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Deductive Morphology and Genetic Classification Of Coasts

C. A. COTTON

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COASTS, or shorelines, have been variously classified, but a perfect system of classification has not yet been found for them. Systematic arrangement is appreciated by all students faced with the task of describing geomorphic features; for they see the advantage of having some system of pigeonholes with the help of which an unfamiliar and as yet imperfectly understood form can be placed for comparison beside others already known and reasonably well understood. The master geomorphologist W. M. Davis, though he deprecated precise definition, devised and developed explanatory description as a rather loose form of classification, which he made more precise by recognition of stages of the cycle of erosion.

Coast and Shoreline

It has been claimed by Lucke (1938, p. 993) that a specific distinction between definitions of "coast" and "shoreline" implies that a classification of coasts is not necessarily applicable to shorelines, and vice versa. The distinction is one, however, which students ostensibly of shorelines have been unable to make without unduly limiting the meaning of the word "coast" and perhaps unduly expanding the meaning of "shoreline." Johnson's definition restricts "coast" to a belt of land (1919, p. 168); but his studies dealt with a considerably wider zone than this and were certainly not limited to the mere "shoreline," or boundary between land

and sea, as the title of his book would seem to imply. Wooldridge and Morgan (1937, p. 360) have remarked: "It is inexpedient, if not impracticable, rigidly to separate coastline and shoreline features."

Valentin (1952), in a recently published work on the coasts of the world, sensibly defines "coast" so as to take in a strip seaward as well as landward of the present-day position of the shoreline, including not only the "shore zones" recognized by Johnson (1919, p. 162) in the existing coast profile but the whole belt at the intersection of land, atmosphere, and ocean—a broad belt in some regions—across which the shoreline migrates, or has migrated from time to time.

The continental shelf itself is part of the coast in so far as it has been partly emergent in very recent episodes of earth history and may have to be investigated when an effort is made to elucidate the history of present-day shores. There is, of course, a tendency to pay particular attention to the visible (and perhaps beautiful) coastscape; the sea floor in front of this being out of sight is in danger of being also "out of mind."

Genetic Classification

Empirical classifications have been based mainly on such distinctions as that between flat (or low) and mountainous (or high) coasts; and others, more ambitious though not fully explanatory, take

into account the geological structure of coastal lands. Thus Suess (1888; 1906, p. 201) has distinguished between coastal terrains of massive rocks together with stratified rocks that either lie horizontally or exhibit a grain transverse to the sea margin, on the one hand, and longitudinally folded coastal belts on the other, thus defining Atlantic and Pacific types, respectively. Though it is implied that fault boundaries are particularly characteristic of the Atlantic type and absent from the Pacific, such a classification throws little light on coastal origins. When "explanatory" terminology and classification have been attempted, practically the only systems so far found to be of wide practical application have been those based primarily on a dichotomous distinction between coasts due to emergence of a sea floor and those produced by (partial) submergence of marginal land, or, as it used to be the fashion to say, between uplifted and depressed coasts.

Very recently Valentin (1952) has attempted a primary separation of *advancing* from *retreating* coasts, which would allow him to recognize *four* main classes, seeing that advance of the shoreline may be due either to emergence or outbuilding of the coast by secondary processes, and retreat may be due either to a movement of submergence or to erosion. The older-fashioned primary distinction between emergent and submergent coasts* relegates erosion and coastwise accumulation to a secondary role, for they have been treated (though perhaps in some cases artificially and even incorrectly) not as taking place contemporaneously with emergence or submergence of the coastal belt but subsequently, in a long or short interval during which no further emergence or submergence is in progress. In such a pause, or stillstand, a marine "cycle" of coastal changes unrolls, characteristic "stages" of which afford further pigeonholes for use in classification. Valentin's alternative, on the other hand, envisages a possibility which certainly should not be overlooked, namely, that in the ordinary process of coastal evolution there are no such stillstands and that upheaval and sinking of coasts, to say nothing of changes of ocean level, are always going on. If this is the case, cliffing by erosion and the outgrowth of deltas and other built features of advancing coasts must accompany, instead of follow, changes of base level. The concept of base level might, indeed, in such cases be abandoned, a noncyclic approach being adopted reminiscent

* The writer finds it convenient to adopt an artificial definition of "emergent" as meaning having emerged, rather than in the act of emerging; and of "submergent" as partly submerged.

of the revolutionary geomorphology of Penck (1924), which postulates landscape development dominated by secular upheaval, and of objections more recently raised by Cailleux (1950) to the peneplain concept.

Emergence and Submergence: The Classic Dichotomy

The distinction between emergent and submergent coasts was emphasized by Johnson (1919), but it had already been employed in classification by W. M. Davis (1898) and by Gulliver (1899). This distinction became indeed clear cut much earlier, when the American geologist J. D. Dana, looking down in 1840 on the deeply dissected volcanic island of Tahiti from one of its highest peaks, realized that drowning of the valleys of such a land by submergence must produce a coast with a typically embayed outline (Dana, 1849). Davis (1928, p. 45) has, therefore, recognized this as "*Dana's principle* of shoreline development." As Davis points out, Dana's contemporary, Charles Darwin, though he already believed that volcanic islands subsided, and though he was aware that some of them were deeply dissected by erosion, did not "perceive that the subsidence of dissected islands would give them embayed shorelines." Davis (1928, p. 45) continues: "A notable discovery was therefore left for Dana," who was able "for the first time in the then slow progress of physiographic interpretation" to explain the origin of bays by partial submergence. The view from the mountain top inspired Dana to write: "Sunk to any level above that of 500 feet the erosion-made valleys of Tahiti would become deep bays, and above that of 1000 feet fiord-like bays, with the ridges spreading in the water like spiders' legs." (Compare Photograph 1.) He saw just as clearly that features like these could not be produced by the erosive activity of the sea itself, but must as a rule be eventually destroyed by it.

Submergent coasts constitute a major class in every recognized genetic classification; but this does not imply that all others are emergent. In reality coasts of other origin constitute a composite group, but in such a group those of emergence must figure as an important class.

Gulliver (1899), who was impressed by the value of intricacy of coastal outline as a criterion of submergence, attributed it in all cases to sinking of the land, though Suess had much earlier suggested control by actual change of ocean level, which, in 1888, he termed "eustatic." He had earlier (1880) employed the noncommittal description "positive"

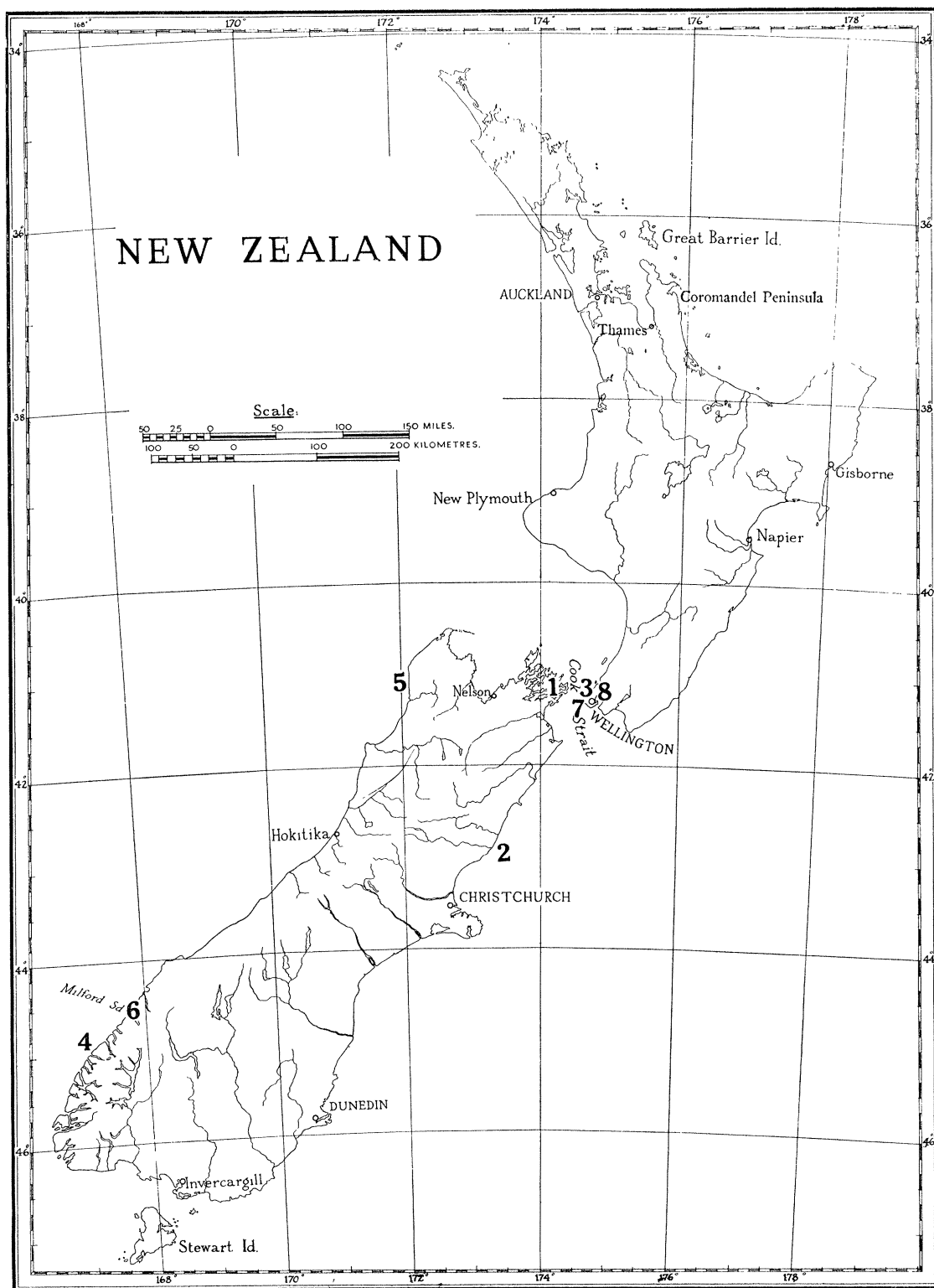


FIG. 1. Map shows location of photographic illustrations.

and “negative” for the (relative) movements of ocean level and of the shoreline which are accompanied by submergence and emergence, respectively, a usage taken up by Richthofen (1886, p. 367).

As regards evidence of emergence, or negative movement of ocean level, marine terraces (Photograph 2) and young, that is, little dissected, coastal plains are generally acceptable—though the distinction between the latter and strand plains must be kept in mind. (“Strand plains,” so called by Davis, have been built out from a hinterland by beach accumulation while sea level has remained stationary, whereas true “coastal” plains are exposed strips of former sea bottom.)

Gulliver realized the necessity of making allowance for oscillation of level, which he thought of, however, as oscillation of the land, the ocean level remaining unchanged. He, and Davis also, was impressed by evidence of oscillation of the coast of Maine, where features due to recent upheaval, attributable to uprise consequent on unloading of the crust due to melting of the continental glacier, fringe a drowned land margin.

The recognition that considerable oscillation of the ocean level itself must have taken place, as much ice has accumulated on the lands in glacial ages and has melted away again, dispenses with the necessity for assuming oscillation of the land; but neither Gulliver nor Davis realized this fifty-five years ago. Davis began to make allowance for such glacio-eustatic oscillation only when his attention was drawn to it by R. A. Daly in the coral-reef controversy; and apart from the coral-reef ques-

tion he gave little attention to its implications until confronted with a problem of marine terracing in Southern California, when he attributed the terrace-making to rapid cliffing back of the coast at times when positive movements of ocean level overtook and outpaced a continuously operating upheaval of the land (Davis, 1933).

The Marine Cycle: A Device for Classification

In his *Physical Geography* Davis (1898) classified “shorelines” on the twofold basis, placing those of emergence in a “first” class (“where the sea lies on an uplifted sea bottom”) and those of submergence in a “second” class (“where the sea lies on a depressed land surface”). Such separation of main categories is applicable more especially to initial, that is, as yet uneroded, forms of the coast; but for subdivision Davis outlined cyclic erosional stages characteristic of derived, or sequential, forms in each class separately. His brief treatment of the cyclic development of emergent coasts assumes the outline of the new land to be straight or nearly so, an inference which is usually more justifiable in the case of emergence of a new coastal plain with appreciable slope seaward than in the only case Davis subjected to analysis, that of extremely gentle declivity.

In such a case the slope of the adjacent sea bottom, continuing that of the newly emergent land, is so gentle that sand is stirred up from the bottom by breaking waves in the process of development of a graded under-sea profile, and thrown up, in a manner already recognized by Élie de Beaumont (1845), as a long “sand reef,”* which emerges from the sea some distance out from and parallel to the initial shoreline.

Cyclic Development from Emergent Coasts. The sand reef, or barrier, encloses a “lagoon,” and its continuity is broken in places by gaps (“inlets”) kept open by tidal currents. The barrier or chain of barrier islands so formed has some degree of permanence, for, as pointed out by Davis, “about as much sand is brought in from the sea-bottom as is ground up on the beach and taken away.” Subsequent conversion of the lagoon into salt marsh

* Davis (1896) had earlier called this feature an “off-shore bar”; he continued later (1912) to call it a “sand reef,” but offshore bar was preferred by Johnson (1919). More recently Price (1951) has proposed to substitute “barrier island” for this as usually applied. “Barrier” was used by G. K. Gilbert (1885, p. 87), and has continued in use as a synonym (Cotton, 1922, p. 389; 1942b, p. 432). Shepard (1952) has suggested a general use of barrier for above-water and “bar” for under-water ridges of sand, but proposes no genetic significance for this distinction between barrier and bar.



PHOTOGRAPH 1. Submergent coast resulting from deep drowning (plus postglacial redrowning) of mountainous land, Queen Charlotte Sound, Cook Strait, (N. Z.). (From N. Z. Ministry of Works.)



PHOTOGRAPH 2. Coast of emergence, North Canterbury (N. Z.). A coastal plain has been cut back by marine erosion to a narrow terrace. (By V. C. Browne.)

by infilling is followed, in the normal course of events, by retreat of the shore under wave attack, this having become possible owing to offshore deepening brought about by removal from the bottom of the sand that has been thrown up as a barrier. All the salt-marsh flats may eventually be cut away in this process, so that now "the mainland is directly attacked and slowly cut back in a long low bluff," or line of cliffs. Thus a cyclic stage of coastal development is reached which Davis later called "maturity." He was unable, however, to find examples of coastal-plain coasts cut back so far by the sea that they "terminate in cliffs of great dimensions" (1898, p. 355). The high chalk-cliffed coast of Normandy (northwest France), which he mistakenly described at this time as such (but an "exceptional case") he later (1912) diagnosed as due to continuous cliffing of an initially submergent (not emergent) coast.

Davis did not, either at this time or later, realize the importance as a coastal type of the other case in which the offshore profile of an emergent coast

is relatively steep, though he was not unaware of examples of cliffing at the margins of some rather steep coastal plains immediately on their emergence, so as to cause elision of the barrier-fringed stage of development (Davis, 1896; 1909, p. 709). Owing, however, to failure of the classic systematists to analyze the development of such coasts, which are characterized by marine terraces, emergent coasts on which these are prominent features for long escaped full recognition.

Cyclic Development from Submergent Coasts. Davis outlined also a cycle of sequential forms derived from his "second" (submergent) class of coasts; but he did not follow this out beyond the stage he later called "submaturity," that at which headlands are cliffed and the mouths of bays are bridged across by the extended growth of spits of sand or gravel, leading to great simplification of coastal outline (Fig. 9, A, B, C).

Oscillating Coasts. Davis was, like Gulliver, well aware of complications in the developmental history of coasts which are due to oscillation of level.

A coast previously submergent might emerge, so that "its former cliffs and beaches may be found at a greater or less distance inland." Thus the "compound" category of Johnson (1919) was foreshadowed. The existence of coasts (later termed "neutral" by Johnson) which could not be classed as either submergent or emergent was also recognized by Davis, for he described "delta shorelines" in a separate category.

The "Outline of Cape Cod." The elementary, but systematic, treatment of coasts in Davis's *Physical Geography* had been preceded two years earlier by a deductive essay on coastal forms with special application to those of Cape Cod (1896), in which he analyzed development of shore profiles and shore outlines separately. In his discussion of the coastal profile the concept of a "graded condition" was introduced, with also the idea of a cycle of development. "A graded profile being once attained, its graded condition will be preserved through all the rest of an undisturbed or normal cycle of shore development" (Davis, 1896; 1909, p. 702). The grade and cycle concepts were found useful also in the treatment of outline. "The initial irregularity of shore outline [due to submergence] is replaced by a graded outline," during the cyclic change from a youthful to an "adolescent" (in later writings termed "submature") stage. The "graded" outline he described is the rectified line resulting from a trimming back of headlands under wave attack and a bridging of the mouths of bays by "bars" (so called by Gilbert, 1885, p. 92). Davis felt it necessary to distinguish these as "tangent" bars, named from their relation to shoreline drift,* for, disregarding Gilbert's term "barrier," he had substituted "offshore bar," a name destined to survive for years, for the description of ridges of sand "built up from the bottom in shallow water."

He developed the theory of development of these offshore bars, but without at this time specifically declaring them characteristic of emergent coasts. They enclose lagoons, and this early stage is followed by filling of the lagoons, migration of the barriers landward, and eventual elimination of the ensemble of fringing features during the progress of a cycle in which he recognized stages of youth and "adolescence." His statement of this cycle is a model of clarity. Illustrated by prototypes of diagrams employed later by Johnson, it is on the lines of later treatments by Davis himself (1898; 1912) and by Johnson (1919).

* Without questioning the diverse origin of such bars ("bay bars" of Johnson, 1919), Shepard (1952) has included them in an empirical category of "barriers" along with offshore bars ("barrier islands").

Gulliver's "Shoreline Topography." Further exploitation of the "cycle of shore development" recognized by Davis in 1896 was left to Gulliver (1899), according to whom "the forms of any coastal belt [N.B. not merely shoreline] may be grouped in the appropriate stages of a cycle. These forms will be consistently related to the associated land area on the one hand and to the sea bottom on the other. When considered together, the forms of a coastal belt indicate the relative time since the last considerable uplift or depression, as well as the ratio existing between the several activities, in their dynamic effect upon the forms of the coast and the shore."

Gulliver's work is in the main a study of topographic maps selected from various regions, the maps being sorted, with an eye to classification, into two groups, the first to demonstrate and classify "initial" forms and the second "sequential." Initial forms, on which primary classification must depend, are grouped as originating from: (1) uniform uplift, (2) uniform depression, and (3) diverse movements. The third category foreshadows coasts of "transverse deformation" (Cotton, 1942a, b); but few maps were available to Gulliver for the study of these, and the only example he found it possible to cite of strong differential movement bringing close together coastal features attributable to emergence and submergence was in Southern California. There, following Lawson (1893), he recognized that coasts with high flights of marine terraces on the mainland at San Pedro and the island of Santa Catalina had between them the partly drowned island of Santa Barbara.

European Classification

An important discussion of coasts was included by de Martonne (1909) in the first edition of his monumental textbook of physical geography. His use of the concept of a "cycle of littoral erosion" was limited to an account of the straightening, or rectification, of the outline of a coast initially embayed by submergence. Stages of youth, maturity, and senility were recognized; but that termed "maturity" was "adolescence" of Davis, later termed "submaturity" by Davis and by Johnson, while "senility" was the equivalent of "maturity" in the usage of Davis and Johnson.

In the classification of initial forms the categories of emergence and submergence, though not specifically mentioned, are recognizable in the main divisions: (1) coastal plain types (emergence), and (2) coasts of folded regions (implicitly assumed to be embayed by drowned valleys). Here, following

Richthofen,* a distinction, of minor value in *genetic* classification, is introduced between types based on contrasting geological structures of the land, whether the grain of the terrain is parallel or transverse to the general line of the coast. Naturally, where a mature land with valleys adjusted to geological structure is invaded by the sea, *geographically* contrasting types of outline are found in these two cases.

In addition to those listed above, a miscellaneous assortment of other categories of initial coasts are mentioned, such as fault, volcanic, and glacial coasts.

Coastal Morphology in Davis's "Erklärende Beschreibung"

The treatment of coasts by Davis in his German textbook (1912) was extensive as regards process and stages of development, but he did not specifically recognize primary categories of initial coasts other than the "first" and "second," or emergent and submergent, classes. He again discussed separately the modification by marine processes of profiles and outlines; it is noteworthy that this time he specifically set out to describe not shorelines merely but "coastal forms" as these develop in a "marine cycle," with "initial," "sequential," and "ultimate" forms. Consistently with cyclic treatment, the ocean level is assumed to remain constant (in relation to the land) during development. Necessarily still-stand both of land and of ocean level must be very prolonged if advanced cyclic development, as deduced by Davis, is to take place with the formation of a broad wave-abraded platform that grows in width progressively at the expense of the land at the foot of complementary retreating cliffs, for, toward the last, when the shoreline has receded far and the abraded platform has become wide, cliffs must retreat very slowly indeed. He did not, however, ignore the possible alternative of much more rapid, noncyclic erosional destruction of a coast that is cliffed back progressively with constantly rising water level, or sinking of the land (1912, p. 518), as it had been visualized by various geologists,

* The classification of Richthofen (1886), though it introduces numerous *types based on localities* and though it is not a *genetic* classification, did recognize one principal genetic group, that in which the sea "invades" valleys of the land. Subdivisions of this group are: (1) fiord coasts, (2) the Dalmatian type, with trend parallel to the grain resulting from folded structure of the land, and (3) rias coasts, with trend transverse to this grain. Though the name "ria" was taken from that locally applied to the bays of northwest Spain, the chief examples cited of rias coasts were those of Brittany and southwest Ireland, in both of which the general line of the Atlantic border is transverse to the strike of the Armorican structure to which landscape ridges and valleys are adjusted.

notably Gilbert (1885, p. 110) and Richthofen (1886, pp. 353–361). (Gilbert pointed out that with "slow and gradual submergence . . . the erosion of sea cliffs is exceptionally rapid, because the gradually deepening water upon the wave-cut terraces . . . enables [the waves] to spend their full force against the cliffs.") Davis again invoked this mechanism to account for rapid coastal erosion, in 1928 (p. 194) and in 1933.

Emergent Coasts. Davis discussed at considerable length the erosional changes affecting coastal outline; but his treatment of emergent coasts was still incomplete, being based on the tacit assumption that there was only one case worthy of consideration, namely, that one with so gentle an initial slope of the sea floor seaward that cyclic development must begin with a deepening of the sea offshore and a piling up of the sand so derived into a barrier. His analysis of further development of this coast was presented on similar lines to his earlier treatments (1896, 1898). He now described such a coast as "young" while it was bordered by barrier islands and the more or less infilled lagoons they enclose, and "mature" when these are eliminated in the course of cyclic change and a line of cliffs borders the low coastal plain at the rear—an example of this stage being the Adriatic coastal-plain coast of Italy.* An "old" stage, Davis suggested, might be defined as that which will be reached when the coastal cliffs, retreating more and more slowly and progressively gaining height, though still in coastal-plain strata, lose the steepness they retained when the coast was mature because they are now subaerially graded. The slowing down of cliff retreat which allows of this is due to increasing width of the complementary abraded platform seaward of the shoreline, which absorbs the energy of breaking waves. Elimination of the coastal plain and cliffing back into the hinterland are not envisaged.

Submergent Coasts. The remainder of Davis's (1912) discussion of coasts consists mainly of an elaboration of the scheme of cyclic development of embayed coasts (those of his "second" class). He described the focusing of wave energy by refraction on headlands, which are therefore actively trimmed back; development of beaches and spits and the bridging of bays by bars; infilling of bay heads and bar-enclosed bays; and so forth. The coast is to be termed "submature" when its outline, initially intricate, has been smoothed by these processes; and "mature" only when, or where, erosion has forced the shoreline to retreat beyond the heads of the initial bays (produced by drowning of valleys) so

* As noted later, this is a concept of maturity differing from that of Putnam.

that the line of cliffs has become continuous. Such a definition of coastal maturity as synonymous with development of an unbroken line of wave-cut cliffs is acceptable with application to coasts in general, in whatever way they were initiated.

Davis described the chalk cliffs of northwestern France (facing the white cliffs of Dover, which are similar) as a coast of submergence now in the fully mature stage of development. The outline is certainly fully mature; but Davis (1912, p. 513), as Johnson (1919, p. 250) has pointed out, elliptically described the cliffs themselves as late-mature instead of as cliffs of a fully mature coast. In a cycle of erosion formulated for the cliff form itself—apart from the cycle of coastal development—the cliff's must, as Johnson claims, be called "young," because they are retreating so rapidly that they remain nearly vertical.

Davis was aware of the rapid retreat of the chalk coasts; he was so impressed by it that he at one time (1898, p. 356) attributed the separation of Great Britain from Europe at the Strait of Dover to marine erosion, though familiar with the biological evidence which indicates a very late date for this separation. It is known now, however, that the retreat of these cliffs, though measurable, has been quite small since the reopening by drowning of the Strait of Dover when the ocean water returned only a few thousand years ago (after the drying out of the Strait during the last glacial age).

The chalk coast of northwestern France is an example cited by de Martonne, as well as by Davis, of coast retreat so far advanced that rivers are be-trunked (so that valley mouths now "hang" above sea level); some river systems are even dismembered so that former tributaries now enter the sea independently. The great retreat thus indicated suggested to Davis (1912, p. 485) possibility of a secular sinking of the region, which would keep wave action vigorous while it was in progress. The retreat has certainly been going on for a long time, though it has necessarily been interrupted by the glacial-age episodes of low ocean level. Davis did not realize the short duration of postglacial time.

Miscellaneous Coasts. Davis indicated how interruption of a marine cycle must take place, with initiation of a new one, if relative levels of sea and land change. Being little interested, however, in formal definition and in tabulation, he did not extend his classification beyond the two main classes by enumerating miscellaneous initial categories of coast which are not conveniently included in either, such as volcanic, glacial (fiord-wall), or tectonic (fault and monoclin) coasts. He did, nevertheless, describe, though without placing it in any special

category, one of those coasts which are transversely warped so that forms due to upheaval and submergence appear side by side—the Italian Riviera di Levante (Fig. 2).

He also indirectly attacked the question of fault coasts by suggesting other explanations for the Atlantic coasts which Suess (1888; 1906, p. 203) had claimed as due primarily to foundering of former land to seaward along great fractures. As a specific example he described the coast of Cornwall and Devon (Davis, 1912, p. 502), offering an explanation of it which is an extension of his "morvan" concept of mountain form, embodying the principle of intersecting peneplains. A strip of the more ancient of two intersecting peneplains, which is steeply inclined and which has been buried under strata and much more recently re-exposed by erosion, forms a nearly rectilinear range front—that of the Front Range of the Rocky Mountains in Colorado being a typical example. The initial outline of a "morvan" coast might be most simply pictured as resembling that which would result from such Noachian flooding of North America as would allow the sea to lap against the Rocky Mountain front.

Systematic Treatment by Johnson

In Johnson's major work (1919) he enlarged the classification of coasts by adding other primary categories to the already well-established emergent and submergent classes. One, which he termed "neutral," was designed to include those coasts the essential characteristics of which depend on causes other than change of level, or submergence and emergence. Necessarily this is a miscellaneous group, including: (*a, b, c*) delta "shorelines," alluvial-plain "shorelines," and outwash-plain "shorelines" (though these are scarcely separable from one another); (*d*) volcano "shorelines," described as "of more or less circular pattern"; (*e*) coral-reef "shorelines"—not only fringing reefs but all such, for all are "independent of changes of level," the outline marking the "contact . . . with newly made land in progress of formation"; (*f*) fault "shorelines," that is, *newly made* fault scarps, the infantile slopes of which have descended below sea level.

Johnson's fourth main category, which he termed "compound," was created to meet the case of coasts that "combine elements of at least two of the preceding classes." This indispensable, not to say omnivorous, group includes more particularly those coasts which preserve features impressed on them as a result of both positive and negative movement of an oscillating ocean surface (or, alternatively, of oscillatory diastrophism).

In subdividing submergent coasts Johnson (1919) abandoned the traditional (European) distinction between “rias” coasts (Richthofen, 1886; de Martonne, 1909) in which the coast crosses the grain, or strike, of structures of the marginal land, and a “Dalmatian” type of coast, with the grain parallel to the generalized coast line so that a trellised pattern of valleys is drowned. He included both these types under the one head of “ria shore-lines.” In addition to these he placed fiord shore-lines in the submergent class, that is, those formed by the entry of the sea into troughs excavated by glaciers, though such entry does not require a change in relative levels of land and sea. Inclusion of these in the same class with normally drowned coasts seems tacitly to indicate close community of origin, but it was not Johnson’s intention to imply that the submergence of fiords was necessarily accompanied by either sinking of the land or rise of ocean level.

Sequential Forms of Submergent Coasts. Johnson, like Davis, made use of the stages of cyclic coastal development for subdivision of his genetic categories, particularly that of submergent coasts.

In a stage of early youth a coast of submergence, which might alternatively have been called “infantile,” was termed by Johnson “crenulate.” Characteristic of this stage (recognized and figured earlier, though not so named, by Davis) is a small-scale irregularity of outline which has early replaced smoother curves of the initial line of intersection of the sea-level plane with a dissected land. Development of this condition may be expected to follow quickly upon submergence, because of the vigorous activity of wave erosion, picking out small differences of rock resistance and so revealing the bare ribs of any small-scale heterogeneity of terrain, when it begins to work on the moderately inclined to rather steep shore profiles afforded by submergence of land slopes.

“Maturity” was reserved, as it had been by Davis, for a late-developing condition of continuous coastal cliffing, which, in the nature of the case, is very long delayed if the embayment of the coast by drowning has extended far up the valleys. In conformity with Davis’s usage (1912) he described as “submature” the important and long-enduring stage that begins with the rectification, or smoothing, of the outline of the shore brought about by the truncation of headlands and the building of “bay bars” as barriers across bays. A continuous strand thus developed affords a path for transportation of gravel or sand alongshore, some of which finds temporary lodgement in the shore zone, forming beaches (Fig. 9, C).

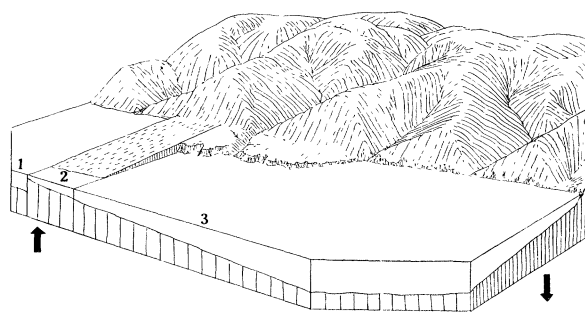


FIG. 2. Diverse movement of the Riviera di Levante coast, Italy, as interpreted by W. M. Davis. (1) Earlier condition, followed by (2) deformation (local by upheaval), (3) features of existing coast generalized; upheaval (at Genoa) to left; submergence (at Santa Margherita) to right. (After a diagram by Davis.)

Mature Coasts. Johnson neglected to take structure of the land fully into consideration in the analysis of mature coasts. When a coast is thus cut back to a continuous line of cliffs, whether from a shoreline initially embayed by submergence or from any other initial outline, the line of cliffs may be nearly straight, as it is shown in Johnson’s diagram of the mature stage (1919, Fig. 88); but this will be only in the special case of homogeneous rock terrain, as, for example, in the chalk cliffs of France. If a definite structural grain in the landmass be allowed for, such as is present at Wellington (N. Z.), a grain sufficiently well marked to produce adjustment of the mature ridges and valleys of the landscape to the structure, this must be reflected also in an adjustment of the mature coastal outline to the same structure, so that the line of cliffs will be far from straight. In the case of the cliffs on west and south coasts at Wellington (Photographs 3 and 7) maturity of outline is provided by continuity of the line of cliffs, but the outline is strongly sinuous (Cotton, 1951a, p. 104; 1952a, p. 55). On the somewhat embayed coast thus produced cliffs are continuous around bay heads as well as headlands. Profiles and details of the cliffs indicate that vigorous marine erosion is in progress, so that the cliffs must now be retreating rapidly. Yet, generally speaking, the coastal outline will not become any more nearly straight. Johnson did not realize how intricate a maturely developed shoreline may become through such adjustment to structure, and pictured it with only broad and “simple but distinct” curves (Johnson, 1919, p. 344). He was aware, however, that, while at an earlier stage there will be “more rapid retrogression of the shoreline on weak rocks,” after “maturity is attained . . . all parts of the shoreline retreat at the same rate.”

Sequential Forms of Emergent Coasts. John-



PHOTOGRAPH 3. Maturity of development indicated by continuous cliffing, with outline adjusted to structure, Cook Strait coast, near Wellington (N. Z.). Postglacial eustatic submergence has here been neutralized by probably concurrent upheaval. (From N. Z. Ministry of Works.)

son's typical emergent coast ("shoreline" of emergence) was (following Davis) that bordering a low, broad coastal plain which is fringed (in its infancy) by barriers; but he pointed out that features of sequential development such as (still following Davis) he described as *characteristic* of such coastal-plain margins might be found on some coasts that are not emergent, where, for example, very nearly level land surfaces have become slightly submerged (1919, p. 201). He thus anticipated and supported in advance a perfectly valid claim made more recently that such features are not *criteria* of emergence (Shepard, 1937). It will not be out of place to mention here another cause of upgrowth of offshore barriers which is independent of changes of level, namely a shallowing of the sea by infilling with disturbance of pre-existing equilibrium of profile, such as will result from *showering* of abundant sandy debris of volcanic origin. Such development of a coast that would be placed in Johnson's "neutral" category appears to have been the origin of the sand-built barrier island at Tauranga (N. Z.) (Cotton, 1942b, p. 433; 1951b, p. 349), which fringes a drowned coast along the dissected margin of a terrain of volcanic rocks (not a coastal plain) (Fig. 3). It is known that at least one explosive eruption of extreme ("Plinian") violence has showered rhyolitic volcanic ash in this vicinity at a date which must be later than that of the postglacial drowning of the coast* (Cotton, 1944, p. 190).

* Radiocarbon investigations have shown that these volcanic "showers" fell within the last 3000 years.

Johnson's discussion, like that of Davis, was limited to the case of emergence of a sea floor not far from dead level. He did not, apparently, consider it worth while to analyze a hypothetical case of emergence with steeper submarine slope seaward. One of the few later suggestions to include such (in part terraced) coasts within the purview of coastal classification has been made by Putnam (1937), who has outlined the marine cycle for a "steeply sloping shoreline (*sic*) of emergence." This is the process of further narrowing an initially narrow coastal plain by cliffing, so that it is reduced shortly after its emergence to a marine terrace, marking "early youth," and further narrowed in "late youth" (stages which might respectively have been called *youth* and *submaturity*). This is followed by ultimate destruction of the terrace by continued wave attack, when the hinterland becomes cliffed so as to make of it a typically *mature* coast (Fig. 4).

Such development may take place in a small fraction of the time that would be required to produce a similar mature, that is, continuously cliffed, outline by cliffing back an embayed submergent coast of similar rocks. As a consequence, emergent coasts retrograded to a continuous line of cliffs (Photograph 3) are relatively common (Cotton, 1951a, p. 103; 1953a, p. 54). There are also very numerous examples known of the younger stage at which marine terraces survive (Fig. 5 and Photograph 7).

In his discussion of the sequential history of a coast on which "offshore bars" (barriers) are formed (on the lines of the earlier classic treatment by Davis) Johnson retained Davis's description of the coast as young while it remains fringed by barrier and lagoon, and mature when the lagoon has disappeared and the barrier after having been driven landward has eventually been eliminated, so that cliffing of the margin of the coastal plain at the rear begins. The aspect of the coast, continuously cliffed from now on, contrasts so strongly with its former fringed condition that it seems appropriate to retain this definition of maturity. It would seem unrealistic to insist instead on the analogy of this marginal cliffing with the cliffing back to a marine terrace of the much narrower coastal plain that emerges bordering a high coast with relatively steep submarine profile. In that case all stages of the cliffed, marine-terraced condition are by definition young (Putnam, 1937), or at any rate no farther advanced than submature; maturity is achieved only when cliffs are cut back into the hinterland, a condition which does not always require a very great span of time for its attainment. In the Davis-Johnson case, on the other hand,

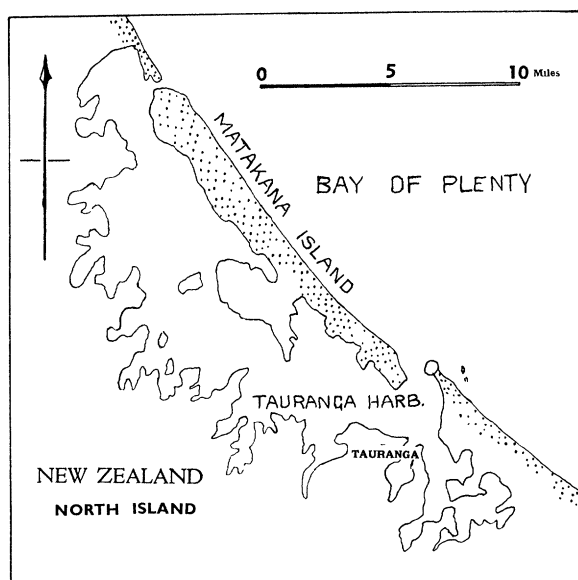


FIG. 3. Barrier island (Matakana Island) enclosing Tauranga Harbour (N. Z.) as a lagoon. This borders an embayed coast at the submergent margin of a dissected terrain of volcanic rocks.

maturity would in most cases be indefinitely postponed if it were delayed (by definition) until a broad coastal plain of gentle declivity had been destroyed by marine erosion, even though such destruction might theoretically be remotely possible.

Cliffed Mountainous Coasts. In New Zealand there are some mountainous coasts bordered by continuous or almost continuous cliffs (examples at Wellington have already been mentioned) which apparently have been developed during retreat of *moderate amplitude* either from tectonic scarps or from very steep coasts of emergence. Described examples of coasts bordering mountainous land that has been cut *far back* by marine erosion have been hard to find, however, in regional geographical reports that can be accepted as geomorphically trustworthy, whether scarps so formed remain coastal or have been forced inland by more modern advance of the shoreline. Two major scarps were cited as examples by Johnson, one along the rear margin of a fringing plain in southern India and the other backing the "strandflat" of Norway; but the correctness in each case of the explanation of the scarp as due to marine cliffing may be doubted (Cotton, 1942c, pp. 85, 197).

Johnson theoretically developed the concept of secular retreat of cliffs on a coast of submergence, carrying the analysis even further so as to include the case in which a landmass is largely or perhaps wholly cut away by erosion (at "old age" of such a cycle of development). It can be deduced that a

large area of land may thus be progressively replaced by a surface worn flat by abrasion at a level considerably below that of the sea (Johnson, 1919, p. 256). This is a theory of some geological importance, but, as it implies an almost infinitely prolonged period of stability of sea level, a condition not compatible with the oscillation known to have occurred rather recently, it is not helpful in explanation of the origin of existing coasts. Richthofen's theory, previously referred to, of somewhat similar development accompanied by rapid coastal cliff retreat during a relative (and commonly real) rise of sea level demands much less time and seems applicable to some coastal segments in soft-rock terrains.

Fault-Scarp Coasts. In his book *The New England—Acadian Shoreline* (1925), Johnson was more specific than he had been in 1919 in justifiable limitation of the definition of true fault coasts. It is not enough that the sea now laps against a fault scarp, for in the great majority of instances in which this is the case the present outline is due to recent submergence, so that the coast must strictly be placed in the primary submergence category. If it has clearly been a fault coast prior to a recent positive movement of ocean level (or a general subsidence of the land), it can be placed also in the "compound" group (for it can be claimed as a fault

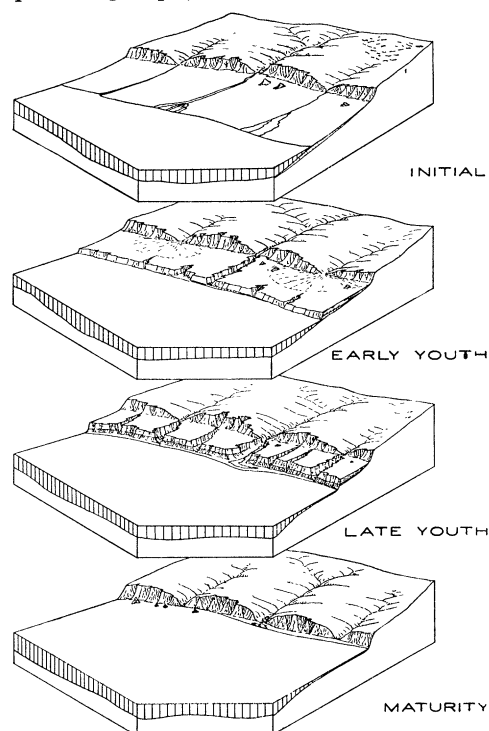


FIG. 4. Stages of erosional development of an upheaved coast. (After Putnam.)

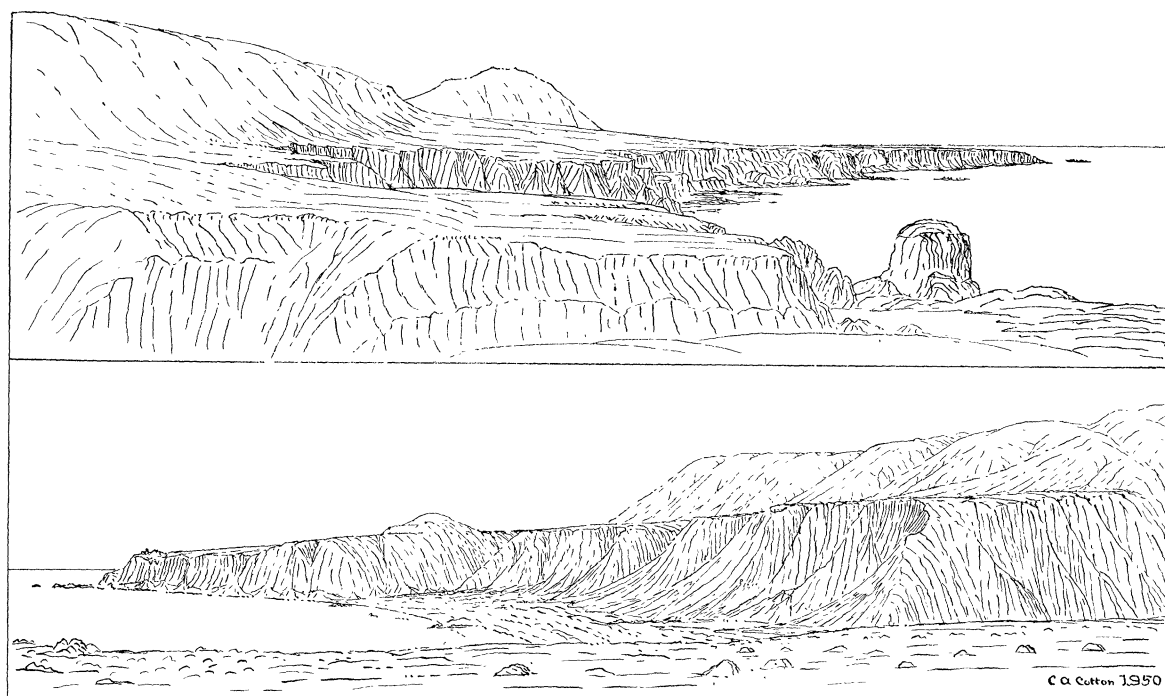


FIG. 5. Young erosional development of emergent coast (from a photograph). Above, on Islay Island, west Scotland (reputedly postglacial emergence). Below, Baring Head, Wellington (N. Z.) (possibly postglacial emergence).

coast in a second cycle). If, however, it has not been a fault coast in a former marine cycle, a coast formed by intersection of the present level of the ocean with a fault scarp is, in technical terminology proposed by Johnson (1925, p. 32), a "fault-scarp" (not "fault") shoreline, or coast, although, as he has pointed out, the class thus defined is merely a subdivision of submergent coasts. (As shown in Fig. 6, it cannot but be embayed to a certain extent.) He

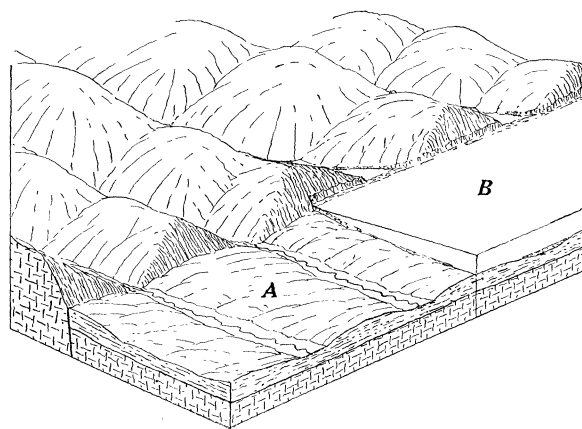


FIG. 6. A straight coast produced by partial submergence of a landscape traversed by a fault scarp or fault-line scarp. A, dissected condition prior to submergence; B, after a rise of ocean level (or regional subsidence).

claimed, on the other hand, that the place of a true fault coast was in his "neutral" category. Among submergent coasts, he observed that some other rectilinear examples were of a "fault-line-scarp" variety, in particular some parts of the New England—Acadian coast, which he described.

Shepard's Classification

Shepard's classification of "primary," that is, young or initial, coasts, as set out more recently in *Submarine Geology* (1948, pp. 71–73), was proposed in 1937. It is chiefly remarkable for its abandonment of the classic dichotomy of categories of emergence and submergence, for its author refuses to recognize the existence of emergent coasts anywhere. A dichotomy substituted (though this is not apparent from the author's tabulation, which presents four main heads) is one between coasts of submergence (A, below) and a group of others (B, C, and D), which might all be placed in Johnson's "neutral" category. The classification is as follows:

A. "Shaped by terrestrial erosion and drowned by deglaciation or downwarping" and, we may add, positive movement of ocean level. Here are included "ria coasts" and "drowned glacial-erosion coasts."

B. "Shaped by terrestrial depositional agencies."



PHOTOGRAPH 4. The fault-bounded outer coast of mountainous Fiordland (southwest New Zealand). (By V. C. Browne.)

Here are included coasts formed by “river deposition,” “glacial deposition,” “wind deposition,” and “vegetation extending the coast.”

C. “Shaped by volcanic activity.”

D. “Shaped by diastrophism,” including “fault-scarp coasts” and “due to folding,” that is, monoclinical coasts.

It would be difficult to agree with Shepard’s rejection of emergent coasts as a worth-while category in classification. It appears that, being misled by the conspicuously incomplete treatment of emergent coasts offered by Davis and Johnson, he has failed to realize the significance of important features indicative of emergence, such as raised beaches and marine terraces, and has thus focused too closely on the doubtful “criterion” of offshore bars. The regions affected by postglacial isostatic “rebound,” when relieved of a heavy load of ice by its melting, afford abundant evidence of genuine upheaval of coasts, as do also many parts of the “mobile belts” of the world—parts in which dias-

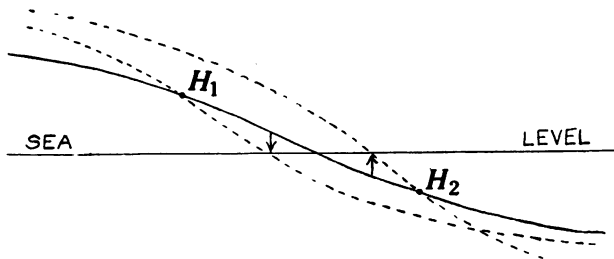


FIG. 7. Hypothetical continental marginal flexure. H_1 , H_2 : Alternative positions of the hingeline of flexure.

trophism is still active. Writing in the same year as Shepard, Wooldridge, and Morgan (1937, p. 357), though fully aware of the fact of a postglacial rise of ocean level that has affected the coasts of the world very generally, continued to regard the distinction between emergent and submergent coasts as of first importance in classification.

Even if it could be granted that the postglacial rise of ocean level was so recent, or, conversely, that recent diastrophism has been so feeble, that every coast must now afford evidence of drowning as a result of it, there are so many coasts still dominated by features imposed on them by earlier, though not very remote, uplift that discussion of the features of such coasts is desirable and necessary. Geomorphologists must be prepared also to restore the appearance of the coasts initially, immediately after their uplift, in whatever more or less ancient cycle that took place. Such compound coasts cannot logically be left out of a scheme of genetic classification unless it is confined very strictly to “shorelines” (in a restricted sense) as they now are, that is, to “secondary” features, as defined by Shepard (1948, p. 70).

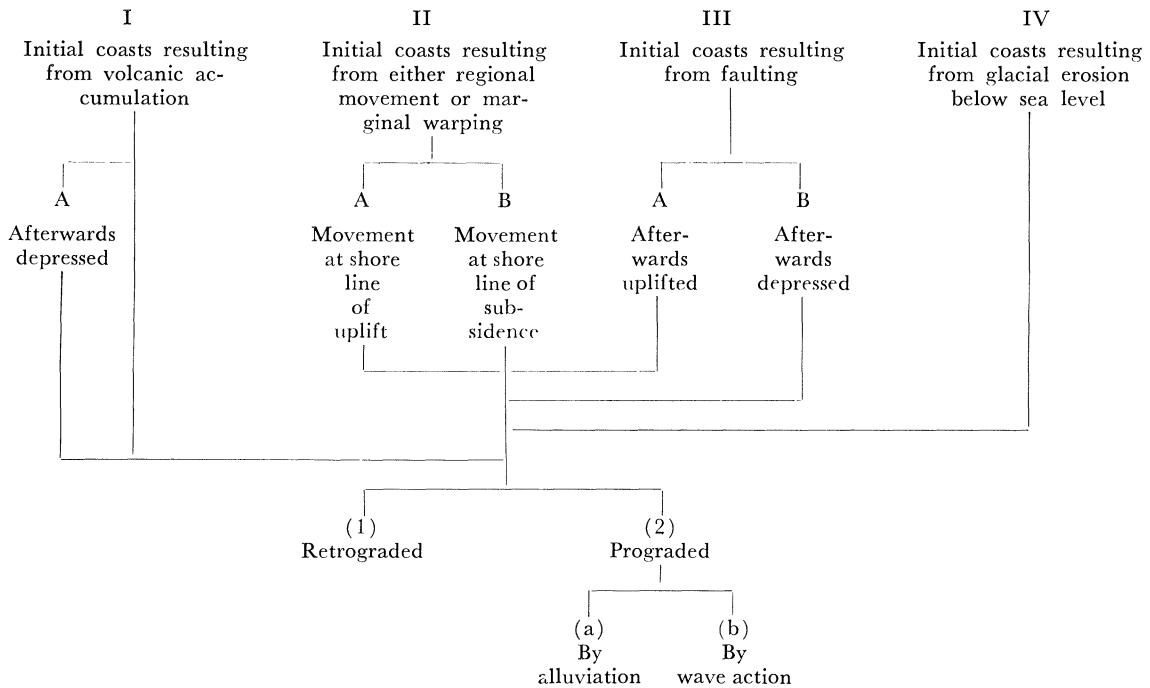


PHOTOGRAPH 5. Monoclinical-flexure coast, north of Karamea River (N. Z.). Note the hogback ridge on a seaward-dipping homocline of young covering strata. (By V. C. Browne.)

The Continental Marginal Flexure

In a scheme of classification proposed in 1918 (Cotton, 1918) and since used in textbooks (Cotton, 1922, 1942b), the possibility has been recognized not only of regional movement uniformly up or down (now more conveniently explained in many cases as movement of ocean level) but also of marginal warping or flexure of the landmasses on longitudinal axes, that is, parallel to coasts. Either one or other or some combination of these may produce coasts of the two main classes, emergent and

CLASSIFICATION OF COASTS (COTTON, 1918)



submergent. The idea of an inherent tendency of lands to rise and of ocean floors to sink, which has been given prominence in recent writings by Bourcart (1950), has long been a familiar one in geological theory. It was a favorite theme of T. C. Chamberlin's and was implied in Davis's preconceptions of land and coast development; even the elementary concept of the coastal plain, in the geological sense, implies a seaward tilting which has given coastal-plain strata an appreciable inclination away from their hinterland.

Assuming such marginal warping to occur at least in some places, the hingeline of the longitudinal flexure so formed may, obviously, be either landward (H_1) or seaward (H_2) of the pre-existing shoreline (Fig. 7). This tends to reduce the importance of the distinction between emergent and submergent coasts, not for purposes of geographical classification, but as regards interpretation of regional geological history in comparatively recent times. Flexure on a hingeline to seaward will cause upheaval at the shoreline; whereas flexure on a hingeline situated landward will depress the shore zone. A coast already diversified with bights separated by promontories is likely to be upheaved in the bights and depressed toward the ends of the promontories, if the hingeline is between these zones. King (1951, p. 190) claims to recognize continental marginal warping in South Africa, where

commonly the hingeline has been out at sea, and the coast has therefore risen; but some parts of the coast are intersected by drowned valleys, which King regards as indications of an inland sweep of the hingeline, causing local submergence.

Coastal Categories in the Classification Proposed by Cotton (1918)

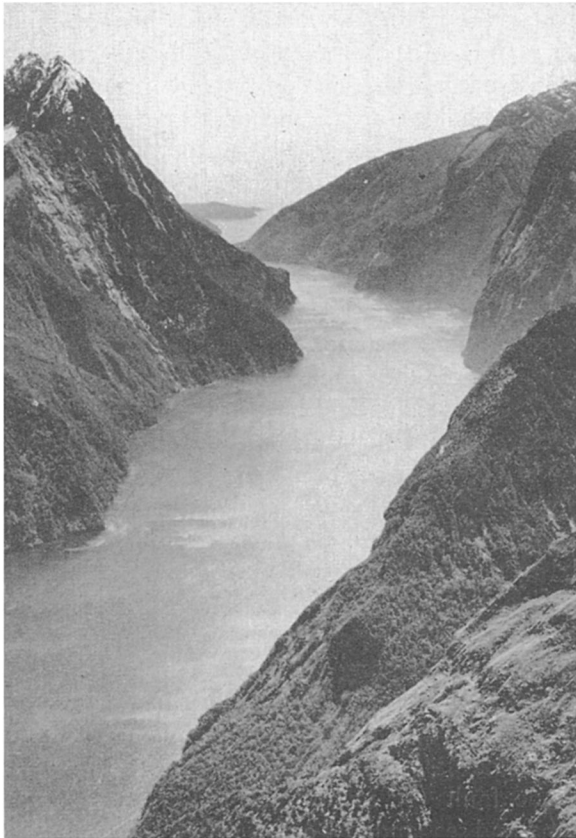
Besides emergent and submergent coasts (both attributable to either marginal flexure of the land or regional change of relative level of sea and land). Cotton's classification (1918, p. 326) recognized additional classes which Johnson would place in the "neutral" group. These were coasts produced by (*a*) volcanic accumulation; (*b*) faulting* (Photographs 4 and 8); and (*c*) glacial overdeepening below sea level (Photograph 6).

* Closely related to fault coasts in origin, and best placed with them in a single "tectonic" major category, are those initiated by *sharp* monoclinal flexure, as recognized in theory (and termed "fold coast") by Shepard (1948, p. 71). There is remarkable development of outline thus initiated in a middle segment of the west coast of the South Island of New Zealand (Fig. 1), where the trend conforms strictly for long stretches to the strike of young strata which dip seaward at about sixty degrees (Healy, 1938; Wellman and Willett, 1942; Wellman 1951). Quite possibly this coastal monocline, rather than the "Alpine" fault (Wellman and Willett, 1942, Plate 48), which runs inland northeastward is the continuation of the great coastal fault bounding Fiordland (Fig. 1, locality 4). This *monocline* type recurs near the northern end of the west coast, north of Karamaea River (Photograph 5).

Fault Coasts and Compound Coasts. It was already on record (Cotton, 1916) that there are coasts of fault origin (and undoubtedly there are some of monoclinial origin also) that were initiated at a date earlier than that of the current marine cycle. Some of them have been subsequently upheaved (or the sea has receded from them) so that they have become also coasts of emergence (Photograph 7); others have become partly submerged. In either case their place is now strictly in the "compound" category, as Johnson (1919, p. 400) has recognized.

On the other hand, extensively developed tectonic coasts (fault or monoclinial) that are still in their first cycle cannot be common, for the obvious reason that there has been little time for the formation of great faults or flexures since the last oscillation of ocean level. Nevertheless, there are some such coasts (Photograph 8); and the deductive theory of the development of fault coasts is of value not only for interpretation of these but also for the study of coasts of remote fault origin.

In his "compound" category Johnson (1919, p. 401) included a combination of fault coast and coast of submergence which, it might be deduced, would result from complete submergence of an off-



PHOTOGRAPH 6. Fiord-wall shorelines, Milford Sound (N. Z.). (By V. C. Browne.)



PHOTOGRAPH 7. Emergent, or "multicycle", coast, very probably a fault coast of an earlier cycle, Tongue Point, near Wellington (N. Z.). (From N. Z. Ministry of Works.)

shore block separated by a fault from land that is partly submerged as a result of its having subsided at the same time as the offshore block (Cotton, 1916, Fig. 4; Johnson, 1919, Fig. 124). Thus valleys are drowned, while the outer shore is defined by an interrupted fault scarp. Though no well-preserved example of a coast resembling that figured has been described in detail, a west-facing fault-bounded coast at Thames (N.Z.) is succeeded northward by that of the embayed northern end of Coromandel Peninsula so as to introduce the compound type in the transition area (Fig. 8A). The peninsula is generally regarded as a large faulted earth-block with endwise tilt northward, in which direction it tapers to a point and its high axial range appears to plunge. Deep submergence of a land surface is there indicated by the presence of outlying islands, but such coastal evidence of submergence is overlaid by a redrowning of the shores due to regional positive movement of ocean level, probably eustatic and postglacial, which is conspicuous around the whole northern end of the North Island.

"Multicycle" Fault Coasts. The diagnosis of a fault coast is not necessarily a claim for such origin within the current cycle, that is, since the postglacial rise of ocean level. That fault coast in particular which outlines the vast sweeping curve of the outer border of Fiordland, in southwestern New Zealand (Photograph 4), cannot be of such recent development. If, however, such outlines originated as tectonic scarps in an earlier though possibly rather remote cycle, they are still fault coasts, though in the compound category also. Parts of some of them are recognizable as fault coasts in a second, or later, cycle because now bordered by marine terraces indicative of considerable emer-

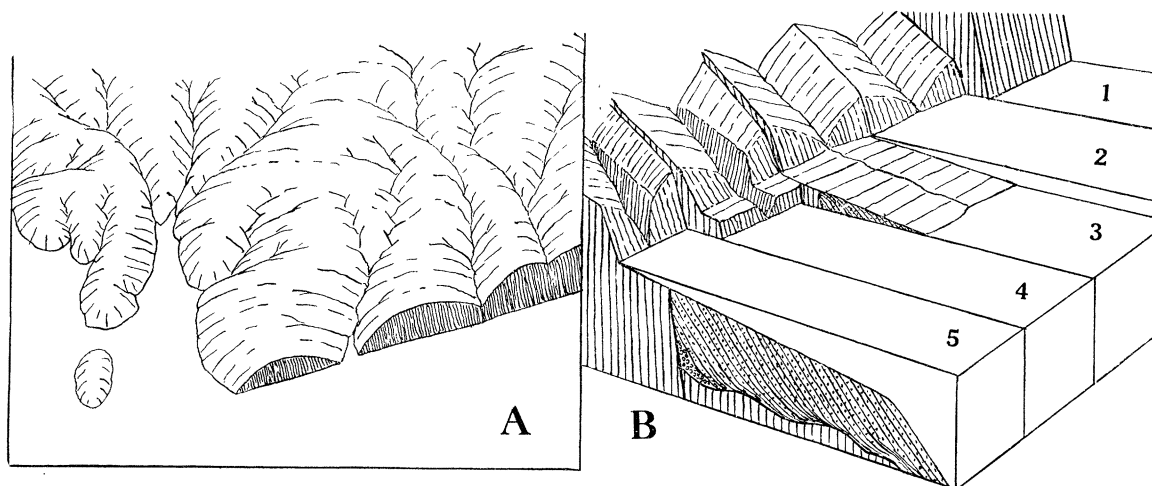


FIG. 8. A. A fault-scarp bounds a tilted block of country (right), as at Thames (N. Z.), while there is a submergent coastal outline on the plunging end of the block (left), as on the north end of Coromandel Peninsula (after Cotton, 1916). B. A "two-cycle" fault coast. Stages of development are numbered 1-5 (after Cotton, 1916).

gence since the (remote) faulting period* (Fig. 8B and Photograph 7).

Coasts of Transverse Deformation. In 1942 (Cotton, 1942a, b; see also 1951a) a further addition was made to the main classes of Cotton's classification of 1918, namely, coasts of "transverse deformation," which revived Gulliver's category of "diverse movement." Since flexure on a hingeline parallel to a coast is called longitudinal, the description "transverse" is applicable to deformation more or less at right angles to this. Either dislocation or strong warping on such lines can bring together side by side contrasting coastal types showing features characteristic of emergence and submergence, associated also in some cases with stretches of fault coast (Photograph 8). The combination and juxtaposition of these affect the general aspect of a coastal province, and in addition the deformation causes large-scale sinuosity or zigzag development of outline by producing major salients separated by embayments of tectonic origin, examples of which are prominent features of the coast around the southern end of the North Island of New Zealand (Photograph 8). These features are generally much larger than are most embayments and headlands due to marginal drowning of dissected land.

Coasts of Stable and Mobile Regions Contrasted

It has recently been suggested (Cotton, 1952b, p. 15) that the distinction between emergent and

* This description does not imply such renewal of faulting on the line of the primitive coast, when a second upheaval has taken place, as is shown in a textbook illustration by Lobeck (1939, p. 354, B), which misinterprets the geological history of the type (compare Fig. 8B).

submergent coasts, though still important, might perhaps be relegated to secondary rank by recognizing as a new basis of primary classification a dichotomy of coasts of stable and of mobile regions, the latter being exemplified in the still-writhing parts of the mobile belts of the world in which are seen the effects of diastrophism that has been active within the last few thousand years. For full implementation of such classification there is as yet insufficient information on record regarding the geomorphology of the mobile regions. Even their coasts, relatively accessible as they are, have received insufficient attention; but there are certainly features indicating recent emergence of parts of the coasts of New Zealand, California, Japan, Persia, and South America.

If differentiation of stable and mobile regions ever becomes a major line of division for coastal classification, the former will be seen to have experienced only changes of base level due to oscillation of the ocean surface, while the latter have moved up or down or have been warped. Notwithstanding this, coasts initially very similar might be formed in each of the two main classes; but a different basis of subdivision could conveniently be adopted for each. In those regions where, owing to one cause or another, upheaval or deformation has taken place in postglacial time, it would be advisable to subdivide into coasts of submergence and emergence, with provision also, of course, for additional classes, for example, those with (a) newly made fault (or monoclinal) boundaries between land and sea, and (b) constructional (volcanic and sedimentary-depositional) outlines.

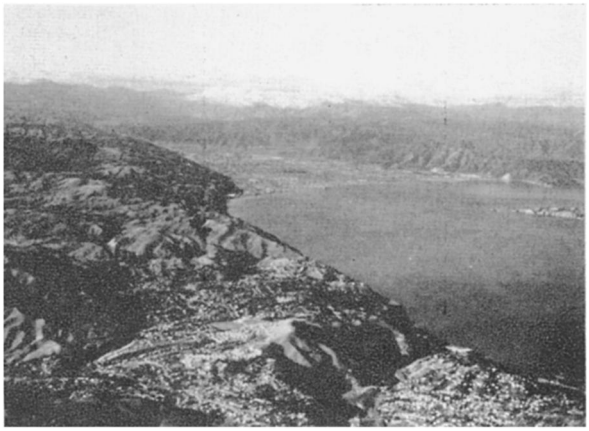
In the case of stable regions, on the other hand,

clearly all the coasts, with the exception of growing delta margins, outbuilding sandy coasts, and new volcanic forms, must show a drowned outline due to the postglacial rise of ocean level. Even here, however, a dichotomy based on recognition of features due to emergence and submergence may prove to be the most satisfactory for subdivision. Owing to locally slow tempo of change of land form due to subaerial or marine erosion some coasts may still be dominated by features characteristic of emergence, in spite of the fact that there is evidence of a more recent drowning of their outlines.

It is obvious that nearly every coast can be described as "compound," as defined by Johnson; but, because this category is so omnivorous, it is of little real use for purposes of classification. It might, therefore, be divided into classes as follows:

A. *Coasts of stable regions.* All drowned in the most recent submergence (though all in reality compound): (1) dominated by features due to the most recent submergence; (2) dominated by features resulting from some earlier emergence; (3) miscellaneous (volcanic, fiord-wall, etc.) coasts.

B. *Coasts of mobile regions.* All compound but affected by diastrophic as well as eustatic changes of base level: (1) coasts on which the most recent movement of base level, however caused, has resulted in submergence; (2) coasts on which the most recent diastrophic movements have resulted in emergence; (3) fault and monoclinical coasts; (4) miscellaneous (volcanic, fiord-wall, etc.) coasts.



PHOTOGRAPH 8. First-cycle fault coast at Wellington (N. Z.) as seen from above. Beyond it is the Port Nicholson embayment, occupying a tectonic basin recently submerged by transverse deformation affecting the southern end of the North Island. (From N. Z. Ministry of Works.)

Whether this suggestion is practically applicable or not it has at least the merit of re-emphasizing the importance of the distinction between emergent and submergent coasts, which "with their contrasted morphology and development have a very real existence" (Wooldridge and Morgan, 1937, p. 358).

Primary Classification on the Basis of Sequential Development

Genetic classification begins almost necessarily with the initial forms of coasts; but most coasts as

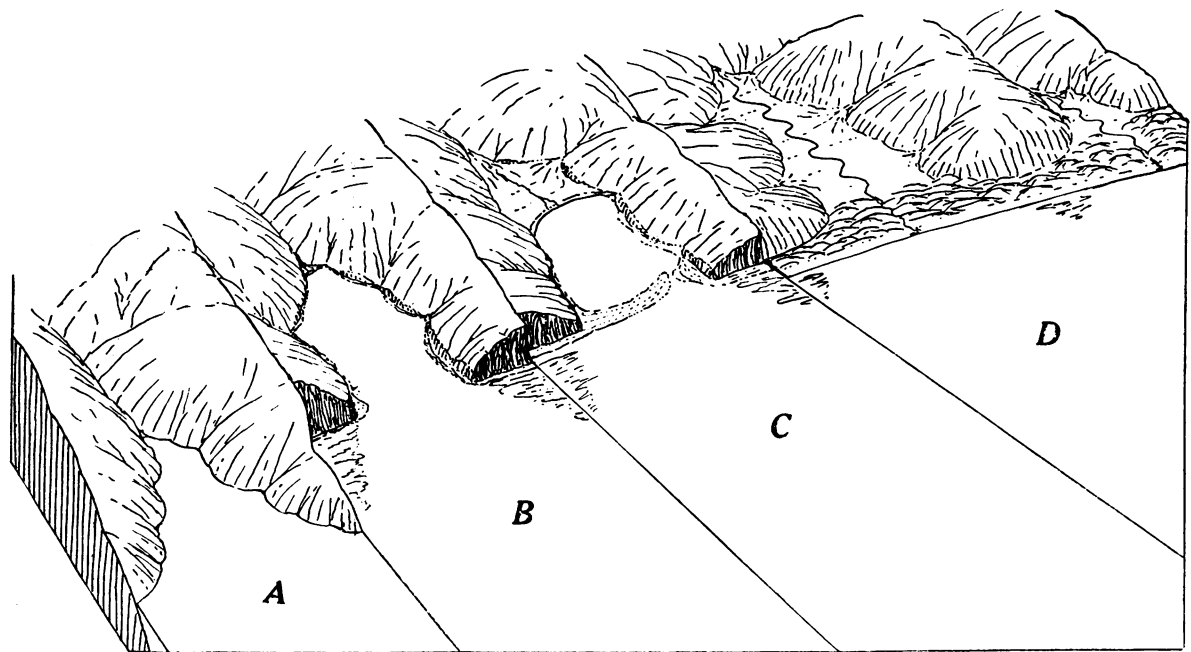


FIG. 9. Progradation beginning (D) after a submergent coast (initial form, A; young condition, B) has reached submaturity (C).

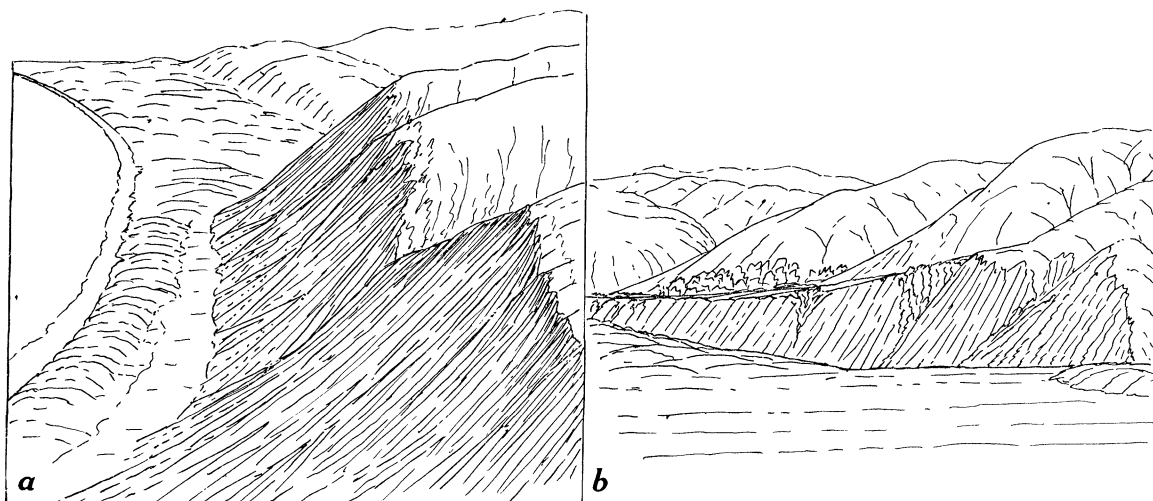


FIG. 10. Prograded coast at Paekakariki, Cook Strait (N. Z.) *a.* Progradation is extending southwestward along the base of high, fresh wave-cut cliffs, thus fending off the sea so as to prevent further cliffing. *b.* Evidence of oscillation between cliff-cutting and progradation. Fans have been built out over a foreland; these are truncated by sea cliffs that are still fresh; and the sea has again been forced back from the line of cliff by renewed progradation (northeast of locality 3, Fig. 1).

we find them have been transformed into highly developed sequential coasts in the course of the marine cycle. So complete may be the metamorphosis that it may now be well-nigh impossible to form a reliable opinion as to the nature of the initial coast and its origin. Complications may be introduced by:

1. *Tempo of development.* One coast may run through a cycle of changes a thousand times as rapidly as another, even though on such coasts the dominant process is erosion little complicated by the effects of accumulation.

2. *Convergence of development.* Very similar coastal forms and assemblages may have very different histories. When developed to full maturity coasts of emergence and of submergence, fault coasts, monoclinical coasts, and perhaps others can become indistinguishable from one another, though this presupposes a very fast erosional tempo in the case of some coasts.

3. *Progradational development.* While variation of tempo of erosion might offer a convenient method of subdividing main classes of coasts, progradation, with the transformation it can produce, seems to offer greater possibilities.

Coast Affected by a Progradational Accident. A progradational accident (Cotton, 1951b), that is, a change from coastal erosion to outbuilding, generally by the piling up of a succession of beaches, may supervene at almost any stage of the erosional development of a coast. In the case of a cyclically developing coast of submergence, however, the

stage of youth must be past, bays being by this time bridged by barriers of the bay-bar variety, so that there is already in existence a continuous beach along the shore. Here must be noted another enormous contrast in tempo of development, namely, that between the case in which all the gravel or sand for potential beach-building (and spit- and bar-building (must be produced in place by local erosion of cliffs, especially if these are composed of hard rock, and that in which, independently of local rock hardness and of the local tempo of coast erosion, such materials are supplied in abundance by drift alongshore from some more distant source, usually the mouth of a large river.

When, however, in a few centuries or in tens or hundreds of thousands of years, cliff erosion is superseded by coastal accumulation (Figs. 9, 10), as it must be, eventually almost everywhere if still-stand continues long enough, the shoreline advances and beach after beach is built along the front of a flat or dune-covered foreland (strand plain) of growing width, so that the character of the coast soon becomes entirely changed. A similar result may be produced by alluvial accumulation—the growth of a large delta or a fringe of smaller confluent deltas—in front of a former shore.*

* The varied character of the coasts of the present day is due very largely to the instability of levels, including that of the ocean surface, in recent geological time. In the long-past ages of great stability of base level in which extensive peneplanation of lands took place, low prograded coasts must have been monotonously prevalent, except in those regions then affected by diastrophism, if there were any such regions.

Yet another major dichotomy is thus indicated, for an important line must be drawn, perhaps the most important of all for geographical purposes, between those coasts which are more or less continuously prograded and those which are not (compare Shepard, 1948, pp. 73–74). Such distinction may be made either between primary categories of coasts or at a lower level. If the genesis of coasts as a whole, or of coastal outlines, is the object of study and must therefore be given first place in the classification adopted, the separation of coasts dominated by erosion and accumulation, respectively, may be useful only as of minor subdivisional rank. Thus, all the categories of coast, originating in every imaginable way, may be made to branch into a final trichotomy: (1) retrograded (eroded); (2a) prograded by alluviation (delta-fringed); (2b) prograded by beach-building (fringed by strand plains) (Cotton, 1918).

If, on the other hand, a classification for purely geographical purposes is aimed at, it may be established on this primary basis, thus:

A. Coasts undergoing erosion (cliffed coasts).

B. Prograded coasts, with progradation commonly still in progress.

The contents of the classes thus defined would be roughly the same as of the empirical but geographically useful categories steep or high and flat or low coasts.

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