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THE THEORY OF SECULAR MARINE PLANATION

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ABSTRACT. Douglas Johnson's theory of very extensive marine planation implies fixity of sea level over a vast period. While such stability of the relations of land and sea may have prevailed in past geological ages, possibly then leading to the development of widespread plains of marine denudation that have since been fossilized, it is more usual to picture the planation of these as generally accompanying and as facilitated by gradual submergence, with progressive burial of the abraded surface under thick sedimentary strata.

In his attempt to apply his theory to geomorphology Johnson had no option but to ignore the evidence of changes of ocean level during the long period that must be allowed for the attainment of "old age" in the marine cycle on coasts consisting of resistant or mixed rocks.

Neither of the flats or plains with cliffs at rear (in Norway and India) selected by Johnson as examples of such old-age development is acceptable as the product of marine erosion. More recently the north coast of Spain has been described as geomorphically developed during the recession of cliffs through a distance of about six miles over a very long period (possibly millions of years) during which, it is claimed, there has been no significant change in the relative levels of land and sea. It is doubtful, however, whether this case can be accepted as an illustration of the marine cycle as deduced by Johnson, for the premises are inconsistent with modern knowledge of frequent changes of ocean level, and features of the coast may be alternatively explained by attributing the retreat of cliffs and coastal development generally to erosion at successively lower levels.

INTRODUCTION

In his *Shore Processes and Shoreline Development* Douglas Johnson examined and developed the hypothesis of marine abrasion, making, however, the speculative preliminary assumption that sea level might remain stable for a vast period—certainly for millions of years (1919, p. 224-257). If ever this condition of fixity of base level without *significant* oscillation has prevailed it seems almost certain to have been so long ago that the question of development of plains of marine denudation under such conditions must be treated as one not of geomorphology (as applied to landscape forms of the present day) but of what may be called paleogeomorphology, which is pure geology. As such the question is worthy of the attention of geologists; it recalls Davis' well-known study of "Plains of marine and subaerial denudation" (1896), with all its geologic and paleogeographic implications.

Application of the hypothesis, as Johnson developed it, to the explanatory description of existing coasts can be made only if it is possible to adopt the questionable postulate that the Pleistocene glacio-eustatic oscillations were temporary oceanic retreats of little significance in the long-term development of coasts. The integration of a succession of interrupted partial cycles into a composite major cycle by progressive elimination of the effects of a succession of temporary withdrawals of the ocean to lower levels is not part of Johnson's grand concept; but latter-day appreciation of Pleistocene sea-level oscillations seems to make theoretical elaboration of such a composite scheme necessary for the explanation of many steep coasts. "The cumulative effect of an integrated series of episodes of marine erosion may be the production of very high and steep seaward-facing slopes" (Cotton, 1952, p. 49), notably some descending to the shores of Cook Strait, New Zealand (such as one figured by Davis, 1928, fig. 186), and of course of complementary cut surfaces now forming parts of the marginal shelf.

Long-term theories of development which carry the history of present-day forms back even beyond the beginning of the geologically brief Pleistocene into the ample but vague and misty Pliocene are particularly applicable to discussion of the *broad outlines* of coasts and islands, though the *geomorphic details* of these may be all attributable to modern activity of the erosional and depositional processes.

Daly (1927, p. 78) must have had in mind the composite cycle theory referred to above to explain the cliffing of the dissected volcanic island of St. Helena; for he can have had no intention of denying Pleistocene oscillation of ocean level, on which he had so often insisted. The "sea-cut" cliffs, he wrote, "have heights so great [up to 1600 feet] that we must believe the island has kept a nearly constant relation to sea level . . . probably since a preglacial epoch. . . . There is no hint of subsidence since preglacial time."

Davis (1928, p. 164) has remarked on the obvious fact that "stellate" embayed oceanic islands of the kind he described as "like Banks Peninsula", though common in the coral seas, are rare in cooler seas. St. Helena, though not embayed, is exceptional as being a "maturely-dissected, cliff-walled volcanic island" (1928, p. 160).

Others as a rule are much younger, much less dissected, and as yet less strongly cliffed. These latter being reasonably abundant, Davis (1928, p. 164) inferred that many other volcanic islands have been entirely cut away by marine erosion, and invoked a theory of subsidence to account for absence of "banks" that might be explained as truncated islands, a theory since confirmed to some extent by the discovery of many seamounts.

Coral-reef encirclement has allowed such long survival of very numerous islands that they have become thoroughly dissected, whereas in the reefless seas marine erosion working unimpeded has had time to destroy many islands. It appears, therefore, that the period required for one process or the other to dissect or destroy a large volcanic island must have been far longer than the geologically brief episode of glacio-eustatic oscillation of ocean level, i.e. it involves "long-enduring preglacial erosion" (Davis, 1928, p. 161).

If Johnson's concept of unchanging sea level (except for the phase of Pleistocene oscillation) is to be applied to any actual coasts, it must be assumed, however, that preglacial, interglacial, and postglacial ocean levels were at least approximately the same, that late-Pliocene eustatic high stands of ocean level are mythical, that suboceanic tectonic and volcanic accidents and other like events that might alter the capacity of ocean basins are negligible, and that the volume of water on the Earth's surface has not changed appreciably in the last few million years—or, alternatively, that there has been so nice a balance among all these that sea level has remained almost unchanged. It would be incorrect to attribute to Johnson a belief in an absolutely unchanging sea level, but he perhaps subscribed to the "average sea-level" idea of Davis (1896), "above and below which the land long hovers in many minor oscillations"—in fact may do so for many millions of years.

Making such an assumption, for the sake of argument, one may tentatively approve Johnson's contentions: (1) that, in a region unaffected by diastrophism, marine erosion will, given sufficient time, eventually destroy an island or even a land mass of considerable size, replacing it with a submarine abraded platform but little above the local level of wave base;[1] and (2) that it will cut back a continental margin an appreciable distance, replacing the land with a submarine abraded surface of very gentle slope that descends nearly to local wave base, though this cut platform will be bordered by a wide built shelf. Johnson summed up: "Careful analysis of the process of marine erosion must lead to the conclusion that marine planation is possible without coastal subsidence" (1919, p. 235).

JOHNSON'S HYPOTHESIS AND SUPPORTING EXAMPLES

Contention (1) was embodied by Johnson in a diagram (1919, fig. 40), which is redrawn as figure 1 herewith, with the important emendation that the depth of the edge of the marginal shelf ("continental terrace" of Johnson) is kept the same at successive stages. (This error in the design of Johnson's diagram, which is here corrected, and which appears also in some of his other figures, was probably introduced by careless or delegated drafting. It has been

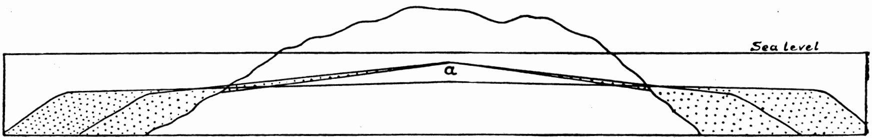

Fig. 1

Emended copy of D. W. Johnson's fig. 40: "Stages in the reduction of a land mass, first to a flat cone [with apex at *a*] covered with marine veneer, later to a still flatter rock cone free from veneer but bordered by a broader continental terrace."

perpetuated in the copying of some of the diagrams for use as illustrations in a number of other works.)

Contention (2) was illustrated by Johnson in his figure 32 (repeated as fig. 35) and in his figure 37, which shows development of the submarine platform to much greater width than in figure 32. Figure 2, herewith, is copied

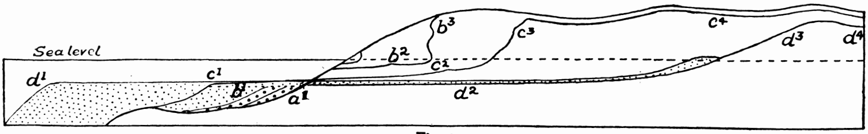

Fig. 2

Emended copy of D. W. Johnson's fig. 35: "Stages in the development of the shore profiles of a shoreline of submergence." Successive profiles: a^1, $b^1b^2b^3$, $c^1c^2c^3c^4$, $d^1d^2d^3d^4$.

from Johnson's figure 32 (or 35), with a similar emendation to that introduced in figure 1. (In fig. 37 also the depth of the edge of the shelf at successive stages should be made to correspond with wave base, which presumably does not change between stages.) A profile in the smaller-scale diagram (fig. 37) which corresponds to $d^1d^2d^3d^4$ in figure 2 is described by Johnson as "early

[1] "The depth at which the bottom is no longer sensibly stirred by wave action" (Cotton, 1918, p. 144).

old age," and another that is drawn to show the submarine abraded platform developed to double the width is referred to as "advanced old age." In the design of the latter (smaller-scale) diagram even more than in that of figure 2, which carries the process only to "early old age," the concept of a simultaneous wearing down of the surface of the remaining land by subaerial processes is introduced. In Johnson's figure 37, indeed, such a process is carried practically to the stage of peneplanation, so that a very extensive and more or less uniformly planed surface is in course of development which will eventually be in one part a peneplain and in another a plain of marine erosion. (The introduction of the concept of contemporaneous subaerial peneplanation of mountainous land makes it clear that Johnson was willing to postulate millions of years for the duration of his marine cycle.)

On a marine abraded surface there is normally a cover, though it may be thin, as on the Pliocene upland surface of southern England[2] (Wooldridge and Linton, 1938; 1955), fossilizing the plain of marine erosion. Johnson, however, envisaged the possibility of planation without the deposit of any cover, and has shown this in his figure 40 (fig. 1, herewith), though this is obviously a special case, namely that in which there is no longer any land left in the vicinity as a source of sediment. Unless submergence (positive movement of ocean level) has accompanied the process of planation—a quite different condition from that postulated, and apparently a commoner one in past ages—the cover, though it may be present, will be very thin.

Much of the foregoing argument is highly speculative, depending as it does on the improbable postulate of secular stillstand. Most geologists have been content to assume slow submergence (positive movement of ocean level) as almost or quite a necessary accompaniment of marine planation, whether preceded or not by subaerial peneplanation (Davis, 1896); and certainly Richthofen (1886, p. 354-355) has shown that the process of marine erosion must be greatly speeded up thereby. Johnson, however, concerned himself with examination of the theoretical process of submarine planation while sea level remained stable, reasoning that such planation was possible, whereas others had assumed that under this condition marine erosion would be so far slowed down when the abraded platform and bordering built shelf began to grow wide that it would thereafter be negligible. As examples, he could cite only two notable cases in which it appeared to him that very wide abraded plains had developed while sea level had remained stable. These were the "strand flat" of Norway and a low-lying plain that borders the east coast of the peninsula of India.

Citing the description given by Cushing (1913; compare also Davis, 1912, p. 209), and reproducing some of Cushing's photographs, however, he

[2] Thinness of Pliocene sands covering this surface may be held to exclude the hypothesis of any considerable positive movement during its formation by marine abrasion; but the covering beds are progressively younger westward (Wooldridge and Linton, 1955, p. 48), indicating a certain amount of progressive submergence. A low cliff (since "degraded") that is recognized (1955, p. 49-52) as separating the late-Pliocene plain of marine erosion from the Miocene-Pliocene peneplain of southern England is a feature that distinguishes this local combination from the (deduced) combination of *simultaneously* planed surfaces of subaerial and marine origin, development of which implies the stricter exclusion of any shift of ocean level while the marine cycle is in progress.

was compelled to regard the 50-mile-wide plain of the Indian coast as backed by very high and steep—even in places overhanging—sea cliffs (Johnson, 1919, pls. 29, 30), an association that is inconsistent with the theory that the process of marine planation becomes so slow after considerable retrogradation has taken place that it is then accompanied by subaerial destruction of the relief of the hinterland. For this reason alone it seems that to explain the Indian landscape in question the theory of marine planation is scarcely plausible, and the balance of probability seems to favor a theory of subaerial development of the plain under the climatic conditions that shape monadnocks into steep-sided inselbergs, or bornhardts (Cotton, 1942, figs. 31, 32).

The case of the strand flat of Norway has been examined by Nansen (1922), and according to him this somewhat irregular rocky surface of small relief—duplicated in some other subpolar regions—is attributable very largely to glacial sapping effected by ice-foot glaciers at the bases of cliffs that have been caused to retreat and have been thus kept very steep at the rear of a rocky coastal flat developed in this way (Cotton, 1942, figs. 70-72). The steepness and also the very great height of the slopes at the rear of the strand flat of Norway are of course, like the steep boundaries of bornhardts in the case of the Indian example, inconsistent with Johnson's theory of development of the coast to old age in a marine cycle with constant sea level.

THE CANTABRIAN COAST AS A POSSIBLE EXAMPLE

If a one-cycle theory advocated by F. Hernández-Pacheco (1950) to account for features of the coast of eastern Asturias and western Santander, north Spain, be accepted, this coast seems to afford a better example than any hitherto described of secular marine planation with a stable sea level. It is still in process of development and it has also this further advantage over the examples claimed by Johnson in Norway and India that it is not backed by very high and at the same time steep cliffs such as would discount the idea of secular marine erosional development. The height of land slope is there, but this has not such steepness throughout as rules out the marine theory of cliff origin in the other cases mentioned. Much of the descent to the sea is gradual, though broken into steps, and a very considerable lowering of the surface by subaerial erosion has been claimed in explanation of the present low altitude of a belt of land that is separated from the sea by cliffs only 150 to 200 feet high. With such wasting the down-wearing of the land surface shown in Johnson's diagrams (fig. 2) may be compared. The lowering claimed to be due to subaerial wasting is that from level A to level C in figures 3 and 4. The descent from the edge of the bench A, figure 4, including the scarp that borders this bench and the surface of the lower bench C, is in a sense part of the sea cliff.

Steepness and even overhang of the low cliffs at the sea margin, such as are described and figured by F. Hernández-Pacheco, seem quite inconsistent with old age, i.e. with the culmination of prolonged and uninterrupted cliff retreat. An apologist, however, who did not hesitate to introduce a variant into the cyclic process in the form of a late-glacial and postglacial oscillation of sea level, eustatically down and then up again to the former level, might

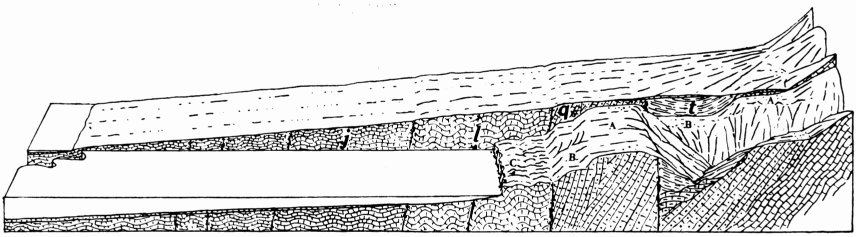

Fig. 3

Coastal retrogradation as postulated by F. Hernández-Pacheco to account for features of part of the north coast of Spain (eastern Asturias and part of Santander). At rear: Assumed initial condition, a pediment sloping (with original gradient unchanged) from the foot of the Cantabrian Mountains to the Bay of Biscay.

In front: Condition after the coast has been cliffed back 6 miles during a period (possibly millions of years in length) of approximate stability of land and sea levels. The sea cliffs, at present vigorously attacked by the sea, do not exceed 150-200 feet in height because the land of the belt C, behind them, consisting of limestone and so subject to karst erosion, has been thus lowered some hundreds of feet below the original pediment surface, becoming an even-topped bench, though without base-level control. On resistant non-calcareous rocks high benches, A, survive, in which the pediment surface has been little modified and in places still retains a cover of cobbles. Intermediate benches, B, are relics of planed areas, the levelling of which has been controlled by a local base level. Geological formations: *j*, Jurassic non-calcareous rocks; *l*, Carboniferous limestone; *q*, late Paleozoic non-calcareous rocks; *t*, weak Tertiary formation (underlain by Cretaceous, also weak).

Topographic features, from left to right: Bay of Biscay; Rasa de Vidiago (bench C); Sierra Plana de Borbollo (bench A); Valle del Dovedal, bordered by relic of bench B; further remnants of pediment surface (bench A); Sierra de Cuera. (Profiles and structure after F. Hernández-Pacheco.)

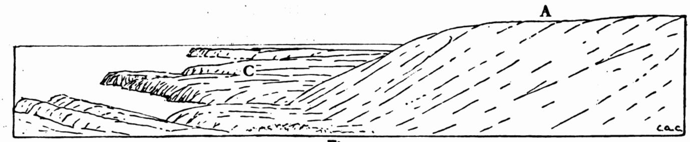

Fig. 4

High bench (*rasa* A) and low bench (*rasa* C, bordering the sea) at Pechón, Santander (compare fig. 3). (From a photograph by F. Hernández-Pacheco.)

explain the youthful character of the low cliffs as merely an ephemeral rejuvenation, such as might also have occurred earlier from time to time.

Unfortunately for its putative value as an example of Johnsonian wholesale marine erosion, it seems doubtful whether the one-cycle explanation of coastal development, even with such variation as has been suggested above, is really correct for this coast; and an alternative, which incorporates a concept of several significant and permanent shifts of sea level (or rather of the land relatively to sea level) has been presented at some length by F. Hernández-Pacheco to apease skeptical readers.[3] Though he concedes the possibility of the occurrence of vertical movements of the land, he follows E. Hernández-Pacheco (1930) in ignoring the necessity for assuming any changes of ocean level. It is irrelevant for the present purpose, however, whether the alternative

[3] A theory of marine bench development at a not very remote date is preferred to that of subaerial denudation by Birot and Solé Sabarís (1954, p. 54).

history that has been suggested or some other that recognizes a greater number of emergences and involves very considerable oscillation of the ocean level in the Pleistocene best fits the features of the coast.

The fact cannot be overlooked, however, that the shore is indented by embayments which obviously originated as drowned valleys, though now partly filled in by sedimentation, and which are in this as well as in other respects quite similar to those of other coasts that show clearly the effects of *postglacial* positive movement of ocean level. These "rias" are reported by E. Hernández-Pacheco (1930, p. 50) to have a measured depth of more than 160 feet in some places. (It seems legitimate to suspect that the excavation, followed by drowning, of these valleys may be attributed to glacio-eustatic oscillation of levels.) F. Hernández-Pacheco, in agreement with E. Hernández-Pacheco, dates the submergence thus indicated as late Pliocene, but, rather surprisingly, reduces his estimate of its amplitude to 30 feet. This, if correct, would justify neglect of such a fluctuation of level as an interruption of a major cycle of retrogradation of the coast that is of such vast duration.

Whatever the details, this coast, like a great many others, has obviously a long history that involves very extensive retrogradation, possibly, as is claimed, throughout most of the considerable width of a continental shelf that now borders it; but it is only if this retrogradation took place in a single marine cycle, more or less in accord with the favored hypothesis of F. Hernández-Pacheco, which is set out more fully below, that it serves to illustrate and support Johnson's thesis. For the sake of argument, therefore, the theory of one-cycle development with little or no interruption may be tentatively accepted, seeing that it postulates the kind of extensive coastal retrogradation, without progressive subsidence *à la* Richthofen, that Johnson has claimed as possible. The postulate that the relative levels of land and sea remain unchanged during the long period of cliff retreat is embodied in a series of successive profiles illustrating stages of development (F. Hernández-Pacheco, 1950, fig. 7), though the accompanying text (p. 56, 82) is not so clear on this point.

Coastal benches (locally termed *rasas*) have been developed, but though alternatively some at least of these may be explained as marine-cut terraces, indicating various positions of sea level in late Pliocene and Pleistocene times, the theory of landscape development without change in the relative levels of land and sea attributes their origin to subaerial processes of degradation. These are assumed to have operated in some cases without any base-level control and in no case with a base-level control that is satisfactorily explained, which makes it difficult to understand why they have very smooth and approximately horizontal surfaces (though they are not structural) and are present at fairly uniform altitudes.

Initially a broad pediment, it is postulated, descended northward from the foot of the Cantabrian Mountains. F. Hernández-Pacheco dates the origin of this as late Miocene to early Pliocene; but if it is indeed a pediment it may be younger, for it would seem advisable to give serious consideration to correlation on paleoclimatic grounds with pediplaned surfaces overspread by and of contemporaneous origin with the ubiquitous *rañas* (fanglomerate sheets) of western Spain and of Portugal, which, as they have nowhere been dislocated or deformed by Pliocene earth movements, Ribeiro and Feio (1950) date as late Pliocene, referring them to a hot-arid episode, probably Villafranchian.[4]

There is little suggestion of activity of Bourcart's (1939; 1950) "continental flexure" along this stretch of coast, such as would cause strong seaward tilting, and no significant change is reported in either the altitude or the attitude of the pediment, its gradual northward slope remaining unchanged at about 2 percent from a rear altitude of about 800 feet. It became submerged, however, northward of a line some six miles north of and parallel to the present coast (fig. 3, rear strip). Thus a marine cycle was initiated, during which it is assumed that cliffs have receded to their present position during an interval of probably at least a million years and possibly measurable in millions of years, but to all appearance without the progressive slowing down of the marine erosive process it is usual to postulate in such a case—though perhaps, as suggested above, this is a specious appearance due to a recent rejuvenation that has followed an oscillation of ocean level.

The benches (*rasas*) bordering the coast in places to a depth of three miles inland fall into three main groups, A, B, C (fig. 3), all of which at first sight suggest well preserved erosional terraces, mainly or at least partly marine, an origin that is actually allowed as possible by F. Hernández-Pacheco, though only in an alternative, not his preferred, hypothesis, for the B and C benches. According to both hypotheses the remarkably level-surfaced high benches and table tops he has grouped as A (at altitudes up to 800 feet) are relics of the initial pediment only very slightly lowered by denudation and so still sprinkled in places with cobbles from a formerly widespread alluvial cover. This almost undamaged survival of parts of the ancient surface was possible only where the rocks under it were non-calcareous (quartzitic) resistant strata of late Paleozoic age (fig. 3, *q*). Both Carboniferous limestone and Cretaceous and Eocene formations have on the other hand (according to the constant sea-level hypothesis) been much degraded subaerially, thus affording an analogy, as already pointed out, with Johnson's deduction. The denudation has been effected in the one case by solution and in the other by mechanical erosion, very different theories being thus adopted to explain development of the benches of the B and C (i.e. intermediate and low-level) series during the postulated long retreat of sea cliffs from the initial shoreline to that of the present day (fig. 3, front strip).

For about three-quarters of the amplitude of the retreat (though not necessarily a like fraction of the time it occupied) marine erosion was engaged in cutting away the rocks of a non-calcareous Jurassic belt (fig. 3, *j*) said to be exposed offshore on the present-day shelf, and during this retreat dissection and erosion by rivers of the remnant of the pediment was (though

[4] According to Birot and Solé Sabarís (1954, p. 54), however, it is scarcely probable that semi-arid climatic conditions such as would favor pediplanation have ever prevailed on the north coast of Spain.

in a manner that has not been fully explained) held up at a high local base level. This controlled the development inland of maturely opened valleys, parts of the flat floors of which survive as benches of the intermediate (B) group. After the receding cliffs at the sea margin had reached the belt of Carboniferous limestone (fig. 3, *l*), by now cavernous, the former temporary base level, which was situated on the impermeable Jurassic rock belt, no longer functioned, and, in response to cliff recession, streams cut more deeply, and thus terraces were abandoned by them at the level B.

As regards the benches of the much lower group (C), these are on the limestone belt. Here, where karst conditions of erosion had long been maintained, denudation by chemical erosion is claimed to have proceeded so far as to lower the surface (very remarkably evenly) to the C level.

If the foregoing explanations of very smooth terraces at the intermediate and low levels is not regarded as entirely plausible, it may be suspected that some at least of the benches of this coast were cut at times when ocean levels (and base levels thus controlled) were considerably higher than they are now, thus throwing grave doubt on the premise of a single marine cycle. In particular, some benches at the intermediate (B) level and those at two lower levels grouped as C strongly suggest tentative correlation possibly with Sicilian and certainly with later Pleistocene sea levels in adjacent regions, which according to some authors are recognizable also in remote parts of the world. An argument that none of these benches has as yet been found to have a cover of recognizable and datable marine deposits is an appeal to negative evidence.[5] It is true of many obviously marine terraces—in New Zealand, for example—that no marine shells have been found in their sedimentary cover. Gravels and coarse sands on terraces that border mountainous coasts (yielding mainly such sediments) are subject to leaching, and commonly they are completely decalcified.

The settled belief of F. Hernández-Pacheco in the non-marine origin of the surface on the highest (A) benches (though he allows of some doubt with regard to lower ones) recalls the claim of Johnson (1932, p. 397; 1944, p. 796-798) that many other somewhat similar benches (supposedly marine) were likewise pediments. Johnson did not advance this alternative explanation to attack any particular theory of progressively lower sea level, but all such theories are challenged by it.

Excellent as F. Hernández-Pacheco's favored concept of the development of the north Spanish coast may appear as an example of rather advanced age in Johnson's marine cycle of planation, doubt as to the applicability of the concept greatly reduces the value of the example. We are thus still without a completely satisfying demonstration of the validity of Johnson's theory of secular marine planation.

From a geological point of view the classic deduction may, however, be regarded (in Johnson's own phraseology, 1933, p. 492) as "highly probable theory," though not "as demonstrated fact."

[5] At Ribadeo, 100 miles farther west, where the only bench (A?) is at a low level (descending westward owing to the transverse warping of the coast that has drowned the deep rias of Galicia) Birot and Solé Sabarís (1954, p. 54) report the presence on it of typical marine deposits, beach sands, and grits.

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