

THE DENUDATION CHRONOLOGY OF SOUTH-WEST ENGLAND

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I. INTRODUCTION

The physical features of South-West England can be summed up in the statement that it is a region of deep, narrow, V-shaped valleys, alternating with flat-topped interfluvies which rise in step like formation inland from the surrounding coast. In this respect the peninsula stands out as unique among the physical regions of Britain. This generalization however simplifies a fascinating morphology which has resulted from a complex history of river dissection punctuated by phases of marine planation. It is the form, distribution, age and origin of the erosion surfaces, which largely constitute the flat-topped interfluvies, combined with the evolution of the drainage pattern, that enables the geomorphologist to piece together the denudation chronology of the area.

Although much of the peninsula still awaits detailed morphological analysis and the majority of research workers to date have concentrated on either drainage evolution or erosion surfaces within their chosen areas we now have a sufficient number of studies to provide the main elements in the geomorphological story. Differences of opinion occur within the literature as the story unfolds, but an increasing measure of agreement seems to be emerging with continuing research. A review of our present state of knowledge falls naturally into three divisions: the erosion surfaces, the drainage evolution, and the denudation chronology which emerges when we consider the drainage in relation to the erosion surfaces.

II. THE EROSION SURFACES

Whilst the purist might argue that most morphological features consist of erosion surfaces, the term is here used in the commonly accepted sense of plateau like areas constituting geographical features which can be mapped. Such surfaces usually mark the end of sub-aerial, marine or arid cycles of erosion and often provide keys to the recognition of past base levels, (Pls. 1—4).

Erosion surfaces corresponding to long periods of still-stand in the base level are locally of a generally horizontal nature. *In extenso* however the surfaces are not flat although this is a term which is often used in descriptions. Thus the marine surface will normally be a gently inclined plane rising landwards: the

average submarine declivities of existing shallow seas reveal gradients of up to 20 ft. per mile, whilst off stormy coasts marine peneplanes at present in course of formation may have gradients of some 90 ft. per mile. This however is a slope of less than one degree which although capable of producing considerable height differences in short distances actually forms an apparently flat surface when subsequently exposed to human inspection.

It may be anticipated that after exposure the rear of a marine surface will be terminated in regions of resistant rocks by a steeper rise or bluff marking the position of an old cliff line. With an alteration in base level however an emergent marine surface becomes subject to sub-aerial erosion and soon begins to lose its characteristics as a result of river dissection. Evidence of the former existence of the marine surface may be found in flat topped hills and interfluvies separating more or less angular V-shaped valleys. A marked acceleration in the rate of change of slope on interfluvial crests will terminate the surface and bluffs may denote the position of an old cliff line. Successive bluffs at correlative heights may enable an old cliff line and hence the base level to be traced over the face of the country.

The sub-aerial surface on the other hand is not quite so simple. Even in the stage of old age a great variety of forms will be possible in the morphology and we may find a rolling relief with an amplitude of perhaps 100 ft. to 150 ft. Hence when dissected by later erosion related to lower base levels no extensive flat surfaces will be found, but rather a general accordance of summit heights with rejuvenated polycyclic valleys. When the possibility of subsequent warping or tilting is also envisaged it is clear that the separation of sub-aerial surfaces will be more difficult than with marine surfaces for there may be no convenient cliff line remnants.

Arid erosion surfaces of the pediment type constitute a third possibility. Pediments now in course of formation are usually found in piedmont zones, have slopes of from $\frac{1}{2}$ to 7 degrees, and are normally backed by mountain fronts some hundreds of feet in height rising at slopes of up to 30 degrees from the pediment. In a degraded form confusion of the pediment with the marine erosion surface might seem possible, but the scale of the features and any associated deposits usually enables a distinction to be made.

The first recorded recognition of erosion surfaces in south-west England appears to be Clement Reid's description towards the end of the last century of the narrow shelf fringing the south and west coasts of Cornwall. This shelf, being backed above 430 ft. by a steep bluff suggesting a worn down cliff line clearly seemed to be of marine origin. Further support for this hypothesis came from the marine deposits at St. Erth which appeared to be associated with the surface, although the deposits were located in a valley cut in the shelf. The included fossils led Clement Reid (1896) to postulate an early Pliocene origin but there now seems some doubt as to this dating. H. B. Milner (1922) suggests an Eocene age in view of the mode of occurrence and elevation of the deposits whilst more recently S. W. Wooldridge (1950) has shown that a late Pliocene or even later age is more likely.

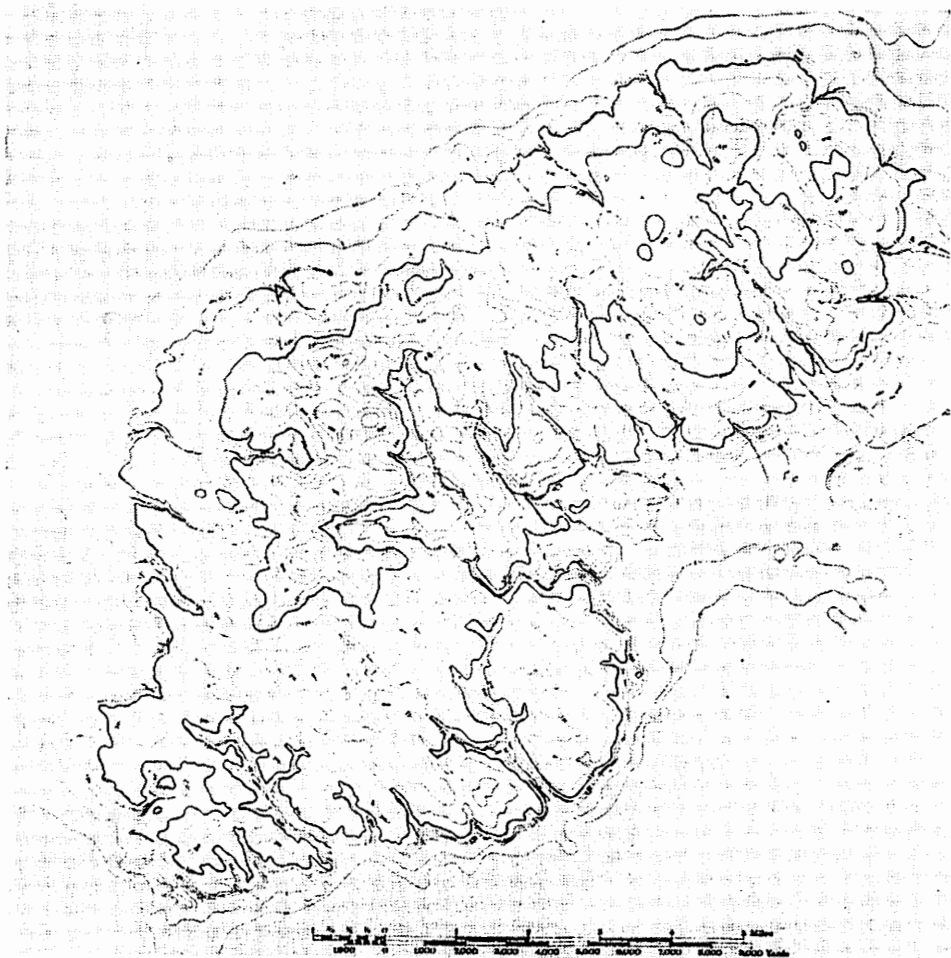


Fig. 1. Part of the Contours-only plate of O.S. Sheet 189 showing the erosion surfaces of the Penwith Peninsula. The north-west coast shows the 400 ft. surface and the conspicuous bluff which backs it at 430 ft. The broad expanse of the 400 ft. surface on the south is also revealed together with the deeply incised valleys.



Fig. 2. Part of the Contours-only plate of O.S. Sheet 174 showing the erosion surfaces in the vicinity of Boscastle and Tintagel. Along the coast are remnants of the 400 ft. surface backed by the conspicuous bluff at 430 ft. The extract also shows parts of the 850 ft. surface and Condolden bluff at 920 ft. together with Davidstow Moor at 1,000 ft.

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In 1907 Jukes-Brown described the coastal plateaux in the neighbourhood of Torquay and in 1908 G. Barrow drew attention to further erosion surfaces at 750 ft. and nearly 1000 ft. on Bodmin Moor, which were again thought to be of marine origin and probably of Miocene age, although no definite evidence for the latter suggestion was available.

In keeping with the nineteenth century British geological tradition initiated by A. C. Ramsey in Wales all these erosion surfaces were attributed to marine agencies. A completely divergent view was however put forward by the great American geomorphologist W. M. Davis in 1909: influenced by his United States background he proposed that the landscape of Devon and Cornwall could be explained by two cycles of sub-aerial denudation surrounding a monadnock. Sub-aerial origins were also suggested by L. Sawicki (1912) who after visiting Wales with W. M. Davis in 1911 subsequently travelled through Devon and Somerset with three French geographers. These divergent views were based on brief and superficial visits and they did not at the time, nor subsequently, command much support. The new ideas however might well have influenced later opinions held by Clement Reid, who, in the Newton Abbot Memoir, is inclined to invoke a sub-aerial origin for the upper Dartmoor surfaces.

Both in south-west England and elsewhere in Britain a considerable amount of contradictory evidence was, up to the outbreak of the First World War, being assembled with no clear acceptance of either point of view. Although observations continued elsewhere in Britain the next advance in the south-west did not come until the nineteen thirties since when there has been a steady flow of research papers. In 1936 C. W. F. R. Gullick suggested that further planations existed in south-west Cornwall at approximately 600 ft. and 180 ft. in addition to the already demonstrated and by then accepted level at 430 ft. In the same year J. F. N. Green (1936) further suggested that the Bodmin Moor features which Barrow had described could be traced eastwards into east Devon. Green also draws attention to the difficulty of determining with accuracy the heights of the sea level related to any particular marine erosion surface, locally complicated in the west because of the accumulation of head upon the platform.

The erosion surfaces of the south-west were also discussed in 1936 by P. Macar of Belgium. Whilst recognizing marine levels terminating at 430, 750 and 1000 ft. with a further level at 1200 ft. he introduces a somewhat discordant note by a resuscitation of the Jukes-Brown concept of local warping.

The following year a paper on the erosion surfaces of North Cornwall was published by the present writer and this included for the first time a distribution map of the already accepted surfaces together with an indication of a further lower level in the Padstow area. Attention was also drawn to the dangers of using heights for designating the surfaces since the same surface can vary in height from place to place. The proposal was made that local place names be used rather than heights. The numerous bluffs terminating the surfaces were also mapped for the first time and this data along with the distribution of the surfaces enabled a map of the earlier coastlines to be reconstructed. No warping was revealed by this

analysis and there seemed little doubt that in this part of Cornwall all the recognized surfaces were of marine origin. The sequence which emerged was as follows:

Davidstow	circa 1,000 ft.
Condolden	base level at 920 ft., height range from 920—850 ft.
Treswallock	base level at 820 ft., height range from 820—600 ft.
Trevena	base level at 430 ft., height range from 430—300 ft.
Rosken	base level at 285 ft., height range from 285—240 ft.

On the basis of Clement Reid's and Barrow's dating the Rosken and Trevena surfaces were placed in the Pliocene whilst the upper surfaces were thought to be of Miocene age.

In 1938 there came a notable paper from S. E. Hollingworth in which a purely statistical approach to the problem was made by means of altimetric frequency curves covering the higher ground of western England and Wales. Devon and Cornwall are considered separately and the results of the statistical investigations correlate closely with the field information as then recorded. The Trevena (430 ft.), Treswallock (280 ft.) and Davidstow (1,000 ft.) planations emerged very clearly from the analysis but in addition the curves revealed the possibility of further surfaces at intermediate altitudes.

By this time the multiplicity of levels which were appearing not only in south-west England but elsewhere in Britain and on the Continent began to be viewed with suspicion in some quarters. The evidence was however clearly pointing towards a widespread and substantial eustatic shift of sea level in post Alpine time and this being so the development of both sub-aerial and sub-marine erosion surfaces at a wide variety of levels according to the length of the still-stands, local lithological conditions etc. was only to be expected. The magnitude of the changes appeared very large and many geologists found difficulty in accepting the idea, for the solution of one problem was it seemed merely leading to the creation of another.

Subsequent detailed studies have however tended to confirm this thesis. N. J. G. Pounds in 1939 dealt with the Lizard area and J. F. N. Green followed in 1941 with a description of the high platforms of East Devon distinguishing at least six erosion surfaces in the height range between 440—920 ft. These stages were all considered to be of marine origin and Miocene to Pliocene in age. In a further paper in 1949 Green examines the River Dart area and traces at least eight levels between 430 and 1150 ft. which are again all thought to be of Mio-Pliocene origin. At about the same time S. W. Wooldridge (1950) reviewed the origin and geographical significance of the upland plains of Britain as a whole and in this notable contribution we find south-west England discussed in relation to the rest of the country.

A detailed analysis of the Exmoor region by the present writer followed in 1952 and this also revealed a staircase of levels, separated by bluffs interpreted as the worn down remnants of earlier cliff-lines, ranging up towards an elevation of 1225 ft. Above this height there appeared to be undulating traces of an early

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Tertiary sub-aerial peneplain together with a suspicion of remnants of a sub-Cretaceous peneplain in the summit regions. The sequence which emerged from the analysis was as follows:

Summit 'Surface'	Remnants
Exmoor Surface	Sub-aerial peneplain above 1250 ft.
Lynton Surface	base level at 1225 ft., height range 1225—1000 ft.
Molland Surface	base level at 925 ft., height range 925—850 ft.
Anstey Surface	base level at 825 ft., height range 825—700 ft.
Buckland Surface	base level at 675 ft., height range 675—500 ft.
Georgeham Surface	base level at 425 ft., height range 425—300 ft.
Instow Surface	base level at 280 ft., height range 280—200 ft.

Detailed distribution maps of the erosion surface remnants were also presented in support of the text. The sequence agreed with much that had already been observed elsewhere in the south-west.

In the same year N. Stephens investigated the erosion cycles of South West Devon and produced similar evidence of a staircase of levels, his conclusions in summary form being:

Above 1100 ft.	Broad expanses of undulating mature slopes, but no clear divisions possible.
1100—1000 ft. surface	Probably composite, in part marine, in part large valley facets. Well developed around the Dartmoor periphery.
840—750 ft. surface	A marine abrasion surface. Widespread throughout the area. Bounded by bluffs at both upper and lower limits.
680—550 ft. surface	Sub-aerially modified seaward end of the preceding marine surface.
430—350 ft. surface	A marine abrasion surface. Well marked and indicative of a long still-stand.
320—300 ft. surface	Sub-aerially modified seaward end of the preceding marine surface.
280—250 ft.	} A series of marine abrasion surfaces cut during the retreat of the sea from the 430 ft. level.
210 ft. surface	
190—160 ft.	

Both Balchin (1952) and Stephens (1952) recognized the importance of the sub-aerial modification of emergent marine surfaces and also the possibility of sub-marine trimming of pre-existing sub-aerial surfaces.

More recently further detailed studies on erosion surfaces have been undertaken on Bodmin Moor by M. R. Weller (1959), in North Devon by Miss M. A. Arber (1960), in the Kerrier Peninsula by G. Fryer (1957-1958, published 1960) and in North-west Devon by M. J. Bradshaw (1961). The first two studies follow earlier approaches and largely agree with previous work. Weller supports the view that the 1000 ft. Bodmin surface is marine in origin but he thinks that

Barrow's next lower surface can be divided into two sub-aerial phases. He devotes considerable attention, for the first time in print, to the conspicuous remnants of a shoreline at 650-675 ft. on the south side of Bodmin Moor and this emerges from his analysis as a major phase in the denudation chronology. It is significant that a conspicuous feature at this level is also found on Exmoor (Balchin 1952), on Dartmoor (Stephens 1952), throughout the coastal regions of Wales (Brown 1957) and in south-east England (Wooldridge and Linton 1939). Below this important base level evidence was found of two further major still-stands at 430 ft. and 180 ft. In North Devon Miss Arber continues the major staircase of surfaces noted on Exmoor (Balchin 1952) downwards with two further stages below the Instow (280 ft.) level. These are the Hele (150—100 ft.) and Croyde (approximately 50 ft.). Both these surfaces are restricted in area, they cut and therefore postdate the periglacial deposits of head and with them we begin to pass into the raised beaches of the glacial period.

M. J. Bradshaw's (1961) very detailed study of a restricted area of north-west Devon reveals the importance of the pre-submergence landscape in the present day topography. He agrees with previous researchers that a major marine incursion up to the 690 ft. level took place, with a subsequent withdrawal punctuated by still-stands at 650, 570, 520, 480, 430, 350 and 290 ft. Bradshaw accumulates however a considerable amount of evidence throughout his description of this part of Devon pointing to the re-occupancy of a pre-existing drainage system with re-emergence.

The conclusions of G. Fryer (1960) introduce a somewhat discordant note into the story. In his investigation of the land forms of Kerrier he rejects the marine hypothesis apart from the 430 ft. transgression and argues in favour of the sub-aerial denudation of a single extensive surface which he claims as a pediplain dating from Triassic time. This thesis echoes views put forward by O. T. Jones (1951) for Wales. It represents the third possibility, already mentioned in our introduction, of explaining erosion surfaces: but one which in south-west England as a whole raises almost as many problems as it solves and which so far has found few supporters. At present the majority of the evidence points to a eustatic marine hypothesis with emergent surfaces being subjected to sub-aerial modification, and rejuvenation affecting the rivers after each marine regression.

As this chapter was being written an account of the geomorphology of southern Dartmoor was published by A. R. Orme (1964). The polygenetic and polycyclic origins of the landforms in southern Dartmoor and the adjacent plateau country are described and four principal planation surfaces are distinguished at the higher levels. An early Tertiary peneplain from 1,620 - 1,520 ft. is flanked by a less well developed 1,375 - 1,050 ft. surface which probably post-dates the mid-Tertiary earth movements. Below these are late Tertiary surfaces at 1,000 - 875 ft. and 820 - 730 ft. Orme suggests a sub-aerial origin for these upper surfaces but introduces a new note into the literature by discussing the possibility of a form of pediplanation under warm humid conditions. Below these elevations the late Tertiary landscape is thought to have been drowned to a height of approximately 700 ft. by an early

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Pleistocene marine transgression. The subsequent regression was punctuated by stillstands at 690, 600, 550, 460, 400, 327, 150, 126, 25, 14 and – 150 ft. within the area studied by Orme.

The task of assembling all these studies into a detailed geomorphological map for the whole of south-west England has yet to be attempted. It will not be an easy task for the identification of erosion surface fragments and the determination of their origin is a subjective exercise leaving much room for discussion. That surfaces exist there can be no doubt, but a divergency of opinion clearly exists as to the number and the origin of the features. These divergences however need not occasion alarm, for clearly at any particular still-stand we have both a sub-aerial and submarine surface in course of production: and if sufficient time elapses and a eustatic fall next occurs then the geomorphologist should be able to trace a sub-aerial surface grading down into a submarine surface. But since the exposed submarine surface will itself be open to sub-aerial attack it will clearly tend to disappear and its preservation will depend on the local resistance of the rocks. A variety of conditions will hence be possible and the intrusion of a sub-aerial surface into a sequence of submarine surfaces, or vice versa is quite possible. For correlative purposes the really important criterion in all cases is the identification of the associated base levels.

Dating the surfaces is also problematical. Only two lines of evidence exist—structural information and superficial deposits, neither of which are often conclusive. Unwarped surfaces must clearly post-date major orogenic movements such as the Alpine and this somewhat narrows possibilities for marine surfaces in the south-west. Sub-aerial surfaces will clearly be difficult to date in any circumstances, but marine surfaces with deposits offer some basis. Unfortunately few deposits have come to light on the marine surfaces in south-west England. Indeed despite the strong morphological evidence suggesting a marine origin for the majority of the erosion surfaces there is a remarkable absence of clearly correlative marine deposits.

Sands and gravels have been found at Polcrebo (500 ft.), Trenhale (430 ft.), Crousa Common (360 ft.) and St. Agnes (375 ft.) at various times and whilst quite probably of marine origin they are of little help for dating purposes as no included fossils have come to light. The Fremington and Filleigh clays of north-west Devon are likely to prove to be alluvial infillings of an earlier river valley. Probably the only significant deposits in the west are those at St. Erth and Orleigh Court. The deposits at St. Erth are fossiliferous and undoubtedly marine but unfortunately have complications in that they occur within a valley cut in the erosion surface. Originally identified towards the end of the last century and placed in the Older Pliocene by Clement Reid these deposits have been a key factor in early efforts at dating the lower surfaces in Cornwall. Wooldridge has suggested however that both the St. Erth deposits and the dating need re-examination in the light of new geological data. The discovery of Red Crag fauna in the Netley Heath beds (which rest on the undoubted 600 ft. marine bench of south-east England) and the decision of the International Geological Congress of 1948 to redraw the Pliocene/

Pleistocene boundary such that the Red Crag now falls within the Pleistocene, suggests that some, if not all, of the 'Pliocene' features of south-west England must now be regarded as early Pleistocene.

The second significant deposit is that at Orleigh Court which stretches, on the Georgeham surface, from Orleigh Mill to Yeo Bridge near Bideford. It consists of a superficial sand and flint cover extending for some three quarters by a quarter of a mile. The postwar Geological Survey's Regional Handbook describes the deposit as an outlier of Greensand—"the most westerly limit of the Cretaceous". The author, however, appears to have overlooked a paper by Inkerman Rogers and Brian Simpson (1937) which gives a petrological analysis of the deposits. The regional handbook seems to echo an early suggestion made by De la Beche in his classical report. A later opinion was given by W. A. F. Ussher (1879) who suggested that the deposit was probably a "re-assorted Cretaceous material, perhaps a Tertiary gravel" rather than Greensand *in situ*. P. G. H. Boswell in 1923 ascribed the deposit to the Eocene but Milner in the discussion of this paper favoured a Pliocene age. Rogers and Simpson considered that it must be a derived deposit of at least post-Eocene age and that it was probably laid down on part of the 400 ft. platform. It is very significant that the deposit extends up to, but not beyond, the 400 ft. contour, and that it is very near to the 430 ft. bluff. This flint gravel appears to have been originally a beach deposit analogous to the flint gravel beaches which occur at the modern sea-level in Padstow Bay, Mount's Bay and Gunwalloe.

The most recent consideration of superficial deposits comes from R. S. Waters (1960) with references to East Devon, West Dorset and South Somerset. Here we pass out of the Palaeozoic zone into a region dominated by an upland plateau of Cretaceous rocks comparatively rich in superficial deposits. Waters has managed to show that these consist of two types. West of a dividing line which runs north-south near Axminster 'typical' Clay with flints and chert occurs, but east of this line and at lower levels there is found in addition to the clay with flint patches of well rounded gravels in a sandy matrix. These contain unmistakable beach cobbles of flint with beach-hammered and chatter marked flints. Waters interpretation of these deposits does not entirely fit the general consensus of opinion regarding denudation chronology in south-west England but his identification of marine deposits is of considerable interest to those supporting the marine hypothesis.

The lack of marine deposits has sometimes been advanced by sub-aerial protagonists as a serious weakness in the submarine argument. Recently, however, aqualung divers have shown that deposits on the west coast of Cornwall are confined to a very narrow beach zone and that a bare rock platform is soon reached. If past offshore conditions on the staircase of platforms resembled those of the present wave cut abrasion platform, it is not difficult to account for the absence of deposits on the relatively narrow submarine shelves which are now exposed. It must further be remembered that there was no large adjacent land mass in south-west England upon which substantial debris carrying rivers could arise.

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III. THE EVOLUTION OF THE DRAINAGE PATTERN

In contrast to the growing volume of literature on erosion surfaces in south-west England there have been few attempts to analyse the drainage system and its evolution. One of the earliest studies was by A. W. Clayden in his *History of Devonshire Scenery* (1906). Although he perceived certain drainage reversals in north-west Devon much of his work must now be regarded as superceded. An interesting paper on river gorges in Devon and Cornwall by H. Dewey (1916) introduced the concept of extended consequent drainage upon emergent coastal platforms accompanied by rejuvenation as a result of lowered base levels. Later contributions have until recently been largely incidental to erosion surface enquiries. Even J. F. N. Green's *History of the River Dart* (1949) largely becomes an account of the erosion surfaces and terraces associated with the river.

In 1951 R. S. Waters examined the drainage evolution of south-west Devon in detail and like Dewey in north Cornwall (1916) came to the conclusion that the majority of the rivers are extended consequents upon emergent platforms which have received successive waves of rejuvenation. The drainage pattern was considered to have developed since the early Miocene and westerly flowing streams were thought to have grown at the expense of easterly flowing. The general direction taken by each small stream was determined mainly by the seaward slope of the successively emergent late Pliocene and early Pleistocene strand flats. No simple relationship of the drainage pattern with the geology could be traced.

These studies were of restricted localities however and the peninsula as a whole was not reconsidered until S. W. Wooldridge (1954) drew attention to a number of fundamental facts in the drainage pattern that provide clues for the denudation chronology. The main water parting, which can be traced for some 250 miles through Devon and Cornwall, throws light on the competition between north and south flowing drainage. A number of cols on this line suggest river piracy and much adjustment. (Fig. 3.) Three of these cols are of major significance. In the far west an original southward drainage has been reversed in the Hayle-Marazion depression. To the north east of this reversal the peculiar looped course of the Camel suggests reversal on an even larger scale. At Red Moor a broad gap at about 450 ft. probably represents the old drainage line of the upper Camel southwards to Lostwithiel and the present Fowey estuary. Northwards the imminent capture of the headstream of the Tamar by the Bude Haven drainage repeats the pattern and when complete will closely imitate the great Camel loop.

These features also throw light on the remarkable course of the Torridge. This river rises near Hartland and flows south-eastwards for twelve miles parallel to the Tamar. The high ground of Dartmoor blocks the continuation of this line and the original flow might well have been eastwards to the Exe drainage. The lower Torridge from Hatherleigh to Bideford Bay flows north-westwards and is either of much more recent origin or the reversed descendent of a stream formerly flowing south-east. The line of the Taw continued in that of the Yeo may also mark the line of a former stream flowing south-eastwards to join an ancestor of the Creedy.

The Exe and its tributaries also rise close to the northern coast and these too exhibit a south-east trend, but eastwards a series of captures has broken the continuity of similar southward flowing streams. The Bathern has beheaded the Loman and the upper Tone has been diverted eastwards by a subsequent tributary of the Parrett. This capture is analogous to that of the Bray by the Taw. Wooldridge suggests that it has originated by a simple adjustment to structure in the ready excavation of the Triassic rocks.

Considering the rivers as whole Wooldridge suggested that the evidence points to the existence of a former drainage to the south or south-east of which the Exe and the Tamar remain as substantial witnesses. Elsewhere reversal of drainage in the headstreams has occurred which suggests that originally the peninsular water parting was probably located well beyond the present north and west coast. All this implies an 'initial surface' sloping south. But there is also another element which implies an original easterly slope. This shows in the rivers of Dartmoor and Exmoor.

More recently detailed drainage studies have been made of the Lyn system by Scott Simpson (1953), the Exe River by C. Kidson (1962) and the Dart system by D. Brunsten (1963). The River Lyn is notable for its rejuvenation history and for the series of four captures by coastal erosion which throw light on much that has happened elsewhere on the Cornish coast. The Exe valley, according to Kidson's detailed levelling of the longitudinal profile, reveals nine major control stages of which two, the Westermill (690 ft.) and Nethercote (330 ft.) are significant. A major marine transgression seems to have marked both of these base levels. The evidence from the Exe valley supports the generally held thesis of a falling, albeit oscillatory, base level producing both erosion surfaces and river rejuvenations.

A similar but even more complicated story has been worked out on the River Dart by D. Brunsten. Seventeen stages are claimed of which the upper six are within the moorland area and the lower eleven in the coastal zone below 690 ft. The lower surfaces are dominantly submarine in origin but Brunsten favours sub-aerial origins for the upper surfaces. The summit peneplain from 1900—1500 ft. is thought to be tilted and hence of early Tertiary age, but none of the lower features show signs of warping and are hence considered to be post Alpine. A major change in the landscape is again detected above and below the 690 ft. level. The earliest drainage pattern recognizable on Dartmoor is thought to have been eastward and to have produced the early Tertiary peneplain. With the uplift and southerly tilting of this surface the drainage was rejuvenated and the south flowing tributaries extended themselves into the northern moor and the north flowing streams were suppressed. The eastward drainage was rejuvenated at the intermediate stage but the pattern was interrupted by the transgressive 690 ft. sea. Following the retreat of the shore during Pleistocene time the drainage was extended across the intermittently emerging sea floor and superimposed across the east-west lineaments in the Palaeozoic rocks.

IV. THE DENUDATION CHRONOLOGY

A point has now been reached where the varied evidence provided by the erosion surfaces, superficial deposits, drainage patterns and river profiles may be reviewed in an effort to provide a summary denudation chronology for south-west England. The total of the data now recorded provides material more appropriate to a Ph.D. thesis than to a short chapter, but in either case the broad outlines of the denudation chronology can be distinguished and despite differences of opinion on detail there is a notable and increasing measure of agreement on the main sequence.

One early geological episode which has influenced the present morphology was the pre-Triassic faulting (Thomas 1940) which led to the formation of basin-like depressions in which Triassic conglomerates and red sandstones were laid down. Certain of these faults and other new ones moved some hundreds of feet in late Triassic time and again to a minor extent in post-Triassic time. This produced a block fault system in some areas, e.g. eastern Exmoor. Although subsequently buried to a greater or lesser extent by Mesozoic deposits the faulting where it existed has influenced dissection during Tertiary time and in parts the topography could be regarded as partly exhumed. Such faulting must clearly have disrupted any Triassic peneplain that may have existed and much doubt is thereby cast on the pediment thesis.

Evidence from the geological deposits now ceases and the story can only be continued by reference to erosional features. It seems clear from the entrenched meanders of the Barle, Exe and other rivers on Exmoor (Balchin, 1952) that the drainage pattern has in the higher reaches of certain rivers been superimposed. This could only have occurred from a Cretaceous cover, for the Palaeozoic rocks are known to have been exposed in Eocene time. J. F. N. Green (1949) advanced a somewhat similar suggestion for Dartmoor but in terms of an Eocene planation with a cover of Eocene sediments. This dating however does not fit the known Eocene deposits of southern England which become coarser and more gravelly as they are traced from Hampshire into Dorset, and both the Reading beds and lower Bagshot sands may be shown to pass westwards into true sub-angular river gravels. The constituents of the gravels clearly indicate the exposure of Palaeozoic and Permian rocks further west.

Of the possible Cretaceous cover of Exmoor no trace now remains and we can only point to the so called 'summit surface' which, with a gentle slope of seven minutes of a degree to the east, runs approximately into the level at which Cretaceous deposits occur in southern England. This strongly suggests that in the 'summit surface' we may have fragmentary traces of a sub-Cretaceous surface.

With the retreat of the sea from the west sub-aerial agencies immediately began the task of removing the cover and by mid-Eocene time this appears to have been largely completed. But in the process the river system had in part been let down onto the Palaeozoic rocks. There is reason to suppose that this cycle of sub-aerial erosion extended through the Eocene period into the Oligocene and achieved a fairly advanced stage of maturity, traces of which are now left in the

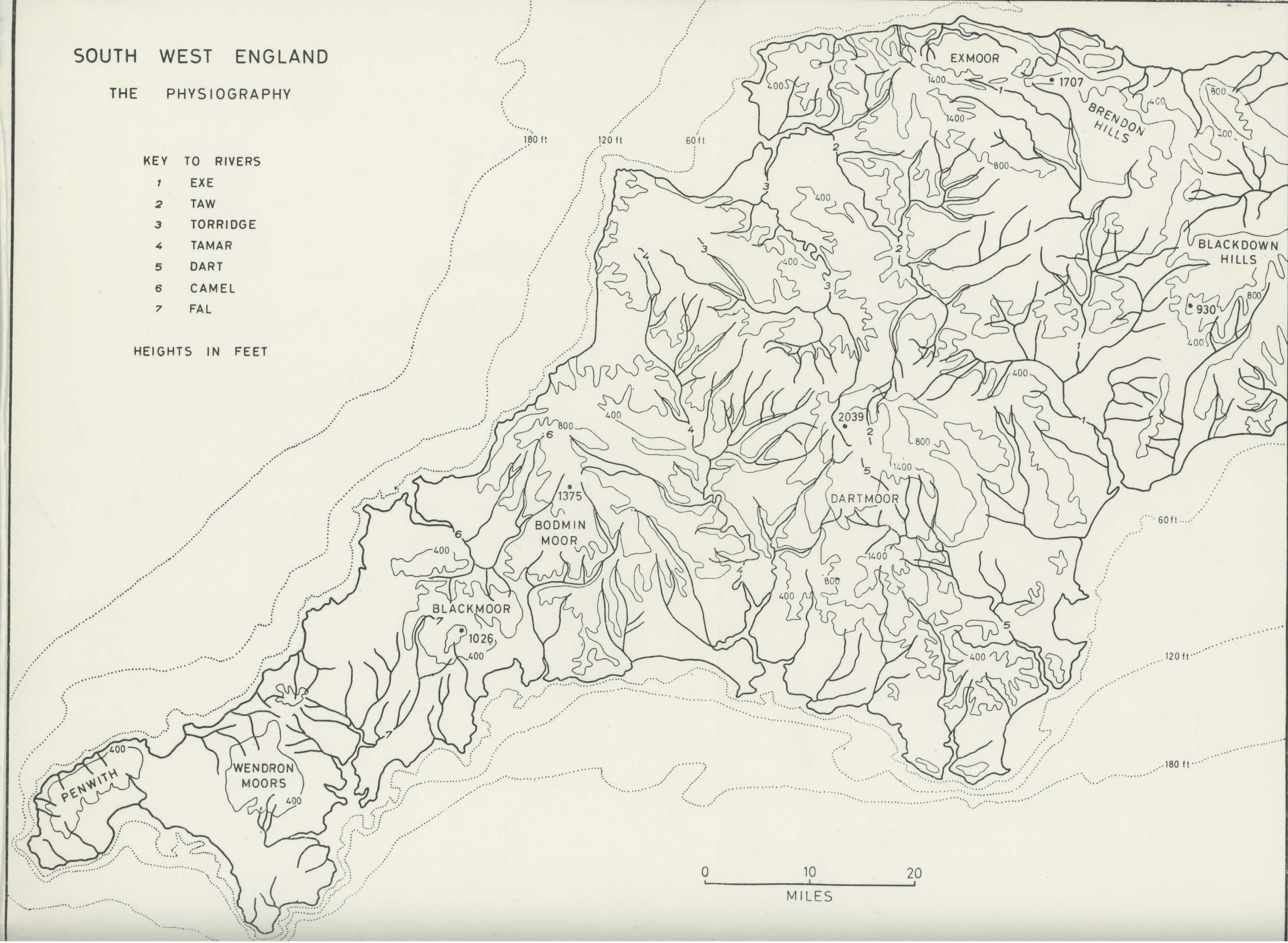
SOUTH WEST ENGLAND

THE PHYSIOGRAPHY

KEY TO RIVERS

- 1 EXE
- 2 TAW
- 3 TORRIDGE
- 4 TAMAR
- 5 DART
- 6 CAMEL
- 7 FAL

HEIGHTS IN FEET



Exmoor surface (Balchin 1952) high above the direct influence of the marine transgressions which came later.

The topography of the early Tertiary sub-aerial cycle was next modified by two agencies. In the first place there now seems agreement (Hollingworth 1938) that the late Oligocene and early Miocene folding associated with the Alpine orogeny extended to some degree into Devon and Cornwall. Secondly there is clear evidence of a widespread submergence of the greater part of the area, which as has been seen, is now dominated by a series of platforms or narrow shelves fringing all the high ground. Most authors submit that none of these features show any conspicuous signs of warping so that the agreed influence of the Alpine movements enables us to fix a limit to the age of the surfaces. Throughout south-west England research workers agree that the plateau like erosion surfaces below the 690 ft. level are primarily of marine origin but above this level opinion is divided between sub-aerial and submarine agencies. Doubtless some of the difficulty in interpretation is related to the later sub-aerial modification of earlier submarine surfaces, and also to the submarine trimming of pre-existing sub-aerial surfaces.

Whatever the explanation for a particular local feature there seems little doubt that there was a falling base level from late Miocene time onwards which was interrupted by a major transgression at approximately the 675+ ft. level in the early Pleistocene (according to recent dating). Subsequent to this transgression there seems to have been a gradual re-emergence of the region punctuated by still-stands of the main base level of which that at the 430 ft. stage is the most pronounced. The multiplicity of levels and surfaces that characterise the literature is at first confusing, but also understandable, since we are apparently dealing with eustatic shifts of sea level which would not necessarily leave the same record everywhere, although of course a prolonged still-stand should be easily traceable. This is indeed so in the case of the 430 and 675 ft. levels.

It is in these major oscillations of the base level that we may seek explanations for some of the more puzzling drainage reversals, river captures and the like. With the re-emergence of the land from the sea some rivers will doubtless have re-occupied such traces of their old courses as still existed but others will have fashioned new valleys. In many cases it is possible to distinguish both pre-platform and post-platform valley types. Rejuvenation has clearly influenced the great majority of the river courses as the polycyclic longitudinal and transverse profiles show. We cannot however explain the whole drainage pattern on the basis of extended streams consequent upon the slope of the emergent platforms. Elements of the early Tertiary sub-aerial surface were not completely erased by the marine transgressions and this palimpsest of an earlier period has clearly influenced many of the river courses. In some areas this control, as we have seen, can be traced back still earlier to superimposition from a Cretaceous cover. Other valleys have been formed by ancient coastal waterfalls which have migrated back inland. All these facts plus the possibility of oscillations in the lowering of the base level, adjustment to structure and river capture must be taken into account when unravelling the denudation chronology of any particular river.

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PLATE 1. Deeply incised valleys in the 400 ft. marine erosion surface near Polperro.

PLATE 2. Lamorna Cove, the '400' ft. platform of marine abrasion in the Penwith peninsula.

PLATE 3. Kelsey Head from Holywell near Newquay. Part of the lower 200 ft. marine erosion surface.

PLATE 4. Logan Rock near Porthcurno, the coastal platform of marine abrasion near Land's End.

PLATE I



With acknowledgements to Aerofilms and Aero Pictorial Ltd.

PLATE 2



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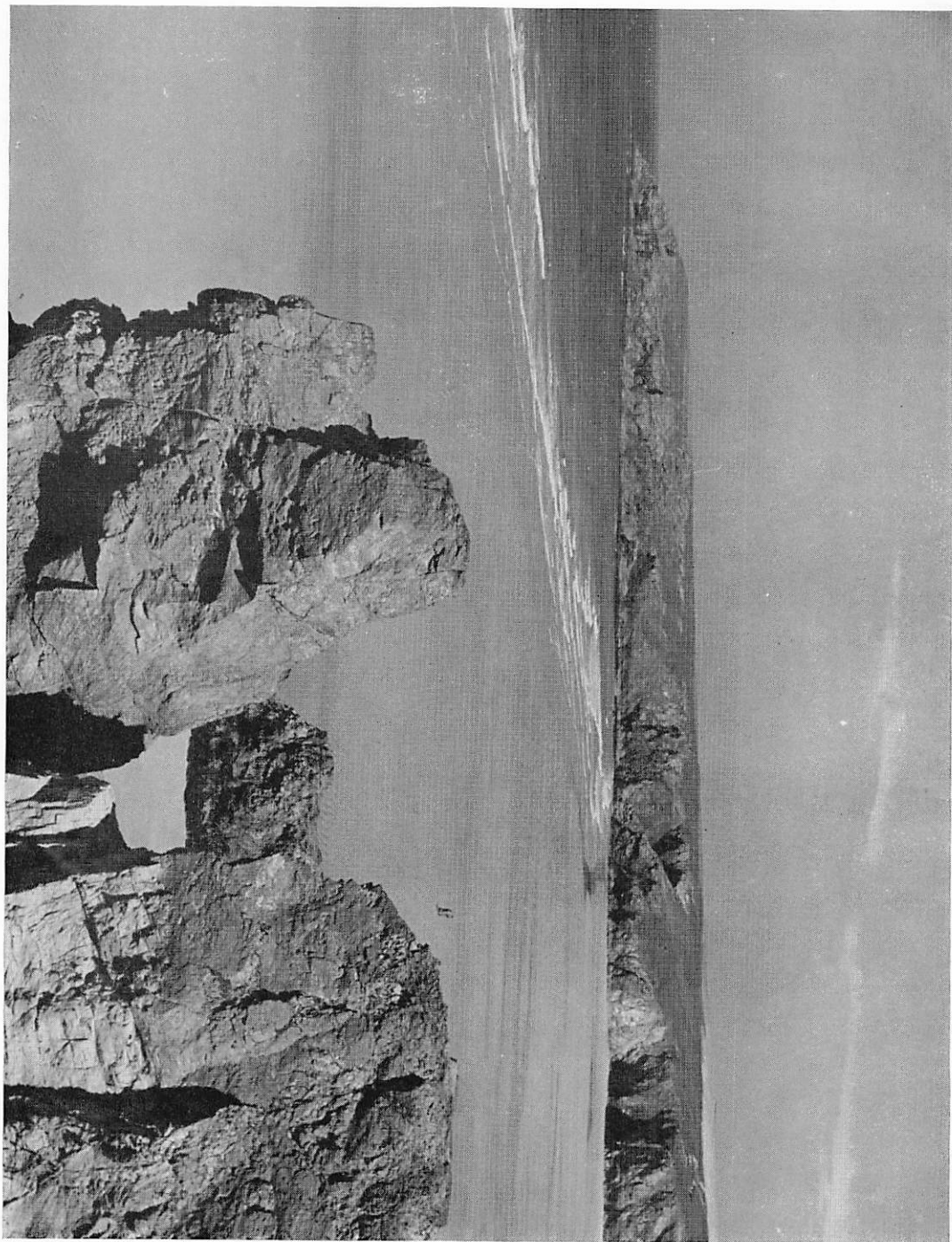
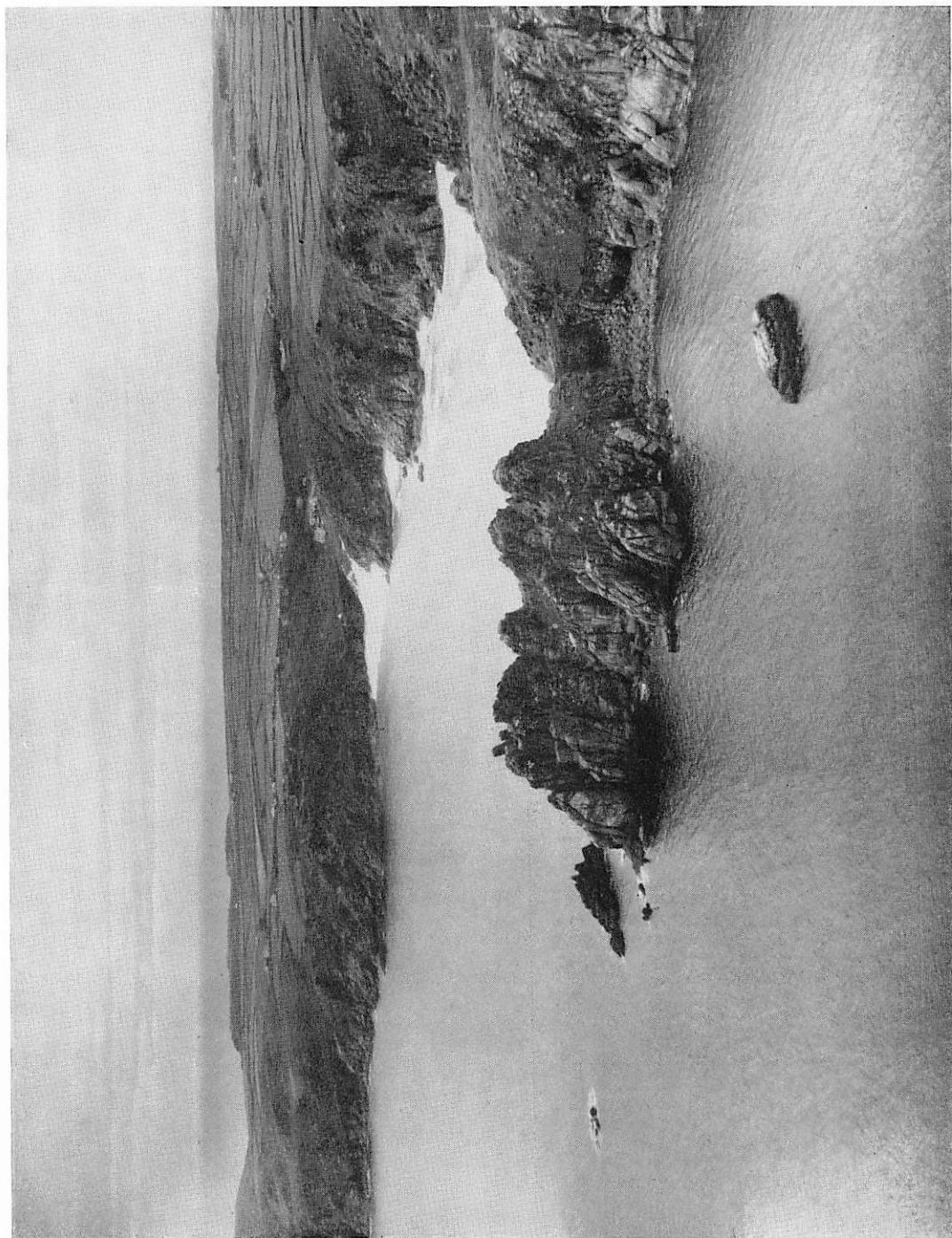


PLATE 4



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