY at first believed the depth of 4 m to be that at which a level surface of marine abrasion is developed close inshore, at any rate off headlands; but in 1927, in his Saint Helena report, he reduced this estimate of abrasion-platform depth to 2 metres.

If the Saint Helena and Tutuila benches really owe their present altitude to emergence they may have been cut not at four or even two metres below mean sea level but at high-water level or perhaps up to one metre above mean sea level at the time of the recent +2m stance of sea level demonstrated by MAC NEIL at Okinawa Island (1950), which is probably the 5-6ft stance of 2300 years ago on FAIRBRIDGE's curves—the "Abrolhos submergence".

To return to the question of the level of the landward margin of the "normal" seaward-sloping platform of marine erosion—or of the lower platform where the sea is making two horizontal saw-cuts. The depth of 4m or even of 2m observed by DALY (at places with very small tidal range) may be exceptional, though the latter is probably common enough in exposed positions off headlands. The most casual observations at cliff bases reveal that the cut platform there can be at very various levels. Quite commonly it is at about high-water level on the more sheltered of the eroded parts of a coast, but on the same coasts it can be considerably below mean sea level and even far below low-water level at the extremities of exposed headlands (compare ROBINSON, 1961, figs. 1, 3). Different parts of such a cut platform would, if they became emergent, give very misleading information as to the former position of sea-level. FAIRBRIDGE's claim that the cut is made horizontally at mean low-water level is,



as discussed earlier, based, on somewhat rash extrapolation from his observations on some limestone coasts, where such a cut is developed by chemical corrosion to form a terrace.

FAIRBRIDGE has claimed that all the benches of the Auckland coasts have been cut at low-water levels. He has included with these the platforms of the Old Hat type, adopting a variant of BARTRUM's explanation of their origin which assumes subaerial weathering of rock material down to low-water instead of high-water level. If correct this involves the assumption that these platforms are relict from a time when sea-level stood about 3m higher than it does now. The theory would apply equally to the wave-cut benches at the level of high water spring tides in Hauraki Gulf. It would mean that these, though exposed to breaking waves, now suffer no erosion but have remained intact for 3600 years (according to FAIRBRIDGE's chronology), which is paradoxical and unacceptable.

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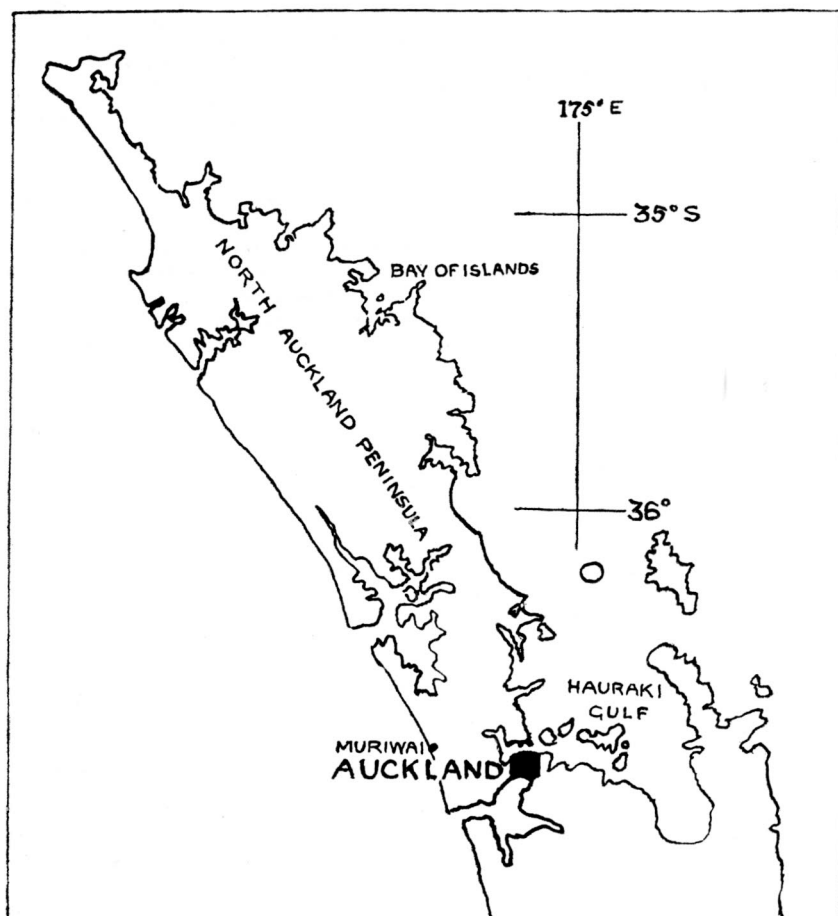


FIG. 1. Northern New Zealand, showing localities of some described shore platforms.

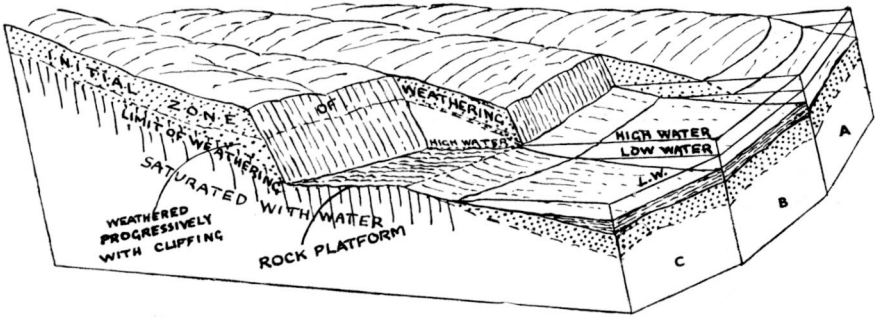


FIG. 2. Origin of high-water rock platforms of the Old Hat type. A: initial high-water and low-water shorelines on a drowned coast; B: early stage of cliffing, confined to ancient regolith; C: later stage of cliffing, confined to progressively forming regolith, with development of a shore platform on rocks immunized against weathering by water-saturation. Based on a diagram by BARTRUM.

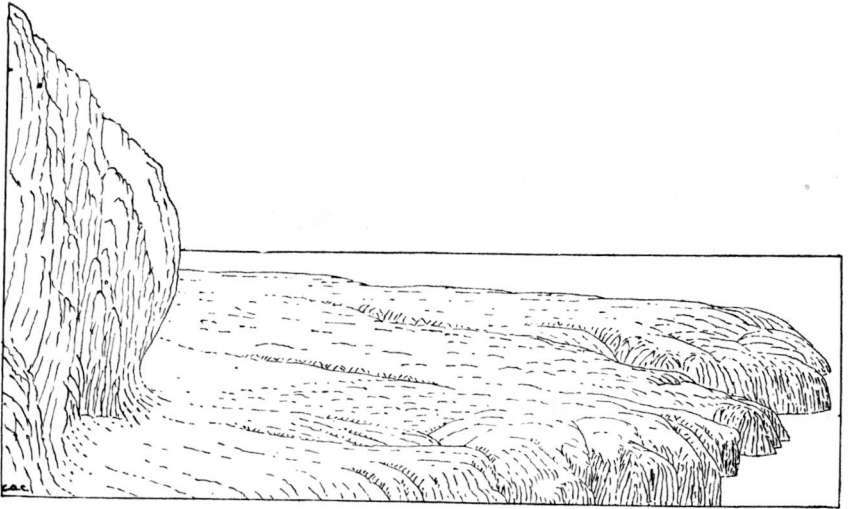


FIG. 3. Storm-wave shore platform cut in massive tuffaceous sandstone, Muriwai, New Zealand. One metre to 1.5m above high-water. Drawn from a photograph by DOUGLAS JOHNSON.

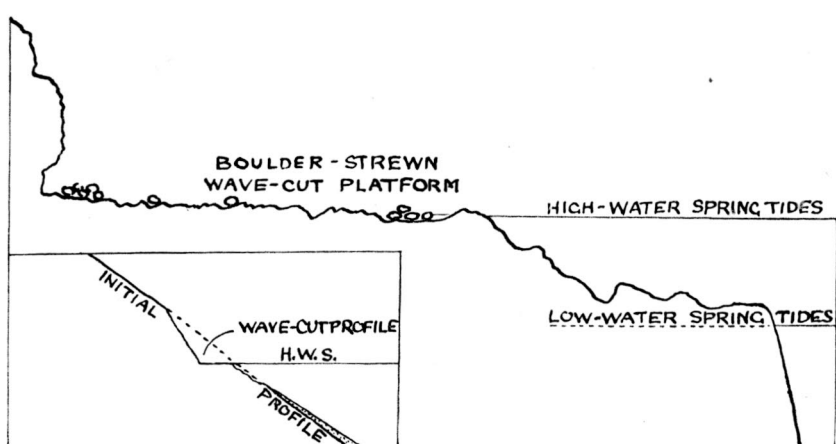


FIG. 4. Shore platform cut in deformed greywacke Coromandel Peninsula, east side of Hauraki Gulf, New Zealand. After DELLOW. Inset shows platform and complementary cliff.

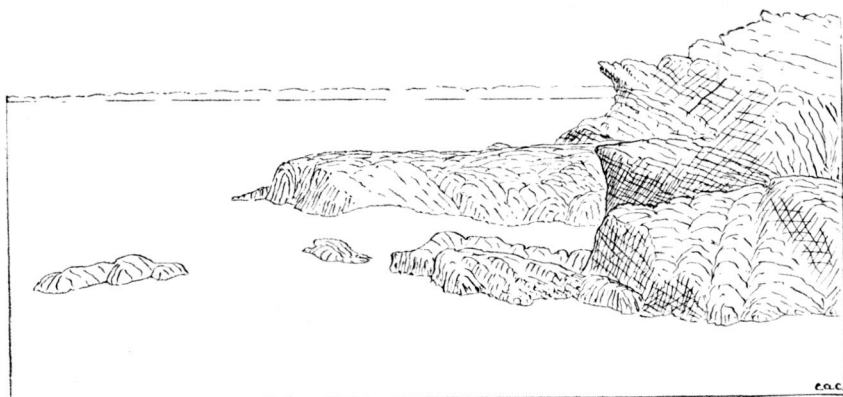


FIG. 5. Shore platform in mica schist, Cabo Frio, Rio de Janeiro, Brazil. Drawn from a photograph by TRICART.

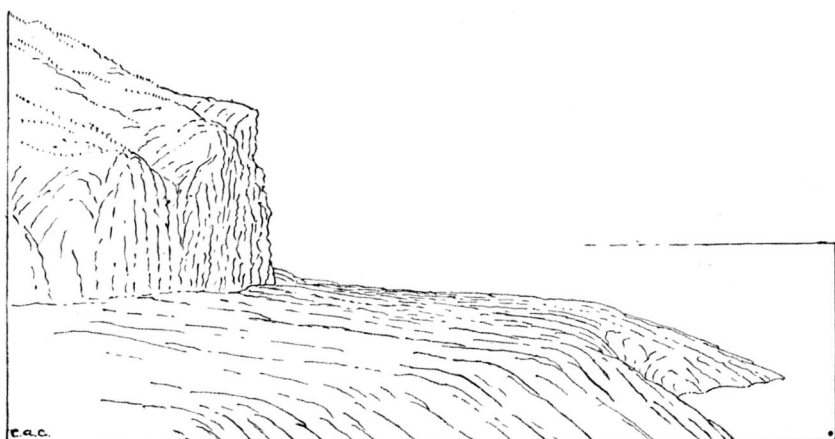


FIG. 6. Marine bench cut in basalt, Tutuila Island, Samoa. Copied from part of a drawing by W. M. DAVIS.